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-ECAS-
WESTINGHOUSE PHASE I FINAL REPORT

Volume III — COMBUSTORS, FURNACES, AND LOW BTU GASIFIERS

by

J.R. Hamm, et al

WESTINGHOUSE ELECTRIC CORPORATION RESEARCH LABORATORIES

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Project Managers:
W. J. Brown, NASA Lewis Research Center, Cleveland, OH 44135
D. T. Beecher, Westinghouse Research Laboratories, Pittsburgh, PA 15235

16. Abstract

Information on the design, performance, operating characteristics, cost, and development status of coal preparation equipment, combustion equipment, furnaces, low-Btu gasification processes, low-temperature carbonization processes, desulfurization processes, and particulate removal equipment was compiled for use by the various cycle concept leaders in determining the performance, capital costs, energy costs, and natural resource requirements of each of their system configurations.

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- D. F. Ciliberti who prepared design, performance, and cost information for cyclone separators, tornado separators, and electrostatic precipitators.
- J. A. Dilmore who compiled MHD combustor technology and cost information.
- J. R. Hamm who compiled design, performance, and cost information for fuel preparation equipment, combustors, furnaces, low-temperature carbonization, and pollution-control equipment and prepared the environmental intrusion summary.
- E. J. Lahoda who prepared the desulfurization process design for open-cycle MHD.
- B. W. Lancaster who developed design, performance, and cost information for electrostatic precipitators for open-cycle MHD and compiled design and performance information on low-temperature desulfurization processes.
- E. P. O'Neil who provided design information on high-temperature desulfurization processes.
- C. H. Peterson who described alternatives for solid waste disposal.

- E. J. Vidt who provided technology and cost information for the Westinghouse multi-stage fluidized bed gasifier.
- K. D. Weeks who made computer runs on gasification models, thermodynamic properties of combustion products and pressurized fired heater subsystems and provided design and cost information for pressurized fluidized bed boilers, atmospheric pressure fluidized bed boiler, and fired heaters.
- W. L. Wright who compiled design, performance, and cost information for flue gas desulfurization processes.
- W. C. Yang who provided fluidized bed combustion technology.

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SUMMARY

Information on the design, performance, operating characteristics, and cost of combustors, furnaces, and low-Btu gasification processes was compiled for the various cycle concept leaders to use in determining the performance, capital costs, energy costs, natural resource requirements, and environmental intrusion of each of their system configurations. The scope of this work was divided into the following categories:

- Coal preparation
- Combustion technology
- Low-Btu gasification technology
- Pollution control technology
- Solid waste disposal.

The grinding and drying requirements of the three coals for application to various types of combustors, furnaces, and gasification processes are identified and the power requirements for grinding and the power and heat requirements for drying are determined.

For each coal and moisture content combination, the ultimate analysis, lower and higher heating values, and stoichiometric fuel/air ratio were calculated and tabulated. In addition, the thermodynamic properties of the products of combustion of the three coals with the various moisture contents were calculated and tabulated over a range of air equivalence ratios. The above data are also compiled for distillate from coal derived liquids and for high- and intermediate-Btu fuel gas.

The combustor/furnace requirements for each of the coal and cycle concept combinations are established. The types of combustor/furnace selected for these applications includes:

- Cell and circular registers burners for gaseous, liquid, and pulverized fuel
- Cyclone furnace for crushed coal
- Fluidized bed combustion for crushed coal
- Swirl combustor for gaseous and liquid fuels
- Conventional gas turbine combustors for gaseous and liquid fuels
- Special gas turbine combustors for low-Btu fuel gas
- Blast furnace gas type burners for low-Btu fuel gas.

The state of the art of low-Btu gasification is reviewed and preferred processes are selected for each of the three principal generic types, i.e., fixed-bed, fluidized bed, and suspension. For each combination of coal and gasification process, the composition of the product fuel gas and the quantities of the reactants are calculated using computer programs based on simplified models of the gasification processes.

A state-of-the-art review is also made for low-temperature carbonization processes. A preferred carbonization process is selected and estimates are made of product yields for each of the three coals. Typical fuel gas compositions were obtained from the literature.

Heating values, enthalpies, and stoichiometric fuel/air ratios were calculated for each of the fuel gases from the low-Btu gasification and low-temperature carbonization processes. Thermodynamics properties of the products of combustion of each of these fuel gases are calculated over a range of air equivalence ratios.

Correlations of capital costs as a function of capacity and operating conditions were made for both low-Btu gasification and low-temperature carbonization processes.

A survey of leading flue gas desulfurization processes was made and a preferred process (limestone slurry) is selected for this study.

Performance and cost data for the limestone slurry process are correlated as a function of capacity and sulfur content of the coal.

The Westinghouse multi-stage fluidized bed gasification process has integrated high-temperature desulfurization and its cost is included in the gasifier cost. Similarly, the fluidized bed combustors have integrated high-temperature desulfurization and its cost is included in the cost of the boiler or fired heater employing fluidized bed combustion.

In open-cycle MHD systems, the plasma seed material was used as a sorbent for sulfur. Cost estimates were made for the seed regeneration process.

All cases using flue gas desulfurization are assumed to have integrated scrubbers for removal of the particulates.

High-temperature cyclones, tornado separators, and granular bed filters are used for particulate removal in the Westinghouse fluidized bed gasification process and for high-pressure fluidized bed combustion. Electrostatic precipitators are used for particulate removal in open-cycle MHD and for atmospheric and high-pressure fluidized bed combustion. Correlations of equipment cost as a function of capacity and operating conditions are prepared for all of the particulate removal equipment.

For all cycle concepts, techniques are identified for minimizing the formation of NO in the combustion process either from thermal mechanisms or by conversion of fuel nitrogen. All concepts have projected NO emission levels lower than the specified limit except for the combined cycle plant with the Westinghouse gasification process with high-temperature desulfurization and particulate removal. The emission limits which were specified for this power system are those for gaseous fuel (i.e., natural gas). The limits for solid fuel can be met by this system.

A summary of the environmental intrusion was made for the base cases and the recommended case for each power system concept.

4. COMBUSTORS, FURNACES, AND LOW-BTU GASIFIERS

4.1 Introductions

Information on the design, performance, operating characteristics, cost, and development status of combustors, furnaces, and low-Btu gasification processes was supplied to the various cycle concept leaders for use in determining the performance, capital costs, energy costs, natural resource requirements, and environmental intrusion of each of their system configurations.

The scope of the work in this area divided into the following subsections:

- 4.2 Coal Preparation
- 4.3 Combustion Technology
- 4.4 Low-Btu Gasification Technology
- 4.5 Pollution Control Technology
- 4.6 Solid Waste Disposal.

4.2 Coal Preparation

The properties of the Illinois No. 6 bituminous, Montana subbituminous, and North Dakota lignite coals specified are given in Table 2.1.

4.2.1 Grinding Requirements

All of the direct-fired integrated conversion processes considered in this study require that the as-mined coal be either crushed or pulverized prior to utilization. Crushing requirements for bituminous, subbituminous, and lignite coal for use in a cyclone furnace are given in Figure 4.1. These are generally applicable to fluidized bed combustion and gasification processes, as well.

In pulverized fuel furnaces fine grinding of the coal is necessary to assure complete combustion of the carbon and to minimize the deposition of ash and carbon on the heat-absorbing surfaces. Figure 4.2 shows a typical size distribution of pulverized coal for use in conventional

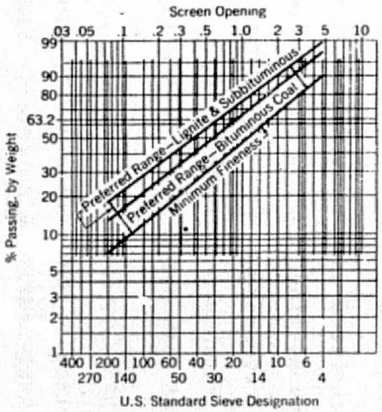

Fig. 4.1—Sizing of crushed coal fired in the cyclone furnace (Reference 4.1)

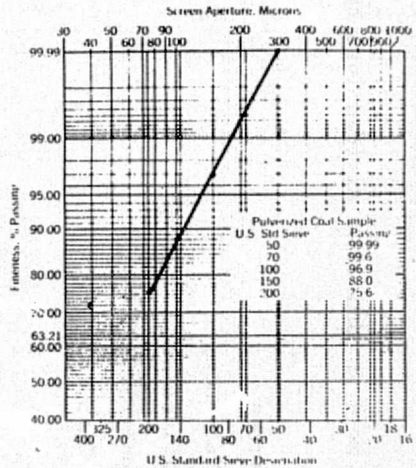

Fig. 4.2—Rosin and Rammler chart for plotting pulverized-coal-sample sieve analyses (Reference 4.1)

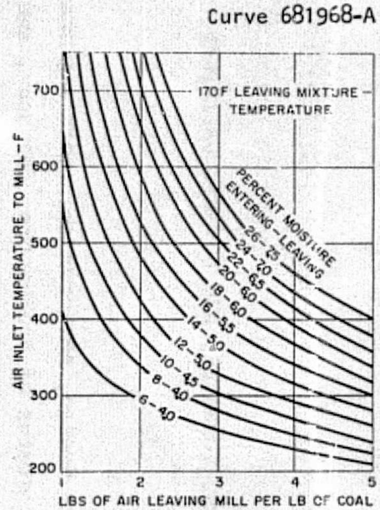

Fig. 4.3—Temperature of air to mill midwestern coals (Reference 4.4)

pulverized coal furnaces. The capacity of coal pulverizers is a function of the coal fineness, grindability index, and moisture content. Pulverizers are nominally rated on a grindability index of 50, a fineness of 70% through 200 mesh, and 8% moisture.

4.2.2 Drying Requirements

The moisture content of the three solid fossil fuels which have been specified for the ECAS study are as follows:

- Illinois bituminous coal - 13.0%
- Montana subbituminous coal - 24.3%
- North Dakota lignite - 36.7%

The values are fairly typical as-mined moisture concentations for these fuels.

Since the Middletown site specified for this study is not mine-mouth for any of these fuels, it is possible that additional moisture would be picked up during transportation and storage. A typical moisture content for bituminous coal in a storage pile at an eastern U.S. site is 10%, so it is not likely that the moisture content of the bituminous coal would increase. The subbituminous coal and the lignite could, however, pick up significant quantities of moisture during transportation and storage. It was assumed, however, that the moisture contents specified are for the fuels at the time of utilization.

The moisture content of the solid fuel is important because of its effect on the power system performance and operation. In combustion processes there are both sensible and latent heat losses associated with the moisture in the fuel. Excess surface moisture causes problems in grinding, transport, and storage of solids.

Bituminous coal is a compact material, and all but a small percentage of its moisture content is surface moisture. Reduction of the total moisture to approximately 3% is required to obtain good handling properties.

Subbituminous coal and lignite, on the other hand, are very porous materials and have the physical properties of dry materials with substantial moisture contents. Lignite can be pulverized and handled satisfactorily with moisture contents in the range of 25 to 30%. (Reference 4.2) It is assumed that the moisture content of subbituminous coal will have to be reduced to about 20% to obtain satisfactory physical properties.

It is easy to dry bituminous coal to a 3% moisture level. Lignite and subbituminous coal can be dried to 16 to 18% moisture level relatively easily, but higher temperatures and inert gases are required to dry them below this level. (Reference 4.3)

There are two basic techniques for drying coal. The technique most often used is mill drying, where a stream of hot gas dries the coal during the pulverizing or crushing operation. Alternatively, the coal can be dried prior to grinding. There are several types of separate driers available, but fluidizing bed driers are widely used for this purpose.

There are two methods of firing coal in conventional boiler furnaces - direct and indirect. In the direct method, mill drying is normally used, and preheated combustion air is used for drying and transporting the pulverized or crushed coal. Figure 4.3 shows the air preheat temperature required for mill drying as a function of the air/coal ratio and the moisture content of the coal. Since the moisture evaporated from the coal goes into the combustion air, it enters into the mass and energy balance of the combustion process the same as it would if the coal had not been dried.

In the indirect firing system, the coal is transported to a holding bin after being pulverized or crushed. Mill drying is also widely used with indirect firing, in which case the drying gas is used for transporting the ground coal to the holding bin. Whichever drying system is used with indirect firing, the evaporated moisture is vented along with the drying gas and, therefore, does not enter into the mass and energy balance of the combustion process.

If fuel is used to supply the heat for drying, the latent heat losses associated with the moisture evaporated from the coal are independent of the drying and firing methods. There may be differences in the sensible heat losses associated with the moisture in the coal, however. When wet coal is fired directly, or coal is mill dried and fired directly, the sensible heat loss of the moisture in the coal is proportionate to the stack-gas temperature minus ambient temperature. Stack-gas temperatures range from 408 to 450°K (275 to 350°F). The temperature of the gas stream leaving a drier is typically about 355°K (180°F) or less. The sensible heat loss associated with the moisture evaporated from the coal, therefore, is about half as much when the moisture is vented as it is when the moisture is carried through the combustion process along with the combustion air.

When the drying gas stream is vented, a sensible heat loss is incurred over and above the sensible heat losses of the dry products of combustion. On the assumption that the parametric values in Figure 4.3 can be treated as moisture decrements, computations show that the sensible heat loss due to venting drying air exceeds the difference between the sensible heat losses of the evaporated moisture by a factor of approximately 10.

In view of the above, it is concluded that the amount of drying air to be vented should be kept to a minimum when fuel is used to supply the heat to the drying air. Venting of drying air is mandatory only in high-pressure combustion and gasification systems when lockhoppers are used. In all low-pressure systems, direct firing with mill drying is feasible. If waste heat is available for drying, there is a substantial advantage in evaporating the maximum amount of moisture from the coal and venting it.

In most gasification processes steam is used as a reactant. If the process is cocurrent, the moisture in the coal will enter into the reaction and will reduce the quantity of process steam required from outside sources. Compared to the case with dry coal, the composition of the

Table 4.1 - Moisture Conditions for Three Levels of Drying

Coal Type	Moisture		
	(1) As Received	(2) Normal	(3) Maximum
Illinois No. 6 Bituminous	13.0%	3%	0
Montana Subbituminous	24.3%	20%	16%
North Dakota Lignite	36.7%	27%	18%

1. As received - Applicable to those cases where mill drying and direct firing are used.
2. Minimum drying for good handling properties - Applicable to those cases where venting of the drying gas and evaporated moisture is mandatory.
3. Maximum practicable drying - Applicable to those cases where sufficient waste heat is available to do the maximum practicable amount of drying with venting.

product fuel gas will be nearly the same, but the temperature will be lower because of the heat of evaporating the moisture in the coal.

If the gasification process is countercurrent, the moisture will be evaporated into the product fuel gas and will not enter into the gasification reaction. The dry fuel gas composition will not be affected, but the temperature of the wet fuel gas will. The losses associated with the moisture in the coal are the same as those described in the combustion systems. As in the combustion systems, therefore, venting of drying air should be kept to a minimum unless waste heat is available.

Suspension gasification processes are cocurrent, but fixed bed processes are countercurrent. The Westinghouse fluidized bed gasification process is countercurrent.

It is indicated that mill drying will be adequate for drying the three coals specified to the moisture levels required for good physical properties. For all low-pressure combustion systems, mill drying and direct firing is the preferred method. For high-pressure combustion and gasification systems, the preferred method is the minimum degree of mill drying to obtain the desired physical properties with venting of the drying gas and the evaporated moisture. When waste heat is available, however, the maximum amount of drying with venting is advantageous.

In view of the above, three sets of moisture conditions, shown in Table 4.1, are of interest for heat and mass balances in this study.

The ultimate analyses of the three coals for each of the thre moisture contents and for moisture-free solids are given in Table 4.2.

4.2.3 Power Requirements

The power requirement for coal crushers is independent of the type of coal and is typically about 0.04 $kWh/10^6$ Btu input (Reference 4.1). The power requirement for pulverizers is a function of the coal type and the grindability indices. The power requirements for each of the specified coals at its average grindability index is shown in Table 4.3.

Table 4.2 - Ultimate Analysis of Coals with Various Percent Moisture

Illinois No. 6 Bituminous				
Moisture content	13.0	3.0	0	
Ultimate analysis				
Ash	9.6	10.7	11.0	
Sulfur	3.9	4.3	4.5	
Hydrogen	5.9	5.3	5.2	
Carbon	59.6	66.3	68.5	
Nitrogen	1.0	1.1	1.1	
Oxygen	20.0	12.3	9.7	
	100.0	100.0	100.0	
Montana Subbituminous				
Moisture content	24.3	20.0	16.0	0
Ultimate analysis				
Ash	7.5	7.8	8.2	9.9
Sulfur	0.8	0.85	0.9	1.1
Hydrogen	6.1	5.9	5.7	4.5
Carbon	52.2	54.6	56.9	69.0
Nitrogen	0.8	0.85	0.9	1.0
Oxygen	32.6	30.0	27.4	14.5
	100.0	100.0	100.0	100.0
N. Dakota Lignite				
Moisture content	36.7	27.0	18.0	0
Ultimate analysis				
Ash	6.2	6.9	7.6	9.8
Sulfur	0.7	0.8	0.9	1.1
Hydrogen	6.9	6.4	5.9	4.4
Carbon	41.1	45.5	50.6	64.9
Nitrogen	0.6	0.7	0.7	1.0
Oxygen	44.5	39.7	34.3	18.8
	100.0	100.0	100.0	100.0

Air fans are required for both direct and indirect-fired systems to overcome the pressure losses in the mill dryer and to transport the pulverized coal to either the burners or the holding bin. Power requirements for these fans are also shown in Table 4.3.

Table 4.3 - Power Requirements for Coal Preparation

Coal	Average Grindability Index	Pulverizer Power Required kWh/10^6 Btu*	Primary Air Fan Power Required kWh/10^6 Btu*
Illinois No. 6 Bituminous	55	0.33	0.44
Montana Subbituminous	53	0.36	0.54
North Dakota Lignite	50	0.48	0.68

*Reference 4.1.

4.2.4 Final Requirements for Drying

For those cases where direct-fired heaters are used for heating the drying air, and the air leaving the drier or the mill is vented, the fuel required for drying can be calculated by using data from Figure 4.3 in the following expression:

$$\frac{\text{Fuel for drying, lb}}{\text{Wet coal dried, lb}} = \left(\frac{0.25\ (t_{air} - 59)}{(LHV - 0.25 \times t_{air})}\right)\left(\frac{W_a}{W_f}\right) \qquad (4.1)$$

Where: (W_a/W_f) = air/coal ratio leaving the mill, lb/lb

t_{air} = air inlet temperature to mill, °F

LHV = lower heating value of fuel used for heating drying air, Btu/lb.

The approximate energy requirements for minimum drying of coal in indirect-firing applications are shown in Table 4.4.

Table 4.4 - Energy Requirements for Drying Coal

Coal	Energy - Btu/lb Coal As Received
Illinois No. 6 Bituminous	235
Montana Subbituminous	100
North Dakota Lignite	230

4.2.5 Costs Mill/Drying Equipment

Mill drying was recommended for both direct and indirect systems. The equipment costs for crusher/driers and pulverizer/drier equipment on a July 1974 base are as follows:

- Crusher/drier equipment (Reference 4.5)

$$\text{Installed cost, \$} = 550{,}000 \left(\frac{\text{Coal Rate, tons/hr as received}}{50}\right)$$

- Pulverizer/drier equipment (Reference 4.6)

$$\text{Installed cost, \$} = 3{,}575{,}000 \left(\frac{\text{Coal Rate, tons/hr as received}}{100}\right)$$

Both of these installed costs are assumed to be 60% materials and equipment and 40% field installation labor. The cost of pulverizing/drying equipment for the atmospheric pulverized coal boiler for advanced steam conditions was included in the cost estimate for these boiler subsystems provided by the Foster Wheeler Corporation under subcontract.

The fluidized bed combustion and gasification processes with in-bed desulfurization using a sorbent such as limestone or dolomite must be provided with sorbent preparation facilities in addition to the coal preparation facilities. The requirements for grinding and drying the sorbent are similar to those for crushing coal, so the same kind of equipment used for crushing and drying the coal was used for crushing and drying the dolomite. In some cases the coal and dolomite could be crushed and dried together using a single system with a larger capacity. In other cases, however, the coal and dolomite had to be fed separately, so independent crushing/drying facilities were required for the coal and the dolomite.

4.3 Combustion Technology

4.3.1 Background Information

Calculation of the performance and design of equipment for the various cycles considered in this study required information such as fuel heating values, stoichiometric fuel/air ratios, thermodynamic properties of combustion products, adiabatic flame temperatures, combustion efficiencies for specific combustion conditions, and pressure losses for the various types of combustion equipment. These factors were included in the writing of a set of computer programs which performed the computations (see Appendix A 4.7).

The lower and higher heating values for each of the three coals for four moisture categories are given in Table 4.5.

The stoichiometric fuel/air ratios of the three coals for each of the four moisture categories are given in Table 4.6.

The stoichiometric fuel/air ratios for the various coal-derived fuels are shown in Table 4.7.

Table 4.5 - Heating Values of Coals with Various Moisture Contents

Coal	Illinois No. 6 Bituminous	Montana Subbit.	N. Dakota Lignite
As Received			
Moisture, %	13.0	24.3	36.7
HHV, Btu/lb	10788	8944	6890
LHV, Btu/lb	10230	8372	6248
Minimum Drying			
Moisture, %	3	20	27
HHV, Btu/lb	12028	9452	7946
LHV, Btu/lb	11525	8907	7365
Maximum Practicable Drying			
Moisture, %	0	16	18
HHV, Btu/lb	12400	9925	8926
LHV, Btu/lb	11913	9405	8401
Moisture Free			
HHV, Btu/lb	12400	11816	10885
LHV, Btu/lb	11913	11394	10473

Table 4.6 - Stoichiometric Fuel/Air Ratios for Coals with Different Moisture Contents

Coal	Moisture Content, %	Stoichiometric Fuel/ Air Ratio
Illinois No. 6 Bituminous	13.0	0.122
	3.0	0.109
	0	0.106
Montana Subbituminous	24.3	0.148
	20.0	0.140
	16.0	0.133
	0	0.112
North Dakota Lignite	36.7	0.191
	27.0	0.166
	18.0	0.148
	0	0.121

Table 4.7 - Stoichiometric Fuel/Air Ratios

	Stoichiometric Fuel/ Air Ratio
Intermediate-Btu Fuel Gas	0.308
High-Btu Fuel Gas	0.0617
Syncrude/Naphtha	0.0688
Syncrude/Distillate	0.071
Syncrude/Oil	0.07725
PAMCO SRC Solid	0.0842

The stoichiometric fuel/air ratios for low-Btu fuel gases are included on the fuel gas data sheets, Tables 2.7 to 2.29 of this report.

The thermodynamic properties of the products of combustion of the various coals and coal-derived fuels were computed using a program developed by the Westinghouse Gas Turbine Systems Division. In this program enthalpy and referred pressure are determined as a function of temperature and air equivalence ratio. For this study calculations were made over a range of temperatures from 255.6 to 1663°K (0 to 2540°F) with increments of 2.78°K (5°F), and over a range of air equivalence ratios from 1 to 4 with increments of 1. Other output of the program are molecular weight, composition expressed as weight fractions, fuel to dry air ratios, and the ratio of moisture to dry air in the ambient air.

Tables of the thermodynamic properties were generated for the products of combustion of the specified ambient air and the following fuels:

1. Illinois No. 6 bituminous coal - 3% moisture
2. Illinois No. 6 bituminous coal - 13% moisture
3. Montana subbituminous coal - 20% moisture
4. Montana subbituminous coal - 24.3% moisture
5. North Dakota lignite - 27% moisture
6. North Dakota lignite - 36.7% moisture
7. Low-Btu fuel gas/Ⓦ fluidized bed/Illinois No. 6 bituminous/$T_{process\ air}$ = 350°F
8. Low-Btu fuel gas/Ⓦ fluidized bed/Illinois No. 6 bituminous/T_{air} = 550°F
9. Low-Btu fuel gas/Ⓦ fluidized bed/Montana subbituminous/T_{air} = 750°F
10. Low-Btu fuel gas/Ⓦ fluidized bed/Montana subbituminous/T_{air} = 350°F

11. Low-Btu fuel gas/ Ⓦ fluidized bed/Montana subbituminous/T_{air} = 550°F

12. Low-Btu fuel gas/ Ⓦ fluidized bed/Montana subbituminous/T_{air} = 750°F

13. Low-Btu fuel gas/ Ⓦ fluidized bed/North Dakota lignite/T_{air} = 350°F

14. Low-Btu fuel gas/ Ⓦ fluidized bed/North Dakota lignite/T_{air} = 550°F

15. Low-Btu fuel gas/ Ⓦ fluidized bed/North Dakota lignite/T_{air} = 750°F

16. High-Btu fuel gas

17. Intermediate-Btu fuel gas

18. PAMCO SRC solid

19. Syncrude naphtha

20. Syncrude distillate

21. Syncrude oil.

These tabulations are included in Appendix A 4.1. In addition, coefficients for polynomial expressions representing these data are listed.

Adiabatic flame temperatures for high-Btu fuel gas, distillate from coal-derived liquid, and Illinois No. 6 bituminous coal are obtainable from existing correlations for natural gas, No. 2 fuel oil, and bituminous coal. Adiabatic flame temperature calculations were made for two specific fuels used in this study. These were an intermediate-Btu fuel gas from the atmospheric-pressure Koppers Totzek gasification process using Illinois No. 6 bituminous coal (see Figure 4.4) and low-Btu fuel gas from the Westinghouse fluidized gasification process using Illinois No. 6 bituminous coal and high-temperature fuel gas cleanup (see Figure 4.5).

The recommended minimum excess air quantities for each type of fuel considered in this study were as follows:

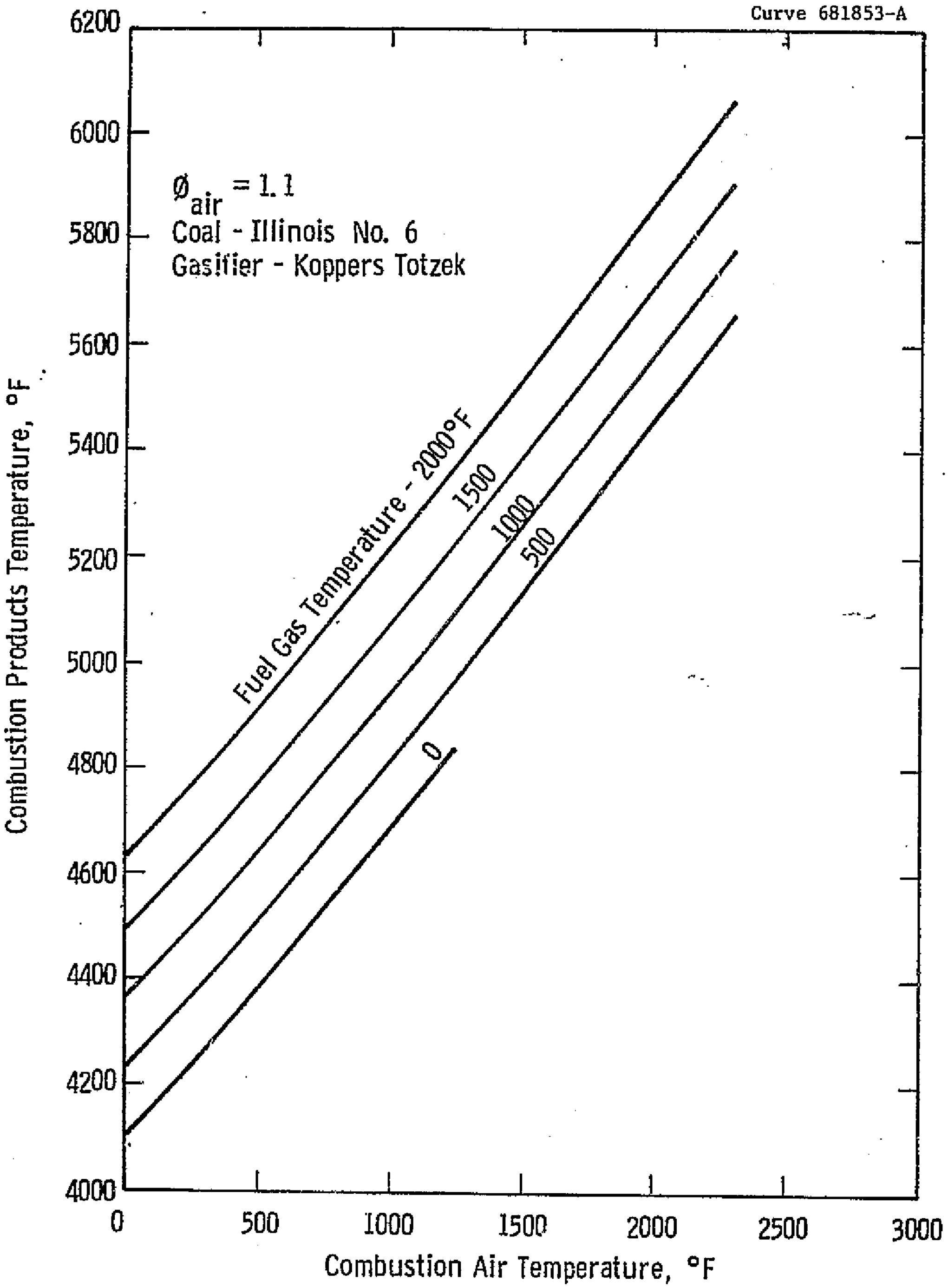

Fig. 4.4—Adiabatic flame temperature for intermediate - Btu fuel gas and air

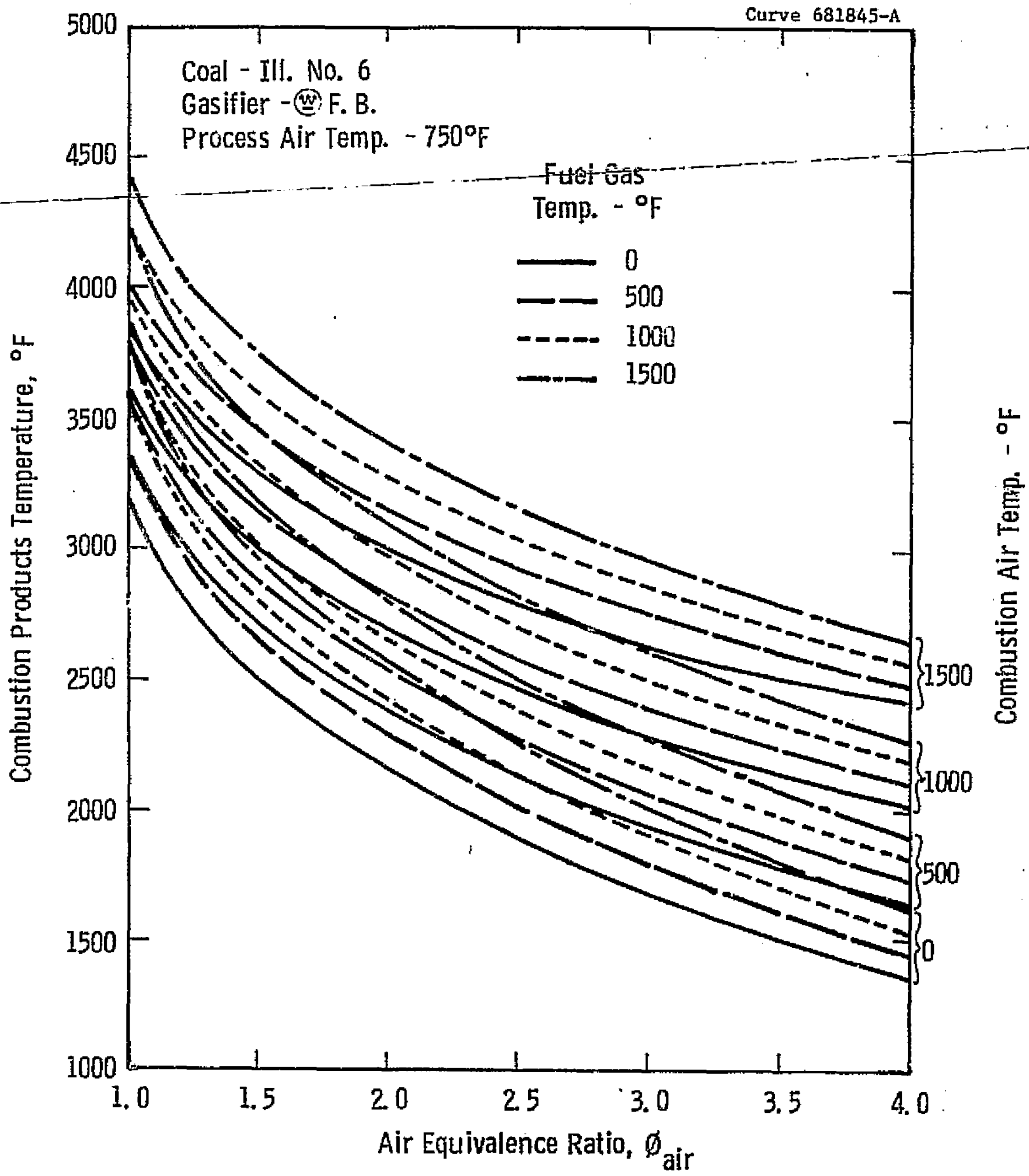

Fig. 4.5— Adiabatic flame temperature for low-Btu fuel gas as a function of fuel gas temperature, combustion air temperature, and air equivalence ratio

Solid fuels - 15 to 20%

Coal-derived liquid - ~~10 to 15%~~

High-Btu fuel gases - 10%

Intermediate-Btu fuel gases - 10%

Low-Btu fuel gases - 20%

The effect of combustion equipment type on the minimum excess air is second order.

4.3.2 Equipment Design and Performance

Five basic types of combustion equipment were considered in the study of advanced energy conversion techniques:

1. Furnaces for primary boilers
2. Gas turbine combustors
3. Burners for supplemental firing of heat recovery steam generators
4. Burners for fired heaters
5. Burners for MHD systems.

4.3.2.1 Furnaces for Primary Boilers

The fundamental classification of coal-fired boilers is according to furnace type. Most of the furnaces in conventional coal-fired boilers burn pulverized coal (70% less than 200 mesh) in suspension. Pulverized coal furnaces have a number of arrangements of the burners—for example, front- and corner-mounted. The only other type of boiler furnace currently in use in commerical utility boilers is the cyclone furnace which burns crushed coal [< 6.35 to 9.52 mm (0.25 to 0.37 in)]. The manufacturers of cyclone furnaces have a number of criteria for determining the suitability of a given coal for use in the cyclone furnace. These include constraints on volatile matter, ash content, ash viscosity, sulfur content, and iron to calcium-plus-magnesium ratio. The three ECAS-specified coals were examined and found to meet all the criteria for cyclone furnace suitability.

A third type of coal-fired boiler which is under development uses fluidized bed combustion. In the fluidized bed boiler concept, crushed coal [< 6.35 mm (0.25 in)] is burned in a fluidized bed in which boiler tubes are submerged. The bed enclosure would probably be of water-wall construction. The advantages of the fluidized bed boiler are:

- High bed-side convection heat transfer coefficients
- Ability to incorporate sorbents in the bed to remove the sulfur during the combustion process
- An operating temperature range of about 1006 to 1283°K (1350 to 1850°F). These low combustion temperatures give near-zero fixations of free nitrogen.
- Corrosion of the boiler tubes submerged in a fluidized bed is less than in a conventional boiler, as indicated by small-scale test results. This may make the use of steam superheat and reheat temperatures higher than the 811 to 866°K (1000 to 1100°F) currently used value for conventional boilers economically feasible.

Boiler furnaces can be classified according to the state of the coal ash. Most pulverized fuel furnaces operate with dry bottom ash; in other words, the ash temperature is below the melting point. Pulverized fuel furnaces, however, are sometimes designed to operate with wet bottoms for utilization of coals with low melting points. Slagging operation is inherent in the cyclone furnace design. Fluidized bed combustion boilers are necessarily nonslagging.

Boiler furnaces can also be classified according to operating pressure. Conventional coal-fired furnaces of both pulverized fuel and cyclone types operate at near-atmospheric pressures. Supercharged boilers have been operated on fuel oils principally in marine applications. The Velox is a well-known boiler of this type. In the Velox boiler, a turboexpander is used only to drive the combustion air compressor. The Velox concept has been applied to coal-firing in the high-pressure fluidized bed combustion boiler concept. There a power-generating gas turbine is used to supply the combustion air for the supercharged boiler.

The conventional[7] boiler efficiencies were calculated for each of the ECAS coals in the as received condition and are given in Table 4.8. Drying is required during pulverizing, but direct firing is assumed so the evaporated moisture is retained in the combustion air. These efficiencies are applicable to pulverized coal and cyclone furnaces.

Table 4.8 - Conventional Boiler Efficiencies

Coal	Illinois No. 6	Montana	North Dakota
Excess Air, %	20	20	20
Moisture, %	13	24.3	36.7
Stack Temperature, °F	320	260	260
Losses, %			
Incomplete combustion	0.50	0.50	0.50
Radiation	0.10	0.10	0.10
Latent heat	5.14	6.35	9.20
Sensible heat	6.10	4.60	5.06
Unaccounted & mfr. margin*	1.50	1.50	1.50
Total	13.34	13.05	16.36
Boiler Efficiency, %	86.66	86.95	83.64

*This item is primarily a manufacturers margin on guaranteed performance. To make heat rate calculations for conventional boilers consistent with those of other power systems, it should be deleted. It was recommended, therefore, that efficiency values of 88.16, 88.45, and 85.14 be used for the above cases.

Boiler efficiencies were estimated for atmospheric-pressure fluidized bed boilers for each of the three ECAS coals in the as received condition and are given in Table 4.9. Drying is also required during crushing, but direct firing is assumed so the evaporated moisture is retained in the combustion air.

Table 4.9 - Atmospheric Efficiencies for Fluidized Bed Boilers

Coal	Ill. No. 6	Montana	N. Dakota
Moisture	13.0	24.3	36.7
Excess Air	20	20	20
Stack Temperature, °F	260	260	260
Losses, %			
Incomplete combustion	2.40	2.40	2.40
Radiation	0.18	0.18	0.18
Solids sensible	0.10	0.10	0.10
Latent heat	5.14	6.35	0.20
Sensible heat	4.70	4.60	5.06
Sulfur reactions	2.10	0.50	0.60
Unaccounted & mfr. margin*	1.50	1.50	1.50
Total	16.12	15.63	19.04
Boiler efficiency, %			
With margin	83.88	84.37	80.94
Without margin	85.38	85.87	82.46

*This item is primarily a manufacturers margin on guaranteed performance. To make heat rate calculations consistent with those of other power systems, it should be deleted.

The conventional boiler efficiency format is not applicable to supercharged boilers. The procedure for calculating the plant heat rate for supercharged boilers, including high-pressure fluidized bed boilers, is as follows:

$$\text{Ideal fuel rate} = \left[\frac{(\text{Heat to steam} + \text{heat to gas turbine})}{\text{LHV}}\right] \quad (4.2)$$

$$\text{Plant heat rate (HHV)} = \left(\frac{\text{Ideal fuel rate}}{\text{Combustion efficiency}}\right) \left(\frac{\text{Higher heating value of fuel}}{\text{Net plant power}}\right) \qquad (4.3)$$

$$\text{Plant heat rate (HHV)} = \left(\frac{\text{(Heat to steam + heat to gas turbine)}}{\text{Net plant power}}\right) \left(\frac{\text{(HHV/LHV)}}{\text{Combustion efficiency}}\right) \qquad (4.4)$$

The combustion efficiencies for high-, intermediate-, and low-Btu fuel gases from coal and for distillates from coal-derived liquid were assumed to be 100%.

The combustion efficiencies for fluidized bed combustors with once-through desulfurization were estimated for each of the ECAS coals and are given in Table 4.10.

Table 4.10 - Combustion Losses in Fluidized Bed Combustion

Coals	Illinois No. 6 Bituminous	Montana Subbituminous	North Dakota Lignite
Incomplete Combustion	1.5 %	1.5 %	1.5 %
Radiation Losses	0.15	0.15	0.15
Solids Sensible Heat	0.1	0.1	0.1
Desulfurization Reactions	2.1	0.5	0.6
TOTAL LOSSES	3.85%	2.25%	2.35%
Combustion Efficiency	96.15%	97.75%	97.65%

The pressure loss in a conventional burner for pulverized coal is about 995 Pa (4 in H_2O) (1%) (Reference 4.7). Typical fan pressure heads for the conventional pulverized coal boilers are shown in Table 4.11 (Reference 4.7).

Table 4.11 - Fan Pressure Levels

Fan	ΔP-in H_2O
Primary	5.0
Forced Draft	10.0
Induced Draft	12.0

The allowance for fan power for conventional pulverized fuel boilers was 1%* of plant output power. The fan power requirements for cyclone furnace boilers are about one-third greater than for pulverized fuel boilers. The fan power allowance for cyclone furnace boilers, therefore, is 1.3% of plant output power.

The estimated pressure drops for the atmospheric-pressure fluidized bed boiler are shown in Table 4.12.

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*This does not include the pressure losses associated with flue gas desulfurization. The total loss including an allowance for flue gas desulfurization is 2.7%.

Table 4.12 - Pressure Drops in Atmospheric Fluid Bed Boilers (Reference 4.8) Gas-Side Pressure Drops, in H_2O

Ducts		1.43
Distributor Plate		10.8
Bed		27.5
Convection Bank		0.1
Dust Collector		3.0
Air Heater, Air Side		3.0
Air Heater, Gas Side		1.5
Electrostatic Precipitator		3.0
	TOTAL	50.33 in H_2O

The pressure drops across the distributor plate and the bed are shown to be substantial, so the overall pressure losses are about double those of a conventional pulverized coal boiler. The allowance for fan power for atmospheric pressure fluidized bed boilers, therefore, is 2% of plant output power.

The estimated pressure losses for the high-pressure fluidized bed boiler are given in Table 4.13.

The overall pressure loss for supercharged boilers with conventional burners is about 6% (Reference 4.9). For supercharged boilers the effect of pressure loss on plant performance is manifested in the gas turbine cycle performance. No allowance for fan or compressor powers to overcome the pressure loss is required.

4.3.2.2 Gas Turbine Combustors

Gas turbine combustors can be classified according to configuration and to fuel used. There are two basic combustor configurations (integrated and external). Industrial and utility gas turbines manufactured in the United States use integrated combustors almost exclusively. Industrial and utility gas turbines made in Europe generally use external combustors.

Table 4.13 - Pressure Drop Through a Pressurized Fluidized Bed Boiler (Reference 4.8)

Component	ΔP/P,%
Air Outlet Transition	0.75
Piping between Transition and Boiler	0.20
Control Valves in Open Position	0.10
Internal Air Passages to Plenum	0.05
Distribution Plate	1.00
Bed	3.10
Internal Gas Passage to Inlet of First-Stage Coll ctor	0.10
First-Stage Collector	0.50
Second-Stage Collector	0.50
Third-Stage Collector	0.75
Piping from Third-Stage Separator to Transition	0.20
Hot Gas Inlet Transition	0.75
TOTAL	8.00

Integrated combustors have volumetric constraints but avoid the high-temperature ducting problem associated with external combustors. Historically, United States gas turbines have operated with turbine inlet temperatures several hundred degrees higher than those used in European gas turbines.

Commercial gas turbine combustors are nominally designed for operation on natural gas and/or No. 2 distillate but will operate satisfactorily on most crude oils and on treated residual oils. These conventional combustors are applicable to high-and intermediate-Btu fuel gas from coal and to distillates from coal-derived liquids. External combustors which had to be developed for use with blast furnace gas are applicable to low-Btu fuel gas produced by a gasifier with either hot or cold gas cleanup. The integrated combustor will probably be suitable for hot low-Btu fuel gas but may not be suitable for cold low-Btu fuel gas.

The higher heating value of the fuel gas from air blast coal gasification processes is in the range of from 3.725 to 6.519 MJ/std m^3 (100 to 175 Btu/scf), while that of blast furnace gas is from 2.980 to 3.352 MJ/std m^3 (80 to 90 Btu/scf). More importantly, the hydrogen content of low-Btu fuel gas is about an order of magnitude higher than that of blast furnace gas. It is possible, therefore, that the integrated gas turbine combustor will also be applicable to cold low-Btu fuel gas. The development of gas turbine combustors for low-Btu fuel gas over a range of inlet temperature is currently under way at the Westinghouse Research Laboratories.

Direct use of pulverized coal in gas turbine combustors has been investigated extensively in the United States and Australia without success. During the 20-year period starting in 1945, the Locomotive Development Committee (LDC) and later the Bureau of Mines (BOM), Morgantown, tested a coal-fired gas turbine intended for locomotive application (References 4.9 and 4.10). The rate of erosion of the turbine vanes and blades was so high that they concluded the concept was not economically feasible. Volume constraints on gas-cleaning equipment probably made a significant contribution to the high erosion rates.

More recently, the Australians spent about 10 years trying to develop a gas turbine which would operate on brown coal, but with limited success (Reference 4.12).

Currently, Combustion Power is investigating the feasibility of burning coal in a gas turbine with a fluidized bed combustor (Reference 4.13). Earlier tests of the unit, using prepared refuse, indicated that the erosion problem may be significantly less than with the pulverized coal combustors used in the LDC test unit. The deposition of alumina derived from aluminum foil in the refuse, however, presented a serious problem which should not exist with coal. This coal-fired gas turbine with the fluidized bed combustor may be more successful than the earlier units with pulverized coal combustors for two reasons. First, the physical properties of the ash from the fluidized bed combustor are considerably different from those from a pulverized coal combustor. Ash particles from the fluidized bed combustor are fragile flakes rather than the hard cenospheres from pulverized coal combustion. Secondly, significant advances have been made in particulate removal technology since the earlier development programs. In addition, the fluidized bed combustor is capable of in-bed desulfurization.

A typical pressure loss for an integrated gas turbine combustor is 5.5% (Reference 4.14). This is also considered to be applicable to an external gas turbine combustor.

4.3.2.3 Burners for Supplemental Firing of Heat Recovery Steam Generators

There are two types of afterburners for heat recovery steam generators. One type operates on 100% vitiated combustion air and is suitable for application to high- and intermediate-Btu fuel gases and to distillates from coal-derived liquids. The second type uses supplemental combustion air, either partially or wholly. While the second type can be used for the above listed fuels, it is probably mandatory with low-Btu fuel gas. The pressure loss of an afterburner for firing a heat recovery steam generator is about 1% (Reference 4.14).

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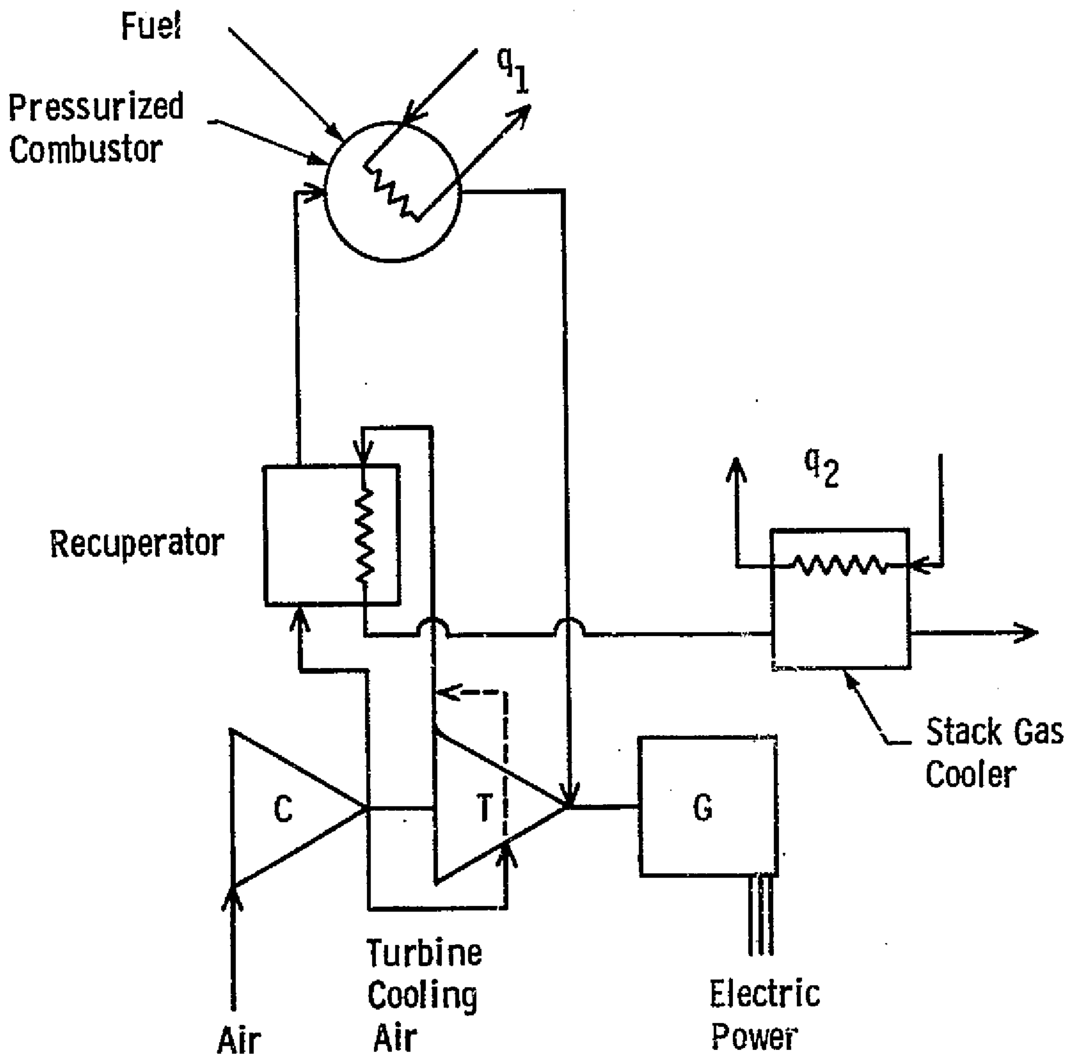

Fig. 4.6—Pressurized combustor subsystem

The combustion efficiencies for afterburners for heat recovery steam generators burning high-, intermediate-, and low-Btu fuel gases, and distillates from coal-derived liquid, were assumed to be 98%.

4.3.2.4 Pressurized Fired Heaters

All of the closed-cycle power systems studied considered pressurized-fired heaters as one of the configuration options. Figure 4.6 is a schematic diagram of the pressurized combustor subsystem for fired heater application of coal or coal-derived fuels. As shown in Figure 4.6, there are two points at which heat can be transferred from the pressurized combustor subsystem to the primary power cycle: directly from the combustor and from the stack-gas cooler.

A computer program was written to calculate the performance of a pressurized combustor subsystem. This program was used to make a parametric analysis of this subsystem to determine the effects of turbine inlet temperature, compressor pressure ratio, air equivalence ratio, and recuperator effectiveness on the quantities of heat available from the combustor and the stack-gas cooler and the power generated by the gas turbine generator. The fuel used for these runs was Illinois No. 6 bituminous coal, dried to a moisture content of 3%.

The assumptions made for the characteristics of the various components of this subsystem are as follows:

- Ambient conditions:

  Pressure = 101.3 kPa (14.7 psi) abs
  Dry bulb temp. = 307°K (93°F)
  Wet bulb temp. = 298°K (77°F)

- Compressor:

  Inlet duct $\Delta P/P = 0.0075$
  $\eta_c = 1/(1.0983 + 0.00422 \times PR) - 0.0242$
  PR - treated parametrically

- Recuperator:

  $\Delta P/P$ (cold side) = 0.03
  $\Delta P/P$ (hot side) = 0.03
  Effectiveness (ϵ_{REC}) = treated parametrically

- Combustor:

  Type – fluidized bed with in-bed desulfurization and heat exchangers

  Efficiency = 96% (includes effect of desulfurization)

  $\Delta P_B/P$ – treated parametrically

  Air equivalence ratio – treated parametrically

- Turbine:

  $\eta_{tpoly} = 0.89$
  Cooling air fraction (Z) = (T(5) – 1280)/6400

  Inlet temperature (T(5)) – treated parametrically

- Stack-gas cooler:

  $\Delta P/P = 0.03$

  Outlet temperature – 422°K (300°F)

- Exit ducting:

  $\Delta P/P = 0.0039$

The values used for the parametric variables are as follows:

- Turbine inlet temperature (T(5))

  1200[a], 1500, 1800, and 2100[b] °F

- Compressor pressure ratio (PR)

  5, 10, 15, and 20

- Air equivalence ratio (ϕ_{air})

  1.0, 1.2[c], 2.0, and 3.0

- Combustor pressure loss, $\Delta p/p$

  0.03, 0.06, and 0.09[d]

- Recuperator effectiveness (ε_{REC})

  0, 0.8, 0.9, and 0.95

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[a]The minimum operating temperature for a fluidized bed combustor with in-bed desulfurization is about 978°K (1300°F). For those cases where the turbine inlet temperature is less than 978°K (1300°F), it is assumed that the bed temperature would be 978°K (1300°F) and that there would be a convection-type heat exchanger to cool the products of combustion to the turbine inlet temperature after they leave the fluidized bed combustor.

The results of this parametric study are given in Tables 4.14 through 4.17. The trends exhibited here are generally applicable to all fuels and combustion apparatus. However, there are a few differences among the fuels and types of combustion apparatus. It was noted above that the minimum value of ϕ_{air} for fluidized bed combustion of solid fuels is 1.2. For distillate fuel combustors the minimum ϕ_{air} is 1.10 to 1.15, and for high-Btu gaseous fuel combustors it is 1.05 to 1.10. Since the heat available from the combustor (q_1) is a rather strong function of ϕ_{air} for values near 1.0, the effect of fuel type on q_1/W_a at minimum ϕ_{air} is significant.

The pressure loss in the combustor/heat exchanger will vary significantly with combustor type. For fluidized bed combustion with in-bed heat transfer surface, the estimated pressure loss is about 8%. For a clean liquid or for gaseous fuel combustors and a conventional heat exchanger, the pressure loss may be as low as 6%. It is shown, however, in Table 4.16 that the q_1 and q_2 values are a weak function of this pressure loss. Gas turbine power is shown to decrease about 1% for each 1% increase in combustor pressure loss.

Mechanical design of the gas turbine limits the turbine exit temperature to about 811°K (1000°F). In a number of the cases with high turbine inlet temperatures and low pressure ratios, the turbine outlet

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[b] The maximum operating temperature for fluidized bed combustion with in-bed desulfurization is about 1283°K (1850°F). This temperature was used only to determine general trends.

[c] This is considered to be the minimum value of air equivalence ratio for fluidized bed combustion.

[d] The estimated pressure loss for the fluidized bed combustor with in-bed desulfurization and heat exchanger is 9%.

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TABLE 4.14– EFFECT OF AIR EQUIVALENCE RATIO AND TURBINE INLET TEMPERATURE

Fuel	Illinois No. 6 Bituminous Coal												→
Moisture, %	3												→
$(W_f / W_a)_{st}$	.109												→
η_b	.96												→
ϕ_{air}	1.2	2.0	3.0	1.2	2.0	3.0	1.0	1.2	2.0	3.0	1.2	2.0	3.0
PR	15												→
T(5), °F	1200		→	1500		→	1800			→	2100		→
ε_{rec}	0					→	0.8						→
$\Delta P_b/P$	0.09												→
q_1/W_a, Btu/lb.	907.4	505.3	303.6	783.5	400.2	207.8	845.4	663.6	299.1	116.5	572.7	231.4	60.40
t_{bed}, °F	1300		→	1500		→	1800			→	2100		→
q_2/W_a, Btu/lb	51.3	44.1	40.9	108.4	97.70	92.71	162.4	157.3	147.4	142.8	177.3	164.5	158.5
t_9, °F	483	465	457	682	661	652	853	849	839	835	918	901	893
t_{10}, °F	300												→
P/W_a, kW/(lb/s)	30.73	24.37	20.85	62.53	55.14	51.07	89.84	85.04	77.54	73.21	107.5	99.20	94.41
$(W_f/W_a)_{overall}$	0.0946	0.0568	0.0378	0.0914	0.0549	0.0366	0.1065	0.0869	0.0522	0.0348	0.0825	0.0495	0.0329

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TABLE 4.15— EFFECT OF RECUPERATOR EFFECTIVENESS AND COMBUSTOR/HEAT EXCHANGER PRESSURE LOSS

Fuel	Illinois No. 6 Bituminous Coal							→			→
Moisture, %	3							→			→
$(W_f/W_a)_{st}$	.109							→			→
η_b	.96							→			→
ϕ_{air}	1.2							→			→
PR	15							→			→
T(5), °F	1800			→	2100			→	1800		→
ϵ_{rec}	0	0.8	0.9	0.95	0	0.8	0.9	0.95	0.8		→
$\Delta P_b/P$	0.09							→	0.09	0.06	0.03
q_1/W_a, Btu/lb.	654.3	663.6	664.7	665.3	532.4	572.7	577.8	580.4	663.4	661.7	660.0
t_{bed}, °F	1800			→	2100			→	1800		→
q_2/W_a, Btu/lb	161.6	157.3	156.2	155.7	212.4	177.3	172.3	169.6	157.4	156.5	155.6
t_9, °F	863	849	845	843	1033	918	901	892	849	846	843
t_{10}, °F	300							→			→
P/W_a, kW/(lb/s)	90.16	85.04		→	112.8	107.5		→	84.97	87.71	90.33
$(W_f/W_a)_{overall}$	.0869			→	.0825			→	.0869		→

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TABLE 4.16— EFFECT OF COMPRESSOR PRESSURE RATIO - NO RECUPERATOR

Fuel	Illinois No. 6 Bituminous Coal															→
Moisture, %	3															→
$(W_f / W_a)_{st}$	.109															→
η_b	.96															→
ϕ_{air}	1.2															→
PR	5	10	15	20	5	10	15	20	5	10	15	20	5	10	15	20
T(5), °F	1200			→	1500			→	1800			→	2100			→
ε_{rec}	0															→
$\Delta P_b/P$	0.09															→
q_1/W_a, Btu/lb.	811.9	868.4	907.4	941.5	691.3	745.9	783.5	816.5	566.6	618.5	654.3	685.7	449.1	498.4	532.4	562.2
t_{bed}, °F	1300			→	1500			→	1800			→	2100			→
q_2/W_a, Btu/lb.	128.8	79.2	51.3	33.2	193.9	136.6	108.4	89.66	255.0	192.8	161.6	141.8	309.6	245.8	212.4	192.5
t_9, °F	750	580	483	419	968	777	682	617	1169	966	863	796	1345	1142	1033	968
t_{10}, °F	300															→
P/W_a, kW/(lb/s)	49.03	42.01	30.73	14.45	69.51	72.18	62.53	48.14	84.45	94.92	90.16	78.44	98.7	113.4	112.8	102.8
$(W_f/W_a)_{overall}$	.0946			→	.0914			→	.0869			→	.0825			→

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TABLE 4.17 – EFFECT OF COMPRESSOR PRESSURE RATIO - WITH RECUPERATOR

Fuel	Illinois No. 6 Bituminous Coal									→
Moisture, %	3									→
$(W_f / W_a)_{st}$	.109									→
η_b	.96									→
$\emptyset_{air}$	1.2									→
PR	5	→	10	5	10	15	5	10	15	20
T(5), °F	1200	1500	→	1800		→	2100			→
ε_{rec}	0.8									→
$\Delta P_b/P$	0.09									→
q_1/W_a, Btu/lb.	874.2	795.8	768.1	705.6	676.3	663.6	614.5	586.3	572.7	566.3
t_{bed}, °F	1300	1500	→	1800		→	2100			→
q_2/W_a, Btu/lb.	71.2	94.89	119.0	122.2	140.1	157.3	150.7	163.7	177.3	193.0
t_9, °F	552	635	718	730	791	849	828	872	918	970
t_{10}, °F	300									→
P/W_a, kW/(lb/s)	44.30	63.92	67.49	76.14	89.68	85.04	92.0	107.5	→	98.0
$(W_f/W_a)_{overall}$	.9046	.0914	→	.0869		→	.0825			→

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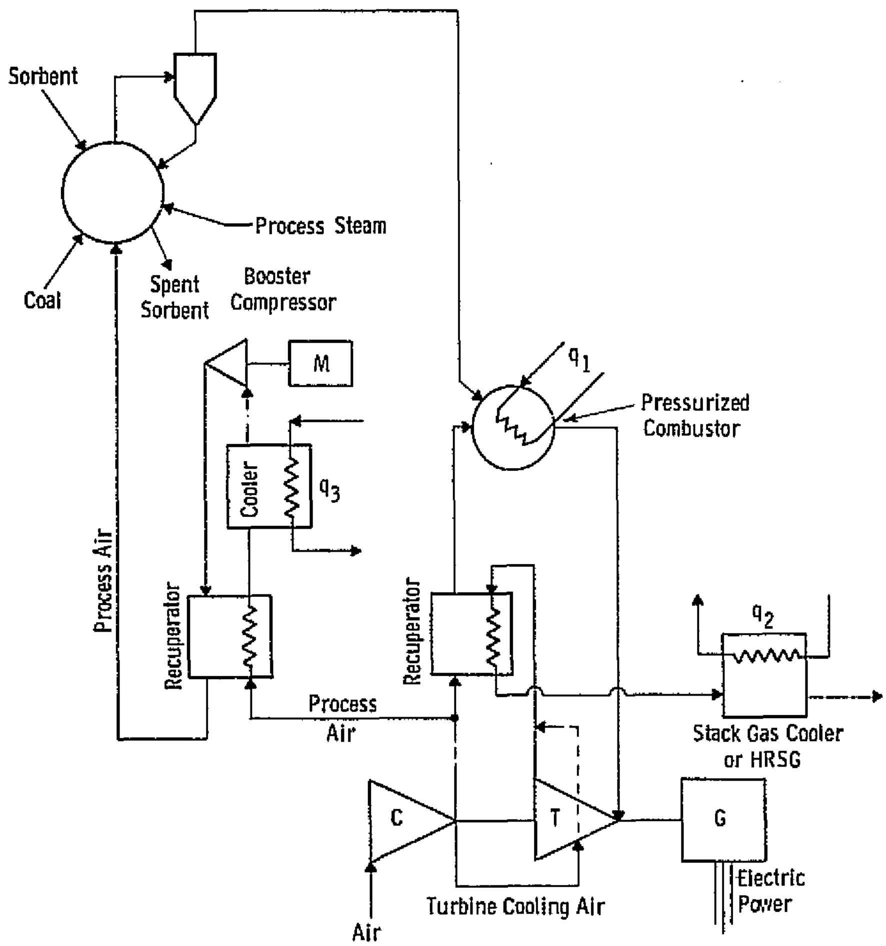

Fig. 4.7- Pressurized combustor sub-system with integrated low-Btu gasification

temperature exceeds 811°K (1000°F). These cases, therefore, may be only of academic interest.

A schematic diagram of a pressurized combustor subsystem with integrated low-Btu gasification is shown in Figure 4.7. In this configuration there is an additional source of waste heat available from the process air cooler ahead of the booster compressor.

A wide selection of commercial combustors is available for application to pressurized fired heaters. These are applicable to high- and intermediate-Btu fuel gases, coal-derived liquids, low-Btu fuel gas, and solid fuels. Fluidized bed combustors are also applicable to fired heaters for direct combustion of coal. Conventional burners of the cell or circular register types were assumed for use with high-, intermediate-, and low-Btu fuel gases and distillates from coal-derived liquids. Fluidized bed combustion was assumed for direct firing of coal.

The combustion efficiencies for high-, intermediate-, and low-Btu fuel gases and for distillates from coal-derived liquids were assumed to be 100%. The combustion efficiencies for fluidized bed combustion of each of the three coals are given in Table 4.10.

The conventional burners (cell and circular register types) have pressure drops in the range of from 1 to 2%. The fluidized bed combustors have estimated pressure drops of about 8%.

4.3.2.5 Burners for MHD Systems

Open-Cycle MHD Combustion Design

Combustion chambers such as may be used for pilot plants or first-generation MHD power plants are discussed here. Although experience with such plants is lacking, there is a body of technology regarding gas and oil combustion systems (References 4.15 and 4.16).

Gas fired furnaces for high output temperatures can be made with zirconium oxide liners (Reference 4.17). Operation is found to be highly satisfactory.

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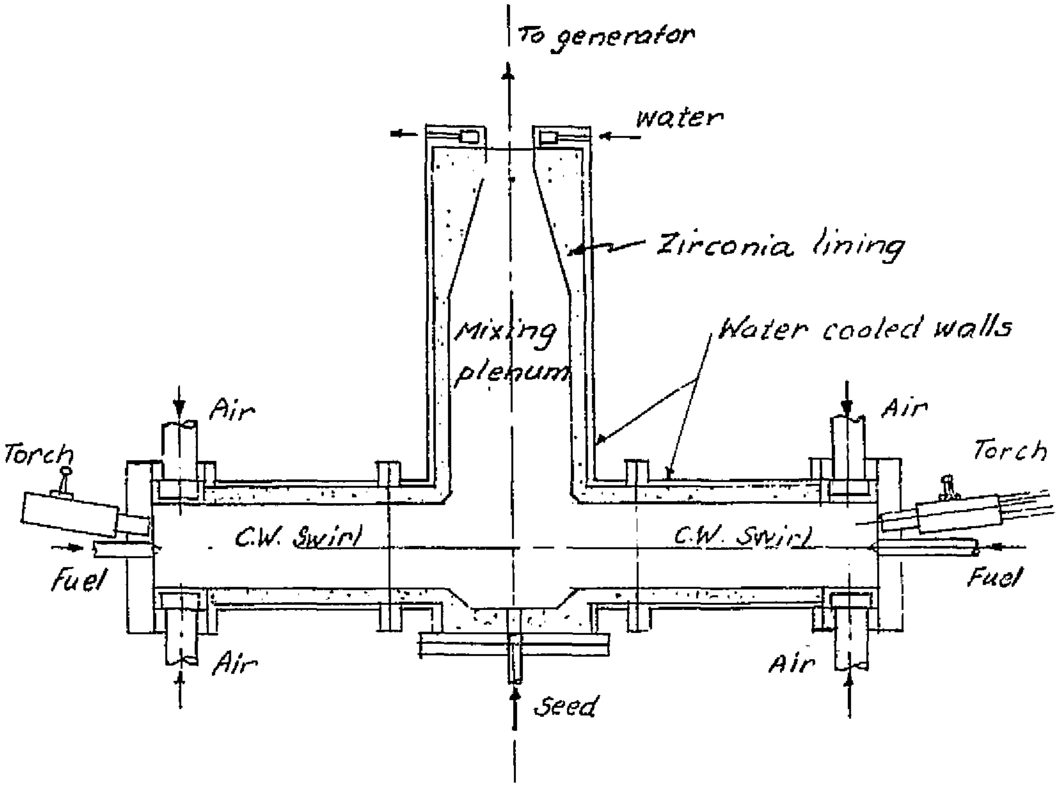

Fig. 4.8—Two-burner opposed swirl combustor

A fairly reliable system is that in which one has a vortex flow, followed by a blending region to minimize the swirl of gases entering the generator. It may be advisable to use opposed burners to eliminate swirls, as in Figure 4.8.

In cyclonic combustion chambers using liquid or gaseous fuels, the fuel is normally injected from a source at the center of the upstream end plate. With liquid fuels a swirl-type atomizer can be used. Some primary air admission around the burner is desirable. With gaseous fuels a multiple port injector is appropriate but with swirling primary air to improve circumferential uniformity.

Alternatively to vortex combustors, straight-through plug-flow burners may be used. In such burners, the burning takes place throughout the volume, and a volume basis for loading designation is appropriate. An example of a combustor of this type is the oil-burning chamber used in the British Marchwood experiments (Reference 4.18). The ultimate goal was a 2000 MWt (6.825×10^9 Btu/hr) power plant, and this was to be preceded by a 60 MWt (2.047×10^8 Btu/hr) plant. To assure a sound design for the 60 MWt (2.047×10^8 Btu/hr) unit, an experimental rig was first designed and operated with the following parameters:

Total thermal input	12 MW
Assumed residence time	50 ms
L/D ratio of combustor	5:1
Diameter of chamber	0.33 m
Length of chamber	1.53 m
Maximum operating pressure	9 atm
Air preheat	1700°F
Equivalent ratio (design)	1.025
Oil-heating value (HHV)	42.9 MJ/kg
Design airflow	2.9 kg/s.

The thermal input here includes the air preheat energy. The thermal input from the fuel oil alone is about 9 MW (3.071×10^7 Btu/hr) The chamber is of cylindrical form with water-cooled metal walls (11 Cr, 0.6 Ni, 0.8 Mo, 0.25 V). A single oil burner (Babcock & Wilcox Mark P Simplex) with a

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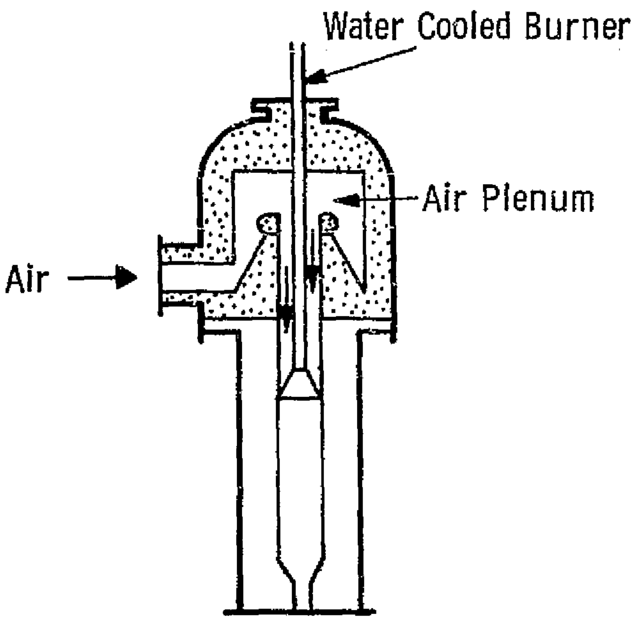

Fig. 4.9—Layout of liquid fuel MHD combustor. (Ref. 4.18)

water-cooled jacket was used. Best results were obtained with an inverted "flower pot" -type mixer with eight radial air admission holes, the ring of holes being about 0.1 m (3.9 in) below the burner. When operated in a plug-flow mode (without the mixer) the combustion was incomplete and very smoky. Typical test conditions in the stirred mode were 2.64 kg/s (5.82 lb/s) air and 0.195 kg/s (0.43 lb/s) oil. Heat fluxes averaged about 1 MW/m^2 (3.17×10^5 $Btu/hr\text{-}ft^2$) in the combustion chamber. (Calculated value with unit emissivity was 4.7 MW/m^2 (1.49×10^6 $Btu/hr\text{-}ft^2$), which included the 0.6 MW/m^2 (1.9×10^5 $Btu/hr\text{-}ft^2$) convective portion.) A flame temperature of about 2700°K (4400°F) was measured with a 1500°K (2240°F) preheat. A general sketch is shown in Figure 4.9.

In the Russian U-02 test facility's latest modification (Reference 4.19), experimental high-intensity combustors have been operated on natural gas at heat release rates up to 4016 W/m^3 Pa (407 MW/m^3 atm or 39.33×10^6 $Btu/hr\text{-}ft^3$ atm) or 1145 W/m^3 Pa (116 MW/m^2 atm or 36.78×10^6 $Btu/hr\text{-}ft^2$ atm). Losses due to incomplete combustion were 1.5 to 3%. This is apparently a vortex-type combustor with zirconia lining. The unit has run over 3.6 Ms (1000 hr).

The Russian U-25 combustor (25 MW-MHD) burns 4.75 kg/s natural gas with a preheated mixture of 10.2 kg/s of oxygen, 33.7 kg/s air, and 1.35 kg/s recycled seed solution. Combustion takes place at 278.6 kPa (2.75 atm), and the outlet temperature is 2870°K (4706°F). In this case a ram-jet type burner is used. Gas is injected through narrow longitudinal slots in the side wall upstream of an array of water-cooled tubes which serve as a radiation screen as well as flame anchors (Reference 4.20).

Combustion systems for coal which send the ash through the generator duct have been studied by the AVCO Corporation and by the CEGB group in England. The former used what is referred to as a ram-jet type combustor, as it involves flame holders to anchor the flame in a mixture of pulverized coal and air (Figure 4.10). The investigators in England favor a plug-type burner similar in some respects to that of AVCO. In both cases satisfactory combustion of coal was obtained (References 4.18 and 4.21).

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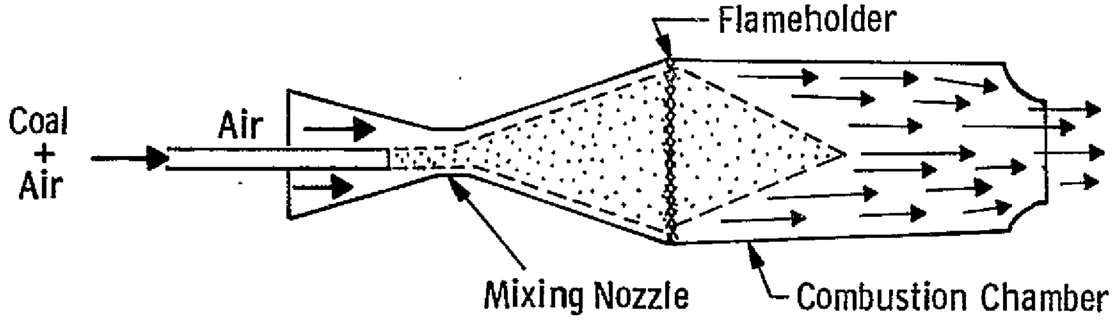

Fig. 4.10—Arrangement of ram-jet type combustion chamber for pulverized coal. (Ref. 4.23)

If ash is sent directly through the generator there may well be condensation of the ash constituents in the downstream section. There can also be condensation even in the upstream section on cooled walls. The behavior of the generator when coated with layers of slag (Reference 4.22), which is electrically conducting at high temperatures, will most certainly be impaired. It seems appropriate, therefore, to consider means of assuring slag-free flow in the generator. This may be accomplished by use of a cyclone combustor.

Conventional cyclone furnaces (e.g., those of the Babcock and Wilcox Company) will remove 80 to 90% of the coal ash as liquid slag. Temperatures in the cyclone chamber will be 2000 to 2100°K (3140 to 3320°F). It is important that the mean temperature exceed by a margin of a few hundred degrees the value T_{250} (i.e., the temperature at which the slag viscosity is 250 poises). It is important to continually drain the slag away, to prevent excessive accumulation in the chamber, and to ensure removal of liquid iron. Liquid iron is most likely to appear in reducing atmospheres. Slight excess air (about 10%) is, therefore, desirable in the cyclone furnace. A sketch of a conventional cyclone furnace as used by the German Babcock and Wilcox Company is shown in Figure 4.11. The coal as well as the air are brought in from secant admission ports. The coal injection is along a secant (rather than tangential) to prevent erosion by particle scouring of the inner surface. Typically the coal fed to cyclone furnaces is crushed to 50% less than 800 μm (31.5 mils). Cyclone chambers, because of the high temperatures prevailing, are capable of burning a wide variety of coals, ranging from lignite to anthracite, and even coal/water slurries. They can also be operated on gas or oil. The ability to retain 80 to 90% of the ash is of considerable advantage in reducing fouling in the boiler, and facilitating final stack-gas cleanup.

The product of the volumetric heat release rate and the diameter of a conventional cyclones, as reported by Seidl (References 4.23 and 4.24) is approximately:

$$qD = 8.8 \text{ MW/m}^2 \text{ or } 2.8 \times 10^6 \text{ Btu/hr-ft}^2$$

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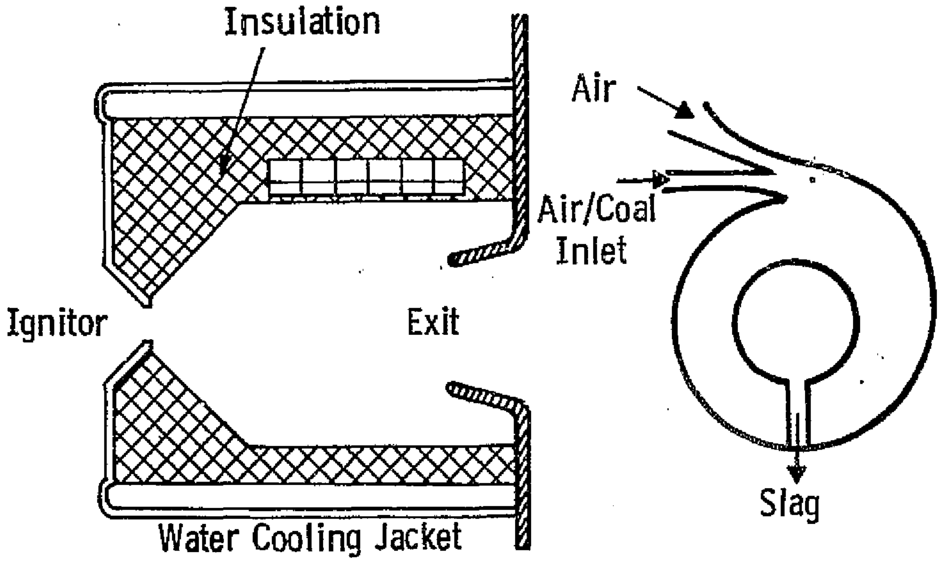

Fig. 4.11—Cyclone furnace of German Babcock and Wilcox design used at Wilton Works of Imperial Chemical Industries, England. Furnace diameter 10 ft., length 20 ft. (Figures from Journal of Institute of Fuel, 1961, Ref. 4.22)

where q is the volumetric heat release rate and D is chamber diameter. For chambers of L/D = 1.5 this is equivalent to:

$$\frac{Q}{A} = 13.2\ \text{MW/m}^2 \text{ or } 4.2 \times 10^6\ \text{Btu/hr-ft}^2$$

where Q is heat release rate and A is chamber cross-sectional area. The above relations are equivalent to the statement that $q\sqrt{Q}$ is constant at the limiting thermal loading. Reference may be made to Figure 4.12 from Seidl (Reference 4.24).

Flow patterns in cyclone chambers generally show an annular region of upstream swirling flow surrounding a core region flowing downstream. In the core region, near the outlet, there may also be a reversal of flow, since a low-pressure region exists at the center of the vortex. Typical flow patterns (Reference 4.23) are shown in Figure 4.13.

In application of the cyclone combustion chamber technique to the MHD power plant we must seek to develop outlet temperatures close to 2700°K (4400°F). Such high temperatures are, of course, attainable by air preheating or oxygen enrichment. However, a problem would arise with excessive vaporization of the ash constituents and a resultant increase in ash carry-over. Therefore, one may use a two-stage cyclone combustion system (Reference 4.25), where the ash is removed in the first-stage cyclone before the highest temperatures are reached.

The heat transferred to the wall depends on a balance between heat received (mainly by radiation) and heat transferred through the slag layers by conduction. There will also be some heat consumed in the partial vaporization of the slag. A thicker slag layer tends to reduce the heat transported. It was shown theoretically by Cohen and Reid (Reference 4.26) that for given slag-flow properties (e.g., viscosity) the heat transferred through the wall tends to vary as the $(\text{slag-flow rate})^{-1/3}$. In the excellent review paper of Roberts (Reference 4.27), results of several other investigators are reported. For example, Marshak tested vertical cyclones and found the heat flux decreased by 40% when the ash quantity was increased by 110%. The percentage of heat loss was about 5% for the lower slag flow. Other investigators have also generally observed as 4 to 5% heat loss.

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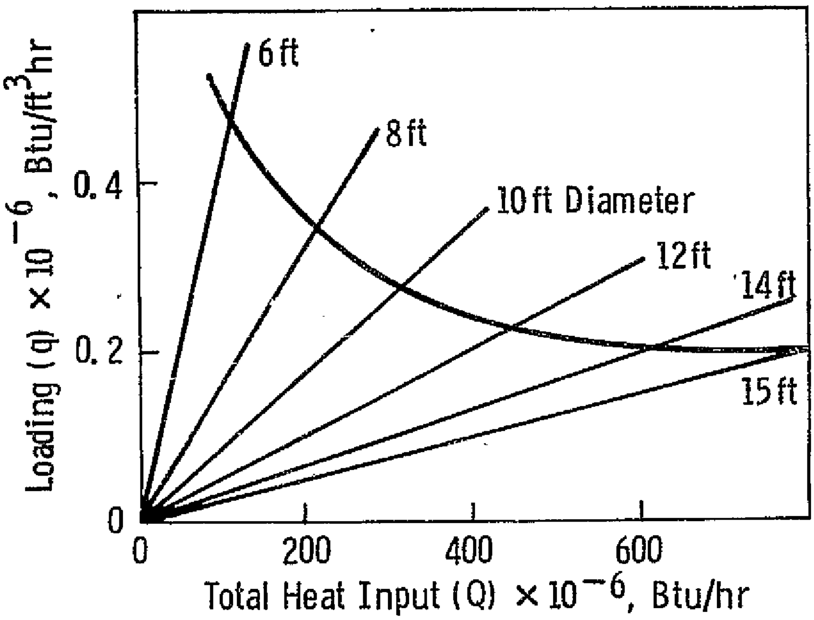

Fig. 4.12—Typical relation of heat release rate to total heat input for horizontal cyclone burners. (Ref. 4.24)

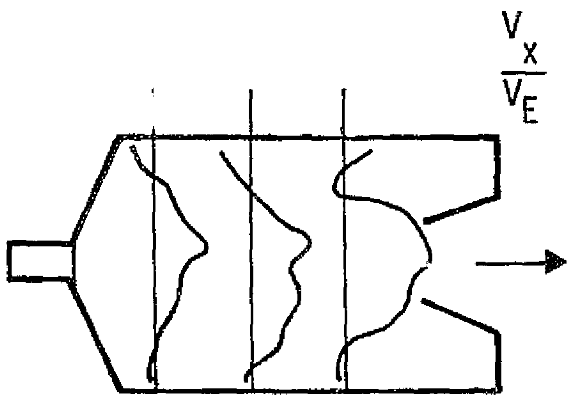

Fig. 4.13—Cyclone combustor. Typical distribution of axial velocities for coal. (Ref. 4.23)

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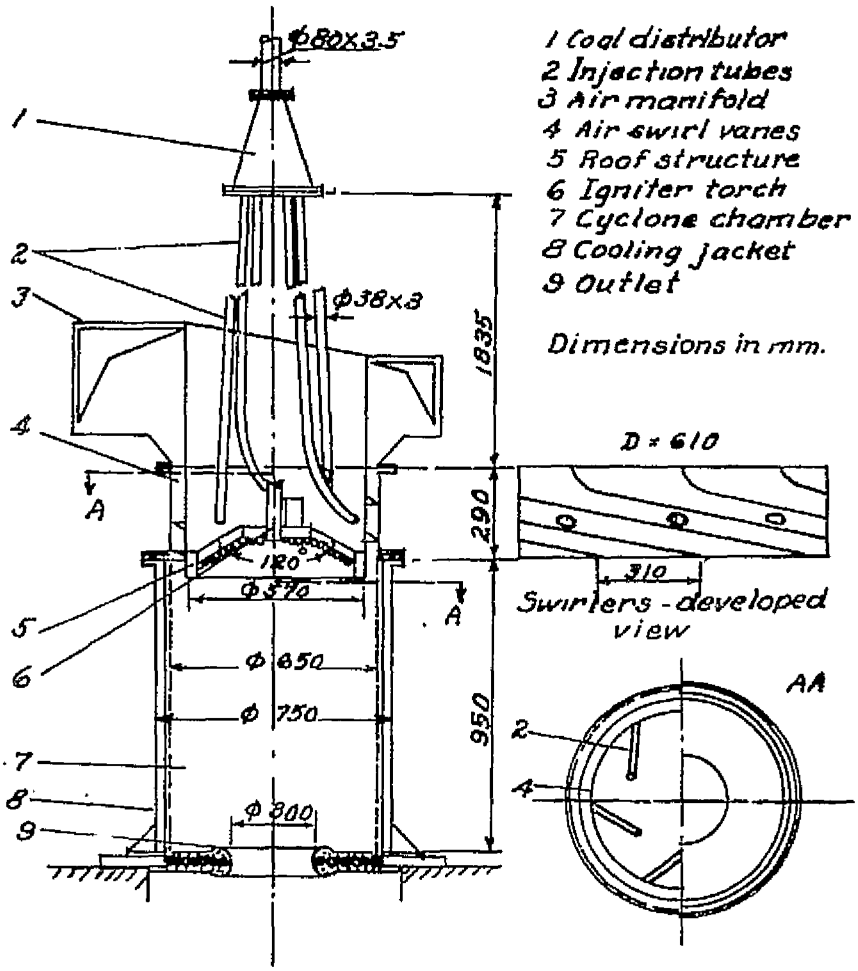

Fig. 4. 14—Single-stage cyclone coal-burning chamber for MHD generator application, as developed at Krzizanovsky Power Institute

An interesting MHD coal combustor experiment has been reported. Tager et al. (Reference 4.28) report tests with a vertical cyclone burning pulverized coal with an outlet temperature of 2573°K (4172°F). A sketch is reproduced in Figure 4.14. This chamber, running at 101.3 kPa (1 atm), had a heat release of 20 MW/m^2 (6.34×10^6 $Btu/hr-ft^2$), and it is estimated it would have a capacity of 100 MW/m^2 (31.7×10^6 $Btu/hr-ft^2$) at 0.506 MPa (5 atm). It retains 80% of the coal ash at 101.3 kPa (1 atm). Increase of pressure should increase ash retention capability.

We should mention, finally, MHD systems using coal as fuel which transform the coal into a clean fuel gas. In principle we could consider, again, the two-stage cyclone with the first stage operating as a gasifier. Thus, the first stage of the two-stage system could be operated at equivalence ratio ϕ_{air}, of about 0.6. It would be an air-blown gas producer and would use no steam. (We wish to keep hydrogen input to a minimum). A gas, consisting of carbon monoxide, carbon dioxide, and nitrogen, with a little hydrogen, would be generated. This gas would then be burned in the second-stage combustion chamber. Such arrangements have been considered from time to time by various investigators (References 4.29 and 4.30).

In the work in England in connection with the Marchwood project (Reference 4.18), both gasifying and nongasifying coal combustion systems were considered. Schematic diagrams are shown in Figure 4.15. The short time scale imposed in the British effort required concentration on a single-stage system, although it was felt that ultimately a two-stage arrangement might be preferable. It was also felt that an axial flow combustor, with turbulent plug flow, would yield higher volumetric heat release in large units, since cyclone burners tend to follow the energy per unit area loading criterion. Therefore, an axial flow combustor of the general configuration shown in Figure 4.16 was used in experiments to establish the design for the 60 MWt (2.047×10^8 Btu/hr) power plant. The approaching air stream, however, was given a moderate swirl. The coal injector was a small cup that contained a high-speed vortex of the coal and air mixture, which emerged from the upstream face in counterflow to the main air stream. Seed (dry) was injected axially. The baffle device downstream

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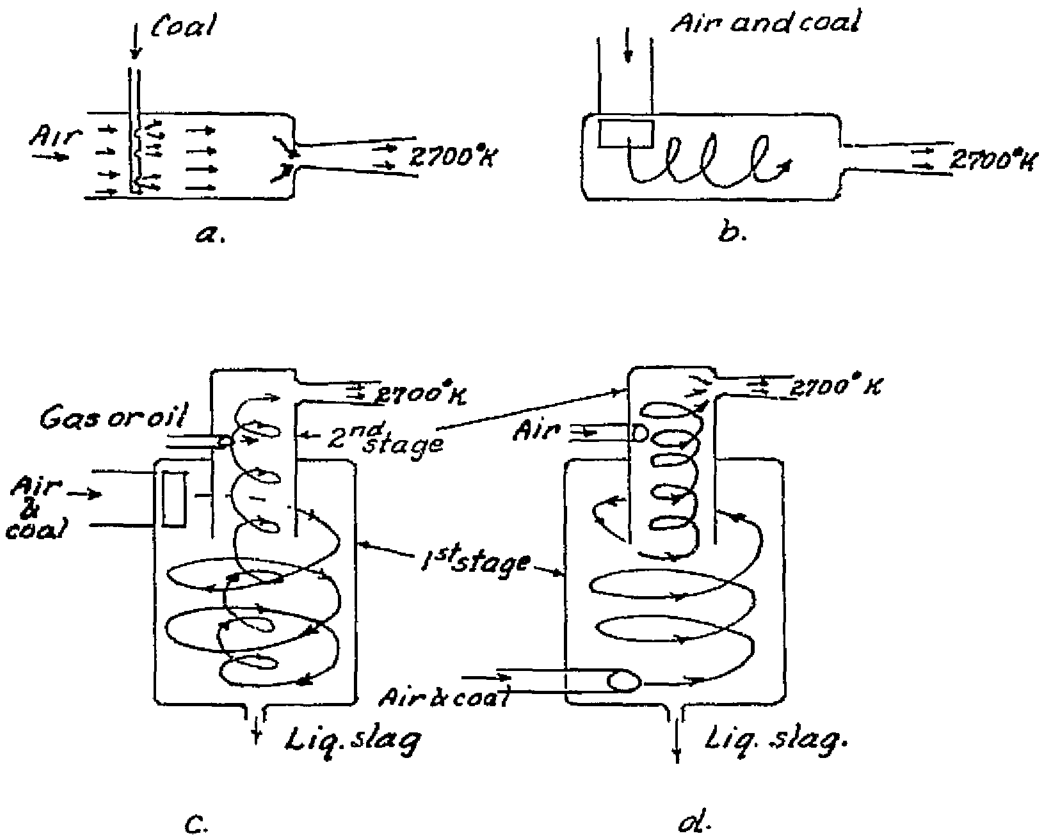

Fig. 4. 15—Schematic representation of type of coal combustors for MHD considered in Marchwood experiments. (a) Axial flow, with fully mixed plug flow, (b) Cyclone single-stage chamber with combustion largely at walls, (c) Two-stage cyclone system with clean fuel combustion in second stage, (d) Two-stage cyclone combustion with coal gasification in first stage. (Reference 4.17)

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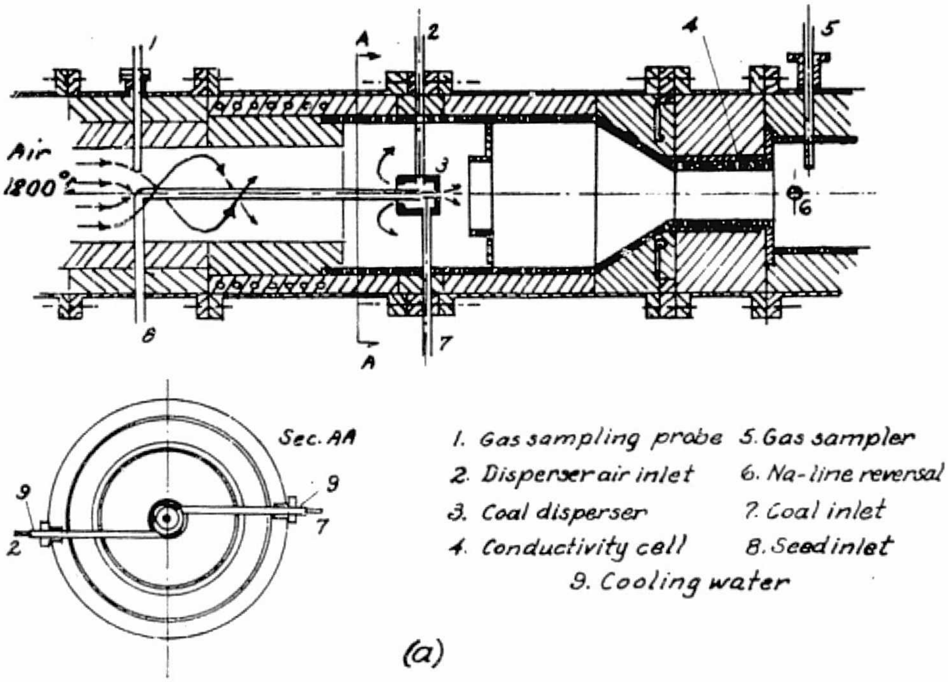

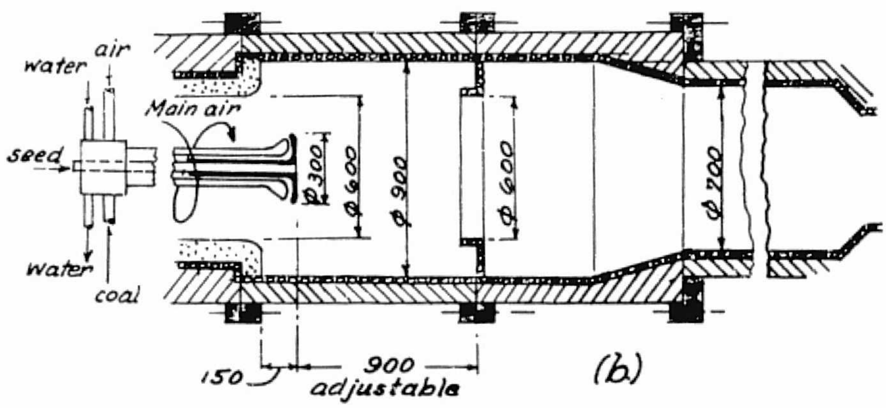

Fig. 4.16—Plug-type coal burners for British Marchwood project. (a) Pilot scale 45 mm combustor, (b) Combustor for proposed 60 MW thermal unit

Table 4.18 - Typical Conditions and Performance of Pilot-Scale Combustor and Proposed 60 MW Combustor

	60 MW Unit	Pilot Unit
Total air + oxygen, kg/s	19.2	0.88
Fraction of oxidant for coal dispersion, %	3	5
Oxygen concentration in oxidant, % wt.	29	33
Oxidant preheat, °K	1470	1470
Oxidant equiv. ratio, ϕ	1.05	1.04
Coal - size index	90%-75 μm	90%-75 μm
mass flow kg/s	2.6	0.13
thermal input, MW	73	3.8
ash content, %	10	10
ash silica ratio, %	80	81
seed	dry K_2SO_4	dry K_2SO_4
concentration in gas, mole % K	0.5	1.0
Combustor pressure, atm	5	5
Gas residence time, ms	45	48
Gas velocity, m/s	45	21
Volume, m^3	1.4	0.07
Wall area, m^2	7.9	1.00
Surface area of baffle, m^2	0.7	0.15
Combustion intensity, MW/m^3	52	52
Performance -		
% carbon reacted	97.5	98
heat transfer to walls, MW/m^2	0.660	0.440
heat transfer to baffle, MW/m^2	0.940	0.580
losses - % thermal input		
cooling combustor	10	18
seed evaporation	3.5	6
heat to slag	3.5	3
outlet temperature, °K	2690	2640

NOTE: Since the heat invested in the seed and slag components remains in the gas stream it is not necessary to regard these heat quantities as "losses", as long as they are taken into consideration in calculating flame temperature.

of the injector was found necessary for good mixing. Some data on typical operating con[illegible] for this experimental combustor, in comparison with conditions f[illegible] [illegible]0 MWt (2.047×10^8 Btu/hr) plant are shown in Table 4.18.

Status of the MHD Combustion Problem

Combustion chambers for liquid or gaseous fuels can be designed and built for MHD systems either by following the principles of vortex burner design or by using a straight-through flow with a mixing device at the upstream end. With vortex burners, heat releases of up to 3947.7 W/m^2-Pa (1.268×10^8 Btu/hr-ft^2-atm) can be obtained in laboratory-scale combustors and over 986.9 W/m^2-Pa (3.1705×10^7 Btu/hr-ft^2-atm) in combustors where pressure loss is a more important consideration.

For coal-fired combustion chambers, experimental work both in the U.S. and the United Kingdom with ram-jet or plug-flow type combustors has shown that coal can be burned successfully. With this type of burner all the ash is carried through the MHD generator. To avoid the ash carry-over, cyclone-type chambers which retain a major part of the slag have been investigated. The single-stage chamber at the Krzyzanovsky Power Institute has been successful in retaining 80% of the ash. Two-stage cyclones (with the first stage serving as a gasifier) have been proposed, as have two-stage systems with the first stage running with excess air. The former appears to be the most promising for direct coal firing, since it does not need a supplemental supply of clean fuel for the second stage. Experimental programs with two-stage cyclone combustors have been virtually nonexistent, and it is hoped that this situation will be rectified in the near future. This type of combustor appears to offer the best prospect for early realization of coal firing in an MHD generator system.

Another topic of great importance for MHD is the perfection of suitable gasification units for production of a clean gas from coal or char. Of particular interest is a gas producer which reacts hot exhaust products with coal or char to give a fuel gas of high carbon monoxide concentration. This is the method referred to as chemical regeneration. It makes possible

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TABLE 4.19 – SUMMARY OF COMBUSTION/FURNACE TECHNOLOGY & APPLICATIONS

Cycle Concept	Pulverized Coal & Char	Crushed Coal & Char		Coal Derived Liquid, High Btu Fuel Gas, Inter. Btu Fuel Gas				Low Btu Fuel Gas		
	Conventional Burners(1)	Cyclone Furnace	Fluid Bed Combustion	Conventional Burners(1)	Swirl Combustor	Conv. G.T.		Blast Furn. Gas Type Burner	Spec. G.T. Combustor	
						Int.	Ext.		Integrated	External
Open & Recuperated Gas Turbines			(X)			C	(LC)		(X)	(LC)
Combined-Cycle Gas Turbines			(X)			C	(LC)		X	(LC)
Closed-Cycle Gas Turbines	(C)	(C)	X	C				C		
Advanced Steam Cycles	C	(C)	X	(C)				C	X	
Metal Vapor Topping Cycles	(C)	(C)	X	(C)				C		
Open-Cycle MHD		X		C	X			C		
Closed-Cycle MHD				(C)				C		
Liquid-Metal MHD	(C)	C	X	(C)				(C)		
Fuel Cells	Not Applicable									

C – Commercial Technology Exists which is Applicable
LC – Commercial For Limited Range of Operating Conditions
X – Experimental Program Currently Active
( ) – Not Applied in This Study

(1) Principal Types are Cell and Circular Register Burners

an appreciable advance in cycle efficiency and reduction of air preheat temperatures. The problems to be solved relate to isolation of seed from ash or slag, and achievement of compact size for the gasifier.

Combustor Performance

In the design of the cyclone combustor for MHD use, several parameters were fixed at levels which the literature indicated to be realistically attainable. Among these parameters were combustion efficiency, pressure loss, ash retention, combustor heat losses, and combustor loading. Combustion efficiency in an MHD combustor is related to the attainment of proper fuel air mixtures in the combustion zone. Proper mixing is essential because the combustor, operating at an air equivalence ratio of 0.95, is fuel rich. The actual heat released by combustion of the given fuels with moist air, and including dissociation effects, is determined as a function of temperature using a Westinghouse computer program (MHD 2502). The entire heating value of the fuel is eventually utilized by injecting air at the outlet of the generator to bring the air equivalence ratio to 1.05. Pressure loss in the combustor was assumed to be 50.66 kPa (0.5 atm), and ash retention was assumed to be a function of the number of stages - 80% for one-stage, 90% for two-stage, and 95% for three-stage combustors. Combustor heat losses were assumed to be 5% of the total heat input to the combustor. Combustor loading was taken from the literature as a conservative 148 W/m^2-Pa (15 MW/m^2 atm or 4.756 x 10^6 Btu/hr-ft^2 atm). General construction weight, and installation (including costs) of the combustors and mixers were determined with the aid of the A/E consultation group.

4.3.2.6 Summary of Combustion/Furnace Technology

Table 4.19 contains a summary of combustion/furnace technology and applications for eight of the nine cycle concepts. Four fuel categories are included. For each fuel category the applicable combustion equipment is identified. For each technically feasible combination of cycle concept and combustion equipment type, the technology status is indicated as commercial, limited commercial, or experimental. Those items in parentheses are technically feasible but were not applied in this study.

4.3.3 Equipment Costs

The cost estimates for pulverized coal-fired steam boilers with advanced steam conditions were provided by the Foster Wheeler Corporation under subcontract and are included in Sections 12.5.1.1. The costs of the coal burners and feeders were included in the boiler costs but were not segregated.

No conventional cyclone furnaces were used in any of the power systems considered in this study, so no estimates of costs were made. Cost estimates were made for cell and circular register burners for atmospheric-pressure applications with capacities up to about 14.65 MWt (50×10^6 Btu/hr) (Reference 4.31). The estimated unit cost for these burners is correlated with capacity in the following expression (Reference 4.32).

$$\text{Equipment cost} = \$2000 \left(\frac{\text{rated capacity}}{5 \times 10^6}\right)^{0.6} \qquad (4.5)$$

where the rated capacity is in Btu/hr. The installation costs are assumed to be 50% of the equipment costs.

A correlation of equipment costs for internal-type gas turbine combustors which are applicable to high- and intermediate-Btu fuel gas and distillate from coal-derived liquids was prepared by the Westinghouse Gas Turbine Engine Division (Reference 4.32).

Cost estimates were prepared in a number of cases for combustor/furnace subsystems which included equipment other than combustion equipment. These subsystems included:

- Atmospheric-pressure fluidized bed boilers
- High-pressure fluidized bed boilers
- Pressurized fired heater subsystems
- Atmospheric-pressure fired heaters

4.3.3.1 Cost Estimates for Atmospheric-Pressure Fluidized Bed Boilers

The atmospheric-pressure fluidized bed boiler designs in this study were based on the preliminary design of an atmospheric-pressure fluidized bed boiler made by Westinghouse and Foster Wheeler in an EPA-funded program

(Reference 4.8). Figure 4.17 shows an elevation drawing of the atmospheric-pressure fluidized bed module.

Costs for 12 atmospheric fluidized bed boilers were estimated, with special attention paid to the cost of pressure parts and its dependence on steam conditions.

Surface area requirements were determined for the primary loops and for each reheat section in each case. In order to simplify these calculations, an average overall heat transfer coefficient was assumed for each steam pressure, and an overall log mean temperature difference (LMTD) for the primary loop was used. This method should not introduce any significant error into the computations.

The most significant effect of different steam temperatures and pressures on boiler cost is, of course, the relative costs of tube materials appropriate for use with the various steam conditions. Since the cases under consideration in this study involved a wide range of conditions with various temperatures and pressures, a method was developed to determine the effect of each parameter on tube cost. Five specific cases were chosen for more detailed inspection.

1. 16.547 MPa/1033°K (2400 psi/1400°F)
2. 24.132 MPa/1033°K (3500 psi/1400°F) } pressure effect (cases 1–3)
3. 34.474 MPa/1033°K (5000 psi/1400°F)
4. 34.474 MPa/922°K (5000 psi/1200°F) } temperature effect (cases 3–5)
5. 34.474 MPa/811°K (5000 psi/1000°F)

Figures 4.18 through 4.20 give steam temperature profiles for each of the five cases, with tube materials identified and with the tube wall thicknesses associated with each material. These plots were the basis for calculating the average tube cost per foot unit length (ATC). Pressure and temperature factors were developed relative to a reference case [34.473 MPa/1033°K (5000 psi/1400°F)] so that an average tube cost for any combination of primary loop steam conditions could be determined.

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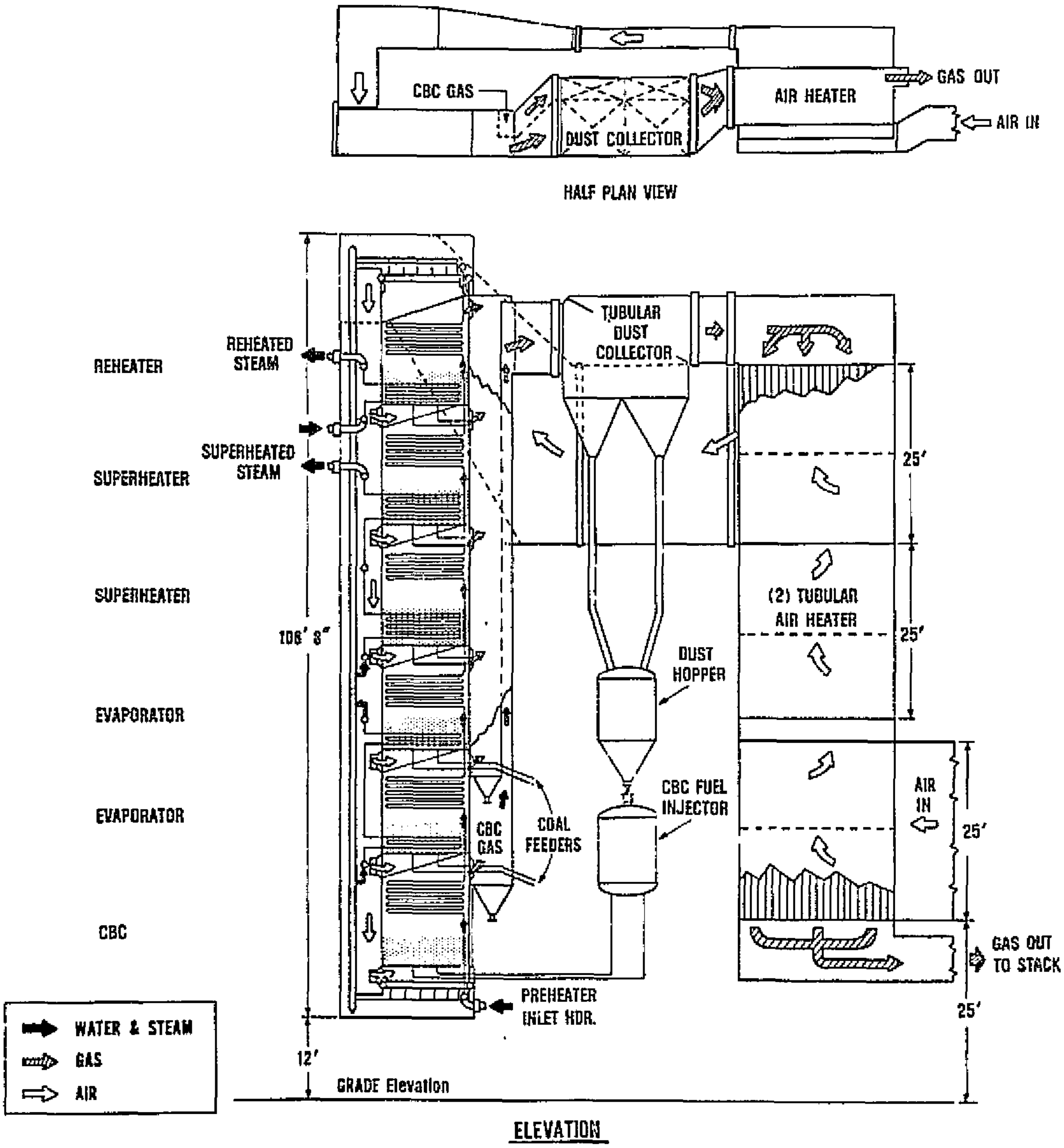

Fig. 4. 17—Atmospheric-pressure fluidized bed steam generator

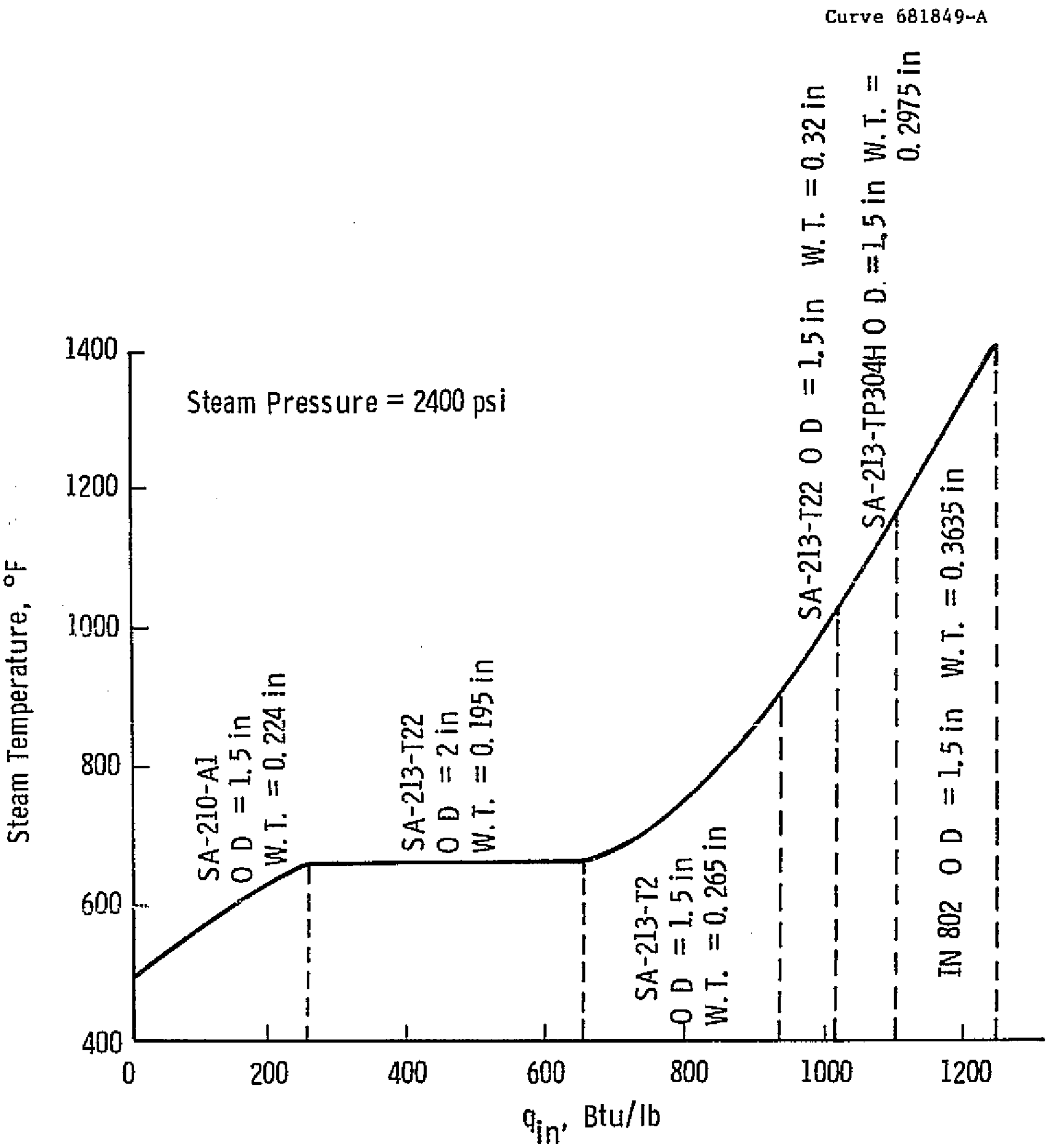

Fig. 4-18—Apportionment of tube materials in primary loops of APFBB

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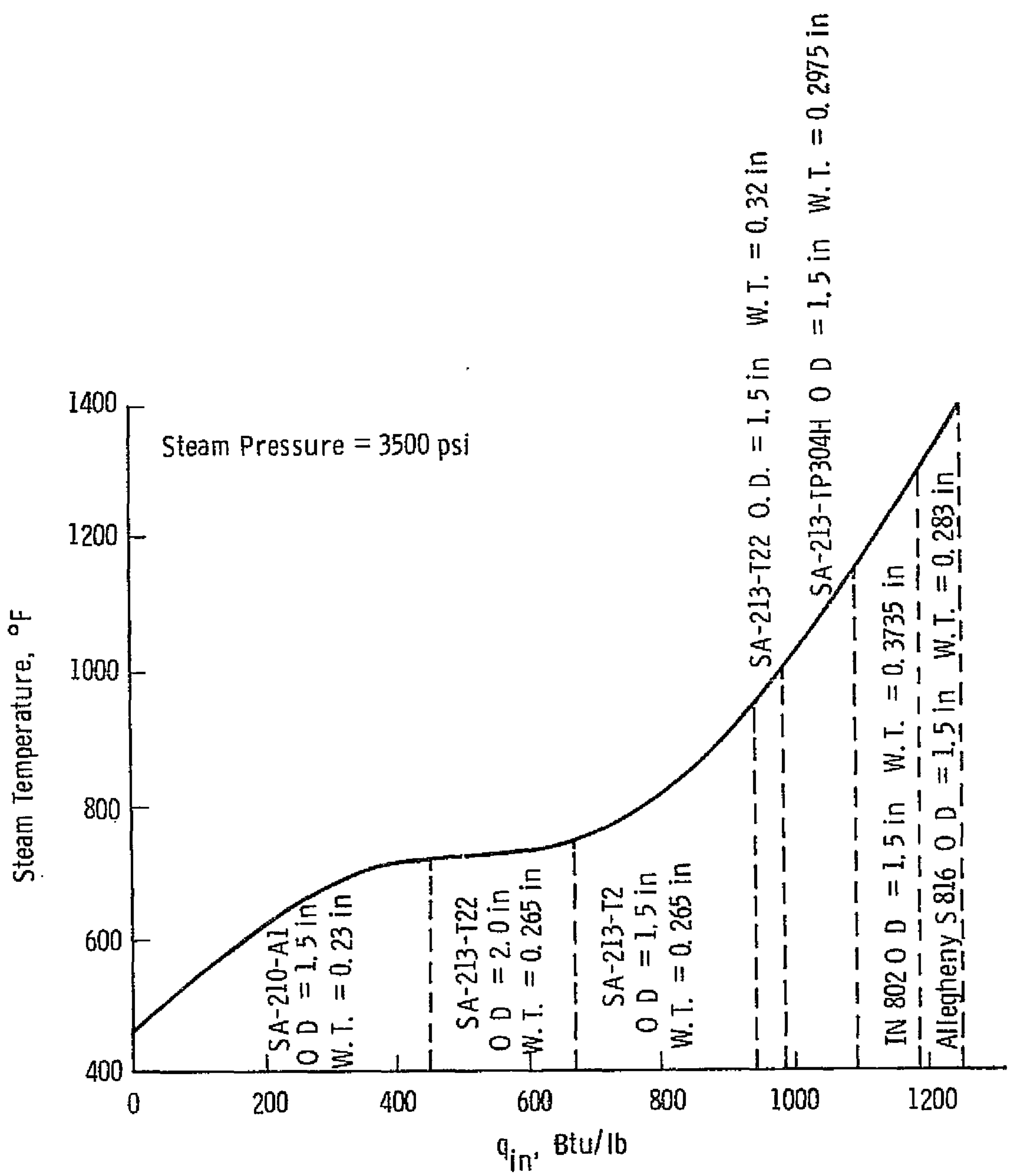

Fig. 4-19—Apportionment of tube materials in primary loops of APFBB

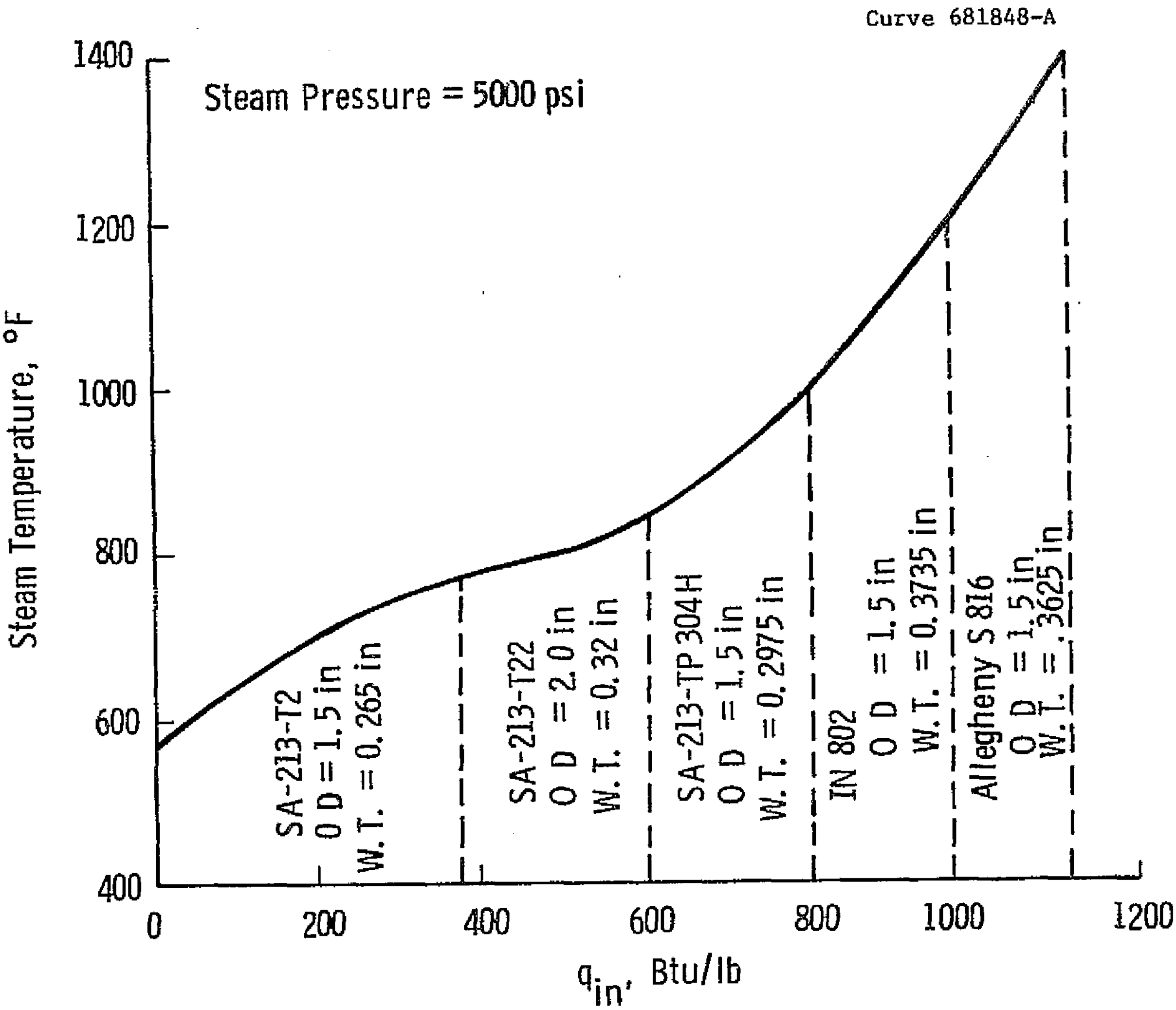

Fig. 4-20—Apportionment of tube materials in primary loops of APFBB

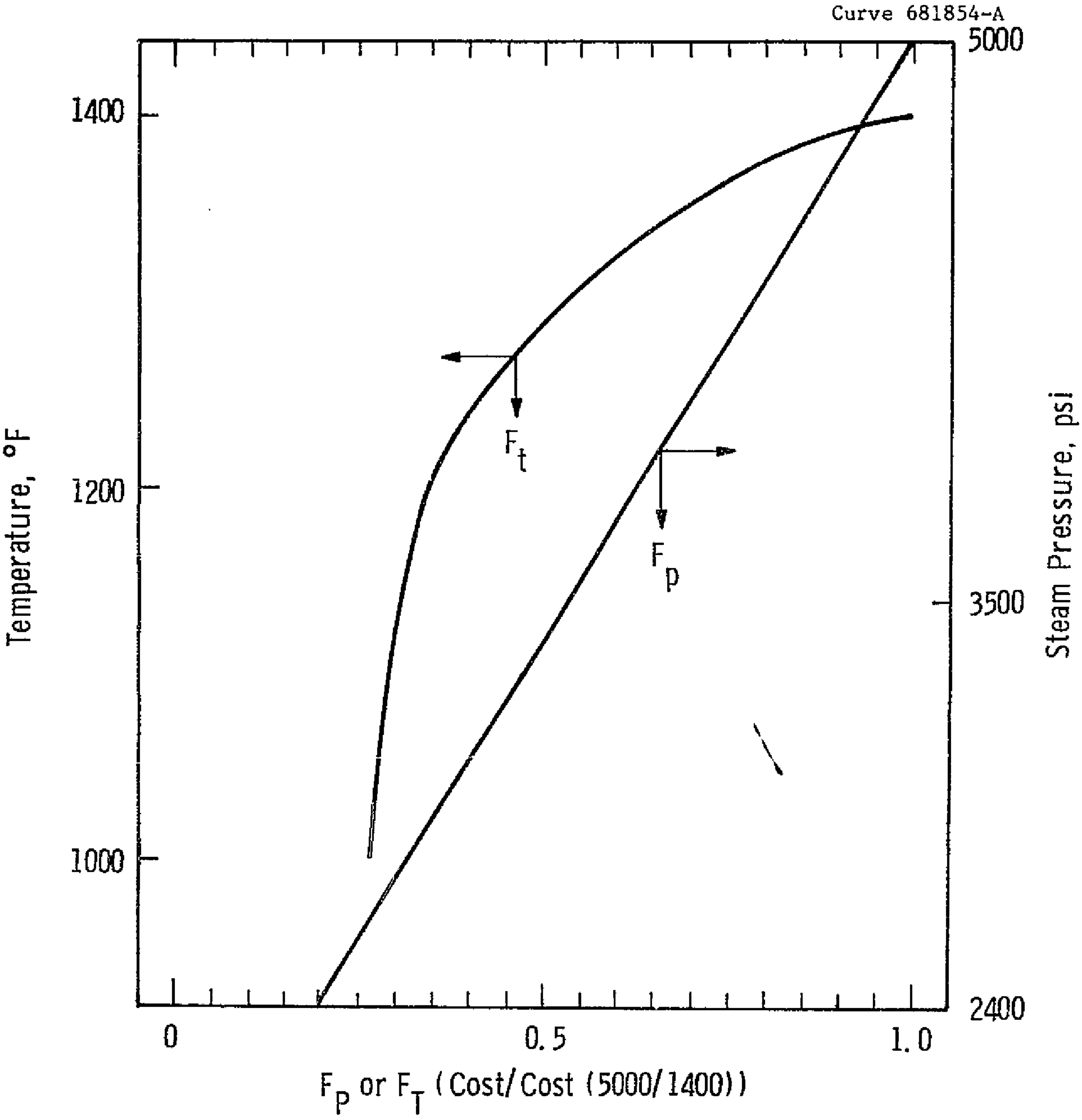

Fig. 4-21—Effect of temperature and pressure on specific tube cost (Reference case = 5000/1400 - $21.30/ft.)

These multipliers are given in Figure 4.21. Their use is demonstrated as follows:

- Given conditions = (3500 psi/1200°F)
- Reference Case ATC = ($21.30/ft) at (5000 psi/1400°F)
- $ATC_{(3500/1200)} = ATC_{(5000/1400)} \; (F_p) \; (F_t)$

$$= (21.30)\ (0.532)\ (0.32)$$

$$= \$3.62/\text{ft}.$$

This corresponds very well with a cost arrived at through an actual apportionment of materials.

The same method was used to estimate tube costs for the reheat section.

Application of this method to each case produced overall tube and pressure parts costs. The same relationship between tube cost and in-bed pressure parts cost was used as in the pressurized fluidized bed boiler, that is:

$$\text{Pressure Parts Cost} = \left[1.6\ (\text{ATC}) + \frac{9.25}{0.705}\left(\frac{0.705\ \text{ATC}}{2.58}\right)^{0.3}\right] \text{TTL} \quad (4.6)$$

where ATC = average tube cost, $/ft

TTL = total tube length, ft.

The economizer surface area was assumed to be equal to approximately 110% of the total in-bed heat transfer surface area.

The scope of component costs considered for the atmospheric-pressure fluidized bed boiler included, in addition to pressure parts, structural steel flues, ducts, and fans; home office and drafting costs; coal preparation and feedings; air heaters; ducts to air heaters; forced draft fans; some miscellaneous equipment; and steam generator erection. These total costs are tabulated in Table 4.20 and are plotted in Figure 4.22 to give some idea of the effect of steam conditions on boiler cost.

Table 4.20: Installed Equipment Costs - Atmospheric Fluidized Bed Boilers, $

Case / Item	1 5000/1000/ 1000/1000	2 5000/1200/ 1200/1200	3 5000/1400/ 1400/1400	4 5000/1000/ 1200/1400	5 3500/1000/ 1000	6 3500/1200/ 1200	7 3500/1400/ 1400	8 3500/1200/ 1400	9 3500/1000	10 2400/1000/ 1000	11 2400/1200/ 1200	12 2400/1400
Pressure Parts	$8,476,000	10,365,000	19,593,000	10,942,000	6,915,600	8,189,700	14,439,700	10,451,000	11,998,000	5,882,000	6,427,700	8,013,500
Structural Steel	1,692,000	1,825,000	2,220,000	1,895,000	1,700,000	1,850,000	2,185,000	1,985,000	2,120.000	1,887,000	2,040,000	2,320,000
Flues, Ducts Insulation	1,705,000											
Home Office Drafting	1,250,000											
Coal Prep. & Feeding	5,320,000											
Air Heater	3,360,000											
Ducts to Air heater	401,000											
E.D. Fans	1,089,000											
Misc.	684,000											
Steam Gen Erection	5,010,000	6,050,000	9,900,000	6,300,000	4,630,000	5,195,000	7,830,000	6,150,000	6,820,000	4,290,000	4,570,000	5,300.000
Total	28,987,000	32,049,000	45,529,000	32,946,000	27,054,600	29,043,700	38,263,700	32,495,000	34,747,000	25,868,000	26,846,000	29,442,500

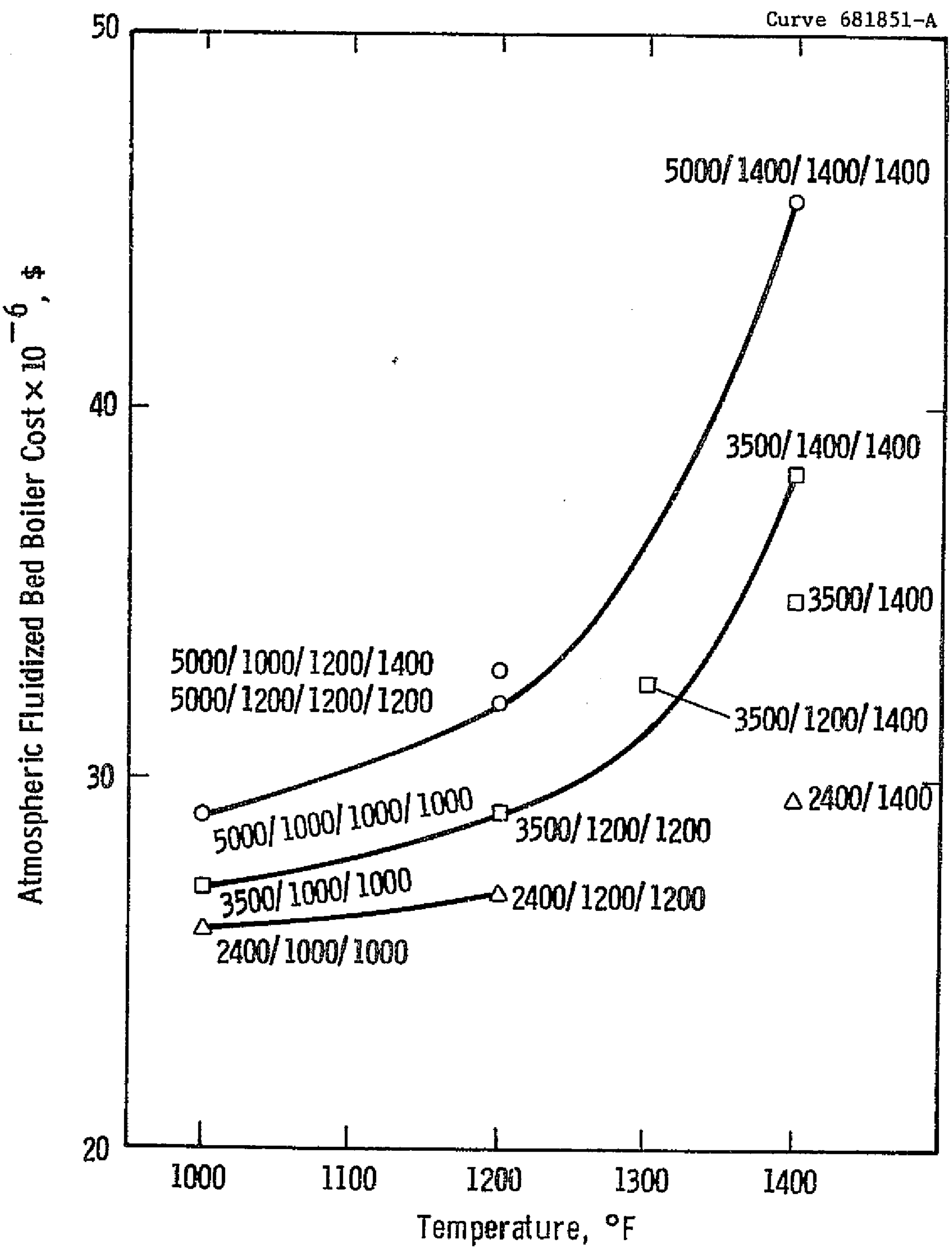

Fig. 4-22—Installed equipment cost for atmosphere fluidized bed boilers - July 1974

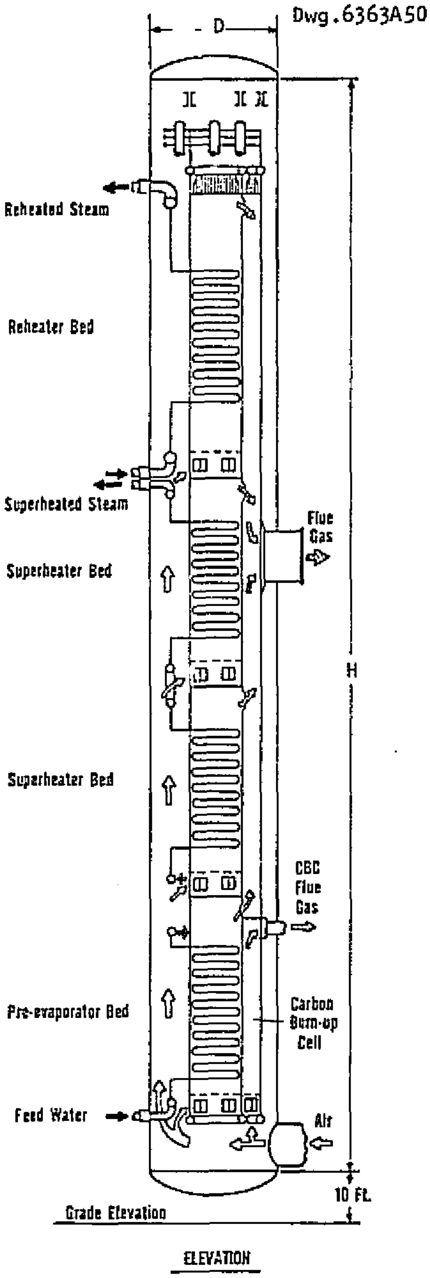

Fig. 4.23—Pressurized fluidized bed steam generator for combined-cycle plant

4.3.3.2 Cost Estimates for High-Pressure Fluidized Bed Boilers

The high-pressure fluidized bed boiler designs in this study were based on the design information compiled by Westinghouse and its subcontractors in EPA-funded programs on fluidized bed combustion (References 4.34 and 4.84). Figure 4.23 shows the elevation drawing of a module of a high-pressure fluidized bed boiler which was made by Foster Wheeler. Each boiler module has four beds with a submerged heat transfer surface in each bed. The bed enclosures are water walls which are used as evaporators. The power system consists of four boiler modules and two gas turbine modules.

Cost estimates were required for pressurized fluidized bed boilers which would generate steam under the following conditions:

1. 24.132 MPa/811°K/811°K (3500 psi/1000°F/1000°F)
   TIT = 1144°K (1600°F)
2. 24.132 MPa/811°K/811°K (3500 psi/1000°F/1000°F)
   TIT = 1200°K (1700°F)
3. 24.132 MPa/811°K/811°K (3500 psi/1000°F/1000°F)
   TIT = 1255°K (1800°F)
4. 31.026 MPa/922°K/922°K (4500 psi/1200°F/1200°F)
   TIT = 1200°K (1700°F)
5. 34.474 MPa/1033°K/1033°K (5000 psi/1400°F/1400°F)
   TIT = 1200°K (1700°F).

For each of these five cases, costs were developed for compressor pressure ratios of 5, 8, 10, and 15. Further, the effects of higher percent excess air on boiler cost were determined. In all, sixty different costs were computed to cover a wide range of boiler operating conditions.

The equipment considered include pressure parts, coal and dolomite preparation equipment, coal- and dolomite-feeding equipment, solid waste disposal equipment, pressure vessels, and particulate removal equipment. All costs are installed costs, with a breakdown into equipment and labor costs provided.

For each of the five basic sets of conditions, a base case was chosen, and a design of the steam generator was carried out with sufficient detail to ensure that certain fundamental operating constraints of fluidized bed boilers were met. The base case parameters are as follows:

- Compressor pressure ratio = 10 to 1
- Steam mass flow = 504 kg/s (4 x 10^6 lb/hr)
- Compressor airflow = 689.5 kg/s (1520 lb/s)
- Air equivalence ratio = 1.15
- Turbine cooling air fraction

  [for TIT = 1144°K (1600°F)] = 6.1%
  [for TIT = 1200°K (1700°F)] = 7.0%
  [for TIT = 1255°K (1800°F)] = 7.9%.

In order to attain a reasonable measure of realism in the costs obtained, as well as to delineate the bounds beyond which operation of a fluidized bed is not feasible, certain important factors were taken into account in the reference boiler design: the reheat pass steam-side pressure drop was fixed at 10% of the reheat inlet pressure; the superficial velocity in the fluidized beds was constrained to a range between 1.83 and 2.44 m/s (6 and 8 ft/s); a drop in product gas temperature of approximately 83.3°K (150°F) in the water-wall duct between the bed exit and the pressure vessel exit was assumed (except as noted); the maximum bed operating temperature was assumed to be approximately 1283°K (1850°F) because of a deterioration in desulfurization reactions at temperatures exceeding that level; and tube wall thicknesses in the primary tube banks were kept below 0.94 cm (0.37 in) wherever possible. Further, it was assumed that each bed would operate at the same air equivalence ratio; that is, the air and fuel flow are matched to the heating duty of the individual bed. To simplify design the heating duty was divided equally among the beds wherever possible. For the 31.026 MPa/922°K/922°K

(4500 psi/1200°F/1200°F) and the 34.474 MPa/1033°K/1033°K·(5000 psi/1400°F/1400°F) cases, the heat entering the steam in the reheat section was less than one quarter of the total absorbed. To equalize heating duty per bed, therefore (and, as a result, airflow and superficial velocity), the bottom portion of what is nominally the reheat bed is filled with a final bank of superheat tubes. This technique also serves to reduce required bed depths to within acceptable limits.

The apportionment of heating duty in the three 24.132 MPa/811°K/811°K (3500 psi/1000°F/1000°F) cases was not so straightforward. The reheat portion exceeds one quarter of the total heat absorbed. Since placing reheat tubes in the superheat beds presents materials problems during start-up, the air and coal feed rates to the reheat beds were increased to match the reheating requirement, resulting in different superficial velocities in the reheat beds. Table 4.21 lists superficial velocities in each of the four beds for the five basic operating condition sets for a pressure of 1.013 MPa (10 atm).

Bed dimensions for each case were calculated from the product gas flow, density, and an assumed superficial velocity.

$$\text{Cross-sectional area} = \frac{\dot{m}}{\rho V_g} \qquad (4.7)$$

where $\dot{m}$ = the mass flow in lb/s

ρ = the density in lb/ft^3

V_g = the superficial velocity in ft/s.

Bed length is fixed by the horizontal tube pitch, the number of loops in each tube bundle, and the number of tubes. The number of tubes was computed by balancing the reheat surface area requirement and the specified pressure drop through the reheat tubes. Horizontal tube pitch was taken to be 8.89 cm (3.5 in).

Bed depths, D_B, were obtained by an expression relating bed width, W_B, tube pitch, P_t, and number of loops per tube bundle, X, to tube length per foot of bed depth, ℓ_t':

$$\ell_t' = \frac{W_B - P_t}{X P_t} \tag{4.8}$$

Table 4.22 lists the bed and vessel dimensions for the five basic operating condition sets for a pressure of 1.013 MPa (10 atm).

Table 4-21 - Superficial Velocities, in the Beds of a Pressurized Fluidized Bed Boiler Operating at 10 atm, ft/s

Case	Bed 1	Bed 2	Bed 3	Reheat
3500 psi/1000°F/1000°F (1600°F)	6.47	6.47	6.47	7
3500 psi/1000°F/1000°F (1700°F)	6.65	6.65	6.65	7
3500 psi/1000°F/1000°F (1800°F)	6.65	6.65	6.65	7
4500 psi/1200°F/1200°F (1700°F)	6	6	6	6
5000 psi/1400°F/1400°F (1700°F)	6	6	6	6

Table 4.22 - Pressurized Fluidized Bed Boiler Dimensions (10 atm Operating Pressure), ft

Case	Bed Width	Bed Length	Vessel Diameter	Vessel Height
3500 psi/1000°F/1000°F (1600°F)	8.02	10.14	18.3	116.2
3500 psi/1000°F/1000°F (1700°F)	8.65	9.77	18.7	106.1
3500 psi/1000°F/1000°F (1800°F)	8.65	9.77	18.7	106.1
4500 psi/1200°F/1200°F (1700°F)	11.50	8.17	19.65	112.4
5000 psi/1400°F/1400°F (1700°F)	16.55	5.69	19.65	118.8

Surface area requirements were calculated from the LMTD, the heat transfer required in a specified bed, and an overall heat transfer coefficient. The last quantity was computed using an assumed bed-tube heat transfer coefficient of 283.86 W/m^2-°K (50 Btu/hr-ft^2-°F) and a steam-side coefficient arrived at through a computer program. Reheat and water-wall tubes are 5.08 cm (2.0 in) od, and all other tubes are 3.81 cm (1.5 in) od. The tubes are arranged in interlooped serpentine bundles of four. The individual tube length is given by Equation 4.9:

$$\ell = \left(\frac{S_{h.t}}{N}\right)\left(\frac{1}{\pi D_t}\right) \qquad (4.9)$$

where $S_{h.t}$ = heat transfer surface area for the specified bed

N = number of tubes

D_t = tube od.

Thus, the bed depth is given for each bed by Equation 4.10:

$$BD = \frac{[Q/(U)(LMTD)]\ (X\ P_t)}{(W_B - P_t)(\pi\ N\ D_t)} \qquad (4.10)$$

Table 4.23 lists the overall heat transfer coefficients for the four beds and the water walls for each of the five basic operating conditions sets for a pressure of 1.013 MPa (10 atm). Table 4.24 lists the corresponding surface area requirements.

Originally, the specified gas turbine inlet temperature for the 31.026 MPa/922°K/922°K (4500 psi/1200°F/1200°F) and the 34.474 MPa/1033°K/1033°K (5000 psi/1400°F/1400°F) cases was 1144°K (1600°F). It was found, however, that, with the bed temperature which corresponds to this temperature level [1228°K (1750°F)], LMTDs were so small that it was impossible to design a boiler with the very large surface area requirements involved and still satisfy the 4.57 to 5.18 m (15 to 17 ft) constraint upon bed depth.

Table 4.23 - Pressurized Fluidized Bed Boiler Overall Heat Transfer Coefficients, Btu/hr-ft^2-°F (10 atm Operating Pressure)

Case	Bed 1	Water Walls	Bed 2	Bed 3	Reheat
3500 psi/1000°F/1000°F (1600°F)	48.0	48.0	46.0	46.0	44.1
3500 psi/1000°F/1000°F (1700°F)	48.0	48.0	46.0	46.0	44.1
3500 psi/1000°F/1000°F (1800°F)	48.0	48.0	46.0	46.0	44.1
4500 psi/1200°F/1200°F (1700°F)	48.5	48.5	48.0	46.5	46.0
5000 psi/1400°F/1400°F (1700°F)	49.0	49.0	48.0	48.0	47.5

Table 4.24 - Pressurized Fluidized Bed Boiler Surface Area Requirements One Module, ft^2 (10 atm Operating Pressure)

Case	Bed 1	Water Walls	Bed 2	Bed 3	Reheat
3500 psi/1000°F/1000°F (1600°F)	4355	3170	4955	5790	5725
3500 psi/1000°F/1000°F (1700°F)	3640	2840	4130	4710	5084
3500 psi/1000°F/1000°F (1800°F)	3640	2100	4130	4710	5084
4500 psi/1200°F/1200°F (1700°F)	4180	2971	4840	7415	5190
5000 psi/1400°F/1400°F (1700°F)	4280	2940	5000	7745	5020

By raising the bed temperature to its maximum value of about 1283°K (1850°F), corresponding to turbine inlet temperatures (TIT) of 1200°K (1700°F), a design which met the bed depth limit was possible.

The high-pressure fluidized bed boiler preliminary design made by Westinghouse/Foster Wheeler (Reference 4.8) utilized a water-wall duct which shares a wall with the actual bed enclosure in order to collect and transport the separate combustion product streams. This arrangement results in a modest increase in heat transfer surface area (although the effectiveness in this pass is roughly 25% of that of the actual bed water wall). It also accounts for a temperature drop of 83.3°K (150°F) in the product gases. As long as the required gas turbine inlet temperature is 1200°K (1700°F) or lower, this presents no problems. Since the maximum obtainable bed temperature is 1283°K (1850°F), however, a TIT of greater than 1200°K (1700°F) cannot be attained with a water-wall duct. For the 24.132 MPa/811°K/811°K (3500 psi/1000°F/1000°F) [TIT = 1256°K (1800°F)] case, therefore, the water-wall duct was replaced by a refractory-lined duct, thus reducing the temperature drop in the duct. Although this reduces the available heat transfer surface area in the water wall by 32%, it necessitates only a 2% increase in surface area for the remainder of the boiler, because of the relatively poor heat transfer which prevailed in the eliminated section. Access to the duct for maintenance of the refractory is not seen to present a problem. Costs for this refractory-lined duct are based on an installed cost of $\$883/m^3$ ($\$25/ft^3$) and are included in the shell cost.

Tube Materials

The greatest single problem imposed on the design of a boiler by advanced steam conditions is selecting materials suitable for the high-temperature sections in the superheat and reheat beds. Materials are available which would be appropriate for the 24.132 MPa/811°K/811°K (3500 psi/1000°F/1000°F) and the 31.026 MPa/922°K/922°K (4500 psi/1200°F/1200°F) cases with substantial, but not prohibitive, penalties in cost. The 34.474 MPa/1033°K/1033°K (5000 psi/1400°F/1400°F) case, however, necessitates the use of an extremely strong, high-temperature alloys. Westinghouse Research Laboratories metallurgists recommend Allegheny S816, a high-temperature, high-strength, cobalt-based superalloy. Conversations with Allegheny Ludlum personnel revealed that S816 was no longer in production, presumably because of lack of demand, but a rough selling price was estimated [$35.27 to $39.68/kg ($16 to $18/lb)]. Cost estimates of tubing for the 34.474 MPa/1033°K/1033°K (5000 psi/1400°F/1400°F) case were carried out under the assumption that S816 could be made available at that price.

Tube costs for all cases were reached by computing minimum wall thicknesses from allowable stress data supplied by A. Vaia of the Westinghouse Research Laboratories and the formula given in the ASME Boiler and Pressure Vessel Code:

$$t = \frac{PD}{2S+P} + 0.0075\ D + 0.04 \qquad (4.11)$$

where t is the tube thickness in inches; P the internal pressure level in psi; S the allowable design stress in psi; and D the tube diameter in inches.

Costs for the various materials were obtained from various sources:

- SA-210-A1 / SA-213-T2 / SA-213-T22 / SA-213-TP304N — Babcock and Wilcox
- IN802 — Huntington Corporation
- S816 — Allegheny-Ludlum

Total cost of the pressurized components were computed by adding up the cost of the several components as calculated using Equation 4.6 which was derived from Reference 4.8.

$$\text{Pressure Parts Cost} = \left[1.6(\text{ATC}) + \frac{9.25}{0.705}\left(\frac{0.705}{2.58}\ \text{ATC}\right)^{0.3}\right](\text{TTL}) \qquad (4.6)$$

where ATC = average tube cost

TTL = total tube length.

Shell Design

Each boiler module is comprised of four fluidized beds, arranged vertically in a water-wall enclosure. Surrounding the bed enclosure is a pressure vessel. Shell diameters for each case were determined by assuming a fixed ratio of shell cross-sectional area to bed area. The Foster Wheeler design has a bed 1.52 by 2.13 m (5 by 7 ft) and is set inside a pressure vessel 3.65 m (12 ft) in diameter (Reference 4.8). This results in an area ratio of 3.24 to 1.

Pressure vessel heights are given by:

$$\text{Height} = 66 + \Sigma\ \text{Bed Depths} \qquad (4.12)$$

The 20.12 m (66 ft) includes overheads [3.048 m (10 ft) each], air plenums [0.6096 m (2 ft) each], and 3.048 m (10 ft) of free space on the top and 2.438 m (8 ft) of free space on the bottom of the vessel for steam piping, air piping, and access.

Correlations for both material and labor costs were provided for determining pressure vessel costs (References 4.19 and 4.35), Equations 4.13 and 4.14.

$$\text{Shell Material Cost, } \$ = (0.35 \times 10^6) \left(\frac{D}{20}\right) \left(\frac{H}{120}\right) \left(\frac{t_w}{1.314}\right) \qquad (4.13)$$

$$\text{Shell Labor Cost, } \$ = (0.31 \times 10^6) \left(\frac{D}{20}\right) \left(\frac{H}{120}\right) \left[\frac{1+2\ [(C_1)\ t_w - 1\ ]}{2}\right] \qquad (4.14)$$

where D = module diameter, ft

H = module height, ft

t_w = shell wall thickness, in = $\frac{12PD}{2\sigma}$

(P = psia, D = ft, σ = 13700 psi)

C_1 = cost base adjustment constant = 1.14

4.3.3.3 Effects of Boiler Pressure on PFBB Cost

A change in pressure level results in two significant changes in boiler design and cost. Since the size of the beds and pressure vessel is a function of gas density for a fixed fluidizing velocity (to pass a given mass flow rate of air), a decrease in pressure must be accompanied by a complementary increase in bed cross-sectional area. This results in wider, shallower beds and a proportionate decrease in shell height and increase in diameter. Since the pressure vessel is, in itself, a minor factor in the total boiler cost, there is no significant change in the total cost.

The reference case for design of the fluidized bed boilers used a pressure of 1.013 MPa (10 atm). As was noted earlier, 34.474 MPa/1033°K/1033°K (5000 psi/1400°F/1400°F) case, bed depths were calculated which were very near the maximum value [4.572 m (15 ft)]. An increase in pressure to 1.53 MPa (15 atm) results in a narrower, deeper bed, and it appeared that the 34.474 MPa/1033°K/1033°K (5000 psi/1400°F/1400°F) case would not be feasible at pressure levels greater than 1.013 MPa (10 atm). An alternative arrangement of the critical beds, however, was developed. By staging the upper superheat bed -- that is, by operating a lower stage at high excess air and allowing the products of combustion to flow directly into a second stage above -- the bed depth limit could be met. There would be no need for a large overhead above the first stage because entrained particles above the bed can be carried into the upper bed.

Changes in boiler pressure also result in dramatic changes in particulate removal equipment requirements since the capacity of this equipment is based on actual gas volume flow rate. When the pressure level is decreased, therefore, from 1.013 to 0.507 MPa (10 to 5 atm), the required capacity of the particulate removal equipment is doubled. Particulate removal equipment costs account for approximately half of the total boiler cost, so the effect of pressure level on total boiler cost is significant, as shown by the plot in Figure 4.24. Higher pressures result in lower costs for this equipment.

4.3.3.4 Effect of Excess Air on Pressurized Fluidized Bed Boiler Costs

Boiler costs were also determined for various air equivalence ratios. For a fixed airflow the effect of increased air equivalence is a decrease in the steam flow. Since the tube surface area is proportionate to the steam flow, decreasing the steam flow would decrease the number of tubes and the bed depth. Decreasing the bed depth results in less than a proportional decrease in vessel height. The reference case steam flow was 504 kg/s (4×10^6 lb/hr) at $\phi_{air} = 1.15$. When the excess air is increased to 90% ($\phi_{air} = 1.9$), the steam flow is 252 kg/s (2×10^6 lb/hr). Thus, the tube cost is cut in half.

Increased excess air for a fixed airflow also means a lower coal feed rate. This has an effect on several component costs. Lowered feed rate reduces the cost of coal and dolomite preparation and feeding - and also decreases the capacity of the solid waste handling equipment. Also, lower coal feed rates result in a lowered loading on particulate removal equipment. For the base case, two Ducon cyclone stages were followed by an Aerodyne cyclone separator. For $\phi_{air} = 1.45$, one of the Ducon stages was eliminated. For $\phi_{air} = 1.90$, the two Ducon stages were deemed sufficient. All of these factors serve to decrease boiler cost. As shown in Table 4.25

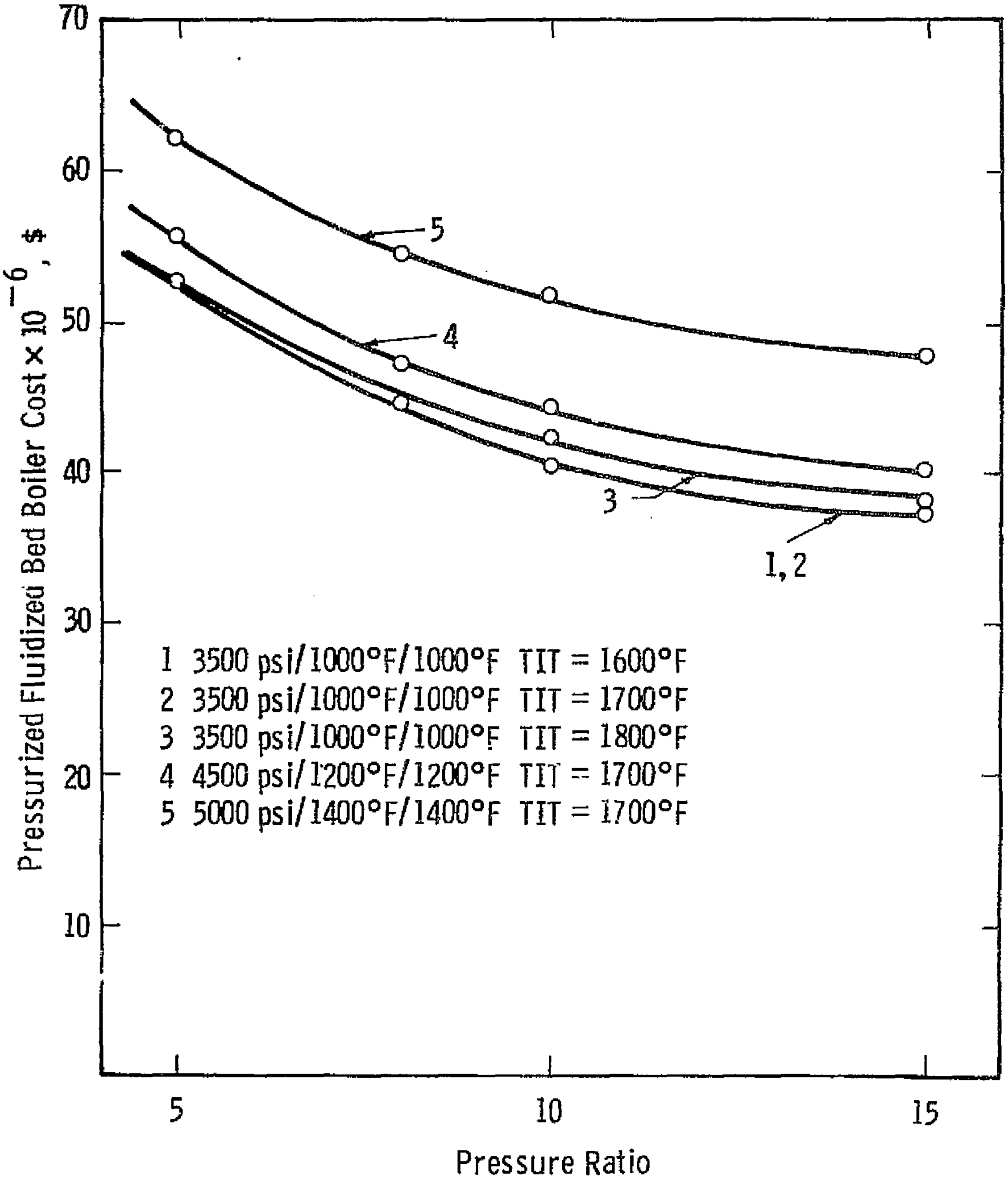

Fig. 4-24—Effect of pressure level on costs of pressurized fluidized bed boilers

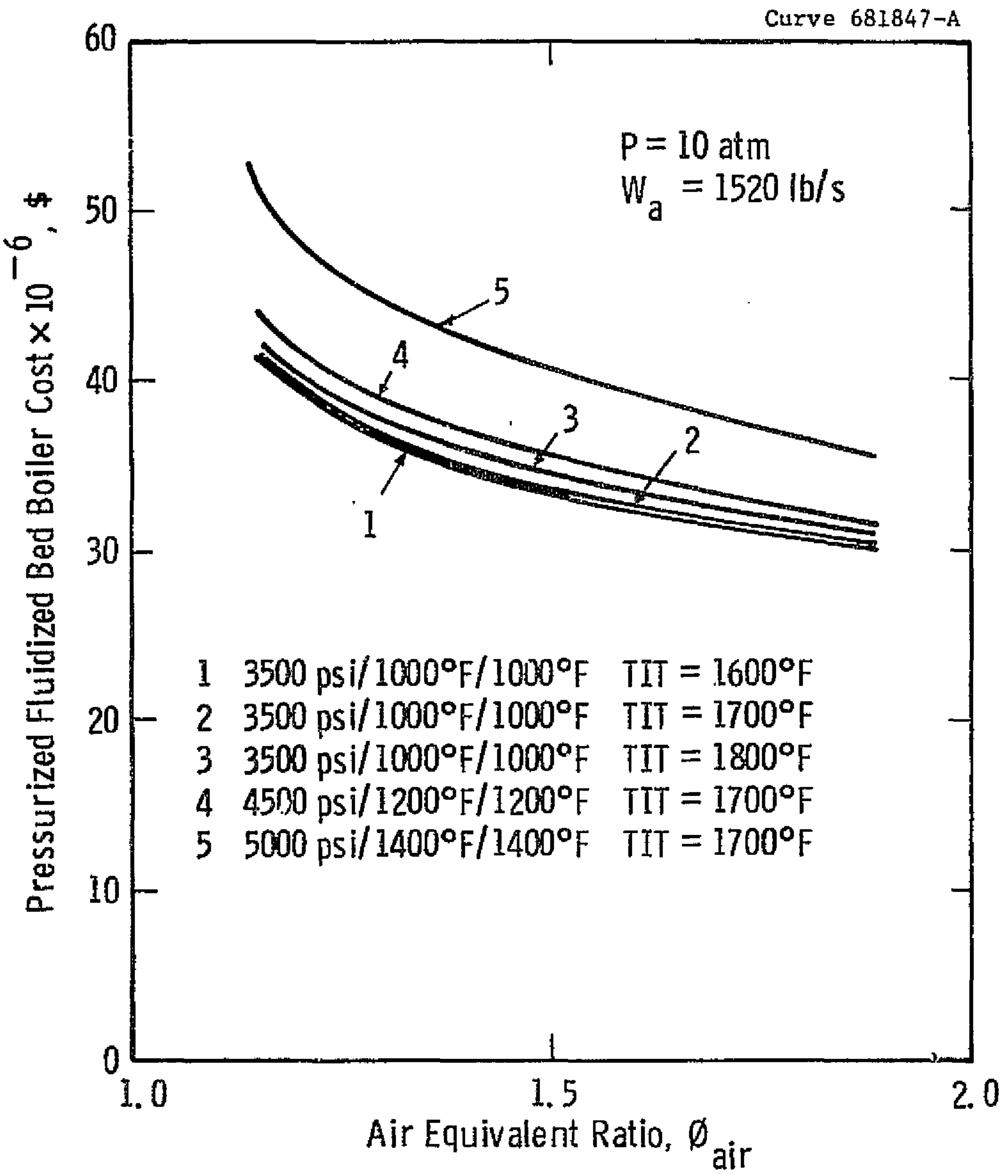

Fig. 4-25—Effect of air equivalence ratio on costs of pressurized fluidized bed boilers

and Figure 4.25, high excess air operation results in significant reductions in capital equipment requirements for a fixed compressor airflow rate.

Tables 4.25 through 4.28 list the installed costs of high-pressure fluidized bed subsystems for each of the five basic operating condition sets for pressure levels of 0.507, 0.810, 1.01, and 1.52 MPa (5, 8, 10, and 15 atm), and for air equivalence ratios of 1.15, 1.45, and 1.90 at a compressor inlet airflow rate of 689.5 kg/s (1520 lb/s). A breakdown of costs for a pressure level of 1.013 MPa (10 atm) and air equivalence ratio of 1.15 is given in Table 4.29. Costs for different airflow rates can be obtained by the use of a scaling exponent of 0.8 on capacity.

Table 4.25 - Pressurized Fluidiz.d Bed Boiler Costs x 10^{-6}, \$
(5 atm; Airflow Rate - 1520 lb/s)

Case	ϕ = 1.15	ϕ = 1.45	ϕ = 1.90
3500 psi/1000°F/1000°F (1600°F)	53.9	43.9	38.0
3500 psi/1000°F/1000°F (1700°F)	54.0	44.5	37.5
3500 psi/1000°F/1000°F (1800°F)	54.7	44.3	38.1
4500 psi/1200°F/1200°F (1700°F)	54.1	46.8	39.9
5000 psi/1400°F/1400°F (1700°F)	63.6	51.4	42.6

Table 4.26 - Pressurized Fluidized Bed Boiler Costs x 10^{-6}, \$
(8 atm; Airflow Rate - 1520 lb/s)

Case	ϕ = 1.15	ϕ = 1.45	ϕ = 1.90
3500 psi/1000°F/1000°F (1600°F)	45.8	38.3	33.4
3500 psi/1000°F/1000°F (1700°F)	46.3	38.7	33.7
3500 psi/1000°F/1000°F (1800°F)	46.1	38.3	33.4
4500 psi/1200°F/1200°F (1700°F)	48.9	40.7	35.0
5000 psi/1400°F/1400°F (1700°F)	56.3	46.3	38.8

Table 4.27 - Pressur ed Fluidized Bed Boiler Costs x 10^{-6}, \$
(10 atm; Airflow Rate - 1520 lb/s)
Detailed Breakdown for ϕ = 1.15,
Totals Only for ϕ = 1.45 and 1.90

Component \ Case	3500/1000/1000 TIT = 1600°F	3500/1000/1000 TIT = 1700°F	3500/1000/1000 TIT = 1800°F	3500/1200/1200 TIT = 1700°F	5000/1400/1400 TIT = 1700°F
Pressure Parts	4.15	3.74	3.44	7.04	14.35
Subcontracted Equip. Home Office Drafting	2.13	2.13	2.13	2.13	2.13
Steam Gen. Erection	1.30	1.30	1.30	1.30	1.30
Shell	2.30	1.22	2.53*	2.57	2.73
Coal & Dolomite Preparation Equipment	2.32	2.31	2.31	2.31	2.31
Coal & Dolomite Feeding Equipment	5.08	5.06	5.06	5.06	5.06
Solid Waste Handling	2.38	2.37	2.37	2.37	2.37
Particulate Removal	21.00	21.43	21.93	20.84	20.84
Instrumentation and Control	2.70	2.70	2.70	2.70	2.70
Totals for ϕ = 1.15	43.4	43.0	44.2	46.3	53.8
Totals for ϕ = 1.45	36.6	36.2	37.3	38.9	44.5
Totals for ϕ = 1.90	32.1	31.8	32.8	33.7	37.5

*In Case 3 the refractory in the hot gas duct is included in the shell cost

Table 4.28 - Pressurized Fluidized Bed Boiler Costs x 10^{-6}, $
(15 atm; Airflow Rate - 1520 lb/s)

Case	ϕ = 1.15	ϕ = 1.45	ϕ = 1.90
3500 psi/1000°F/1000°F (1600°F)	39.4	33.9	30.0
3500 psi/1000°F/1000°F (1700°F)	39.2	33.6	29.8
3500 psi/1000°F/1000°F (1800°F)	40.4	34.9	29.8
4500 psi/1200°F/1200°F (1800°F)	42.6	36.5	31.6
5000 psi/1400°F/1400°F (1700°F)	50.0	42.1	35.4

4.3.3.5 Costs of Pressurized Fluidized Bed Potassium Boiler

Cost estimates for the pressurized fluidized bed potassium boilers were based upon sizes and configurations compatible with certain limitations on design parameters. In general, a four-module configuration with four fluidized beds per module was selected. The potassium vapor was generated in straight vertical tubing [2.54 cm (1 in) od] made of Haynes-25 (Ha-25), a high-temperature superalloy. In some cases, where the mean temperature difference between the bed and the potassium was small and a large heat exchange surface was required, it was necessary to stage the beds to avoid bed depths greater than about 4.57 m (15 ft). Staging the beds, while it minimizes the vapor-side pressure drop by limiting the tube length, introduces an increment in gas-side pressure drop associated with the second distributor plate. This is a penalty which is unavoidable with a fixed airflow and bed temperature.

Quantitative assumptions made included a superficial velocity, V_g, of 1.219 m/s (4 ft/s); an overall heat transfer coefficient, U_o, of 283.86 W/m^2-°K (50 Btu/hr-ft^2-°F); and a bed depth (and tube length) as close to 3 to 4 m (9.84 to 13.12 ft) as possible. Table 4.30 lists the operating conditions for the twelve cases for which cost estimates were prepared. These twelve cases cover all the parametric points required for the Rankine liquid-metal topping cycles.

Table 4.29 - Pressurized Fluidized Bed Boilers Costs x 10^{-6}, \$ (ϕ_{air} = 1.15 and P = 10 atm)

Component \ Case	1 3500 psi/ 1000°F/ 1000°F TIT = 1600°F	2 3500 psi/ 1000°F/ 1000°F TIT = 1700°F	3 3500 psi/ 1000°F/ 1000°F TIT = 1800°F	4 4500 psi/ 1200°F/ 1200°F TIT = 1700°F	5 5000 psi/ 1400°F/ 1400°F TIT = 1700°F
Pressure Parts	4.15	3.74	3.44	7.04	14.35
Subcontracted Equip't. Home Office Drafting	2.13	2.13	2.13	2.13	2.13
Steam Gen. Erection	1.30	1.30	1.30	1.30	1.30
Shell*	2.30	1.22	2.53	2.57	2.73
Coal and Dolomite Preparation Equipment	2.32	2.31	2.31	2.31	2.31
Coal and Dolomite Feeding Equipment	5.08	5.06	5.06	5.06	5.06
Solid Waste Handling	2.38	2.37	2.37	2.37	2.37
Particulate Removal	21.00	21.43	21.93	20.84	20.84
Instrumentation and Control	2.70	2.70	2.70	2.70	2.70
Total	43.36	42.99	43.77	46.32	53.74

*In Case 3, the refractory in the hot gas duct is included in the shell cost.

Table 4.30: Operating Conditions for Potassium Boilers

Case	Coal	Bed Temp., C°	Working Fluid (K or Cs) Tin, °C	T out, °C	P, kPa	Working Fluid	Air Equiv.	Airflow, kg/s	Heat Load, kg-cal/hr	Fluid Vol., m/s	FR, btm
1	Ill. #6	982 (1800°F)	593 (1100)	760 (1400)	103.4 (15 psig)	K	1.2	324.7 (716 lb/sec)	4.15×10^8 (1.65×10^9 Btu/hr)	1.245 (4 ft/s)	15
2	↓	↓	649 (1200)	816 (1500)	165.5 (24)	↓	↓	325.5 (716)	4.09×10^8 (1.625×10^9	↓	↓
3	↓	↓	704 (1300)	871 (1600)	248.2 (36)	↓	↓	322.1 (710)	4.13×10^8 (1.64×10^9)	↓	↓
4	↓	927 (1700)	593 (1100)	760 (1400)	103.4 (15)	↓	↓	313.0 (690)	4.31×10^8 (1.71×10^9)	↓	↓
5	↓	871 (1600)	↓	↓	↓	↓	↓	267.6 (590)	3.88×10^8 (1.54×10^9)	↓	↓
6	↓	982 (1800)	↓	↓	↓	↓	↓	335.7 (740)	4.051×10^8 (1.61×10^9)	↓	10
7	↓	↓	↓	↓	↓	↓	↓	367.4 (810)	4.082×10^8 (1.62×10^9)	↓	5
8	N. Dakota Lignite	↓	↓	↓	↓	↓	↓	336.1 (741)	3.881×10^8 (1.54×10^9)	↓	15
9	Montana Subbit.	↓	↓	↓	↓	↓	↓	327.5 (722)	4.007×10^8 (1.59×10^9)	↓	↓
10	Ill. #6 Bit.	↓	↓	↓	↓	↓	2.0	291.0 (641.5)	1.625×10^8 (6.45×10^8)	↓	↓
11	↓	↓	↓	↓	↓	↓	3.0	323.2 (712.5)	6.45×10^7 (2.56×10^8)	↓	↓
12	↓	↓	↓	↓	↓	Cs	1.2	264.4 (583.0)	3.566×10^8 (1.415×10^9)	↓	↓

Table 4.31 shows the geometry of the pressurized fluidized bed potassium boilers (PFBPB) for each case.

The module geometry without heat transfer surface is shown in Figure 4.26. A disengaging freeboard of 3.048 m (10 ft) was provided above each bed in order to allow heavy particles which are shot from the bed to fall out of the gas stream. In cases where beds are staged, the freeboard is provided for the uppermost bed only. There is a 3.048 m (10 ft) section at the top and bottom of the module for piping, access for maintenance, and so on. The ratio of module area to bed area is fixed at 3.23 to 1.

The arrangement of tubes in the bed is shown in Figure 4.27. The 2.54 cm (1 in) od Ha-25 tubes may be shop fabricated in bundles to minimize field-erection time and labor. The pitch was varied from case to case wherever excessively short tubes would have resulted from the base case of 269 tubes/m^2 (25 tubes/ft^2) of bed cross-sectional area. The tube length was taken to be identical with the bed depth.

As pointed out in a paper by A. P. Fraas (Reference 4.36), the cost of pressurized components is roughly optimized at tube lengths of approximately 3.048 to 6.096 m (10 to 20 ft). This reduces the number of tube-to-header welds required per meter of tubing without incurring excessive penalties in pressure drop.

Since boiling potassium has excellent heat transfer characteristics, it is reasonable to assume that metal temperatures will approximate the potassium temperature. Further, the external pressure exceeds the internal pressure in the tubes [$\sim$ 250 kPa (2.5 atm) for the highest-potassium pressure case considered]. Choice of materials is thus simplified since resistance to corrosion is the only critical factor, and local heat fluxes should not cause significant variation in metal temperatures. For costing purposes, Ha-25 tubes with a wall thickness of 2.54 mm (0.1 in) was assumed for all cases.

Table 4.31: Configuration and Geometry of PFBPB

Case	Modules	Cells per Module	Beds per Cell	Bed Depth, m	Bed Width, m	Bed Length, m	Module Height, m	Module Dia., m	Ht. Area/unit Bed Volume, m^2/m^3	Tube length, m	No. of Tubes
1	4	4	1	4/9 (13.75 ft)	2.743 (9.0 ft)	1.584 (5 ft)	36.88 (121 ft.)	4.145 (13.6 ft)	21.48 (6.55 ft^2/ft^3)	4.191 (13.75 ft)	18,000
2	4	4	1	4.846 (15.9)	2.743 (9.0)	1.524 (5.0)	39.62 (13.n)	4.145 (13.6)	21.48 (6.55)	4.846 (15.9)	18,000
3	4	2	2	3.26 (10.7)	2.719 (8.92)	2.048 (10.0)	28.96 (95)	5.852 (19.2)	21.48 (6.55)	3.261 (10.7)	35,600
4	4	2	2	2.77 (9.1)	2.51 (8.25)	3.048 (10.0)	27.43 (90)	4.663 (15.3)	21.48 (6.55)	2.774 (9.1)	33.050
5	4	2	2	4.51 (14.8)	2.438 (8.0)	2.566 (8.42)	30.48 (100)	5.074 (16.65)	21.48 (6.55)	4.811 (14.8)	26,000
6	4	4	1	3.916 (12.85)	2.126 (6.975)	3.048 (10.0)	40.66 (133.4)	5.151 (16.9)	137.4 (4.18)	3.929 (12.89)	17,850
7	4	4	1	3.209 (10.53)	4.648 (15.25)	3.048 (10.0)	34.84 (114.3)	7.62 (25)	7.743 (2.36)	3.209 (10.53)	21,950
8	4	4	1	3.52 (11.55)	1.829 (6.0)	2.408 (7.9)	37.86 (124.2)	4.25 (13.95)	21.48 (6.55)	3.520 (11.55)	19,000
9	4	4	1	3.76 (12.35)	1.981 (6.5)	2.134 (7.0)	38.71 (127)	4.13 (13.55)	21.48 (6.55)	3.764 (12.35)	
10	4	4	1	2.804 (9.2)	1.524 (5)	2.408 (7.9)	35.05 (115)	3.892 (12.77)	13.714 (4.18)	2.804 (9.2)	
11	2	4	1	1.777 (5.83)	2.201 (7.22)	3.658 (12.0)	29.26 (96)	5.761 18.9)	7.743 (2.36)	1.777 (5.83)	6,230
12	4	2	2	4.115 (13.5)	2.438 (8)	2.362 (7.75)	30.48 (100)	4.862 (15.95)	21.48 (6.55)	4.115 (13.5)	24,800

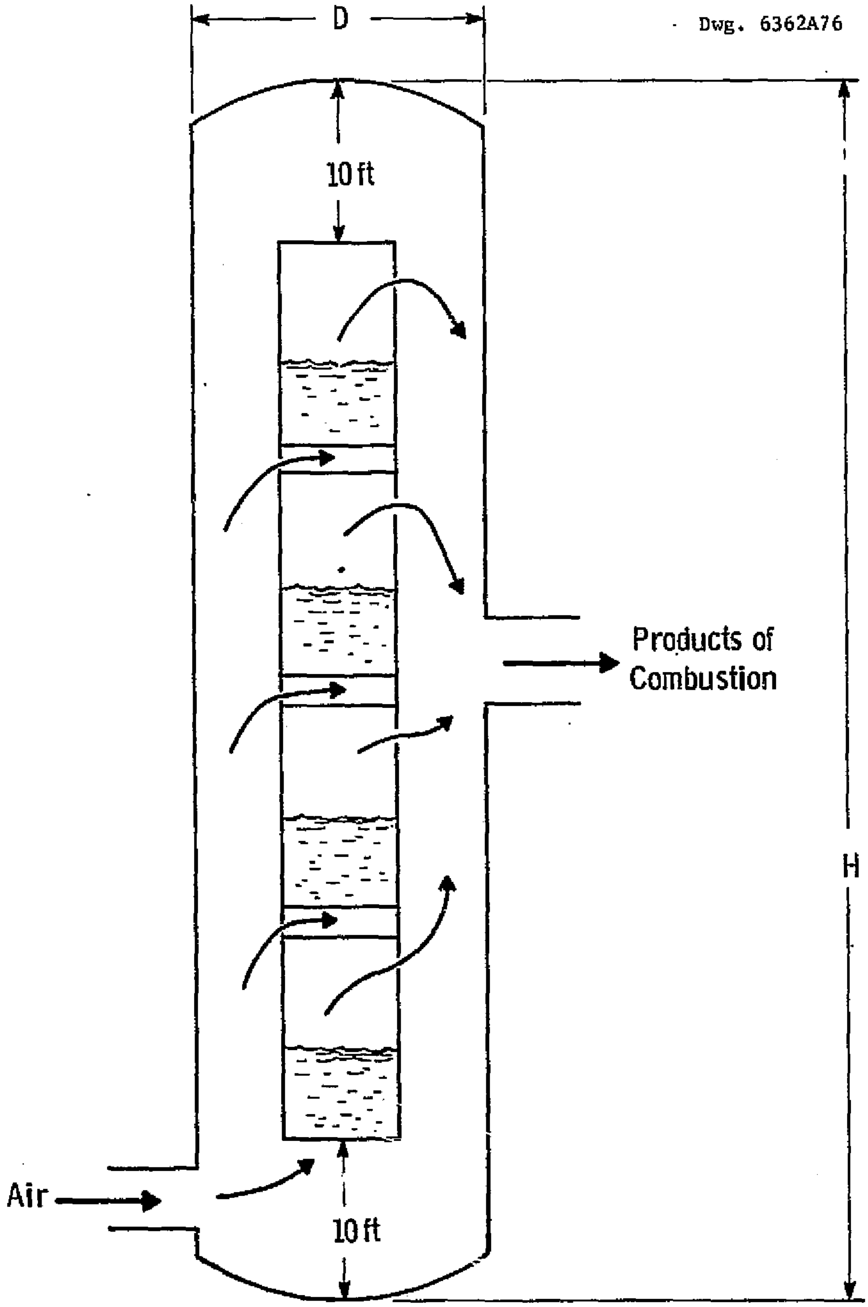

Fig. 4.26—Single-module geometry and arrangement of beds of a pressurized fluidized bed potassium boiler

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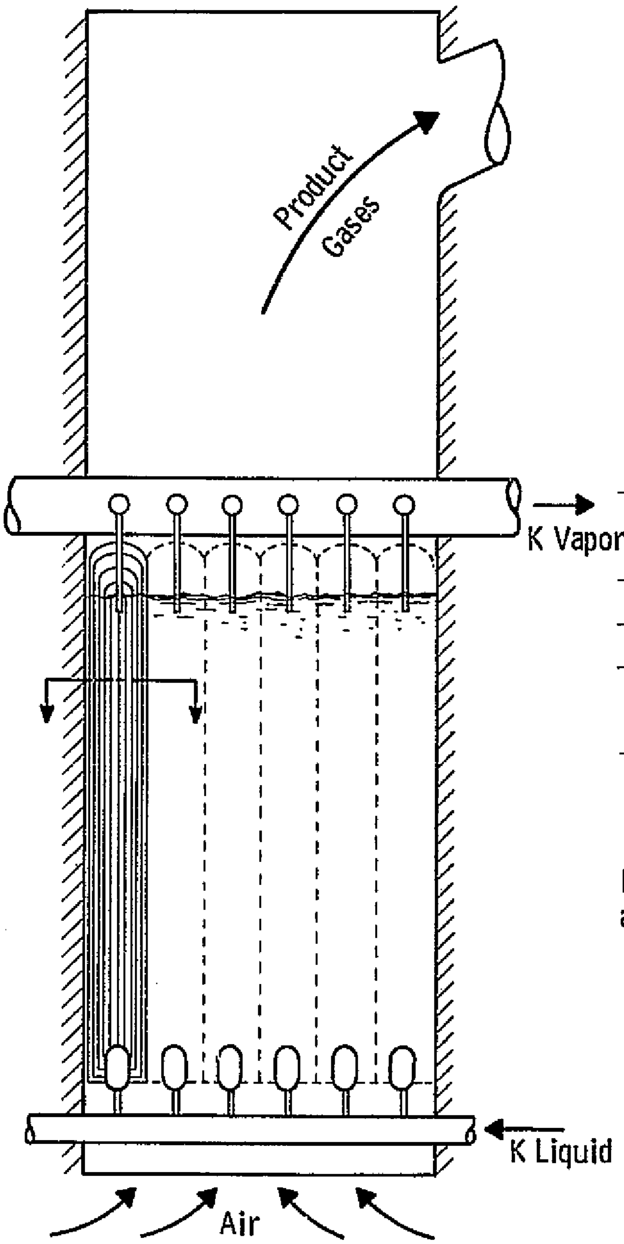

Fig. 4.27a— Possible arrangement of headers & tubes in the pressurized fluidized bed potassium boiler

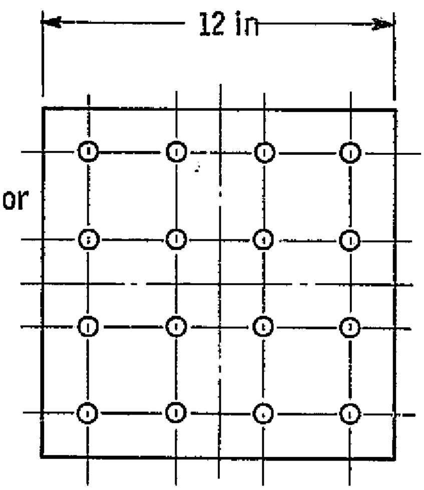

Fig. 4.27b —Rectangular tube arrangement - 3 in centers

Cost estimates for the vapor generator included tubing material costs; tubing fabrication costs; costs for headers, risers, and downcomers; and pressure vessel costs.

The material costs of pressurized components were calculated by applying the following algorithm:

$$\text{Cost} = (\text{TTL}) \left[(\text{ATC}) \left(1 + \left(\frac{10}{\text{TL}} \times 0.5\right)\right)\right] + 2{,}980{,}000 \left(\frac{N}{50{,}400}\right)(\text{ATC}) \tag{4.15}$$

where TTL = total tube length in the generators, ft

TL = individual tube length, ft

N = total number of tubes

ATC = average tube cost, \$/ft.

The cost of installation was assumed to be 50% of the material cost. Shell costs were calculated using Equations 4.13 and 4.14.

$$\text{Shell Material Cost, \$} = 0.35 \times 10^6 \left(\frac{t_w}{1.314}\right)\left(\frac{D}{20}\right)\left(\frac{H}{120}\right) \tag{4.13}$$

$$\text{Shell Labor Cost} = 0.31 \times 10^6 \left[\frac{1 + 2\,(C_1\ t_w - 1)}{2}\right]\left[\frac{D}{20}\right]\left[\frac{H}{120}\right] \tag{4.14}$$

where t_w = shell wall thickness, in = $12\,\frac{PD}{2\sigma}$ (σ = 13,700 psi)

D = vessel diameter, ft

H = vessel height, ft

P = vessel pressure, psi

C_1 = cost base adjustment constant = 1.14.

Table 4.32: Pressurized Fluidized Bed Potassium Boiler Costs x 10^{-6}, $

	1	2	3	4	5	6	7	8	9	10	11	12
Pressure Parts	2.955	3.270	5.450	4.560	4.610	3.325	3.320	2.985	2.953	1.450	0.777	3.140
Pressure Vessel	1.812	1.942	3.028	1.762	2.328	1.958	1.642	1.976	1.892	1.498	1.482	2.132
Coal & Dolomite Prep.	1.510	1.510	1.510	1.400	1.320	1.550	1.675	1.665	1.410	0.910	0.740	1.250
Coal & Dolomite Feeding	4.310	4.310	4.310	4.000	3.770	3.440	3.350	3.770	2.940	1.890	1.520	3.580
Solid Waste Handling	1.835	1.835	1.835	1.750	1.600	1.550	1.555	0.886	0.760	0.490	0.396	1.520
Particulate Removal	9.380	9.380	9.380	8.600	7.720	11.500	19.000	9.640	9.450	5.450	5.850	7.330
Vapor Gen Erection	1.475	1.635	2.7720	2.280	2.305	1.660	1.660	1.490	1.475	0.725	0.388	1.570
Sub total $/Module	23.277	23.882	28.233	24.352	23.653	24.983	32.202	22.412	20.880	12.413	11.153	20.522
No. of Modules	4	4	4	4	4	4	4	4	4	8	12	4
Total V.G. Cost	93.108	95.528	112.942	97.408	94.612	99.932	128.808	89.648	83.520	99.304	133.836	82.088

Table 4.32 presents component, module, and total vapor generator costs for the 12 cases considered. These may be correlated with the specific parametric points for the liquid-metal topping cycle study through Table 4.33.

Table 4.33 - Cross-index for Rankine Liquid-Metal Topping Cycle

Case (Table 4.30)	Parametric Point (Table 8.6)
1	1, 7, 8, 11, 13, 15, 16, 27, 30, 33, 36, 37, 38, 39, 49
2	23, 25, 28, 31, 34
3	24, 26, 29, 32, 35
4	22
5	21, 40, 41, 42
6	18
7	17
8	3
9	2
10	19
11	20
12	46, 47, 48

4.3.3.6 Cost of Pressurized Fired Heater Subsystems for Closed-Cycle Gas Turbines

A schematic diagram of a pressurized combustor subsystem for application to the closed-cycle gas turbine is shown in Figure 4.6. The principal components when using clean fuel are a fired heater (pressurized combustor), a recuperator, a gas turbine generator, and a stack-gas cooler. For those cases in which clean fuel is used, the subsystem costs do not include the heat exchanger surface. For those cases using fluidized bed combustion with direct firing of coal, the heat exchanger surface is integrated with the combustion process, and the cost estimates include the heat exchanger.

In-bed desulfurization of the products of combustion is assumed for those cases using fluidized bed combustion with direct firing of coal. The following additional equipment, therefore, is included in the pressurized combustor subsystem when coal is fired.

- Coal and dolomite preparation equipment
- Coal and dolomite feeding equipment
- Waste solids handling equipment
- Particulate removal equipment.

For the cases with fluidized combustion, multiple fired-heater modules are assumed for each gas turbine. The fired-heater modules are similar to the high-pressure fluidized bed boiler modules. Each module has several separate beds stacked in a vertical cylindrical vessel. In the fired heater, however, each module has the same function, so all beds are identical. The bed enclosure and internal ducting are refractory lined so that the turbine inlet temperature is the same as the bed temperature (assuming no heat loss).

The working fluid for all cases of the closed-cycle gas turbine system is helium. The helium conditions for the base design case are as follows:

- Helium pressure - 6.894 MPa (1000 psi)
- Heater inlet temperature - 733°K (860°F)
- Heater outlet temperature - 1089°K (1500°F)
- Helium-side heat transfer coefficient 1419.3 W/m^2-°K (250 Btu/hr-ft^2-°F)
- Helium-side pressure loss - 2%.

The base case conditions for the pressurized fluidized bed combustion subsystem are as follows:

- Pressure ratio - 10 to 1
- Air equivalence ratio - 1.2

- Turbine inlet temperature - 1255°K (1800°F)
- Compressor airflow rate - 294.8 kg/s (650 lb/s)
- Bed-side heat transfer coefficient 283.86 W/m^2-°K ($50 Btu/hr-ft^2$-°F)
- Maximum bed temperature - 1283°K (1850°F)
- Coal - Illinois No. 6 bituminous
- Turbine coating air fraction - 0.066
- Maximum bed depth - ∿ 4.57 m (15 ft)
- Heater tube pitch to diameter ratio - 2.33
- Heater tube id to od ratio - 0.75
- Ratio of heat transferred to compressor airflow - 1.52 MJ/kg (650 Btu/lb).

The modular heater design generated for this base case has the following features:

- Heater tube diameter - 3.81 cm (1.5 in)
- Superficial velocity - 1.07 m/s (3.5 ft/s)
- Number of beds per module - 4
- Bed length - 3.322 m (10.9 ft)
- Bed width 1.158 m (3.8 ft)
- Bed depth 4.48 m (14.7 ft)
- Vessel diameter 3.962 m (13 ft)
- Vessel height 38.71 m (127 ft).

The tube metal temperature profile was constructed for the 1255°K (1800°F) bed temperature for use in the selection of tube materials. The tube materials selected for the base case are shown in Table 4.34:

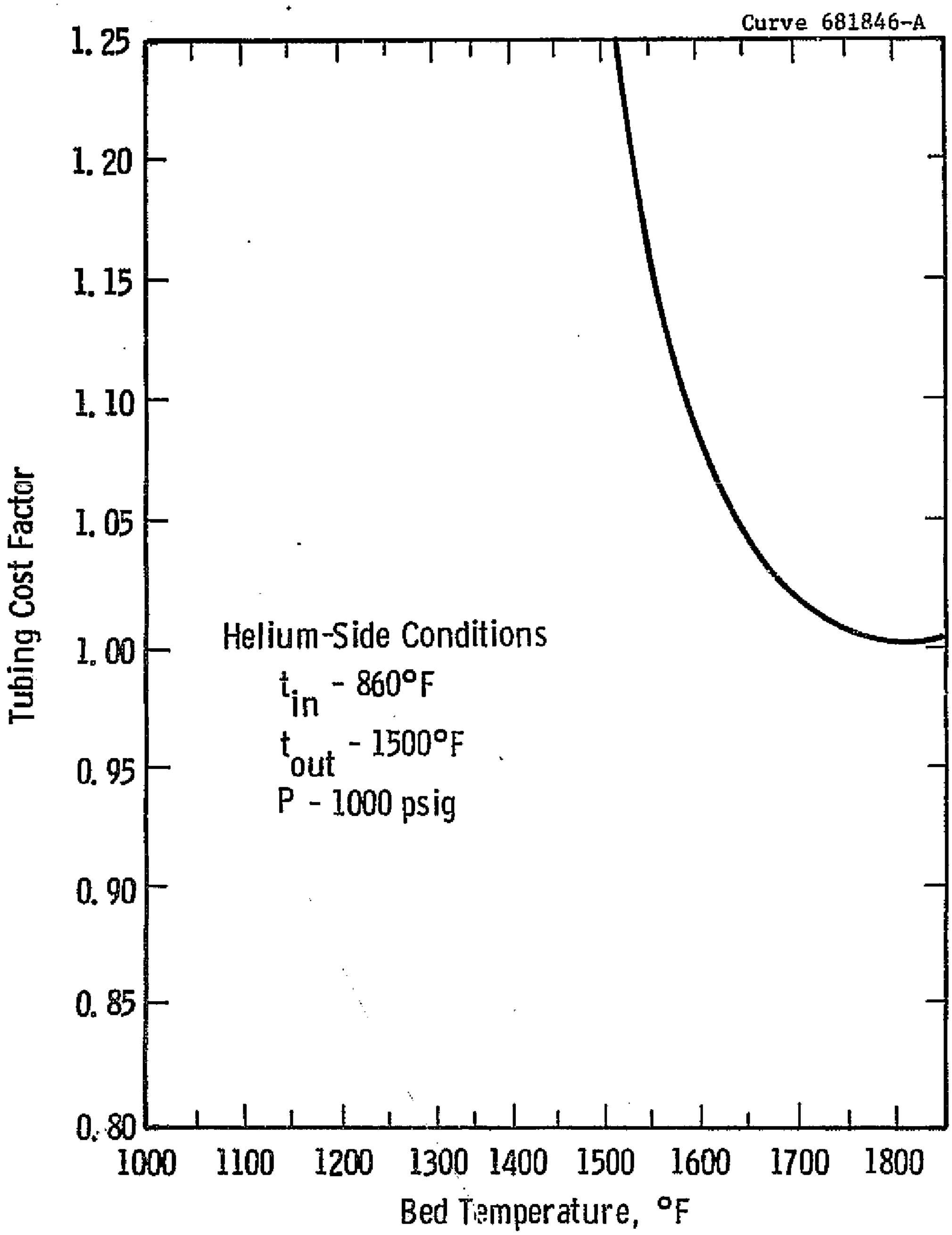

Fig. 4.28—Tubing cost correlation for fluidized bed pressurized fired heater for closed-cycle gas turbine using helium

Table 4.34 - Tube Materials

(t_w) max, °F	Material
1206	SA-213-TP304H
1383	SA-213-TP347
1501	HA-25 (L605)

The relative quantities of tubing required of each of the above materials were calculated, and an average tubing cost of \$64.25/m (\$14.10/ft) was obtained. Tubing costs for various materials were obtained from Babcock and Wilcox and from Allegheny Ludlum.

The above procedure was carried out for a range of bed temperatures, and a tubing cost factor as a function of bed temperature was correlated as shown in Figure 4.28. The minimum average cost of tubing per unit length occurs at a bed temperature of about 1255°K (1800°F). The increase in the log mean temperature difference between the helium and the bed with an increase of bed temperature substantially reduces the total amount of tubing required but demands that an increased fraction of the tubing be made from more expensive high-temperature alloys. The temperature differences for the more expensive materials decrease as the bed temperature decreases below 1255°K (1800°F); and the relative quantity of these expensive materials increases rapidly. The increased cost of the tubing materials as bed temperature increases above 1255°K (1800°F), outweighs the effect of the increased temperature difference.

The cost of the pressure parts of the fired heater is equal to the sum of the tubing cost; the cost of the headers, downcomers, and risers; and the cost of fabrication. The cost of the tubing is equal to the product of the average tubing cost and the total length of tubing required. The cost of the headers, downcomers, and risers was assumed to be 60% of the cost of the tubing (Reference 4.8). The cost of fabrication was determined from Equation 4.16.

$$\text{Fabrication costs} = 10 \left(\frac{\text{Avg. tubing cost}}{3:66}\right)^{0.3} \qquad (4.16)$$

where the average tubing cost is in \$/ft.

This expression was derived from cost data contained in Reference 4.8.

Pressure parts cost factors were developed for the following design parameters on the basis of the quantity of heat transferred per unit of compressor airflow.

- Bed temperature
- Pressure ratio
- Air equivalence ratio
- Log mean temperature difference
- Pressure difference.

These cost factors were applied to the estimated cost of the pressure parts for the base case to obtain cost estimates for the other cases. The scaling exponent for airflow rate was assumed to be 0.85.

The cost correlation expressions used for the coal and dolomite preparation and handling, and/or solid waste handling components, of the pressurized fluidized bed fired heaters for closed-cycle gas turbine application are shown in Equations 4.17 through 4.19:

Coal and dolomite preparation equipment (Reference 4.5):

$$\text{Installed cost} = (\$550{,}000)\left(\frac{\text{Coal rate + dolomite rate}}{50}\right)^{0.7} \qquad (4.17)$$

Coal and dolomite feeding equipment (Reference 4.8):

$$\text{Installed cost} = (\$2{,}400{,}000)\left(\frac{\text{Coal rate + dolomite rate}}{134}\right)^{0.7} \qquad (4.18)$$

Waste solids handling equipment (Reference 4.8):

$$\text{Installed cost} = (\$529{,}000)\left(\frac{\text{ash + spent sorbent rate}}{20}\right)^{0.7} \quad (4.19)$$

where all rates are in tons/hr.

The cost correlations for the particulate removal equipment (cyclone separators, tornado separators, granular bed filters, and electrostatic precipitators) are given in Subsubsection 4.5.3.3.

The surface areas required for the recuperator in the pressurized fired heater subsystems were computed using Equation 4.20.

$$S = W_a\,(q/W_a)/[U_o(1-\varepsilon)(T_{Hi} - T_{Ci})] \quad (4.20)$$

where
S = surface area, ft^2
W_a = compressor airflow rate, lb/hr
q = heat transferred, Btu/hr
U_o = overall heat transfer coefficient, Btu/hr-ft^2-°F
ε = recuperator effectiveness.
T_{Hi} = temperature of hot fluid entering
T_{Ci} = temperature of cold fluid entering

It was assumed that the recuperator would be of shell and finned-tube construction, with the particulates bearing products of combustion on the inside of the tubes, and that the overall heat transfer coefficient would be 56.77 W/m^2-°K (10 Btu/hr-ft^2-°F).* A specific equipment cost of \$107.64/m^2 (\$10/ft^2)* was assumed (Reference 4.37), and an installed cost factor of 1.3 was used. It was assumed, also, that gas-side pressure effects and recuperator costs would be compensating.

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*Based on the products-side area.

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TABLE 4.35—COSTS OF PRESSURIZED FIRED HEATER (FLUIDIZED BED) FOR CLOSED CYCLE GAS TURBINE SYSTEMS

Case									
Conditions									
W_a, lb/s	650	650	650	650	650	650	650	650	650
PR	10	10	15	5	10	10	10	10	10
TIT, °F	1800	1700	1700	1700	1100	1700	1100	1700	1100
ϕ_{Air}	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
t_{He}, °F	1500	1500	1500	1500	1500	1500	1500	1500	1500
P_{He}, psig	1000	1000	1000	1000	1000	1000	1000	1000	1000
Coal Type	Ill. No. 6	Ill. No. 6	Ill. No. 6	Ill. No. 6	Ill. No. 6	Montana	Montana	N. Dakota	N. Dakota
Cost × 10^{-6}, $									
Heater Modules	14.280	16.681	15.722	15.838	17.892	16.681	17.892	16.681	17.892
Coal and Dolomite Prep. Equip.	1.402	1.402	1.402	1.402	1.402	1.255	1.255	1.533	1.533
Coal and Dolomite Feed Equip.	3.060	3.060	4.000	2.754	3.060	2.740	2.740	3.346	3.346
Particulates Removal Equip.	10.404	10.099	8.406	15.508	8.044	10.099	8.044	10.099	8.044
Solid Waste Handling Equip.	1.428	1.428	1.714	1.285	1.428	0.673.	0.673	0.757	0.757
Special Piping	1.984	1.901	1.902	1.901	1.409	1.901	1.409	1.901	1.409
Gas Turbine (Modified)	5.860	5.750	6.640	5.147	5.233	5.750	5.233	5.750	5.233
Subtotal	38.358	40.321	39.786	43.834	38.466	39.099	37.246	40.067	38.214
Recuperator Cost × 10^{-6}, $									
$\varepsilon = 0.8$	3.042	3.042	–	3.042	–	3.042	–	3.042	–
$\varepsilon = 0.9$	6.845	6.845	–	6.845	–	6.845	–	6.845	–
$\varepsilon = 0.95$	14.450	14.450	–	14.450	–	14.450	–	14.450	–
Stack Gas Cooler Cost × 10^{-6}, $									
$\varepsilon = 0$	1.677	1.634	1.558	1.770	1.395	1.634	1.395	1.634	1.395
$\varepsilon = 0.8$	1.226	1.240	–	0.845	–	1.240	–	1.240	–
$\varepsilon = 0.9$	1.108	1.136	–	0.620	–	1.136	–	1.136	–
$\varepsilon = 0.95$	1.057	1.071	–	0.499	–	1.071	–	1.071	–
Total Subsystem Cost × 10^{-6}, $									
$\varepsilon = 0$	40.035	41.955	41.344	45.604	39.863	40.733	38.641	41.701	39.609
$\varepsilon = 0.8$	42.626	44.603	–	47.721	–	43.381	–	44.349	–
$\varepsilon = 0.9$	46.311	48.302	–	51.299	–	47.080	–	48.048	–
$\varepsilon = 0.95$	53.865	55.842	–	58.783	–	54.620	–	55.588	–

The surface areas required for the stack-gas coolers in the pressurized fired heater subsystems were computed using the following expression:

$$S = (W_a)(q/W_a)/[(U_o)(LMTD)] \qquad (4.21)$$

where S = surface area, ft^2

W_a = compressor airflow, Btu/hr

q = heat transferred, Btu/hr

U_o = overall heat transfer coefficient, Btu/hr-ft^2-°F

LMTD = log mean temperature difference, °F.

It was assumed that the stack-gas cooler would have to be of shell-and-tube construction to avoid deposition problems, and that the overall heat transfer coefficient would be 56.77 W/m^2-°K (10 Btu/hr-ft^2-°F). A specific equipment cost of \$107.64/m^2 (\$10/ft^2) was assumed (Reference 4.37), and an installed cost factor of 1.3 was used.

The estimated costs of the pressurized fluidized bed fired heaters for various closed-cycle gas turbine cases with direct firing of coal are listed in Table 4.35.

The estimated costs of the pressurized fired heaters for various closed-cycle gas turbine cases with clean fuels (distillate from coal-derived liquid, and high-Btu fuel gas) are listed in Table 4.36. The costs used here for the recuperators and the stack-gas coolers are the same as those used for the pressurized fluidized bed fired heaters. These values are conservative for clean fuel applications, because plate fin heat exchangers could be used for the recuperators instead of shell and finned tube; and shell and finned-tube heat exchangers could be used for the stack-gas cooler instead of shell and tube.

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TABLE 4.36—COSTS OF PRESSURIZED FIRED HEATER (CLEAN FUEL) FOR CLOSED CYCLE GAS TURBINE SYSTEMS

Case								
Conditions								
W_a, lb/s	650	650	650	650	650	650	650	650
PR	10	15	5	10	15	5	10	15
TIT, °F	2200	2200	1100	1100	1100	1700	1700	1700
$\emptyset_{Air}$	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15
t_{He}, °F	1200, 1500, 1800	1500	1500	1500	1500	1500	1500	1500
P_{He}, psig	1000	1000	1000	500, 1000, 2000	1000	1000	1000	1000
Fuel	Distillate & SNG	Distillate	Distillate	Distillate & SNG	Distillate	Distillate	Distillate	Distillate
Costs $\times 10^{-6}$, $								
Combustor *	0.471	0.512	0.348	0.471	0.512	0.348	0.471	0.512
Special Piping	2.319	2.319	1.409	1.409	1.409	1.900	1.900	1.900
Gas Turbine (Modified)	5.713	6.629	4.937	5.233	6.107	5.147	5.750	6.640
Subtotal	8.503	9.460	6.694	7.113	8.028	7.395	8.121	9.052
Recuperator Cost $\times 10^{-6}$, $								
$\varepsilon = 0.8$	3.042	3.042	3.042	–	–	3.042	3.042	–
$\varepsilon = 0.9$	6.845	6.845	6.845	–	–	6.845	6.845	–
$\varepsilon = 0.95$	14.450	14.450	14.450	–	–	14.450	14.450	–
Stack Gas Cooler Cost $\times 10^{-6}$, $								
$\varepsilon = 0$	1.901	1.814	1.404	1.395	1.385	1.770	1.634	1.558
$\varepsilon = 0.8$	1.672	1.696	1.266	–	–	0.845	1.240	–
$\varepsilon = 0.9$	1.593	1.682	1.250	–	–	0.620	1.136	–
$\varepsilon = 0.95$	1.550	1.670	1.259	–	–	0.499	1.071	–
Total Subsystem Cost $\times 10^{-6}$, $								
$\varepsilon = 0$	10.404	11.274	8.098	8.508	9.413	9.165	9.755	10.610
$\varepsilon = 0.8$	13.217	14.198	11.002	–	–	11.282	12.403	–
$\varepsilon = 0.9$	16.941	17.987	14.789	–	–	14.860	16.102	–
$\varepsilon = 0.95$	24.503	25.580	22.404	–	–	22.344	23.642	–

* Not including the heat exchanger

The estimated costs of the pressurized fired heater for various closed-cycle gas turbine cases with integrated low-Btu gasification are listed in Table 4.37. Here, again, the costs for the recuperators and stack-gas coolers are the same as those used for the pressurized fluidized bed fired heaters. The less expensive heat exchangers probably could be used for low-Btu fuel gas applications as well as for clean fuels.

4.3.3.7 Gas Turbine Costs

The prices for gas turbines were compiled by the Westinghouse Gas Turbine Engine Division and are generalized in Sections 5 and 6.

4.3.3.8 Cost of Atmospheric-Pressure Fired Heater

One of the closed-cycle gas turbine cases with clean fuel used an atmospheric-pressure fired heater. In this case the fired heater subsystem consisted of a combustor, a fan for the combustion air, and a regenerative-type air preheater. The conditions for this case were as follows:

- W_a, 294.8 kg/s (650 lb/s)
- PR, 1.013 MPa (10 atm)
- TIT, 866°K (1100°F)
- ϕ_{air}, 1.15
- T_{He}, 1089°K (1500°F)
- P_{He}, 6.895 MPa (1000 psi)
- Fuel, distillate from coal.

The estimated subsystem cost is:

• Combustor	$ 600,000
• Fan	250,000
• Air preheater	5,900,000
Total	$6,750,000.

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TABLE 4.37 – COSTS OF PRESSURIZED FIRED HEATER (INTEGRATED LOW-BTU GASIFIER) FOR CLOSED CYCLE GAS TURBINE SYSTEMS

Case		
Conditions		
W_a, lb/s	650	650
PR	10	10
TIT, °F	2200	1100
ϕ_{Air}	1.20	1.20
t_{He}, °F	1500	1500
P_{He}, psig	1000	1000
Fuel	Low Btu Fuel Gas	Low Btu Fuel Gas
Costs × 10^{-6}, $		
Gasifier Subsystem	30.900	36.140
Combustor *	0.700	0.700
Special Piping	2.420	1.510
Gas Turbine (Modified)	5.713	5.233
Subtotal	39.733	43.583
Recuperator Cost × 10^{-6}, $		
$\varepsilon = 0.8$	3.042	–
$\varepsilon = 0.9$	6.845	–
$\varepsilon = 0.95$	14.450	–
Stack Gas Cooler Cost × 10^{-6}		
$\varepsilon = 0$	1.901	1.395
$\varepsilon = 0.8$	1.672	–
$\varepsilon = 0.9$	1.593	–
$\varepsilon = 0.95$	1.550	–
Total Subsystem Cost × 10^{-6}, $		
$\varepsilon = 0$	41.634	44.978
$\varepsilon = 0.8$	44.447	–
$\varepsilon = 0.9$	48.171	–
$\varepsilon = 0.95$	55.733	–

* Not including the heat exchanger

4.4 Low-Btu Gasification Technology

4.4.1 Coal Gasification Processes

Gasification of coal is an old technology. Around 1920, thousands of gas producers were in use in the U.S. for the production of town gas. More recently, gasification of coal has been aimed at providing feedstocks for synthesis processes. Currently, substantial programs in the development of high-Btu pipeline gas processes are being carried out under the sponsorship of the Office of Coal Research (OCR), and Department of Interior (DOI).

Nominally complete gasification processes may be classified in a variety of ways, as listed below:

- By the method of supplying the heat required by the gasification reactions
  - Internal heating
    - Autothermic
    - Cyclic
    - Heat-carrying fluids or solids
  - External heating: heat transferred through the walls of the reaction vessel
- By the method of contacting reactants
  - Fixed bed
  - Fluidized bed
  - Suspension of particles in gasifying medium
- By the flow of reactants
  - Concurrent
  - Countercurrent
- By the gasifying medium
  - Steam
  - Hydrogen
  - Carbon dioxide

- By the condition of the residue removed
  - Dry ash in nonslagging operation
  - Slag in slagging operation
- By the pressure used in the reactor
  - Atmospheric pressure
  - Elevated pressure.

In autothermic gasification the heat absorbed by the endothermic reactions with carbon is supplied by the oxidation of some of the carbon by oxygen. In addition, the oxidation reactions must liberate enough energy to maintain the reactants at the reaction temperature, as in the gas producer.

In cyclic heating processes the exothermic oxidation process and endothermic gasification processes are carried out alternately, as in the water-gas set.

The heat absorbed by the gasification reactions may be supplied by heating some of the reactants or an intermediate heat transfer medium outside the reactant vessel. Intermediate materials, for example, are preheated, and then brought into the reaction zone where the heat is transferred directly to the reacting mixture. This process is unique because the heat required for gasification does not necessarily come from oxidation of the carbon being gasified. A variety of intermediate heat transfer media have been used, including steam, a moving fuel bed, a moving pebble bed, and a circulating slag bath.

The heat absorbed by the gasification reaction may be supplied by the transfer of heat through the walls of the reaction vessel. This is another process which does not rely on energy from the oxidation of carbon. It has the disadvantage of low throughput because of the inherent limitation on the rate of heat transfer. External heating has been applied to fixed and fluidized beds.

Both the fixed bed and the suspension-type gasifiers can be designed for either slagging or nonslagging operation. The fluidized bed processes are inherently nonslagging.

In an autothermic gasification process the blast must contain an oxidant, such as oxygen or air. Oxygen is used for the production of high-Btu gas or nitrogen-free gas, but for power fuel production the use of air rather than oxygen is likely to be more economical. Oxidants such as steam, carbon dioxide, and hydrogen are used in the blasts of gasifiers to control the composition of the product gas and the local temperatures within the reactors.

The reactions which occur between these oxidants and hot carbon in the gasification process are:

$$C + H_2O \rightarrow CO + H_2 \quad (4.22)$$

This is known as the steam-carbon reaction. It is endothermic and has a heat of reaction of 10.953 MJ/kg (4,710 Btu/lb) of carbon.

$$C + CO_2 \rightarrow 2\ CO \quad (4.23)$$

This reaction is endothermic and has a heat of reaction of 14.372 MJ/kg (6,180 Btu/lb) carbon.

$$C + 2\ H_2 \rightarrow CH_4 \quad (4.24)$$

This is known as the hydrogasification reaction.

Further reactions which occur in the gasification process are:

$$CO + H_2O \rightarrow CO_2 + H_2 \quad (4.25)$$

Equation 4.25 is commonly known as the water-gas shift.

$$CO + 3H_2 \rightarrow CH_4 + H_2O \quad (4.26)$$

$$2\ CO + 2\ H_2 \rightarrow CH_4 + CO_2 \quad (4.27)$$

These reactions have been discussed in detail by Parent and Katz (Reference 4.38) Von Fredersdorff (Reference 4.39).

To a considerable degree the first step in coal gasification is the same whether the final product is low-Btu fuel gas, high-Btu pipeline gas, or synthesis gas. The chief difference is that an air blast would probably be used in the production of low-Btu fuel gas, but oxygen would be used if the end product were high-Btu pipeline gas or synthesis gas. For the production of high-Btu pipeline gas, the initial gasification step would be followed by methanation and carbon dioxide removal; or by a (partial or total) hydrogenation process. Synthesis gas production requires only the removal of carbon dioxide.

During 1964 and 1965, Bituminous Coal Research, Inc. (BCR) made a comprehensive survey of coal gasification technology and economics under a contract with OCR. (Reference 4.40) The evaluation of gasification processes was done in three categories: synthesis gas processes, fuel gas processes, and other gas processes. The resulting reports constitute a valuable collection of reference material.

4.4.1.1 Fixed Bed Gasifiers

Until recently the only company in the U. S. which could supply fixed-bed gasifiers was the McDowell-Wellman Co. Up to 1948, this company manufactured primarily small brick-lined units for anthracite, coke, and charcoal. In 1948, they introduced a line of water-cooled units equipped with internal stirrers which has been used successfully on strongly caking bituminous coal. The commercial Wellman gasifiers range up to 3.05 m (10 ft) id and operate at 101.3 kPa (1 atm) (Reference 4.41). In the late 1960s Wellman supplied an experimental 1.07 m (42 in) diameter high-pressure gasifier unit to the Bureau of Mines (BOM) at Morgantown, West Virginia, for an investigation of high-pressure coal gasification. This unit has been operated successfully using both anthracite and bituminous coals (Reference 4.42). M. W. Kellogg has recently developed a design capability for fixed-bed coal gasification and is offering such equipment on a commercial basis.

The most advanced process for the gasification of coal is the Lurgi fixed-bed gasifier (Reference 4.43). It is designed to operate at pressures up to 3.039 MPa (30 atm) and has been used commercially since 1936 to produce synthesis and town gas. Units are available in sizes up to 3.66 m (12 ft) in diameter. The most notable installation of Lurgi gasifiers is at Sasolburg, South Africa. Nine Lurgi gasifiers were originally installed in 1955, and four more have been installed since. About four years ago, five Lurgi gasifiers were installed at STEAG's Kellerman station near Lünen, West Germany, for the production of a low-Btu fuel gas from Ruhr Valley coal for use in a combined-cycle plant with a supercharged boiler (Reference 4.44). Operation of this plant on a sustained basis had not yet been attained early in 1974.

A Lurgi unit installed at Westfield, Scotland, has recently been operated using a number of U. S. coals to evaluate it for use in the U. S. El Paso Natural Gas was planning to construct a synthetic natural gas plant using Lurgi gasifiers in the southwestern U. S. but is now restudying the economics of the plant in view of rapidly escalating costs. Several other U. S. gas companies are investigating the Lurgi equipment. Commonwealth Edison, with EPRI support, has made a study of an installation of Lurgi gasifiers in the Chicago area for the production of low-Btu boiler fuel; and General Electric has a fixed-bed gasifier under development in their Research Laboratory at Schenectady.

It has recently been announced that the development of a slagging-type fixed-bed gasifier which was started in the U.K. ten years ago is being reactivated. The Lurgi unit at Westfield will be modified for full-scale tests of the process. Fourteen U.S. companies are funding the $10 million project. The slagging fixed-bed gasifier is expected to have a higher capacity than a grate-type unit of the same size.

The characteristics of the fixed-bed gasification processes are as follows:

- Maximum operating problems with caking coal
- Requires double-screened coal - about 50% of run-of-mine coal is excluded
- Countercurrent flow leads to heat economy
- Long residence time provides good carbon conversion
- Solids content of raw fuel gas is low
- Raw fuel gas temperature is low [811°K (∿ 1000°F)], so tar and ammonia are present.

4.4.1.2 Fluidized Bed Gasification

Since the early 1960s, OCR has been funding the development of a number of coal gasification processes for the production of high-Btu pipeline gas. The majority of these processes utilize fluidized bed technology. Currently, fluidized bed gasification processes for the production of low-Btu fuel gas are under development by the following organizations (Reference 4.45):

- Bituminous Coal Research, Inc.
- U.S. Bureau of Mines, Bruceton
- Institute of Gas Technology (U-Gas)
- Westinghouse Electric Corporation.

Davey Powergas, Inc. is offering Winkler-type gasifiers to U.S. customers on a commercial basis. This process has been widely used in Europe and Asia.

Typically, the fluidized bed gasification process:

- Tolerate a wide variation in fuel quality
- Has excellent heat transfer between gas and solids
- Provides for easy addition and removal of solids
- Permits gas to exit at bed temperature
- Can agglomerate ash in the reactor
- Uses crushed coal, so it can take total ROM
- Has the potential for operating problems with strongly caking coals
- Can be operated at a sufficiently high temperature level to eliminate tars and ammonia from fuel gas
- Is capable of in-bed desulfurization
- Requires multiple beds for countercurrent operation
- Has raw fuels gas temperature range of 1033 to 1255°K (1400 to 1800°F)
- Will probably have tar present at raw fuel gas temperatures 1144°K (1600°F)

4.4.1.3 Suspension Gasifiers

Several suspension-type gasification processes have been developed in Europe to a commercial or semicommercial status. The Ruhrgas Vortex Gas

Producer which gasifies pulverized coal in a refractory-lined cylindrical chamber at atmospheric pressure was being developed in Germany in 1936. The objective of the development was to produce a low-Btu industrial gas from cheap coal. Only air is used in the blast, and the ash is removed as slag. This process is apparently not being considered by any U.S. customers (Reference 4.46).

The Koppers-Totzek process was developed in Germany by Heinrich Koppers GmbH. The first demonstration unit was built for the U.S. Bureau of Mines by the Koppers Co. (U.S.) in 1948. Sixteen commercial plants have been built in Europe and Africa. The Koppers Co. (U.S.) has the sole license for design and construction of K-T plants in the U.S. and Canada (Reference 4.47). Oxygen is used in the blast rather than air, and the raw fuel gas has a temperature of 1922°K (3000°F) and a heating value of 11.18 MJ/std m^3 (300 Btu/scf).

The Szikla-Rosenik process was developed in Hungary. This process was evaluated by the Franklin Institute in the late 1960s under OCR funding and was found to be unsatisfactory (Reference 4.48).

Suspension-type gasification processes are under development in the U.S. by the following organizations (Reference 4.45).

- Babcock & Wilcox Co.
- Combustion Engineering, Inc.
- Bituminous Coal Research, Inc. (BCR) (Bi-Gas).

A four-company consortium has been formed for the purpose of commercializing the airblown version of the BCR process. These are:

- Pittsburgh and Midway Coal Co. (a subsidiary of Gulf Oil Co.)
- Foster-Wheeler
- Turbodyne
- Northern States Power.

A 12.6 kg/s (50 ton/hr) pilot plant is planned for completion in 1978.

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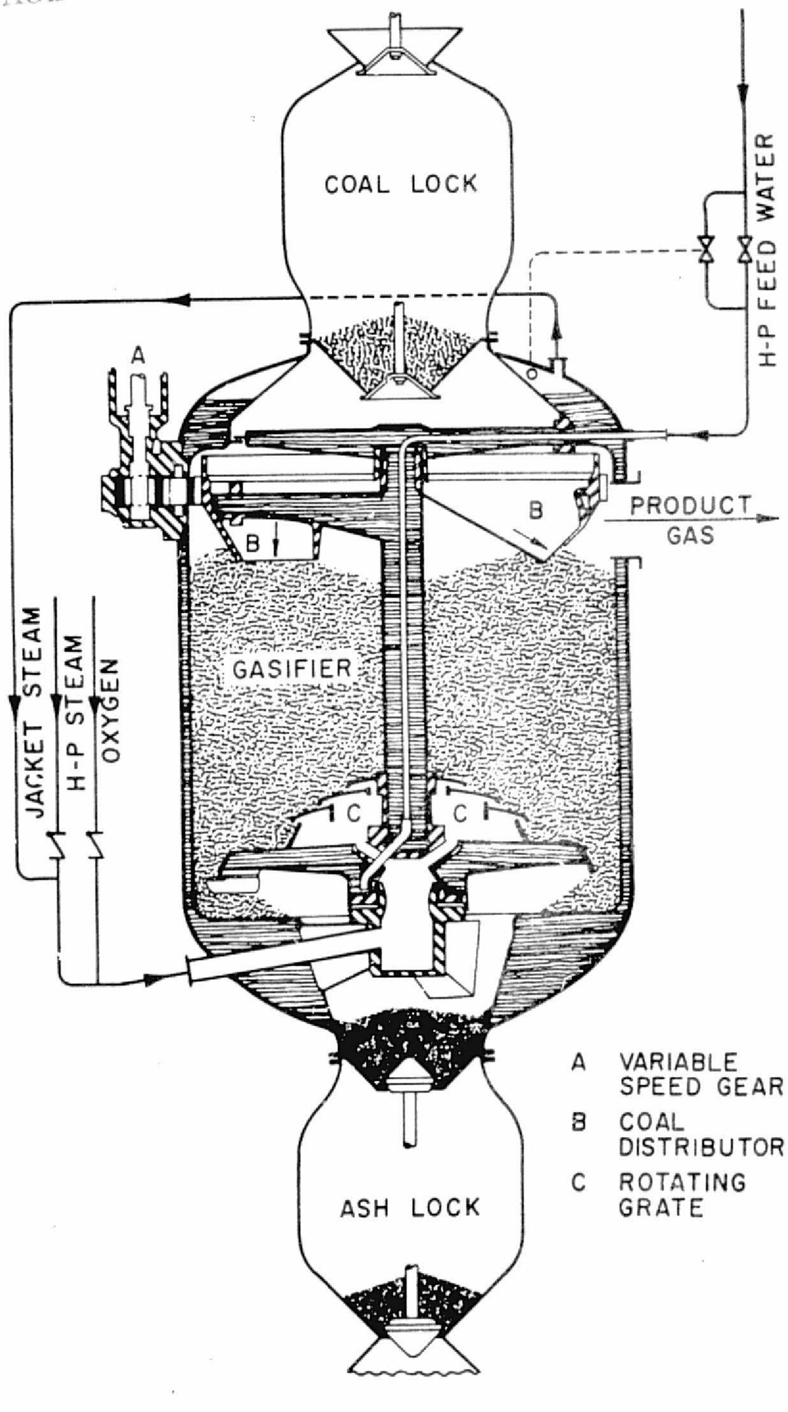

Fig. 4.29 — Lurgi pressure gasifier

The characteristics of suspension-type gasification processes are:

- High fuel gas temperatures [>1255°K (1800°F)] so tars and ammonia are not present
- Use of all grades of coal
- Coal pulverization required
- Recycle of char necessary to achieve acceptable carbon conversion
- Cocurrent flow of reactants
- Slagging of ash.

In addition to the above, there are a number of gasification processes under development which use molten baths. The Applied Technology Corporation process uses a molten iron bath to gasify the coal with air and limestone to remove the sulfur. The M.W. Kellogg process gasifies coal with air in a molten sodium carbonate bath. The North American Rockwell process also uses air to gasify coal in molten sodium carbonate.

4.4.1.4 Low-Btu Processes

The low-Btu fuel gas processes which were considered in this study included one from each of the three generic types: fixed bed, fluidized bed, and suspension. The Lurgi gasifier, which is a fixed bed gasifier, produces a tar-bearing fuel gas at a temperature of about 811°K (1000°F) and is commercially available (see Figure 4.29). Westinghouse is developing a fluidized bed gasification process under OCR funding (see Figure 4.30). The product fuel gas will have a temperature of about 1144°K (1600°F) and will probably be tar free. The BCR suspension-type gasifier is under development with OCR funding. The product fuel gas will have a temperature of about 1366°K (2000°F) and will be tar free. Figure 4.31 shows a flow diagram of the oxygen-blown version of this process.

Mathematical models had previously been developed for the chemical reactions in the gasification processes. One is explicitly for the Westinghouse fluidized bed process, and the other is general. Computer programs were available for both of these models for use in calculating

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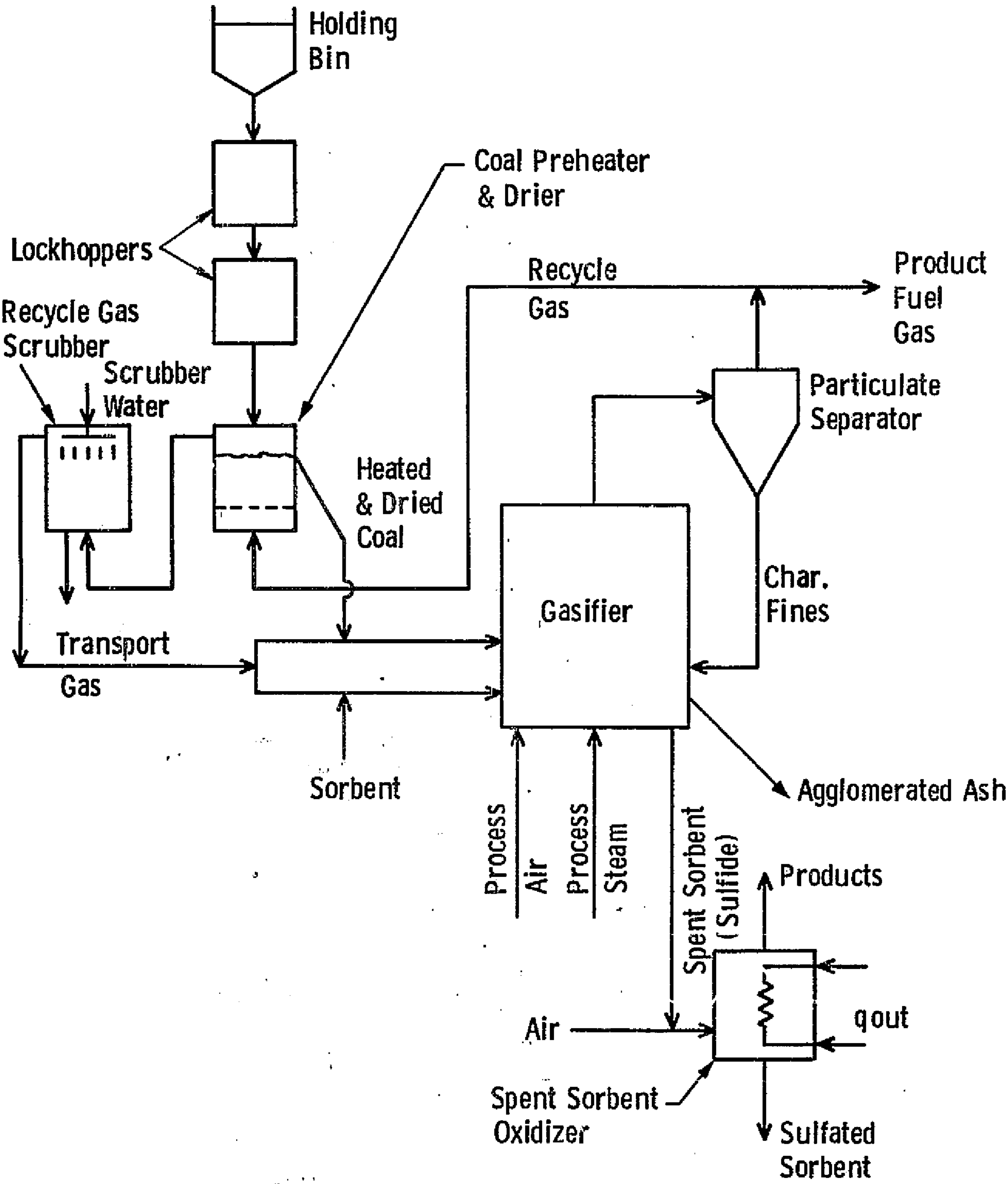

Fig. 4.30—Simplified flow sheet for Ⓦ fluidized bed gasification process with high-temperature sulfur and particulate removal

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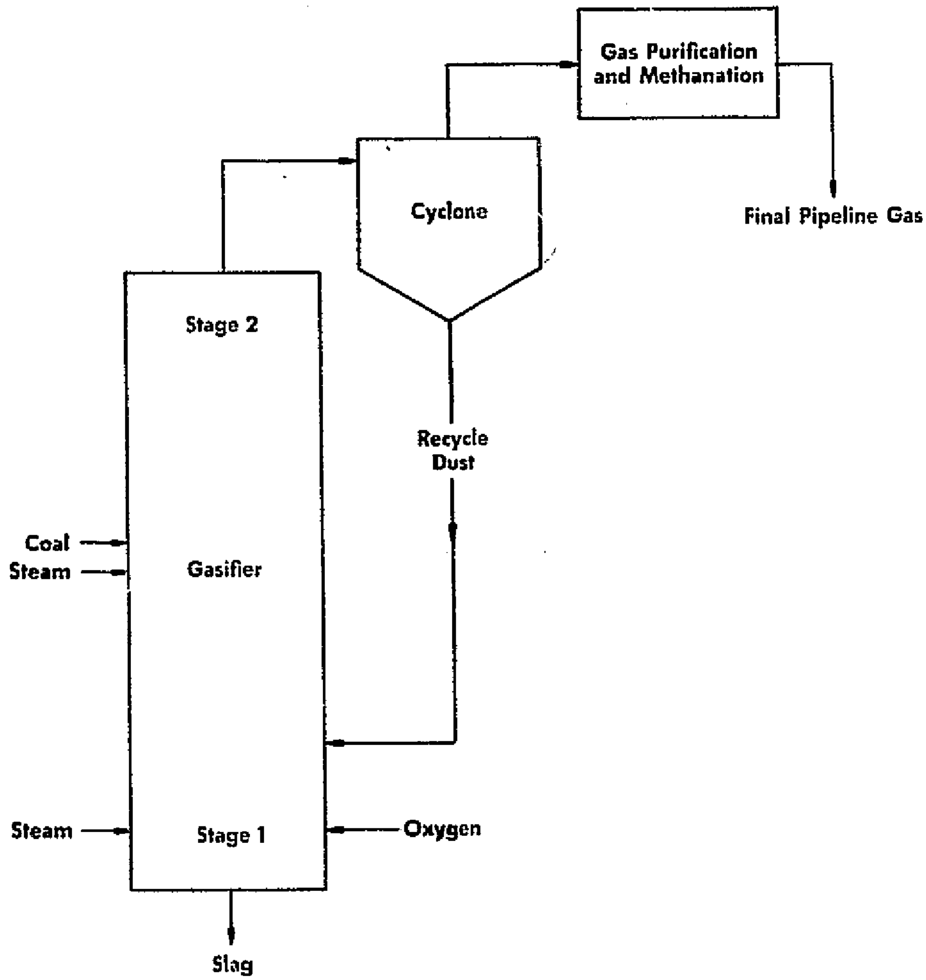

Fig. 4.31—Simplified flow diagram for two-stage suspension gasifier

Table 4.38 - Estimated Hot Gas Efficiency of Westinghouse Fluidized Bed Gasification Process

Operating Conditions	
Coal	- Illinois No. 6
Moisture content of coal	- 3%
Sorbent calcium/sulfur ratio	- 1.5
Process air temperature	- 550°F
Process steam conditions	- saturated @ 250 psia
Product fuel gas temperature	- 1600°F
Losses (Percent of Coal Lower Heating Value)	
Desulfurization reactions	2.6%
Carbon losses in ash, etc.	1.0
Ash sensible heat	0.3
Sorbent sensible heat	1.7
Radiation	1.0
Recycle gas losses	0.3
	6.9%
Heat of combustion of spent sorbent	4.2%
Effective net loss	2.7%

product fuel gas compositions. Other computer programs were available for calculating the fuel gas heating values, molecular weight, and enthalpy.

There are two general categories of fuel gas desulfurization processes: high temperature and low temperature. Experimental programs now under way are investigating the solid sorbents dolomite, limestone, and iron oxide for high-temperature applications. A number of low-temperature desulfurization processes are commercially available. Examples of these are the Benfield hot carbonate process (Reference 4.49), the Stretford process (Reference 4.50), and the Shell Sulfinol process (Reference 4.51). In this study dolomite was assumed for high-temperature sorption, and the Benfield process was used for low-temperature desulfurization.

It is advantageous to recover as much of the sensible heat in the fuel gas as is possible when low-temperature desulfurization is used. This is technically feasible, however, only if the fuel gas is tar free. Since the raw fuel gas contains a high concentration of hydrogen sulfide, heat exchanger metal temperatures must be kept below 811°K (1000°F) to avoid severe corrosion problems.

The losses in the Westinghouse multibed fluidized bed gasification process are listed in Table 4.38. The gross thermal efficiency for the process is about 93%. The spent sorbent contains calcium sulfide, which can be oxidized to calcium sulfate with a heat of combustion equivalent to 4.2% of the lower heating value of Illinois No. 6 coal dried to 3% moisture. This gives an effective net loss of only 2.7% and an overall thermal efficiency of about 97%.

The cold gas efficiency is a function of the low-temperature desulfurization process used and the amount of sensible heat recovered from the fuel gas. If the fuel gas is cooled to ambient temperature, and none of the sensible heat is recovered, the losses are increased by about 18 percentage points.

The auxiliary power requirements for the Westinghouse gasification process, exclusive of the booster compressor, are estimated to be

143 kJ/kg (0.018 kWh/lb) of coal, which is equivalent to about 0.5% of the energy in the coal.

Properties of low-Btu gases were calculated and compiled for various cases, as shown in Table 4.39.

Table 4.39 - Low-Btu Fuel Gas Properties

Fuel Gas	Process Air Temp., °F	Low-Temp. Desulf.	High-Temp. Desulf.
Low-Btu/Westinghouse Fluid Bed, Illinois No. 6 Bituminous	350	x	x
	550	x	x
	750	x	x
Low-Btu/Westinghouse Fluid Bed, Montana Subbituminous	350		x
	550		x
	750		x
Low-Btu/Fluid Bed, North Dakota Lignite	350		x
	550		x
	750		x
Low-Btu/Suspended Bed, Illinois No. 6 Bituminous	350	x	
	550	x	
	750	x	
Low-Btu/Fixed-Bed, Illinois No. 6 Bituminous	350	x	
	550	x	
	750	x	

A sample fuel gas properties tabulation is shown in Table 4.40. The complete set of fuel gas properties tabulations for the listed cases is included in Section 2, Tables 2.7 to 2.29.

Table 4.40:- Low-Btu Fuel Gas Properties (Sample)

GASIFICATION PROCESS Westinghouse Fluidized Bed/High-Temp. Desulfurization

COAL Illinois No. 6 Bituminous

Lockhopper Inlet Conditions

Temperature - °F 150

Moisture Content 3%

SORBENT Dolomite

Sorbent/Coal Ratio 0.59 (0.53)

PROCESS AIR

Air/Coal Ratio	2.95 (2.65)
Temperature - °F	350
Pressure - psia	250

PROCESS STEAM

Steam/Coal Ratio	0.462 (0.414)
Temperature - °F	400
Pressure - psia	250

PRODUCT FUEL GAS

Temperature - °F	1600
Pressure - psia	225

Composition-Mole Fraction

N_2	0.4597
O_2	0
H_2	0.1437
CO	0.2142
CO_2	0.0830
H_2O	0.0681
H_2S	0
CH_4	0.0313
C_2H_4	0

Molecular Wt 24.55

Heating Value

LHV	136.57	Btu/scf	2111.65 Btu/lb
HHV	146.92	Btu/scf	2271.73 Btu/lb

LHV/HHV 0.9295

Enthalpy (400°R Base) - 539.33 Btu/lb

Stoichiometric Fuel/Air Ratio 0.728

Product Fuel Gas/Coal Ratio 4.31 (3.86)

Gasifier Aux. Pwr. 14.4 (kW/lb/s)

Spent Sorbent Oxidizer Exhaust Products

T_{in} - °F 1500

T_{out} - °F 300

q-Btu/lb coal 444 (399)

(Values in parenthesis are for as received coal)

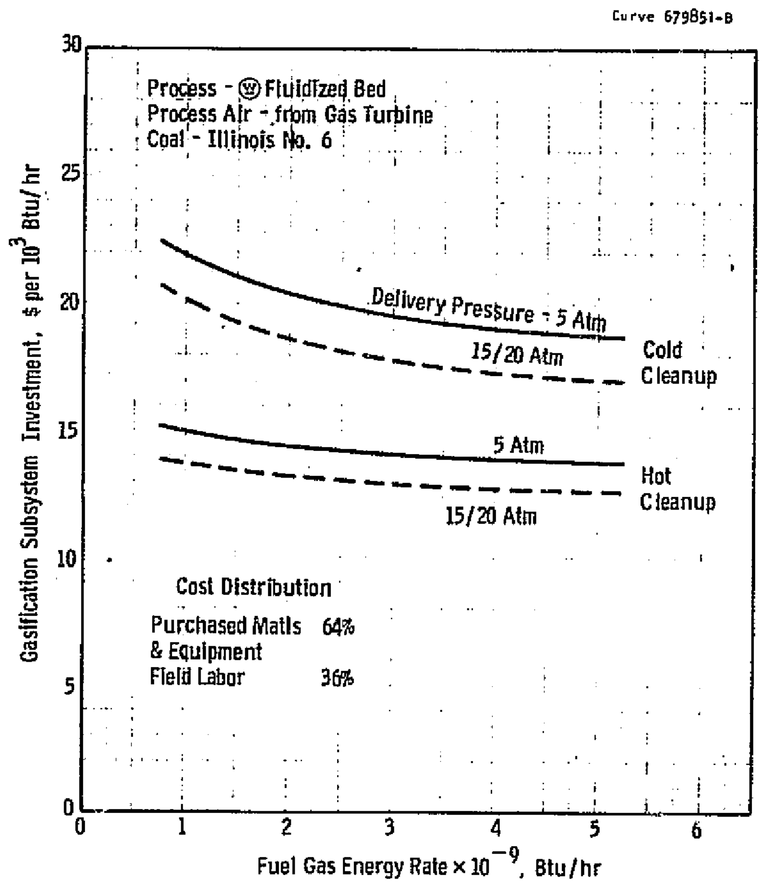

Fig. 4.32—Direct gasification subsystem investment

4.4.2 Cost Correlations for Westinghouse Fluidized Bed Gasifier Subsystem

The coal gasification system, from coal/dolomite feed bins to the flange in the discharge line from the particulate removal system, is described in some detail in Appendix A 4.2. This information is derived from Bechtel's facility description for a single gasifier installation as prepared under OCR Contract 19-32-0001-1514 (Reference 4.52).

Correlations of the estimated costs of this subsystem as a function of capacity have been prepared for each of the specified ECAS coals (see Figures 4.32, 4.33, and 4.34). Plots of estimated costs are given for both high-temperature and low-temperature desulfurization processes.

The costs given are total direct costs, including installation, foundations, and support structures. The costs for the low-temperature desulfurization cases include the heat exchanger for recovering the sensible heat of the fuel gas in a waste heat boiler.

The investment costs for the gasification systems are based on one gasification reactor per turbine [a 4.27 m (14 ft) diameter reactor for a W 501-D turbine up to a 5.18 m (17 ft) diameter reactor for a W 1501 turbine] and on the use of proportionately larger diameter reactors at lower pressure [a 0.5074 MPa (5 atm) system would have a 7.32 m (24 ft) diameter reactor].

4.4.3 Low-Temperature Carbonization Technology

During the 1950s, a number of low-temperature carbonization processes were investigated for the production of fuel gas and char for utility application. One such program was started in 1952 at Southern Research Institute (SRI) to investigate the possibilities of lower cost fuel for electrical power generation through the use of low-temperature carbonization. This program was sponsored by the Alabama Power Company and was aimed specifically at the utilization of caking Alabama coals (References 4.22 and 4.23).

A survey of existing information indicated that a process using fluidized beds offered the most promise of being an economical method of processing large quantities of coal. In addition, it was indicated that preoxidation of the coal would prevent agglomeration of the coal particles. A small pilot plant was built to study the preoxidation and

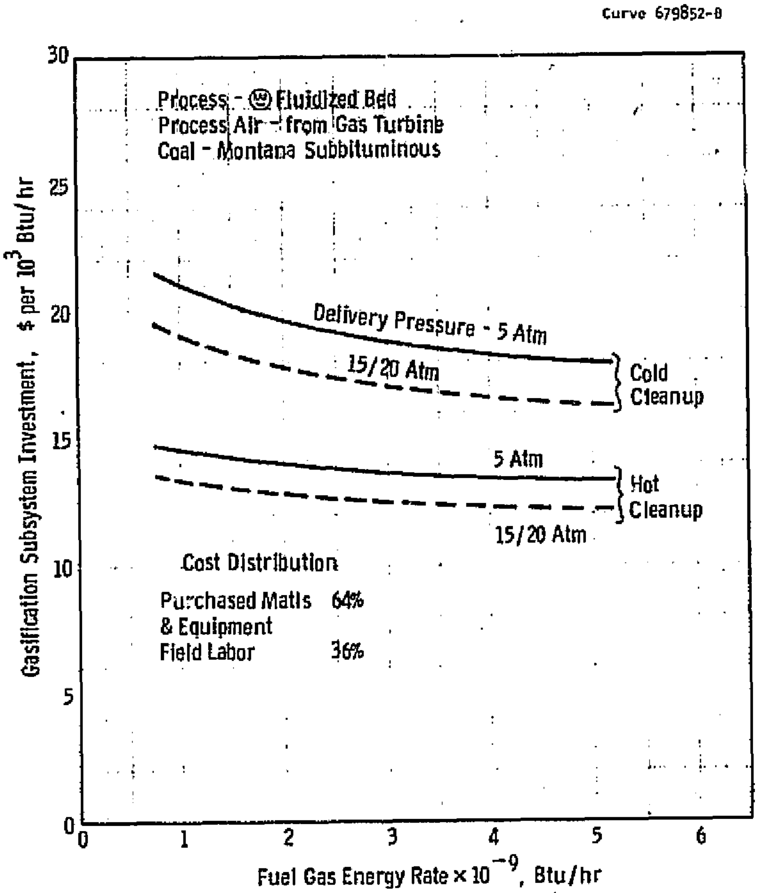

Fig. 4.33—Direct gasification subsystem investment

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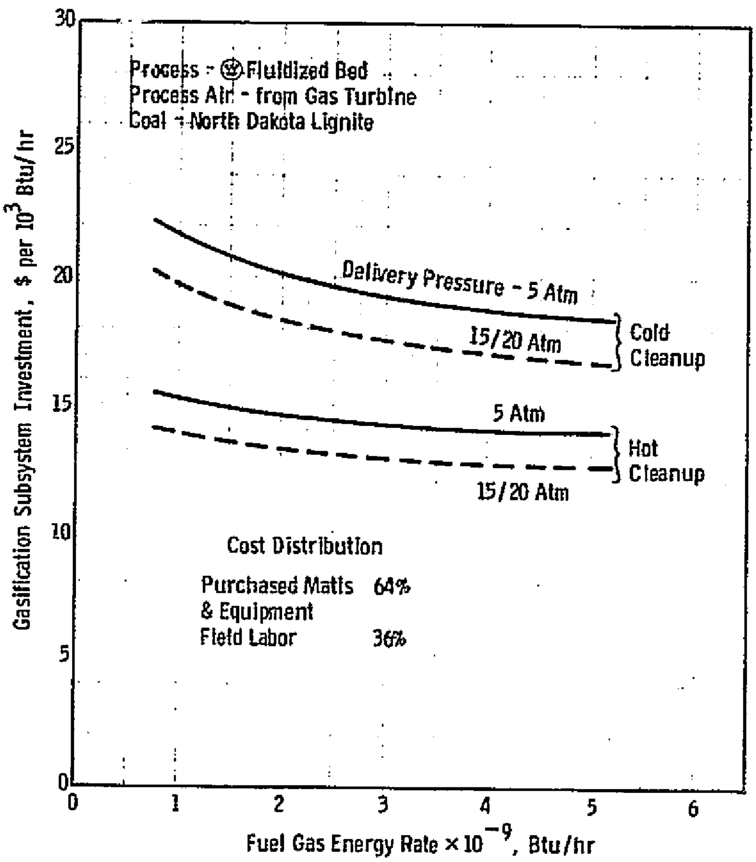

Fig. 4.34 – Direct gasification subsystem investment

carbonization process reactions which used fluidized beds for both the preoxidizer and the carbonizer. After several modifications satisfactory operation of the pilot plant was attained with the following operating conditions:

- Carbonizer bed temperature of about 755°K (900°F)
- Superficial gas velocity in the carbonizer of 0.335 m/s (1.1 ft/s)
- Average retention time of char in bed of 1200 s (∿ 20 min)
- Coal feed rate of about 0.490 $kg/s^3/m^3$ (50 $lb/hr\text{-}ft^3$) of fluidized bed volume
- Combustion air rate maintained to release 930.2 kJ/kg (400 Btu/lb) of coal fed into the carbonizer.

Operating data from the SRI lists were used to make a conceptual design of a low-temperature carbonization process for application to open-cycle MHD, where the fuel gas would be used at atmospheric pressure and the char would be used at about 0.608 MPa (6 atm) (see Figure 4.35). The preoxidizer would be used only for Illinois No. 6 bituminous coal, which has a free swelling index (FSI) of about 4.5 and is a caking coal. For the Montana subbituminous coal and the North Dakota lignite, which are noncaking, the preoxidizer would be eliminated, and the raw coal would be fed directly into the carbonizer.

Assays of coals after low-temperature carbonization found in the literature (Reference 4.55 and 4.56) were used to estimate the yield and composition of the various carbonization products for each of the three coals considered in this study. Table 4.41 gives the yields and properties of the carbonization products from Illinois No. 6 bituminous coal for an operating temperature of 755°K (900°F). Since the coal is preoxidized at 589°K (600°F), it is dry when it enters the carbonizer.

Tables 4.42 and 4.43 give the estimated yields and properties of the products of carbonization of Montana subbituminous coal and

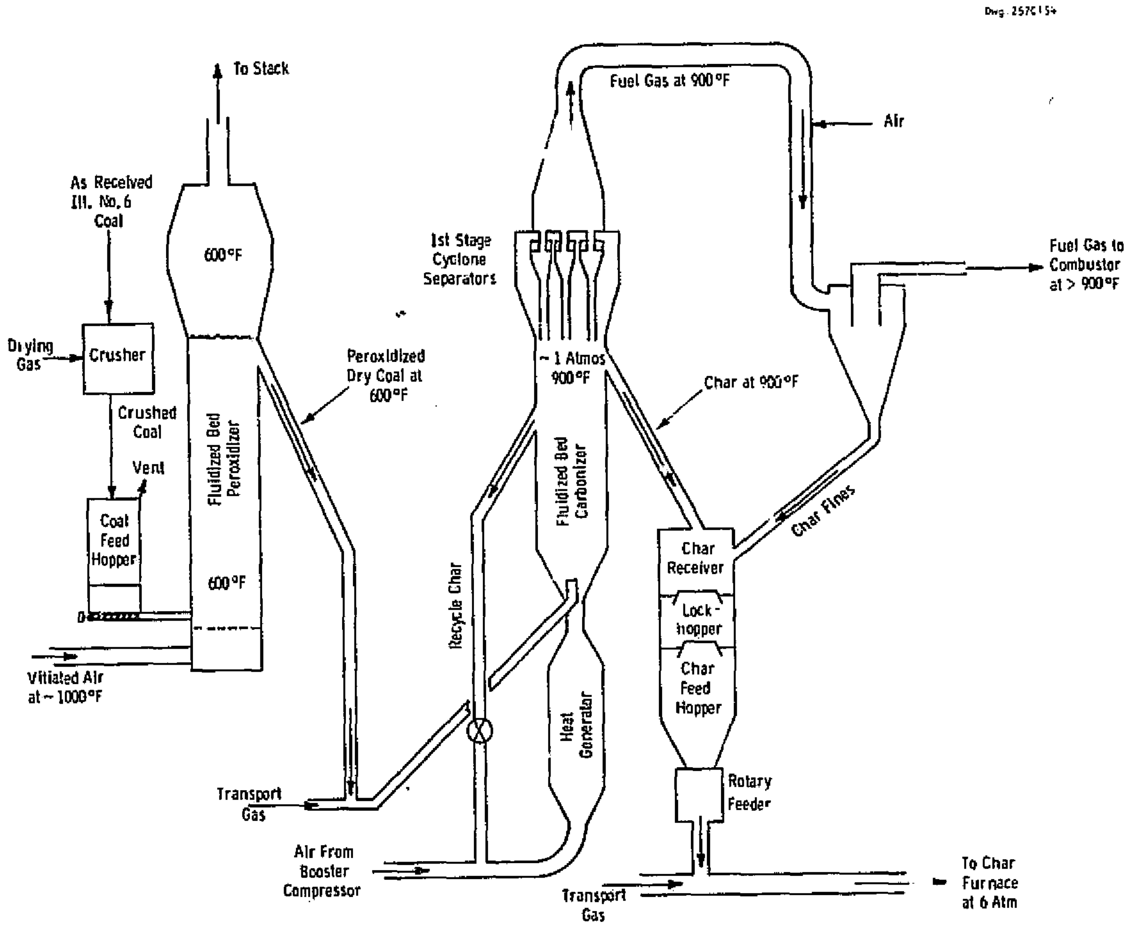

Fig. 4.35 — Low temperature carbonization process

Table 4.41 - Properties of Products of Low-Temperature Carbonization of Illinois No. 6 Bituminous Coal (Dry)

Temperature of Products - 900°F

Char

Weight fraction - 68%
HHV - 11,900 Btu/lb

Tar

Weight fraction - 5.9%
HHV vapor - 16,200 Btu/lb

Fuel Gas

Weight fraction - 23.1%
HHV - 3873 Btu/lb
Enthalpy - 305.7 Btu/lb
Composition - mole fraction

CO_2	-	0.1635
O_2	-	0.0060
CO	-	0.0217
H_2	-	0.0554
C_2H_6	-	0.0425
CH_4	-	0.1724
N_2	-	0.5209
H_2S	-	0.0177

Light Oil

Weight fraction - 0.4%
HHV vapor - 17,000 Btu/lb

Ammonia

Weight fraction - 0.1%
HHV vapor - 8500 Btu/lb

Water - 2.5%

Table 4.42 - Properties of Products of Low-Temperature Carbonization of Montana Subbituminous Coal

Temperature of Products - 900°F		
Moisture content of coal as fired - %	20	16
Char		
Weight fraction	0.3395	0.3687
HHV - Btu/lb	12,230	12,240
Tar		
Weight fraction	0.0485	0.0517
HHV vapor - Btu/lb	16,200	16,200
Fuel Gas		
Weight fraction	0.4410	0.4257
HHV - Btu/lb	789.2	869.3
Enthalpy - Btu/lb	250.7	252.1
Composition - mole fraction		
CO_2	0.2304	0.2314
CO	0.0182	0.0199
H_2	0.0105	0.0113
CH_4	0.0433	0.0481
C_2H_4 = 0.043	0.0049	0.0054
H_2S	0.0056	0.0055
N_2	0.6872	0.6785
Light Oil		
Weight fraction	0.0070	0.0070
HHV vapor	17,000	17,000
Water		
Weight fraction	0.1640	0.1460

Table 4-43 — Properties of Products of Low-Temperature Carbonization of North Dakota Lignite

Temperature of Products - 900°F		
Moisture content of lignite as fired- %	27	18
Char		
Weight fraction	0.2597	0.3129
HHV - Btu/lb	11,955	11,995
Tar and Light Oil		
Weight fraction	0.0262	0.0307
HHV vapor - Btu/lb	16,300	16,300
Fuel Gas		
Weight fraction	0.4955	0.4712
HHV - Btu/lb	438.8	521.5
Enthalpy - Btu/lb	245.1	246.2
Composition - mole fraction		
CO_2	0.2506	0.2679
CO	0.0119	0.0144
H_2	0.0109	0.0132
CH_4	0.0220	0.0267
C_2H_4	0.0023	0.0028
H_2S	0.0050	0.0050
N_2	0.6973	0.6700
Water		
Weight fraction	0.2186	0.1852

North Dakota lignite, respectively, for two values of moisture content at an operating temperature of 755°K (900°F). Preoxidization is not required with these feedstocks, so they enter the carbonizer with the as-fired moisture content.

The combustion air requirements for the fine carbonization cases are given in Table 4.43.

In the early 1950s, United Engineers and Constructors carried out an engineering study of low-temperature carbonization processes. On the basis of available technical information, a preliminary design of a carbonization system was prepared. An engineering cost estimate was then made for a plant of this type having a capacity of 8.946 kg/s (8520 tons/day) of Ohio bituminous coal (Reference 4.26). The results of this cost analysis were used as the basis for a cost estimate of the carbonization subsystem for application to open-cycle MHD. Figure 4.36 is a correlation of carbonization subsystem module cost as a function of module capacity. Cost factors for each of the fine carbonization cases are listed. The maximum diameter for the fluidized bed carbonization module was assumed to be 15.24 m (50 ft). The maximum module capacity (tons/hr) is listed for each of the five coal conditions.

Table 4.44 - Air Requirements for SRI Carbonization Process

Coal	Illinois No. 6 Bituminous	Montana Subbituminous		North Dakota Lignite	
Moisture, %	0	20	16	27	18
Temp., °F	800	900	900	900	900
Air, lb/lb coal	0.27	0.56	0.52	0.67	0.59

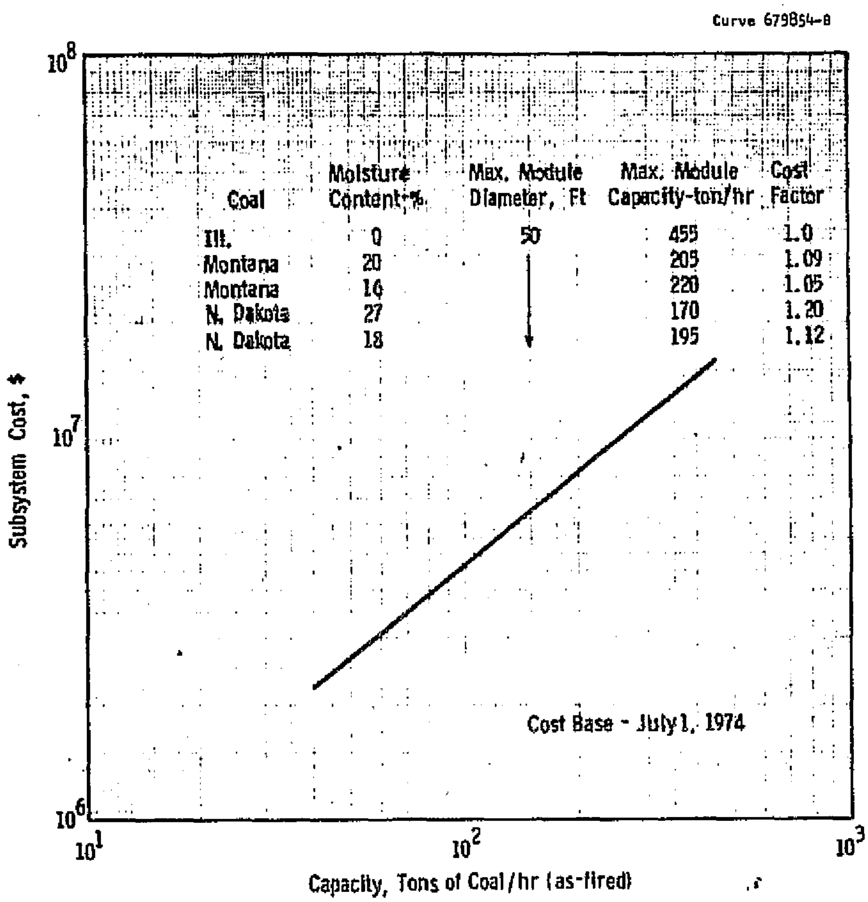

Fig. 4.36—Installed equipment costs of low-temperature carbonization subsystems

4.4.4 Composition of Intermediate-Btu Fuel Gas

The Koppers-Totzek suspension gasifier was selected as the preferred process for production of intermediate-Btu fuel gas from the specified coals. Since the feedstock has a measurable effect on the fuel gas composition from airblown low-Btu gasification processes, it was assumed that there would be a comparable feedstock effect on the composition of fuel gas from the oxygen-blown intermediate-Btu gasification process.

An existing gasification model was modified to simulate the Koppers-Totzek process so that computed fuel gas composition would match published composition for specified coals. This computer program was then used to calculate the fuel gas composition from the Koppers-Totzek gasifier for each of the ECAS coals. The reactant data and the calculated composition of the raw fuel gas for each of the three specified coals are listed in Table 4.45.

Table 4.45 - Koppers-Totzek Reactant Data and Intermediate-Btu Fuel Gas Compositions

	Illinois No. 6 Bituminous	Montana Subbituminous	North Dakota Lignite
N_2 (% vol)	0.004	0.004	0.004
H_2	0.303	0.287	0.281
CO	0.505	0.481	0.463
CO_2	0.053	0.068	0.074
H_2O	0.128	0.159	0.177
H_2S	0.007	0.001	0.001
Total	1.000	1.000	1.000
O_2/coal lb/lb	0.790	0.643	0.561
Stm/coal lb/lb	0.290	0.130	0.110
Raw gas/coal lb/lb	2.030	1.750	1.651

Tables 4.46, 4.47, and 4.48 give the properties of the intermediate-Btu fuel gas for each of the three coals after it has been desulfurized using the Stretford low-temperature desulfurization process.

Table 4.46 - Intermediate-Btu Fuel Gas Properties

GASIFICATION PROCESS Koppers-Totzek/Stretford Desulf.

COAL Illinois No. 6 Bituminous

Lockhopper Inlet Conditions

Temperature - °F 150

Moisture Content 3

PROCESS OXYGEN

O_2/Coal Ratio 0.790

Temperature - °F 220

Pressure - psia 14.7

PROCESS STEAM GASIFIER

Steam/Coal Ratio 0.290

Temperature - °F 400

Pressure - psia 14.7

PRODUCT FUEL GAS

Temperature - °F 100

Pressure - psia 14.7

Composition-Mole Fraction

N_2	0.0043
O_2	- - -
H_2	0.3276
CO	0.5460
CO_2	0.0573
H_2O	0.0647
H_2S	- - -
CH_4	- - -
C_2H_4	- - -

Product Fuel Gas/Coal Ratio 1.87

STOICH. F/A 0.3289

Molecular Wt 19.76

Heating Value

LHV	265.0 Btu/scf	5089.2 Btu/lb
HHV	281.5 Btu/scf	5405.9 Btu/lb

LHV/HHV 0.9414

Enthalpy (400°R Base) 57.16 Btu/lb

Table 4.47 - Intermediate-Btu Fuel Gas Properties

GASIFICATION PROCESS Koppers-Totzek/Stretford Desulf.

COAL Montana Subbituminous

Lockhopper Inlet Conditions

Temperature - °F 150

Moisture Content 20

PROCESS OXYGEN

O_2/Coal Ratio 0.643

Temperature - °F 220

Pressure - psia 14.7

PROCESS STEAM	GASIFIER
Steam/Coal Ratio	130
Temperature - °F	400
Pressure - psia	14.7

PRODUCT FUEL GAS

Temperature - °F	100
Pressure - psia	14.7

Composition-Mole Fraction

N_2	0.0045
O_2	- - -
H_2	0.3196
CO	0.5356
CO_2	0.0757
H_2O	0.0647
H_2S	- - -
CH_4	- - -
C_2H_4	- - -

Product Fuel Gas/Coal Ratio 1.38

Molecular Wt 20.27

STOICH. F/A 0.3446

Heating Value

LHV	259.4 Btu/scf	4858.3 Btu/lb
HHV	275.5 Btu/scf	5159.5 Btu/lb

LHV/HHV 0.9416

Enthalpy (400°R Base) 55.97 Btu/lb

Table 4.48 - Intermediate-Btu Fuel Gas Properties

GASIFICATION PROCESS Koppers-Totzek/Stretford Desulf.

COAL North Dakota Lignite

Lockhopper Inlet Conditions

Temperature - °F 150

Moisture Content 27

PROCESS OXYGEN

O_2/Coal Ratio 0.561

Temperature °F 220

Pressure - psia 14.7

PROCESS STEAM	GASIFIER
Steam/Coal Ratio	0.110
Temperature - °F	400
Pressure - psia	14.7

PRODUCT FUEL GAS

Temperature - °F 100

Pressure - psia 14.7

Composition-Mole Fraction

N_2	0.0046
O_2	
H_2	0.3197
CO	0.5268
CO_2	0.0842
H_2O	0.0647
H_2S	
CH_4	
C_2H_4	

Product Fuel Gas/Coal Ratio 1.29

Molecular Wt 20.4

Heating Value

STOICH. F/A 0.350

LHV 256.6 Btu/scf 4775.6 Btu/lb

HHV 272.7 Btu/scf 5075.1 Btu/lb

LHV/HHV 0.9410

Enthalpy (400°R Base) 55.72 Btu/lb

4.5 Pollution Control Technology

4.5.1 Emission Standards

The current emission standard and several advanced targets were specified for use and/or evaluation in this study (see Table 4.49). In order to put these in perspective, the overall pollution removal re quirements for sulfur, particulates (ash), and fuel nitrogen have been compiled for direct firing of coal (Table 4.50, coal-derived liquid (Table 4.51), and coal-derived gases (Table 4.52).

4.5.2 Particulate Removal Requirements

The NASA-specified emission and advanced targets limits for particulates from solid fuels are given in Table 4.50. The overall degree of ash removal required to meet these emission standards for each of the three coals as shown in Tables 4.50, 4.51, and 4.52 indicates that the degree of ash removal required is a weak function of the type of coal. Thus, the general requirement for ash removal for each emission standard is as follows:

Standard	Overall Ash Removal Requirement - %
Current	98.9
Advanced 1	99.9
Advanced 2	99.94
Advanced 2a	99.99

In many combustion and gasification processes only a fraction of the ash in the coal will be entrained in the combustion products or in the product fuel gas. In grate-type processes a major part of the ash is removed from the grate; in slagging processes a major part of the ash is removed as slag; in fluidized beds the ash can be agglomerated. In many cases, therefore, the degree of ash removal from either combustion products or from product fuel gas will be substantially less rigorous than the overall values given above.

The requirements for residual ash particulate removal from products of combustion from the several types of furnaces to be considered in this study are tabulated in Tables 4.53 to 4.56.

Table 4.49 - Emission Targets for the ECAS Study

			lb/10^6 Btu input		
Pollutant	Fuel	Present Standard (1b)	Standard 1	Standard 2	Standard 2 (a)
SO_X	Solid	1.2	0.2	0.1	0.1
	Liquid	0.8	0.04	0.02	0.02
	Gaseous	0.2	0.3	0.12	0.12
NO_X	Solid	0.7	0.15	0.11	0.11
	Liquid	0.3	0.1	0.1	0.1
	Gaseous	0.2			
Particulates	All Fuels	0.1	0.01*	0.005*	0.001*
Hydrocarbons	All Fuels		0.01	0.01	0.01
CO	All Fuels		0.04	0.02	0.02

*(< 1 μm)

Table 4.50 - Overall Pollutant Removal Requirements for Direct Firing of Coal[a]

	Removal Required, % by Wt.		
	Illinois	Montana	North Dakota
Current Emission Standard			
Sulfur	83.3	32.5	41.4
Particulates	98.9	98.8	98.9
Nitrogen	77.0	76.3	75.0
Advanced Target 1			
Sulfur	97.2	88.8	90.0
Particulates	99.9	99.9	99.9
Nitrogen	90.2	89.8	89.5
Advanced Target 2			
Sulfur	98.6	94.4	95.0
Particulates	99.94	99.94	99.94
Nitrogen	96.1	95.9	95.8
Advanced Target 2a			
Particulates	99.99	99.99	99.99

[a]100% conversion assumed for fuel nitrogen.

Table 4.51 - Overall Pollutant Removal Requirements for Coal-Derived Liquid Fuels[a]

	Removal Required, % by Wt.		
	Illinois	Montana	North Dakota
Current Emission Standard			
Sulfur	89.0	55.0	61.4
Particulates	98.9	98.8	98.9
Nitrogen	90.0	89.9	89.3
Advanced Target 1			
Sulfur	97.2	88.8	90.0
Particulates	99.9	99.9	99.9
Nitrogen	95.1	94.9	94.7
Advanced Target 2			
Sulfur	98.6	94.4	95.0
Particulates	99.94	99.94	99.94
Nitrogen	96.4	96.3	96.2
Advanced Target 2a			
Particulates	99.99	99.99	99.99

[a]100% conversion assumed for fuel nitrogen.

Table 4.52 - Overall Pollutant Removal Requirements for Coal-Derived Gaseous Fuels[a]

	Removal Required, % by Wt.		
	Illinois	Montana	North Dakota
Current Emission Standard			
Sulfur	97.2	88.8	90.3
Particulates	98.9	98.8	98.9
Nitrogen	93.4	93.3	92.8
Advanced Target 1			
Sulfur	99.4	97.8	98.0
Particulates	99.9	99.9	99.9
Nitrogen	96.7	96.6	96.5
Advanced Target 2			
Sulfur	99.7	98.9	99.0
Particulates	99.94	99.94	99.94
Nitrogen	96.7	96.6	96.5
Advanced Target 2a			
Particulates	99.99	99.99	99.99

[a]100% conversion assumed for fuel nitrogen.

Table 4.53 - Particulate Removal Requirements for Products of Combustion from a Dry-Bottom Pulverized Fuel Furnace

	Illinois No. 6 Bituminous	Montana Subbituminous	N. Dakota Lignite
Coal			
Ash Content, %	9.6	7.5	6.2
Emission Standard and Targets, Equivalent in Fuel, wt %			
Current Federal	0.107	0.089	0.069
Advanced Target 1	0.0107	0.0089	0.0069
Advanced Target 2	0.0054	0.0044	0.0034
Advanced Target 2a	0.0011	0.00089	0.00069
Retention of Ash in Furnace			
Furnace Type, Pulverized Fuel, Dry Bottom			
Retention of Ash, %	20		
Effective Ash in Fuel, %	7.68	6.0	4.96
Removal Required from Flue Gas, %			
Current Federal	98.6	98.5	98.6
Advanced Target 1	99.9	99.9	99.9
Advanced Target 2	99.94	99.94	99.94
Advanced Target 2a	99.99	99.99	99.99

Table 4.54 - Particulate Removal Requirements for Products of Combustion from a Wet-Bottom Pulverized Fuel Furnace

	Illinois No. 6 Bituminous	Montana Subbituminous	N. Dakota Lignite
Coal			
Ash Content, %	9.6	7.5	6.2
Emission Standard and Targets, Equivalent in Fuel, wt %			
Current Federal	0.107	0.089	0.069
Advanced Target 1	0.0107	0.0089	0.0069
Advanced Target 2	0.0054	0.0044	0.0034
Advanced Target 2a	0.0011	0.00089	0.00069
Retention of Ash in Furnace			
Furnace Type, Pulverized Fuel, Wet Bottom			
Retention of Ash, %	50		
Effective Ash in Fuel, %	4.8	3.75	3.1
Removal Required from Flue Gas, %			
Current Federal	97.8	97.6	97.8
Advanced Target 1	99.8	99.8	99.8
Advanced Target 2	99.9	99.9	99.9
Advanced Target 2a	99.98	99.98	99.98

Table 4.55 - Particulate Removal Requirements for Products of Combustion from a Cyclone Furnace

	Illinois No. 6 Bituminous	Montana Subbituminous	N. Dakota Lignite
Coal			
Ash Content,	9.6	7.5	6.2
Emission Standard and Targets, Equivalent in Fuel, wt %			
Current Federal	0.107	0.089	0.069
Advanced Target 1	0.0107	0.0089	0.0069
Advanced Target 2	0.0054	0.0044	0.0034
Advanced Target 2a	0.0011	0.00089	0.00069
Retention of Ash in Furnace			
Furnace Type, Cyclone-Slagging			
Retention of Ash, %	70-80		
Effective Ash in Fuel, %	2.4	1.88	1.55
Removal Required from Flue Gas, %			
Current Federal	95.5	95.3	95.5
Advanced Target 1	99.6	99.5	99.6
Advanced Target 2	99.8	99.8	99.8
Advanced Target 2a	99.95	99.95	99.96

Table 4.56 - Ash Particulate Removal Requirements for Products of Combustion from a Fluidized Bed Boiler[a]

	Illinois No. 6 Bituminous	Montana Subbituminous	N. Dakota Lignite
Coal			
Ash Content, %	9.6	7.5	6.2
Emission Standard and Targets, (Equivalent in Fuel, wt %)			
Current Federal	0.107	0.089	0.069
Advanced Target 1	0.0107	0.0089	0.0069
Advanced Target 2	0.0054	0.0044	0.0034
Advanced Target 2a	0.0011	0.00089	0.00069
Retention of Ash in Furnace			
Furnace Type, Fluidized Bed			
Retention of Ash, %	0		
Effective Ash in Fuel, %	9.6	7.5	6.2
Removal Required From Flue Gas, %			
Current Federal	98.9	98.8	98.9
Advanced Target 1	99.9	99.9	99.9
Advanced Target 2	99.94	99.94	99.94
Advanced Target 2a	99.99	99.99	99.99

[a]In fluidized bed combustion, unburned carbon and attrited sorbent particles are elutriated from the bed in addition to 100% of ash.

There are other sources of particulates in addition to the ash in the coal. In fluidized bed combustion and gasification processes the bed materials, either inert or sorbent, are subject to attrition. All or part of these attrited particles will be entrained in the products of combustion or the product fuel gas and will have to be removed along with the ash particles. The quantity of attrited bed material which is elutriated from the bed is a function of the sorbent or bed material and whether the sorbent is regenerated or not. In general, the projected particulate loading from the sorbent is of the same order as that of the ash.

In addition, in a number of combustion processes (e.g., fluidized bed combustion) and gasification processes (e.g., suspension type), unburned carbon is entrained in the combustion products or the product fuel gas and will also have to be removed, not only to meet the emission standards but also to attain a high degree of utilization of the fuel or feedstock. In general, carbon losses should be maintained at 1 to 2% of the total carbon in the fuel. In integrated, low-Btu fuel gas processes with high-temperature cleanup, fine carbon particles in the fuel gas would be burned in the combustion apparatus and would not contribute to either the carbon loss or the emissions.

In those power systems where products of combustion or product fuel gas are expanded through a gas turbine or turboexpander, a high degree of particulate removal is required to prevent erosion of, corrosion of, and deposition on the gas turbine vanes and blades. The allowable concentration of particulates in the gas stream at the inlet of a gas turbine has been predicted by Reference 4.58 to be:

- Dust loading less than 0.343 g/std m^3 (0.15 gr/scf).
- Concentration of particles greater than 2 μm less than 0.023 g/std m^3 (0.01 gr/scf).

A concentration of 0.343 g/std m^3 (0.15 gr/scf) is equivalent to about 300 ppm by weight. If the ash in the coal is the only source of particulates, the maximum possible particulate concentration in products of combustion of the Illinois bituminous coal is about 1% by weight. This indicates that the maximum degree of ash removal necessary for satisfactory turbine life may be as low as 97%, which is significantly lower than the degree of removal required to meet the current emission standard.

4.5.3 Particular Removal Apparatus Technology

4.5.3.1 Introduction and Review of State of the Art

Several of the advanced energy conversion techniques for utility applications using coal and coal-derived fuels require the removal of particulates from hot, high-pressure fuel gas streams as well as treatment of cooler flue gases. The extent to which particulates must be removed is determined by turbine erosion specifications and ecological requirements.

Particulate removal from low-temperature gas streams is a relatively mature technology, and virtually any degree of emission control from usual industrial sources can be obtained by use of one or more conventional dust control devices. These devices include cyclones, wet scrubbers, electrostatic precipitators, and fabric filters. A short review of the current status of these devices is presented here.

Low Temperature Gas Cleaning Systems

Cyclones. Cyclone dust collectors have been in common use for many years and the device is well understood from an empirical point of view. The device basically operates by imparting a swirling motion to the dust-laden stream. The heavy dust particles are then separated from the gas stream by centrifugal force. Cyclones have the following attributes:

- No moving parts and therefore highly reliable, requiring low maintenance
- Low initial cost
- Low to moderate pressure drop and, consequently, low operating cost
- Can be refractory lined to allow use in high temperature
- Can be used in situations with high dust loadings.

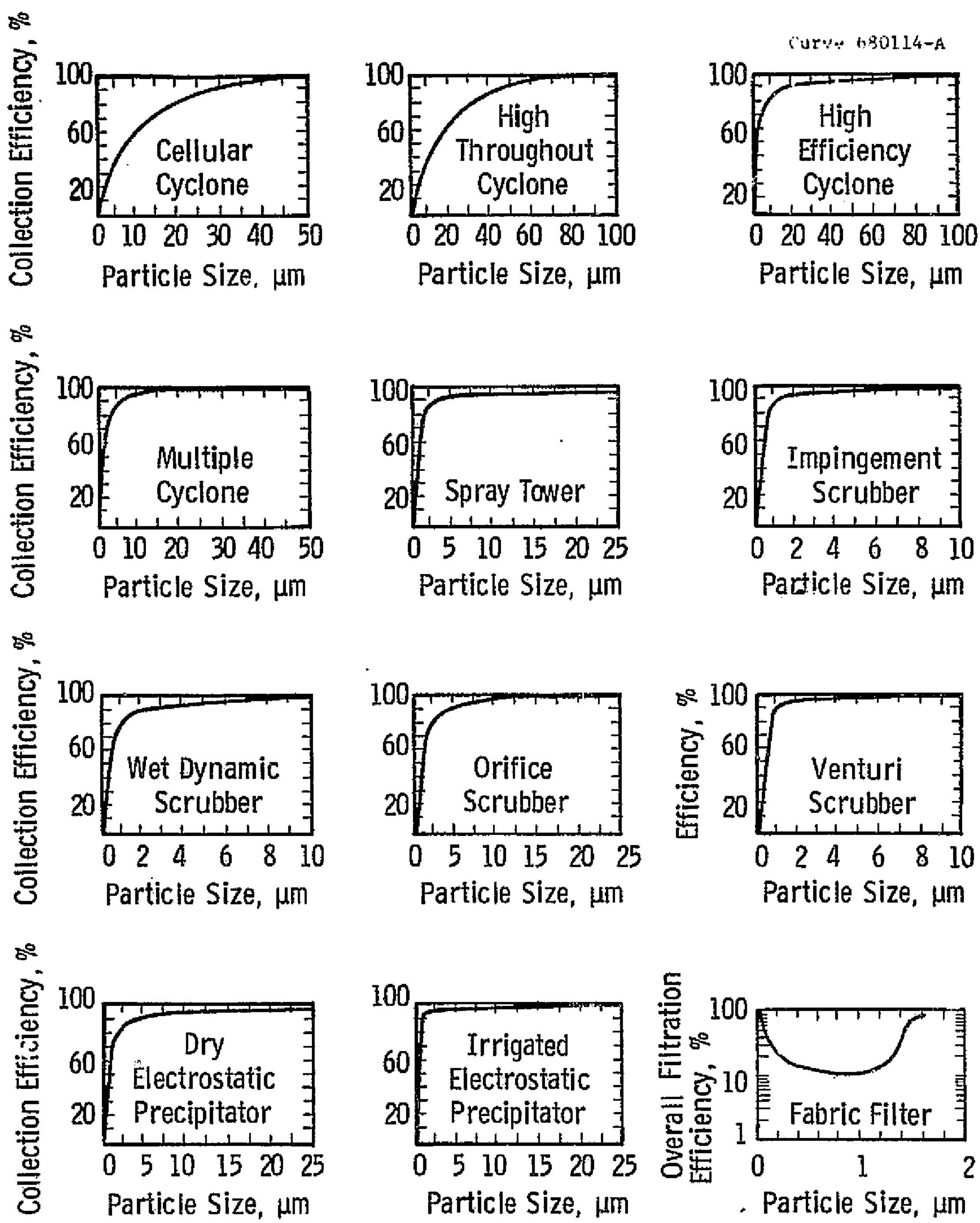

Fig. 4.37 — Grade efficiency curves of various particulate removal devices

The major disadvantage of the cyclones is that they generally have relatively low collection efficiency for particles smaller than about 5 μm, as can be seen from Figure 4.37.

Recently, two manufacturers introduced cyclones which they claim have significantly better performance than previous high-efficiency cyclones. The first is the Aerodyne dust collector which is marketed by the Aerodyne Development Corporation for the Siemens Company. Grade efficiency curves published by the manufacturer indicate a cut point at about 0.5 μm with 95% collection of 2 μm particles, but initial laboratory testing at the Westinghouse Research Laboratories indicates that when operated in the recommended manner there is no collection below 2 μm and the cut point is about 2.5 μm, which is more typical of standard high-efficiency cyclones. The Aerodyne collector does have one potential advantage: its performance is claimed to be independent of diameter. This implies that a single, large unit could be fabricated rather than a multiplicity of small units, as would be the case for conventional high-volume, high-efficiency cyclones. The resultant reduction in complexity and cost could be appreciable.

The other new high-efficiency cyclone is the Tan Jet Collector which is manufactured by the Donaldson Company Inc. This device is claimed to have a cut point in the 0.5 μm range and a 95% efficiency for 3 μm particles. Westinghouse is evaluating a laboratory-scale unit.

Wet Scrubbers Wet-scrubbing devices for particulate removal include a vast range of equipment types of widely varying design. The basic collection mechanism of all of these devices is the impaction and collection of dust particles on atomized droplets of the scrubbing liquid. The various types of scrubbers differ in the manner in which the dust-laden gas is contacted with the scrubbing liquid. One of the most successful of these devices is the Venturi scrubber, in which very high relative velocities between particles and droplets are obtained. This results in very good particle collection efficiencies down to the 0.5 μm range and lower, as indicated in Figure 4.37.

The advantages and disadvantages of wet scrubbers are summarized as follows:

Advantages:

- Gas can be cooled simultaneously
- Can simultaneously remove vapors or gaseous contaminants
- Can give moderate to very high efficiency
- Are useful on explosive streams
- Have moderate installed costs.

Disadvantages:

- Gas must be cooled and humidified.
- Soluble particulates may cause water pollution problems.
- Have liquid reintrainment and vapor plumes
- Require sludge removal treatment
- Have freezing problems
- Operating costs are relatively high.

Electrostatic Precipitators Electrostatic precipitation usually requires four basic steps: (1) corona generation at the electrode which leads to (2) particle charging because of impaction of ions on particles, yielding a particle with a net charge, (3) the migration and collection of the charged particle in the electric field, and, finally, (4) removal of the collected particles by mechanical rapping or washing of the collection electrodes. Electrostatic precipitators have been found to be very effective in the control of particulate emissions since they maintain high efficiencies even into the submicron particle size region, as indicated in Figure 4.37. Precipitators have the following principal advantages and disadvantages.

Advantages:

- Can handle large volumes of relatively high-temperature [up to 672°K (750°F)] gas
- Have negligible pressure drop
- Have very high collection efficiency over wide range of particle size and loadings

- Have low operating and maintenance costs
- Have been used widely and are reliable.

Disadvantages:

- Require large installation area
- Have high initial cost
- Are limited to noncombustible gases
- Cannot be operated at high temperatures.

Current efforts in the field seem to be directed toward increasing the upper limit of operating temperatures and pressures and in the investigation of various conditioning agents to enhance collection efficiency. Work is also being carried out to overcome the problems associated with the collection of emissions from low-sulfur coals.

Fabric Filters Fabric filters for industrial use are usually in the form of bags grouped into what is called a baghouse. The principle of these collections is a simple filtration of dust by the filter fibers and the formation of a dust cake which enhances collection efficiency by filling voids in the fabric. Periodically the bags must be cleaned by a reverse air blast or mechanical shaking. Fabric filters are capable of very high (99+ %) efficiencies down to μm-sized particles (Figure 4.37).

The principal attributes of fabric filters are:

- Very high collection efficiency
- Relative insensitivity to turndown
- Mechanical simplicity.

Problems associated with fabric filtration are:

- Temperature limitations [usually less than 561°K (550°F)]
- Relatively large space requirements
- Relatively high initial expense
- Possible high cost of bag replacement.

As with other dust collection equipment, current work is aimed at increasing the operating temperature for fabric filters. The introduction of felted fluorocarbon materials has been one step in this direction, and work is being done on special glass and metal fibers for use at temperatures ranging from 866 to 1478°K (1100 to 2200°F).

High Temperature Gas Cleanup

Recently, emphasis has been placed on maximizing power generating efficiency in order to conserve natural resources, and this has inevitably led to higher operating temperatures and the need to clean particulates from hot, high-pressure fuel gases. Cleaning hot gas is a much more difficult problem than is cleaning cool gases, for the following reasons:

- Wet scrubbing cannot be used.
- Electrostatic precipitators do not work well because most dusts are conductive at high temperatures.
- Fabric filters that can withstand high temperatures for extended periods of time are not yet commercially available.
- Cyclone performance is impaired by the increase in gas viscosity at high temperatures.

As has been noted, a great deal of effort is being exerted in an attempt to modify these devices to allow them to operate at high temperature. There have been two recent reviews of the current efforts on hot gas cleanup technology. The first is a report done by Aerotherm for EPA (Reference 4.59), and the second is a report done for EPRI by Stone and Webster (Reference 4.60).

Of the several devices being considered, only two are presently developed to the point of commercial use. These are cyclones and granular bed filters. As discussed earlier, cyclones can be refractory lined and used at high temperature to remove the bulk of large particles.

Granular Bed Filters Granular beds are simply beds of inert refractory particles through which the dirty gas is passed. As a cake of dust forms on the bed surface, the efficiency is increased because of the cake formed. Such beds are capable of 99+% efficiency on submicron particles, and these filters are capable of operation on corrosive, hot, high-pressure gases. The problems associated with granular bed filters are the high-pressure drop through the bed and the necessity for periodic cleaning of the dust cake from the bed surface. Presently, there are two granular beds offered commercially, one by Rexnord Air Pollution Control and one by Ducon Company. Several other schemes are under development, such as the Squires Panel Bed and Combustion Power Company's Pebble Bed. The consensus seems to be that a system of cyclones and granular bed filters presently offers the best solution to the problem of hot fuel gas cleanup.

4.5.3.2 Specific Particulate Removal Systems

Fluidized Bed Combustion The particulate removal system for a fluidized bed combustion process is shown schematically in Figure 4.38. Combustion gases containing char, sorbent, and ash are emitted from the bed, enter a conventional cyclone which sends the bulk of the particulates to a carbon burnup cell where most of the char is burned. The gas stream from the carbon burnup cell is combined with the effluent gas stream of the first cyclone and led to a second, conventional cyclone, where 96.3% of the remaining particulates are removed. The gas then enters a high-efficiency Aerodyne cyclone which reduces the particulates to a level that is acceptable for current turbine specifications. After the gas has passed through the turbines, coolers, and so on, it must be cleaned further to meet ambient air quality specifications. At this point the gas is relatively cool and at low pressure, so a conventional electrostatic precipitator has been chosen to accomplish the final cleaning.

As a specific case for examination, a 300 MW coal-fired fluidized bed combustion process has been chosen. Pertinent material flows are given in Table 4.57.

The following list of assumptions was made:

- Estimates of particulate loading and size distributions from the primary beds can be made from elutriation considerations (Reference 4.61).

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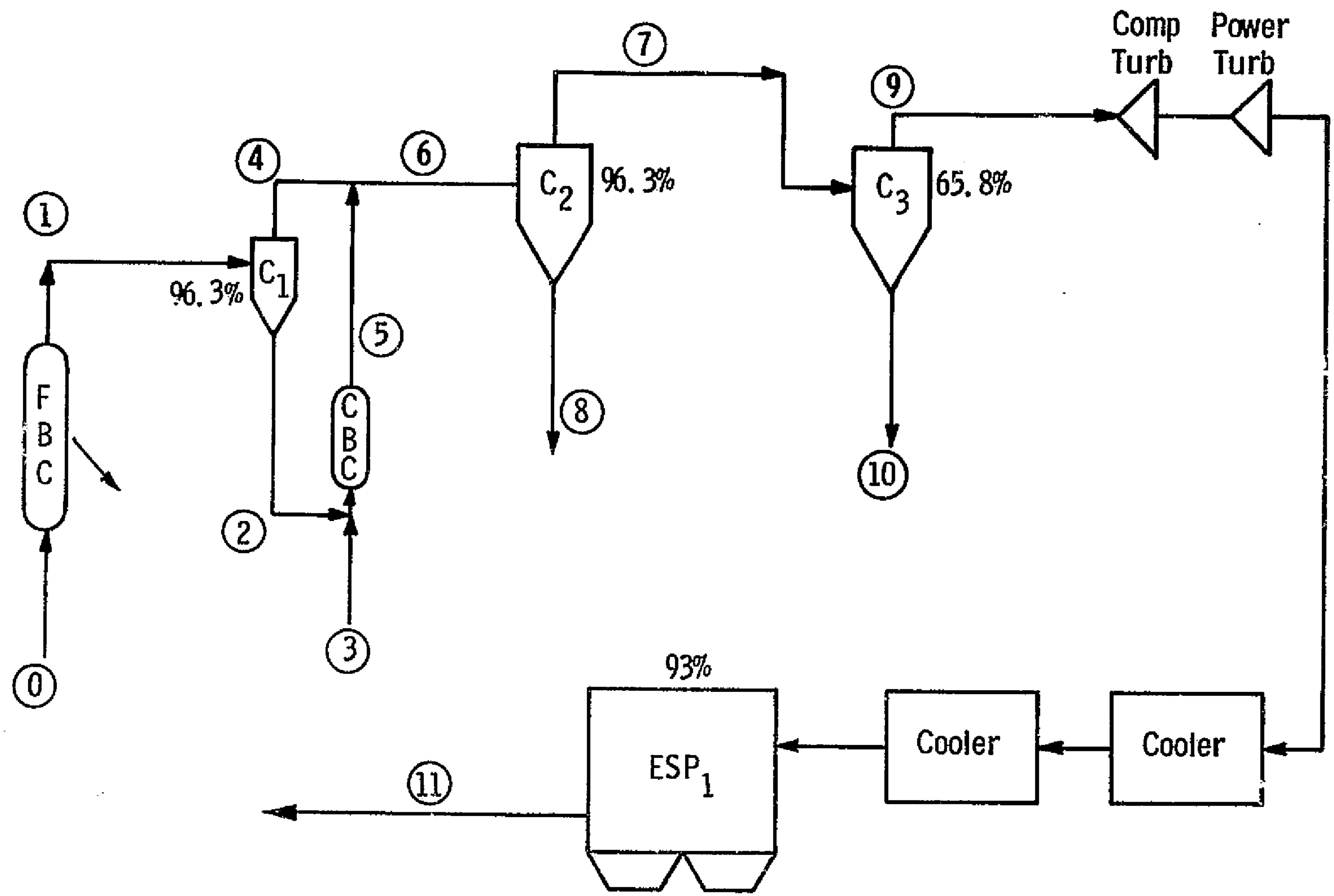


Fig. 4.38—Flow diagram of particulate removal sub-system for high pressure fluidized bed boiler

Table 4.57 - Material Flows for Fluidized Bed Combustion

Station		0	1	2	3	4	5	6	7	8	9	10	11
Solids (lb/hr)	Carbon	48,142	2,302	2,217	-	85	222	307	11.36	296	3.88	7.47	.49
	Ash	5,768	5,768	5,555	-	213	5,555	5,768	213.41	5,555	72.99	140.42	9.24
	Dolomite	44,500	5,768	5,555	-	213	5,555	5,768	213.41	5,555	72.99	140.42	9.24
	Total	98,410	13,838	13,327	-	511	11,332	11,843	438	11,406	149.8	288.3	19
Loading (gr/scf)			12.38					0.35	.365		.125		.0087
Gas (lb/hr)	Flue Gas	- -	631,800	- -		631,800	47,797	679,597	679,597	- -	679,597	- -	679,597
	Air	586,500	- -	- -	45,803								

- The Aerodyne cyclone will perform as well as its manufacturer claims
- Turbine specifications require total loadings to be less than 0.343 g/std m^3 (0.15 gr/scf) with a concentration of 2 µm and larger particles less than 0.0229 g/std m^3 (0.01 gr/scf)
- Current ambient air specifications [43 g/GJ (0.10 lb/10^6 Btu)] correspond to 0.121 g/std m^3 (0.053 gr/scf)
- The amounts of ash and char elutriated are equal
- The carbon loss is 1.5%.

A complete set of calculations for each piece of equipment is presented in Appendix A 4.3, along with grade efficiency curves for each apparatus and inlet and outlet size distributions.

The salient features of the calculations are that a level of 0.286 g/std m^3 (0.125 gr/scf) with 0.0132 g/std m^3 (0.0058 gr/scf) greater than 2 µm can be achieved with the use of two standard cyclones and one Aerodyne unit. An electrostatic precipitator (ESP) is required for final cleanup to meet ambient air quality standards.

An estimate of equipment costs* for this plant is included below:

Ducon Cyclones C_1 and C_2	$ 335,000	each
Aerodyne Cyclone C_3	336,942	each
Research Cottrell Electrostatic Precipitator	4,246,619	high efficiency
	2,150,187	low efficiency

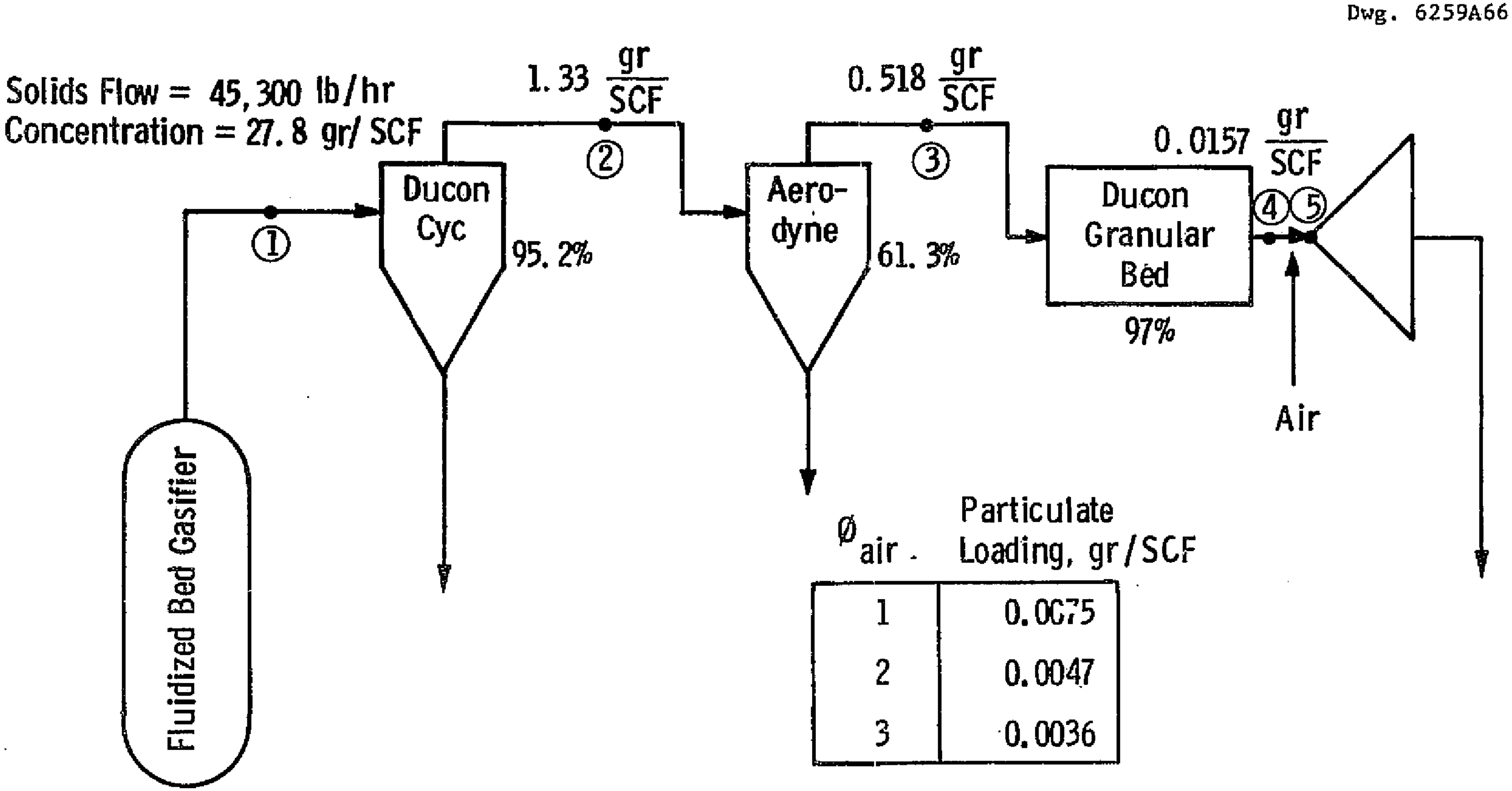
For the plant assumed, eight Ducon Cyclone units, four Aerodyne units, and one electrostatic precipitator are required. A reduction in ESP costs by a factor of 2 can be realized by using a low-efficiency ESP which will just make current air quality standards. It may make more sense to pay more initially for the high-efficiency ESP and avoid future problems with stricter future air standards.

*Cost base - June 1974.

Westinghouse Fluidized Bed Gasifier The particulate removal scheme envisioned for the Westinghouse fluidized bed gasifier is shown in Figure 4.39. Three major pieces of dust collection equipment are required to meet turbine and ambient air quality standards. The raw fuel gas from the gasifier is fed into a conventional cyclone, which returns the bulk of the char fines to the bed. The fuel gas then is passed through a high-efficiency Aerodyne unit which removes 61.3% of the remaining entrained particulates and reduces the loading to 1.185 g/std m^3 (0.518 gr/scf). The fuel gas is then passed through a granular bed filter for final cleaning. The granular bed filter cleans the gas to the extent that it meets both the turbine specifications and the ambient air quality standards.

Three cases have been considered, corresponding to different air/fuel ratios. Case 1 had an air/fuel ratio equal to the stoichiometric ratio; Case 2 was twice Case 1; and Case 3 was three times Case 1. Because of the high dilution of the fuel gas with clean combustion air in Case 3, the concentration of particulates leaving the Aerodyne unit is low enough to meet turbine specifications, but it is not low enough to meet air quality standards. One, therefore, has the option in the third case of eliminating the final high-temperature cleanup system, the granular bed, and choosing to place a final cleaning unit after the turbines at lower pressure and temperature. The granular bed should be left in the system for Case 3 for two reasons: (1) it allows more flexibility in operating the system, since it will handle large variations in dust loadings and still protect the turbine; and (2) the volume of gas treated after the addition of air and reduction of pressure and temperature is so large that very little cost reduction is realized by being able to treat low-temperature flue gas.

As a basis for calculation, the 15.1? kg/s (60 ton/hr) fluidized bed coal gasification system described in Reference 4.62 has been chosen. A higher elutriation rate for the ash has been assumed; it was also assumed that an equal amount of sorbent would be elutriated. This raises the initial grain loading from 30.66 g/std m^3 (13.4 gr/scf) to a more conservative 64.07 g/std m^3 (28 gr/scf).



$Ø_{air}$	Particulate Loading, gr/SCF
1	0.0075
2	0.0047
3	0.0036

Fig. 4.39—Flow diagram of particulate removal sub-system for low Btu gasifier

Initial particle size distributions were reached from the same considerations as those used in determining the distributions for the fluidized bed combustion process. The grade efficiency curves for the cyclones were modified to reflect the somewhat lower particle densities. This had very little effect on their predicted performance. A complete set of calculations is included in Appendix A 4.3.

Estimates for the costs* of the equipment are as follows:

Ducon Cyclone	$ 361,000
Aerodyne Unit	349,000
Ducon Granular Bed	765,000

4.5.3.3 Cost Correlations for Particulate Removal Equipment

An attempt has been made to correlate the cost of frequently used, high-pressure, high-temperature dust collection equipment as a function of volumetric throughput, and of temperature and pressure in the region encountered here, in other words, 811°K < T < 1366°K (1000°F < T < 2000°F) and 1.013 MPa < 2.026 MPa (10 atm <P< 20 atm). The effect of pressure on equipment cost is reflected in the pressure vessel cost. In the pressure range considered here the cost variations due to pressure are small compared with uncertainties in other costs, so an explicit dependence on pressure has not been included.

Temperature affects the equipment cost through the cost of insulation in the pressure vessels that enclose the particulate removal equipment. Refractory costs are about $\$883/m^3$ ($\$25/ft^3$) installed and can, therefore, be an important consideration. If one assumes an acceptable heat loss for the vessel and a skin temperature of about 422°K (300°F), the insulation thickness is a linear function of the inside temperature; and the cost of insulation is, then proportional to the temperature of operation.

Cost correlations were obtained by costing out systems for which quotations have been obtained, and applying scaling exponents for the various

*Cost base - June 1974

components. This result was then normalized to the quoted price for the equipment. The results of these calculations are shown in Equations 4.28 through 4.32. Where Q is acfm, T is in °F, and C(T, Q) is the equipment cost in dollars.

<u>Ducon Cyclone System</u>

$$C(T, Q) = \left(\frac{335}{87.6}\right) \left[\left(6500 \left(\frac{T}{1000}\right) + 4134\right) \left(\frac{Q}{62,000}\right) + 46,980 \left(\frac{Q}{62,000}\right)^{0.67} + 26,100 \left(\frac{Q}{62,000}\right) \right]^{0.85} \quad (4.28)$$

<u>Aerodyne Unit</u>

$$C(T, Q) = \left(\frac{191}{87.5}\right) \left[\left(9544 \left(\frac{T}{1000}\right) + 6070\right) \left(\frac{Q}{31,200}\right) + 66,120 \left(\frac{Q}{31,200}\right) \right]^{0.67} + 165,882 \left(\frac{Q}{31,200}\right)^{0.85} \quad (4.29)$$

<u>Ducon Granular Bed</u>

$$C(T, Q) = \left(\frac{191}{65}\right) \left[\left(7284 \left(\frac{T}{1000}\right) + 4638\right) \left(\frac{Q}{10,000}\right) + 48,720 \left(\frac{Q}{10,000}\right)^{0.67} \right] + \left[41,400 \left(\frac{Q}{10,000}\right) + 8470 \left(\frac{Q}{10,000}\right)^{0.47} \right] \quad (4.30)$$

Electrostatic Precipitator 408°K (275°F), 101.3 kPa (14.7 psi) abs

$$C(Q) = 99.24\ (Q)^{0.78} \qquad \text{High Efficiency ESP (99.5\%)} \qquad (4.31)$$

$$C(Q) = 50.24\ (Q)^{0.78} \qquad \text{Low Efficiency ESP (90\%)} \qquad (4.32)$$

In reality, the equipment is modular, so the cost is really a discontinuous function of throughput rather than the continuous-type function indicated; but the expressions can be used to give estimates of costs sufficiently accurate for generalized comparison of power system concepts.

It should also be noted that installed costs for electrostatic precipitators and high-efficiency cyclones are as follows:

- ESP - Installed Cost = 1.65 x Purchase Cost
- Cyclones - Installed Cost = 1.8 x Purchase Cost
- Aerodyne - Installed Cost = 1.225 x Purchase Cost.

The power requirements for the various types of particulate removal equipment are approximately as follows:

Apparatus	Power Requirement kW/acfm
Medium-efficiency cylone	0.84×10^{-3}
High-efficiency cyclone	1.12×10^{-3}
Electrostatic precipitator	0.50×10^{-3}
Granular bed filter	4.70×10^{-3}

4.5.4 Sulfur Removal Requirements

The overall requirements for sulfur removal for the current standard and the advanced targets are given in Table 4.58 for each of the specified coals. Since essentially all of the sulfur in the coal appears in the products of combustion as sulfur dioxide (SO_2) [with 2 to 3% sulfur trioxide (SO_3)] or in coal-derived fuel gas as hydrogen sulfide (H_2S) [with small quantities of carbonyl sulfide (COS)], the requirements for overall removal listed in Table 4.58 are specifically applicable to flue gas and fuel gas desulfurization processes.

In recent months flue gas desulfurization (FGD) systems* have reached a turning point with respect to technical success and the number of orders placed by utilities. This is not to say that all problems have been solved. Most prototype FGD systems with chemical problems, such as scaling, seem to be finding satisfactory solutions; mechanical problems (e.g., venturi plugging, fan vibration, etc.) have been more troublesome. While most of these problems are not major, they have led to low availability.

Table 4.59 (Reference 4.63) summarizes the number and total megawatts of FGD systems in operation, under construction, or planned in the U. S. as of November, 1974. Of the 98 units totaling about 38,000 MW, approximately 87% will be on stream by 1980 (Figure 4.40 from Reference 4.63). Many more units undoubtedly will be ordered if clean air standards are enforced.

*In the context of this discussion FGD systems remove not only sulfur compounds but particulates as well.

Table 4.58 - Pollutant Removal Requirements[a]

	Removal Required, % by Wt.		
	Illinois	Montana	North Dakota
Current Emission Standard			
Sulfur	83.3	32.5	41.4
Particulates	98.9	98.8	98.9
Nitrogen	77.0	76.3	75.0
Advanced Target 1			
Sulfur	97.2	88.8	90.0
Particulates	99.9	99.9	99.9
Nitrogen	90.2	89.8	89.5
Advanced Target 2			
Sulfur	98.6	94.4	95.0
Particulates	99.94	99.94	99.94
Nitrogen	96.1	95.9	95.8
Advanced Target 2a			
Particulates	99.99	99.99	99.99

[a]100% conversion assumed for fuel nitrogen.

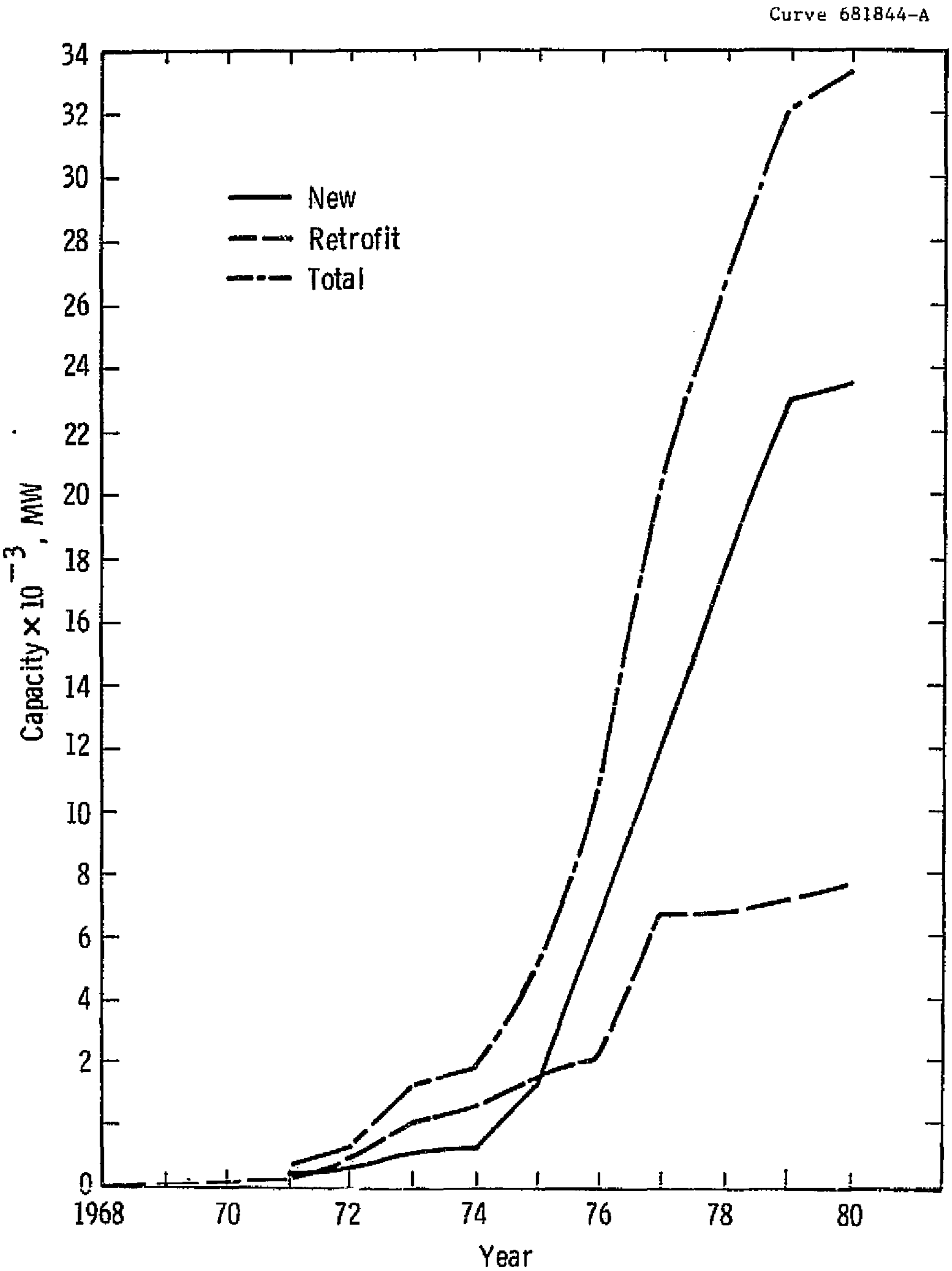


Fig. 4.40—Present and projected FGD systems capacity new/ retrofit/ total vs year

Table 4.59 - Number of Units and Total MW of FGD Systems

Status	Units	MW
Operational	19	3,291
Under Construction	17	6,777
Planned		
Contract awarded	12	6,640
Letter of intent	4	905
Requesting/evaluating bids	9	3,751
Considering FGD	37	16,472
	98	37,836

Sulfur dioxide removal efficiencies for operating units range from 70 to 90%, and particulate removal efficiencies are approximately 99%. Installation sizes vary from 30 to 800 MW. FGD systems have been applied to both low- (0.4 to 1%) and high- (6%) sulfur coals. The non-regenerable (throwaway) systems have used various methods of disposal, including ponding, dewatering for landfill, and fixation for landfill. Regenerable systems to date have been for the production of sulfuric acid, but elemental sulfur recovery units will be coming on stream in the near future.

4.5.4.1 TVA Appraisal of Five Flue Gas Desulfurization Systems

TVA, under contract to EPA, recently made a cost appraisal of the five most advanced flue gas desulfurization processes-limestone slurry scrubbing, lime slurry scrubbing, magnesia slurry scrubbing with regeneration to produce sulfuric acid, sodium solution scrubbing with regeneration to produce sulfur, and catalytic oxidation (Reference 4.64). A brief description of these processes and the organizations supplying representative system data are given in Appendix A 4.5. The process data represent the state of technology in late 1973 and are the most recent available.

Table 4.60 - Limestone Slurry Process
Summary of Estimated Fixed Investment[a]

(500-MW new coal-fired power unit, 3.5% S in fuel;
90% SO_2 removal; onsite solids disposal)

	Investment, $	Percent of subtotal direct investment
Limestone receiving and storage (hoppers, feeders, conveyors, elevators, and bins)	419,000	2.6
Feed preparation (feeders, crushers, elevators, ball mills, tanks, and pumps)	899,000	5.6
Particulate scrubbers and inlet ducts (4 scrubbers including common feed plenum, effluent hold tanks, agitators, and pumps)	3,203,000	19.9
Sulfur dioxide scrubbers and ducts (4 scrubbers including mist eliminators, effluent hold tanks, agitators, pumps, and exhaust gas ducts to inlet of fan)	4,745,000	29.5
Stack gas reheat (4 indirect steam reheaters)	556,000	3.5
Fans (4 fans including exhaust gas ducts and dampers between fan and stack gas plenum)	854,000	5.3
Calcium solids disposal (onsite disposal facilities including feed tank, agitator, slurry disposal pumps, pond, liner, and pond water return pumps)	3,923,000	24.4
Utilities (instrument air generation and supply system, plus distribution systems for obtaining process steam, water, and electricity from the power plant)	67,000	0.4
Service facilities (buildings, shops, stores, site development, roads, railroads, and walkways)	638,000	4.0
Construction facilities	765,000	4.8
Subtotal direct investment	16,069,000	100.0
Engineering design and supervision	1,446,000	9.0
Construction field expense	1,768,000	11.0
Contractor fees	803,000	5.0
Contingency	1,607,000	10.0
Subtotal fixed investment	21,693,000	135.0
Allowance for startup and modifications	1,735,000	10.8
Interest during construction (8%/annum rate)	1,735,000	10.8
Total capital investment	25,163,000	156.6

[a]Basis:
Stack gas reheat to 175°F by indirect steam reheat.
Disposal pond located 1 mile from power plant.
Midwest plant location represents project beginning mid-1972, ending mid-1975. Average cost basis for scaling, mid-1974.
Minimum in process storage; only pumps are spared.
Investment requirements for disposal of fly ash excluded.
Construction labor shortages with accompanying overtime pay incentive not considered.

The limestone slurry flue gas desulfurization process is the preferred process for use in this study. It is capable of at least 90% sulfur removal, which will meet the current sulfur removal requirements for all three coals. This degree of sulfur removal will also meet Advanced Target 1 requirements for the Montana and North Dakota coals. It is probable that this process could be designed for greater than 90% sulfur removal. The cost of the equipment for higher degrees of sulfur removal, however, is not known.

The cost estimate for the limestone slurry process made by TVA assumed that the particulate removal in the process was sufficient to meet the current emission standards, in other words, 98.9%. High-energy scrubbers are capable of a significantly higher degree of particulate removal than that, but the cost of the more efficient scrubber is not known.

The estimated fixed investment for the limestone slurry process from the TVA study (Reference 4.64) is tabulated in Table 4.60. The total capital investment for a 500 MW unit with 3.5% sulfur coal, 90% sulfur removal, and on-site disposal of waste solids comes to $50.30/kW. Table 4.61 shows that modification of project scope and use of more pessimistic assumptions can drive the capital investment estimate up by 125%. An accuracy analysis of the cost estimate for the limestone slurry process showed the variance for the total capital investments to be -22.5% and +57.1%. The equipment and material and construction labor cost estimates are shown in Table 4.62 as follows:

Table 4.62 - Cost Estimates

	Cost - $/kW		
	Min.	Base	Max.
Process Equipment and Materials	$13.71	$15.62	$18.54
Construction Labor	6.31	7.42	9.28
	$20.02	$23.04	$27.82
Percent Variance	-13.1		+20.7

Table 4.61 - Limestone Slurry Process Investment with Modified Project Scope

	Investment, $/kW
BASE INVESTMENT - LIMESTONE SLURRY PROCESS (Including Fly Ash Removal but Not Disposal)	
500-MW new coal-fired unit burning coal with 3.5% S, 12% ash, 90% SO_2 removal, 30-year life 127,500 hours operation, onsite solids disposal, proven systems, only pumps spared, no by-pass ducts, experienced design and construction team, no overtime, 3-year program, 5% per year escalation, mid-1974 cost basis for scaling	50.30
A. Overtime to accelerate project or cover local demand requirements (50% of construction labor requirements)	3.20
B. Research and development costs for first of a kind process technology (as allowed by FPC accounting practice)	5.00
C. Power generation capital for lost capacity (normally covered by appropriate operating costs for power used in process)	4.50
D. Reliability provisions with added redundancy of scrubbers, other equipment, ducts and dampers, instrumentation for change over (assumes no permission to run power plant without meeting SO_2 removal emission standards at all times)	6.00
E. Additional by-pass ducts and dampers	2.00
F. Retrofit difficulty--moderate, space available beyond stack, less than three shutdowns required for tie-ins, field fabrication feasible	10.00
G. Fly ash pond including closed-loop provisions	5.50
H. 500-ft stack added to project cost	6.00
I. Air quality monitoring system, 2 to 15 mile radius, 10 stations	0.70
J. Cost escalation of 10% per year instead of 5%	4.80
K. Possible delay of up to 2 years in equipment and material deliveries (1977 completion instead of 1975)	15.00
Total	113.00

The TVA study assumed a wet-wet system for the limestone slurry process. A scrubber was used ahead of the sulfur dioxide removal process to remove most of the particulates. Chas. T. Main, Inc. and a principal supplier of limestone slurry systems (Reference 4.65) recommended the use of a low-efficiency electrostatic precipitator ahead of the sorbent scrubber. The cost for the limestone slurry process, excluding the electrostatic precipitator, was assumed to be as follows (Reference 4.66):

Equipment and Materials		\$27.70/kW
Installation Labor		12.70
	Total	\$40.20

The correlations of cost as a function of capacity and sulfur content of the coal given in Appendix A 4.5 were used to generate multipliers to apply to the above base cost. The limestone/coal ratios for Illinois No. 6 and Montana coals, and for North Dakota Lignite, were assumed to be 0.15, 0.031, and 0.027, respectively.

For a number of years, Westinghouse has been engaged in the study of in-bed desulfurization of the products of combustion of a fluidized bed combustor under EPA Contract No. 68-02-0605 (References 4.8 and 4.34). Consideration has been given to both regenerative and once-through processes, with limestone or dolomite being used as the sorbent. The cycle of reactions for the regenerative process are shown in Figure 4.41, and the process reactions for the regenerative cycle are given in Table 4.63.

The quantities of dolomite required for in-bed desulfurization of the products of combustion of the three specified coals are as follows:

Coal	Illinois No. 6	Montana	N. Dakota
Moisture content -%	3	20	27
Dolomite/coal ratio	0.59	0.12	0.11

4.5.4.2 Fuel Gas Desulfurization Processes

There are two general categories of fuel gas desulfurization - high and low temperature. High-temperature fuel gas desulfurization processes

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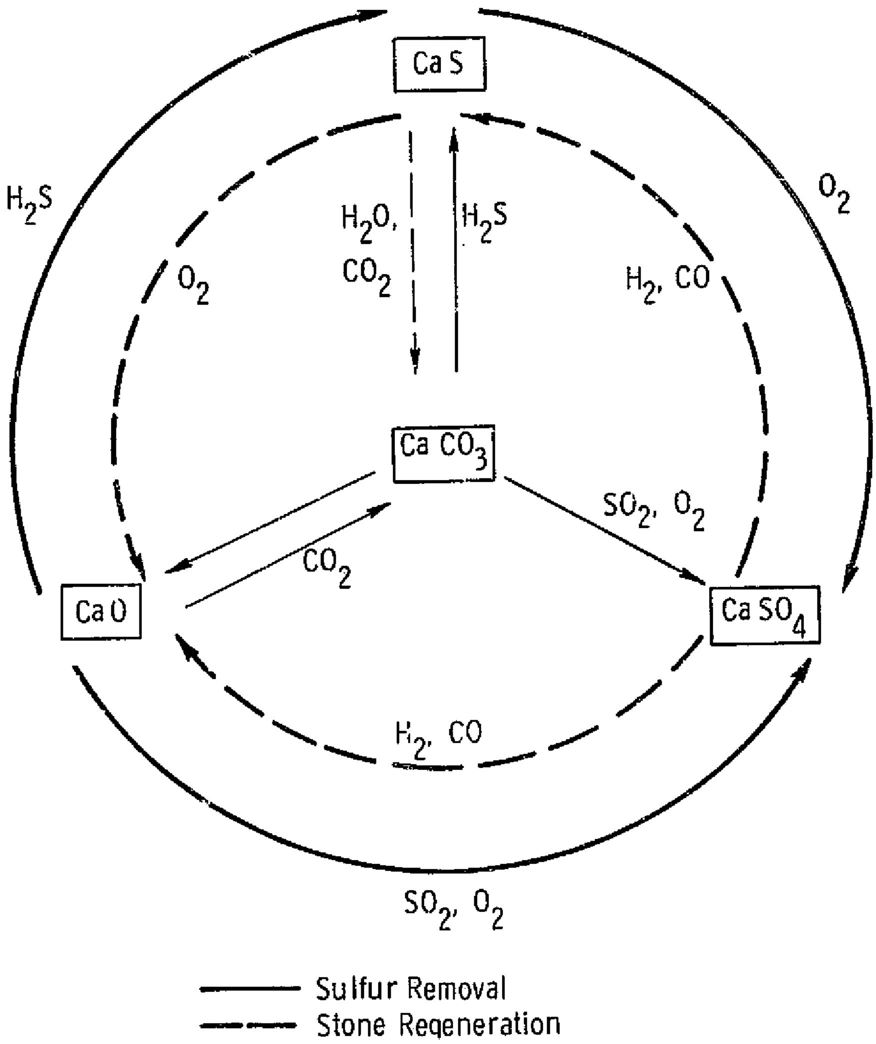

Figure 4.41—The calcium carbonate/ sulfur cycle basic reactions

Table 4.63 - Calcium Carbonate/Sulfur Cycle Basic Reactions

Reaction	Operating Conditions	Applicable Fuel Processing Option
Sulfur Removal		
1. $\begin{pmatrix} CaO \\ CaCO_3 \end{pmatrix} + SO_2 + 1/2\ O_2 \rightarrow CaSO_4 + \begin{pmatrix} CO_2 \end{pmatrix}$	1300°F < T < 1850°F P: 1 to 20 atm	Combustion
Stone Regeneration		
2. $CaSO_4 + \begin{pmatrix} 4\ H_2 \\ 4\ CO \end{pmatrix} \rightarrow CaS + \begin{pmatrix} 4\ H_2O \\ 4\ CO_2 \end{pmatrix}$	T < 1600°F	Combustion (at elevated pressure)
3. $CaS + H_2O + CO_2 \rightarrow CaCO_3 + H_2S$	T < 1500°F P > 5 atm	Combustion (at elevated pressure)

under development use dolomite or limestone and iron oxide. Numerous low-temperature desulfurization processes are commercially available, among them the Benfield, Stretford, Sulfinex, and Selexol processes.

Westinghouse is engaged in the development of a high-temperature fuel gas desulfurization process under OCR Contract No. 14-32-0001-1514 (Reference 4.67). Dolomite has been identified as the preferred sorbent for operating temperatures of approximately 1144°K (1600°F). The sulfur in the fuel is converted primarily to hydrogen sulfide, which reacts with the sorbent as follows:

$$MgCO_3 \cdot CaCO_3 \rightleftarrows MgO \cdot CaCO_3 + CO_2$$

$$MgO \cdot CaCO_3 + H_2S \rightarrow MgO \cdot CaS + CO_2 + H_2O$$

In the first-generation, once-through version of this process, the spent sorbent is oxidized to the sulfate form to obtain a waste solid which is more easily disposed of. In the regenerative process, the spent stone is regenerated and by-product sulfur is produced by the following reactions:

$$MgO \cdot CaS + H_2O + CO_2 \rightleftarrows MgO \cdot CaCO_3 + H_2S$$

$$H_2S + \frac{3}{2} O_2 \rightleftarrows H_2O + SO_2$$

$$2H_2S + SO_2 \rightleftarrows \frac{3}{x} S_x + 2 H_2O$$

The once-through and regenerative dolomite desulfurization processes remove about 95% of the hydrogen sulfide in the hot fuel gas and little or none of the carbonyl sulfide. The carbonyl sulfide concentration in the fuel gas from the Westinghouse fluidized bed gasification process is projected to be equivalent to approximately 5% of the sulfur in the fuel gas. The fraction of the sulfur removed is, therefore, about 90%.

In order to meet the NASA-specified sulfur dioxide emission requirement for gaseous fuels (i.e., 0.2 lb $SO_2/10^6$ Btu input), 97.2% of the sulfur in Illinois No. 6 coal must be removed. Because of the inability of dolomite to remove carbonyl sulfide, the fraction removed is significiently below the target value. The more appropriate emission limit for solid fuels [516 g/GJ (1.2 lb/10^6Btu)] can easily be met by the use of dolomite for high-temperature desulfurization.

The Morgantown Energy Research Center of ERDA tested 48 materials for their ability to absorb hydrogen sulfide from hot producer gas in the temperature range of 811 to 1089°K (1000 to 1500°F) (Reference 4.68). It was determined that the material that is best from the standpoint of absorption capacity, durability, and amenability to regeneration is sintered pellets of 75% fly ash and 25% ferrous oxide.

Tests of this sorbent in a side stream of fuel gas from the Morgantown Energy Research Center stirred, fixed-bed, airblown gasifier at a temperature of 866°K (1100°F) shows that 90 to 94% of the hydrogen sulfide was removed, the operation was not adversely affected by the tars and particulates in the fuel gas stream, and sorbents remained in good condition during the 54 ks (15 hr) runs (Reference 4.69). Fine carboneous material accumulates in the sorbent bed but is burned off during the regeneration cycle. The main problem with this process is controlling the temperature during regeneration so as to prevent excessive pore fusing or glassing of the sorbent.

Dolomite sorption was selected as the high-temperature fuel gas desulfurization process for use in this study. The quantities of dolomite required for desulfurization of the low-Btu fuel gas from the three specified coals were given previously. The energy required for the desulfurization reactions are included in the gasification process performance calculations. Costs for desulfurization using dolomite were included in the estimates of the costs of the Westinghouse gasification process.

The Benfield process was selected for use in low-temperature desulfurization of product fuel gas at pressures greater than 101.3 kPa (1 atm). The Benfield process was developed by the BOM at Bruceton near Pittsburgh and is marketed by the Benfield Corporation.

Approximately 50 installations of this process have been made around the world. The sorbent used is hot potassium carbonate, and the operating temperature is in the range of 366 to 394°K (200 to 250°F). This sorbent removes about 95% of the hydrogen sulfide and 30% of the carbon dioxide from the product fuel gas. The sorbent is regenerated and sulfur is recovered by the use of a Claus process.

In gas turbine applications extreme care must be taken to prevent the carry-over of the sorbent. The use of a demister in the stream following the sorbent is indicated to provide adequate control of the carry-over of potassium compounds. Cost estimates for this process were based on quotes from the Benfield Corporation.

The Stretford process was selected for use in low-temperature desulfurization of product fuel gas at near atmospheric pressure. It was developed in England by the North Western Gas Board. The sorbent medium in the Stretford process is an aqueous alkaline solution of a commercial dye intermediate containing salts of one or more of the anthraquinone disulfonic acids. Sodium metavanadates are added to assist the dye intermediate. Three stages are involved in the desulfurization and regeneration process. These are:

- The removal of hydrogen sulfide from the fuel gas by the alkaline washing medium
- The reaction between the hydrosulfide ions formed in the washing stage with carbonyl radical of the anthraquinone disulfonic acid which give sulfuric acid and a reduced form of the reagent
- The regeneration of the original anthraquinone disulfonic acid from the reduced form by oxidation with air.

Costs for this process were based on information from the U. S. licensee of the process.

The July 1974 cost of dolomite was assumed to be \$3.31/Mg (\$3.00/ton) at the quarry. Assuming 6.85 mills/Mg-km (10 mills/ton-km) transportation cost and 483 km (300 mi) transport distance gives a transportation cost of \$2.59/Mg (\$2.35/ton) and a total cost of (\$5.35/ton).

Ground limestone stored in an open pile in a humid region will equilibrate at a moisture content of about 4%.

4.5.5 Nitric Oxide Control Technology

The current emission standards for NO_x emissions from power plants are as follows:

Fuel Type	NO_x Limit - $lb/10^6$ Btu
Solid	0.7
Liquid	0.3
Gaseous	0.2

Oxides of nitrogen are produced during the combustion of hydrocarbon fuels with air. Oxides of nitrogen come from two sources: fixation of the free nitrogen in the combustion air and conversion of the bound nitrogen in the fuel. Nitric oxide (NO) forms initially in the combustion reaction zone or immediately following the reaction zone. The nitric oxide is converted to nitrogen dioxide when it is mixed with atmospheric air. Air pollution regulations are written around the sum of nitrogen oxides commonly referred to as NO_x but measured as nitrogen dioxide.

The mechanism of formation of nitric oxide in flames from the nitrogen in the combustion air is well understood in quantitative detail. From the nitric oxide formation rate equations, it can be observed that the basic parameters which control the formation of NO_x are flame temperature, residence time at flame temperature, pressure, and the mole fractions of nitrogen, oxygen, and nitric oxide at the end of the combustion process. Any NO_x control method involves one or more of these basic parameters.

In diffusion flames the chemically bound nitrogen in the fuel reacts with atomic oxygen to form nitric oxide during the short period of time (microseconds) characteristic of the carbon-hydrogen-oxygen reaction. During this time period, the fixation of molecular nitrogen from the combustion air through the Zeldovich mechanism is, for all practical purposes, negligible. In addition, the presence of the nitric oxide derived from the chemically bound nitrogen tends to suppress the subsequent formation of nitric oxide through the Zeldovich mechanism of thermal nitric oxide. Consequently, the net conversion of bound nitrogen is less than 100% when conditions are conducive to thermal nitric oxide formation. The net conversion of bound nitrogen is not a fixed number but is a function of the nitrogen content of the fuel and the flame temperature.

Fluidized bed combustion of coal takes place at temperatures approximately 111°K (200°F) below the ash fusion temperature [∿ 1533°K (2300°F)]. With in-bed desulfurization using limestone/dolomite the operating temperature range is restricted to 978 to 1283°K (1300 to 1850°F). This temperature range is well below the level where fixation of free nitrogen through the Zeldovich mechanism becomes negligible [1611°K (about 2800°F)]. Experimental investigations by Exxon (Reference 4.70) and NRDC (Reference 4.71), however, have shown that the conversion of bound nitrogen is substantially below 100%.

Several techniques have been developed for nitric oxide control in conventional pulverized coal-fixed boilers (Reference 4.72). These are:

- Low excess air combustion
- Flue gas recirculation
- Water injection
- Staged combustion
- Reduced air preheat temperature
- Load reduction
- Combustion modifications.

Current nitric oxide emission standards can readily be met by application of the above techniques or combinations thereof. The cost of nitric oxide control ranges from about $1/kW for low excess air combustion to about $3/kW for staged combustion.

Techniques for nitric oxide control in cyclone furnaces are somewhat restricted because of the limited flexibility of this design (Reference 4.72). Investigations of staged cyclone combustors for MHD applications, however, indicate that this technique should be generally applicable for cyclone furnaces.

As stated earlier, there is essentially no fixation of free nitrogen in fluidized bed combustion, and the conversion of bound nitrogen is substantially less than 100%. Figure 4.42 is a composite plot of the NO_x emission data from Exxon and NRDC which shows that the NO_x emissions from fluidized bed combustion of coal is well below the current EPA emission standard over a range of excess air levels up to about 50%.

Extrapolation of the Exxon and NRDC data indicates that the NO_x emissions for adiabatic fluidized bed combustion would also be below the EPA emission standard of 0.7 lb $NO_2/10^6$ Btu input. Data from the Combustion Power Company's process development unit indicates that the NO_x emission level from an adiabatic combustor (excess air 200 to 300%) is in the order of 0.4 lb $NO_2/10^6$ Btu input.

The predicted nitric oxide concentrations in the products of combustion of various fuels when burned in conventional cell or circular register burners applied to fired heat exchangers are given in Table 4.64.

The current emission standards for power plants are specifically for plants having heat inputs greater than 73.25 MJ/s (250 x 10^6 Btu/hr), which is equivalent to a gas turbine of 20 to 25 MW capacity. Utility gas turbine models recently put on the market by the major manufacturers generally exceed this capacity level. These emission limits, however, have not been generally applied to gas turbines.

The current emission standards for NO_x as applied to gas turbines in this study are expressed in lb of nitrogen dioxide/10^6 Btu heat input. The coresponding allowable stack-gas concentration as a function of air equivalence ratio (ϕ_{air}) and fuel are shown in Table 4.65.

Curve 681840-A

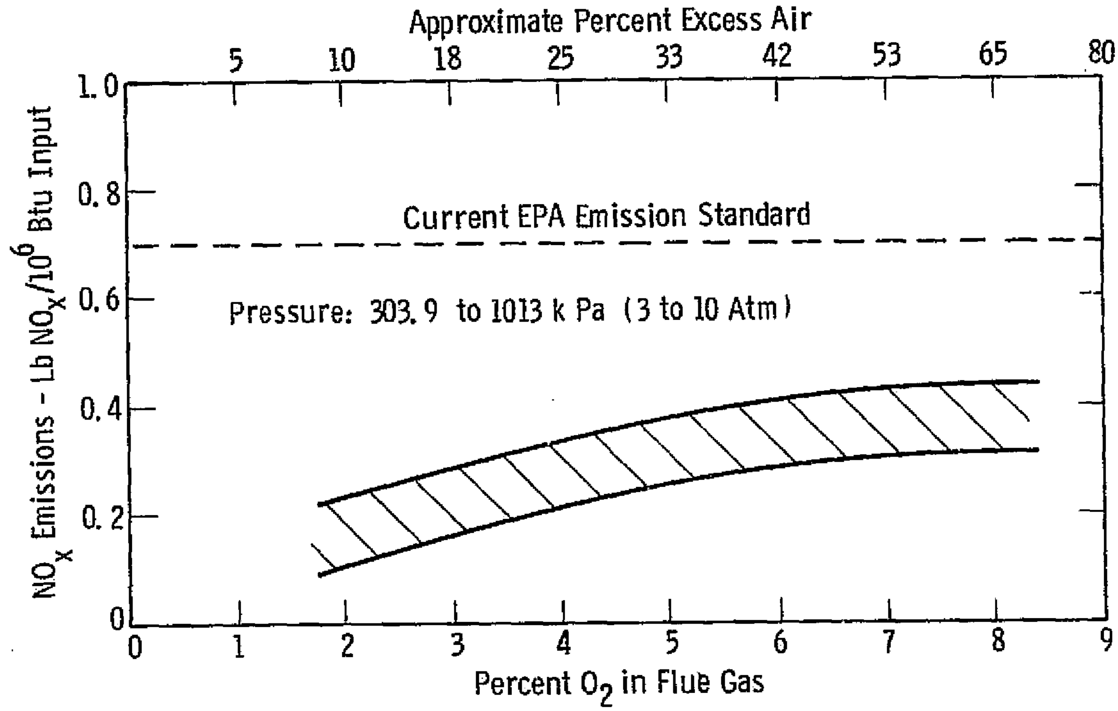

Fig. 4.42 – Composite plot of data for NO_x emissions from fluidized combustion of coal

Table 4.64 - Predicted Nitric Oxide Concentrations in Conventional Burners Applied to Fired Heat Exchangers

Fuel	Concentration in Combustion Products (ppm by volume)		
	Minimum	Maximum	Mean
High-Btu Fuel Gas[a]	50	375	213
Distillate from Coal-Derived Liquids[b]	90	715	400
Intermediate-Btu Fuel Gas[c]	100	800	450

[a]Values given in Reference 4.43 for natural gas.

[b]Concentration for natural gas given in Reference 4.43 x computed ratio of No. 2 distillate to natural gas.

[c]Concentration for natural gas given in Reference 4.43 x computed ratio of intermediate-Btu fuel gas to natural gas.

Table 4.65 - Allowable Stack-Gas Concentration as a Function of Air Equivalence Ratio

Air Equivalence Ratio, ϕ_{air}	NO_x Concentration, ppm by volume, Fuel Type	
	Liquid	Gaseous
2.5	103	67
3.0	87	56
3.5	72	48
4.0	64	42

For a period of about 63.07 Ms (2 yr), EPA has been involved in generating a set of emission standards specifically for gas turbines. These emission standards have not yet been released, but preliminary information indicates that the maximum allowable NO_x concentrations will be 75 ppm by volume for oil and 55 ppm by volume for natural gas. These quantities are normalized to 15% oxygen in the combustion products. The corresponding allowable concentrations as a function of air equivalence ratio are shown in Table 4.66.

Table 4.66 - Allowable NO_x Concentrations for Gas Turinbes as Function of Air Equivalence Ratio

Air Equivalence Ratio, ϕ_{air}	NO_x Concentration, ppm by volume, Fuel Type	
	Liquid	Gaseous
2.5	110	80
3.0	92	67
3.5	79	57
4.0	69	50

Comparison of these values with the earlier values based on the general emission standards shows that the general standards are significantly more rigorous than the anticipated gas turbine emission standards, especially for gaseous fuels.

NO_x emissions from current production model gas turbines in the 35-to-60 MW size range at design load without steam water injection are shown in Table 4.67 (Reference 4.73).

Table 4.67 - NO_x Emissions from Current Model Gas Turbines

Fuel	NO_x Concentration, ppm by volume	
	No. 2 Distillate	Natural gas
Air Equivalence Ratio		
2.5	310	145
3.0	260	120
3.5	220	100
4.0	195	90

The minimum NO_x emission levels anticipated from improved combustor designs without steam or water injection are shown in Table 4.68 (Reference 4.73).

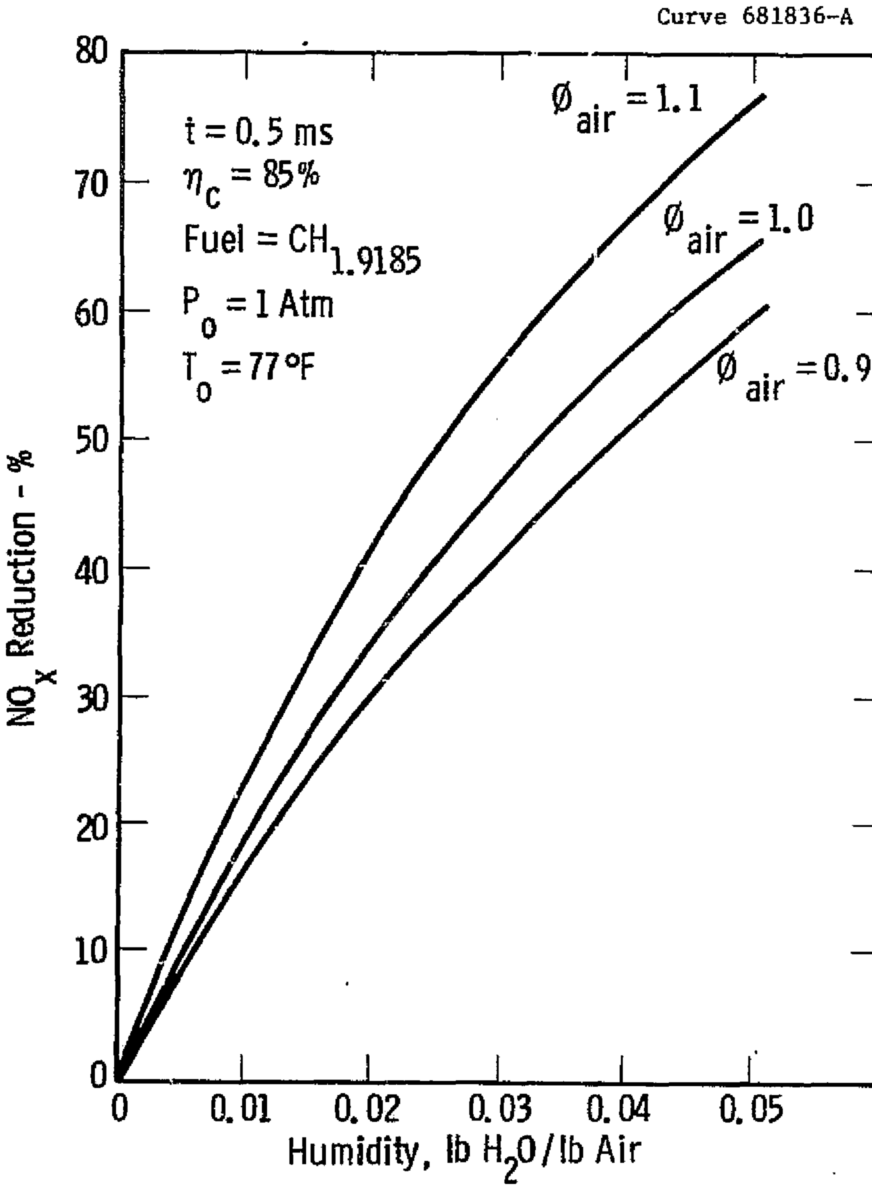

Fig. 4.43 – Calculated effectiveness of water injection on NO_x reduction as a function of primary zone equivalence ratio

Table 4.68 - Minimum NO_x Emissions Anticipated

Fuel	NO_x Concentration, ppm by volume	
	No. 2 Distillate	Natural gas
Air Equivalence Ratio		
2.5	160	75
3.0	135	65
3.5	115	55
4.0	100	45

It is apparent from the above that water injection will be required to meet both the general emission standards being applied in this study and the anticipated gas turbine emission standards with an improved combustor design operating on liquid fuels similar to No. 2 distillate oil. For gas turbines burning fuels similar to natural gas, the NO_x emission levels for advanced combustor designs are marginal for dry operation over the full range of air equivalence ratio. Water injection will probably be required to meet the general emission limits when operating on natural gas. Shaw (Reference 4.74) has developed NO_x emission indices for gas turbine combustors with water injection. Figure 4.43, which is taken from Reference 4.74, shows the percent of NO_x reduction as a function of the fraction of water injection with fuel equivalence ratio parameters for a fuel similar to No. 2 distillate. For the purpose of this study it is assumed that comparable percentage reductions in NO_x emission would be obtained with natural gas.

The above described data for No. 2 distillate oil was assumed, for the purpose of this study, to be applicable to distillate from coal-derived liquids and intermediate-Btu fuel gas,* and the data for natural gas were assumed to be applicable to high-Btu fuel gas.

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*Computations made by the Westinghouse Gas Turbine Engine Division indicate that the NO_x produced from this type of fuel would be equivalent to that from distillate oils.

Westinghouse is currently the team leader for an industry/utilities group developing a 120 MW coal gasification plant with a low-Btu gas-burning turbine under U. S. Energy Research and Development Administration Contract No. 14-32-0001-1514 (Reference 4.46). Westinghouse has constructed facilities and gained considerable experience in the combustion of low-Btu gases under this program since August 1972.

NO_x measurements have been made for both small-scale laboratory combustors and full-scale rigs. With simulated, low-Btu fuel gas having a heating value of 5.03 MJ/std m^3 (135 Btu/scf), the measured NO_x concentrations for turbine inlet temperatures of 1366°K (2000°F) are about 10 ppm by volume. With 7.45 MJ/std m^3 (200 Btu/scf) simulated fuel gas, the NO_x concentration for a turbine inlet temperature of 1366°K (2000°F) was found to be about 75 ppm by volume. Good agreement was obtained with analytically predicted values (Reference 4.76).

The above test and analytical results on NO_x emissions from gas turbine combustors burning simulated low-Btu fuel gas are for fuel gas temperatures approximately equal to those which would result from the use of the Benfield low-temperature desulfurization process [394°K (∿ 250°F)]. With high-temperature fuel gas desulfurization using a dolomite sorbent, the fuel gas temperature to the gas turbine combustor will be about 1144°K (1600°F). The sensible heat associated with a temperature of 1144°K (1600°F) is typically about 25% of the lower heating value of the fuel gas. The adiabatic flame temperature will, therefore, be significantly higher with the hot fuel gas than with the cold fuel gas. This will, of course, result in higher NO_x emissions with the hot fuel gas than those shown above for the low-temperature fuel gas. Analytically predicted values of NO_x concentration for a fuel gas temperature of 1144°K (1600°F) are ∿ 12 times those for low-temperature fuel gas (Reference 4.76). The estimated NO_x concentrations from thermal nitric oxide formation for a gas turbine burning low-Btu fuel gas for low and high fuel gas temperatures are shown in Table 4.69.

Table 4.69 - Estimated NO_x Concentrations

Air Equivalence Ratio	Thermal NO_x Concentration, ppm volume, Fuel Gas Temperature, °F	
	250	1600
2.5	12 (2390)	180 (2665)
3.0	10 (2135)	150 (2420)
3.5	8.5 (1965)	129 (2200)
4.0	7.5 (1830)*	113 (2065)

*Numbers in parenthesis are typical turbine inlet temperatures (°F) corresponding to the combinations of air equivalence ratio and fuel gas temperature for combustion air temperatures of 700°F.

A significant fraction of the nitrogran in coal is converted to ammonia during a gasification process, and this ammonia will be a constituent of the raw low-Btu fuel gas. When high-temperature desulfurization is used, the ammonia will probably persist in the clean fuel gas. Since ammonia is a form of bound nitrogen, it is probable that 25 to 50% of the nitrogen in the ammonia will be converted to nitric oxide in the gas turbine combustor. This level of net conversion is typical of a combustion situation in which a substantial amount of thermal nitric oxide is formed, as would be the case in the combustion of hot, low-Btu fuel gas. If water is injected to suppress the formation of thermal nitric oxide, the net conversion of bound nitrogen will tend to increase. Combustion tests on low-Btu fuel gas at Westinghouse Research Laboratories have shown that the conversion of ammonia nitrogen is 75 to 100% when thermal nitric oxide is low.

Where low-temperature desulfurization is used, a scrubber-cooler will probably be located ahead of the low-temperature desulfurization which could remove the ammonia from the fuel gas. If for some reason the ammonia is not taken out in low-temperature desulfurization, the bound nitrogen in the ammonia will have a high net conversion to nitric oxide (∿ 75%) (Reference 4.75). This is so because there will be very little thermal nitric oxide produced in the combustion of cold low-Btu fuel gas.

The fraction of the nitrogen in Illinois No. 6 coal which will be released as ammonia in the Westinghouse fluidized bed gasifier is estimated to be about 15% (Reference 4.77). This will give a concentration of ammonia in the product fuel gas of about 700 ppm by volume. The resultant concentration of NO_x in the products of combustion of the fuel gas from the conversion of the ammonia nitrogen is given in Table 4.70 as a function of air equivalence and percent conversion.

The estimated NO_x from both thermal nitric oxide and bound nitrogen conversion in the exhaust of a gas turbine burning 1144°K (1600°F) low-Btu fuel gas from the Westinghouse gasification process, assuming a 25% conversion of the ammonia nitrogen, is given in Table 4.71.

Table 4.70 - Concentration of NO_x in Gas Turbine Exhaust from Conversion of Bound Nitrogen in Fuel Gas

% Conversion	NO_x Concentration, ppm by volume		
	25	50	75
ϕ_{air}			
2.5	45	90	135
3.0	39	78	117
3.5	35	69	103
4.0	31	62	93

Table 4.71 - Concentration and Emission of NO in Gas Turbine Exhaust -25% Conversion of Ammonia Nitrogen - 1600°F Fuel Gas Temperature No Water Injection

ϕ_{air}		NO_x Concentration, ppm by volume		
	Thermal NO_x	Bound Nitrogen NO_x	Total	NO_x Emission ($lb/10^6$ Btu)
2.5	180	45	225	0.57
3.0	150	39	189	0.55
3.5	129	35	164	0.54
4.0	113	31	144	0.53

The estimated NO_x from both thermal nitric oxide and bound nitrogen conversion in the exhaust of a gas turbine burning 1144°K (1600°F) low-Btu fuel gas from the Westinghouse gasification process, assuming 5% water injection and 75% conversion of ammonia nitrogen, is given in Table 4.72. These tabulations indicate that the NO_x emission standards for clean gaseous fuels [86 g NO_2/GJ input (0.2 lb $NO_2/10^6$ Btu input)] cannot be met when the low-Btu fuel gas temperature is 1144°K (1600°F), even by the use of water injection, if the estimated ammonia content of the fuel gas is correct.

Table 4.72 - Concentration and Emissions of NO_x in Gas Turbine Exhaust 1600°F Fuel Gas Temperature - 75% Conversion of Ammonia Nitrogen -5% Water Injection

ϕ_{air}	NO_x Concentration, ppm by volume			
	Thermal NO_x	Bound Nitrogen NO_x	Total	NO_x Emission (lb/10^6 Btu)
2.5	4.5	135	180	0.46
3.0	38	117	155	0.45
3.5	32	103	135	0.45
4.0	28	93	121	0.45

Without water injection the thermal nitric oxide exceeds the limit, and water injection the nitric oxide from the conversion of the ammonia nitrogen exceeds the limit. The more appropriate emission limit for a plant with integrated low-Btu fuel gasification, in other words, the 301 g NO_2/GJ (0.7 lb $NO_2/10^6$ Btu) limit for solid fuel, can be met without water injection, even if the ammonia conversion is as high as 50%.

For low-temperature desulfurization, a water scrubber would almost certainly be used ahead of the low-temperature desulfurization process, and the ammonia in the raw fuel gas would be removed by this scrubber. There would, therefore, be no nitric oxide from bound nitrogen. If the fuel gas is burned in the gas turbine combustor without reheating, the thermal nitric oxide will be well below the general NO_x limits for gaseous fuels. It is estimated that these limits could be met with fuel gas reheat temperatures up to about 700°K (800°F).

A possible technique for meeting the general gaseous fuel NO_x limit with high-temperature desulfurization of the fuel gas is catalytic decomposition of the ammonia in the fuel gas prior to combustion, coupled with water injection during the combustion process to control the formation of thermal nitric oxide. The equilibrium concentrations of ammonia in a typical low-Btu fuel gas at a temperature of 1144°K (1600°F) and a pressure of 506.5 kPa (5 atm), is about 100 ppm by volume (Reference 4.78).

The environmental impact of NO_x (lb $NO_2/10^6$ Btu input) is computed from the volumetric concentration of NO_x in the combustion products by Equation 4.33.

$$NO_2\ (lb/10^6\ Btu) = [NO\ concentration\ (ppm\ vol)]\ (1.59) \left[\frac{(1 + \phi_{air})(W_a/W_f)_{st}}{HHV_f}\right]$$

where $(W_a/W_f)_{st}$ is the stoichiometric air-fuel ratio.

4.5.6 Fuel Uranium Emissions and Recovery

4.5.6.1 Background

Coals and lignites in the western U.S. are occasionally found to have abnormally high uranium (U) contents. Usually the uranium is concentrated in the uppermost zones of the coal. Presumably the coal was formed first, and uranium-bearing minerals were deposited above it; in subsequent weathering, water-soluble uranium compounds were leached, seeped downward, and reacted chemically with the uppermost layers of the coal to form stable compounds.

The higher-uranium coals and lignites have been exploited as ores. The coal or lignite is mined carefully to segregate the high-uranium layers. The latter material is burned on the ground, and the ashes are processed in conventional uranium-winning facilities. The economic value of this process has been marginal.

At present there are two main reasons for renewed interest in the uranium contents of western states coals and lignites. The first is hygienic. There are plans to burn more western states coal than previously, and this will result in increased emissions of uranium in fly ash, and so on, unless the ash is collected.

The second reason is that the ash from burning uraniferous coals may be an economical source of uranium in the future. If the ash must be collected anyway, it can be viewed as a cost-free source of uranium that is available in geographic locations and in chemical and physical forms that are more desirable than those of the original coal.

The amount of uranium in the North Dakota (Mercer County) lignite is given as 50 to 240 ppm by weight, as contrasted with 10 ppm uranium in Illinois No. 6 coal. The latter coal is typical of those now being burned in power plants.

The ash content of the lignite is 6.2% by weight and that of the Illinois No. 6 coal is 9.6%. If all of the uranium initially present in the coal were recoverable in the ash, therefore, the uranium content of the lignite ash would be from 806 to 3870 ppm, while that of the Illinois No. 6 coal ash would be 104 ppm. In practice, however, not all of the uranium in the coal is recovered in the ash. Relevant data assembled by Morris (Reference 4.79) are presented in Table 4.73. Coal from the northern part of the Red Desert area of Wyoming was reported to contain from 10 to 16% ash and from 20 to 60 ppm U_3O_8. The theoretical U_3O_8 content of the ash, assuming complete recovery, was from 150 to 510 ppm. The analyzed U_3O_8 content of the ash was from 43 to 67% of theoretical, varying from 100 to at most 230 ppm U_3O_8.

The causes of the apparent uranium losses are unknown. It is possible that the analyses were in error and that the apparent losses were not real. A possible reason is the difficulty of chemically extracting the uranium from the ash, particularly if the latter had been fused at high temperature. Similar difficulty would be expected in an industrial extraction operation.

Alternatively, the uranium loss might be due to the formation of gaseous or vaporous uranium compounds during combustion. Uranium forms such compounds with halogens, the best known being UF_6. If such compounds formed, a portion of the uranium would have been lost up the stack and not collected with the ash. Emissions of uranium in such a form are potentially troublesome in the industrial combustion of high-uranium coals.

Table 4.73 - Uranium Content of Coals from Northern Part of Red Desert, Wyoming, and Ashes Therefrom[a]

% U_3O_8	% Ash	% U_3O_8 in Ash	C.F.[b]	Theoretical % U_3O_8 in Ash	Loss	Fraction Loss
0.002	12.94	0.010	7.73	0.015	0.005	0.33
0.006	21.72	0.023	4.61	0.028	0.005	0.18
0.004	10.87	0.016	9.20	0.037	0.021	0.57
0.004	13.10	0.013	7.63	0.031	0.016	0.52
0.005	15.93	0.020	6.28	0.031	0.011	0.35
0.006	11.78	0.022	8.49	0.051	0.029	0.57

[a]Reference 4.50

[b]C.F. - concentration factor = 10^2/ash content (%).

On the basis of the above information, it is here assumed that 60% of the uranium initially present in the coal is recovered in the ash. The expected uranium content of the North Dakota lignite ash is, therefore, about 500 to 2300 ppm, and that of the Illinois No. 6 coal ash is about 62 ppm.

Two other potential sources of radioactivity in coal ash are thorium and potassium. The thorium (Th) contents of the coals for the present study are not given but are probably of the order of 10 ppm. The potassium (K) contents are 1.7% potassium oxide (K_2O) in the ash of Illinois No. 6 and 0.4% potassium oxide each in the ash of the Montana Rosebud coal and the North Dakota lignite. The radioactive isotope of concern is potassium 40 (K^{40}) which has an abundance of 0.0118% in natural potassium.

Atomic Proportions and Radioactivity

It is desirable that the concentrations of the natural radioactive elements present in coal be expressed in atomic as well as weight proportions. The most abundant element in coal, hydrogen, is also the

Table 4.74 Computation of Average Atomic Weights of Coal Ash and Coals

				Illinois No. 6			Montana Rosebud			North Dakota Lignite		
Ash Analyses	Formula Weight (g/mole)	No. atoms	Avg. at. wt	wt %	g.atom 100.6	at. %	wt.%	98.4 g	at %	wt. %	g.atom 98.6	at.%
SO_2	60.1	3	20.0	46.6	2.33	52.4	22.1	1.10	24.1	17.9	0.89	20.1
Al_2O_3	101.9	5	20.4	19.3	0.95	21.4	1[illegible].5	0.76	16.6	9.9	0.49	11.1
Fe_2O_3	159.7	5	31.9	20.8	0.65	14.6	6.4	0.20	4.4	10.2	0.32	7.2
TiO_2	79.9	3	26.6	0.8	0.03	0.7	1.2	0.05	1.1	0.3	0.01	.2
P_2O_5	142.0	7	20.3	0.24	0.01	0.2	0.11	0.01	0.2	0.4	0.02	.5
CaO	56.1	2	28.0	7.7	0.28	6.3	18.9	0.68	14.9	23.6	0.84	19.0
MgO	40.3	2	20.2	0.9	0.04	0.9	6.6	0.33	7.2	6.7	0.33	7.5
Na_2O	62.0	3	20.7	0.2	0.01	0.2	1.0	0.05	1.1	7.4	0.36	8.1
K_2O	94.2	3	31.4	1.7	0.05	1.1	0.4	0.01	0.2	0.4	0.01	.2
SO_3	80.1	4	20.0	2.4	0.12	2.7	26.2	1.31	28.6	21.8	1.09	24.6
TOTAL				100.6	4.47	100.5	98.4	4.50	98.4	98.6	4.36	98.5
Ash Avg at. wt					22.5			21.9			22.6	
Ultimate Analyses												
Ash			22.3	9.6	0.43	3.4	7.5	0.34	2.6	6.2	0.28	2.1
S			32.1	3.9	0.12	0.9	0.8	0.02	0.2	0.7	0.02	0.1
H			1.0	5.9	5.90	46.3	6.1	6.10	47.3	6.9	6.90	51.3
C			12.0	59.6	4.97	39.0	52.2	4.35	33.7	41.1	3.42	25.4
N			14.0	1.0	0.07	0.5	0.8	0.06	0.5	0.6	0.04	0.3
O			16.0	20.0	1.25	9.8	32.6	2.04	15.8	44.5	2.78	20.7
TOTAL				100.0	12.74	99.9	100.0	12.91	100.1	100.0	13.44	99.9
Coal Avg at.					7.85			7.75			7.44	

lightest natural element, with an atomic mass of 1; and the trace element of major interest, uranium, is the heaviest natural element, with an atomic mass of 238. Thus, uranium dihydride, UH_2, contains only 33.3 atomic % uranium but 99.2 wt % uranium. The use of atomic rather than weight proportions is appropriate also in dealing with the thorium and uranium content of coals and coal ash. As demonstrated below, the average atomic mass of the North Dakota lignite is 7.5, and the weight proportion of uranium in this coal must be divided by 32 to yield the atomic proportion. The results are 1.6 to 7.5 at. ppm uranium in the lignite.

The method of evaluating the average atomic weights (at. wt) of the coals is demonstrated in Table 4.74. The first step is to determine the average atomic weight of the ash. This is 22.5 in the case of Illinois No. 6 coal, 21.9 for Montana Rosebud coal, and 22.6 for the North Dakota lignite. For simplicity, the average of the three atomic weights, namely 22.3, is taken as the atomic weight of the ash from all coals. The corresponding divisor for converting uranium wt % in the ash to at. % is 10.7.

The average atomic weight of the ash is then combined with the atomic weights of the other coal constituents (sulfur, hydrogen, carbon, nitrogen, and oxygen) to yield the average atomic mass of the coal, as demonstrated in Table 4.74. The results are 7.85, 7.75, and 7.45 for the Illinois, Montana, and North Dakota coals, respectively.

The uranium content of the Illinois No. 6 coal is given as 10 ppm by weight or 0.33 at. ppm. The expected uranium content of the ash from this coal is 62 ppm by weight or 5.9 at. ppm.

In like manner, we compute the proportion of K^{40} in the Illinois coal as 0.032 at. ppm, and that in the resultant ash (assuming 100% recovery) as 0.95 at. ppm.

The thorium content of the coals is assumed to be 10 ppm. On this basis the Illinois coal would contain 0.34 atomic ppm thorium. The ash from this coal would contain 10 atomic ppm thorium on the assumption of 100% thorium recovery, or 6 at. ppm thorium on the assumption (used for uranium) of 60% recovery.

Radioactivity Units

The halflife, t_h, of any radioactive species is the length of time for the amount of that species to decrease to one-half its original value. The change of the concentration, c, of the species with time, t, is related to t_h and to the original concentration, c_o, by

$$c/c_o = e^{-t/t_h} \tag{4.34}$$

The radioactivity of the species may be expressed as the number of nuclear disintegrations per unit time. This is proportional to c/t_h. The molar radioactivity is the number of nuclear disintegrations per unit time of 1 g-at. wt of the substance, such as 238 g of U^{238} or 40 g of K^{40}. The commonly used unit of radioactivity is the curie (Ci), which is defined as the radioactivity of 1 g of radium, Ra^{226}. Thus, the molar radioactivity of radium is 226 Ci. The halflife, t_h, of Ra^{226} is 50.457/Gs (1600 years)

The halflife of K^{40} is 1.4 billion years. The molar radioactivity of K^{40} is, thus, 226 Ci (1600) 1.4 x 10^9 = 0.00026 Ci or 260 μCi.

Preferred units for expressing the radioactivities of coal ash are picocuries (pCi = 10^{-6} μCi) per gram of ash. One gram of ash from the Illinois No. 6 coal is 1/22.5 g at. The K^{40} content of this ash (assuming 100% recovery) is 0.95 at. ppm or 4.2 x 10^{-8} g at./g ash. The corresponding radioactivity is 11 pCi/g ash.

This result is confirmed quantitatively by the results of a Westinghouse Research study of the radioactivity of fly ash from a coal-fired power plant in Cheswick, Pa. The study was performed by Goldstein, Sun, and Gonzalez and reported in 1970 (Reference 4.80) The coal was mined in Pennsylvania; its chemical analysis was not supplied. The radioactivity of K^{40} in the fly ash was found to be 10.7 pCi/g, in excellent agreement with the above estimate for the ash from the Illinois No. 6 coal.

Natural uranium is 99.3% U^{238}, which has a halflife of 4.5 x 10^9 years. The molar radioactivity of U^{238} is 80 μCi. The concentration of U^{238} in the ash from Illinois No. 6 coal (assuming 60% recovery) is 5.9 at. ppm or 0.26 x 10^{-9} g at/g ash. The corresponding radioactivity is 21 pCi/g ash.

Natural thorium is essentially 100% Th^{232} which has a halflife of 14 billion years. The molar radioactivity of this isotope is 26 μCi. For the assumed thorium concentration in coal of 10 ppm by weight or 0.34 at. ppm, and also assuming 60% recovery of thorium in the ash, the concentration of Th^{232} in the ash is 6 at. ppm. The corresponding radioactivity is 6.9 pCi/g ash.

A more conventional way of calculating these results is to utilize the fact that the radioactivity of U^{238} is 0.33 μCi/g. In the case of the Illinois No. 6 coal, this leads to a U^{238} radioactivity of 3.3 pCi/g coal or 21 pCi/g ash, assuming 60% recovery of uranimum in the ash.

The radioactivity of Th^{232} is 0.11 μCi/g. The corresponding radioactivities for Illinois No. 6 coal are 1.1 pCi/g coal and 6.9 pCi/g ash, again assuming an initial thorium content of 10 ppm and 60% thorium recovery in the ash.

A general formula for such conversions is given in Equation 4.35.

$$\text{Radioactivity of ash, pCi/g} = \frac{(W_i)\ (\text{Recovery})\ (s)}{\text{Ash}} \qquad (4.35)$$

in which S is the specific radioactivity in μCi per gram, being 0.33 for U^{238}, 0.11 for Th^{232}, and 6.5 for K^{40}; W_i is the number of ppm (by weight) of a constituant in the coal; recovery is the percent recovered; and ash is the percent of ash in the coal.

4.5.6.2 Natural Radioactive Series

Both U^{238} and Th^{232} are the progenitors of natural radioactive series. Detailed information on these series is presented in Tables 4.75 and 4.76. Each disintegrating U^{238} atom decays in 14 successive stages, transmuting through 13 radioactive daughter species with halflives varying from 0.00016 to 7.569 Ts (240,000 yr). Similarly, each Th^{232} atom passes through 10 radioactive stages.

Table 4.75 - Daughter Products of U^{238} Radioactive Decay

Nucleus	$T_{1/2}$	Primary Decay Mode
$^{238}_{92}U$	4.5×10^9 y	α
$^{234}_{90}Th$	24 d	β
$^{234}_{91}Pa$	6.7 h	β
$^{234}_{92}U$	2.4×10^5 y	α
$^{230}_{90}Th$	8×10^4 y	α
$^{226}_{88}Ra$	1602 y	α
$^{222}_{86}Rn$	3.8 d	α
$^{218}_{84}Po$	3 min	α
$^{214}_{82}Pb$	26 min	β
$^{214}_{83}Bi$	19.7 m	β
$^{214}_{84}Po$	1.6×10^{-4}s	α
$^{210}_{82}Pb$	20 y	β
$^{210}_{83}Bi$	5 d	β
$^{210}_{84}Po$	138 d	α
$^{206}_{82}Pb$	Stable	-

Table 4.76 - Daughter Products of Th^{232} Radioactive Decay

Nucleus	$T_{1/2}$	Primary Decay Mode
$^{232}_{90}Th$	1.4×10^{10} y	α
$^{228}_{88}Ra$	6.7 y	β
$^{228}_{89}Ac$	6.13 h	β
$^{228}_{90}Th$	1.9 y	α
$^{224}_{88}Ra$	3.64 d	α
$^{220}_{86}Rn$	55.3 s	α
$^{216}_{84}Po$	0.145 s	α
$^{212}_{82}Pb$	10 h	β
$^{212}_{83}Bi$	60.6 m	α (34%), β (66%)
$^{212}_{84}Po$ (66%)	3×10^{-7} s	α
$^{208}_{81}Tl$ (34%)	3.1 m	β
$^{208}_{82}Pb$	Stable	-

Over the years (millenia, actually) a secular equilibrium or steady state is established. The amount of each daughter species becomes essentially constant in time: that is, the number of atomic nuclei of a given species that disintegrates in a given time interval exactly equals the number of identical nuclei created by decomposition of the parent species. At such a steady state the radioactivity of each radioactive daughter is just equal to that of every other daughter and of the parent.

In uranium or thorium minerals that have remained undisturbed for sufficient lengths of time to allow secular equilibrium to be established locally, all daughter species are usually present with the parent and all have the same radioactivity. The total radioactivity of such an undisturbed uranium mineral is 14 times that of the parent U^{238}. Similarly, the total radioactivity of all members of the TH^{232} series is 10 times that of the TH^{232} alone.

A convenient check of this conclusion is provided by U^{234}, which is a daughter product of U^{238} decay. The abundance of U^{234} in natural uranium is 0.0058% and the halflife is 240,000 yr. The contribution of this species to the molar radioactivity of uranium is 226 Ci (1600/240,000) (0.0058/99.3) = 88μCi, which, by no coincidence, is approximately equal to that of the U^{238} parent.

All other daughter species of the decomposition of U^{238} are elements other than uranium. The existence of U^{234} in secular equilibrium with the parent U^{238} doubles the latter's radioactivity, even in freshly chemically separated uranium. (An additional 5% increment of radioactivity originates from the presence of U^{235}, but this contribution is not considered further here.) In long-undisturbed ore bodies, coals, and even in some coal ash, it is reasonable to assume that all daughter species are present and to use 14 as the uranium radioactivity multiplier.

The possibility of natural separation of the daughter elements must also be considered, especially with respect to the formation of radon, an inert gas. The halflife of Rn^{222}, the seventh radioactive member of the U^{238} series, 328.3 ks (2.8 days). That of Rn^{220}, the sixth member of the Th^{232} series, is 55 s. Some or all of the radon may escape if the mineral is thin and/or porous and/or near the surface of the ground. The subsequent members of the radioactive series are then precipitated elsewhere.

Similarly, if leaching or some other chemical separation has occurred such that the daughter species are separated from the parent uranium or thorium, the radioactivity multiplier will be less than 14 or 10. In the case of the Illinois No. 6 coal, it is here arbitrarily assumed that no such separation has occurred and that all daughter species are present in the coal in secular equilibrium with their parents. Accordingly, each gram of ash resulting from combustion of this coal is estimated to contain 11 pCi from K^{40}, a total of 14 times 21 or 294 pCi from U^{238}, and 10 times 6.9 pCi or 69 pCi from the thorium.

4.5.6.3 Hygienic Aspects of Different Radioactive Emissions

The entries under "Primary Decay Mode" in Tables 4.75 and 4.76 indicate that certain isotopes decay by α emission and others by β emission. The decay mode of K^{40} is entirely β.

The α emissions are far more hazardous to life than the β emissions. For this reason we shall disregard the hygienic impact of the K^{40}, even though its contribution to the total radioactivity is higher than that of any other single species. We shall similarly disregard the effects of the β-emitting daughter isotopes of both U^{238} and Th^{232}.

Table 4.75 indicates that U^{238} and seven of its daughter products are α-emitting species. Accordingly, it is reasonable to apply a multiplier of 8 to the radioactivity of the U^{238} to indicate the total α-emitting potential of the uranium in the coal.

Four of the eight α emitters of the U^{238} series precede radon in the radioactivity sequence; the Rn^{222} and three (in effect) of its daughter products are α emitters. If all the radon in the ash escaped promptly into the atmosphere, therefore, the α-emitting potential of the ash would be four rather than eight times that of the parent U^{238}.

The escape of the radon into the atmosphere results in a corresponding amount of α radioactivity released to the environment, where it is potentially more hazardous than would be the case if it remained in the ash. To prevent this released it might be necessary to collect all the ash and to bury it promptly. The radon subsequently released locally will then be contained and will transmute back into solid species (daughter products) without contaminating the atmosphere. Such containment of the ash restores the naturally occurring radioactive elements to underground deposits resembling those of their natural occurrence.

Of the ten stages of radioactive decay originating with Th^{232}, six are α emitting. The radon member of this series, Rn^{220}, has a half-life of 55S and probably does not escape from the fly ash. Accordingly, the α-emitting potential of the Th^{232} series is assumed to be six times that of the parent thorium.

In summary, the α-emitting radioactive potential of thorium in the coal and coal ash is six times that of the parent Th^{232}, and that of the uranium is from four to eight times that of the parent U^{238}. Serious hygiene problems might originate from the escape to the atmosphere of the radon gas generated from the latter. No α radiation is emitted from K^{40}.

Experimental Evaluations of Coal Ash Radioactivity

The aforementioned 1970 Westinghouse study of radioactivity of fly ash (Reference 4.51) detected, in addition to the 10.7 pCi/g of K^{40} already discussed, 2.8 pCi/g of U^{238} and 1.2 pCi/g of Th^{232}. The experimental technique was to determine the γ-ray energy spectrum of the fly ash with a Ge(Li) detector. The presence and amounts of the uranium and thorium parent isotopes were inferred from the activities of the γ-emitting daughter isotopes, using an instrument calibrated with known amounts of uranium, thorium, and radium. The latter, Ra^{226}, is a daughter isotope of U^{238} decay.

In the case of the thorium radioactive series it was inferred that all daughter species are present in secular equilibrium with the

Th^{232} in the fly ash. Accordingly, a multiplier of 10 is justified, and the total radioactivity from the thorium source is 12 pCi ash.

In the case of the U^{238} series it was determined that only the first six member species were present in secular equilibrium at the full strength of 2.8 pCi/g ash; these would account for 16.8 pCi/g. The seventh member, Rn^{222}, and all subsequent species were present at the reduced radioactivity of 1.2 pCi/g. These would account for 9.6 pCi/g. Hence, the total radioactivity of the ash was 49.1 pCi/g.

A serious discrepancy between the calculated and experimental results is now evident in the fact that the radioactivity levels measured are far lower than those computed from the 10 ppm each of uranium and thorium in the Illinois No. 6 coal. In the case of uranium the amount found in the fly ash is only about 13% of that expected on the basis of 60% recovery, and in the case of thorium the proportion is 17%. These results could be reconciled if we assume that the actual recovery of uranium and thorium in the fly ash was only 8 to 10% rather than the 40 to 70% determined in other studies based solely on chemical analyses. If the actual recovery is so small, of course, we must be concerned with what has happened to the other 90% of the uranium, thorium, and their radioactive daughter products initially present in the coal.

Other measurements of the radioactivity of coal ash are reviewed in Reference 4.51. A common experimental method was to monitor Ra^{226}, a daughter of U^{238}. The radioactivity of this isotope in Appalachian coal ash was as high as 3.8 pCi/g. The highest such radioactivity reported was 8 pCi/g in the ash of an unidentified coal, as reported by Bayliss et al. (Reference 4.81). The latter is still well below the 21 pCi/g computed here for 60% uranium recovery from 10 ppm uranium in coal. Unfortunately, Reference 4.81 does not give analyzed uranium or thorium contents of any of the coals. Nevertheless, there are serious discrepancies that suggest either that most of the uranium in the coal is not being detected in the ash by the radiometric technique, or that the chemical analyses of the uranium contents of the coals are erroneously high.

Another such study was performed in East Germany by Marquardt et al and reported in 1970 (Reference 4.82). The radium content of coal ash was found to vary from 0.6 to 4.7 pCi/g. According to the abstract, "No inadmissibly high emission values by coal-fed power stations in East Germany were found.... The Ra concentration caused by the coal-fed power stations is ... at least 2 to 3 potencies below the admissible values for dwelling areas."

For hygienic control of radioactive emissions (ash and vapor) from coal-burning installations, it is a matter of some urgency that the available analysis results be reconciled. In particular, it is recommended that an effort be made immediately to establish an accurate radioactive materials balance for the coal combustion process. At present, up to 90% of the radioactive material in the coal is not satisfactorily accounted for. The problem might be particularly serious in the case of high-uranium coal combustion, as will be discussed.

Variability of Analyses

A study of the available literature on uranium in coal and coal ash yields the impression that the different techniques of analysis yield results differing from each other by as much as a factor of 10. It would be of interest to make statistically significant comparisons of the respective methods of using analysis, standard samples. No such comparison has been found in the literature reviewed for the present study.

Laboratory studies of uranium in coal and coal ash have focused on two main areas. One concentrates on the hygienic consequences of the radioactive ash emitted from coal combustion. Such studies include the Westinghouse Research Laboratories work and others cited earlier. The analysis methods used in these hygienic studies are, quite properly, radiometric techniques to determine the levels and types of radioactivity of the ashes as well as to identify the radioactive species. Most results for Ra^{226} and the other daughter products of U^{238} are in the range of 3 to 9 pCi/g ash for each daughter species. This radioactivity range is the equivalent of 9 to 27 ppm of uranium in the ash. If we approximate the ash content of the coal as 10%, the uranium content of the coal (assuming 100% recovery) is computed as 0.9 to 2.7 ppm.

Coal uranium contents of this order of magnitude are confirmed by the results of neutron activation analysis, which indicate uranium contents of the order of 1 ppm in eastern states low-uranium coals. The factor-of-10 concentration of uranium in the ash is also confirmed by the neutron activation technique.

The second kind of study concentrates primarily on the economical recovery of the uranium. Here the attention is not on the radioactivities of the respective isotopes but is solely on the uranium content of the coal. More conventional methods of chemical analysis are normally used for such assay purposes. The low-uranium eastern states coals are normally reported to contain at least 10 ppm uranium or up to ten times as much as that inferred from the radiometric-hygienic studies. Examples of such analyses are presented in Table 4.77, which was part of a recent (1973) report to EPA by Exxon Research (Reference 4.83). In three cases the lower limit of the uranium content of the coal is reported as <0.001%. In most other cases, however, the lower limit is given as 0.001% (10 ppm).

It is possible that the limiting sensitivity of the analysis method is of the order of 0.001% (10 ppm) uranium. Chemical analysis authorities in Westinghouse Research have stated, however, that the limiting sensitivity of such methods is about 1 ppm.

It is of considerable importance to know the uranium contents of coals. Those who study the hygienic aspects of coal combustion are currently basing their conclusions on the lower figures obtained radiometrically, while the uranium prospectors and miners are basing their decisions on the apparently higher figures derived from more conventional analyses. Each group is satisfied with its own numbers, but this will certainly change if either the hygienists find their figures are erroneously low or the prospectors find theirs are erroneously high by a factor of up to 10.

It is essential that all reported values, for all purposes, of the uranium contents of coals and coal ash be both self-consistent and accurate.

Table 4.77 - Uranium in Coal[a]

Source of Caol	Researchers	Reference	Percentage of Uranium in Coal
United States:			
California	Moore and Stephens	(49)	0.02 max.
Idaho			
Bonneville County	Vine	(70, 71)	0.02 avg.
"	Vine and Moore	(72)	0.13 max.
Cassia County	Gray	(29)	0.0 to 0.1
"	Mapel and Hail	(42)	0.097 max.
Illinois	Patterson	(55)	< 0.001 to 0.008
Indiana	Snider	(61)	0.001
Montana	Gill	(27)	0.001 to 0.034
"	Hail and Gill	(31)	0.013 max.
Nevada			
Esmeralds County	Moore and Stephens	(49)	0.003
Churchill County	Lovering	(41)	0.059
New Mexico			
Sandoval County	Bachman and others	(5, 4)	0.001 to 0.62
North Dakota	Moore, Melin, and Kepferle	(48)	0.045 max.
"	Bergstrom	(6)	0.14 max.
Ohio	Snider	(60)	0.001
Pennsylvania	Ferm	(25)	0.002 to 0.014
"	Patterson	(53)	0.019 max.
Pennsylvania, anthracite	Welch	(75)	0.001
South Dakota	King and Young	(39)	0.08 to 0.73
"	Denson, Bachman, and Zeller	(22)	0.005 to 0.02
"	Zeller and Schopf	(82)	0.01
"	Gill, Zeller, and Schopf	(28)	0.005 avg.
Utah	Zeller	(81)	0.002
Northern West Virginia	Patterson	(54)	< 0.001 to 0.003
Southern West Virginia and Eastern Kentucky	Welch	(76)	0.001
Southern West Virginia and Southwestern Virginia	Snider	(62)	< 0.001
Wyoming	Masursky	(44)	0.001 to 0.051
"	Breger and others	(11)	0.0022
"	Pipiringos	(57)	0.003 to 0.016
"	Masursky and Pipiringos	(45)	0.001 to 0.014
"	Love	(40)	0.10 max.
"	Wyant, Sharp, and Sheridan	(80)	0.002 to 0.007

[a]Reference 4.83.

Accordingly, it is proposed that standard samples of coal having various uranium contents be prepared and analyzed by different methods to obtain direct comparisons of these methods. Because of the inherent variability of the uranium content of each coal, it will probably be necessary to conduct numerous analyses by each method. The results should indicate whether, in spite of the variability, the different analysis methods actually do deliver consistent average values.

The various coals and their ashes should both be analyzed. Preferably, the ashes will be prepared by combustion under controlled conditions to prevent uranium losses. Useful figures for uranium recovery in ashes should be obtained from such a study.

The most difficult analysis problems will be presented by the lowest-uranium coals and by the ash therefrom, because the percentage errors of the results are then the largest. An important objective, therefore, will be to obtain consistent results from different analyses of low-uranium coals and coal ash. Another objective will be to determine valid recovery ratios of uranium in the ash derived from such low-uranium coals.

A typical low-uranium eastern states coal is Illinois No. 6, which is reported to contain 10 ppm uranium. There is reason to expect that this coal will be found to contain as low as 1 ppm uranium if analyzed either radiometrically or by neutron activation. Carefully prepared samples of Illinois No. 6 coal should by analyzed by the various available methods to determine its actual uranium content.

It is interesting that Pennsylvania bituminous coal is shown in Table 4.77 to contain from 20 to 190 ppm uranium. Again, such amounts of uranium in coal can be hygienically significant, and they might be economically significant as well.

Uranium Contents of High-Uranium Coals

The North Dakota lignite of the present study is reported to contain 50 to 240 ppm uranium. If this range is correct, a serious hygienic problem could result from the combustion of such lignite. Even at 50 ppm, the hygienic problem is probably more than five times as serious as is the case in burning Illinois No. 6 coal, for reasons that will next be explained.

As already suggested, the conventional analysis methods used in generating the above figures might have high percentage errors at the lowest uranium content of 1 to 10 ppm and decreasing percentage errors as the uranium content increases. As an example, let us assume arbitrarily that the error is 5 ppm uranium. Thus, an actual uranium content of 5 ppm would be reported as 10 ppm, which would be in error by 50%. Similarly, an actual uranium content of 45 ppm would be reported as 50 ppm, which would be in error by 10%. Finally, an actual lignite uranium content of 235 ppm would be reported as 240 ppm, which would be in error by only 2%. Analytical errors that behave in this way would have the effect of compressing the proportions of the reported uranium content in the different coals. Thus, the reported proportion of uranium of North Dakota lignite to that of Illinois No. 6 is at least 50 to 10, or 5; but more accurate analysis might reveal that the actual proportion is 45 to 5, or 9. This would mean that the hygienic problem of burning the lignite is at least 9 times, rather than 5 times, as serious as that of burning the Illinois No. 6 coal. The difference originates mainly in the high percentage error of the reported uranium content of the lower-uranium coal. The percentage error is lower in the case of the higher-uranium coal. This is one reason for placing more confidence in the reported uranium contents of the higher uranium coals.

Another reason is derived from the fact that the latter coals and their ashes have been exploited as uranium ores. The reported uranium contents of these coals are of the nature of assays for prospectors and miners, whose work requires the analyses to be accurate. Such accuracy is not required for much lower-uranium coals that are not used as uranium sources.

Comparative Hygienic Aspects of Burning Low- and High-Uranium Coals

In this section we compare, from a hygienic point of view, the consequences of burning high-uranium lignite with those of burning low-uranium bituminous coal. For the purposes of comparison we shall here assume that the specified uranium contents of these coals, 10 ppm in Illinois No. 6 and 50 to 240 ppm uranium in North Dakota lignite, are accurate.

As already shown, the estimated uranium content of the ash from combustion of the Illinois No. 6 coal is 104 ppm as based on the assumption of 100% recovery, or 62.5 ppm on the basis of 60% recovery of the uranium in the coal. The North Dakota lignite has a lower ash content of 6.2%. The computed figures for the uranium content of the ash based on 100% recovery are 806 to 3871 ppm uranium, and those based on 60% recovery are 484 to 2323 ppm uranium. Because of both the higher uranium content and the lower ash content of the lignite, therefore, the calculated uranium content of the lignite ash is higher than that of the Illinois No. 6 coal ash by a factor of 8 to 37.

The relative radioactivities of the lignite combustion products are increased further, in effect, by the relatively low heating value of this fuel. Thus, more tons of the lignite must be burned to produce a given amount of electrical energy, and this additional tonnage increases the amount of radioactive combustion products emitted to the environment. A comparison of the respective heating values suggests that about 60% more lignite than Illinois No. 6 coal, on a weight basis, must be burned to produce the same amount of heat. The lignite penalty increases further if its flame temperature is lower, or if the energy detraction for materials transport and handling is significantly increased. For example, the ash load from the lignite is actually about 3% larger than that from the Illinois No. 6 coal on a per-calorie basis. The <u>effective</u> uranium content is similarly increased by at least 60%, being from 8 to 38 times that for the Illinois No. 6 coal. Thus, the environmental impact, due to uranium, of burning lignite is from 8 to 38 times that of burning Illinois No. 6 to produce the same amount of heat.

A major part of the lignite penalty comes from its high moisture content of 36.7 wt %, as compared with 13.0% moisture in the Illinois No. 6 coal. Let us imagine that the moisture difference of 23.7% is removed from the lignite while all of its other chemical constituents remain. The lignite analysis is then revised to that shown in Table 4.78, which indicates that the amounts of the major constituents of the as-dried lignite are approximately the same as those in the Illinois No. 6 coal. Notable exceptions are much lower sulfur content of the lignite, the higher remaining oxygen content, and the considerably higher uranium content.

It has already been computed that the theoretical uranium content of the ash from the lignite, assuming identical recovery ratios; is 8 to 37 times that from the Illinois No. 6 coal. The corresponding radioactivity due to U^{238} alone is 168 to 777 pCi/g lignite ash. This must be multiplied by a factor of up to 14 to account for the presence of all daughter products in secular equilibrium. Thus, the total radioactivity of the ash due to uranium alone is estimated as at least 1500 pCi/g.

Past studies of radioactivity of fly ash have included coals from Utah and Wyoming, but no coal was specifically identified as having a high uranium content. The highest uranium content determined radiometrically in the ash from any coal was 8 pCi/g.

Table 4.78 - Effects on Lignite Composition of Drying to Same Moisture Content as Illinois No. 6 Coal

	North Dakota Lignite		Illinois No. 6 Coal
	Initial	As Dried	
Proximate:			
% Moisture	36.7	13.0	13.0
Volatile	26.6	36.5	36.7
Fixed C	30.5	41.9	40.7
Ash	6.2	8.5	9.6
Ultimate:			
% Ash	6.2	8.5	9.6
S	0.7	1.0	3.9
H	6.9	5.4	5.9
C	41.1	56.5	59.6
N	0.6	0.8	1.0
O	44.5	27.9	20.0
ppm U	50 to 240	69 to 330	10

The combustion of lignite generates about 3% more ash per calorie than does that of Illinois No. 6 coal. The uranium content of the lignite ash is then from 8 to 38 times that of the Illinois No. 6 coal ash. The radioactivity of the U^{238} in the ash has been estimated as 21 pCi/g for the Illinois No. 6 coal ash. In the case of lignite combustion approximately the same tonnage of ash per unit of electrical energy produced is being generated, but its uranium content is estimated to vary from 160 to 800 pCi/g. The latter is 100 times the highest previously reported radioactivity from such a source. Again, a multiplier of up to 14 must be applied to account for the radioactivity of all U^{238} daughter products in secular equilibrium.

The latter estimates are based on ash uranium recovery of 60%, and we have not yet speculated on what happens to the other 40% of the uranium initially present in the coal. It is very important from a hygienic point of view to know whether this uranium escaped from the combustion process in gaseous (or vaporous) form, in which event it would have entered the atmosphere directly and not been collectible by conventional precipitation and filtration techniques. The missing 40% might, therefore, be the source of a far more serious hygienic problem than is the 60% that is collectible as solid ash.

The 60% recovery figure was an average based on analyses of Wyoming coals containing from 20 to 50 ppm uranium and of their ashes (Table 4.73). Another serious question is that of how the uranium recovery rate might change as the uranium content of the coal increases from 50 to 240 ppm, as in the case of the North Dakota lignite. With such an increase of the uranium content of the coal, does the recovery rate increase or does it decrease?. Again, what is the physical and chemical form of the uranium not recovered in the ash? Does it escape as a gas or vapor; and if so, where does it go? These are important questions that must be properly answered long <u>before</u> the large-scale combustion of high-uranium western states coals is seriously contemplated.

Eastern coals, such as Illinois No. 6, having a high sulfur content are preferably combusted with stack-gas scrubbers to remove those sulfur-containing products that are emitted from the combustor as gases and vapors. Such stack-gas cleanup might be effective, also, in collecting uranium containing products of combustion. It is hoped that the use of stack-gas cleanup provisions would recover the now-missing 40% of the uranium in the combustion products.

Unfortunately, there is not a close technical compatibility between stack-gas cleanup provisions designed to remove sulfur and those which might be used for recovering uranium. The sulfurous gases (sulfur dioxide, sulfur trioxide, and hydrogen sulfide) are acidic and must be collected in alkaline media. The uraniferous products of coal combustion are alkaline and, hence, are not collectible in the same solutions that would be used for sulfur cleanup; rather, the uranium must be collected in acid solutions. This may be technically feasible; but it is not so attractive economically, because an additional stack-gas cleanup facility would be required for the uranium.

Another problem originates from the disparity between the relatively low uranium content of the higher-sulfur (eastern states) coals and the higher-uranium, lower sulfur (western states) coals. A plant designed for burning eastern coals will preferably have stack-gas cleanup provisions (for sulfur removal), but this is not necessarily true of a plant designed for burning the western coals. There is no assurance, therefore, that stack-gas cleanup provisions being planned for some power plants will be effective in preventing emissions of uranium into the atmosphere.

The magnitude of the hygienic problem resulting from combustion of high-uranium coals is a function of stack height, wind velocity, and other factors beyond the scope of this report. For this reason the present discussion of the seriousness of the problem has been limited to making comparisons between existing practice using conventional low-uranium fuel, as typified by Illinois No. 6 coal, and the same practice using high-uranium fuel, as typified by North Dakota lignite. As we have seen, the quantitative comparison of the uranium contents of these coals and of the ashes derived therefrom is still unsatisfactory and deserves immediate attention. Such a comparison is viewed as a prerequisite to arriving at a final judgement concerning the hygienic and environmental consequences of burning high-uranium fuels.

In all past studies of the hygienic aspects of burning coals containing (usually small amounts of) uranium, it has been concluded that the emissions are safe. The levels of radioactivity (particularly emissions) inhaled from ashes and dusts emitted from coal-fired plants have apparently been lower than the levels of similar radioactivity ingested in food, and so forth. It appears, however, that all such studies performed thus far have been confined to low-uranium fuels.

Lignite-burning power plants are currently in operation in North Dakota. It is proposed that future studies of the hygienic aspects of uraniferous coal combustion be concentrated on such power plants.

4.5.6.4 Economic Recovery of Uranium from Coal Combustion

The specified uranium content of the North Dakota lignite (50 to 240 ppm) is well below that normally considered to be of interest for economic extraction of uranium. As mentioned earlier, the usual procedure to recover uranium from lignite is to burn the latter on the ground and then to process the ashes in conventional uranium-winning equipment. Although it would not be economically feasible to extract the uranium from the North Dakota lignite in this manner, it is nevertheless worthwhile to reexamine the economics of uranium recovery from the products of combustion of this lignite, particularly if thorough techniques of collecting these combustion products are practiced for hygienic reasons.

It is assumed that the products of combustion in a conventional boiler or burner are in three forms: (1) bottom ash or clinker, (2) fly ash, and (3) gases and vapors. It is assumed also that the highest uranium content occurs in the ash or clinker. This material is also the most resistant to uranium recovery attempts. In conventional burners the clinker is a fused mass from which the extraction of the uranium is different and costly. Hence, the use of the clinker as a source of uranium is difficult to justify economically.

The economics of recovery of uranium from fly ash might be another matter. Usually the fly ash has not been fused and is available in finely divided form. Hence, the uranium in the as-collected fly ash should be more readily recoverable than that in the clinker. The amounts of uranium available in this form, however, may not be high enough to justify the extraction attempt economically. As already indicated, the largest amount of uranium found in fly ash is about 8 pCi/g or 24 ppm, which is less than 1 at. ppm. To justify the recovery attempt, about 2000 ppm uranium is needed.

A preliminary, small-scale attempt to recover uranium from collected fly ash has been reported recently by Schruben of the Westinghouse Nuclear Fuel Division (Reference 4.84). The ash was collected at Carnegie-Mellon University and reputedly contained 20 ppm uranium. The aqueous acid extractive procedures applied to 22.69 kg (50 lb) batches of the ash failed to produce any weighable amount of yellow cake (U_3O_8). There was apparently excessive interference in the extraction process by iron. Further process development efforts were deemed desirable. It now appears dubious, however, that such extraction processes can be justified economically.

Sulfurous gases in combustion exhaust gases are conventionally removed by caustic scrubbing, as already discussed. Presumably, an additional, acid-scrubbing step would be needed for removal of uranium. Both the hygienic need and the possible economic justification of this method of uranium recovery from the stack gas should be considered.

Shruben reported that lignite ashes are highly alkaline and would require the consumption of large amounts of acid to allow uranium extraction. The forms of the sulfur in the stack gas are sulfur dioxide and sulfur trioxide. The former is converted to the latter in conventional methods of sulfuric acid manufacture. If such a conversion could be carried out as part of a stack-gas scrubbing process, a sufficient amount of sulfuric acid might be produced for extracting uranium from the stack gas and ash. No known attempt, however, has yet been made to incorporate a sulfuric acid plant into a smokestack.

In any case, there may be an opportunity to use acid scrubbing for collection of uranium in the exhaust gas. This might be important hygienically, and it also might prove to yield economically significant quantities of uranium. At worst, it would consume excessive acid without a sufficient uranium yield.

It is probable that far more uranium ends up on the ash and clinker than in all other combustion products. At the high operating temperatures of conventional boilers, the ash and clinker fuse, with the consequence that the uranium is difficult to extract economically. The fluidized bed combustor, however, is an alternative design of coal-burning installation that operates at a relatively low temperature, where there is a much lower likelihood that the ash will fuse. If the high-uranium lignite or coal is burned in such a fluidized bed combustor, the ash is withdrawn unfused with the calcium sulfate that is generated as a product of sulfur removal. Actually, the latter might be unnecessary because lignite combustion is characterized by caustic ashes that would themselves remove sulfur and thereby decrease or eliminate the need for calcium oxide additions for such a purpose. Thus, desulfurization may not be a problem in lignite combustion.

If the fluidized bed combustor is to be used for lignite combustion, the ashes produced will be more nearly suitable for economical uranium extraction than would those obtained from a conventional boiler. Thus, the fluidized bed combustor may be the best hope at present for economically extracting uranium from coal or from its products of combustion.

If the use of the fluidized bed combustor cannot be economically justified on the basis of sulfur removal alone, its economic justification might have to come mainly from the uranium recovery possibilities. This should be studied further.

For the present, it would appear that the highest priority should be given to the matter of determining with improved accuracy the actual amounts of uranium in the various coals, lignites, and the products of combustion derived therefrom. Such improved analyses are necessary for making future decisions concerning both the hygienic aspects of uraniferous fuel combustion and the economical recovery of uranium therefrom.

4.6 Solid Waste Disposal

This study is concerned with three types of fossil fuel utilization in which solid waste disposal is a consideration.

1. Complete combustion in a conventional boiler with flue gas desulfurization
2. Complete combustion in a fluidized bed boiler or fired heater with in-bed desulfurization at
   - Atmospheric pressure
   - High pressure
3. Partial combustion in a pressurized fluidized bed gasifier with
   - High-temperature desulfurization
   - Low-temperature desulfurization.

The first case involves removal of the major part of the fly ash by an electrostatic precipitator or a scrubber, followed by a flue gas desulfurization process using either an organic or an inorganic sorbent.

The quantity of fly ash collected is a function of the type of furnace being used. Conventional pulverized-coal furnaces retain about 20% of the ash in the coal as bottom ash. The bottom ash will be either slag or unfused granular material, depending on whether the furnace is wet bottom or dry bottom.

The cyclone furnace retains about 85% of the ash as slag. The balance is carried over as fly ash.

In fluidized bed combustion, 100% of the ash in the coal is carried over as suspended particulates. Of the total carbon, 1 to 3% is lost in the ash. The physical properties of the ash from fluidized bed combustion are quite different from those of fly ash from pulverized fuel furnaces, since it is not fused. The ash particles are characterized as fragile platelets.

For this study the limestone slurry process is preferred. The quantities of waste solids generated by this process for each of the specified coals are as follows:

Coal	Waste Solids to Coal Ratio (as received coal)
Illinois No. 6	0.18
Montana	0.037
North Dakota	0.033

In the Westinghouse fluidized bed gasification process, all of the ash in the coal is agglomerated in the combustor. These ash particles are expected to be in the range of 3.175 to 6.35 mm (1/8 to 1/4 in) diameter. Chemically, these ash particles will be nearly the same as those from fluidized bed combustion, but the physical properties will be significantly different.

The most promising sorbents for in-bed desulfurization in fluidized bed combustion are dolomite and limestone.

Appendix A 4.6 summaries the various methods available and under consideration for the disposal and utilization of ash from coal combustion. The method selected for ash disposal in this study was on-site ponding. With either material only the calcium combines with the sulfur in the coal to form calcium sulfate ($CaSO_4$). Both once-through and regenerative processes are under investigation. In the regenerative process, blowdown may occur before or after regeneration. In the former case the chemical composition of the blowdown is the same as the waste from the once-through process, but the volume of waste is substantially reduced. In the latter case, the chemical composition of the solid waste is magnesium oxide-calcium carbonate. The spent sorbent may be used as road base, concrete aggregates, neutralizing agents for acid mine drainage, and so on. Appendix A 4.7 treats the environmental impact of the spent stone when it is dumped or used as a landfill.

In this study once-through desulfurization of fluidized bed combustion products was assumed. The quantities of solid wastes generated for each of the specified coals are as follows:

Coal	Spent Sorbent - lb/lb of as received coal
Illinois No. 6	0.53
Montana	0.11
North Dakota	0.10

Dolomite and limestone are also under investigation for high-temperature desulfurization of low-Btu fuel gas. Desulfurization with these sorbents may be either in-bed or external. The chemical reactions are the same whether in-bed or external techniques are used. For this study it was assumed that dolomite would be used as the sorbent in the Westinghouse fluidized bed gasification process. Both once-through and regenerative processes are under investigation, but once-through was assumed for this study.

The chemical composition of the spent sorbent from the gasifier desulfurization reactor is $Mg\,O \cdot \frac{CaCO_3}{CaS}$. The sulfided sorbent will be oxided to the sulfate form since a significant amount of heat can be recovered, and it is difficult to avoid release of hydrogen sulfide in the disposal of the sulfided sorbent. When a spent sorbent oxidization is used in conjunction with the gasifier, the waste solids are identical to those from fluidized bed combustion, and the quantities thereof are essentially the same.

Low-Btu fuel gas properties were generated for low-temperature desulfurization using the Benfield hot carbonate process. The solid waste from this process is considered to be negligible.

4.7 Environmental Intrusion

Environmental intrusion summaries for the base cases and the recommended cases for each of the nine power system concepts are given in Tables 4.79 through 4.97 as listed below:

Concept	Base Cases	Recommended Case
1. Open-Cycle Gas Turbine	4.79	4.79
2. Combined Cycle	4.80 and 4.81	
3. Closed-Cycle Gas Turbine	4.82, 4.83, and 4.84	
4. Liquid-Metal Topping	4.84 and 4.86	4.87
5. Open-Cycle MHD	4.88, 4.89, and 4.90	
6. Closed-Cycle MHD	4.91	4.91
7. Liquid-Metal MHD	4.92	4.92
8. Advanced Steam	4.93, 4.94, 4.95, and 4.96	4.97
9. Fuel Cells	--	--

Table 4.79 - Environmental Intrusion of Recuperated Open Gas Turbine Base Case, Point 1 and Recommended Case

	$lb/10^6$ Btu	lb/kWh	Btu/kWh
Emission from Stack			
SO_2	0.15	0.0014	
NO_x	2.10[(1)]	0.0190	
HC	0	0	
CO	0	0	
Particulates	0	0	
Solid Wastes			
Ash		0	
Spent sorbent		0	
Heat Rejection			
Heat to water			0
Heat to air			4966
Heat, total rejected			4966

(1) Value without water injection. It is estimated that the injection of 1.5 lb of water per lb of fuel would reduce the NO_x emissions to the specified value of 0.3 lb $NO_2/10^6$ Btu while increasing the power output by 9.1% and the heat rate by 4.7%.

Table 4.80 - Environmental Intrusion of Combined Gas Turbine-Steam Turbine Base Case, Point 1

	$lb/10^6$ Btu	lb/kWh	Btu/kWh
Emission from Stack			
SO_2	0.72[1]	0.0057	
NO_x	0.54[2]	0.0043	
HC	0	0	
CO	0	0	
Particulates	0.013	0.0001	
Solid Wastes			
Ash		0.071	
Spent sorbent		0.309[1]	
Heat Rejection			
Heat to water			2051
Heat to air			1076
Heat, total rejected			3127

[1] Based on 90% desulfurization efficiency corresponding to a Ca/S atom ratio of 2.4, a 97.5% desulfurization efficiency would be required to meet the SO_2 emission limit for gaseous fuels (0.2 lb $SO_2/10^6$ Btu). About 5% of the sulfur in the coal appears in the fuel gas as COS which is not removed by the dolomite sorbent. The maximum degree of desulfurization is, therefore, about 95% regardless of the Ca/S atom ratio and it is not possible to meet the SO_2 emission limit for gaseous fuels with high-temperature desulfurization using dolomite.

[2] Value without water injection. Water injection will reduce formation of thermal NO but increase conversion of bound nitrogen. It is estimated that 5% water injection would reduce total NO_x emission to 0.45 lb $NO_2/10^6$ Btu while increasing plant power 18% and plant heat rate 9%. Emission limit for gaseous fuels (0.2 lb $NO_2/10^6$ Btu) cannot be attained by water injection.

Table 4.81 - Environmental Intrusion of Combined Gas-Steam Turbine Base Case B, Point 2

	$lb/10^6$ Btu	lb/kWh	Btu/kWh
Emission from Stack			
SO_2	0.15	0.0011	
NO_x	1.10(1)	0.0082	
HC	0	0	
CO	0	0	
Particulates	0	0	
Solid Wastes			
Ash		0	
Spent sorbent		0	
Heat Rejection			
Heat to water			2370
Heat to air			1062
Heat, total rejected			3432

(1) Value without water injection. It is estimated that the injection of 1.1 lb of water per lb of fuel would reduce the NO_x emissions to the specified value of 0.3 lb $NO_2/10^6$ Btu while increasing the power output by 8.9% and the heat rate by 4.5%.

Table 4.82 - Environmental Intrusion of Closed Cycle Gas-Turbine Base Case A, Point R25

	$lb/10^6$ Btu	lb/kWh	Btu/kWh
Emission from Stack			
SO_2	0.72	0.0074	
NO_x	0.30	0.0031	
HC	0	0	
CO	0	0	
Particulates	0.013	0.00013	
Solid Wastes			
Ash		0.0916	
Spent sorbent		0.404	
Heat Rejection			
Heat to water			4101
Heat to air			2414
Heat, total rejected			6515

Table 4.83 - Environmental Intrusion of Closed Cycle Gas-Turbine Base Case B, Point R48

	$lb/10^6$ Btu	lb/kWh	Btu/kWh
Emission from Stack			
SO_2	0.15	0.0016	
NO_x	0.20	0.0021	
HC	0	0	
CO	0	0	
Particulates	0	0	
Solid Wastes			
Ash		0	
Spent sorbent		0	
Heat Rejection			
Heat to water			5583
Heat to air			549
Heat, total rejected			6132

Table 4.84 - Environmental Intrusion of Closed Cycle Gas-Turbine, Point C5

	$lb/10^6$ Btu	lb/kWh	Btu/kWh
Emission from Stack			
SO_2	0.15	0.0013	
NO_x	< 0.3	0.0025	
HC	0	0	
CO	0	0	
Particulates	0	0	
Solid Wastes			
Ash		0	
Spent sorbent		0	
Heat Rejection			
Heat to water			3042
Heat to air			1046
Heat, total rejected			4088

Table 4.85 - Environmental Intrusion of Liquid Metal Topping Base Case No. 1, Point 1

	$lb/10^6$ Btu	lb/kWh	Btu/kWh
Emission from Stack			
SO_2	0.715	0.0067	
NO_x	0.30	0.0028	
HC	0	0	
CO	0	0	
Particulates	0.100	0.00094	
Solid Wastes			
Ash		0.084	
Spent sorbent		0.370	
Heat Rejection			
Heat to water			2996
Heat to air			1882
Heat, total rejected			4878

Table 4.86 - Environmental Intrusion of Liquid Metal Topping Base Case No. 2, Point 4

	$lb/10^6$ Btu	lb/kWh	Btu/kWh
Emission from Stack			
SO_2	0.715	0.0071	
NO_x	0.20	0.0020	
HC	0	0	
CO	0	0	
Particulates	0.0125	0.00012	
Solid Wastes			
Ash		0.089	
Spent sorbent		0.391	
Heat Rejection			
Heat to water			2987
Heat to air			1937
Heat, total rejected			4924

Table 4.87 - Environmental Intrusion of Liquid Metal Topping Recommended Case, Point 46

	$lb/10^6$ Btu	lb/kWh	Btu/kWh
Emission from Stack			
SO_2	0.14	0.0013	
NO_x	0.30	0.0028	
HC	0	0	
CO	0	0	
Particulates	0.10	0.00093	
Solid Wastes			
Ash		0.0777	
Spent sorbent		0.0913	
Heat Rejection			
Heat to water			2797
Heat to air			1822
Heat, total rejected			4619

Table 4.88 - Environmental Intrusion of Open Cycle MHD Base Case 1, Point 1

	$lb/10^6$ Btu	lb/kWh	Btu/kWh
Emission from Stack			
SO_2	< 1.2	0.0086	
NO_x	∿ 0.3	0.0021	
HC	0	0	
CO	0	0	
Particulates	< 0.10	0.00071	
Solid Wastes			
Ash		0.064	
Spent sorbent		0	
Heat Rejection			
Heat to water			2809
Heat to air			534
Heat, total rejected			3343

Table 4.89 - Environmental Intrusion of Open Cycle MHD
Base Case 2, Point 1

	$lb/10^6$ Btu	lb/kWh	Btu/kWh
Emission from Stack			
SO_2	< 1.20	0.0088	
NO_x	∿ 0.3	0.0022	
HC	0	0	
CO	0	0	
Particulates	< 0.1	0.00073	
Solid Wastes			
Ash		0.065	
Spent sorbent		0	
Heat Rejection			
Heat to water			2761
Heat to air			520
Heat, total rejected			3281

Table 4.90 - Environmental Intrusion of Open Cycle MHD
Base Case 3, Point 1

	$lb/10^6$ Btu	lb/kWh	Btu/kWh
Emission from Stack			
SO_2	0.72	0.0050	
NO_x	0.3	0.0021	
HC	0	0	
CO	0	0	
Particulates	< 0.10	0.00070	
Solid Wastes			
Ash		0.062	
Spent sorbent		0.275	
Heat Rejection			
Heat to water			2530
Heat to air			530
Heat, total rejected			3060

Table 4.91 - Environmental Intrusion of Closed Cycle MHD
Base Case, Point 2

	$lb/10^6$ Btu	lb/kWh	Btu/kWh
Emission from Stack			
SO_2	0.18	0.0013	
NO_x	0.3	0.0022	
HC	0	0	
CO	0	0	
Particulates	0.013	0.0001	
Solid Wastes			
Ash		0.0616	
Spent sorbent		0.0662	
Heat Rejection			
Heat to water			2395
Heat to air			420
Heat, total rejected			2815

Table 4.92 - Environmental Intrusion of Liquid Metal MHD Base Case, Point 16

	$lb/10^6$ Btu	lb/kWh	Btu/kWh
Emission from Stack			
SO_2	0.72	0.0072	
NO_x	0.70	0.0070	
HC	0	0	
CO	0	0	
Particulates	0.10	0.0010	
Solid Wastes			
Ash		0.089	
Spent sorbent		0.139	
Heat Rejection			
Heat to water			4688
Heat to air			1850
Heat, total rejected			6538

Table 4.93 - Environmental Intrusion of Advanced Steam Systems, Point 20 (Atmospheric Boiler)

	$lb/10^6$ Btu	lb/kWh	Btu/kWh
Emission from Stack			
SO_2	0.72	0.0070	
NO_x	0.7	0.0068	
HC	0	0	
CO	0	0	
Particulates	0.10	0.00097	
Solid Wastes			
Ash		0.0864	
Spent sorbent		0.135	
Heat Rejection			
Heat to water			4924
Heat to air			1502
Heat, total rejected			6426

Table 4.94 - Environmental Intrusion of Advanced Steam Systems Base Case, Point 36 (Atmospheric Fluidized Bed Boiler)

	$lb/10^6$ Btu	lb/kWh	Btu/kWh
Emission from Stack			
SO_2	0.72	0.0070	
NO_x	0.6	0.0058	
HC	0	0	
CO	0.3	0.0029	
Particulates	0.10	0.00097	
Solid Wastes			
Ash		0.086	
Spent sorbent		0.380	
Heat Rejection			
Heat to water			4906
Heat to air			1589
Heat, total rejected			6495

Table 4.95 - Environmental Intrusion of Advanced Steam Systems Base Case, Point 16 (Pressurized Boiler)

	$lb/10^6$ Btu	lb/kWh	Btu/kWh
Emission from Stack			
SO_2	0.72	0.0066	
NO_x	0.2	0.0018	
HC	0	0	
CO	0	0	
Particulates	0.013	0.00012	
Solid Wastes			
Ash		0.0811	
Spent sorbent		0.357	
Heat Rejection			
Heat to water			1200
Heat to air			4515
Heat, total rejected			5715

Table 4.96 - Environmental Intrusion of Advanced Steam Systems Base Case, Point 7 (Pressurized Fluidized Bed Boiler)

	$lb/10^6$ Btu	lb/kWh	Btu/kWh
Emission from Stack			
SO_2	0.72	0.0065	
NO_x	0.30	0.0027	
HC	0	0	
CO	0	0	
Particulates	0.10	0.00091	
Solid Wastes			
Ash		0.0806	
Spent sorbent		0.355	
Heat Rejection			
Heat to water			1234
Heat to air			4441
Heat, total rejected			5675

Table 4.97 - Environmental Intrusion of Advanced Steam Systems, Point 31 (Pressurized Fluidized Bed Boiler Recommended Case)

	$lb/10^6$ Btu	lb/kWh	Btu/kWh
Emission from Stack			
SO_2	0.72	0.0063	
NO_x	0.30	0.0026	
HC	0	0	
CO	0	0	
Particulates	0.10	0.00088	
Solid Wastes			
Ash		0.0784	
Spent sorbent		0.345	
Heat Rejection			
Heat to water			1187
Heat to air			4299
Heat, total rejected			5486

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Appendix A 4.1

Properties of Combustion Products

Tables A 4.1.1 through A 4.1.6 are lists of the properties of combustion products for the six fuels listed below over a temperature range of 255 to 1642°K (0 to 2495°F) and for air equivalence ratios of 1.0, 2.0, 3.0, and 4.0. These properties were calculated for combustion air drawn from the ISO ambient.

The fuels included here are as follows:

- Low-Btu fuel gas/Westinghouse gasification/Illinois No. 6 bituminous T_{air} = 750°F
- Low-Btu fuel gas/Westinghouse gasification/Montana subbituminous T_{air} = 750°F
- Low-Btu fuel gas/Westinghouse gasification/North Dakota lignite T_{air} = 750°F
- Direct-fired Illinois No. 6 bituminous 3% moisture
- Direct-fired Montana subbituminous 20% moisture
- Direct-fired North Dakota lignite 27% moisture.

A separate appendix* will include tables containing the properties of combustion products for a wider selection of fuels at the non-ISO (hot day) conditions which were originally specified for the present study. The tables included here are for fuels which were selected for special attention in the combustion subsystem performance calculations and were thus rerun at ISO conditions.

The first page of Tables A 4.1.1 through A 4.1.3 is the fuel gas analysis. Included as the second page of Tables A 4.1.1 through

*Delivered to NASA but not included in this report for purposes of brevity.

A 4.1.3 and the first page to Table A 4.1.4 are the coefficients of a series of polynomials generated using curve-fit programs for mathematical correlations of properties of the products of combustion. These polynomials were utilized with the programs described in Appendix A 4.8. The generalized form of the polynomial is:

$$f(x) = A0 + (A1)(x) + (A2)(x)^2 + (A3)(x)^3 + (A4)(x)^4 + (A5)(x)^5.$$

The properties listed are enthalpy, H, above a reference of 0 at 222°K (400°R) and given in Btu/lb and relative pressure, P. These are given in terms of the absolute temperature, T, in °R which is varied in 5°R steps from 460 to 2955°R. Also listed at the top of each page are the gas constant, R, in ft lb/lbm-°R; the products molecular weight, MOL. WGT; percent oxygen, PCT. O2; percent carbon dioxide, PCT. CO2; percent water, PCT. H2O; percent sulfur dioxide, PCT. SO2; percent nitrogen, PCT. N2; percent argon, PCT. A; fuel to dry air ratio, F/DA; and moisture to dry air ratio, M/DA. The percentages referred to are by weight, that is weight percent.

Table A 4.1.1 - Properties of the Products of Combustion of Low-Btu Fuel Gas from a Westinghouse Fluidized Bed Gasifier with High Temperature Desulfurization and Particulate Removal Generated from Illinois No. 6 Bituminous Coal

- LOW-BTU FUEL GAS PROPERTIES

GASIFICATION PROCESS: Westinghouse Fluidized Bed/High-Temp. Desulfurization

COAL: Illinois No. 6 bituminous

Lockhopper Inlet Conditions

Temperature: 150

Moisture Content: 3%

SORBENT: Dolomite

Sorbent/Coal Ratio: 0.59 (0.53)

PROCESS AIR

Air/Coal Ratio: 2.77 (2.49)

Temperature - °F: 750

Pressure - psia: 250

PROCESS STEAM

Steam/Coal Ratio: 0.535 (0.480)

Temperature - °F: 400

Pressure - psia: 250

PRODUCT FUEL GAS

Temperature - °F: 1600

Pressure - psia: 225

Composition-Mole Fraction

N_2	.4346
O_2	0
H_2	.1594
CO	.2152
CO_2	.0837
H_2O	.0757
H_2S	0
CH_4	.0315
C_2H_4	0

Product Fuel Gas/Coal Ratio: 4.15 (3.72)

Gasifier Aux. Pwr. (kW/lb/s): 14.4

Spent Sorbent Oxidizer Exhaust Products

T_{in} - °F: 1500

T_{out} - °F: 300

q-Btu/lb coal: 444 (399)

Molecular Wt: 24.08

Heating Value

LHV -	141.37	Btu/scf	2228.89	Btu/lb
HHV -	152.53	Btu/scf	2404.88	Btu/lb

LHV/HHV: .9268

Enthalpy (400°R Base) - 550.75 Btu/lb

Stoichiometric Fuel/Air Ratio: 0.699

(Values in parenthesis are for as received coal)

Table A 4.1.1 Polynomial Cofficients

H-LHTU GAS-TAIR=750-ILL G--150

	RANGE OF VALIDITY	A0	A1	A2	A3	A4	A5
STOICHIOMETRIC AIR							
H=F(T)	460.0<T<2940.0	-9.86014+01	2.49319-01	-6.38292-07	1.60519-08	-5.06572-12	5.23113-16
P=F(T)	460.0<T<2940.0	-1.65326+01	6.28181-02	-1.60850-04	1.66380-07	-6.61972-11	2.70412-14
H=F(P)	6.0<P< 90.0	3.03120+01	6.62977+00	-1.19297-01	1.31082-03	-7.17570-06	1.51296-08
H=F(P)	91.0<P< 600.0	1.41969+02	1.26712+00	-2.79560-03	3.78790-06	-2.68323-06	7.46682-13
H=F(P)	601.0<P<3300.0	2.62269+02	4.02659-01	-2.09224-04	7.19478-08	-1.30842-11	9.54694-16
P=F(H)	14.0<H< 700.0	1.00184+00	3.77043-02	4.60994-04	3.01141-06	4.15959-09	4.27709-12
T=F(H)	14.0<H< 700.0	3.99834+02	4.01756+00	-1.20810-03	2.01608-08	1.01165-09	-6.21191-13
100 PERCENT EXCESS AIR							
H=F(T)	460.0<T<2940.0	-9.84368+01	2.47647-01	-1.15573-05	2.07672-08	-6.32422-12	6.61029-16
P=F(T)	460.0<T<2940.0	-7.34610+00	3.49410-02	-6.55360-05	7.40624-08	-2.06716-11	1.42585-14
H=F(P)	6.0<P< 90.0	2.67475+01	7.31762+00	-1.48383-01	1.86530-03	-1.17612-05	2.86740-08
H=F(P)	91.0<P< 600.0	1.31095+02	1.52027+00	-4.02362-03	6.88540-06	-6.09742-09	2.13147-12
H=F(P)	601.0<P<3300.0	2.43673+02	5.15079-01	-3.48458-04	1.58003-07	-3.81659-11	3.71627-15
P=F(H)	14.0<H< 700.0	9.74797-01	3.67834-02	4.78625-04	2.69587-06	3.95863-09	2.60627-12
T=F(H)	14.0<H< 700.0	3.99833+02	4.07960+00	-9.02114-04	-8.14527-07	2.12620-09	-1.18040-12
200 PERCENT EXCESS AIR							
H=F(T)	460.0<T<2940.0	-9.84111+01	2.49371-01	-1.68369-05	2.30920-08	-6.94320-12	7.27987-16
P=F(T)	460.0<T<2940.0	-5.31096+00	2.40656-02	-4.30543-05	5.16306-08	-9.30569-12	1.04602-14
H=F(P)	6.0<P< 90.0	2.51375+01	7.65049+00	-1.63737-01	2.18792-03	-1.47105-05	3.83132-08
H=F(P)	91.0<P< 600.0	1.26390+02	1.65091+00	-4.78350-03	9.02680-06	-8.84707-09	3.43059-12
H=F(P)	601.0<P<3300.0	2.35215+02	5.76271-01	-4.38899-04	2.25470-07	-6.18079-11	6.86748-15
P=F(H)	14.0<H< 700.0	1.01552+00	3.56968-02	4.89471-04	2.56114-06	3.80622-09	2.01470-12
T=F(H)	14.0<H< 700.0	3.99575+02	4.10719+00	-7.32839-04	-1.29269-06	2.78734-09	-1.52301-12
300 PERCENT EXCESS AIR							
H=F(T)	460.0<T<2940.0	-9.83773+01	2.50364-01	-1.98726-05	2.49289-08	-7.29920-12	7.66511-16
P=F(T)	460.0<T<2940.0	-4.53324+00	1.97903-02	-3.40915-05	4.25179-08	-4.63552-12	8.74275-15
H=F(P)	6.0<P< 90.0	2.42200+01	7.84664+00	-1.73175-01	2.39612-03	-1.67126-05	4.52034-08
H=F(P)	91.0<P< 600.0	1.23733+02	1.73039+00	-5.27960-03	1.05354-05	-1.09417-08	4.50194-12
H=F(P)	601.0<P<3300.0	2.30381+02	6.14935-01	-5.00747-04	2.76275-07	-8.16252-11	9.75582-15
P=F(H)	14.0<H< 700.0	1.02491+00	3.52009-02	4.93981-04	2.49263-06	3.69789-09	1.72000-12
T=F(H)	14.0<H< 700.0	3.99549+02	4.12282+00	-6.28152-04	-1.59235-06	3.20900-09	-1.79558-12

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
52.983	29.167	-.00039	.24753	.09518	0.00000	.64975	.00792	.69900	.00640

T	460.0	465.0	470.0	475.0	480.0	485.0	490.0	495.0
H	15.015	16.272	17.531	18.791	20.052	21.313	22.576	23.841
P	1.671	1.739	1.809	1.882	1.956	2.033	2.111	2.192
T	500.0	505.0	510.0	515.0	520.0	525.0	530.0	535.0
H	25.105	26.370	27.637	28.905	30.174	31.443	32.714	33.985
P	2.276	2.362	2.450	2.540	2.633	2.729	2.827	2.928
T	540.0	545.0	550.0	555.0	560.0	565.0	570.0	575.0
H	35.258	36.531	37.805	39.081	40.358	41.635	42.913	44.193
P	3.032	3.138	3.247	3.359	3.474	3.592	3.713	3.837
T	580.0	585.0	590.0	595.0	600.0	605.0	610.0	615.0
H	45.473	46.754	48.035	49.319	50.603	51.888	53.174	54.461
P	3.964	4.094	4.227	4.364	4.503	4.647	4.793	4.944
T	620.0	625.0	630.0	635.0	640.0	645.0	650.0	655.0
H	55.748	57.037	58.327	59.617	60.909	62.202	63.495	64.793
P	5.097	5.255	5.415	5.580	5.749	5.921	6.097	6.278
T	660.0	665.0	670.0	675.0	680.0	685.0	690.0	695.0
H	66.085	67.382	68.679	69.978	71.277	72.577	73.879	75.180
P	6.462	6.650	6.843	7.040	7.241	7.446	7.656	7.870
T	700.0	705.0	710.0	715.0	720.0	725.0	730.0	735.0
H	76.484	77.789	79.094	80.400	81.708	83.016	84.325	85.635
P	8.089	8.313	8.541	8.774	9.012	9.255	9.503	9.755
T	740.0	745.0	750.0	755.0	760.0	765.0	770.0	775.0
H	86.947	88.259	89.573	90.887	92.202	93.519	94.836	96.155
P	10.014	10.277	10.545	10.820	11.099	11.384	11.675	11.971
T	780.0	785.0	790.0	795.0	800.0	805.0	810.0	815.0
H	97.474	98.795	100.117	101.439	102.763	104.088	105.413	106.741
P	12.273	12.581	12.895	13.215	13.541	13.873	14.212	14.557

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
52.983	29.167	-.00039	.24753	.03516	0.00000	.64975	.00792	.09900	.00640

T	820.0	825.0	830.0	835.0	840.0	845.0	850.0	855.0
H	108.068	109.397	110.727	112.058	113.390	114.723	116.058	117.393
P	14.908	15.266	15.631	16.002	16.380	16.765	17.157	17.555
T	860.0	865.0	870.0	875.0	880.0	885.0	890.0	895.0
H	118.729	120.067	121.405	122.745	124.066	125.427	126.770	128.114
P	17.963	18.377	18.798	19.226	19.663	20.107	20.558	21.018
T	900.0	905.0	910.0	915.0	920.0	925.0	930.0	935.0
H	129.459	130.805	132.153	133.501	134.850	136.201	137.553	138.905
P	21.486	21.961	22.445	22.938	23.438	23.946	24.460	24.992
T	940.0	945.0	950.0	955.0	960.0	965.0	970.0	975.0
H	140.259	141.614	142.970	144.327	145.685	147.045	148.405	149.767
P	25.528	26.073	26.625	27.189	27.762	28.343	28.935	29.535
T	980.0	985.0	990.0	995.0	1000.0	1005.0	1010.0	1015.0
H	151.129	152.493	153.858	155.224	156.591	157.959	159.329	160.593
P	30.146	30.767	31.398	32.039	32.690	33.352	34.024	34.707
T	1020.0	1025.0	1030.0	1035.0	1040.0	1045.0	1050.0	1055.0
H	162.071	163.444	164.817	166.192	167.568	168.946	170.324	171.703
P	35.401	36.106	36.822	37.549	38.288	39.038	39.799	40.573
T	1060.0	1065.0	1070.0	1075.0	1080.0	1085.0	1090.0	1095.0
H	173.084	174.466	175.849	177.233	178.618	180.004	181.391	182.780
P	41.358	42.155	42.965	43.787	44.621	45.468	46.328	47.203
T	1100.0	1105.0	1110.0	1115.0	1120.0	1125.0	1130.0	1135.0
H	184.169	185.560	186.952	188.345	189.739	191.134	192.531	193.928
P	48.086	48.985	49.898	50.823	51.763	52.716	53.684	54.665
T	1140.0	1145.0	1150.0	1155.0	1160.0	1165.0	1170.0	1175.0
H	195.327	196.726	198.127	199.529	200.932	202.337	203.742	205.149
P	55.661	56.672	57.597	58.737	59.792	60.852	61.947	63.043

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
52.983	29.167	-.00039	.24753	.09510	0.00000	.64975	.00792	.09900	.00640

T	1180.0	1185.0	1190.0	1195.0	1200.0	1205.0	1210.0	1215.0
H	206.556	207.965	209.375	210.786	212.198	213.611	215.026	216.441
P	64.164	65.297	66.445	67.610	68.791	69.989	71.202	72.433
T	1220.0	1225.0	1230.0	1235.0	1240.0	1245.0	1250.0	1255.0
H	217.858	219.275	220.694	222.114	223.535	224.959	226.381	227.805
P	73.682	74.947	76.230	77.531	78.849	80.185	81.540	82.913
T	1260.0	1265.0	1270.0	1275.0	1280.0	1285.0	1290.0	1295.0
H	229.231	230.658	232.085	233.514	234.944	236.375	237.808	239.241
P	84.305	85.715	87.145	88.594	90.063	91.550	93.058	94.585
T	1300.0	1305.0	1310.0	1315.0	1320.0	1325.0	1330.0	1335.0
H	240.676	242.111	243.549	244.986	246.424	247.864	249.305	250.748
P	95.134	97.703	99.292	100.902	102.533	104.185	105.860	107.555
T	1340.0	1345.0	1350.0	1355.0	1360.0	1365.0	1370.0	1375.0
H	252.191	253.635	255.081	256.527	257.975	259.424	260.873	262.324
P	109.273	111.013	112.775	114.561	116.369	118.200	120.055	121.933
T	1380.0	1385.0	1390.0	1395.0	1400.0	1405.0	1410.0	1415.0
H	263.776	265.229	266.684	268.139	269.595	271.053	272.511	273.971
P	123.835	125.761	127.711	129.686	131.686	133.710	135.761	137.836
T	1420.0	1425.0	1430.0	1435.0	1440.0	1445.0	1450.0	1455.0
H	275.431	276.893	278.355	279.820	281.284	282.750	284.217	285.685
P	139.938	142.065	144.219	146.399	148.606	150.841	153.102	155.392
T	1460.0	1465.0	1470.0	1475.0	1480.0	1485.0	1490.0	1495.0
H	287.155	288.625	290.095	291.569	293.042	294.516	295.992	297.468
P	157.709	160.054	162.429	164.830	167.261	169.722	172.212	174.732
T	1500.0	1505.0	1510.0	1515.0	1520.0	1525.0	1530.0	1535.0
H	298.946	300.424	301.904	303.385	304.866	306.349	307.833	309.318
P	177.282	179.852	182.473	185.115	187.789	190.494	193.230	195.999

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/OA	M/OA
52.983	29.167	-.00039	.24753	.09518	0.00000	.64975	.00792	.09946	.00640

T	1540.0	1545.0	1550.0	1555.0	1560.0	1565.0	1570.0	1575.0
H	310.804	312.290	313.778	315.267	316.757	318.248	319.740	321.233
P	198.800	201.634	204.501	207.401	210.335	213.303	216.305	219.342
T	1580.0	1585.0	1590.0	1595.0	1600.0	1605.0	1610.0	1615.0
H	322.727	324.222	325.718	327.215	328.713	330.212	331.712	333.213
P	222.413	225.520	228.662	231.840	235.055	238.305	241.593	244.918
T	1620.0	1625.0	1630.0	1635.0	1640.0	1645.0	1650.0	1655.0
H	334.715	336.218	337.722	339.227	340.732	342.239	343.747	345.255
P	248.281	251.681	255.119	258.595	262.112	265.667	269.261	272.895
T	1660.0	1665.0	1670.0	1675.0	1680.0	1685.0	1690.0	1695.0
H	346.766	348.277	349.789	351.301	352.815	354.329	355.845	357.362
P	276.570	280.286	284.042	287.839	291.679	295.559	299.464	303.450
T	1700.0	1705.0	1710.0	1715.0	1720.0	1725.0	1730.0	1735.0
H	358.879	360.398	361.917	363.437	364.959	366.481	368.004	369.528
P	307.460	311.513	315.610	319.752	323.938	328.169	332.445	336.767
T	1740.0	1745.0	1750.0	1755.0	1760.0	1765.0	1770.0	1775.0
H	371.053	372.579	374.105	375.634	377.163	378.692	380.223	381.754
P	341.136	345.551	350.013	354.523	359.080	363.686	368.340	373.043
T	1780.0	1785.0	1790.0	1795.0	1800.0	1805.0	1810.0	1815.0
H	383.287	384.820	386.354	387.890	389.426	390.963	392.500	394.039
P	377.795	382.598	387.450	392.353	397.308	402.314	407.371	412.482
T	1820.0	1825.0	1830.0	1835.0	1840.0	1845.0	1850.0	1855.0
H	395.579	397.119	398.661	400.203	401.746	403.290	404.835	406.381
P	417.644	422.861	428.130	433.454	438.833	444.265	449.755	455.300
T	1860.0	1865.0	1870.0	1875.0	1880.0	1885.0	1890.0	1895.0
H	407.928	409.475	411.024	412.573	414.123	415.674	417.226	418.779
P	460.961	466.559	472.274	478.047	483.878	489.757	495.716	501.724

R	HOL.HGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	M/DA
52.983	29.167	-.00039	.24753	.09518	0.00000	.64975	.00792	.69900	.00640

T	1900.0	1905.0	1910.0	1915.0	1920.0	1925.0	1930.0	1935.0
H	420.332	421.887	423.442	424.998	426.555	428.113	429.671	431.231
P	507.792	513.921	520.111	526.362	532.676	539.051	545.490	551.992
T	1940.0	1945.0	1950.0	1955.0	1960.0	1965.0	1970.0	1975.0
H	432.791	434.352	435.914	437.477	439.040	440.605	442.170	443.735
P	558.558	565.189	571.884	578.645	585.472	592.365	599.326	606.353
T	1980.0	1985.0	1990.0	1995.0	2000.0	2005.0	2010.0	2015.0
H	445.303	446.870	448.439	450.008	451.578	453.149	454.720	456.293
P	613.449	620.614	627.847	635.150	642.523	649.967	657.462	665.063
T	2020.0	2025.0	2030.0	2035.0	2040.0	2045.0	2050.0	2055.0
H	457.866	459.440	461.015	462.590	464.167	465.744	467.322	468.900
P	672.727	680.459	688.264	696.143	704.097	712.125	720.230	728.410
T	2060.0	2065.0	2070.0	2075.0	2080.0	2085.0	2090.0	2095.0
H	470.480	472.060	473.641	475.223	476.805	478.388	479.972	481.557
P	735.667	745.002	753.414	761.905	770.474	779.124	787.853	796.554
T	2100.0	2105.0	2110.0	2115.0	2120.0	2125.0	2130.0	2135.0
H	483.142	484.729	486.315	487.903	489.492	491.081	492.671	494.262
P	805.556	814.529	823.585	832.725	841.949	851.256	860.649	870.128
T	2140.0	2145.0	2150.0	2155.0	2160.0	2165.0	2170.0	2175.0
H	495.853	497.445	499.038	500.631	502.226	503.821	505.416	507.013
P	879.692	889.344	899.083	908.910	918.826	928.831	938.927	949.113
T	2180.0	2185.0	2190.0	2195.0	2200.0	2205.0	2210.0	2215.0
H	508.610	510.208	511.806	513.405	515.005	516.605	518.207	519.809
P	959.390	969.750	980.222	990.777	1001.426	1012.170	1023.009	1033.944
T	2220.0	2225.0	2230.0	2235.0	2240.0	2245.0	2250.0	2255.0
H	521.412	523.016	524.620	526.224	527.830	529.435	531.043	532.650
P	1044.976	1056.105	1067.332	1078.657	1090.062	1101.607	1113.233	1124.360

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/OA	H/DA
52.983	29.167	-.00039	.24753	.03518	0.00000	.64975	.00792	.69966	.00640

T	2260.0	2265.0	2270.0	2275.0	2280.0	2285.0	2290.0	2295.0
H	534.259	535.867	537.477	539.087	540.698	542.309	543.922	545.534
P	1135.790	1148.722	1160.758	1172.698	1185.143	1197.493	1209.951	1222.515
T	2300.0	2305.0	2310.0	2315.0	2320.0	2325.0	2330.0	2335.0
H	547.148	548.762	550.377	551.992	553.608	555.225	556.843	558.461
P	1235.187	1247.968	1260.859	1273.858	1286.969	1300.192	1313.527	1326.975
T	2340.0	2345.0	2350.0	2355.0	2360.0	2365.0	2370.0	2375.0
H	560.079	561.699	563.319	564.939	566.560	568.162	569.805	571.428
P	1340.537	1354.214	1368.005	1381.914	1395.940	1410.082	1424.344	1438.725
T	2380.0	2385.0	2390.0	2395.0	2400.0	2405.0	2410.0	2415.0
H	573.052	574.676	576.301	577.926	579.553	581.179	582.807	584.435
P	1453.226	1467.848	1482.531	1497.457	1512.446	1527.560	1542.798	1558.153
T	2420.0	2425.0	2430.0	2435.0	2440.0	2445.0	2450.0	2455.0
H	586.064	587.693	589.323	590.953	592.584	594.216	595.848	597.481
P	1573.653	1589.272	1605.019	1620.894	1636.899	1653.036	1669.304	1685.704
T	2460.0	2465.0	2470.0	2475.0	2480.0	2485.0	2490.0	2495.0
H	599.115	600.749	602.384	604.019	605.655	607.291	608.928	610.565
P	1702.238	1718.906	1735.709	1752.648	1769.724	1786.937	1804.290	1821.781
T	2500.0	2505.0	2510.0	2515.0	2520.0	2525.0	2530.0	2535.0
H	612.204	613.843	615.482	617.122	618.763	620.404	622.046	623.688
P	1839.413	1857.186	1875.102	1893.160	1911.363	1929.710	1948.204	1966.844
T	2540.0	2545.0	2550.0	2555.0	2560.0	2565.0	2570.0	2575.0
H	625.331	626.974	628.618	630.263	631.908	633.554	635.200	636.847
P	1985.631	2004.568	2023.654	2042.890	2062.278	2081.818	2101.511	2121.359
T	2580.0	2585.0	2590.0	2595.0	2600.0	2605.0	2610.0	2615.0
H	638.494	640.142	641.791	643.440	645.089	646.740	648.390	650.042
P	2141.362	2161.522	2181.838	2202.313	2222.947	2243.742	2264.697	2285.815

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/OA	H/OA
52.983	29.167	-.00039	.24753	.09518	0.00000	.64975	.00792	.69944	.00640

T	2620.0	2625.0	2630.0	2635.0	2640.0	2645.0	2650.0	2655.0
H	651.694	653.346	654.999	656.652	658.307	659.961	661.616	663.272
P	2307.695	2328.540	2350.151	2371.927	2393.871	2415.983	2438.264	2460.715
T	2660.0	2665.0	2670.0	2675.0	2680.0	2685.0	2690.0	2695.0
H	664.926	666.585	668.242	669.900	671.559	673.218	674.877	676.537
P	2483.339	2506.134	2529.164	2552.247	2575.567	2599.053	2622.736	2646.389
T	2700.0	2705.0	2710.0	2715.0	2720.0	2725.0	2730.0	2735.0
H	678.198	679.859	681.521	683.183	684.846	686.509	688.173	689.837
P	2670.622	2694.836	2719.232	2743.811	2768.574	2793.523	2818.659	2843.982
T	2740.0	2745.0	2750.0	2755.0	2760.0	2765.0	2770.0	2775.0
H	691.502	693.168	694.834	696.500	698.167	699.835	701.503	703.172
P	2869.495	2895.197	2921.090	2947.175	2973.455	2999.923	3026.599	3053.465
T	2780.0	2785.0	2790.0	2795.0	2800.0	2805.0	2810.0	2815.0
H	704.841	706.511	708.181	709.852	711.523	713.195	714.867	716.540
P	3080.530	3107.794	3135.259	3162.925	3190.794	3218.857	3247.146	3275.631
T	2820.0	2825.0	2830.0	2835.0	2840.0	2845.0	2850.0	2855.0
H	718.213	719.887	721.562	723.237	724.912	726.588	728.265	729.942
P	3304.324	3333.226	3362.339	3391.662	3421.198	3450.948	3480.914	3511.095
T	2860.0	2865.0	2870.0	2875.0	2880.0	2885.0	2890.0	2895.0
H	731.620	733.298	734.977	736.656	738.336	740.016	741.697	743.378
P	3541.496	3572.115	3602.955	3634.016	3665.300	3696.809	3728.543	3760.504
T	2900.0	2905.0	2910.0	2915.0	2920.0	2925.0	2930.0	2935.0
H	745.060	746.742	748.425	750.109	751.793	753.477	755.162	756.848
P	3792.693	3825.112	3857.752	3890.644	3923.759	3957.110	3990.697	4024.522
T	2940.0	2945.0	2950.0	2955.0	0.0	0.0	0.0	0.0
H	758.534	760.220	761.908	763.595	0.000	0.000	0.000	0.000
P	4058.587	4092.891	4127.439	4162.228	0.000	0.000	0.000	0.000

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/OA	M/DA
53.193	29.051	.08525	.15557	.05221	0.00000	.6969[illegible]	.00997	.3495[illegible]	.0064[illegible]

T	460.0	465.0	470.0	475.0	480.0	485.0	490.0	495.0
H	14.801	16.038	17.275	18.515	19.754	20.995	22.235	23.477
P	1.656	1.722	1.790	1.860	1.932	2.005	2.082	2.160
T	500.0	505.0	510.0	515.0	520.0	525.0	530.0	535.0
H	24.719	25.962	27.205	28.449	29.694	30.939	32.185	33.432
P	2.240	2.323	2.408	2.495	2.584	2.675	2.770	2.865
T	540.0	545.0	550.0	555.0	560.0	565.0	570.0	575.0
H	34.679	35.927	37.175	38.425	39.676	40.925	42.178	43.430
P	2.965	3.066	3.170	3.277	3.386	3.498	3.613	3.730
T	580.0	585.0	590.0	595.0	600.0	605.0	610.0	615.0
H	44.683	45.936	47.191	48.446	49.701	50.957	52.214	53.472
P	3.851	3.974	4.100	4.229	4.361	4.495	4.634	4.775
T	620.0	625.0	630.0	635.0	640.0	645.0	650.0	655.0
H	54.731	55.990	57.250	58.510	59.772	61.034	62.297	63.560
P	4.920	5.068	5.219	5.373	5.531	5.692	5.857	6.025
T	660.0	665.0	670.0	675.0	680.0	685.0	690.0	695.0
H	64.825	66.090	67.355	68.622	69.889	71.157	72.426	73.695
P	6.197	6.372	6.551	6.734	6.921	7.112	7.306	7.505
T	700.0	705.0	710.0	715.0	720.0	725.0	730.0	735.0
H	74.966	76.238	77.510	78.782	80.056	81.330	82.606	83.882
P	7.708	7.914	8.125	8.340	8.560	8.783	9.011	9.244
T	740.0	745.0	750.0	755.0	760.0	765.0	770.0	775.0
H	85.159	86.436	87.715	88.994	90.274	91.555	92.837	94.119
P	9.481	9.723	9.969	10.220	10.476	10.736	11.002	11.272
T	780.0	785.0	790.0	795.0	800.0	805.0	810.0	815.0
H	95.403	96.687	97.972	99.258	100.545	101.833	103.122	104.411
P	11.548	11.828	12.114	12.405	12.701	13.003	13.310	13.622

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/OA	H/DA
53.193	29.051	.08525	.15567	.06221	0.00000	.6869[illegible]	.00[illegible]97	.34950	.00640

T	820.0	825.0	830.0	835.0	840.0	845.0	850.0	855.0
H	105.761	106.993	108.265	109.578	110.872	112.165	113.462	114.759
P	13.941	14.254	14.594	14.929	15.270	15.617	15.971	16.330
T	860.0	865.0	870.0	875.0	880.0	885.0	890.0	895.0
H	116.056	117.354	118.654	119.954	121.255	122.557	123.860	125.164
P	16.695	17.067	17.445	17.829	18.220	18.618	19.022	19.432
T	900.0	905.0	910.0	915.0	920.0	925.0	930.0	935.0
H	126.468	127.774	129.081	130.388	131.697	133.006	134.316	135.628
P	19.850	20.275	20.705	21.144	21.590	22.043	22.503	22.971
T	940.0	945.0	950.0	955.0	960.0	965.0	970.0	975.0
H	136.940	138.253	139.567	140.882	142.198	143.515	144.833	146.152
P	23.446	23.929	24.419	24.917	25.423	25.937	26.459	26.989
T	980.0	985.0	990.0	995.0	1000.0	1005.0	1010.0	1015.0
H	147.472	148.792	150.114	151.437	152.761	154.085	155.411	156.737
P	27.527	28.074	28.629	29.192	29.764	30.345	30.935	31.533
T	1020.0	1025.0	1030.0	1035.0	1040.0	1045.0	1050.0	1055.0
H	158.065	159.393	160.723	162.053	163.385	164.717	166.051	167.385
P	32.141	32.758	33.383	34.019	34.663	35.317	35.981	36.654
T	1060.0	1065.0	1070.0	1075.0	1080.0	1085.0	1090.0	1095.0
H	168.721	170.057	171.394	172.733	174.072	175.412	176.754	178.095
P	37.338	38.031	38.734	39.448	40.171	40.905	41.650	42.405
T	1100.0	1105.0	1110.0	1115.0	1120.0	1125.0	1130.0	1135.0
H	179.439	180.784	182.129	183.475	184.822	186.171	187.520	188.870
P	43.171	43.948	44.735	45.535	46.345	47.165	47.999	48.843
T	1140.0	1145.0	1150.0	1155.0	1160.0	1165.0	1170.0	1175.0
H	190.222	191.574	192.927	194.281	195.637	196.993	198.350	199.709
P	49.699	50.567	51.447	52.339	53.243	54.159	55.088	56.029

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	W/DA
53.193	29.051	.08525	.15567	.06221	0.00000	.6869	.00997	.34956	.00646

T	1180.0	1185.0	1190.0	1195.0	1200.0	1205.0	1210.0	1215.0
H	201.068	202.428	203.789	205.151	206.515	207.879	209.244	210.613
P	56.983	57.950	58.933	59.922	60.928	61.948	62.981	64.027
T	1220.0	1225.0	1230.0	1235.0	1240.0	1245.0	1250.0	1255.0
H	211.978	213.346	214.715	216.085	217.456	218.829	220.202	221.575
P	65.088	66.162	67.253	68.353	69.470	70.601	71.747	72.907
T	1260.0	1265.0	1270.0	1275.0	1280.0	1285.0	1290.0	1295.0
H	222.951	224.328	225.705	227.083	228.462	229.843	231.224	232.605
P	74.083	75.273	76.479	77.700	78.937	80.189	81.458	82.742
T	1300.0	1305.0	1310.0	1315.0	1320.0	1325.0	1330.0	1335.0
H	233.989	235.373	236.759	238.145	239.532	240.920	242.309	243.699
P	84.042	85.358	86.691	88.041	89.407	90.790	92.191	93.608
T	1340.0	1345.0	1350.0	1355.0	1360.0	1365.0	1370.0	1375.0
H	245.091	246.483	247.876	249.270	250.665	252.061	253.458	254.856
P	95.043	96.495	97.965	99.454	100.960	102.484	104.027	105.588
T	1380.0	1385.0	1390.0	1395.0	1400.0	1405.0	1410.0	1415.0
H	256.255	257.655	259.055	260.458	261.861	263.265	264.669	266.075
P	107.168	108.768	110.385	112.023	113.680	115.357	117.053	118.769
T	1420.0	1425.0	1430.0	1435.0	1440.0	1445.0	1450.0	1455.0
H	257.482	268.890	270.299	271.708	273.119	274.530	275.943	277.357
P	120.506	122.263	124.040	125.838	127.658	129.498	131.359	133.242
T	1460.0	1465.0	1470.0	1475.0	1480.0	1485.0	1490.0	1495.0
H	278.771	280.186	281.603	283.020	284.438	285.858	287.278	268.699
P	135.147	137.074	139.023	140.994	142.987	145.003	147.042	149.104
T	1500.0	1505.0	1510.0	1515.0	1520.0	1525.0	1530.0	1535.0
H	290.121	291.544	292.968	294.393	295.819	297.246	298.673	300.102
P	151.190	153.299	155.431	157.588	159.768	161.973	164.203	166.457

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
53.193	29.051	.08525	.15567	.06221	0.00000	.68693	.00997	.349[illegible]6	.00640

T	1540.0	1545.0	1550.0	1555.0	1560.0	1565.0	1570.0	1575.0
H	301.532	302.962	304.394	305.826	307.259	308.693	310.128	311.564
P	168.736	171.041	173.373	175.726	178.107	180.514	182.947	185.407
T	1580.0	1585.0	1590.0	1595.0	1600.0	1605.0	1610.0	1615.0
H	313.001	314.439	315.878	317.318	318.758	320.200	321.642	323.085
P	187.894	190.408	192.943	195.516	198.112	200.735	203.388	206.058
T	1620.0	1625.0	1630.0	1635.0	1640.0	1645.0	1650.0	1655.0
H	324.530	325.975	327.421	328.868	330.315	331.764	333.213	334.664
P	208.776	211.514	214.280	217.075	219.901	222.756	225.641	228.557
T	1660.0	1665.0	1670.0	1675.0	1680.0	1685.0	1690.0	1695.0
H	336.115	337.567	339.020	340.474	341.929	343.385	344.841	346.299
P	231.502	234.479	237.485	240.525	243.595	246.697	249.631	252.998
T	1700.0	1705.0	1710.0	1715.0	1720.0	1725.0	1730.0	1735.0
H	347.757	349.216	350.675	352.137	353.598	355.061	356.524	357.988
P	256.197	259.428	262.693	265.991	269.322	272.668	276.087	279.521
T	1740.0	1745.0	1750.0	1755.0	1760.0	1765.0	1770.0	1775.0
H	359.453	360.919	362.385	363.854	365.322	366.791	368.261	369.732
P	282.990	286.493	290.032	293.606	297.215	300.861	304.544	308.262
T	1780.0	1785.0	1790.0	1795.0	1800.0	1805.0	1810.0	1815.0
H	371.204	372.676	374.150	375.624	377.099	378.574	380.051	381.529
P	312.018	315.811	319.641	323.509	327.415	331.359	335.342	339.364
T	1820.0	1825.0	1830.0	1835.0	1840.0	1845.0	1850.0	1855.0
H	383.007	384.485	385.965	387.446	388.927	390.409	391.892	393.375
P	343.424	347.525	351.665	355.845	360.066	364.327	368.630	372.973
T	1860.0	1865.0	1870.0	1875.0	1880.0	1885.0	1890.0	1895.0
H	394.860	396.346	397.832	399.319	400.806	402.295	403.784	405.274
P	377.358	381.786	386.255	390.767	395.322	399.920	404.561	409.246

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	M/DA
53.193	29.051	.08525	.15567	.06221	0.00000	.68691	.00997	.34956	.00640

T	1900.0	1905.0	1910.0	1915.0	1920.0	1925.0	1930.0	1935.0
H	405.764	408.256	409.748	411.241	412.734	414.229	415.724	417.223
P	413.975	418.749	423.569	428.431	433.341	438.295	443.296	448.344
T	1940.0	1945.0	1950.0	1955.0	1960.0	1965.0	1970.0	1975.0
H	418.717	420.214	421.712	423.211	424.710	426.211	427.712	429.214
P	453.438	458.579	463.768	469.004	474.288	479.621	485.003	490.434
T	1980.0	1985.0	1990.0	1995.0	2000.0	2005.0	2010.0	2015.0
H	430.716	432.219	433.723	435.228	436.733	438.239	439.746	441.253
P	495.914	501.444	507.025	512.656	518.338	524.071	529.855	535.692
T	2020.0	2025.0	2030.0	2035.0	2040.0	2045.0	2050.0	2055.0
H	442.761	444.270	445.780	447.290	448.801	450.312	451.825	453.338
P	541.581	547.523	553.517	559.566	565.668	571.824	578.035	584.300
T	2060.0	2065.0	2070.0	2075.0	2080.0	2085.0	2090.0	2095.0
H	454.851	456.366	457.881	459.396	460.913	462.430	463.947	465.465
P	590.621	596.998	603.430	609.919	616.465	623.068	629.729	636.448
T	2100.0	2105.0	2110.0	2115.0	2120.0	2125.0	2130.0	2135.0
H	466.985	468.504	470.024	471.545	473.067	474.589	476.112	477.636
P	643.225	650.060	656.955	663.910	670.924	677.999	685.134	692.331
T	2140.0	2145.0	2150.0	2155.0	2160.0	2165.0	2170.0	2175.0
H	479.160	480.685	482.210	483.736	485.263	486.790	488.318	489.847
P	699.589	706.909	714.292	721.737	729.246	736.818	744.454	752.155
T	2180.0	2185.0	2190.0	2195.0	2200.0	2205.0	2210.0	2215.0
H	491.376	492.906	494.435	495.967	497.499	499.031	500.564	502.099
P	759.921	767.751	775.648	783.611	791.640	799.735	807.900	816.132
T	2220.0	2225.0	2230.0	2235.0	2240.0	2245.0	2250.0	2255.0
H	503.632	505.166	506.702	508.238	509.774	511.311	512.849	514.387
P	824.431	832.800	841.239	849.746	858.323	866.971	875.690	884.481

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	M/DA
53.193	29.051	.08525	.15567	.06221	0.00000	.68693	.00997	.34956	.00646

T	2260.0	2265.0	2270.0	2275.0	2280.0	2285.0	2290.0	2295.0
H	515.926	517.466	519.005	520.546	522.087	523.629	525.172	526.715
P	893.343	902.278	911.285	920.366	929.521	938.750	948.053	957.432
T	2300.0	2305.0	2310.0	2315.0	2320.0	2325.0	2330.0	2335.0
H	528.258	529.802	531.347	532.892	534.438	535.984	537.531	539.078
P	966.886	976.416	986.023	995.706	1005.467	1015.307	1025.224	1035.221
T	2340.0	2345.0	2350.0	2355.0	2360.0	2365.0	2370.0	2375.0
H	540.627	542.175	543.724	545.274	546.824	548.375	549.925	551.478
P	1045.297	1055.453	1065.689	1076.005	1086.405	1096.885	1107.448	1118.094
T	2380.0	2385.0	2390.0	2395.0	2400.0	2405.0	2410.0	2415.0
H	553.031	554.584	556.137	557.691	559.246	560.801	562.357	563.913
P	1128.824	1139.637	1150.535	1161.517	1172.585	1183.739	1194.980	1206.308
T	2420.0	2425.0	2430.0	2435.0	2440.0	2445.0	2450.0	2455.0
H	565.470	567.027	568.585	570.143	571.702	573.261	574.821	576.382
P	1217.723	1229.226	1240.819	1252.499	1264.270	1276.131	1288.082	1300.125
T	2460.0	2465.0	2470.0	2475.0	2480.0	2485.0	2490.0	2495.0
H	577.943	579.504	581.066	582.629	584.192	585.755	587.320	588.884
P	1312.260	1324.487	1336.808	1349.221	1361.729	1374.332	1387.029	1399.823
T	2500.0	2505.0	2510.0	2515.0	2520.0	2525.0	2530.0	2535.0
H	590.450	592.015	593.581	595.148	596.715	598.283	599.851	601.420
P	1412.712	1425.699	1438.783	1451.965	1465.245	1478.625	1492.105	1505.685
T	2540.0	2545.0	2550.0	2555.0	2560.0	2565.0	2570.0	2575.0
H	602.989	604.559	606.129	607.700	609.272	610.843	612.416	613.989
P	1519.3 6	1533.148	1547.033	1561.020	1575.111	1589.305	1603.604	1618.008
T	2580.0	2585.0	2590.0	2595.0	2600.0	2605.0	2610.0	2615.0
H	615.562	617.136	618.710	620.285	621.860	623.436	625.013	626.591
P	1632.519	1647.135	1661.859	1676.690	1691.629	1706.677	1721.835	1737.103

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
53.193	29.651	.08525	.15567	.06221	0.00000	.68693	.00997	.34956	[illegible]

T	2520.0	2625.0	2630.0	2635.0	2640.0	2645.0	2650.0	2655.0
H	628.167	629.745	631.323	632.902	634.482	636.061	637.642	639.223
P	1752.481	1767.971	1783.573	1799.288	1815.116	1831.058	1847.115	1863.287
T	2660.0	2665.0	2670.0	2675.0	2680.0	2685.0	2690.0	2695.0
H	640.804	642.386	643.969	645.552	647.135	648.719	650.303	651.888
P	1879.576	1895.980	1912.503	1929.143	1945.902	1962.780	1979.778	1996.897
T	2700.0	2705.0	2710.0	2715.0	2720.0	2725.0	2730.0	2735.0
H	653.474	655.060	656.645	658.233	659.821	661.409	662.998	664.587
P	2014.138	2031.500	2048.985	2065.595	2084.328	2102.186	2120.170	2138.280
T	2740.0	2745.0	2750.0	2755.0	2760.0	2765.0	2770.0	2775.0
H	666.176	667.766	669.357	670.948	672.540	674.132	675.725	677.318
P	2156.517	2174.882	2193.375	2211.999	2230.752	2249.636	2268.651	2287.799
T	2780.0	2785.0	2790.0	2795.0	2800.0	2805.0	2810.0	2815.0
H	678.911	680.506	682.100	683.696	685.292	686.888	688.485	690.082
P	2307.080	2326.494	2346.043	2365.727	2385.548	2405.505	2425.600	2445.833
T	2820.0	2825.0	2830.0	2835.0	2840.0	2845.0	2850.0	2855.0
H	691.680	693.279	694.879	696.477	698.077	699.678	701.279	702.881
P	2466.206	2486.719	2507.372	2528.167	2549.105	2570.166	2591.410	2612.780
T	2860.0	2865.0	2870.0	2875.0	2880.0	2885.0	2890.0	2895.0
H	704.483	706.086	707.689	709.293	710.897	712.502	714.108	715.714
P	2634.296	2655.958	2677.767	2699.725	2721.831	2744.088	2766.495	2789.054
T	2900.0	2905.0	2910.0	2915.0	2920.0	2925.0	2930.0	2935.0
H	717.321	718.928	720.536	722.144	723.753	725.363	726.973	728.583
P	2811.766	2834.631	2857.650	2880.824	2904.155	2927.642	2951.287	2975.091
T	2940.0	2945.0	2950.0	2955.0	0.0	0.0	0.0	0.0
H	730.195	731.806	733.419	735.032	0.000	0.000	0.000	0.000
P	2999.055	3023.179	3047.455	3071.913	0.000	0.000	0.000	0.000

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/OA	M/OA
53.290	28.998	.12454	.11353	.04710	0.00000	.70393	.01090	.23360	.00640
T	460.0	465.0	470.0	475.0	480.0	485.0	490.0	495.0	
H	14.702	15.931	17.159	18.388	19.618	20.848	22.079	23.310	
P	1.649	1.714	1.781	1.850	1.921	1.994	2.068	2.145	
T	500.0	505.0	510.0	515.0	520.0	525.0	530.0	535.0	
H	24.542	25.774	27.007	28.240	29.474	30.708	31.943	33.178	
P	2.224	2.305	2.388	2.474	2.562	2.651	2.744	2.833	
T	540.0	545.0	550.0	555.0	560.0	565.0	570.0	575.0	
H	34.414	35.650	36.887	38.125	39.363	40.601	41.841	43.080	
P	2.935	3.034	3.135	3.240	3.347	3.456	3.568	3.583	
T	580.0	585.0	590.0	595.0	600.0	605.0	610.0	615.0	
H	44.321	45.561	46.803	48.045	49.288	50.531	51.774	53.013	
P	3.800	3.920	4.043	4.169	4.297	4.429	4.563	4.701	
T	620.0	625.0	630.0	635.0	640.0	645.0	650.0	655.0	
H	54.264	55.510	56.755	58.003	59.250	60.498	61.747	62.995	
P	4.841	4.984	5.131	5.281	5.434	5.590	5.750	5.913	
T	660.0	665.0	670.0	675.0	680.0	685.0	690.0	695.0	
H	54.246	65.497	66.749	68.000	69.253	70.506	71.760	73.015	
P	6.079	6.249	6.423	6.600	6.780	6.964	7.152	7.344	
T	700.0	705.0	710.0	715.0	720.0	725.0	730.0	735.0	
H	74.270	75.526	76.783	78.040	79.299	80.557	81.817	83.077	
P	7.540	7.739	7.942	8.150	8.361	8.575	8.796	9.023	
T	740.0	745.0	750.0	755.0	760.0	765.0	770.0	775.0	
H	84.338	85.600	86.862	88.126	89.390	90.654	91.920	93.185	
P	9.248	9.480	9.715	9.958	10.203	10.453	10.708	10.967	
T	780.0	785.0	790.0	795.0	800.0	805.0	810.0	815.0	
H	94.453	95.720	96.989	98.258	99.528	100.799	102.070	103.343	
P	11.231	11.500	11.774	12.052	12.336	12.624	12.918	13.215	

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
53.290	28.998	.12454	.11353	.04716	0.00000	.73393	.01090	.23300	.00640

T	820.0	825.0	830.0	835.0	840.0	845.0	850.0	855.0
H	104.816	105.890	107.165	108.440	109.716	110.993	112.271	113.550
P	13.520	13.830	14.144	14.454	14.789	15.120	15.457	15.793
T	860.0	865.0	870.0	875.0	880.0	885.0	890.0	895.0
H	114.830	116.110	117.391	118.674	119.956	121.240	122.525	123.810
P	16.147	16.501	16.861	17.226	17.598	17.975	18.360	18.750
T	900.0	905.0	910.0	915.0	920.0	925.0	930.0	935.0
H	125.096	126.383	127.671	128.960	130.250	131.540	132.832	134.124
P	19.146	19.549	19.958	20.374	20.796	21.225	21.661	22.104
T	940.0	945.0	950.0	955.0	960.0	965.0	970.0	975.0
H	135.417	136.711	138.005	139.302	140.599	141.896	143.194	144.494
P	22.554	23.010	23.474	23.945	24.423	24.909	25.401	25.902
T	980.0	985.0	990.0	995.0	1000.0	1005.0	1010.0	1015.0
H	145.794	147.095	148.397	149.700	151.004	152.309	153.614	154.920
P	26.410	26.925	27.448	27.980	28.519	29.065	29.621	30.184
T	1020.0	1025.0	1030.0	1035.0	1040.0	1045.0	1050.0	1055.0
H	156.228	157.536	158.845	160.155	161.466	162.778	164.091	165.405
P	30.756	31.335	31.924	32.521	33.126	33.740	34.364	34.997
T	1060.0	1065.0	1070.0	1075.0	1080.0	1085.0	1090.0	1095.0
H	166.719	168.035	169.351	170.669	171.987	173.306	174.627	175.948
P	35.636	36.286	36.945	37.614	38.292	38.980	39.677	40.383
T	1100.0	1105.0	1110.0	1115.0	1120.0	1125.0	1130.0	1135.0
H	177.270	178.593	179.917	181.242	182.567	183.894	185.222	186.550
P	41.100	41.826	42.563	43.309	44.066	44.833	45.610	46.398
T	1140.0	1145.0	1150.0	1155.0	1160.0	1165.0	1170.0	1175.0
H	187.880	189.210	190.542	191.874	193.207	194.542	195.877	197.213
P	47.197	48.006	48.825	49.657	50.499	51.352	52.217	53.093

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	M/DA
53.290	28.998	.12454	.11353	.04716	0.00000	.70393	.01090	.23300	.00640

T	1180.0	1185.0	1190.0	1195.0	1200.0	1205.0	1210.0	1215.0
H	198.550	199.888	201.227	202.567	203.908	205.249	206.592	207.935
P	53.981	54.880	55.791	56.713	57.648	58.595	59.554	60.525
T	1220.0	1225.0	1230.0	1235.0	1240.0	1245.0	1250.0	1255.0
H	209.280	210.626	211.973	213.320	214.668	216.018	217.368	218.719
P	61.509	62.505	63.514	64.536	65.571	66.619	67.680	68.754
T	1260.0	1265.0	1270.0	1275.0	1280.0	1285.0	1290.0	1295.0
H	220.071	221.424	222.778	224.133	225.489	226.845	228.204	229.563
P	69.842	70.944	72.059	73.188	74.331	75.488	76.659	77.845
T	1300.0	1305.0	1310.0	1315.0	1320.0	1325.0	1330.0	1335.0
H	230.923	232.283	233.645	235.007	236.371	237.735	239.100	240.467
P	79.045	80.260	81.489	82.734	83.993	85.268	86.558	87.863
T	1340.0	1345.0	1350.0	1355.0	1360.0	1355.0	1370.0	1375.0
H	241.834	243.202	244.571	245.941	247.312	248.684	250.057	251.431
P	89.184	90.521	91.874	93.243	94.628	96.029	97.447	98.881
T	1380.0	1385.0	1390.0	1395.0	1400.0	1405.0	1410.0	1415.0
H	252.805	254.181	255.557	256.935	258.313	259.693	261.073	262.454
P	100.332	101.800	103.286	104.788	106.308	107.845	109.400	110.973
T	1420.0	1425.0	1430.0	1435.0	1440.0	1445.0	1450.0	1455.0
H	263.836	265.219	266.603	267.988	269.374	270.760	272.148	273.535
P	112.564	114.173	115.801	117.447	119.111	120.795	122.497	124.219
T	1460.0	1465.0	1470.0	1475.0	1480.0	1485.0	1490.0	1495.0
H	274.926	276.316	277.707	279.099	280.492	281.885	283.281	284.677
P	125.960	127.720	129.500	131.300	133.120	134.960	136.820	138.701
T	1500.0	1505.0	1510.0	1515.0	1520.0	1525.0	1530.0	1535.0
H	286.074	287.471	288.870	290.269	291.669	293.070	294.472	295.875
P	140.602	142.525	144.469	146.433	148.419	150.426	152.455	154.507

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
53.290	28.998	.12454	.11353	.04710	0.00000	.70393	.01090	.23300	.00640

T	1540.0	1545.0	1550.0	1555.0	1560.0	1565.0	1570.0	1575.0
H	297.279	298.684	300.089	301.495	302.903	304.311	305.720	307.130
P	155.580	158.675	160.794	162.934	165.098	167.264	169.494	171.728
T	1580.0	1585.0	1590.0	1595.0	1600.0	1605.0	1610.0	1615.0
H	308.541	309.952	311.365	312.778	314.193	315.608	317.024	318.440
P	173.984	176.265	178.570	180.899	183.252	185.630	188.032	190.463
T	1620.0	1625.0	1630.0	1635.0	1640.0	1645.0	1650.0	1655.0
H	319.858	321.277	322.695	324.116	325.537	326.959	328.382	329.805
P	192.913	195.391	197.894	200.424	202.979	205.561	208.169	210.804
T	1660.0	1665.0	1670.0	1675.0	1680.0	1685.0	1690.0	1695.0
H	331.230	332.655	334.081	335.508	336.936	338.365	339.794	341.224
P	213.466	216.154	218.870	221.613	224.384	227.183	230.010	232.865
T	1700.0	1705.0	1710.0	1715.0	1720.0	1725.0	1730.0	1735.0
H	342.655	344.087	345.520	346.953	348.388	349.823	351.259	352.695
P	235.749	238.661	241.603	244.574	247.574	250.603	253.663	256.753
T	1740.0	1745.0	1750.0	1755.0	1760.0	1765.0	1770.0	1775.0
H	354.133	355.571	357.010	358.450	359.891	361.332	362.775	364.218
P	259.873	263.024	266.205	269.417	272.661	275.936	279.243	282.582
T	1780.0	1785.0	1790.0	1795.0	1800.0	1805.0	1810.0	1815.0
H	365.662	367.106	368.552	369.998	371.445	372.892	374.341	375.790
P	285.953	289.356	292.793	296.262	299.764	303.300	306.869	310.472
T	1820.0	1825.0	1830.0	1835.0	1840.0	1845.0	1850.0	1855.0
H	377.240	378.691	380.142	381.595	383.048	384.501	385.956	387.411
P	314.109	317.781	321.487	325.228	329.005	332.817	336.664	340.547
T	1860.0	1865.0	1870.0	1875.0	1880.0	1885.0	1890.0	1895.0
H	388.867	390.324	391.781	393.239	394.698	396.158	397.618	399.079
P	344.467	348.423	352.415	356.445	360.511	364.615	368.757	372.937

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	W/DA
53.290	28.998	.12454	.11353	.04710	0.00000	.70393	.01090	.23300	.00640

T	1900.0	1905.0	1910.0	1915.0	1920.0	1925.0	1930.0	1935.0
H	400.541	402.004	403.467	404.931	406.395	407.861	409.327	410.794
P	377.155	381.412	385.708	390.042	394.416	398.830	403.263	407.777
T	1940.0	1945.0	1950.0	1955.0	1960.0	1965.0	1970.0	1975.0
H	412.261	413.729	415.199	416.668	418.138	419.609	421.080	422.553
P	412.311	416.885	421.501	425.158	430.857	435.598	440.380	445.205
T	1980.0	1985.0	1990.0	1995.0	2000.0	2005.0	2010.0	2015.0
H	424.026	425.499	426.974	428.449	429.924	431.401	432.877	434.355
P	450.073	454.964	459.938	464.936	469.977	475.053	480.193	485.363
T	2020.0	2025.0	2030.0	2035.0	2040.0	2045.0	2050.0	2055.0
H	435.833	437.312	438.792	440.272	441.753	443.235	444.717	446.200
P	490.589	495.854	501.165	506.522	511.926	517.375	522.873	528.417
T	2060.0	2065.0	2070.0	2075.0	2080.0	2085.0	2090.0	2095.0
H	447.683	449.167	450.652	452.137	453.623	455.110	456.597	458.085
P	534.008	539.648	545.335	551.071	556.856	562.690	568.573	574.507
T	2100.0	2105.0	2110.0	2115.0	2120.0	2125.0	2130.0	2135.0
H	459.574	461.063	462.552	464.043	465.534	467.025	468.517	470.010
P	580.490	586.523	592.607	598.742	604.929	611.157	617.457	623.800
T	2140.0	2145.0	2150.0	2155.0	2160.0	2165.0	2170.0	2175.0
H	471.503	472.997	474.492	475.987	477.483	478.979	480.476	481.973
P	630.195	636.643	643.144	649.700	656.309	662.972	669.690	676.464
T	2180.0	2185.0	2190.0	2195.0	2200.0	2205.0	2210.0	2215.0
H	483.471	484.970	486.469	487.969	489.469	490.970	492.472	493.974
P	683.292	690.177	697.117	704.114	711.168	718.278	725.447	732.573
T	2220.0	2225.0	2230.0	2235.0	2240.0	2245.0	2250.0	2255.0
H	495.477	496.980	498.484	499.988	501.493	502.998	504.504	506.011
P	739.957	747.300	754.702	762.163	769.683	777.254	784.905	792.507

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	W/DA
53.290	28.998	.12454	.11353	.04710	0.00000	.73393	.01090	.23300	.00640

T	2260.0	2265.0	2270.0	2275.0	2280.0	2285.0	2290.0	2295.0
H	507.518	509.025	510.534	512.042	513.552	515.061	516.572	518.083
P	800.369	808.194	816.380	824.028	832.039	840.113	848.251	856.452
T	2300.0	2305.0	2310.0	2315.0	2320.0	2325.0	2330.0	2335.0
H	519.594	521.106	522.619	524.131	525.645	527.159	528.674	530.189
P	864.717	873.047	881.441	889.901	898.426	907.018	915.676	924.401
T	2340.0	2345.0	2350.0	2355.0	2360.0	2365.0	2370.0	2375.0
H	531.704	533.220	534.737	536.254	537.772	539.290	540.809	542.329
P	933.193	942.053	950.981	959.977	969.042	978.175	987.360	996.654
T	2380.0	2385.0	2390.0	2395.0	2400.0	2405.0	2410.0	2415.0
H	543.848	545.368	546.889	548.410	549.932	551.454	552.977	554.500
P	1005.999	1015.414	1024.901	1034.459	1044.090	1053.793	1063.569	1073.419
T	2420.0	2425.0	2430.0	2435.0	2440.0	2445.0	2450.0	2455.0
H	556.024	557.548	559.073	560.598	562.124	563.650	565.177	566.704
P	1083.342	1093.340	1103.412	1113.560	1123.783	1134.082	1144.457	1154.909
T	2460.0	2465.0	2470.0	2475.0	2480.0	2485.0	2490.0	2495.0
H	568.232	569.760	571.289	572.818	574.348	575.878	577.409	578.940
P	1165.439	1176.046	1186.732	1197.496	1208.339	1219.262	1230.265	1241.349
T	2500.0	2505.0	2510.0	2515.0	2520.0	2525.0	2530.0	2535.0
H	580.472	582.004	583.535	585.069	586.603	588.137	589.672	591.207
P	1252.513	1263.758	1275.085	1286.495	1297.988	1309.564	1321.223	1332.967
T	2540.0	2545.0	2550.0	2555.0	2560.0	2565.0	2570.0	2575.0
H	592.742	594.278	595.815	597.352	598.889	600.427	601.965	603.504
P	1344.795	1356.709	1368.708	1380.793	1392.965	1405.224	1417.571	1430.005
T	2580.0	2585.0	2590.0	2595.0	2600.0	2605.0	2610.0	2615.0
H	605.044	606.584	608.124	609.665	611.206	612.748	614.290	615.833
P	1442.528	1455.141	1467.842	1480.634	1493.517	1506.490	1519.555	1532.713

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	M/DA
53.290	28.998	.12454	.11353	.04710	0.00000	.70393	.01090	.23300	.00640

T	2620.0	2625.0	2630.0	2635.0	2640.0	2645.0	2650.0	2655.0
H	617.376	618.920	620.464	622.009	623.554	625.100	626.646	628.192
P	1545.963	1559.306	1572.742	1586.273	1599.899	1613.620	1627.436	1641.349
T	2660.0	2665.0	2670.0	2675.0	2680.0	2685.0	2690.0	2695.0
H	629.739	631.287	632.835	634.384	635.933	637.482	639.032	640.583
P	1655.359	1669.466	1683.571	1697.975	1712.378	1726.880	1741.482	1756.185
T	2700.0	2705.0	2710.0	2715.0	2720.0	2725.0	2730.0	2735.0
H	642.134	643.685	645.237	646.790	648.343	649.897	651.451	653.005
P	1770.990	1785.896	1800.904	1816.016	1831.231	1846.550	1861.974	1877.504
T	2740.0	2745.0	2750.0	2755.0	2760.0	2765.0	2770.0	2775.0
H	654.560	656.116	657.572	659.228	660.785	662.343	663.901	665.459
P	1893.139	1908.880	1924.729	1940.685	1956.750	1972.924	1989.207	2005.600
T	2780.0	2785.0	2790.0	2795.0	2800.0	2805.0	2810.0	2815.0
H	667.019	668.578	670.138	671.699	673.260	674.822	676.384	677.947
P	2022.103	2038.718	2055.445	2072.285	2089.238	2106.305	2123.486	2140.782
T	2820.0	2825.0	2830.0	2835.0	2840.0	2845.0	2850.0	2855.0
H	679.510	681.074	682.638	684.203	685.769	687.335	688.901	690.469
P	2158.194	2175.723	2193.368	2211.131	2229.013	2247.014	2265.134	2283.375
T	2860.0	2865.0	2870.0	2875.0	2880.0	2885.0	2890.0	2895.0
H	692.036	693.604	695.173	696.743	698.312	699.883	701.454	703.025
P	2301.737	2320.221	2338.827	2357.556	2376.410	2395.387	2414.490	2433.719
T	2900.0	2905.0	2910.0	2915.0	2920.0	2925.0	2930.0	2935.0
H	704.598	706.171	707.744	709.318	710.892	712.457	714.043	715.619
P	2453.075	2472.558	2492.169	2511.909	2531.779	2551.779	2571.910	2592.173
T	2940.0	2945.0	2950.0	2955.0	0.0	0.0	0.0	0.0
H	717.196	718.774	720.352	721.931	0.000	0.000	0.000	0.000
P	2612.569	2633.097	2653.760	2674.558	0.000	0.000	0.000	0.000

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
53.345	28.968	.14710	.03933	.03841	0.00000	.71372	.01144	.17470	.00640

T	450.0	465.0	470.0	475.0	460.0	485.0	490.0	495.0
H	14.646	15.869	17.092	18.316	19.540	20.764	21.989	23.214
P	1.645	1.709	1.775	1.844	1.914	1.987	2.061	2.137
T	500.0	505.0	510.0	515.0	520.0	525.0	530.0	535.0
H	24.440	25.666	26.893	28.120	29.347	30.575	31.803	33.032
P	2.215	2.295	2.378	2.462	2.549	2.638	2.729	2.822
T	540.0	545.0	550.0	555.0	560.0	565.0	570.0	575.0
H	34.261	35.491	36.721	37.952	39.183	40.415	41.647	42.879
P	2.918	3.016	3.115	3.219	3.325	3.433	3.543	3.656
T	580.0	585.0	590.0	595.0	600.0	605.0	610.0	615.0
H	44.112	45.346	46.580	47.815	49.050	50.286	51.522	52.758
P	3.772	3.890	4.011	4.135	4.261	4.391	4.523	4.658
T	620.0	625.0	630.0	635.0	640.0	645.0	650.0	655.0
H	53.996	55.234	56.472	57.711	58.950	60.190	61.431	62.672
P	4.796	4.937	5.082	5.229	5.379	5.533	5.690	5.850
T	660.0	665.0	670.0	675.0	680.0	685.0	690.0	695.0
H	53.914	65.156	66.399	67.643	68.887	70.132	71.378	72.624
P	6.013	6.180	6.350	6.524	6.701	5.881	7.065	7.253
T	700.0	705.0	710.0	715.0	720.0	725.0	730.0	735.0
H	73.870	75.118	76.365	77.614	78.863	80.113	81.364	82.615
P	7.445	7.640	7.839	8.042	8.249	8.460	8.675	8.893
T	740.0	745.0	750.0	755.0	760.0	765.0	770.0	775.0
H	83.867	85.120	86.373	87.627	88.881	90.137	91.393	92.649
P	9.116	9.343	9.575	9.810	10.050	10.294	10.543	10.795
T	780.0	785.0	790.0	795.0	800.0	805.0	810.0	815.0
H	93.907	95.165	96.424	97.683	98.944	130.205	101.466	102.729
P	11.054	11.316	11.583	11.855	12.131	12.412	12.698	12.989

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	M/DA
53.345	28.968	.14710	.08933	.03841	0.00003	.71372	.01144	.17470	.00646

T	820.0	825.0	830.0	835.0	840.0	845.0	850.0	855.0
H	103.992	105.256	106.521	107.785	109.053	110.323	111.567	112.855
P	13.265	13.557	13.893	14.204	14.521	14.843	15.170	15.503
T	860.0	865.0	870.0	875.0	880.0	885.0	890.0	895.0
H	114.125	115.395	116.665	117.938	119.210	120.484	121.758	123.033
P	15.841	16.185	16.535	16.890	17.251	17.618	17.991	18.369
T	900.0	905.0	910.0	915.0	920.0	925.0	930.0	935.0
H	124.308	125.585	126.862	128.140	129.419	130.699	131.979	133.260
P	18.754	19.145	19.542	19.945	20.355	20.771	21.193	21.622
T	940.0	945.0	950.0	955.0	960.0	965.0	970.0	975.0
H	134.543	135.826	137.109	138.394	139.680	140.966	142.253	143.541
P	22.058	22.500	22.949	23.405	23.868	24.338	24.815	25.299
T	980.0	985.0	990.0	995.0	1000.0	1005.0	1010.0	1015.0
H	144.830	146.120	147.410	148.702	149.994	151.287	152.581	153.876
P	25.790	26.288	26.794	27.308	27.829	28.357	28.893	29.437
T	1020.0	1025.0	1030.0	1035.0	1040.0	1045.0	1050.0	1055.0
H	155.172	156.469	157.766	159.065	160.364	161.664	162.965	164.267
P	29.989	30.549	31.117	31.693	32.277	32.869	33.470	34.079
T	1060.0	1065.0	1070.0	1075.0	1080.0	1085.0	1090.0	1095.0
H	165.570	166.873	168.178	169.483	170.789	172.097	173.405	174.714
P	34.697	35.323	35.959	36.603	37.256	37.918	38.589	39.269
T	1100.0	1105.0	1110.0	1115.0	1120.0	1125.0	1130.0	1135.0
H	176.024	177.334	178.645	179.959	181.272	182.586	183.902	185.219
P	39.958	40.657	41.365	42.084	42.811	43.549	44.296	45.053
T	1140.0	1145.0	1150.0	1155.0	1160.0	1165.0	1170.0	1175.0
H	186.535	187.853	189.172	190.491	191.812	193.134	194.456	195.780
P	45.820	46.598	47.385	48.183	48.992	49.811	50.641	51.481

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
53.345	28.968	.14710	.08933	.03841	0.00000	.71372	.01144	.17470	.00646

T	1180.0	1185.0	1190.0	1195.0	1200.0	1205.0	1210.0	1215.0
H	197.104	198.429	199.755	201.082	202.410	203.739	205.069	206.399
P	52.332	53.195	54.058	54.953	55.849	56.755	57.675	58.605
T	1220.0	1225.0	1230.0	1235.0	1240.0	1245.0	1250.0	1255.0
H	207.731	209.064	210.397	211.731	213.067	214.403	215.740	217.078
P	59.548	60.502	61.458	62.447	63.437	64.446	65.455	66.463
T	1260.0	1265.0	1270.0	1275.0	1280.0	1285.0	1290.0	1295.0
H	218.417	219.756	221.097	222.439	223.781	225.125	226.469	227.815
P	67.523	68.575	69.543	70.722	71.814	72.920	74.039	75.171
T	1300.0	1305.0	1310.0	1315.0	1320.0	1325.0	1330.0	1335.0
H	229.161	230.508	231.856	233.205	234.555	235.905	237.257	238.610
P	76.317	77.477	78.651	79.839	81.040	82.257	83.487	84.732
T	1340.0	1345.0	1350.0	1355.0	1360.0	1365.0	1370.0	1375.0
H	239.963	241.317	242.673	244.029	245.386	246.744	248.103	249.463
P	85.992	87.267	88.555	89.861	91.181	92.516	93.866	95.232
T	1380.0	1385.0	1390.0	1395.0	1400.0	1405.0	1410.0	1415.0
H	250.823	252.185	253.548	254.911	256.275	257.640	259.007	260.374
P	96.614	98.012	99.425	100.856	102.302	103.765	105.244	106.740
T	1420.0	1425.0	1430.0	1435.0	1440.0	1445.0	1450.0	1455.0
H	261.741	263.110	264.480	265.850	267.222	268.594	269.968	271.342
P	108.253	109.783	111.330	112.894	114.476	116.075	117.693	119.328
T	1460.0	1465.0	1470.0	1475.0	1480.0	1485.0	1490.0	1495.0
H	272.717	274.093	275.469	276.847	278.225	279.605	280.985	282.365
P	120.981	122.652	124.342	126.050	127.777	129.523	131.288	133.071
T	1500.0	1505.0	1510.0	1515.0	1520.0	1525.0	1530.0	1535.0
H	283.748	285.131	286.515	287.900	289.285	290.671	292.059	293.447
P	134.875	136.697	138.540	140.402	142.284	144.185	146.108	148.051

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/OA	W/DA
53.345	28.968	.14710	.08933	.03841	0.00000	.71372	.01144	.17470	.00040
T	1540.0	1545.0	1550.0	1555.0	1560.0	1565.0	1570.0	1575.0	
H	294.836	296.226	297.515	299.008	300.400	301.793	303.187	304.582	
P	150.015	151.999	154.004	156.031	158.078	160.147	162.238	164.351	
T	1580.0	1585.0	1590.0	1595.0	1600.0	1605.0	1610.0	1615.0	
H	305.978	307.375	308.772	310.170	311.570	312.969	314.370	315.772	
P	156.485	168.642	170.821	173.022	175.247	177.494	179.764	162.057	
T	1620.0	1625.0	1630.0	1635.0	1640.0	1645.0	1650.0	1655.0	
H	317.174	318.578	319.982	321.387	322.792	324.199	325.606	327.015	
P	184.374	186.714	189.379	191.467	193.879	196.315	198.777	201.263	
T	1560.0	1665.0	1670.0	1675.0	1680.0	1685.0	1690.0	1695.0	
H	328.424	329.833	331.244	332.655	334.068	335.481	336.895	338.309	
P	203.773	206.309	208.870	211.457	214.069	216.707	219.372	222.062	
T	1700.0	1705.0	1710.0	1715.0	1720.0	1725.0	1730.0	1735.0	
H	339.725	341.141	342.558	343.976	345.394	346.814	348.234	349.655	
P	224.779	227.523	230.293	233.091	235.915	238.758	241.648	244.555	
T	1740.0	1745.0	1750.0	1755.0	1760.0	1765.0	1770.0	1775.0	
H	351.076	352.499	353.922	355.346	356.771	358.197	359.623	361.050	
P	247.491	250.456	253.448	256.470	259.520	262.599	265.708	268.840	
T	1780.0	1785.0	1790.0	1795.0	1800.0	1835.0	1810.0	1815.0	
H	362.478	363.9.6	365.335	366.766	368.197	369.629	371.060	372.493	
P	272.015	275.213	278.441	281.700	284.989	288.309	291.661	295.043	
T	1820.0	1825.0	1830.0	1835.0	1840.0	1845.0	1850.0	1855.0	
H	373.927	375.362	376.797	378.233	379.670	381.107	382.545	383.984	
P	298.457	301.903	305.381	308.891	312.434	316.069	319.617	323.258	
T	1860.0	1865.0	1870.0	1875.0	1880.0	1885.0	1890.0	1895.0	
H	385.424	386.864	388.305	389.747	391.189	392.632	394.076	395.521	
P	325.933	330.641	334.383	339.159	341.969	345.814	349.693	353.608	

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	M/DA
53.345	28.968	.14713	.08933	.03841	0.00000	.71372	.01144	.17470	.00640

T	1900.0	1905.0	1910.0	1915.0	1920.0	1925.0	1930.0	1935.0
H	396.966	398.412	399.858	401.306	402.754	404.202	405.652	407.102
P	357.557	361.543	365.564	369.621	373.714	377.844	382.010	386.213
T	1940.0	1945.0	1950.0	1955.0	1960.0	1965.0	1970.0	1975.0
H	408.552	410.004	411.455	412.909	414.362	415.816	417.271	418.725
P	390.454	394.732	399.047	403.401	407.793	412.223	416.692	421.2[illegible]
T	1980.0	1985.0	1990.0	1995.0	2000.0	2005.0	2010.0	2015.0
H	420.182	421.639	423.095	424.554	426.013	427.472	428.932	430.392
P	425.748	430.335	434.961	439.628	444.335	449.082	453.870	458.7[illegible]
T	2020.0	2025.0	2030.0	2035.0	2040.0	2045.0	2050.0	2055.0
H	431.853	433.315	434.778	436.241	437.704	439.169	440.633	442.099
P	463.570	468.483	473.437	478.433	483.472	488.553	493.678	498.845
T	2060.0	2065.0	2070.0	2075.0	2080.0	2085.0	2090.0	2095.0
H	443.565	445.032	446.499	447.967	449.436	450.905	452.375	453.845
P	504.057	509.312	514.611	519.955	525.343	530.775	536.254	541.778
T	2100.0	2105.0	2110.0	2115.0	2120.0	2125.0	2130.0	2135.0
H	455.316	456.788	458.260	459.732	461.206	462.680	464.154	465.629
P	547.348	552.963	558.626	564.334	570.090	575.893	581.743	587.642
T	2140.0	2145.0	2150.0	2155.0	2160.0	2165.0	2170.0	2175.0
H	467.105	468.581	470.059	471.535	473.013	474.492	475.971	477.450
P	593.588	599.583	605.627	611.719	617.861	624.053	630.294	636.585
T	2180.0	2185.0	2190.0	2195.0	2200.0	2205.0	2210.0	2215.0
H	478.930	480.411	481.892	483.374	484.857	486.339	487.823	489.307
P	642.928	649.322	655.765	662.262	668.809	675.409	682.061	688.765
T	2220.0	2225.0	2230.0	2235.0	2240.0	2245.0	2250.0	2255.0
H	490.791	492.277	493.762	495.248	496.735	498.222	499.710	501.193
P	695.524	702.335	709.200	716.119	723.092	730.120	737.203	744.341

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	M/DA
53.345	28.968	.14713	.08933	.03841	0.00000	.71372	.01144	.17470	.00640

T	1900.0	1905.0	1910.0	1915.0	1920.0	1925.0	1930.0	1935.0
H	396.966	398.412	399.858	401.306	402.754	404.202	405.652	407.102
P	357.557	361.543	365.564	369.621	373.714	377.844	382.010	386.213
T	1940.0	1945.0	1950.0	1955.0	1960.0	1965.0	1970.0	1975.0
H	408.552	410.004	411.456	412.909	414.362	415.816	417.271	418.726
P	390.454	394.732	399.047	403.401	407.793	412.223	416.692	421.20[illegible]
T	1980.0	1985.0	1990.0	1995.0	2000.0	2005.0	2010.0	2015.0
H	420.182	421.639	423.095	424.554	426.013	427.472	428.932	430.392
P	425.748	430.335	434.951	439.628	444.335	449.082	453.870	458.70[illegible]
T	2020.0	2025.0	2030.0	2035.0	2040.0	2045.0	2050.0	2055.0
H	431.853	433.315	434.778	436.241	437.704	439.169	440.633	442.099
P	463.570	468.483	473.437	478.433	483.472	488.553	493.678	498.845
T	2060.0	2065.0	2070.0	2075.0	2080.0	2085.0	2090.0	2095.0
H	443.565	445.032	446.499	447.967	449.436	450.905	452.375	453.845
P	504.057	509.312	514.611	519.955	525.343	530.775	536.254	541.778
T	2100.0	2105.0	2110.0	2115.0	2120.0	2125.0	2130.0	2135.0
H	455.316	456.788	458.260	459.732	461.206	462.680	464.154	465.629
P	547.348	552.963	558.626	564.334	570.090	575.893	581.743	587.642
T	2140.0	2145.0	2150.0	2155.0	2160.0	2165.0	2170.0	2175.0
H	467.105	468.581	470.058	471.535	473.013	474.492	475.971	477.450
P	593.588	599.583	605.627	611.719	617.861	624.053	630.294	636.585
T	2180.0	2185.0	2190.0	2195.0	2200.0	2205.0	2210.0	2215.0
H	478.930	480.411	481.892	483.374	484.857	486.339	487.823	489.307
P	642.928	649.322	655.765	662.262	668.809	675.409	682.061	688.765
T	2220.0	2225.0	2230.0	2235.0	2240.0	2245.0	2250.0	2255.0
H	490.791	492.277	493.762	495.248	496.735	498.222	499.710	501.193
P	695.524	702.335	709.200	716.119	723.092	730.120	737.203	744.341

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/OA	H/OA
53.345	28.968	.14710	.08933	.03841	0.00000	.71372	.01144	.17476	.00646

T	2260.0	2265.0	2270.0	2275.0	2280.0	2285.0	2290.0	2295.0
H	502.687	504.177	505.655	507.157	508.648	510.139	511.631	513.124
P	751.535	758.785	766.091	773.454	780.874	788.351	795.885	803.479
T	2300.0	2305.0	2310.0	2315.0	2320.0	2325.0	2330.0	2335.0
H	514.617	516.110	517.604	519.098	520.593	522.089	523.585	525.081
P	811.129	818.838	826.567	834.435	842.322	850.276	858.278	866.347
T	2340.0	2345.0	2350.0	2355.0	2360.0	2365.0	2370.0	2375.0
H	526.579	528.075	529.574	531.073	532.572	534.071	535.571	537.071
P	874.476	882.668	890.920	899.236	907.613	916.054	924.557	933.125
T	2380.0	2385.0	2390.0	2395.0	2400.0	2405.0	2410.0	2415.0
H	538.572	540.074	541.575	543.078	544.581	546.084	547.588	549.093
P	941.756	950.451	959.212	968.037	976.928	985.884	994.907	1003.995
T	2420.0	2425.0	2430.0	2435.0	2440.0	2445.0	2450.0	2455.0
H	550.598	552.103	553.609	555.115	556.622	558.129	559.636	561.145
P	1013.152	1022.375	1031.665	1041.025	1050.453	1059.949	1069.515	1079.150
T	2460.0	2465.0	2470.0	2475.0	2480.0	2485.0	2490.0	2495.0
H	562.653	564.162	565.672	567.182	568.693	570.204	571.715	573.227
P	1088.855	1098.631	1108.477	1118.394	1128.363	1138.444	1148.578	1158.784
T	2500.0	2505.0	2510.0	2515.0	2520.0	2525.0	2530.0	2535.0
H	574.739	576.252	577.765	579.279	580.794	582.308	583.824	585.339
P	1169.063	1179.416	1189.843	1200.345	1210.921	1221.572	1232.299	1243.103
T	2540.0	2545.0	2550.0	2555.0	2560.0	2565.0	2570.0	2575.0
H	586.855	588.372	589.889	591.407	592.924	594.443	595.962	597.481
P	1253.982	1264.939	1275.973	1287.085	1298.275	1309.543	1320.691	1332.318
T	2580.0	2585.0	2590.0	2595.0	2600.0	2605.0	2610.0	2615.0
H	599.001	600.521	602.042	603.564	605.085	606.607	608.130	609.653
P	1343.825	1355.413	1367.081	1378.831	1390.662	1402.575	1414.572	1426.651

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
53.345	28.968	.14710	.08933	.03841	0.00000	.71372	.01144	.17470	.00640

T	2620.0	2625.0	2630.0	2635.0	2640.0	2645.0	2650.0	2655.0
H	611.177	612.701	614.226	615.751	617.276	618.802	620.328	621.855
P	1438.814	1451.060	1463.392	1475.808	1488.309	1500.857	1513.571	1526.331
T	2660.0	2665.0	2670.0	2675.0	2680.0	2685.0	2690.0	2695.0
H	623.383	624.911	626.439	627.968	629.497	631.027	632.557	634.088
P	1539.179	1552.115	1565.139	1578.251	1591.453	1604.745	1618.127	1631.599
T	2700.0	2705.0	2710.0	2715.0	2720.0	2725.0	2730.0	2735.0
H	635.619	637.151	638.683	640.216	641.749	643.283	644.817	646.352
P	1645.163	1658.818	1672.565	1686.406	1700.340	1714.367	1728.488	1742.705
T	2740.0	2745.0	2750.0	2755.0	2760.0	2765.0	2770.0	2775.0
H	647.887	649.422	650.959	652.495	654.032	655.570	657.108	658.647
P	1757.016	1771.424	1785.928	1800.528	1815.226	1830.022	1844.917	1859.911
T	2780.0	2785.0	2790.0	2795.0	2800.0	2805.0	2810.0	2815.0
H	660.186	661.726	663.266	664.807	666.348	667.890	669.432	670.975
P	1875.004	1890.197	1905.491	1920.886	1936.383	1951.983	1967.685	1983.491
T	2820.0	2825.0	2830.0	2835.0	2840.0	2845.0	2850.0	2855.0
H	672.519	674.063	675.607	677.152	678.698	680.244	681.791	683.338
P	1999.401	2015.416	2031.536	2047.762	2064.094	2080.533	2097.080	2113.735
T	2860.0	2865.0	2870.0	2875.0	2880.0	2885.0	2890.0	2895.0
H	684.886	686.434	687.983	689.532	691.083	692.633	694.184	695.735
P	2130.499	2147.373	2164.356	2181.451	2198.656	2215.974	2233.404	2250.947
T	2900.0	2905.0	2910.0	2915.0	2920.0	2925.0	2930.0	2935.0
H	697.289	698.841	700.395	701.949	703.504	705.059	706.615	708.172
P	2268.604	2286.376	2304.263	2322.265	2340.384	2358.620	2376.974	2395.447
T	2940.0	2945.0	2950.0	2955.0	0.0	0.0	0.0	0.0
H	709.729	711.287	712.845	714.404	0.000	0.000	0.000	0.000
P	2414.038	2432.750	2451.581	2470.535	0.000	0.000	0.000	0.000

Table A 4.1.2 - Properties of the Products of Combustion of Low-Btu Fuel Gas from a Westinghouse Fluidized Bed Gasifier with High Temperature Desulfurization and Particulate Removal Generated from Montana Subbituminous Coal

- LOW-BTU FUEL GAS PROPERTIES

GASIFICATION PROCESS Westinghouse Fluidized Bed/High-Temp. Desulfurization

COAL Montana subbituminous

Lockhopper Inlet Conditions

Temperature 150

Moisture Content 20%

SORBENT Dolomite

Sorbent/Coal Ratio 0.12 (0.11)

PROCESS AIR

Air/Coal Ratio 2.18 (2.06)

Temperature - °F 750

Pressure - psia 250

PROCESS STEAM

Steam/Coal Ratio 0.450 (0.425)

Temperature - °F 400

Pressure - psia 250

PRODUCT FUEL GAS

Temperature - °F 1600

Pressure - psia 225

Composition-Mole Fraction

N_2	.4291
O_2	0
H_2	.1677
CO	.2244
CO_2	.0791
H_2O	.0722
H_2S	0
CH_4	.0276
C_2H_4	0

Product Fuel Gas/Coal Ratio 3.31 (3.13)

Gasifier Aux. Pwr. (kW/lb/s) 14.4

Spent Sorbent Oxidizer Exhaust Products

T_{in} - °F 1500

T_{out} - °F 300

q-Btu/lb coal 70 (67)

Molecular Wt 23.87

Heating Value

LHV -	143.02	Btu/scf	2274.75	Btu/lb
HHV -	154.21	Btu/scf	2452.76	Btu/lb

LHV/HHV .9274

Enthalpy (400°R Base) - 552.09 Btu/lb

Stoichiometric Fuel/Air Ratio 0.685

(Values in parenthesis are for as received coal)

Table A 4.1.2 Polynomial Cofficients

A*LHID GAS-TAIR=750-MONTANA--150

STOICHIOMETRIC AIR

	RANGE OF VALIDITY	A0	A1	A2	A3	A4	A5
H=F(T)	460.0<T<2940.0	-9.83987+01	2.43663-01	-7.50370-08	1.57004-08	-4.97723-12	5.15630-16
P=F(T)	460.0<T<2940.0	-1.63522+01	8.18849-02	-1.59109-04	1.64629-07	-6.53586-11	2.68412-14
H=F(P)	6.0<P< 90.0	3.02465+01	6.63224+00	-1.19499-01	1.31492-03	-7.20876-06	1.52221-08
H=F(P)	91.0<P< 600.0	1.41256+02	1.26853+00	-2.75452-03	3.80830-06	-2.70381-09	7.95415-12
H=F(P)	601.0<P<3300.0	2.58596+02	4.15256-01	-2.26897-04	8.24988-08	-1.59114-11	1.23500-02
P=F(H)	14.0<H< 700.0	8.86764-01	4.18300-02	4.25383-04	3.13487-06	4.00745-09	4.34631-12
T=F(H)	14.0<H< 700.0	3.99796+02	4.02302+00	-1.22272-03	6.20185-08	9.60928-10	-5.99695-13

100 PERCENT EXCESS AIR

	RANGE OF VALIDITY	A0	A1	A2	A3	A4	A5
H=F(T)	460.0<T<2940.0	-9.83768+01	2.47526-01	-1.16397-05	2.07993-08	-6.33500-12	6.62403-16
P=F(T)	460.0<T<2940.0	-7.26534+00	3.45095-02	-6.46534-05	7.31866-08	-2.02364-11	1.41328-14
H=F(P)	6.0<P< 90.0	2.66956+01	7.32256+00	-1.48694-01	1.87223-03	-1.18250-05	2.88796-08
H=F(P)	91.0<P< 600.0	1.30910+02	1.52285+00	-4.09014-03	6.93156-06	-6.15474-09	2.15739-12
H=F(P)	601.0<P<3300.0	2.43339+02	5.16341-01	-3.50399-04	1.59404-07	-3.86345-11	3.77483-15
P=F(H)	14.0<H< 700.0	9.93434-01	3.68325-02	4.78823-04	2.69980-06	3.96047-09	2.59688-12
T=F(H)	14.0<H< 700.0	3.99632+02	4.08253+00	-9.00745-04	-8.22598-07	2.14145-09	-1.18955-12

200 PERCENT EXCESS AIR

	RANGE OF VALIDITY	A0	A1	A2	A3	A4	A5
H=F(T)	460.0<T<2940.0	-9.83699+01	2.49295-01	-1.69242-05	2.31273-08	-6.95400-12	7.29279-16
P=F(T)	460.0<T<2940.0	-5.26776+00	2.37981-02	-4.25520-05	5.11176-08	-9.04548-12	1.03956-14
H=F(P)	6.0<P< 90.0	2.50934+01	7.65555+00	-1.64049-01	2.19506-03	-1.47805-05	3.85543-08
H=F(P)	91.0<P< 600.0	1.26236+02	1.65353+00	-4.80130-03	9.08118-06	-8.92155-09	3.46788-12
H=F(P)	601.0<P<3300.0	2.34933+02	5.77603-01	-4.41159-04	2.27308-07	-6.26039-11	6.96635-15
P=F(H)	14.0<H< 700.0	1.01623+00	3.56719-02	4.90182-04	2.56002-06	3.80918-09	2.00448-12
T=F(H)	14.0<H< 700.0	3.99577+02	4.91094+01	-7.30392-04	-1.30299-06	2.80503-09	-1.53334-12

300 PERCENT EXCESS AIR

	RANGE OF VALIDITY	A0	A1	A2	A3	A4	A5
H=F(T)	460.0<T<2940.0	-9.83637+01	2.50308-01	-1.99545-05	2.94467-07	-7.31126-12	7.67974-16
P=F(T)	460.0<T<2940.0	-4.50821+00	1.96451-02	-3.37763-05	4.21890-08	-4.46660-12	8.68304-15
H=F(P)	6.0<P< 90.0	2.41801+01	7.85150+00	-1.73467-01	2.40302-03	-1.67817-05	4.54486-08
H=F(P)	91.0<P< 600.0	1.23576+02	1.73274+00	-5.29626-03	1.05890-05	-1.10193-08	4.59306-12
H=F(P)	601.0<P<3300.0	2.30152+02	6.15627-01	-5.02903-04	2.78155-07	-8.23909-11	9.87294-15
P=F(H)	14.0<H< 700.0	1.02616+00	3.51613-02	4.94755-04	2.49100-06	3.70098-09	1.71111-12
T=F(H)	14.0<H< 700.0	3.99547+02	4.12465+00	-6.25972-04	-1.60193-06	3.22578-09	-1.75555-12

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
52.944	29.188	.00057	.24723	.09399	0.00000	.65012	.00798	.08500	.00640

T	460.0	465.0	470.0	475.0	480.0	485.0	490.0	495.0
H	14.999	16.256	17.513	18.772	20.031	21.292	22.553	23.816
P	1.671	1.739	1.809	1.881	1.956	2.032	2.111	2.192
T	500.0	505.0	510.0	515.0	520.0	525.0	530.0	535.0
H	25.079	26.344	27.609	28.876	30.143	31.411	32.681	33.951
P	2.275	2.361	2.449	2.540	2.633	2.728	2.827	2.927
T	540.0	545.0	550.0	555.0	560.0	565.0	570.0	575.0
H	35.222	36.494	37.768	39.042	40.317	41.593	42.870	44.148
P	3.031	3.137	3.246	3.358	3.473	3.591	3.711	3.835
T	580.0	585.0	590.0	595.0	600.0	605.0	610.0	615.0
H	45.425	46.705	47.987	49.269	50.551	51.835	53.120	54.405
P	3.962	4.092	4.225	4.362	4.501	4.645	4.791	4.941
T	620.0	625.0	630.0	635.0	640.0	645.0	650.0	655.0
H	55.692	56.979	58.257	59.557	60.847	62.138	63.431	64.724
P	5.095	5.252	5.413	5.578	5.746	5.918	6.094	6.274
T	660.0	665.0	670.0	675.0	680.0	685.0	690.0	695.0
H	66.018	67.313	68.609	69.906	71.204	72.503	73.803	75.104
P	6.459	6.647	6.839	7.036	7.237	7.442	7.652	7.866
T	700.0	705.0	710.0	715.0	720.0	725.0	730.0	735.0
H	76.406	77.709	79.013	80.318	81.624	82.931	84.239	85.548
P	8.085	8.308	8.536	8.769	9.007	9.249	9.497	9.749
T	740.0	745.0	750.0	755.0	760.0	765.0	770.0	775.0
H	86.858	88.169	89.481	90.794	92.108	93.423	94.739	96.056
P	10.007	10.270	10.539	10.812	11.092	11.376	11.667	11.963
T	780.0	785.0	790.0	795.0	800.0	805.0	810.0	815.0
H	97.375	98.694	100.014	101.335	102.658	103.981	105.305	106.631
P	12.264	12.572	12.886	13.205	13.531	13.863	14.201	14.545

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	M/DA
52.944	29.198	.00067	.24723	.09399	0.00000	.65012	.00799	.68500	.00640

T	820.0	825.0	830.0	835.0	840.0	845.0	850.0	855.0
H	107.957	109.235	110.614	111.943	113.274	114.606	115.939	117.273
P	14.895	15.254	15.618	15.989	16.367	15.751	17.143	17.542
T	860.0	865.0	870.0	875.0	880.0	885.0	890.0	895.0
H	118.608	119.944	121.281	122.619	123.958	125.299	126.640	127.983
P	17.948	18.361	18.782	19.210	19.645	20.089	20.540	20.999
T	900.0	905.0	910.0	915.0	920.0	925.0	930.0	935.0
H	129.326	130.671	132.017	133.364	134.712	136.061	137.411	138.762
P	21.466	21.941	22.425	22.917	23.417	23.925	24.443	24.969
T	940.0	945.0	950.0	955.0	960.0	965.0	970.0	975.0
H	140.115	141.468	142.823	144.179	145.535	146.893	148.252	149.612
P	25.504	26.048	26.601	27.163	27.734	28.315	28.906	29.506
T	980.0	985.0	990.0	995.0	1000.0	1005.0	1010.0	1015.0
H	150.974	152.336	153.699	155.064	156.430	157.797	159.164	160.533
P	30.116	30.736	31.366	32.006	32.657	33.317	33.989	34.671
T	1020.0	1025.0	1030.0	1035.0	1040.0	1045.0	1050.0	1055.0
H	161.904	163.275	164.647	166.021	167.395	168.771	170.148	171.526
P	35.364	36.068	36.783	37.509	38.246	38.995	39.756	40.528
T	1060.0	1065.0	1070.0	1075.0	1080.0	1085.0	1090.0	1095.0
H	172.905	174.285	175.667	177.049	178.433	179.818	181.204	182.591
P	41.312	42.108	42.917	43.737	44.570	45.416	46.275	47.146
T	1100.0	1105.0	1110.0	1115.0	1120.0	1125.0	1130.0	1135.0
H	183.979	185.368	186.758	188.150	189.542	190.936	192.331	193.727
P	48.031	48.928	49.839	50.764	51.702	52.654	53.620	54.600
T	1140.0	1145.0	1150.0	1155.0	1160.0	1165.0	1170.0	1175.0
H	195.124	196.522	197.922	199.322	200.724	202.127	203.531	204.936
P	55.594	56.603	57.627	58.665	59.718	60.787	61.870	62.969

4-282

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
52.944	29.188	.00067	.24723	.09309	0.00000	.65012	.00799	.68500	.00640

T	1180.0	1185.0	1190.0	1195.0	1200.0	1205.0	1210.0	1215.0
H	206.342	207.749	209.157	210.567	211.977	213.389	214.802	216.216
P	64.084	65.215	66.361	67.524	68.703	69.898	71.111	72.340
T	1220.0	1225.0	1230.0	1235.0	1240.0	1245.0	1250.0	1255.0
H	217.631	219.047	220.465	221.883	223.303	224.723	226.145	227.568
P	73.586	74.849	76.130	77.428	78.745	80.079	81.431	82.802
T	1260.0	1265.0	1270.0	1275.0	1280.0	1285.0	1290.0	1295.0
H	228.992	230.417	231.843	233.271	234.699	236.129	237.560	238.991
P	84.192	85.600	87.027	88.473	89.939	91.425	92.930	94.455
T	1300.0	1305.0	1310.0	1315.0	1320.0	1325.0	1330.0	1335.0
H	240.424	241.858	243.293	244.730	246.167	247.605	249.045	250.485
P	96.000	97.566	99.152	100.760	102.388	104.037	105.708	107.401
T	1340.0	1345.0	1350.0	1355.0	1360.0	1365.0	1370.0	1375.0
H	251.927	253.370	254.814	256.259	257.705	259.152	260.600	262.050
P	109.115	110.853	112.612	114.394	116.199	118.027	119.878	121.753
T	1380.0	1385.0	1390.0	1395.0	1400.0	1405.0	1410.0	1415.0
H	263.500	264.951	266.404	267.858	269.312	270.768	272.225	273.683
P	123.651	125.573	127.520	129.492	131.488	133.508	135.555	137.626
T	1420.0	1425.0	1430.0	1435.0	1440.0	1445.0	1450.0	1455.0
H	275.142	276.602	278.063	279.526	280.989	282.453	283.919	285.385
P	139.724	141.847	143.997	146.173	148.376	150.606	152.863	155.148
T	1460.0	1465.0	1470.0	1475.0	1480.0	1485.0	1490.0	1495.0
H	286.853	288.321	289.791	291.262	292.733	294.206	295.680	297.155
P	157.461	159.802	162.171	164.568	166.995	169.451	171.936	174.451
T	1500.0	1505.0	1510.0	1515.0	1520.0	1525.0	1530.0	1535.0
H	298.631	300.108	301.585	303.065	304.545	306.026	307.508	308.991
P	176.996	179.571	182.177	184.814	187.481	190.181	192.912	195.675

P	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	M/DA
52.944	29.188	.00067	.24723	.09399	0.00000	.65012	.00799	.68500	.00640

T	1540.0	1545.0	1550.0	1555.0	1560.0	1565.0	1570.0	1575.0
H	310.475	311.960	313.447	314.93[illegible]	316.422	317.911	319.402	320.893
P	198.470	201.293	204.159	207.054	209.982	212.943	215.939	218.970
T	1580.0	1585.0	1590.0	1595.0	1600.0	1605.0	1610.0	1615.0
H	322.385	323.879	325.373	326.868	328.365	329.862	331.360	332.859
P	222.035	225.135	228.271	231.442	234.650	237.894	241.174	244.492
T	1620.0	1625.0	1630.0	1635.0	1640.0	1645.0	1650.0	1655.0
H	334.360	335.861	337.363	338.866	340.371	341.875	343.382	344.889
P	247.847	251.240	254.671	258.141	261.649	265.196	2[illegible]8.783	272.410
T	1660.0	1665.0	1670.0	1675.0	1680.0	1685.0	1690.0	1695.0
H	346.397	347.906	349.416	350.927	352.439	353.952	355.466	356.981
P	276.076	279.783	283.531	287.321	291.151	295.024	298.939	302.897
T	1700.0	1705.0	1710.0	1715.0	1720.0	1725.0	1730.0	1735.0
H	358.497	360.014	361.531	363.050	364.569	366.090	367.611	369.134
P	306.893	310.942	315.030	319.162	323.338	327.560	331.826	336.139
T	1740.0	1745.0	1750.0	1755.0	1760.0	1765.0	1770.0	1775.0
H	370.657	372.181	373.706	375.232	376.759	378.287	379.816	381.346
P	340.498	344.903	349.354	353.854	358.400	362.995	367.639	372.331
T	1780.0	1785.0	1790.0	1795.0	1800.0	1805.0	1810.0	1815.0
H	382.877	384.408	385.941	387.474	389.008	390.544	392.080	393.617
P	377.072	381.863	386.705	391.596	396.539	401.533	406.579	411.677
T	1820.0	1825.0	1830.0	1835.0	1840.0	1845.0	1850.0	1855.0
H	395.154	396.693	398.233	399.773	401.315	402.857	404.400	405.944
P	416.828	42[illegible].031	427.289	432.600	437.965	443.386	448.861	454.393
T	1860.0	1865.0	1870.0	1875.0	1880.0	1885.0	1890.0	1895.0
H	407.489	409.035	410.581	412.129	413.677	415.226	416.776	418.327
P	459.980	465.624	471.325	477.084	482.901	488.776	494.710	500.703

P	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/OA	W/OA
52.944	29.138	.00067	.24723	.09399	0.00000	.65012	.03799	.06800	.00040

T	1900.0	1905.0	1910.0	1915.0	1920.0	1925.0	1930.0	1935.0
H	419.879	421.432	422.985	424.539	426.094	427.650	429.207	430.765
P	506.757	512.870	519.045	525.281	531.578	537.938	544.360	550.846
T	1940.0	1945.0	1950.0	1955.0	1960.0	1965.0	1970.0	1975.0
H	432.323	433.882	435.443	437.003	438.565	440.128	441.691	443.255
P	557.396	564.009	570.688	577.432	584.241	591.117	598.059	605.069
T	1980.0	1985.0	1990.0	1995.0	2000.0	2005.0	2010.0	2015.0
H	444.820	446.386	447.952	449.520	451.088	452.657	454.227	455.797
P	612.147	619.293	626.507	633.791	641.145	648.570	656.065	663.632
T	2020.0	2025.0	2030.0	2035.0	2040.0	2045.0	2050.0	2055.0
H	[illegible]	458.941	460.514	462.087	463.662	465.237	466.813	468.390
P	[illegible]	678.982	685.767	694.025	702.558	710.565	718.648	726.806
T	2060.0	2065.0	2070.0	2075.0	2080.0	2085.0	2090.0	2095.0
H	469.967	471.546	473.125	474.704	476.285	477.866	479.448	481.031
P	735.041	743.353	751.743	760.211	768.758	777.384	786.090	794.876
T	2100.0	2105.0	2110.0	2115.0	2120.0	2125.0	2130.0	2135.0
H	482.615	484.199	485.784	487.370	488.956	490.544	492.132	493.720
P	803.744	812.693	821.725	830.840	840.038	849.320	858.687	868.139
T	2140.0	2145.0	2150.0	2155.0	2160.0	2165.0	2170.0	2175.0
H	495.310	496.900	498.491	500.082	501.675	503.268	504.862	506.456
P	877.677	887.302	897.014	906.814	916.702	926.680	936.747	946.904
T	2180.0	2185.0	2190.0	2195.0	2200.0	2205.0	2210.0	2215.0
H	508.051	509.647	511.244	512.841	514.439	516.038	517.637	519.237
P	957.153	967.493	977.925	988.450	999.069	1009.783	1020.591	1031.495
T	2220.0	2225.0	2230.0	2235.0	2240.0	2245.0	2250.0	2255.0
H	520.838	522.439	524.041	525.644	527.248	528.852	530.457	532.062
P	1042.495	1053.592	1064.787	1076.080	1087.472	1098.963	1110.555	1122.248

P	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	W/DA
52.944	29.188	.00967	.24723	.09399	0.00000	.65012	.00799	.68500	.00640

T	2260.0	2265.0	2270.0	2275.0	2280.0	2285.0	2290.0	2295.0
H	533.669	535.275	536.883	538.491	540.100	541.709	543.320	544.930
P	1134.043	1145.941	1157.941	1170.046	1182.255	1194.569	1206.989	1219.517
T	2300.0	2305.0	2310.0	23[illegible]	2320.0	2325.0	2330.0	2335.0
H	546.542	548.154	549.767	55[illegible]	552.994	554.609	556.225	557.841
P	1232.151	1244.894	1257.746	1270.[illegible]	1283.779	1296.962	1310.258	1323.665
T	2340.0	2345.0	2350.0	2355.0	2360.0	2365.0	2370.0	2375.0
H	559.457	561.075	562.692	564.311	565.930	567.550	569.170	570.792
P	1337.187	1350.822	1364.572	1378.438	1392.421	1406.521	1420.739	1435.076
T	2380.0	2385.0	2390.0	2395.0	2400.0	2405.0	2410.0	2415.0
H	572.413	574.036	575.658	577.282	578.906	580.531	582.156	583.782
P	1449.533	1464.110	1478.808	1493.628	1508.571	1523.638	1538.829	1554.146
T	2420.0	2425.0	2430.0	2435.0	2440.0	2445.0	2450.0	2455.0
H	585.409	587.036	588.664	590.293	591.922	593.551	595.181	596.812
P	1569.589	1585.158	1600.856	1616.682	1632.637	1648.723	1664.939	1681.288
T	2460.0	2465.0	2470.0	2475.0	2480.0	2485.0	2490.0	2495.0
H	598.444	600.076	601.708	603.342	604.975	606.610	608.245	609.880
P	1697.770	1714.385	1731.135	1748.020	1765.042	1782.200	1799.497	1816.933
T	2500.0	2505.0	2510.0	2515.0	2520.0	2525.0	2530.0	2535.0
H	611.516	613.153	614.790	616.428	618.067	619.706	621.345	622.986
P	1834.508	1852.225	1870.082	1888.083	1906.227	1924.515	1942.948	1961.528
T	2540.0	2545.0	2550.0	2555.0	2560.0	2565.0	2570.0	2575.0
H	624.625	626.268	627.910	629.552	631.195	632.839	634.483	636.127
P	1980.254	1999.129	2018.152	2037.326	2056.650	2076.126	2095.755	2115.538
T	2580.0	2585.0	2590.0	2595.0	2600.0	2605.0	2610.0	2615.0
H	637.773	639.419	641.065	642.712	644.360	646.008	647.656	649.305
P	2135.475	2155.558	2175.817	2196.224	2216.789	2237.514	2258.400	2279.447

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	M/DA
52.944	29.188	.00067	.24723	.09399	0.00000	.65012	.00799	.06500	.00040

T	2620.0	2625.0	2630.0	2635.0	2640.0	2645.0	2650.0	2655.0
H	650.955	652.605	654.255	655.908	657.560	659.212	660.865	662.519
P	2300.657	2322.030	2343.563	2365.271	2387.141	2409.178	2431.384	2453.760
T	2660.0	2665.0	2670.0	2675.0	2680.0	2685.0	2690.0	2695.0
H	664.173	665.827	667.483	669.138	670.795	672.452	674.109	675.767
P	2476.305	2499.024	2521.915	2544.980	2568.220	2591.635	2615.228	2638.999
T	2700.0	2705.0	2710.0	2715.0	2720.0	2725.0	2730.0	2735.0
H	677.425	679.084	680.744	682.404	684.065	685.726	687.387	689.050
P	2662.949	2687.080	2711.392	2735.886	2760.564	2785.427	2810.475	2835.710
T	2740.0	2745.0	2750.0	2755.0	2760.0	2765.0	2770.0	2775.0
H	690.712	692.376	694.039	695.704	697.369	699.034	700.700	702.366
P	2861.134	2886.747	2912.550	2938.544	2964.732	2991.113	3017.689	3044.461
T	2780.0	2785.0	2790.0	2795.0	2800.0	2805.0	2810.0	2815.0
H	704.033	705.701	707.369	709.038	710.707	712.376	714.047	715.717
P	3071.430	3098.598	3125.965	3153.534	3181.304	3209.278	3237.456	3265.840
T	2620.0	2825.0	2830.0	2835.0	2840.0	2845.0	2850.0	2855.0
H	717.388	719.060	720.733	722.405	724.079	725.753	727.427	729.102
P	3294.430	3323.229	3352.237	3381.456	3410.886	3440.530	3470.388	3500.461
T	2860.0	2865.0	2870.0	2875.0	2880.0	2885.0	2896.0	2895.0
H	730.777	732.453	734.130	735.807	737.484	739.162	740.841	742.520
P	3530.752	3561.260	3591.988	3622.937	3654.108	3685.502	3717.121	3748.966
T	2900.0	2905.0	2910.0	2915.0	2920.0	2925.0	2930.0	2935.0
H	744.200	745.880	747.561	749.242	750.924	752.606	754.289	755.972
P	3781.033	3813.338	3845.869	3878.631	3911.625	3944.854	3978.318	4012.018
T	2940.0	2945.0	2950.0	2955.0	0.0	0.0	0.0	0.0
H	757.656	759.341	761.026	762.711	0.000	0.000	0.000	0.000
P	4045.957	4080.135	4114.554	4149.216	0.000	0.000	0.000	0.000

P	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	M/DA
53.170	29.364	.08637	.15500	.06130	0.00000	.68732	.01002	.34250	.00640

T	460.0	465.0	470.0	475.0	480.0	485.0	490.0	495.0
H	14.790	16.027	17.264	18.502	19.740	20.979	22.219	23.460
P	1.655	1.721	1.789	1.859	1.931	2.005	2.081	2.159
T	500.0	505.0	510.0	515.0	520.0	525.0	530.0	535.0
H	24.701	25.943	27.185	28.428	29.672	30.917	32.162	33.407
P	2.240	2.322	2.407	2.494	2.583	2.675	2.769	2.865
T	540.0	545.0	550.0	555.0	560.0	565.0	570.0	575.0
H	34.654	35.901	37.149	38.397	39.646	40.896	42.147	43.398
P	2.964	3.065	3.169	3.276	3.385	3.497	3.612	3.729
T	580.0	585.0	590.0	595.0	600.0	605.0	610.0	615.0
H	44.650	45.902	47.156	48.410	49.664	50.920	52.176	53.432
P	3.849	3.972	4.098	4.227	4.359	4.494	4.632	4.773
T	620.0	625.0	630.0	635.0	640.0	645.0	650.0	655.0
H	54.690	55.948	57.207	58.467	59.727	60.988	62.250	63.512
P	4.917	5.065	5.216	5.370	5.528	5.689	5.853	6.021
T	660.0	665.0	670.0	675.0	680.0	685.0	690.0	695.0
H	64.776	65.040	67.305	68.570	69.837	71.104	72.372	73.640
P	6.193	6.368	5.548	6.730	6.917	7.107	7.302	7.500
T	700.0	705.0	710.0	715.0	720.0	725.0	730.0	735.0
H	74.910	76.180	77.451	78.723	79.995	81.269	82.543	83.818
P	7.703	7.909	8.120	8.335	8.554	8.777	9.005	9.237
T	740.0	745.0	750.0	755.0	760.0	765.0	770.0	775.0
H	85.094	86.370	87.648	88.926	90.205	91.485	92.766	94.047
P	9.474	9.716	9.962	10.212	10.468	10.728	10.993	11.263
T	780.0	785.0	790.0	795.0	800.0	805.0	810.0	815.0
H	95.330	96.613	97.897	99.182	100.468	101.754	103.042	104.330
P	11.539	11.819	12.104	12.395	12.691	12.992	13.298	13.611

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	W/DA
53.170	29.064	.08637	.15500	.06130	0.00000	.68732	.01002	.34250	.00640

T	820.0	825.0	830.0	835.0	840.0	845.0	850.0	855.0
H	105.620	106.910	108.201	109.493	110.786	112.079	113.374	114.669
P	13.929	14.252	14.581	14.916	15.257	15.603	15.956	16.315
T	860.0	865.0	870.0	875.0	880.0	885.0	890.0	895.0
H	115.965	117.263	118.561	119.860	121.160	122.461	123.763	125.066
P	16.680	17.051	17.428	17.812	18.202	18.599	19.003	19.413
T	900.0	905.0	910.0	915.0	920.0	925.0	930.0	935.0
H	126.369	127.674	128.979	130.286	131.593	132.902	134.211	135.521
P	19.831	20.254	20.685	21.123	21.568	22.020	22.479	22.946
T	940.0	945.0	950.0	955.0	960.0	965.0	970.0	975.0
H	136.832	138.144	139.457	140.771	142.086	143.402	144.719	146.036
P	23.421	23.903	24.392	24.890	25.395	25.908	26.429	26.958
T	980.0	985.0	990.0	995.0	1000.0	1005.0	1010.0	1015.0
H	147.355	148.675	149.995	151.317	152.639	153.963	155.287	156.613
P	27.495	28.042	28.595	29.158	29.730	30.309	30.898	31.496
T	1020.0	1025.0	1030.0	1035.0	1040.0	1045.0	1050.0	1055.0
H	157.939	159.267	160.595	161.924	163.255	164.586	165.918	167.252
P	32.102	32.718	33.343	33.977	34.620	35.273	35.936	36.608
T	1060.0	1065.0	1070.0	1075.0	1080.0	1085.0	1090.0	1095.0
H	168.586	169.921	171.257	172.594	173.933	175.272	176.612	177.953
P	37.290	37.982	38.684	39.397	40.119	40.852	41.595	42.349
T	1100.0	1105.0	1110.0	1115.0	1120.0	1125.0	1130.0	1135.0
H	179.295	180.638	181.982	183.328	184.674	186.021	187.369	188.718
P	43.114	43.889	44.676	45.473	46.282	47.102	47.933	48.776
T	1140.0	1145.0	1150.0	1155.0	1160.0	1165.0	1170.0	1175.0
H	190.068	191.419	192.771	194.124	195.478	196.833	198.189	199.546
P	49.630	50.496	51.377	52.265	53.167	54.082	55.009	55.948

P	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
53.170	29.064	.05637	.15500	.06130	0.00000	.68732	.01002	.34250	.00640

T	1180.0	1185.0	1190.0	1195.0	1200.0	1205.0	1210.0	1215.0
H	200.905	202.264	203.624	204.985	206.347	207.710	209.074	210.439
P	56.900	57.865	58.843	59.834	60.838	61.856	62.887	63.931
T	1220.0	1225.0	1230.0	1235.0	1240.0	1245.0	1250.0	1255.0
H	211.805	213.172	214.540	215.909	217.279	218.650	220.022	221.395
P	64.990	66.062	67.148	68.248	69.363	70.492	71.635	72.794
T	1260.0	1265.0	1270.0	1275.0	1280.0	1285.0	1290.0	1295.0
H	222.763	224.144	225.520	226.897	228.275	229.654	231.034	232.415
P	73.967	75.155	76.358	77.577	78.811	80.061	81.336	82.608
T	1300.0	1305.0	1310.0	1315.0	1320.0	1325.0	1330.0	1335.0
H	233.797	235.180	236.564	237.949	239.335	240.722	242.110	243.498
P	83.905	85.219	86.549	87.896	89.259	90.640	92.037	93.451
T	1340.0	1345.0	1350.0	1355.0	1360.0	1365.0	1370.0	1375.0
H	244.888	246.279	247.671	249.064	250.458	251.852	253.248	254.645
P	94.883	96.332	97.799	99.284	100.787	102.308	103.848	105.406
T	1380.0	1385.0	1390.0	1395.0	1400.0	1405.0	1410.0	1415.0
H	256.043	257.441	258.841	260.242	261.643	263.046	264.449	265.854
P	106.982	108.576	110.192	111.826	113.479	115.152	116.845	118.557
T	1420.0	1425.0	1430.0	1435.0	1440.0	1445.0	1450.0	1455.0
H	267.260	268.666	270.073	271.482	272.891	274.301	275.713	277.125
P	120.290	122.043	123.816	125.610	127.425	129.261	131.118	132.997
T	1460.0	1465.0	1470.0	1475.0	1480.0	1485.0	1490.0	1495.0
H	278.538	279.952	281.367	282.783	284.200	285.618	287.037	288.457
P	134.897	136.820	138.764	140.730	142.719	144.730	146.764	148.822
T	1500.0	1505.0	1510.0	1515.0	1520.0	1525.0	1530.0	1535.0
H	289.879	291.299	292.722	294.146	295.570	296.996	298.422	299.849
P	150.902	153.006	155.133	157.285	159.460	161.660	163.884	166.132

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	M/DA
53.179	29.064	.08637	.15500	.06130	0.00000	.68732	.01002	.34250	.00640

T	1540.0	1545.0	1550.0	1555.0	1560.0	1565.0	1570.0	1575.0
H	301.278	302.707	304.137	305.568	307.000	308.433	309.867	311.301
P	168.406	170.705	173.029	175.378	177.753	180.155	182.582	185.036
T	1580.0	1585.0	1590.0	1595.0	1600.0	1605.0	1610.0	1615.0
H	312.737	314.173	315.611	317.049	318.488	319.928	321.369	322.811
P	187.516	190.024	192.558	195.120	197.709	200.326	202.971	205.644
T	1620.0	1625.0	1630.0	1635.0	1640.0	1645.0	1650.0	1655.0
H	324.254	325.698	327.143	328.588	330.034	331.482	332.930	334.379
P	208.346	211.076	213.835	216.624	219.442	222.269	225.167	228.075
T	1660.0	1665.0	1670.0	1675.0	1680.0	1685.0	1690.0	1695.0
H	335.829	337.280	338.731	340.184	341.637	343.091	344.546	346.002
P	231.013	233.981	236.981	240.012	243.074	246.168	249.293	252.451
T	1700.0	1705.0	1710.0	1715.0	1720.0	1725.0	1730.0	1735.0
H	347.459	348.917	350.376	351.835	353.295	354.756	356.218	357.681
P	255.641	258.864	262.120	265.409	268.732	272.088	275.478	278.903
T	1740.0	1745.0	1750.0	1755.0	1760.0	1765.0	1770.0	1775.0
H	359.145	360.609	362.075	363.541	365.008	366.475	367.944	369.414
P	282.362	285.855	289.384	292.949	296.548	300.184	303.856	307.564
T	1780.0	1785.0	1790.0	1795.0	1800.0	1805.0	1810.0	1815.0
H	370.884	372.355	373.827	375.299	376.773	378.247	379.722	381.198
P	311.310	315.092	318.911	322.768	326.663	330.596	334.568	338.578
T	1820.0	1825.0	1830.0	1835.0	1840.0	1845.0	1850.0	1855.0
H	382.675	384.153	385.631	387.110	388.590	390.071	391.552	393.035
P	342.627	346.716	350.844	355.013	359.221	363.470	367.760	372.091
T	1860.0	1865.0	1870.0	1875.0	1880.0	1885.0	1890.0	1895.0
H	394.518	396.001	397.486	398.971	400.457	401.944	403.432	404.920
P	376.464	380.878	385.334	389.833	394.374	398.959	403.586	408.258

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/OA	H/OA
53.170	29.064	.08637	.15500	.06130	0.00000	.68732	.01002	.34250	.00640
T	1900.0	1905.0	1910.0	1915.0	1920.0	1925.0	1930.0	1335.0	
H	406.410	407.900	409.393	410.882	412.374	413.867	415.361	416.855	
P	412.973	417.733	422.537	427.386	432.280	437.220	442.205	447.238	
T	1940.0	1945.0	1950.0	1955.0	1960.0	1965.0	1970.0	1975.0	
H	418.350	419.846	421.343	422.840	424.338	425.837	427.337	428.837	
P	452.317	457.443	462.616	467.836	473.104	478.421	483.786	489.201	
T	1980.0	1985.0	1990.0	1995.0	2000.0	2005.0	2010.0	2015.0	
H	430.338	431.839	433.342	434.845	436.349	437.853	439.359	440.864	
P	494.664	500.177	505.740	511.354	517.018	522.733	528.500	534.318	
T	2020.0	2025.0	2030.0	2035.0	2040.0	2045.0	2050.0	2055.0	
H	442.371	443.878	445.386	446.895	448.405	449.915	451.425	452.937	
P	540.189	546.112	552.088	558.117	564.200	570.336	576.527	582.773	
T	2060.0	2065.0	2070.0	2075.0	2080.0	2085.0	2090.0	2095.0	
H	454.449	455.962	457.475	458.989	460.504	462.020	463.536	465.052	
P	589.074	595.430	601.842	608.310	614.835	621.417	628.056	634.753	
T	2100.0	2105.0	2110.0	2115.0	2120.0	2125.0	2130.0	2135.0	
H	466.570	468.088	469.607	471.126	472.646	474.167	475.688	477.210	
P	641.508	648.322	655.194	662.126	669.117	676.169	683.281	690.454	
T	2140.0	2145.0	2150.0	2155.0	2160.0	2165.0	2170.0	2175.0	
H	478.733	480.256	481.780	483.304	484.830	486.355	487.882	489.409	
P	697.688	704.984	712.342	719.763	727.247	734.794	742.404	750.079	
T	2180.0	2185.0	2190.0	2195.0	2200.0	2205.0	2210.0	2215.0	
H	490.936	492.465	493.993	495.523	497.053	498.584	500.115	501.647	
P	757.819	765.623	773.493	781.429	789.431	797.500	805.636	813.840	
T	2220.0	2225.0	2230.0	2235.0	2240.0	2245.0	2250.0	2255.0	
H	503.179	504.713	506.246	507.781	509.316	510.851	512.387	513.924	
P	822.111	830.451	838.860	847.339	855.887	864.505	873.194	881.954	

P	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
53.170	29.064	.08637	.15500	.16130	0.00000	.68732	.01002	.34250	.00640

T	2260.0	2265.0	2270.0	2275.0	2280.0	2285.0	2290.0	2295.0
H	515.461	516.999	519.537	520.076	521.616	523.156	524.697	526.238
P	890.785	899.690	908.666	917.715	926.838	935.034	945.305	954.651
T	2300.0	2305.0	2310.0	2315.0	2320.0	2325.0	2330.0	2335.0
H	527.780	529.323	530.865	532.409	533.953	535.498	537.043	538.589
P	964.072	973.568	983.141	992.790	1002.517	1012.321	1022.204	1032.165
T	2340.0	2345.0	2350.0	2355.0	2360.0	2365.0	2370.0	2375.0
H	540.136	541.683	543.230	544.778	546.327	547.876	549.426	550.976
P	1042.205	1052.324	1062.524	1072.804	1083.165	1093.608	1104.133	1114.740
T	2380.0	2385.0	2390.0	2395.0	2400.0	2405.0	2410.0	2415.0
H	552.527	554.078	555.630	557.182	558.735	560.289	561.843	563.397
P	1125.431	1136.205	1147.063	1158.005	1169.033	1180.146	1191.345	1202.632
T	2420.0	2425.0	2430.0	2435.0	2440.0	2445.0	2450.0	2455.0
H	564.952	566.508	568.064	569.621	571.178	572.736	574.294	575.853
P	1214.005	1225.465	1237.015	1248.653	1260.380	1272.197	1284.104	1296.102
T	2460.0	2465.0	2470.0	2475.0	2480.0	2485.0	2490.0	2495.0
H	577.412	578.972	580.532	582.093	583.655	585.217	586.779	588.342
P	1308.192	1320.373	1332.647	1345.014	1357.475	1370.030	1382.680	1395.425
T	2500.0	2505.0	2510.0	2515.0	2520.0	2525.0	2530.0	2535.0
H	589.906	591.469	593.034	594.599	596.165	597.731	599.297	600.864
P	140[illegible].266	1421.203	1434.237	1447.369	1460.599	1473.928	1487.356	1500.884
T	2540.0	2545.0	2550.0	2555.0	2560.0	2565.0	2570.0	2575.0
H	602.432	604.000	605.568	607.138	608.707	610.277	611.848	613.419
P	1514.512	1528.242	1542.073	1556.006	1570.043	1584.182	1598.426	1612.775
T	2580.0	2585.0	2590.0	2595.0	2600.0	2605.0	2610.0	2615.0
H	614.991	616.563	618.135	619.709	621.282	622.856	624.431	626.006
P	1627.228	1641.788	1656.454	1671.227	1686.108	1701.097	1716.195	1731.403

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	M/DA
53.170	29.064	.08637	.15500	.06130	0.00000	.68732	.01002	.34250	.00640

T	2620.0	2625.0	2630.0	2635.0	2640.0	2645.0	2650.0	2655.0
H	627.582	629.158	630.735	632.312	633.890	635.468	637.046	638.626
P	1746.721	1762.150	1777.690	1793.343	1809.108	1824.987	1840.980	1857.088
T	2660.0	2665.0	2670.0	2675.0	2680.0	2685.0	2690.0	2695.0
H	640.205	641.786	643.366	644.947	646.529	648.111	649.694	651.277
P	1873.311	1889.651	1906.107	1922.680	1939.372	1955.182	1973.112	1990.162
T	2700.0	2705.0	2710.0	2715.0	2720.0	2725.0	2730.0	2735.0
H	652.861	654.445	656.030	657.615	659.201	660.768	662.374	663.962
P	2007.333	2024.626	2042.040	2059.578	2077.239	2095.025	2112.935	2130.971
T	2740.0	2745.0	2750.0	2755.0	2760.0	2765.0	2770.0	2775.0
H	665.549	667.138	668.727	670.316	671.906	673.496	675.087	676.679
P	2149.134	2167.424	2185.842	2204.389	2223.065	2241.871	2260.808	2279.877
T	2780.0	2785.0	2790.0	2795.0	2800.0	2805.0	2810.0	2815.0
H	678.271	679.863	681.455	683.050	684.644	686.238	687.833	689.429
P	2299.079	2318.412	2337.880	2357.483	2377.221	2397.096	2417.107	2437.256
T	2820.0	2825.0	2830.0	2835.0	2840.0	2845.0	2850.0	2855.0
H	691.025	692.622	694.219	695.817	697.415	699.014	700.614	702.213
P	2457.544	2477.970	2498.537	2519.245	2540.095	2561.087	2582.223	2603.503
T	2860.0	2865.0	2870.0	2875.0	2880.0	2885.0	2890.0	2895.0
H	703.814	705.415	707.017	708.619	710.221	711.825	713.428	715.033
P	2624.927	2646.498	2668.215	2690.080	2712.093	2734.255	2756.567	2779.030
T	2900.0	2905.0	2910.0	2915.0	2920.0	2925.0	2930.0	2935.0
H	716.638	718.243	719.849	721.456	723.063	724.671	726.279	727.888
P	2801.645	2824.413	2847.334	2870.409	2893.640	2917.026	2940.570	2964.272
T	2940.0	2945.0	2950.0	2955.0	0.0	0.0	0.0	0.0
H	729.497	731.107	732.718	734.329	0.000	0.000	0.000	0.000
P	2988.132	3012.153	3036.334	3060.677	0.000	0.000	0.000	0.000

P	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	W/DA
53.273	29.007	.12551	.11288	.04637	0.00000	.70431	.01094	.22830	.00640

T	460.0	465.0	470.0	475.0	480.0	485.0	490.0	495.0
H	14.694	15.922	17.150	18.378	19.607	20.837	22.067	23.297
P	1.648	1.714	1.781	1.850	1.920	1.993	2.068	2.145
T	500.0	505.0	510.0	515.0	520.0	525.0	530.0	535.0
H	24.529	25.759	26.991	28.224	29.457	30.691	31.925	33.159
P	2.274	2.305	2.388	2.473	2.561	2.651	2.743	2.837
T	540.0	545.0	550.0	555.0	560.0	565.0	570.0	575.0
H	34.394	35.630	36.865	38.103	39.340	40.578	41.816	43.055
P	2.934	3.033	3.135	3.239	3.346	3.455	3.567	3.682
T	580.0	585.0	590.0	595.0	600.0	605.0	610.0	615.0
H	44.295	45.535	46.775	48.017	49.259	50.501	51.744	52.988
P	3.799	3.919	4.042	4.167	4.296	4.427	4.561	4.699
T	620.0	625.0	630.0	635.0	640.0	64[illegible].0	650.0	655.0
H	54.232	55.477	56.723	57.969	59.215	60.463	61.711	62.959
P	4.839	4.982	5.129	5.278	5.431	5.588	5.747	5.910
T	660.0	665.0	670.0	675.0	680.0	685.0	690.0	695.0
H	64.208	65.458	66.709	67.960	69.212	70.464	71.718	72.971
P	6.075	6.246	6.419	6.596	6.776	6.961	7.148	7.340
T	700.0	705.0	710.0	715.0	720.0	725.0	730.0	735.0
H	74.225	75.481	76.737	77.994	79.251	80.509	81.768	83.027
P	7.535	7.734	7.938	8.145	8.356	8.571	8.790	9.014
T	740.0	745.0	750.0	755.0	760.0	765.0	770.0	775.0
H	84.288	85.548	86.810	88.072	89.336	90.599	91.864	93.129
P	9.242	9.474	9.710	9.951	10.196	10.446	10.700	10.960
T	780.0	785.0	790.0	795.0	800.0	805.0	810.0	815.0
H	94.395	95.662	96.930	98.198	99.467	100.737	102.008	103.280
P	11.223	11.492	11.765	12.043	12.327	12.615	12.908	13.206

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
53.273	29.007	.12551	.11283	.04637	0.00000	.70431	.01094	.02030	.00640

T	820.0	825.0	830.0	835.0	840.0	845.0	850.0	855.0
H	104.552	105.325	107.099	108.374	109.649	110.925	112.202	113.480
P	13.510	13.319	14.133	14.453	14.778	15.108	15.444	15.786
T	860.0	865.0	870.0	875.0	880.0	885.0	890.0	895.0
H	114.759	116.039	117.319	118.600	119.882	121.165	122.449	123.733
P	16.134	16.487	16.846	17.212	17.583	17.960	18.343	18.733
T	900.0	905.0	910.0	915.0	920.0	925.0	930.0	935.0
H	125.019	126.305	127.592	128.880	130.169	131.458	132.749	134.040
P	19.179	19.531	19.940	20.355	20.777	21.206	21.641	22.083
T	940.0	945.0	950.0	955.0	960.0	965.0	970.0	975.0
H	135.333	136.626	137.920	139.215	140.510	141.807	143.104	144.403
P	22.532	22.988	23.451	23.922	24.399	24.884	25.376	25.876
T	980.0	985.0	990.0	995.0	1000.0	1005.0	1010.0	1015.0
H	145.702	147.002	148.303	149.605	150.908	152.212	153.517	154.822
P	26.383	26.898	27.420	27.951	28.489	29.035	29.590	30.152
T	1020.0	1025.0	1030.0	1035.0	1040.0	1045.0	1050.0	1055.0
H	156.129	157.436	158.744	160.053	161.363	162.674	163.986	165.299
P	30.723	31.302	31.889	32.485	33.090	33.703	34.325	34.956
T	1060.0	1065.0	1070.0	1075.0	1080.0	1085.0	1090.0	1095.0
H	166.613	167.928	169.243	170.560	171.877	173.195	174.515	175.835
P	35.595	36.245	36.904	37.571	38.248	38.934	39.630	40.336
T	1100.0	1105.0	1110.0	1115.0	1120.0	1125.0	1130.0	1135.0
H	177.156	178.478	179.801	181.125	182.450	183.776	185.102	186.430
P	41.051	41.776	42.512	43.257	44.012	44.778	45.554	46.341
T	1140.0	1145.0	1150.0	1155.0	1160.0	1165.0	1170.0	1175.0
H	187.759	189.088	190.419	191.750	193.082	194.416	195.750	197.085
P	47.138	47.946	48.765	49.595	50.435	51.287	52.150	53.025

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
53.273	29.007	.12551	.11288	.04637	0.00000	.70431	.01094	.22830	.00640

T	1180.0	1185.0	1190.0	1195.0	1200.0	1205.0	1210.0	1215.0
H	196.421	199.7[illegible]	[illegible]1.095	202.435	203.775	205.116	206.457	207.800
P	53.911	54.808	55.718	56.639	57.572	58.517	59.474	60.444
T	1220.0	1225.0	1230.0	1235.0	1240.0	1245.0	1250.0	1255.0
H	209.144	210.488	211.834	213.180	214.528	215.876	217.225	218.576
P	61.426	62.421	63.428	64.448	65.481	66.527	67.586	68.659
T	1260.0	1265.0	1270.0	1275.0	1280.0	1285.0	1290.0	1295.0
H	219.927	221.279	222.632	223.986	225.341	226.697	228.053	229.411
P	69.745	70.844	71.957	73.084	74.225	75.380	76.549	77.732
T	1300.0	1305.0	1310.0	1315.0	1320.0	1325.0	1330.0	1335.0
H	230.770	232.130	233.490	234.852	236.214	237.578	238.942	240.307
P	78.930	80.142	81.370	82.612	83.869	85.141	86.429	87.732
T	1340.0	1345.0	1350.0	1355.0	1360.0	1365.0	1370.0	1375.0
H	241.673	243.040	244.409	245.778	247.147	248.518	249.890	251.263
P	89.050	90.384	91.735	93.101	94.493	95.881	97.296	98.728
T	1380.0	1385.0	1390.0	1395.0	1400.0	1405.0	1410.0	1415.0
H	252.637	254.011	255.387	256.763	258.140	259.519	260.898	262.278
P	100.175	101.641	103.124	104.623	106.140	107.674	109.226	110.796
T	1420.0	1425.0	1430.0	1435.0	1440.0	1445.0	1450.0	1455.0
H	263.659	265.041	266.424	267.808	269.192	270.578	271.965	273.352
P	112.384	113.989	115.614	117.256	118.917	120.597	122.296	124.014
T	1460.0	1465.0	1470.0	1475.0	1480.0	1485.0	1490.0	1495.0
H	274.740	276.130	277.520	278.911	280.303	281.696	283.090	284.484
P	125.751	127.598	129.284	131.080	132.896	134.732	136.589	138.465
T	1500.0	1505.0	1510.0	1515.0	1520.0	1525.0	1530.0	1535.0
H	285.880	287.276	288.674	290.072	291.471	292.871	294.272	295.674
P	140.363	142.281	144.220	146.181	148.162	150.165	152.190	154.237

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	M/DA
53.273	29.107	.12551	.11288	.04637	0.00000	.70431	.01094	.22630	.00640

T	1540.0	1545.0	1550.0	1555.0	1560.0	1565.0	1570.0	1575.0
H	297.977	298.430	299.865	301.290	302.696	304.103	305.511	306.920
P	156.305	158.396	160.513	162.646	164.805	166.986	169.191	171.419
T	1580.0	1565.0	1590.0	1595.0	1600.0	1605.0	1610.0	1615.0
H	308.330	309.740	311.152	312.564	313.977	315.391	316.806	318.222
P	173.671	175.947	178.246	180.570	182.918	185.290	187.687	190.109
T	1520.0	1625.0	1630.0	1635.0	1640.0	1545.0	1650.0	1655.0
H	319.639	321.056	322.474	323.893	325.313	326.734	328.156	329.578
P	192.555	195.029	197.526	200.050	202.600	205.175	207.777	210.406
T	1660.0	1665.0	1670.0	1675.0	1680.0	1685.0	1690.0	1695.0
H	331.001	332.426	333.851	335.276	336.703	338.131	339.559	340.988
P	213.061	215.743	218.453	221.189	223.954	226.746	229.566	232.414
T	1700.0	1705.0	1710.0	1715.0	1720.0	1725.0	1730.0	1735.0
H	342.418	343.849	345.280	346.713	348.146	349.580	351.014	352.450
P	235.291	238.196	241.131	244.094	247.087	250.109	253.162	256.244
T	1740.0	1745.0	1750.0	1755.0	1760.0	1765.0	1770.0	1775.0
H	353.886	355.324	356.762	358.200	359.640	361.080	362.521	363.963
P	259.356	262.499	265.673	268.877	272.113	275.380	278.678	282.009
T	1780.0	1785.0	1790.0	1795.0	1800.0	1805.0	1810.0	1815.0
H	365.405	366.849	368.294	369.739	371.184	372.631	374.078	375.526
P	285.371	288.766	292.194	295.654	299.147	302.674	306.234	309.828
T	1820.0	1825.0	1830.0	1835.0	1840.0	1845.0	1850.0	1855.0
H	376.975	378.425	379.875	381.326	382.778	384.231	385.684	387.138
P	313.456	317.118	320.815	324.546	328.313	332.115	335.952	339.825
T	1860.0	1865.0	1870.0	1875.0	1880.0	1885.0	1890.0	1895.0
H	388.593	390.048	391.[illegible]	392.962	394.419	395.878	397.337	398.797
P	343.734	347.680	351.662	355.681	359.737	363.830	367.961	372.130

P	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	M/DA
53.273	29.007	.12551	.11288	.14637	0.00000	.70431	.01094	.22830	.00640

T	1900.0	1905.0	1910.0	1915.0	1920.0	1925.0	1930.0	1935.0
H	400.257	401.719	403.181	404.644	406.107	407.571	409.036	410.502
P	376.337	380.582	384.866	389.189	393.551	397.953	402.394	406.676
T	1940.0	1945.0	1950.0	1955.0	1960.0	1965.0	1970.0	1975.0
H	411.969	413.435	414.902	416.371	417.840	419.310	420.780	422.251
P	411.397	415.960	420.563	425.207	429.893	434.620	439.390	444.202
T	1980.0	1985.0	1990.0	1995.0	2000.0	2005.0	2010.0	2015.0
H	423.723	425.195	426.669	428.142	429.616	431.092	432.567	434.044
P	449.056	453.953	458.894	463.677	468.905	473.976	479.092	484.253
T	2020.0	2025.0	2030.0	2035.0	2040.0	2045.0	2050.0	2055.0
H	435.521	436.999	438.477	439.956	441.436	442.916	444.397	445.878
P	489.458	494.709	500.005	505.347	510.735	516.169	521.651	527.179
T	2060.0	2065.0	2070.0	2075.0	2080.0	2085.0	2090.0	2095.0
H	447.361	448.844	450.327	451.811	453.296	454.781	456.267	457.754
P	532.754	538.378	544.049	549.768	555.537	561.353	567.220	573.135
T	2100.0	2105.0	2110.0	2115.0	2120.0	2125.0	2130.0	2135.0
H	459.241	460.729	462.217	463.707	465.196	466.686	468.177	469.669
P	579.101	585.117	591.183	597.300	603.469	609.688	615.960	622.284
T	2140.0	2145.0	2150.0	2155.0	2160.0	2165.0	2170.0	2175.0
H	471.161	472.654	474.147	475.641	477.135	478.630	480.126	481.622
P	628.660	635.089	641.571	648.107	654.696	661.340	668.038	674.791
T	2180.0	2185.0	2190.0	2195.0	2200.0	2205.0	2210.0	2215.0
H	483.119	484.616	486.114	487.613	489.112	490.611	492.112	493.612
P	681.599	688.462	695.382	702.357	709.389	716.479	723.625	730.829
T	2220.0	2225.0	2230.0	2235.0	2240.0	2245.0	2250.0	2255.0
H	495.114	496.616	498.118	499.621	501.125	502.629	504.134	505.639
P	738.091	745.411	752.790	760.228	767.726	775.283	782.900	790.578

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	M/DA
53.273	29.007	.12551	.11288	.04637	0.00000	.70431	.01094	.22830	.00640

T	2260.0	2265.0	2270.0	2275.0	2280.0	2285.0	2290.0	2295.0
H	507.143	508.651	510.158	511.665	513.173	514.682	516.191	517.700
P	798.317	806.117	813.978	821.902	829.887	837.936	846.048	854.223
T	2300.0	2305.0	2310.0	2315.0	2320.0	2325.0	2330.0	2335.0
H	519.210	520.721	522.232	523.744	525.256	526.769	528.282	529.796
P	862.462	870.765	879.133	887.566	896.065	904.629	913.259	921.956
T	2340.0	2345.0	2350.0	2355.0	2360.0	2365.0	2370.0	2375.0
H	531.310	532.825	534.340	535.856	537.373	538.889	540.407	541.925
P	930.720	939.551	948.450	957.418	966.453	975.558	984.732	993.976
T	2380.0	2385.0	2390.0	2395.0	2400.0	2405.0	2410.0	2415.0
H	543.443	544.962	546.481	548.001	549.522	551.043	552.564	554.086
P	1003.290	1012.675	1022.131	1031.658	1041.257	1050.928	1060.672	1070.489
T	2420.0	2425.0	2430.0	2435.0	2440.0	2445.0	2450.0	2455.0
H	555.609	557.131	558.655	560.179	561.703	563.228	564.754	566.279
P	1080.380	1090.344	1100.383	1110.497	1120.686	1130.951	1141.291	1151.709
T	2460.0	2465.0	2470.0	2475.0	2480.0	2485.0	2490.0	2495.0
H	567.806	569.333	570.860	572.388	573.916	575.445	576.974	578.504
P	1162.203	1172.775	1183.424	1194.152	1204.959	1215.845	1226.811	1237.856
T	2500.0	2505.0	2510.0	2515.0	2520.0	2525.0	2530.0	2535.0
H	580.034	581.565	583.096	584.628	586.160	587.693	589.226	590.760
P	1248.983	1260.190	1271.479	1282.850	1294.303	1305.839	1317.459	1329.162
T	2540.0	2545.0	2550.0	2555.0	2560.0	2565.0	2570.0	2575.0
H	592.294	593.829	595.364	596.899	598.436	599.972	601.509	603.047
P	1340.950	1352.822	1364.780	1376.823	1388.953	1401.170	1413.473	1425.864
T	2580.0	2585.0	2590.0	2595.0	2600.0	2605.0	2610.0	2615.0
H	604.585	606.123	607.662	609.201	610.741	612.282	613.823	615.364
P	1438.344	1450.912	1463.570	1476.317	1489.154	1502.082	1515.101	1528.212

P	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	M/DA
53.273	29.[illegible]7	.12551	.11288	.04637	0.00000	.70431	.0109[illegible]	.22830	.00640

T	2620.0	2625.0	2630.0	2635.0	2640.0	2645.0	2650.0	2655.0
H	616.905	618.448	619.991	621.534	623.078	624.622	626.167	627.712
P	1541.415	1554.711	1568.100	15[illegible]1.583	1595.160	1608.832	1622.599	1636.463
T	2660.0	2665.0	2670.0	2675.0	2680.0	2685.0	2690.0	2695.0
H	629.254	630.804	632.351	633.898	635.446	636.994	638.542	640.092
P	1650.422	1664.479	1678.633	1692.885	1707.236	1721.686	1736.236	1750.886
T	2700.0	2705.0	2710.0	2715.0	2720.0	2725.0	2730.0	2735.0
H	641.641	643.191	644.742	646.293	647.845	649.397	650.949	652.502
P	1765.[illegible]37	1780.489	1795.443	1810.500	1825.660	1840.923	1856.291	1871.763
T	2740.0	2745.0	2750.0	2755.0	2760.0	2765.0	2770.0	2775.0
H	654.056	655.610	657.165	658.720	660.276	661.832	663.388	664.946
P	1887.341	1903.025	1918.816	1934.713	1950.719	1966.833	1983.056	1999.388
T	2780.0	2785.0	2790.0	2795.0	2800.0	2805.0	2810.0	2815.0
H	666.503	668.061	669.620	671.179	672.739	674.299	675.860	677.422
P	2015.631	2032.385	20[illegible].050	2065.827	2082.716	2099.720	2116.837	2134.068
T	2820.0	2825.0	2830.0	2835.0	2840.0	2845.0	2850.0	2855.0
H	678.983	680.546	682.109	683.672	685.236	686.801	688.366	689.932
P	2151.415	2168.878	2186.458	2204.154	2221.969	2239.902	2257.954	2276.126
T	2860.0	2865.0	2870.0	2875.0	2880.0	2885.0	2890.0	2895.0
H	691.498	693.065	694.632	696.200	697.769	699.338	700.907	702.477
P	2294.419	2312.833	2331.368	2350.027	2368.808	2387.714	2406.744	2425.900
T	2900.0	2905.0	2910.0	2915.0	2920.0	2925.0	2930.0	2935.0
H	704.048	705.619	707.191	708.764	710.337	711.911	713.485	715.060
P	2445.182	2464.591	2484.127	2503.792	2523.585	2543.509	2563.562	2583.747
T	2940.0	2945.0	2950.0	2955.0	0.0	0.0	0.0	0.0
H	716.635	718.211	719.788	721.365	0.000	0.000	0.000	0.000
P	2604.064	2624.514	2645.098	2665.815	0.000	0.000	0.000	0.000

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
53.332	28.375	.14790	.09877	.13782	0.00000	.71403	.01147	.17125	.00640

T	460.0	465.0	470.0	475.0	480.0	485.0	490.0	495.0
H	14.643	15.852	17.085	18.308	19.531	20.755	21.979	23.204
P	1.645	1.789	1.775	1.844	1.914	1.986	2.060	2.137
T	500.0	505.0	510.0	515.0	520.0	525.0	530.0	535.0
H	24.429	25.655	26.881	28.107	29.334	30.561	31.789	33.017
P	2.215	2.295	2.377	2.462	2.548	2.637	2.728	2.822
T	540.0	545.0	550.0	555.0	560.0	565.0	570.0	575.0
H	34.246	35.475	36.704	37.934	39.165	40.396	41.628	42.859
P	2.917	3.015	3.116	3.219	3.324	3.432	3.542	3.655
T	580.0	585.0	590.0	595.0	600.0	605.0	610.0	615.0
H	44.092	45.325	46.558	47.792	49.027	50.262	51.498	52.734
P	3.771	3.889	4.010	4.134	4.260	4.389	4.521	4.657
T	620.0	625.0	630.0	635.0	640.0	545.0	650.0	655.0
H	53.970	55.208	56.445	57.684	58.923	60.162	61.402	62.643
P	4.795	4.936	5.080	5.227	5.377	5.531	5.687	5.847
T	660.0	665.0	670.0	675.0	680.0	685.0	690.0	695.0
H	63.884	65.126	66.369	67.611	68.854	70.099	71.343	72.589
P	6.011	6.177	6.347	6.521	6.698	6.878	7.062	7.250
T	700.0	705.0	710.0	715.0	720.0	725.0	730.0	735.0
H	73.835	75.081	76.329	77.577	78.825	80.075	81.325	82.575
P	7.441	7.637	7.835	8.038	8.245	8.456	8.670	8.889
T	740.0	745.0	750.0	755.0	760.0	765.0	770.0	775.0
H	83.826	85.078	86.331	87.584	88.838	90.093	91.348	92.604
P	9.112	9.338	9.570	9.805	10.045	10.289	10.537	10.790
T	780.0	785.0	790.0	795.0	800.0	805.0	810.0	815.0
H	93.861	95.118	96.377	97.635	98.895	100.155	101.417	102.678
P	11.047	11.309	11.576	11.847	12.124	12.405	12.690	12.981

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
53.332	28.975	.14790	.08877	.03782	0.00000	.71403	.01147	.17125	.00640

T	820.0	825.0	830.0	835.0	840.0	845.0	850.0	855.0
H	103.941	105.204	106.453	107.733	108.999	110.265	111.532	112.800
P	13.277	13.578	13.884	14.195	14.511	14.833	15.160	15.493
T	860.0	865.0	870.0	875.0	880.0	885.0	890.0	895.0
H	114.069	115.338	116.608	117.879	119.151	120.423	121.697	122.971
P	15.831	16.174	16.523	16.878	17.239	17.605	17.978	18.356
T	900.0	905.0	910.0	915.0	920.0	925.0	930.0	935.0
H	124.245	125.522	126.798	128.076	129.354	130.633	131.913	133.193
P	18.740	19.131	19.527	19.930	20.339	20.755	21.177	21.606
T	940.0	945.0	950.0	955.0	960.0	965.0	970.0	975.0
H	134.475	135.757	137.040	138.324	139.609	140.894	142.181	143.468
P	22.041	22.482	22.931	23.386	23.849	24.318	24.794	25.278
T	980.0	985.0	990.0	995.0	1000.0	1005.0	1010.0	1015.0
H	144.755	146.045	147.335	148.626	149.918	151.210	152.503	153.797
P	25.768	26.266	26.772	27.284	27.805	28.332	28.868	29.411
T	1020.0	1025.0	1030.0	1035.0	1040.0	1045.0	1050.0	1055.0
H	155.092	156.388	157.685	158.983	160.281	161.581	162.881	164.182
P	29.962	30.522	31.089	31.664	32.247	32.839	33.439	34.048
T	1060.0	1065.0	1070.0	1075.0	1080.0	1085.0	1090.0	1095.0
H	165.484	166.787	168.091	169.395	170.701	172.007	173.315	174.623
P	34.665	35.290	35.925	36.568	37.220	37.881	38.551	39.231
T	1100.0	1105.0	1110.0	1115.0	1120.0	1125.0	1130.0	1135.0
H	175.932	177.242	178.553	179.865	181.177	182.491	183.805	185.121
P	39.919	40.617	41.325	42.041	42.768	43.504	44.251	45.007
T	1140.0	1145.0	1150.0	1155.0	1160.0	1165.0	1170.0	1175.0
H	186.437	187.754	189.072	190.391	191.711	193.032	194.354	195.676
P	45.773	46.549	47.335	48.133	48.940	49.758	50.587	51.426

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
53.332	28.975	.14790	.08877	.03782	0.00000	.71403	.01147	.17125	.00640

T	1180.0	1185.0	1190.0	1195.0	1200.0	1205.0	1210.0	1215.0
H	197.003	198.324	199.653	200.976	202.303	203.631	204.960	206.290
P	52.276	53.137	54.010	54.893	55.788	56.694	57.611	58.541
T	1220.0	1225.0	1230.0	1235.0	1240.0	1245.0	1250.0	1255.0
H	207.621	208.953	210.285	211.619	212.953	214.289	215.625	216.962
P	59.482	60.434	61.399	62.376	63.365	64.366	65.380	66.406
T	1260.0	1265.0	1270.0	1275.0	1280.0	1285.0	1290.0	1295.0
H	218.300	219.639	220.979	222.320	223.662	225.004	226.348	227.692
P	67.445	68.496	69.561	70.638	71.729	72.833	73.950	75.081
T	1300.0	1305.0	1310.0	1315.0	1320.0	1325.0	1330.0	1335.0
H	229.039	230.384	231.731	233.079	234.428	235.778	237.129	238.481
P	76.225	77.383	78.555	79.741	80.941	82.155	83.384	84.627
T	1340.0	1345.0	1350.0	1355.0	1360.0	1365.0	1370.0	1375.0
H	239.834	241.187	242.542	243.897	245.253	246.611	247.969	249.328
P	85.885	87.157	88.445	89.747	91.065	92.398	93.746	95.110
T	1380.0	1385.0	1390.0	1395.0	1400.0	1405.0	1410.0	1415.0
H	250.687	252.048	253.410	254.773	256.136	257.500	258.866	260.232
P	96.490	97.885	99.296	100.724	102.168	103.628	105.105	106.598
T	1420.0	1425.0	1430.0	1435.0	1440.0	1445.0	1450.0	1455.0
H	261.599	262.967	264.335	265.705	267.076	268.447	269.820	271.193
P	108.109	109.636	111.180	112.742	114.321	115.918	117.532	119.164
T	1460.0	1465.0	1470.0	1475.0	1480.0	1485.0	1490.0	1495.0
H	272.567	273.942	275.318	276.695	278.073	279.451	280.831	282.211
P	120.814	122.483	124.170	125.875	127.599	129.341	131.103	132.884
T	1500.0	1505.0	1510.0	1515.0	1520.0	1525.0	1530.0	1535.0
H	283.592	284.974	286.357	287.741	289.125	290.511	291.897	293.285
P	134.684	136.503	138.342	140.201	142.079	143.978	145.897	147.836

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
53.332	28.975	.14790	.08877	.03762	0.00000	.71433	.01147	.17125	.00640

T	1540.0	1545.0	1550.0	1555.0	1560.0	1565.0	1570.0	1575.0
H	294.673	296.062	297.451	298.842	300.233	301.626	303.019	304.413
P	149.796	151.777	153.779	155.801	157.845	159.910	161.997	164.105
T	1580.0	1585.0	1590.0	1595.0	1600.0	1605.0	1610.0	1615.0
H	305.808	307.204	308.600	309.998	311.396	312.795	314.195	315.596
P	166.235	168.389	170.564	172.761	174.981	177.224	179.489	181.778
T	1620.0	1625.0	1630.0	1635.0	1640.0	1645.0	1650.0	1655.0
H	316.997	318.400	319.803	321.207	322.612	324.017	325.424	326.831
P	184.091	186.427	188.786	191.170	193.577	196.009	198.465	200.946
T	1660.0	1665.0	1670.0	1675.0	1680.0	1685.0	1690.0	1695.0
H	328.239	329.648	331.058	332.468	333.880	335.292	336.705	338.119
P	203.452	205.983	208.539	211.121	213.728	216.361	219.019	221.705
T	1700.0	1705.0	1710.0	1715.0	1720.0	1725.0	1730.0	1735.0
H	339.533	340.948	342.364	343.781	345.199	346.618	348.037	349.457
P	224.416	227.154	229.919	232.711	235.530	238.376	241.250	244.152
T	1740.0	1745.0	1750.0	1755.0	1760.0	1765.0	1770.0	1775.0
H	350.878	352.299	353.721	355.145	356.568	357.993	359.418	360.845
P	247.082	250.040	253.027	256.042	259.086	262.159	265.261	268.393
T	1780.0	1785.0	1790.0	1795.0	1800.0	1805.0	1810.0	1815.0
H	362.271	363.699	365.127	366.557	367.987	369.417	370.849	372.281
P	271.554	274.746	277.967	281.219	284.501	287.815	291.159	294.534
T	1820.0	1825.0	1830.0	1835.0	1840.0	1845.0	1850.0	1855.0
H	373.713	375.147	376.581	378.016	379.452	380.889	382.326	383.764
P	297.941	301.380	304.850	308.352	311.887	315.455	319.055	322.688
T	1860.0	1865.0	1870.0	1875.0	1880.0	1885.0	1890.0	1895.0
H	385.202	386.642	388.082	389.523	390.964	392.406	393.849	395.293
P	326.355	330.055	333.788	337.556	341.358	345.194	349.065	352.971

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
53.332	28.975	.14790	.08877	.03782	0.00000	.71403	.01147	.17125	.00640

T	1900.0	1905.0	1910.0	1915.0	1920.0	1925.0	1930.0	1935.0
H	396.737	398.182	399.628	401.074	402.521	403.969	405.417	406.866
P	356.912	360.888	364.900	368.948	373.032	377.153	381.310	385.503
T	1940.0	1945.0	1950.0	1955.0	1960.0	1965.0	1970.0	1975.0
H	408.316	409.766	411.217	412.669	414.121	415.574	417.028	418.483
P	389.734	394.003	398.309	402.652	407.034	411.454	415.913	420.411
T	1980.0	1985.0	1990.0	1995.0	2000.0	2005.0	2010.0	2015.0
H	419.939	421.393	422.850	424.307	425.764	427.222	428.681	430.141
P	424.949	429.524	434.140	438.795	443.491	448.228	453.005	457.823
T	2020.0	2025.0	2030.0	2035.0	2040.0	2045.0	2050.0	2055.0
H	431.601	433.062	434.523	435.985	437.448	438.911	440.375	441.840
P	462.682	467.583	472.525	477.510	482.537	487.606	492.718	497.874
T	2060.0	2065.0	2070.0	2075.0	2080.0	2085.0	2090.0	2095.0
H	443.305	444.771	446.237	447.704	449.171	450.640	452.108	453.578
P	503.072	508.315	513.601	518.932	524.307	529.727	535.192	540.703
T	2100.0	2105.0	2110.0	2115.0	2120.0	2125.0	2130.0	2135.0
H	455.048	456.518	457.989	459.461	460.933	462.406	463.880	465.354
P	546.259	551.861	557.509	563.204	568.946	574.734	580.570	586.454
T	2140.0	2145.0	2150.0	2155.0	2160.0	2165.0	2170.0	2175.0
H	466.828	468.303	469.779	471.256	472.732	474.210	475.688	477.167
P	592.386	598.366	604.394	610.472	616.599	622.775	629.001	635.277
T	2180.0	2185.0	2190.0	2195.0	2200.0	2205.0	2210.0	2215.0
H	478.646	480.125	481.606	483.086	484.568	486.050	487.532	489.015
P	641.603	647.980	654.408	660.888	667.419	674.001	680.637	687.324
T	2220.0	2225.0	2230.0	2235.0	2240.0	2245.0	2250.0	2255.0
H	490.499	491.983	493.467	494.952	496.438	497.924	499.411	500.898
P	694.065	700.859	707.705	714.607	721.563	728.573	735.637	742.757

P	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
53.332	28.975	.14799	.08677	.03762	0.00009	.71403	.01147	.17125	.00640

T	2260.0	2265.0	2270.0	2275.0	2280.0	2285.0	2290.0	2295.0
H	502.385	503.874	505.363	506.852	508.342	509.833	511.323	512.815
P	749.932	757.163	764.450	771.794	779.194	786.651	794.166	801.739
T	2300.0	2305.0	2310.0	2315.0	2320.0	2325.0	2330.0	2335.0
H	514.307	515.799	517.292	518.786	520.279	521.774	523.269	524.764
P	809.370	817.059	824.807	832.614	840.481	848.407	856.394	864.441
T	2340.0	2345.0	2350.0	2355.0	2360.0	2365.0	2370.0	2375.0
H	526.260	527.757	529.254	530.751	532.249	533.747	535.246	536.746
P	872.549	880.718	888.949	897.242	905.597	914.015	922.495	931.039
T	2380.0	2385.0	2390.0	2395.0	2400.0	2405.0	2410.0	2415.0
H	538.246	539.746	541.247	542.748	544.250	545.752	547.255	548.758
P	939.647	948.319	957.056	965.857	974.723	983.655	992.653	1001.717
T	2420.0	2425.0	2430.0	2435.0	2440.0	2445.0	2450.0	2455.0
H	550.262	551.766	553.271	554.776	556.282	557.788	559.294	560.801
P	1010.848	1020.046	1029.311	1038.644	1048.046	1057.516	1067.055	1076.663
T	2460.0	2465.0	2470.0	2475.0	2480.0	2485.0	2490.0	2495.0
H	562.309	563.817	565.325	566.834	568.344	569.854	571.364	572.875
P	1086.341	1096.089	1105.908	1115.798	1125.759	1135.791	1145.896	1156.074
T	2500.0	2505.0	2510.0	2515.0	2520.0	2525.0	2530.0	2535.0
H	574.386	575.898	577.410	578.923	580.436	581.950	583.464	584.978
P	1166.324	1176.647	1187.045	1197.516	1208.062	1218.683	1229.380	1240.152
T	2540.0	2545.0	2550.0	2555.0	2560.0	2565.0	2570.0	2575.0
H	586.493	588.009	589.525	591.041	592.558	594.075	595.593	597.111
P	1251.001	1261.926	1272.928	1284.008	1295.165	1306.401	1317.716	1329.110
T	2580.0	2585.0	2590.0	2595.0	2600.0	2605.0	2610.0	2615.0
H	598.630	600.149	601.669	603.189	604.710	606.231	607.752	609.274
P	1340.594	1352.138	1363.772	1375.487	1387.284	1399.163	1411.124	1423.167

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	W/DA
53.332	28.375	.14790	.08877	.03782	0.00000	.71403	.01147	.17125	.00640

T	2620.0	2625.0	2630.0	2635.0	2640.0	2645.0	2650.0	2655.0
H	610.797	612.320	613.843	615.367	616.892	618.416	619.942	621.467
P	1435.294	1447.505	1459.800	1472.180	1484.644	1497.194	1509.830	1522.553
T	2660.0	2665.0	2670.0	2675.0	2680.0	2685.0	2690.0	2695.0
H	622.994	524.520	526.048	627.575	529.104	630.632	632.161	633.691
P	1535.363	1548.260	1551.245	1574.318	1587.481	1600.732	1614.074	1627.506
T	2700.0	2705.0	2710.0	2715.0	2720.0	2725.0	2730.0	2735.0
H	635.221	636.752	638.283	639.814	641.346	642.879	644.412	645.945
P	1641.029	1654.643	1668.343	1682.147	1696.039	1710.023	1724.102	1738.275
T	2740.0	2745.0	2750.0	2755.0	2760.0	2765.0	2770.0	2775.0
H	647.479	649.014	650.549	652.084	653.621	655.157	656.694	658.232
P	1752.543	1766.907	1781.366	1795.922	1810.575	1825.326	1840.175	1855.122
T	2780.0	2785.0	2790.0	2795.0	2800.0	2805.0	2610.0	2815.0
H	659.770	661.308	662.847	664.387	665.927	667.468	669.009	670.551
P	1870.169	1885.315	1900.562	1915.910	1931.359	1946.910	1962.563	1978.320
T	2820.0	2825.0	2830.0	2835.0	2840.0	2845.0	2850.0	2855.0
H	672.093	673.636	675.179	676.723	678.268	679.813	681.358	682.904
P	1994.181	2010.145	2026.215	2042.390	2058.671	2075.059	2091.554	2108.157
T	2860.0	2865.0	2870.0	2875.0	2880.0	2885.0	2890.0	2895.0
H	684.451	685.998	687.546	689.094	690.643	692.192	693.743	695.293
P	2124.868	2141.689	2158.619	2175.659	2192.810	2210.073	2227.448	2244.936
T	2900.0	2905.0	2910.0	2915.0	2920.0	2925.0	2930.0	2935.0
H	696.844	698.396	699.949	701.502	703.055	704.609	706.164	707.720
P	2262.537	2280.252	2298.082	2316.027	2334.088	2352.266	2370.561	2388.975
T	2940.0	2945.0	2950.0	2955.0	0.0	0.0	0.0	0.0
H	709.276	710.832	712.390	713.948	0.000	0.000	0.000	0.000
P	2407.507	2426.158	2444.930	2463.822	0.000	0.000	0.000	0.000

Table A 4.1.3 - Properties of the Products of Combustion of Low-Btu Fuel Gas from a Westinghouse Fluidized Bed Gasifier with High Temperature Desulfurization and Particulate Removal Generated from North Dakota Lignite

LOW-BTU FUEL GAS PROPERTIES

GASIFICATION PROCESS: Westinghouse Fluidized Bed/High-Temp. Desulfurization

COAL: North Dakota lignite

Lockhopper Inlet Conditions

- Temperature: 150
- Moisture Content: 27%

SORBENT: Dolomite

- Sorbent/Coal Ratio: 0.11 (0.10)

PROCESS AIR

- Air/Coal Ratio: 1.81 (1.57)
- Temperature - °F: 750
- Pressure - psia: 250

PROCESS STEAM

- Steam/Coal Ratio: 0.361 (0.313)
- Temperature - °F: 400
- Pressure - psia: 250

PRODUCT FUEL GAS

- Temperature - °F: 1600
- Pressure - psia: 225

Composition-Mole Fraction

N_2	.4237
O_2	0
H_2	.1657
CO	.2299
CO_2	.0812
H_2O	.0715
H_2S	0
CH_4	.0279
C_2H_4	0

Product Fuel Gas/Coal Ratio: 2.80 (2.42)

Gasifier Aux. Pwr. (kW/lb/s): 14.4

Spent Sorbent Oxidizer Exhaust Products

- T_{in} - °F: 1500
- T_{out} - °F: 300
- q-Btu/lb coal: 69 (60)

Molecular Wt: 23.95

Heating Value

LHV -	144.54	Btu/scf	2290.67	Btu/lb
HHV -	155.66	Btu/scf	2466.91	Btu/lb

LHV/HHV: .9286

Enthalpy (400°R Base) - 550.76 Btu/lb

Stoichiometric Fuel/Air Ratio: 0.686

(Values in parenthesis are for as received coal)

Table A 4.1.3 Polynomial Cofficients

K-LAJU GAS-TAIR=750-ND LIGNITE--150

STOICHIOMETRIC AIR

	RANGE OF VALIDITY	A0	A1	A2	A3	A4	A5
H=F(T)	460.0<T<2940.0	-9.81187+01	2.42708-01	6.97590-07	1.53452-08	-4.89668-12	5.08173-16
P=F(T)	460.0<T<2940.0	-1.69169+01	8.47226-02	-1.64522-04	1.69641-07	-6.77679-11	2.74994-14
H=F(P)	6.0<P< 90.0	3.03291+01	6.59047+00	-1.18139-01	1.29241-03	-7.04217-06	1.47772-08
H=F(P)	91.0<P< 600.0	1.41410+02	1.92558+01	-2.70310-03	3.70212-06	-2.60293-09	7.18802-13
H=F(P)	601.0<P<3300.0	2.62150+02	3.97672-01	-2.05435-04	7.01442-08	-1.26644-11	9.17113-16
P=F(H)	14.0<H< 700.0	8.80757-01	4.21852-02	4.24454-04	3.17448-06	4.04425-09	4.47907-12
T=F(H)	14.0<H< 700.0	3.99804+02	4.03040+00	-1.25023-03	1.19514-07	9.02372-10	-5.76360-13

100 PERCENT EXCESS AIR

	RANGE OF VALIDITY	A0	A1	A2	A3	A4	A5
H=F(T)	460.0<T<2940.0	-9.82026+01	2.46926-01	-1.11478-05	2.05710-08	-6.28199-12	6.57432-16
P=F(T)	460.0<T<2940.0	-7.41461+00	3.52619-02	-6.60900-05	7.45102-08	-2.08779-11	1.43516-14
H=F(P)	6.0<P< 90.0	2.67412+01	7.29540+00	-1.47704-01	1.85340-03	-1.16636-05	2.83792-08
H=F(P)	91.0<P< 600.0	1.31006+02	1.51361+00	-3.99454-03	6.81543-06	-6.01643-09	2.09637-12
H=F(P)	601.0<P<3300.0	2.43495+02	5.12341-01	-3.45356-04	1.56004-07	-3.75371-11	3.64064-15
P=F(H)	14.0<H< 700.0	9.92236-01	3.69500-02	4.79472-04	2.71561-06	3.99362-09	2.64890-12
T=F(H)	14.0<H< 700.0	3.99639+02	4.08733+00	-9.18959-04	-7.83956-07	2.10146-09	-1.17333-12

200 PERCENT EXCESS AIR

	RANGE OF VALIDITY	A0	A1	A2	A3	A4	A5
H=F(T)	460.0<T<2940.0	-9.82427+01	2.48862-01	-1.65723-05	2.29677-08	-6.91796-12	7.23007-16
P=F(T)	460.0<T<2940.0	-5.34051+00	2.41634-02	-4.32470-05	5.17485-08	-9.34686-12	1.05147-14
H=F(P)	6.0<P< 90.0	2.51316+01	7.60000-04	1.07600-02	1.07600-02	1.07600-02	1.07600-02
H=F(P)	91.0<P< 600.0	1.26308+02	1.64630+00	-4.76256-03	8.97121-06	-8.77637-09	3.39673-12
H=F(P)	601.0<P<3300.0	2.35053+02	5.74369-01	-4.56570-04	2.23801-07	-6.13172-11	6.78708-15
P=F(H)	14.0<H< 700.0	1.01624+00	3.27147-02	4.91150-04	2.57041-06	3.83689-09	2.02336-12
T=F(H)	14.0<H< 700.0	3.99579+02	4.11293+00	-7.44146-04	-1.27382-06	2.77499-09	-1.52125-12

300 PERCENT EXCESS AIR

	RANGE OF VALIDITY	A0	A1	A2	A3	A4	A5
H=F(T)	460.0<T<2940.0	-9.87659+01	2.49971-01	-1.96795-05	2.43411-08	-7.28247-12	7.65310-16
P=F(T)	460.0<T<2940.0	-4.55729+00	1.98855-02	-3.42211-05	4.25793-08	-4.64677-12	8.76167-15
H=F(P)	6.0<P< 90.0	2.42070+01	7.63513+00	-1.72822-01	2.38955-03	-1.66540-05	4.50088-08
H=F(P)	91.0<P< 600.0	1.23633+02	1.72685+00	-5.26307-03	1.04897-05	-1.08806-08	4.47097-12
H=F(P)	601.0<P<3300.0	2.30248+02	6.12931-01	-4.98007-04	2.74793-07	-8.10639-11	9.67365-15
P=F(H)	14.0<H< 700.0	1.02511+00	3.52362-02	4.95116-04	2.55048-06	3.72008-09	1.73252-12
T=F(H)	14.0<H< 700.0	3.99550+02	4.12746+00	-6.36750-04	-1.57888-06	3.20188-09	-1.74584-12

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
52.819	29.257	-.00039	.25253	.09313	0.00000	.64674	.00798	.68630	.00040

T	460.0	465.0	470.0	475.0	480.0	485.0	490.0	495.0
H	14.972	16.226	17.481	18.737	19.995	21.253	22.513	23.773
P	1.671	1.739	1.810	1.882	1.956	2.033	2.112	2.193
T	500.0	505.0	510.0	515.0	520.0	525.0	530.0	535.0
H	25.035	26.297	27.560	28.825	30.090	31.357	32.624	33.892
P	2.275	2.362	2.450	2.541	2.634	2.730	2.828	2.929
T	540.0	545.0	550.0	555.0	560.0	565.0	570.0	575.0
H	35.162	36.432	37.703	38.975	40.249	41.523	42.798	44.074
P	3.033	3.140	3.249	3.361	3.476	3.594	3.715	3.839
T	580.0	585.0	590.0	595.0	600.0	605.0	610.0	615.0
H	45.351	46.629	47.908	49.188	50.469	51.751	53.034	54.318
P	3.966	4.096	4.229	4.366	4.506	4.650	4.797	4.947
T	620.0	625.0	630.0	635.0	640.0	645.0	650.0	655.0
H	55.603	56.888	58.175	59.463	60.751	62.041	63.332	64.623
P	5.101	5.259	5.420	5.585	5.754	5.926	6.103	6.283
T	660.0	665.0	670.0	675.0	680.0	685.0	690.0	695.0
H	65.916	67.210	68.504	69.800	71.096	72.394	73.692	74.992
P	6.463	6.657	6.850	7.047	7.248	7.454	7.664	7.879
T	700.0	705.0	710.0	715.0	720.0	725.0	730.0	735.0
H	76.292	77.594	78.896	80.200	81.504	82.810	84.117	85.424
P	8.099	8.323	8.552	8.785	9.024	9.267	9.515	9.769
T	740.0	745.0	750.0	755.0	760.0	765.0	770.0	775.0
H	85.733	88.042	89.353	90.665	91.978	93.291	94.606	95.922
P	10.028	10.291	10.561	10.835	11.116	11.401	11.693	11.990
T	780.0	785.0	790.0	795.0	800.0	805.0	810.0	815.0
H	97.239	98.557	99.876	101.196	102.517	103.839	105.162	106.486
P	12.293	12.601	12.915	13.237	13.564	13.897	14.237	14.582

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	M/DA
52.819	29.257	-.00039	.25253	.19313	0.00000	.64674	.00798	.68030	.00640

T	820.0	825.0	830.0	835.0	840.0	845.0	850.0	855.0
H	107.812	109.138	110.465	111.794	113.123	114.454	115.786	117.118
P	14.935	15.294	15.659	16.032	16.411	16.797	17.191	17.591
T	860.0	865.0	870.0	875.0	880.0	885.0	890.0	895.0
H	118.452	119.787	121.123	122.460	123.799	125.138	126.478	127.820
P	17.999	18.414	18.835	19.267	19.704	20.150	20.603	21.064
T	900.0	905.0	910.0	915.0	920.0	925.0	930.0	935.0
H	129.162	130.506	131.851	133.197	134.543	135.892	137.241	138.591
P	21.533	22.011	22.497	22.991	23.493	24.004	24.524	25.053
T	940.0	945.0	950.0	955.0	960.0	965.0	970.0	975.0
H	139.942	141.295	142.648	144.003	145.359	146.716	148.074	149.433
P	25.590	26.137	26.593	27.258	27.833	28.417	29.010	29.614
T	980.0	985.0	990.0	995.0	1000.0	1005.0	1010.0	1015.0
H	150.793	152.155	153.517	154.881	156.245	157.611	158.978	160.346
P	30.227	30.850	31.483	32.127	32.781	33.446	34.121	34.807
T	1020.0	1025.0	1030.0	1035.0	1040.0	1045.0	1050.0	1055.0
H	161.716	163.086	164.458	165.830	167.204	168.579	169.955	171.332
P	35.503	36.211	36.930	37.661	38.402	39.156	39.921	40.697
T	1060.0	1065.0	1070.0	1075.0	1080.0	1085.0	1090.0	1095.0
H	172.710	174.089	175.470	176.852	178.234	179.618	181.003	182.389
P	41.486	42.287	43.100	43.926	44.764	45.615	46.479	47.356
T	1100.0	1105.0	1110.0	1115.0	1120.0	1125.0	1130.0	1135.0
H	183.777	185.165	186.555	187.945	189.337	190.730	192.124	193.519
P	48.246	49.149	50.065	50.996	51.940	52.898	53.871	54.857
T	1140.0	1145.0	1150.0	1155.0	1160.0	1165.0	1170.0	1175.0
H	194.916	196.313	197.712	199.111	200.512	201.914	203.317	204.721
P	55.858	56.873	57.904	58.949	60.009	61.085	62.176	63.282

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	M/DA
52.819	29.257	-.00039	.25253	.09313	0.00000	.64674	.00798	.68630	.00640

T	1180.0	1185.0	1190.0	1195.0	1200.0	1205.0	1210.0	1215.0
H	206.127	207.533	208.941	210.350	211.759	213.170	214.582	215.996
P	64.404	65.543	66.697	67.868	69.055	70.259	71.480	72.717
T	1220.0	1225.0	1230.0	1235.0	1240.0	1245.0	1250.0	1255.0
H	217.410	218.826	220.242	221.660	223.079	224.499	225.920	227.342
P	73.972	75.245	76.535	77.842	79.168	80.512	81.874	83.255
T	1260.0	1265.0	1270.0	1275.0	1280.0	1285.0	1290.0	1295.0
H	228.765	230.190	231.615	233.042	234.470	235.898	237.328	238.759
P	84.655	86.074	87.511	88.968	90.445	91.942	93.458	94.995
T	1300.0	1305.0	1310.0	1315.0	1320.0	1325.0	1330.0	1335.0
H	240.192	241.625	243.059	244.495	245.931	247.369	248.808	250.248
P	96.552	98.130	99.728	101.348	102.989	104.651	106.335	108.042
T	1340.0	1345.0	1350.0	1355.0	1360.0	1365.0	1370.0	1375.0
H	251.689	253.131	254.574	256.019	257.464	258.910	260.358	261.807
P	109.770	111.520	113.294	115.090	116.909	118.752	120.618	122.507
T	1380.0	1385.0	1390.0	1395.0	1400.0	1405.0	1410.0	1415.0
H	263.256	264.707	266.159	267.612	269.066	270.521	271.977	273.435
P	124.421	126.360	128.322	130.310	132.322	134.360	136.423	138.512
T	1420.0	1425.0	1430.0	1435.0	1440.0	1445.0	1450.0	1455.0
H	274.893	276.353	277.813	279.275	280.737	282.201	283.666	285.132
P	140.627	142.769	144.936	147.131	149.353	151.602	153.878	156.183
T	1460.0	1465.0	1470.0	1475.0	1480.0	1485.0	1490.0	1495.0
H	286.598	288.066	289.535	291.005	292.476	293.949	295.422	296.896
P	158.515	160.876	163.266	165.684	168.132	170.609	173.117	175.654
T	1500.0	1505.0	1510.0	1515.0	1520.0	1525.0	1530.0	1535.0
H	298.371	299.848	301.325	302.803	304.283	305.763	307.245	308.727
P	178.221	180.819	183.448	186.109	188.800	191.524	194.280	197.068

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
52.819	29.257	-.00039	.25253	.09313	0.00000	.64674	.00798	.68630	.00640

T	1540.0	1545.0	1550.0	1555.0	1560.0	1565.0	1570.0	1575.0
H	310.211	311.695	313.181	314.658	316.155	317.644	319.133	320.624
P	199.889	202.743	205.630	208.551	211.505	214.494	217.518	220.577
T	1580.0	1585.0	1590.0	1595.0	1600.0	1605.0	1610.0	1615.0
H	322.115	323.608	325.102	326.597	328.092	329.589	331.087	332.585
P	223.670	226.800	229.965	233.166	236.404	239.670	242.990	246.340
T	1620.0	1625.0	1630.0	1635.0	1640.0	1645.0	1650.0	1655.0
H	334.095	335.586	337.087	338.590	340.094	341.598	343.104	344.610
P	249.727	253.152	256.616	260.119	263.661	267.242	270.864	274.526
T	1660.0	1665.0	1670.0	1675.0	1680.0	1685.0	1690.0	1695.0
H	346.118	347.626	349.136	350.646	352.157	353.670	355.183	356.697
P	278.223	281.971	285.756	289.583	293.451	297.362	301.316	305.313
T	1700.0	1705.0	1710.0	1715.0	1720.0	1725.0	1730.0	1735.0
H	358.212	359.728	361.245	362.763	364.282	365.802	367.323	368.845
P	309.354	313.438	317.567	321.741	325.959	330.223	334.533	338.889
T	1740.0	1745.0	1750.0	1755.0	1760.0	1765.0	1770.0	1775.0
H	370.367	371.891	373.416	374.941	376.467	377.995	379.523	381.052
P	343.292	347.742	352.240	356.785	361.379	366.021	370.712	375.453
T	1780.0	1785.0	1790.0	1795.0	1800.0	1805.0	1810.0	1815.0
H	3[illegible].582	384.113	385.645	387.178	388.711	390.246	391.781	393.318
P	380.243	385.084	389.976	394.919	399.913	404.960	410.059	415.211
T	1820.0	1825.0	1830.0	1835.0	1840.0	1845.0	1850.0	1855.0
H	394.855	396.393	397.932	399.472	401.013	402.554	404.097	405.640
P	420.416	425.675	430.988	436.355	441.778	447.257	452.791	458.382
T	1860.0	1865.0	1870.0	1875.0	1880.0	1885.0	1890.0	1895.0
H	407.184	408.730	410.276	411.822	413.370	414.919	416.468	418.018
P	464.029	469.734	475.497	481.318	487.198	493.138	499.135	505.195

R	MOL.WT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	N/DA
52.819	29.257	-.00039	.25253	.09313	0.00000	.64674	.00798	.68630	.00640

T	1900.0	1905.0	1910.0	1915.0	1920.0	1925.0	1930.0	1935.0
H	419.569	421.121	422.674	424.228	425.782	427.338	428.894	430.451
P	511.315	517.496	523.738	530.043	536.41[illegible]	542.840	549.334	555.092
T	1940.0	1945.0	1950.0	1955.0	1960.0	1965.0	1970.0	1975.0
H	432.009	433.567	435.127	436.687	438.248	439.810	441.373	442.936
P	562.515	569.203	575.955	582.775	589.661	596.615	603.635	610.725
T	1980.0	1985.0	1990.0	1995.0	2000.0	2005.0	2010.0	2015.0
H	444.501	446.066	447.632	449.198	450.766	452.334	453.903	455.473
P	617.882	625.109	632.406	639.773	647.212	654.721	662.302	669.956
T	2020.0	2025.0	2030.0	2035.0	2040.0	2045.0	2050.0	2055.0
H	457.044	458.615	460.188	461.761	463.335	464.909	466.484	468.061
P	677.683	685.484	693.358	701.308	709.332	717.433	725.610	733.864
T	2060.0	2065.0	2070.0	2075.0	2080.0	2085.0	2090.0	2095.0
H	469.637	471.215	472.794	474.373	475.953	477.533	479.115	480.697
P	742.195	750.605	759.093	767.661	776.308	785.036	793.845	802.736
T	2100.0	2105.0	2110.0	2115.0	2120.0	2125.0	2130.0	2135.0
H	482.280	483.864	485.449	487.033	488.619	490.206	491.793	493.381
P	811.709	820.765	829.904	839.128	848.436	857.829	867.309	876.875
T	2140.0	2145.0	2150.0	2155.0	2160.0	2165.0	2170.0	2175.0
H	494.970	496.559	498.150	499.741	501.332	502.925	504.518	506.112
P	886.528	896.269	906.098	916.017	926.025	936.124	946.314	956.595
T	2180.0	2185.0	2190.0	2195.0	2200.0	2205.0	2210.0	2215.0
H	507.706	509.301	510.897	512.494	514.091	515.689	517.288	518.887
P	966.969	977.436	987.996	998.651	1009.401	1020.246	1031.188	1042.226
T	2220.0	2225.0	2230.0	2235.0	2240.0	2245.0	2250.0	2255.0
H	520.487	522.088	523.690	525.292	526.895	528.498	530.102	531.707
P	1053.363	1064.598	1075.932	1087.365	1098.899	1110.535	1122.272	1134.112

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
52.819	29.257	-.00039	.25253	.09313	0.00000	.64674	.00798	.68630	.00640

T	2260.0	2265.0	2270.0	2275.0	2280.0	2285.0	2290.0	2295.0
H	533.313	534.919	536.525	538.133	539.742	541.351	542.960	544.570
P	1146.055	1158.102	1170.253	1182.511	1194.874	1207.344	1219.922	1232.609
T	2300.0	2305.0	2310.0	2315.0	2320.0	2325.0	2330.0	2335.0
H	546.181	547.793	549.405	551.017	552.631	554.245	555.860	557.475
P	1245.404	1258.309	1271.325	1284.452	1297.692	1311.044	1324.510	1338.090
T	2340.0	2345.0	2350.0	2355.0	2360.0	2365.0	2370.0	2375.0
H	559.091	560.708	562.325	563.943	565.561	567.180	568.800	570.421
P	1351.785	1365.597	1379.525	1393.570	1407.734	1422.017	1436.420	1450.944
T	2380.0	2385.0	2390.0	2395.0	2400.0	2405.0	2410.0	2415.0
H	572.042	573.663	575.286	576.908	578.532	580.156	581.781	583.406
P	1465.589	1480.356	1495.247	1510.261	1525.401	1540.665	1556.0[illegible]7	1571.575
T	2420.0	2425.0	2430.0	2435.0	2440.0	2445.0	2450.0	2455.0
H	585.032	586.659	588.285	589.913	591.542	593.171	594.[illegible]	596.431
P	1587.222	1602.997	1618.902	1634.938	1651.105	1667.405	1683.8[illegible]7	1700.404
T	2460.0	2465.0	2470.0	2475.0	2480.0	2485.0	2490.0	2495.0
H	598.061	599.693	601.325	602.957	604.590	606.224	607.858	609.493
P	1717.105	1733.943	1750.917	1768.029	1785.279	1802.669	1820.198	1837.869
T	2500.0	2505.0	2510.0	2515.0	2520.0	2525.0	2530.0	2535.0
H	611.128	612.765	614.401	616.038	617.676	619.314	620.953	622.593
P	1855.682	1873.638	1891.737	1909.982	1928.372	1946.909	1965.593	1984.426
T	2540.0	2545.0	2550.0	2555.0	2560.0	2565.0	2570.0	2575.0
H	624.233	625.874	627.515	629.156	630.799	632.442	634.085	635.729
P	2003.408	2022.541	2041.825	2061.261	2080.850	2100.594	2120.493	2140.548
T	2580.0	2585.0	2590.0	2595.0	2600.0	2605.0	2610.0	2615.0
H	637.374	639.01[illegible]	640.665	642.311	643.958	645.605	647.253	648.901
P	2160.760	2181.1[illegible]	2201.660	2222.350	2243.201	2264.213	2285.389	2306.730

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
52.819	29.257	-.00039	.25253	.09313	0.00000	.64674	.00798	.68630	.00640

T	2620.0	2625.0	2630.0	2635.0	2640.0	2645.0	2650.0	2655.0
H	650.550	652.200	653.850	655.501	657.152	658.804	660.456	662.109
P	2328.235	2349.906	2371.745	2393.752	2415.928	2438.275	2460.793	2483.483
T	2660.0	2665.0	2670.0	2675.0	2680.0	2685.0	2690.0	2695.0
H	663.762	665.416	667.071	668.726	670.382	672.038	673.694	675.351
P	2506.347	2529.385	2552.600	2575.990	2599.559	2623.306	2647.234	2671.342
T	2700.0	2705.0	2710.0	2715.0	2720.0	2725.0	2730.0	2735.0
H	677.009	678.668	680.326	681.986	683.646	685.306	686.967	688.628
P	2695.633	2720.107	2744.766	2769.609	2794.640	2819.858	2845.266	2870.863
T	2740.0	2745.0	2750.0	2755.0	2760.0	2765.0	2770.0	2775.0
H	690.290	691.953	693.616	695.280	696.944	698.608	700.274	701.939
P	2896.651	2922.632	2948.807	2975.176	3001.741	3028.502	3055.463	3082.622
T	2780.0	2785.0	2790.0	2795.0	2800.0	2805.0	2810.0	2815.0
H	703.605	705.272	706.940	708.608	710.276	711.945	713.614	715.284
P	3109.982	3137.544	3165.309	3193.278	3221.453	3249.834	3278.423	3307.221
T	2820.0	2825.0	2830.0	2835.0	2840.0	2845.0	2850.0	2855.0
H	716.955	718.626	720.297	721.969	723.642	725.315	726.989	728.663
P	3336.230	3365.450	3394.883	3424.530	3454.393	3484.472	3514.770	3545.286
T	2860.0	2865.0	2870.0	2875.0	2880.0	2885.0	2890.0	2895.0
H	730.337	732.013	733.688	735.365	737.041	738.719	740.396	742.075
P	3576.023	3606.982	3638.165	3669.571	3701.204	3733.063	3765.151	3797.469
T	2900.0	2905.0	2910.0	2915.0	2920.0	2925.0	2930.0	2935.0
H	743.754	745.433	747.113	748.794	750.475	752.156	753.838	755.521
P	3830.018	3862.799	3895.815	3929.065	3962.552	3996.277	4030.242	4064.447
T	2940.0	2945.0	2950.0	2955.0	0.0	0.0	0.0	0.0
H	757.204	758.887	760.572	762.256	0.000	0.000	0.000	0.000
P	4098.895	4133.586	4168.522	4203.705	0.000	0.000	0.000	0.000

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
53.091	29.107	.08566	.15837	.06076	0.00000	.68518	.01001	.34315	.00644

T	460.0	465.0	470.0	475.0	480.0	485.0	490.0	495.0
H	14.773	16.008	17.244	18.480	19.717	20.955	22.194	23.433
P	1.656	1.722	1.790	1.860	1.932	2.006	2.082	2.160
T	500.0	505.0	510.0	515.0	520.0	525.0	530.0	535.0
H	24.673	25.914	27.155	28.397	29.639	30.882	32.126	33.371
P	2.240	2.323	2.408	2.495	2.584	2.676	2.770	2.866
T	540.0	545.0	550.0	555.0	560.0	565.0	570.0	575.0
H	34.615	35.862	37.109	38.356	39.604	40.853	42.102	43.352
P	2.965	3.067	3.171	3.277	3.387	3.499	3.613	3.731
T	580.0	585.0	590.0	595.0	600.0	605.0	610.0	615.0
H	44.603	45.854	47.107	48.359	49.613	50.867	52.122	53.378
P	3.851	3.974	4.101	4.230	4.362	4.497	4.635	4.776
T	620.0	625.0	630.0	635.0	640.0	645.0	650.0	655.0
H	54.634	55.892	57.150	58.408	59.668	60.928	62.188	63.450
P	4.921	5.069	5.220	5.374	5.532	5.693	5.858	6.027
T	660.0	665.0	670.0	675.0	680.0	685.0	690.0	695.0
H	64.712	65.976	67.239	68.504	69.769	71.036	72.303	73.570
P	6.199	6.374	6.554	6.737	6.924	7.114	7.309	7.508
T	700.0	705.0	710.0	715.0	720.0	725.0	730.0	735.0
H	74.839	76.108	77.378	78.649	79.921	81.193	82.467	83.741
P	7.711	7.918	8.129	8.344	8.563	8.787	9.016	9.248
T	740.0	745.0	750.0	755.0	760.0	765.0	770.0	775.0
H	85.016	86.292	87.568	88.846	90.124	91.403	92.683	93.964
P	9.485	9.727	9.974	10.225	10.481	10.742	11.008	11.279
T	780.0	785.0	790.0	795.0	800.0	805.0	810.0	815.0
H	95.245	96.528	97.811	99.095	100.380	101.666	102.953	104.241
P	11.554	11.835	12.121	12.412	12.709	13.011	13.318	13.631

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	M/DA
53.091	29.107	.08566	.15837	.06078	0.00000	.68518	.01001	.34315	.00640

T	820.0	825.0	830.0	835.0	840.0	845.0	850.0	855.0
H	105.529	106.819	108.109	109.400	110.692	111.985	113.279	114.574
P	13.959	14.274	14.604	14.940	15.281	15.629	15.982	16.342
T	860.0	865.0	870.0	875.0	880.0	885.0	890.0	895.0
H	115.870	117.166	118.464	119.762	121.061	122.362	123.663	124.965
P	16.708	17.080	17.459	17.844	18.235	18.633	19.028	19.449
T	900.0	905.0	910.0	915.0	920.0	925.0	930.0	935.0
H	126.268	127.572	128.877	130.182	131.489	132.797	134.105	135.415
P	19.867	20.292	20.724	21.164	21.610	22.063	22.524	22.993
T	940.0	945.0	950.0	955.0	960.0	965.0	970.0	975.0
H	136.725	138.037	139.349	140.663	141.977	143.292	144.608	145.925
P	23.469	23.952	24.443	24.942	25.449	25.964	26.486	27.017
T	980.0	985.0	990.0	995.0	1000.0	1005.0	1010.0	1015.0
H	147.244	148.563	149.883	151.204	152.526	153.849	155.173	156.497
P	27.556	28.104	28.660	29.224	29.797	30.379	30.970	31.570
T	1020.0	1025.0	1030.0	1035.0	1040.0	1045.0	1050.0	1055.0
H	157.823	159.150	160.478	161.807	163.137	164.467	165.799	167.132
P	32.178	32.796	33.423	34.059	34.705	35.360	36.025	36.700
T	1060.0	1065.0	1070.0	1075.0	1080.0	1085.0	1090.0	1095.0
H	168.466	169.800	171.135	172.473	173.810	175.149	176.489	177.829
P	37.384	38.079	38.784	39.499	40.224	40.959	41.705	42.462
T	1100.0	1105.0	1110.0	1115.0	1120.0	1125.0	1130.0	1135.0
H	179.171	180.513	181.857	183.202	184.547	185.894	187.241	188.590
P	43.230	44.008	44.797	45.598	46.410	47.233	48.067	48.913
T	1140.0	1145.0	1150.0	1155.0	1160.0	1165.0	1170.0	1175.0
H	189.940	191.290	192.642	193.994	195.348	196.703	198.058	199.415
P	49.771	50.641	51.523	52.416	53.322	54.241	55.171	56.115

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	M/DA
53.091	29.107	.08566	.15837	.06078	0.00000	.68518	.01001	.34315	.00640

T	1180.0	1185.0	1190.0	1195.0	1200.0	1205.0	1210.0	1215.0
H	200.772	202.131	203.491	204.851	206.213	207.575	208.939	210.304
P	57.071	58.040	59.022	60.017	61.025	62.047	63.082	64.131
T	1220.0	1225.0	1230.0	1235.0	1240.0	1245.0	1250.0	1255.0
H	211.669	213.036	214.403	215.772	217.141	218.512	219.884	221.256
P	65.194	66.271	67.362	68.467	69.586	70.720	71.869	73.032
T	1260.0	1265.0	1270.0	1275.0	1280.0	1285.0	1290.0	1295.0
H	222.630	224.004	225.380	226.757	228.134	229.513	230.892	232.273
P	74.211	75.404	76.613	77.837	79.077	80.332	81.604	82.891
T	1300.0	1305.0	1310.0	1315.0	1320.0	1325.0	1330.0	1335.0
H	233.654	235.037	236.420	237.805	239.190	240.577	241.964	243.353
P	84.195	85.515	86.851	88.204	89.574	90.960	92.364	93.785
T	1340.0	1345.0	1350.0	1355.0	1360.0	1365.0	1370.0	1375.0
H	244.742	246.133	247.524	248.917	250.310	251.704	253.100	254.496
P	95.224	96.680	98.154	99.646	101.157	102.685	104.232	105.798
T	1380.0	1385.0	1390.0	1395.0	1400.0	1405.0	1410.0	1415.0
H	255.894	257.292	258.691	260.091	261.493	262.895	264.298	265.702
P	107.382	108.985	110.608	112.250	113.911	115.593	117.294	119.015
T	1420.0	1425.0	1430.0	1435.0	1440.0	1445.0	1450.0	1455.0
H	267.107	268.513	269.920	271.328	272.737	274.147	275.558	276.970
P	120.756	122.518	124.301	126.104	127.928	129.774	131.641	133.529
T	1460.0	1465.0	1470.0	1475.0	1480.0	1485.0	1490.0	1495.0
H	278.383	279.796	281.211	282.627	284.043	285.461	286.879	288.299
P	135.439	137.372	139.326	141.303	143.302	145.324	147.369	149.437
T	1500.0	1505.0	1510.0	1515.0	1520.0	1525.0	1530.0	1535.0
H	289.719	291.141	292.563	293.986	295.410	296.835	298.261	299.688
P	151.529	153.644	155.783	157.946	160.133	162.345	164.581	166.842

P	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
53.091	29.107	.08566	.15837	.05078	0.00000	.68518	.01001	.34315	.00640

T	1540.0	1545.0	1550.0	1555.0	1560.0	1565.0	1570.0	1575.0
H	301.116	302.545	303.975	305.405	306.837	308.269	309.703	311.137
P	169.128	171.440	173.776	176.139	178.527	180.942	183.383	185.851
T	1580.0	1585.0	1590.0	1595.0	1600.0	1605.0	1610.0	1615.0
H	312.572	314.009	315.446	316.884	318.322	319.762	321.203	322.644
P	188.345	190.867	193.415	195.992	198.596	201.228	203.888	206.576
T	1620.0	1625.0	1630.0	1635.0	1640.0	1645.0	1650.0	1655.0
H	324.067	325.530	326.974	328.420	329.866	331.312	332.760	334.209
P	209.294	212.040	214.815	217.520	220.454	223.319	226.213	229.138
T	1660.0	1665.0	1670.0	1675.0	1680.0	1685.0	1690.0	1695.0
H	335.658	337.109	338.560	340.012	341.465	342.919	344.374	345.830
P	232.093	235.079	238.097	241.146	244.226	247.338	250.483	253.659
T	1700.0	1705.0	1710.0	1715.0	1720.0	1725.0	1730.0	1735.0
H	347.286	348.744	350.202	351.661	353.121	354.581	356.043	357.505
P	256.869	260.111	253.387	266.696	270.039	273.416	276.827	280.272
T	1740.0	1745.0	1750.0	1755.0	1760.0	1765.0	1770.0	1775.0
H	358.969	360.433	361.898	363.364	364.830	366.298	367.766	369.235
P	283.752	287.268	290.818	294.405	298.027	301.685	305.380	309.112
T	1780.0	1785.0	1790.0	1795.0	1800.0	1805.0	1810.0	1815.0
H	370.705	372.176	373.647	375.119	376.593	378.067	379.541	381.017
P	312.881	316.687	320.530	324.412	328.331	332.289	336.286	340.322
T	1820.0	1825.0	1830.0	1835.0	1840.0	1845.0	1850.0	1855.0
H	382.493	383.971	385.448	386.927	388.407	389.887	391.368	392.850
P	344.397	348.512	352.667	356.862	361.098	365.374	369.692	374.051
T	1860.0	1865.0	1870.0	1875.0	1880.0	1885.0	1890.0	1895.0
H	394.333	395.816	397.301	398.786	400.271	401.758	403.245	404.733
P	378.452	382.895	387.381	391.909	396.480	401.095	405.713	410.455

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	M/DA
53.091	29.107	.08566	.15837	.06078	0.00000	.68518	.01001	.34315	.00640

T	1900.0	1905.0	1910.0	1915.0	1920.0	1925.0	1930.0	1935.0
H	406.222	407.712	409.202	410.693	412.185	413.677	415.171	416.665
P	415.2[illegible]2	419.993	424.829	429.711	434.638	439.611	444.631	449.697
T	1940.0	1945.0	1950.0	1955.0	1960.0	1965.0	1970.0	1975.0
H	418.160	419.655	421.151	422.648	424.146	425.645	427.144	428.644
P	454.810	459.970	465.178	470.434	475.738	481.091	486.493	491.944
T	1980.0	1985.0	1990.0	1995.0	2000.0	2005.0	2010.0	2015.0
H	430.144	431.646	433.149	434.650	436.154	437.658	439.163	440.668
P	497.445	502.996	508.597	514.250	519.953	525.708	531.51[illegible]	537.373
T	2020.0	2025.0	2030.0	2035.0	2040.0	2045.0	2050.0	2055.0
H	442.175	443.682	445.189	446.698	448.207	449.716	451.227	452.738
P	543.285	549.249	555.267	561.338	567.464	573.644	579.878	586.168
T	2060.0	2065.0	2070.0	2075.0	2080.0	2085.0	2090.0	2095.0
H	454.250	455.762	457.275	458.789	460.303	461.819	463.334	464.850
P	592.513	598.915	605.372	611.887	618.458	625.087	631.773	638.518
T	2100.0	2105.0	2110.0	2115.0	2120.0	2125.0	2130.0	2135.0
H	466.368	467.885	469.404	470.923	472.442	473.963	475.484	477.005
P	645.322	652.184	659.105	666.088	673.130	680.233	687.397	694.622
T	2140.0	2145.0	2150.0	2155.0	2160.0	2165.0	2170.0	2175.0
H	478.527	480.050	481.574	483.098	484.623	486.148	487.674	489.201
P	701.909	709.258	716.670	724.145	731.683	739.286	746.953	754.684
T	2180.0	2185.0	2190.0	2195.0	2200.0	2205.0	2210.0	2215.0
H	490.728	492.256	493.784	495.314	496.843	498.374	499.905	501.436
P	762.481	770.343	778.271	786.266	794.328	802.457	810.654	818.918
T	2220.0	2225.0	2230.0	2235.0	2240.0	2245.0	2250.0	2255.0
H	502.968	504.501	506.034	507.568	509.103	510.638	512.174	513.710
P	827.252	835.655	844.127	852.669	861.282	869.965	878.720	887.546

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	M/DA
53.091	29.107	.08566	.15837	.06078	0.00000	.68516	.01001	.34315	00.40

T	2260.0	2265.0	2270.0	2275.0	2280.0	2285.0	2290.0	2295.0
H	515.247	516.784	518.322	519.861	521.400	522.940	524.480	526.021
P	896.445	905.417	914.461	923.679	932.772	942.038	951.380	960.797
T	2300.0	2305.0	2310.0	2315.0	2320.0	2325.0	2330.0	2335.0
H	527.563	529.105	530.648	532.191	533.734	535.279	536.824	538.369
P	970.291	979.860	989.507	999.231	1009.033	1018.913	1028.872	1038.910
T	2340.0	2345.0	2350.0	2355.0	2360.0	2365.0	2370.0	2375.0
H	539.915	541.462	543.009	544.557	546.105	547.654	549.203	550.753
P	1049.028	1059.227	1069.506	1079.866	1090.309	1100.833	1111.441	1122.132
T	2380.0	2385.0	2390.0	2395.0	2400.0	2405.0	2410.0	2415.0
H	552.303	553.854	555.405	556.958	558.510	560.063	561.617	563.171
P	1132.906	1143.765	1154.709	1165.738	1176.853	1188.055	1199.343	1210.719
T	2420.0	2425.0	2430.0	2435.0	2440.0	2445.0	2450.0	2455.0
H	564.725	566.281	567.837	569.393	570.950	572.507	574.065	575.624
P	1222.183	1233.735	1245.376	1257.107	1268.928	1280.840	1292.843	1304.938
T	2460.0	2465.0	2470.0	2475.0	2480.0	2485.0	2490.0	2495.0
H	577.183	578.742	580.302	581.862	583.423	584.985	586.547	588.110
P	1317.125	1329.405	1341.778	1354.245	1366.807	1379.464	1392.216	1405.065
T	2500.0	2505.0	2510.0	2515.0	2520.0	2525.0	2530.0	2535.0
H	589.673	591.236	592.800	594.365	595.930	597.496	599.062	600.629
P	1418.011	1431.054	1444.194	1457.434	1470.772	1484.210	1497.749	1511.388
T	2540.0	2545.0	2550.0	2555.0	2560.0	2565.0	2570.0	2575.0
H	602.196	603.763	605.332	606.900	608.469	610.039	611.609	613.180
P	1525.129	1538.971	1552.917	1566.965	1581.118	1595.375	1609.737	1624.204
T	2580.0	2585.0	2590.0	2595.0	2600.0	2605.0	2610.0	2615.0
H	614.751	616.323	617.895	619.468	621.041	622.615	624.189	625.764
P	1638.778	1653.459	1668.248	1683.144	1698.150	1713.264	1728.489	1743.825

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	M/DA
53.091	29.107	.08566	.15837	.06078	0.00000	.68518	.01001	.34315	.00640

T	2620.0	2625.0	2630.0	2635.0	2640.0	2645.0	2650.0	2655.0
H	627.379	628.915	630.491	632.068	633.645	635.223	636.801	638.380
P	1759.272	1774.830	1790.502	1806.287	1822.185	1838.199	1854.327	1870.572
T	2660.0	2665.0	2670.0	2675.0	2680.0	2685.0	2690.0	2695.0
H	639.960	641.539	643.120	644.700	646.282	647.864	649.446	651.029
P	1886.933	1903.411	1920.007	1936.722	1953.556	1970.510	1987.585	2004.781
T	2700.0	2705.0	2710.0	2715.0	2720.0	2725.0	2730.0	2735.0
H	652.612	654.196	655.780	657.365	658.950	660.536	662.123	663.710
P	2022.099	2039.540	2057.104	2074.793	2092.606	2110.545	2128.610	2146.803
T	2740.0	2745.0	2750.0	2755.0	2760.0	2765.0	2770.0	2775.0
H	665.297	666.885	668.473	670.062	671.652	673.242	674.832	676.423
P	2165.123	2183.571	2202.149	2220.857	2239.695	2258.665	2277.767	2297.002
T	2780.0	2785.0	2790.0	2795.0	2800.0	2805.0	2810.0	2815.0
H	678.015	679.607	681.199	682.792	684.386	685.980	687.575	689.170
P	2316.371	2335.874	2355.513	2375.287	2395.199	2415.248	2435.435	2455.761
T	2820.0	2825.0	2830.0	2835.0	2840.0	2845.0	2850.0	2855.0
H	690.766	692.362	693.959	695.556	697.154	698.753	700.351	701.951
P	2476.223	2496.835	2517.583	2538.474	2559.509	2580.687	2602.010	2623.478
T	2860.0	2865.0	2870.0	2875.0	2880.0	2885.0	2890.0	2895.0
H	703.551	705.152	706.753	708.354	709.957	711.559	713.163	714.767
P	2645.094	2666.856	2688.767	2710.826	2733.036	2755.396	2777.908	2800.572
T	2900.0	2905.0	2910.0	2915.0	2920.0	2925.0	2930.0	2935.0
H	716.371	717.976	719.582	721.188	722.794	724.402	726.010	727.618
P	2823.389	2846.361	2869.488	2892.771	2916.210	2939.807	2963.564	2987.479
T	2940.0	2945.0	2950.0	2955.0	0.0	0.0	0.0	0.0
H	729.227	730.837	732.447	734.058	0.000	0.000	0.000	0.000
P	3011.555	3035.793	3060.193	3084.756	0.000	0.000	0.000	0.000

P	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	M/DA
53.215	29.039	.12497	.11536	.04600	0.00000	.70273	.01094	.22677	.00640

T	460.0	465.0	470.0	475.0	480.0	485.0	490.0	495.0
H	14.692	15.908	17.135	18.363	19.591	20.819	22.048	23.278
P	1.643	1.714	1.781	1.850	1.921	1.994	2.068	2.145
T	500.0	505.0	510.0	515.0	520.0	525.0	530.0	535.0
H	24.508	25.738	26.969	28.201	29.433	30.666	31.899	33.133
P	2.224	2.305	2.389	2.474	2.562	2.651	2.744	2.838
T	540.0	545.0	550.0	555.0	560.0	565.0	570.0	575.0
H	34.367	35.602	36.837	38.073	39.310	40.547	41.784	43.022
P	2.935	3.034	3.136	3.240	3.347	3.457	3.569	3.683
T	580.0	585.0	590.0	595.0	600.0	605.0	610.0	615.0
H	44.261	45.500	45.740	47.981	49.222	50.464	51.706	52.949
P	3.800	3.921	4.043	4.169	4.298	4.429	4.563	4.701
T	620.0	625.0	530.0	635.0	640.0	645.0	650.0	655.0
H	54.192	55.436	56.681	57.926	59.172	60.419	61.666	62.914
P	4.841	4.985	5.132	5.281	5.435	5.591	5.751	5.914
T	660.0	665.0	670.0	675.0	680.0	585.0	690.0	695.0
H	64.163	65.412	56.662	67.912	69.163	70.415	71.668	72.921
P	6.080	6.250	5.423	6.601	6.781	5.965	7.153	7.345
T	700.0	705.0	710.0	715.0	720.0	725.0	730.0	735.0
H	74.175	75.430	76.585	77.941	79.198	80.455	81.713	82.972
P	7.541	7.740	7.944	8.151	8.363	8.578	8.798	9.022
T	740.0	745.0	750.0	755.0	760.0	765.0	770.0	775.0
H	84.232	85.492	86.753	88.015	89.277	90.540	91.804	93.069
P	9.250	9.482	9.719	9.960	10.206	10.456	10.711	10.970
T	790.0	785.0	790.0	795.0	800.0	805.0	810.0	815.0
H	94.335	95.601	96.868	98.136	99.405	100.674	101.944	103.215
P	11.234	11.503	11.777	12.056	12.339	12.628	12.922	13.221

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
53.216	29.039	.12497	.11536	.04600	0.00000	.70273	.01094	.22877	.00640

T	820.0	825.0	830.0	835.0	840.0	845.0	850.0	855.0
H	104.487	105.759	107.033	108.307	109.582	110.858	112.134	113.412
P	13.525	13.834	14.149	14.469	14.795	15.126	15.463	15.805
T	860.0	865.0	870.0	875.0	880.0	885.0	890.0	895.0
H	114.690	115.969	117.249	118.530	119.811	121.094	122.377	123.661
P	16.154	16.508	16.868	17.233	17.605	17.983	18.368	18.758
T	900.0	905.0	910.0	915.0	920.0	925.0	930.0	935.0
H	124.946	126.232	127.518	128.806	130.094	131.383	132.673	133.964
P	19.155	19.558	19.968	20.384	20.807	21.236	21.672	22.115
T	940.0	945.0	950.0	955.0	960.0	965.0	970.0	975.0
H	135.255	136.549	137.842	139.137	140.432	141.728	143.025	144.323
P	22.565	23.022	23.487	23.958	24.436	24.922	25.416	25.916
T	980.0	985.0	990.0	995.0	1000.0	1005.0	1010.0	1015.0
H	145.622	146.922	148.223	149.524	150.827	152.130	153.434	154.739
P	26.425	26.941	27.465	27.996	28.536	29.083	29.639	30.203
T	1020.0	1025.0	1030.0	1035.0	1040.0	1045.0	1050.0	1055.0
H	156.045	157.352	158.660	159.969	161.279	162.589	163.901	165.213
P	30.775	31.355	31.944	32.542	33.148	33.763	34.387	35.019
T	1060.0	1065.0	1070.0	1075.0	1080.0	1085.0	1090.0	1095.0
H	166.527	167.841	169.156	170.472	171.789	173.107	174.426	175.746
P	35.661	36.312	36.972	37.641	38.320	39.008	39.706	40.413
T	1100.0	1105.0	1110.0	1115.0	1120.0	1125.0	1130.0	1135.0
H	177.067	178.389	179.711	181.035	182.359	183.685	185.011	186.338
P	41.131	41.858	42.595	43.342	44.100	44.868	45.646	46.435
T	1140.0	1145.0	1150.0	1155.0	1160.0	1165.0	1170.0	1175.0
H	187.667	188.996	190.326	191.657	192.989	194.322	195.656	196.991
P	47.235	48.045	48.866	49.698	50.541	51.396	52.261	53.138

P	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
53.216	29.039	.12497	.11535	.04600	0.00000	.70273	.01094	.22877	.00040

T	1180.0	1185.0	1190.0	1195.0	1200.0	1205.0	1210.0	1215.0
H	198.327	199.663	201.001	202.340	203.679	205.020	206.361	207.703
P	54.027	54.927	55.839	56.763	57.699	58.647	59.608	60.580
T	1220.0	1225.0	1230.0	1235.0	1240.0	1245.0	1250.0	1255.0
H	209.047	210.391	211.736	213.082	214.429	215.777	217.126	218.476
P	61.565	62.563	63.573	64.597	65.633	66.682	67.745	68.821
T	1260.0	1265.0	1270.0	1275.0	1280.0	1285.0	1290.0	1295.0
H	219.827	221.179	222.532	223.886	225.240	226.596	227.952	229.310
P	69.910	71.013	72.130	73.260	74.405	75.564	76.737	77.924
T	1300.0	1305.0	1310.0	1315.0	1320.0	1325.0	1330.0	1335.0
H	230.669	232.027	233.383	234.749	236.111	237.474	238.838	240.203
P	79.125	80.342	81.574	82.820	84.081	85.358	86.650	87.957
T	1340.0	1345.0	1350.0	1355.0	1360.0	1365.0	1370.0	1375.0
H	241.563	242.936	244.304	245.673	247.042	248.413	249.784	251.157
P	89.281	90.619	91.974	93.345	94.732	96.136	97.556	98.992
T	1380.0	1385.0	1390.0	1395.0	1400.0	1405.0	1410.0	1415.0
H	252.530	253.905	255.280	256.656	258.033	259.411	260.790	262.170
P	100.446	101.916	103.404	104.909	106.431	107.971	109.528	111.104
T	1420.0	1425.0	1430.0	1435.0	1440.0	1445.0	1450.0	1455.0
H	263.551	264.932	266.315	267.698	269.083	270.468	271.855	273.242
P	112.697	114.309	115.939	117.588	119.255	120.942	122.647	124.371
T	1460.0	1465.0	1470.0	1475.0	1480.0	1485.0	1490.0	1495.0
H	274.630	276.019	277.409	278.800	280.191	281.584	282.977	284.372
P	125.115	127.878	129.661	131.464	133.287	135.13[illegible]	136.994	138.878
T	1500.0	1505.0	1510.0	1515.0	1520.0	1525.0	1530.0	1535.0
H	285.767	287.163	288.561	289.959	291.357	292.757	294.158	295.559
P	140.783	142.708	144.655	146.623	148.612	150.623	152.656	154.711

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	M/DA
53.216	29.039	.12497	.11535	.04600	0.00000	.70273	.01094	.22877	.00640

T	1540.0	1545.0	1550.0	1555.0	1560.0	1565.0	1570.0	1575.0
H	296.982	298.365	299.769	301.174	302.580	303.987	305.395	306.804
P	156.783	158.887	161.009	163.154	165.321	167.512	169.725	171.963
T	1580.0	1585.0	1590.0	1595.0	1600.0	1605.0	1610.0	1615.0
H	308.213	309.623	311.035	312.447	313.859	315.273	316.688	318.103
P	174.224	176.509	178.817	181.151	183.506	185.890	188.297	190.729
T	1620.0	1625.0	1630.0	1635.0	1640.0	1645.0	1650.0	1655.0
H	319.520	320.937	322.355	323.774	325.194	326.614	328.035	329.458
P	193.187	195.669	198.178	200.712	203.272	205.859	208.472	211.112
T	1660.0	1665.0	1670.0	1675.0	1680.0	1685.0	1690.0	1695.0
H	330.881	332.305	333.729	335.155	336.581	338.009	339.437	340.866
P	213.778	216.472	219.193	221.941	224.718	227.522	230.354	233.215
T	1700.0	1705.0	1710.0	1715.0	1720.0	1725.0	1730.0	1735.0
H	342.295	343.726	345.157	346.589	348.022	349.456	350.890	352.326
P	236.104	239.022	241.970	244.946	247.952	250.988	254.054	257.149
T	1740.0	1745.0	1750.0	1755.0	1760.0	1765.0	1770.0	1775.0
H	353.762	355.199	356.637	358.075	359.514	360.954	362.395	363.837
P	260.276	263.432	266.620	269.839	273.089	276.371	279.684	283.038
T	1780.0	1785.0	1790.0	1795.0	1800.0	1805.0	1810.0	1815.0
H	365.279	366.723	368.167	369.611	371.057	372.503	373.950	375.398
P	286.408	289.818	293.261	296.737	300.247	303.789	307.366	310.976
T	1820.0	1825.0	1830.0	1835.0	1840.0	1845.0	1850.0	1855.0
H	376.847	378.296	379.746	381.197	382.649	384.101	385.554	387.008
P	314.621	318.300	322.014	325.763	329.547	333.367	337.222	341.114
T	1860.0	1865.0	1870.0	1875.0	1880.0	1885.0	1890.0	1895.0
H	388.462	389.918	391.374	392.830	394.288	395.746	397.205	398.665
P	345.041	349.005	353.006	357.044	361.119	365.232	369.383	373.572

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
53.216	29.039	.12497	.11536	.04600	0.00000	.70273	.01094	.22877	.00640

T	1900.0	1905.0	1910.0	1915.0	1920.0	1925.0	1930.0	1935.0
H	400.125	401.556	403.043	404.510	405.974	407.438	408.902	410.368
P	377.799	382.064	386.369	390.713	395.096	399.519	403.982	408.485
T	1940.0	1945.0	1950.0	1955.0	1960.0	1965.0	1970.0	1975.0
H	411.834	413.300	414.768	416.236	417.705	419.174	420.644	422.115
P	413.029	417.613	422.239	426.906	431.615	436.366	441.159	445.994
T	1980.0	1985.0	1990.0	1995.0	2000.0	2005.0	2010.0	2015.0
H	423.585	425.059	426.532	428.005	429.479	430.954	432.430	433.906
P	450.873	455.794	460.759	465.768	470.821	475.917	481.059	486.245
T	2020.0	2025.0	2030.0	2035.0	2040.0	2045.0	2050.0	2055.0
H	435.383	436.860	438.339	439.817	441.296	442.776	444.257	445.738
P	491.477	496.754	502.077	507.446	512.861	518.323	523.833	529.389
T	2060.0	2065.0	2070.0	2075.0	2080.0	2085.0	2090.0	2095.0
H	447.220	448.703	450.186	451.670	453.155	454.640	456.126	457.612
P	534.993	540.645	546.345	552.094	557.892	563.739	569.636	575.582
T	2100.0	2105.0	2110.0	2115.0	2120.0	2125.0	2130.0	2135.0
H	459.099	460.587	462.075	463.564	465.053	466.543	468.034	469.525
P	581.579	587.626	593.724	599.873	606.073	612.325	618.630	624.987
T	2140.0	2145.0	2150.0	2155.0	2160.0	2165.0	2170.0	2175.0
H	471.017	472.509	474.002	475.496	476.990	478.485	479.980	481.476
P	631.397	637.859	644.376	650.946	657.570	664.249	670.983	677.772
T	2180.0	2185.0	2190.0	2195.0	2200.0	2205.0	2210.0	2215.0
H	482.973	484.470	485.967	487.466	488.965	490.464	491.964	493.464
P	684.616	691.516	698.473	705.486	712.556	719.683	726.868	734.111
T	2220.0	2225.0	2230.0	2235.0	2240.0	2245.0	2250.0	2255.0
H	494.965	496.457	497.969	499.472	500.976	502.479	503.984	505.489
P	741.412	748.772	756.191	763.669	771.208	778.806	786.465	794.185

P	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
53.216	29.039	.12497	.11536	.04600	0.00000	.70273	.01094	.22877	.00640

T	2260.0	2265.0	2270.0	2275.0	2280.0	2285.0	2290.0	2295.0
H	506.994	508.500	510.007	511.514	513.022	514.530	516.039	517.548
P	801.966	809.809	817.713	825.681	833.710	841.803	849.960	858.181
T	2300.0	2305.0	2310.0	2315.0	2320.0	2325.0	2330.0	2335.0
H	519.059	520.568	522.079	523.591	525.103	526.615	528.128	529.642
P	866.455	874.815	883.229	891.709	900.255	908.867	917.546	926.292
T	2340.0	2345.0	2350.0	2355.0	2360.0	2365.0	2370.0	2375.0
H	531.155	532.670	534.185	535.701	537.217	538.734	540.251	541.769
P	935.105	943.936	952.935	961.953	971.040	980.196	989.422	998.718
T	2380.0	2385.0	2390.0	2395.0	2400.0	2405.0	2410.0	2415.0
H	543.287	544.805	546.325	547.844	549.364	550.885	552.406	553.928
P	1008.085	1017.524	1027.033	1036.615	1046.269	1055.995	1065.795	1075.669
T	2420.0	2425.0	2430.0	2435.0	2440.0	2445.0	2450.0	2455.0
H	555.450	556.973	558.496	560.020	561.544	563.068	564.593	566.119
P	1085.615	1095.638	1105.735	1115.907	1126.155	1136.479	1146.880	1157.358
T	2460.0	2465.0	2470.0	2475.0	2480.0	2485.0	2490.0	2495.0
H	567.645	569.172	570.699	572.227	573.755	575.283	576.812	578.342
P	1167.913	1178.547	1189.258	1200.049	1210.919	1221.869	1232.899	1244.009
T	2500.0	2505.0	2510.0	2515.0	2520.0	2525.0	2530.0	2535.0
H	579.872	581.402	582.933	584.465	585.997	587.529	589.062	590.595
P	1255.201	1266.475	1277.830	1289.268	1300.789	1312.393	1324.082	1335.855
T	2540.0	2545.0	2550.0	2555.0	2560.0	2565.0	2570.0	2575.0
H	592.129	593.664	595.198	596.734	598.270	599.806	601.343	602.880
P	1347.712	1359.656	1371.685	1383.800	1396.002	1408.292	1420.669	1433.135
T	2580.0	2585.0	2590.0	2595.0	2600.0	2605.0	2610.0	2615.0
H	604.419	605.956	607.494	609.034	610.573	612.113	613.654	615.195
P	1445.689	1458.333	1471.067	1483.891	1496.805	1509.811	1522.909	1536.100

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
53.216	29.039	.12497	.11535	.04600	0.00000	.70273	.01094	.22677	.00640

T	2620.0	2625.0	2630.0	2635.0	2640.0	2645.0	2650.0	2655.0
H	616.737	618.279	519.821	621.364	622.908	624.452	625.996	627.541
P	1549.383	1562.760	1576.230	1589.795	1603.455	1617.211	1631.062	1645.010
T	2660.0	2665.0	2670.0	2675.0	2680.0	2685.0	2690.0	2695.0
H	629.087	630.632	632.179	633.726	535.273	636.821	638.369	639.918
P	1659.056	1673.199	1687.440	1701.780	1716.219	1730.758	1745.398	1760.138
T	2700.0	2705.0	2710.0	2715.0	2720.0	2725.0	2730.0	2735.0
H	641.458	643.01[illegible]	644.563	646.119	547.670	649.222	650.774	652.327
P	1774.980	1789.925	1804.972	1820.122	1835.376	1850.734	1866.198	1881.767
T	2740.0	2745.0	2750.0	2755.0	2760.0	2765.0	2770.0	2775.0
H	653.880	655.434	556.983	658.543	660.099	661.654	663.211	664.768
P	1897.442	1913.224	1929.113	1945.111	1961.217	1977.432	1993.757	2010.192
T	2780.0	2785.0	2790.0	2795.0	2800.0	2805.0	2810.0	2815.0
H	666.323	667.883	669.441	671.000	572.560	674.120	675.680	677.241
P	2026.738	2043.396	2060.167	2077.050	2094.047	2111.158	2128.383	2145.724
T	2820.0	2825.0	2830.0	2835.0	2840.0	2845.0	2850.0	2855.0
H	678.803	680.365	681.928	683.491	685.055	686.619	688.184	689.749
P	2163.182	2180.756	2198.447	2216.257	2234.185	2252.232	2270.400	2288.689
T	2860.0	2865.0	2870.0	2875.0	2880.0	2885.0	2890.0	2895.0
H	691.315	692.882	694.449	696.016	697.584	699.153	700.722	702.292
P	2307.099	2325.631	2344.286	2363.064	2381.967	2400.994	2420.147	2439.427
T	2900.0	2905.0	2910.0	2915.0	2920.0	2925.0	2930.0	2935.0
H	703.863	705.434	707.005	708.578	710.150	711.724	713.298	714.872
P	2458.833	2478.368	2498.030	2517.822	2537.744	2557.797	2577.981	2598.298
T	2940.0	2945.0	2950.0	2955.0	0.0	0.0	0.0	0.0
H	716.448	718.023	719.600	721.177	0.000	0.000	0.000	0.000
P	2618.747	2639.330	2660.048	2680.901	0.000	0.000	0.000	0.000

P	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	M/DA
53.287	29.000	.14747	.09073	.03754	0.00000	.71279	.01147	.17160	.00640

T	460.0	465.0	470.0	475.0	480.0	485.0	490.0	495.0
H	14.630	15.851	17.073	18.295	19.518	20.741	21.965	23.189
P	1.645	1.709	1.776	1.844	1.914	1.987	2.061	2.137
T	500.0	505.0	510.0	515.0	520.0	525.0	530.0	535.0
H	24.413	25.638	26.863	28.089	29.315	30.542	31.769	32.996
P	2.215	2.295	2.378	2.462	2.549	2.638	2.729	2.822
T	540.0	545.0	550.0	555.0	560.0	565.0	570.0	575.0
H	34.224	35.453	36.682	37.911	39.141	40.371	41.602	42.834
P	2.918	3.016	3.116	3.219	3.325	3.433	3.543	3.656
T	580.0	585.0	590.0	595.0	600.0	605.0	610.0	615.0
H	44.065	45.298	46.531	47.764	48.998	50.232	51.467	52.703
P	3.772	3.890	4.011	4.135	4.262	4.391	4.523	4.658
T	620.0	625.0	630.0	635.0	640.0	645.0	650.0	655.0
H	53.939	55.176	56.413	57.651	58.889	60.128	61.367	62.607
P	4.797	4.938	5.082	5.229	5.380	5.533	5.690	5.850
T	660.0	665.0	670.0	675.0	680.0	685.0	690.0	695.0
H	63.848	65.089	66.331	67.573	68.816	70.060	71.304	72.549
P	6.014	6.180	6.350	6.524	6.701	5.882	7.065	7.254
T	700.0	705.0	710.0	715.0	720.0	725.0	730.0	735.0
H	73.795	75.041	76.288	77.535	78.783	80.032	81.282	82.532
P	7.446	7.641	7.840	8.043	8.250	8.461	8.676	8.895
T	740.0	745.0	750.0	755.0	760.0	765.0	770.0	775.0
H	83.782	85.034	86.286	87.539	88.792	90.047	91.301	92.557
P	9.118	9.345	9.576	9.812	10.052	10.296	10.545	10.798
T	780.0	785.0	790.0	795.0	800.0	805.0	810.0	815.0
H	93.813	95.070	96.328	97.587	98.846	100.106	101.366	102.628
P	11.056	11.318	11.585	11.857	12.133	12.415	12.701	12.992

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	M/DA
53.287	29.000	.14747	.09073	.03754	0.00000	.71279	.01147	.17160	.00646

T	820.0	825.0	830.0	835.0	840.0	845.0	850.0	855.0
H	103.890	105.153	106.416	107.681	108.946	110.212	111.479	112.746
P	13.258	13.590	13.895	14.208	14.524	14.847	15.174	15.507
T	860.0	865.0	870.0	875.0	880.0	885.0	890.0	895.0
H	114.014	115.283	116.553	117.824	119.095	120.367	121.640	122.914
P	15.846	16.190	16.539	16.895	17.256	17.623	17.996	18.375
T	900.0	905.0	910.0	915.0	920.0	925.0	930.0	935.0
H	124.189	125.464	126.740	128.017	129.295	130.574	131.853	133.133
P	18.760	19.151	19.548	19.952	20.362	20.778	21.201	21.630
T	940.0	945.0	950.0	955.0	960.0	965.0	970.0	975.0
H	134.415	135.697	136.979	138.263	139.547	140.833	142.119	143.406
P	22.065	22.508	22.958	23.414	23.877	24.347	24.824	25.308
T	980.0	985.0	990.0	995.0	1000.0	1005.0	1010.0	1015.0
H	144.694	145.982	147.272	148.562	149.854	151.146	152.439	153.733
P	25.800	26.299	26.805	27.319	27.840	28.369	28.905	29.450
T	1020.0	1025.0	1030.0	1035.0	1040.0	1045.0	1050.0	1055.0
H	155.027	156.323	157.619	158.917	160.215	161.514	162.814	164.115
P	30.002	30.562	31.130	31.707	32.291	32.884	33.485	34.095
T	1060.0	1065.0	1070.0	1075.0	1080.0	1085.0	1090.0	1095.0
H	165.415	166.719	168.023	169.327	170.632	171.938	173.245	174.553
P	34.714	35.340	35.975	36.621	37.274	37.937	38.608	39.289
T	1100.0	1105.0	1110.0	1115.0	1120.0	1125.0	1130.0	1135.0
H	175.862	177.172	178.483	179.794	181.107	182.420	183.734	185.049
P	39.979	40.678	41.387	42.106	42.834	43.572	44.320	45.078
T	1140.0	1145.0	1150.0	1155.0	1160.0	1165.0	1170.0	1175.0
H	186.365	187.682	189.000	190.319	191.638	192.959	194.280	195.603
P	45.846	46.624	47.412	48.211	49.020	49.840	50.670	51.512

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	M/DA
53.287	29.000	.14747	.09073	.03754	0.00000	.71279	.01147	.17160	.00640

T	1180.0	1185.0	1190.0	1195.0	1200.0	1205.0	1210.0	1215.0
H	196.926	198.250	199.575	200.901	202.223	203.556	204.889	206.214
P	52.364	53.227	54.101	54.987	55.884	56.792	57.712	58.643
T	1220.0	1225.0	1230.0	1235.0	1240.0	1245.0	1250.0	1255.0
H	207.543	208.877	210.209	211.542	212.876	214.212	215.548	216.885
P	59.586	60.541	61.509	62.488	63.479	64.483	65.499	66.528
T	1260.0	1265.0	1270.0	1275.0	1280.0	1285.0	1290.0	1295.0
H	218.222	219.561	220.901	222.242	223.583	224.925	226.269	227.613
P	67.569	68.623	69.691	70.771	71.864	72.971	74.091	75.225
T	1300.0	1305.0	1310.0	1315.0	1320.0	1325.0	1330.0	1335.0
H	228.958	230.304	231.651	232.999	234.348	235.698	237.048	238.400
P	76.372	77.533	78.708	79.897	81.100	82.318	83.550	84.796
T	1340.0	1345.0	1350.0	1355.0	1360.0	1365.0	1370.0	1375.0
H	239.752	241.106	242.460	243.815	245.171	246.528	247.886	249.245
P	86.057	87.333	88.624	89.930	91.251	92.588	93.940	95.308
T	1380.0	1385.0	1390.0	1395.0	1400.0	1405.0	1410.0	1415.0
H	250.604	251.965	253.326	254.689	256.052	257.416	258.781	260.147
P	96.691	98.091	99.506	100.937	102.385	103.850	105.331	106.828
T	1420.0	1425.0	1430.0	1435.0	1440.0	1445.0	1450.0	1455.0
H	261.514	262.882	264.250	265.620	266.990	268.362	269.734	271.107
P	108.343	109.875	111.424	112.990	114.573	116.175	117.794	119.431
T	1460.0	1465.0	1470.0	1475.0	1480.0	1485.0	1490.0	1495.0
H	272.481	273.856	275.231	276.608	277.985	279.364	280.743	282.123
P	121.086	122.759	124.451	126.161	127.890	129.638	131.405	133.191
T	1500.0	1505.0	1510.0	1515.0	1520.0	1525.0	1530.0	1535.0
H	283.504	284.886	286.259	287.652	289.037	290.422	291.808	293.195
P	134.997	136.821	138.666	140.530	142.415	144.319	146.244	148.189

P	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	M/DA
53.287	29.000	.14747	.09073	.03754	0.00000	.71279	.01147	.17160	.00644

T	1540.0	1545.0	1550.0	1555.0	1560.0	1565.0	1570.0	1575.0
H	294.583	295.972	297.361	298.752	300.143	301.535	302.928	304.322
P	150.155	152.142	154.150	156.179	158.229	160.301	162.394	164.510
T	1580.0	1585.0	1590.0	1595.0	1600.0	1605.0	1610.0	1615.0
H	305.717	307.112	308.509	309.906	311.304	312.703	314.103	315.503
P	166.647	168.806	170.988	173.193	175.420	177.670	179.943	182.239
T	1620.0	1625.0	1630.0	1635.0	1640.0	1645.0	1650.0	1655.0
H	316.904	318.307	319.710	321.114	322.518	323.924	325.330	326.737
P	184.559	186.903	189.270	191.661	194.077	196.517	198.981	201.470
T	1660.0	1665.0	1670.0	1675.0	1680.0	1685.0	1690.0	1695.0
H	328.145	329.554	330.963	332.374	333.785	335.197	336.610	338.023
P	203.984	206.524	209.088	211.678	214.294	216.936	219.604	222.298
T	1700.0	1705.0	1710.0	1715.0	1720.0	1725.0	1730.0	1735.0
H	339.437	340.853	342.269	343.685	345.103	346.521	347.940	349.360
P	225.019	227.766	230.540	233.342	236.171	239.027	241.911	244.823
T	1740.0	1745.0	1750.0	1755.0	1760.0	1765.0	1770.0	1775.0
H	350.780	352.202	353.624	355.047	356.470	357.895	359.320	360.746
P	247.763	250.731	253.728	256.754	259.808	262.892	266.005	269.148
T	1780.0	1785.0	1790.0	1795.0	1800.0	1805.0	1810.0	1815.0
H	362.173	363.600	365.028	366.457	367.887	369.318	370.749	372.181
P	272.321	275.523	278.756	282.020	285.314	288.639	291.995	295.383
T	1820.0	1825.0	1830.0	1835.0	1840.0	1845.0	1850.0	1855.0
H	373.613	375.047	376.481	377.916	379.351	380.788	382.225	383.662
P	298.802	302.253	305.736	309.251	312.798	316.379	319.992	323.639
T	1860.0	1865.0	1870.0	1875.0	1880.0	1885.0	1890.0	1895.0
H	385.101	386.540	387.980	389.420	390.862	392.304	393.746	395.190
P	327.319	331.032	334.780	338.561	342.377	346.228	350.113	354.034

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	W/DA
53.287	29.000	.14747	.09073	.03754	0.00000	.71279	.01147	.17160	.00640

T	1900.0	1905.0	1910.0	1915.0	1920.0	1925.0	1930.0	1935.0
H	396.674	398.079	399.524	400.970	402.417	403.865	405.313	406.762
P	357.989	361.950	366.008	370.071	374.170	378.306	382.479	386.688
T	1940.0	1945.0	1950.0	1955.0	1960.0	1965.0	1970.0	1975.0
H	408.211	409.661	411.112	412.564	414.016	415.469	416.922	418.377
P	390.935	395.220	399.542	403.902	408.301	412.730	417.214	421.729
T	1980.0	1985.0	1990.0	1995.0	2000.0	2005.0	2010.0	2015.0
H	419.831	421.287	422.743	424.200	425.657	427.115	428.574	430.033
P	426.283	430.877	435.511	440.185	444.899	449.654	454.450	459.286
T	2020.0	2025.0	2030.0	2035.0	2040.0	2045.0	2050.0	2055.0
H	431.493	432.954	434.415	435.877	437.339	438.803	440.266	441.731
P	464.165	469.085	474.047	479.051	484.097	489.187	494.319	499.495
T	2060.0	2065.0	2070.0	2075.0	2080.0	2085.0	2090.0	2095.0
H	443.196	444.661	446.127	447.594	449.061	450.529	451.998	453.467
P	504.715	509.978	515.286	520.638	526.035	531.476	536.963	542.496
T	2100.0	2105.0	2110.0	2115.0	2120.0	2125.0	2130.0	2135.0
H	454.937	456.407	457.878	459.350	460.822	462.294	463.768	465.242
P	548.075	553.699	559.370	565.088	570.853	576.666	582.526	588.433
T	2140.0	2145.0	2150.0	2155.0	2160.0	2165.0	2170.0	2175.0
H	466.715	468.191	469.667	471.143	472.619	474.097	475.574	477.053
P	594.389	600.394	606.447	612.550	618.702	624.903	631.155	637.457
T	2180.0	2185.0	2190.0	2195.0	2200.0	2205.0	2210.0	2215.0
H	478.532	480.011	481.491	482.972	484.453	485.935	487.417	488.900
P	643.810	650.213	656.668	663.175	669.733	676.344	683.007	689.722
T	2220.0	2225.0	2230.0	2235.0	2240.0	2245.0	2250.0	2255.0
H	490.383	491.867	493.351	494.836	496.322	497.808	499.294	500.781
P	696.492	703.314	710.190	717.121	724.105	731.145	738.240	745.390

P	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
53.287	29.000	.14747	.09073	.03754	0.00000	.71279	.01147	.17160	.00640

T	2260.0	2265.0	2270.0	2275.0	2280.0	2285.0	2290.0	2295.0
H	502.269	503.757	505.246	506.735	508.224	509.715	511.205	512.696
P	752.596	759.857	767.176	774.551	781.983	789.472	797.019	804.625
T	2300.0	2305.0	2310.0	2315.0	2320.0	2325.0	2330	2335.0
H	514.188	515.680	517.173	518.666	520.160	521.654	523.1[illegible]	524.644
P	812.288	820.011	827.793	835.634	843.534	851.495	859.517	867.599
T	2340.0	2345.0	2350.0	2355.0	2360.0	2365.0	2370.0	2375.0
H	526.140	527.636	529.133	530.630	532.128	533.626	535.125	536.624
P	875.743	883.948	892.215	900.544	908.936	917.390	925.909	934.490
T	2380.0	2385.0	2390.0	2395.0	2400.0	2405.0	2410.0	2415.0
H	538.124	539.624	541.125	542.626	544.127	545.629	547.132	548.635
P	943.136	951.847	960.622	969.462	978.368	987.340	996.378	1005.482
T	2420.0	2425.0	2430.0	2435.0	2440.0	2445.0	2450.0	2455.0
H	550.139	551.643	553.147	554.652	556.158	557.663	559.170	560.677
P	1014.654	1023.893	1033.200	1042.576	1052.019	1061.532	1071.114	1080.766
T	2460.0	2465.0	2470.0	2475.0	2480.0	2485.0	2490.0	2495.0
H	562.184	563.692	565.200	566.709	568.218	569.728	571.238	572.749
P	1090.488	1100.280	1110.143	1120.078	1130.084	1140.163	1150.314	1160.538
T	2500.0	2505.0	2510.0	2515.0	2520.0	2525.0	2530.0	2535.0
H	574.260	575.771	577.283	578.796	580.309	581.822	583.336	584.850
P	1170.835	1181.206	1191.651	1202.170	1212.765	1223.435	1234.181	1245.003
T	2540.0	2545.0	2550.0	2555.0	2560.0	2565.0	2570.0	2575.0
H	586.365	587.880	589.396	590.912	592.429	593.946	595.464	596.982
P	1255.902	1266.877	1277.931	1289.062	1300.271	1311.560	1322.927	1334.375
T	2580.0	2585.0	2590.0	2595.0	2600.0	2605.0	2610.0	2615.0
H	598.500	600.019	601.539	603.059	604.579	606.100	607.621	609.143
P	1345.902	1357.510	1369.199	1380.969	1392.821	1404.756	1416.773	1428.874

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
53.287	29.000	.14747	.09073	.03754	0.00000	.71279	.01147	.17160	.0064

T	2620.0	2625.0	2630.0	2635.0	2640.0	2645.0	2650.0	2655.0
H	610.665	612.188	613.711	615.235	616.759	618.284	619.809	621.334
P	1441.058	1453.326	1465.679	1478.118	1490.641	1503.251	1515.948	1528.731
T	2660.0	2665.0	2670.0	2675.0	2680.0	2685.0	2690.0	2695.0
H	622.861	624.387	625.914	627.442	628.969	630.498	632.027	633.556
P	1541.602	1554.560	1567.607	1580.743	1593.969	1607.284	1620.690	1634.186
T	2700.0	2705.0	2710.0	2715.0	2720.0	2725.0	2730.0	2735.0
H	635.086	636.616	638.147	639.679	641.211	642.743	644.276	645.809
P	1647.774	1661.454	1675.226	1689.091	1703.050	1717.102	1731.249	1745.491
T	2740.0	2745.0	2750.0	2755.0	2760.0	2765.0	2770.0	2775.0
H	647.343	648.877	650.412	651.947	653.483	655.019	656.556	658.093
P	1759.829	1774.262	1788.792	1803.419	1818.143	1832.966	1847.888	1862.908
T	2780.0	2785.0	2790.0	2795.0	2800.0	2805.0	2810.0	2815.0
H	659.631	661.170	662.709	664.248	665.788	667.328	668.869	670.411
P	1878.029	1893.249	1908.571	1923.994	1939.520	1955.147	1970.878	1986.713
T	2820.0	2825.0	2830.0	2835.0	2840.0	2845.0	2850.0	2855.0
H	671.953	673.495	675.039	676.582	678.126	679.671	681.216	682.762
P	2002.652	2018.696	2034.845	2051.100	2067.462	2083.932	2100.509	2117.195
T	2860.0	2865.0	2870.0	2875.0	2880.0	2885.0	2890.0	2895.0
H	684.[illegible]09	685.856	687.403	688.951	690.500	692.049	693.599	695.149
P	2133.96[illegible]	2150.894	2167.908	2185.034	2202.271	2219.620	2237.082	2254.658
T	2900.0	2905.0	2910.0	2915.0	2920.0	2925.0	2930.0	2935.0
H	696.700	698.252	699.804	701.357	702.910	704.464	706.019	707.574
P	2272.347	2290.152	2308.071	2326.107	2344.260	2362.529	2380.917	2399.424
T	2940.0	2945.0	2950.0	2955.0	0.0	0.0	0.0	0.0
H	709.130	710.686	712.243	713.801	0.000	0.000	0.000	0.000
P	2418.050	2436.796	2455.663	2474.651	0.000	0.000	0.000	0.000

Table A 4.1.4 - Properties of the Products of Combustion of Direct Fired Illinois No. 6 Bituminous Coal with 3% Moisture

Table A 4.1.4 Polynomial Coefficients

DIRECT-FIRED ILL 6 BIT.-3% MOISTURE--150

	RANGE OF VALIDITY	A0	A1	A2	A3	A4	A5
			STOICHIOMETRIC AIR				
H=F(T)	460.0<T<2940.0	-9.53750+01	2.36718-01	-1.81560-06	1.60914-08	-5.15432-12	5.39170-16
P=F(T)	460.0<T<2940.0	-9.30083+00	4.63674-02	-9.11705-05	1.01785-07	-3.62793-11	2.00175-14
H=F(P)	6.0<P< 90.0	2.81538+01	6.71296+00	-1.26512-01	1.46353-03	-8.45450-06	1.88365-08
H=F(P)	91.0<P< 600.0	1.34028+02	1.32195+00	-3.08977-03	4.62291-06	-3.56157-09	1.07978-12
H=F(P)	601.0<P<3300.0	2.[illegible]15+02	4.30130-01	-2.47652-04	9.47951-08	-1.92467-11	1.57070-15
P=F(H)	14.0<H< 700.0	9.55199-01	3.97422-02	4.84137-04	3.12532-06	4.62305-09	4.03490-12
T=F(H)	14.0<H< 700.0	3.99639+02	4.16017+00	-1.25308-03	-4.58439-08	1.27808-09	-8.07800-13
			100 PERCENT EXCESS AIR				
	RANGE OF VALIDITY	A0	A1	A2	A3	A4	A5
H=F(T)	460.0<T<2940.0	-9.67960+01	2.44994-01	-1.58055-05	2.24455-08	-6.80690-12	4.16284-16
P=F(T)	460.0<T<2940.0	-4.33751+00	1.92307-02	-3.40802-05	4.34708-08	-5.12874-12	9.76056-15
H=F(P)	6.0<P< 90.0	2.46336+01	7.58023+00	-1.63056-01	2.19071-03	-1.27122-05	3.87995-08
H=F(P)	91.0<P< 600.0	1.24308+02	1.63967+00	-4.78742-03	9.10777-06	-9.00121-09	3.52014-12
H=F(P)	601.0<P<3300.0	2.31317+02	5.73843-01	-4.41699-04	2.29487-07	-6.37509-11	7.15685-15
P=F(H)	14.0<H< 700.0	1.02272+00	3.58425-02	5.07208-04	2.63454-06	4.06329-09	2.06942-12
T=F(H)	14.0<H< 700.0	3.79625+02	4.17180+00	-7.84438-04	-1.27149-06	2.88145-09	-1.61159-12
			200 PERCENT EXCESS AIR				
	RANGE OF VALIDITY	A0	A1	A2	A3	A4	A5
H=F(T)	460.0<T<2940.0	-9.72923+01	2.47899-01	-2.07241-05	2.46710-08	-7.38779-12	7.78158-16
P=F(T)	460.0<T<2940.0	-3.69981+00	1.54636-02	-2.54563-05	3.41768-08	-6.61859-13	7.52861-15
H=F(P)	6.0<P< 90.0	2.34066+01	7.90876+00	-1.77873-01	2.51612-03	-1.79615-05	4.97536-08
H=F(P)	91.0<P< 600.0	1.20911+02	1.76583+00	-5.56574-03	1.15028-05	-1.23886-08	5.29017-12
H=F(P)	601.0<P<3300.0	2.25252+02	6.33835-01	-5.39245-04	3.11343-07	-9.63826-11	1.20806-14
P=F(H)	14.0<H< 700.0	1.03165+00	3.51626-02	5.06902-04	2.50993-06	3.79198-09	1.60012-12
T=F(H)	14.0<H< 700.0	3.99565+02	4.17506+00	-6.02632-04	-1.75634-06	3.53319-09	-1.94800-12
			300 PERCENT EXCESS AIR				
	RANGE OF VALIDITY	A0	A1	A2	A3	A4	A5
H=F(T)	460.0<T<2940.0	-9.75533+01	2.49412-01	-2.32768-05	2.58314-08	-7.69118-12	8.10479-16
P=F(T)	460.0<T<2940.0	-3.51144+00	1.42588-02	-2.25141-05	3.08713-08	1.16657-12	6.58785-15
H=F(P)	6.0<P< 90.0	2.27809+01	8.07112+00	-1.85874-01	2.69885-03	-1.98036-05	5.64338-08
H=F(P)	91.0<P< 600.0	1.19182+02	1.83328+00	-6.00626-03	1.29447-05	-1.45619-08	6.50156-12
H=F(P)	601.0<P<3300.0	2.22169+02	6.66529-01	-5.96517-04	3.63313-07	-1.18813-10	1.57472-14
P=F(H)	14.0<H< 700.0	1.03298+00	3.49471-02	5.05288-04	2.45426-06	3.64345-09	1.39671-12
T=F(H)	14.0<H< 700.0	3.99540+02	4.17643+00	-5.05315-04	-2.01844-06	3.88947-09	-2.13403-12

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	M/DA
51.662	29.912	.00436	.24029	.05289	.00217	.68805	.01224	.10900	.00640

T	460.0	465.0	470.0	475.0	480.0	485.0	490.0	495.0
H	14.494	15.708	16.924	18.140	19.357	20.575	21.794	23.014
P	1.663	1.730	1.799	1.870	1.943	2.018	2.096	2.175
T	500.0	505.0	510.0	515.0	520.0	525.0	530.0	535.0
H	24.235	25.456	26.679	27.903	29.127	30.353	31.579	32.807
P	2.257	2.341	2.428	2.517	2.608	2.702	2.798	2.897
T	540.0	545.0	550.0	555.0	560.0	565.0	570.0	575.0
H	34.035	35.264	36.494	37.725	38.957	40.189	41.423	42.658
P	2.998	3.102	3.209	3.319	3.431	3.546	3.664	3.785
T	580.0	585.0	590.0	595.0	600.0	605.0	610.0	615.0
H	43.893	45.129	46.366	47.605	48.844	50.083	51.324	52.566
P	3.909	4.036	4.166	4.299	4.436	4.575	4.718	4.864
T	620.0	625.0	630.0	635.0	640.0	645.0	650.0	655.0
H	53.808	55.052	56.296	57.541	58.787	60.034	61.282	62.531
P	5.014	5.167	5.324	5.484	5.648	5.815	5.987	6.162
T	660.0	665.0	670.0	675.0	680.0	685.0	690.0	695.0
H	63.781	65.032	66.283	67.536	68.789	70.043	71.298	72.555
P	6.341	6.523	6.710	6.901	7.096	7.295	7.499	7.706
T	700.0	705.0	710.0	715.0	720.0	725.0	730.0	735.0
H	73.812	75.070	76.328	77.588	78.849	80.111	81.373	82.637
P	7.918	8.135	8.356	8.581	8.811	9.046	9.286	9.530
T	740.0	745.0	750.0	755.0	760.0	765.0	770.0	775.0
H	83.901	85.167	86.433	87.701	88.969	90.238	91.509	92.780
P	9.779	10.033	10.293	10.557	10.827	11.102	11.382	11.667
T	780.0	785.0	790.0	795.0	800.0	805.0	810.0	815.0
H	94.052	95.325	96.599	97.874	99.150	100.427	101.705	102.984
P	11.958	12.255	12.557	12.865	13.179	13.499	13.824	14.156

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	M/DA
51.662	29.912	.00436	.24029	.05289	.00217	.68805	.01224	.10900	.00640

T	820.0	825.0	830.0	835.0	840.0	845.0	850.0	855.0
H	104.264	105.545	106.827	108.110	109.394	110.679	111.965	113.252
P	14.494	14.837	15.188	15.544	15.907	16.277	16.653	17.036
T	860.0	865.0	870.0	875.0	880.0	885.0	890.0	895.0
H	114.540	115.829	117.118	118.409	119.701	120.994	122.288	123.583
P	17.426	17.822	18.226	18.637	19.054	19.480	19.912	20.352
T	900.0	905.0	910.0	915.0	920.0	925.0	930.0	935.0
H	124.879	126.176	127.474	128.773	130.074	131.375	132.677	133.980
P	20.799	21.254	21.717	22.188	22.666	23.153	23.648	24.151
T	940.0	945.0	950.0	955.0	960.0	965.0	970.0	975.0
H	135.284	136.590	137.896	139.203	140.511	141.821	143.131	144.443
P	24.662	25.182	25.710	26.247	26.793	27.347	27.911	28.483
T	980.0	985.0	990.0	995.0	1000.0	1005.0	1010.0	1015.0
H	145.755	147.069	148.383	149.699	151.016	152.334	153.652	154.972
P	29.065	29.656	30.257	30.867	31.487	32.116	32.755	33.405
T	1020.0	1025.0	1030.0	1035.0	1040.0	1045.0	1050.0	1055.0
H	156.293	157.615	158.938	160.262	161.587	162.913	164.240	165.569
P	34.064	34.734	35.414	36.105	36.806	37.518	38 240	38.974
T	1060.0	1065.0	1070.0	1075.0	1080.0	1085.0	1090.0	1095.0
H	166.898	168.228	169.560	170.892	172.226	173.560	174.896	176.233
P	39.719	40.475	41.242	42.021	42.812	43.614	44.428	45.254
T	1100.0	1105.0	1110.0	1115.0	1120.0	1125.0	1130.0	1135.0
H	177.571	178.909	180.249	181.590	182.932	184.275	185.619	186.964
P	46.093	46.943	47.806	48.682	49.571	50.472	51.386	52.314
T	1140.0	1145.0	1150.0	1155.0	1160.0	1165.0	1170.0	1175.0
H	188.311	189.658	191.006	192.356	193.706	195.058	196.410	197.764
P	53.254	54.208	55.176	56.158	57.153	58.163	59.186	60.224

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	[illegible]DA
51.662	29.912	.00436	.24029	.05289	.00217	.68805	.01224	.10900	[illegible]0

T	1180.0	1185.0	1190.0	1195.0	1200.0	1205.0	1210.0	1215.0
H	199.118	200.474	201.831	203.189	204.549	205.908	207.269	208.631
P	61.277	62.344	63.426	64.523	65.635	66.762	67.905	69.064
T	1220.0	1225.0	1230.0	1235.0	1240.0	1245.0	1250.0	1255.0
H	209.994	211.358	212.723	214.089	215.457	216.825	218.194	219.565
P	70.238	71.428	72.635	73.857	75.096	76.352	77.625	78.915
T	1260.0	1265.0	1270.0	1275.0	1280.0	1285.0	1290.0	1295.0
H	220.936	222.309	223.682	225.057	226.432	227.809	229.187	230.566
P	80.221	81.545	82.887	84.247	85.624	87.019	88.433	89.865
T	1300.0	1305.0	1310.0	1315.0	1320.0	1325.0	1330.0	1335.0
H	231.945	233.326	234.708	236.091	237.475	238.860	240.246	241.633
P	91.316	92.785	94.274	95.782	97.309	98.855	100.422	102.009
T	1340.0	1345.0	1350.0	1355.0	1360.0	1365.0	1370.0	1375.0
H	243.021	244.410	245.800	247.191	248.583	249.976	251.370	252.765
P	103.615	105.242	106.89[illegible]	108.555	110.248	111.959	113.691	115.445
T	1380.0	1385.0	1390.0	1395.0	1400.0	1405.0	1410.0	1415.0
H	254.162	255.559	256.957	258.356	259.756	261.158	262.560	263.963
P	117.220	119.018	120.838	122.680	124.546	126.434	128.345	130.279
T	1420.0	1425.0	1430.0	1435.0	1440.0	1445.0	1450.0	1455.0
H	265.367	266.772	268.173	269.586	270.994	272.403	273.813	275.225
P	132.237	134.219	136.225	138.256	140.310	142.390	144.494	146.624
T	1460.0	1465.0	1470.0	1475.0	1480.0	1485.0	1490.0	1495.0
H	276.637	278.050	279.464	280.879	282.295	283.712	285.130	286.549
P	148.779	150.960	153.166	155.399	157.658	159.944	162.257	164.597
T	1500.0	1505.0	1510.0	1515.0	1520.0	1525.0	1530.0	1535.0
H	287.969	289.390	290.812	292.235	293.659	295.084	296.509	297.936
P	166.964	169.359	171.782	174.233	176.712	179.220	181.757	184.323

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	M/DA
51.662	29.912	.00436	.24029	.05289	.00217	.68805	.01224	.10900	.00640

T	1540.0	1545.0	1550.0	1555.0	1560.0	1565.0	1570.0	1575.0
H	299.364	300.792	302.222	303.652	305.084	306.516	307.950	309.384
P	186.919	189.544	192.199	194.885	197.601	200.348	203.126	205.935
T	1580.0	1585.0	1590.0	1595.0	1600.0	1605.0	1610.0	1615.0
H	310.819	312.255	313.692	315.130	316.569	318.009	319.450	320.891
P	208.776	211.649	214.554	217.491	220.462	223.465	226.502	229.572
T	1620.0	1625.0	1630.0	1635.0	1640.0	1645.0	1650.0	1655.0
H	322.334	323.778	325.222	326.667	328.114	329.561	331.009	332.458
P	232.676	235.814	238.987	242.195	245.438	248.716	252.030	255.380
T	1660.0	1665.0	1670.0	1675.0	1680.0	1685.0	1690.0	1695.0
H	333.907	335.358	336.810	338.262	339.716	341.170	342.625	344.081
P	258.766	262.189	265.649	269.146	272.681	276.254	279.864	283.514
T	1700.0	1705.0	1710.0	1715.0	1720.0	1725.0	1730.0	1735.0
H	345.538	346.996	348.455	349.914	351.375	352.836	354.298	355.761
P	287.202	290.929	294.696	298.503	302.350	306.238	310.166	314.135
T	1740.0	1745.0	1750.0	1755.0	1760.0	1765.0	1770.0	1775.0
H	357.225	358.690	360.155	361.621	363.089	364.557	366.026	367.496
P	318.146	322.199	326.294	330.432	334.613	338.836	343.104	347.415
T	1780.0	1785.0	1790.0	1795.0	1800.0	1805.0	1810.0	1815.0
H	368.966	370.438	371.910	373.383	374.857	376.332	377.807	379.284
P	351.771	356.171	360.616	365.107	369.644	374.226	378.855	383.531
T	1820.0	1825.0	1830.0	1835.0	1840.0	1845.0	1850.0	1855.0
H	380.761	382.239	383.718	385.197	386.678	388.159	389.641	391.124
P	388.254	393.025	397.844	402.711	407.627	412.592	417.606	422.671
T	1860.0	1865.0	1870.0	1875.0	1880.0	1885.0	1890.0	1895.0
H	392.607	394.092	395.577	397.063	398.550	400.037	401.526	403.015
P	427.785	432.951	438.167	443.435	448.755	454.127	459.591	465.029

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	M/DA
51.662	29.917	.00436	.24029	.05289	.00217	.68805	.01224	.10900	.00640

T	1900.0	1905.0	1910.0	1915.0	1920.0	1925.0	1930.0	1935.0
H	404.505	405.995	407.487	408.979	410.472	411.965	413.460	414.955
P	470.561	476.146	481.785	487.479	493.229	499.034	504.894	510.812
T	1940.0	1945.0	1950.0	1955.0	1960.0	1965.0	1970.0	1975.0
H	416.451	417.948	419.445	420.943	422.442	423.942	425.442	426.943
P	516.786	522.817	528.906	535.053	541.259	547.524	553.848	560.232
T	1980.0	1985.0	1990.0	1995.0	2000.0	2005.0	2010.0	2015.0
H	428.445	429.948	431.451	432.955	434.460	435.966	437.472	438.979
P	566.675	573.181	579.748	586.376	593.066	599.818	606.634	613.513
T	2020.0	2025.0	2030.0	2035.0	2040.0	2045.0	2050.0	2055.0
H	440.486	441.995	443.504	445.013	446.524	448.035	449.547	451.059
P	620.456	627.464	634.536	641.674	648.878	656.148	663.484	670.888
T	2060.0	2065.0	2070.0	2075.0	2080.0	2085.0	2090.0	2095.0
H	452.572	454.086	455.601	457.116	458.632	460.149	461.666	463.184
P	678.360	685.900	693.509	701.187	708.934	716.752	724.640	732.600
T	2100.0	2105.0	2110.0	2115.0	2120.0	2125.0	2130.0	2135.0
H	464.702	466.222	467.742	469.262	470.784	472.306	473.828	475.351
P	740.632	748.735	756.912	765.161	773.485	781.882	790.354	798.902
T	2140.0	2145.0	2150.0	2155.0	2160.0	2165.0	2170.0	2175.0
H	476.875	478.400	479.925	481.451	482.977	484.504	486.032	487.560
P	807.526	816.225	825.002	833.856	842.788	851.799	860.888	870.057
T	2180.0	2185.0	2190.0	2195.0	2200.0	2205.0	2210.0	2215.0
H	489.089	490.619	492.149	493.680	495.212	496.744	498.277	499.810
P	879.307	888.636	898.047	907.540	917.115	926.773	936.515	946.340
T	2220.0	2225.0	2230.0	2235.0	2240.0	2245.0	2250.0	2255.0
H	501.344	502.879	504.414	505.950	507.486	509.023	510.561	512.099
P	956.250	966.245	976.326	986.493	996.747	1007.088	1017.518	1028.036

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	W/DA
51.662	29.912	.00436	.24029	.15269	.00217	.68805	.01224	.10900	.00640

T	2260.0	2265.0	2270.0	2275.0	2280.0	2285.0	2290.0	2295.0
H	513.638	515.177	516.717	518.257	519.799	521.340	522.883	524.426
P	1038.643	1049.340	1060.127	1071.006	1081.976	1093.038	1104.193	1115.441
T	2300.0	2305.0	2310.0	2315.0	2320.0	2325.0	2330.0	2335.0
H	525.969	527.513	529.058	530.603	532.149	533.695	535.242	536.790
P	1126.783	1138.220	1149.752	1161.380	1173.105	1184.926	1196.846	1208.863
T	2340.0	2345.0	2350.0	2355.0	2360.0	2365.0	2370.0	2375.0
H	538.338	539.886	541.435	542.985	544.535	546.086	547.638	549.190
P	1220.980	1233.197	1245.513	1257.931	1270.450	1283.072	1295.796	1308.624
T	2380.0	2385.0	2390.0	2395.0	2400.0	2405.0	2410.0	2415.0
H	550.742	552.295	553.849	555.403	556.958	558.513	560.069	561.625
P	1321.556	1334.593	1347.736	1360.984	1374.340	1387.803	1401.375	1415.055
T	2420.0	2425.0	2430.0	2435.0	2440.0	2445.0	2450.0	2455.0
H	563.182	564.739	566.297	567.855	569.414	570.974	572.534	574.094
P	1428.845	1442.745	1456.757	1470.880	1485.115	1499.463	1513.926	1528.502
T	2460.0	2465.0	2470.0	2475.0	2480.0	2485.0	2490.0	2495.0
H	575.655	577.217	578.779	580.342	581.905	583.468	585.033	586.597
P	1543.194	1558.002	1572.927	1587.969	1603.128	1618.407	1633.806	1649.324
T	2500.0	2505.0	2510.0	2515.0	2520.0	2525.0	2530.0	2535.0
H	588.163	589.728	591.294	592.861	594.428	595.996	597.564	599.133
P	1664.954	1680.726	1696.610	1712.617	1728.748	1745.004	1761.386	1777.894
T	2540.0	2545.0	2550.0	2555.0	2560.0	2565.0	2570.0	2575.0
H	600.702	602.272	603.842	605.413	606.984	608.556	610.128	611.701
P	1794.529	1811.292	1828.184	1845.205	1862.356	1879.638	1897.052	1914.598
T	2580.0	2585.0	2590.0	2595.0	2600.0	2605.0	2610.0	2615.0
H	613.274	614.848	616.422	617.997	619.572	621.148	622.724	624.301
P	1932.278	1950.092	1968.041	1986.126	2004.347	2022.706	2041.202	2059.838

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	M/DA
51.662	29.312	.00436	.24023	.05289	.00217	.68605	.01224	.10900	.00640

T	2620.0	2625.0	2630.0	2635.0	2640.0	2645.0	2650.0	2655.0
H	625.879	627.456	629.034	630.612	632.191	633.771	635.351	636.932
P	2078.614	2097.531	2116.583	2135.790	2155.133	2174.621	2194.254	2214.032
T	2660.0	2665.0	2670.0	2675.0	2680.0	2685.0	2690.0	2695.0
H	638.513	640.094	641.676	643.259	644.841	646.425	648.009	649.593
P	2233.958	2254.030	2274.251	2294.622	2315.142	2335.814	2356.637	2377.614
T	2700.0	2705.0	2710.0	2715.0	2720.0	2725.0	2730.0	2735.0
H	651.178	652.763	654.349	655.935	657.522	659.109	660.697	662.285
P	2398.743	2420.028	2441.468	2463.064	2484.818	2506.730	2528.801	2551.032
T	2740.0	2745.0	2750.0	2755.0	2760.0	2765.0	2770.0	2775.0
H	663.874	665.463	667.053	668.643	670.233	671.824	673.416	675.008
P	2573.425	2595.979	2618.696	2641.577	2664.622	2687.834	2711.212	2734.757
T	2780.0	2785.0	2790.0	2795.0	2800.0	2805.0	2810.0	2815.0
H	676.600	678.193	679.786	681.380	682.975	684.569	686.165	687.760
P	2758.472	2782.356	2806.410	2830.636	2855.035	2879.607	2904.353	2929.275
T	2820.0	2825.0	2830.0	2835.0	2840.0	2845.0	2850.0	2855.0
H	689.357	690.953	692.551	694.148	695.746	697.345	698.944	700.543
P	2954.374	2979.650	3005.105	3030.739	3056.554	3082.551	3108.730	3135.093
T	2860.0	2865.0	2870.0	2875.0	2880.0	2885.0	2890.0	2895.0
H	702.143	703.744	705.345	706.946	708.548	710.151	711.754	713.357
P	3161.641	3188.375	3215.295	3242.404	3269.701	3297.189	3324.868	3352.739
T	2900.0	2905.0	2910.0	2915.0	2920.0	2925.0	2930.0	2935.0
H	714.961	716.565	718.170	719.775	721.381	722.987	724.594	726.201
P	3380.803	3409.062	3437.516	3466.167	3495.016	3524.064	3553.312	3582.761
T	2940.0	2945.0	2950.0	2955.0	0.0	0.0	0.0	0.0
H	727.809	729.417	731.026	732.635	0.000	0.000	0.000	0.000
P	3612.412	3642.267	3672.326	3702.591	0.000	0.000	0.000	0.000

F	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	M/DA
52.562	29.400	.11216	.12563	.03070	.00114	.71751	.01281	.05450	.00540

T	460.0	465.0	470.0	475.0	480.0	485.0	490.0	495.0
H	14.467	15.676	16.885	18.096	19.306	20.517	21.729	22.941
P	1.647	1.712	1.778	1.847	1.918	1.990	2.065	2.142
T	500.0	505.0	510.0	515.0	520.0	525.0	530.0	535.0
H	24.154	25.367	26.581	27.795	29.010	30.225	31.441	32.657
P	2.220	2.301	2.384	2.469	2.556	2.646	2.738	2.832
T	540.0	545.0	550.0	555.0	560.0	565.0	570.0	575.0
H	33.875	35.092	36.310	37.529	38.748	39.968	41.189	42.410
P	2.929	3.027	3.129	3.233	3.339	3.448	3.559	3.673
T	580.0	585.0	590.0	595.0	600.0	605.0	610.0	615.0
H	43.631	44.854	46.076	47.300	48.524	49.748	50.974	52.199
P	3.790	3.910	4.032	4.157	4.285	4.416	4.550	4.687
T	620.0	625.0	630.0	635.0	640.0	645.0	650.0	655.0
H	53.426	54.653	55.880	57.109	58.338	59.567	60.797	62.028
P	4.827	4.970	5.116	5.265	5.417	5.573	5.732	5.894
T	660.0	665.0	670.0	675.0	680.0	685.0	690.0	695.0
H	63.260	64.492	65.725	66.958	68.192	69.427	70.663	71.899
P	6.060	6.229	6.401	6.578	6.757	6.941	7.128	7.319
T	700.0	705.0	710.0	715.0	720.0	725.0	730.0	735.0
H	73.136	74.373	75.611	76.850	78.090	79.330	80.571	81.813
P	7.513	7.712	7.914	8.121	8.331	8.545	8.764	8.986
T	740.0	745.0	750.0	755.0	760.0	765.0	770.0	775.0
H	83.056	84.299	85.543	86.787	88.033	89.279	90.526	91.774
P	9.213	9.445	9.680	9.920	10.164	10.413	10.667	10.925
T	780.0	785.0	790.0	795.0	800.0	805.0	810.0	815.0
H	93.022	94.271	95.521	96.772	98.023	99.275	100.528	101.782
P	11.188	11.455	11.727	12.004	12.287	12.574	12.866	13.163

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
52.562	29.400	.11716	.12563	.13070	.00114	.71751	.01281	.05450	.00640

T	820.0	825.0	830.0	835.0	840.0	845.0	850.0	855.0
H	103.037	104.292	105.548	106.805	108.063	109.322	110.581	111.841
P	13.465	13.773	14.085	14.404	14.728	15.058	15.392	15.733
T	860.0	865.0	870.0	875.0	880.0	885.0	890.0	895.0
H	113.102	114.364	115.627	116.890	118.154	119.419	120.685	121.952
P	16.079	16.431	16.789	17.153	17.522	17.898	18.280	18.668
T	900.0	905.0	910.0	915.0	920.0	925.0	930.0	935.0
H	123.220	124.488	125.758	127.028	128.299	129.570	130.843	132.117
P	19.062	19.463	19.870	20.284	20.704	21.131	21.565	22.005
T	940.0	945.0	950.0	955.0	960.0	965.0	970.0	975.0
H	133.391	134.666	135.943	137.220	138.497	139.776	141.056	142.336
P	22.452	22.906	23.368	23.836	24.311	24.794	25.284	25.782
T	980.0	985.0	990.0	995.0	1000.0	1005.0	1010.0	1015.0
H	143.618	144.900	146.183	147.467	148.752	150.038	151.325	152.612
P	26.287	26.800	27.320	27.848	28.385	28.929	29.481	30.041
T	1020.0	1025.0	1030.0	1035.0	1040.0	1045.0	1050.0	1055.0
H	153.901	155.190	156.480	157.771	159.063	160.356	161.650	162.945
P	30.609	31.186	31.771	32.364	32.967	33.577	34.197	34.825
T	1060.0	1065.0	1070.0	1075.0	1080.0	1085.0	1090.0	1095.0
H	164.241	165.537	166.835	168.133	169.433	170.733	172.034	173.336
P	35.463	36.109	36.764	37.429	38.103	38.787	39.480	40.182
T	1100.0	1105.0	1110.0	1115.0	1120.0	1125.0	1130.0	1135.0
H	174.639	175.943	177.248	178.554	179.860	181.168	182.476	183.786
P	40.895	41.617	42.349	43.091	43.843	44.606	45.379	46.162
T	1140.0	1145.0	1150.0	1155.0	1160.0	1165.0	1170.0	1175.0
H	185.096	186.407	187.720	189.033	190.347	191.662	192.978	194.294
P	46.956	47.760	48.576	49.402	50.239	51.087	51.946	52.817

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	M/DA
52.562	29.400	.11216	.12569	.13070	.00114	.71751	.01281	.05450	.00640

T	1180.0	1185.0	1190.0	1195.0	1200.0	1205.0	1210.0	1215.0
H	195.617	196.931	198.250	199.571	200.892	202.215	203.538	204.862
P	53.699	54.593	55.499	56.416	57.345	58.286	59.239	60.204
T	1220.0	1225.0	1230.0	1235.0	1240.0	1245.0	1250.0	1255.0
H	206.187	207.514	208.841	210.169	211.497	212.827	214.158	215.490
P	61.182	62.172	63.175	64.191	65.219	66.261	67.315	68.383
T	1260.0	1265.0	1270.0	1275.0	1280.0	1285.0	1290.0	1295.0
H	216.822	218.156	219.490	220.826	222.162	223.499	224.837	226.176
P	69.464	70.558	71.667	72.788	73.924	75.074	76.238	77.416
T	1300.0	1305.0	1310.0	1315.0	1320.0	1325.0	1330.0	1335.0
H	227.515	228.857	230.199	231.542	232.886	234.230	235.576	236.922
P	78.608	79.815	81.037	82.273	83.525	84.791	86.073	87.370
T	1340.0	1345.0	1350.0	1355.0	1360.0	1365.0	1370.0	1375.0
H	238.269	239.618	240.967	242.317	243.668	245.020	246.373	247.727
P	88.683	90.011	91.355	92.714	94.090	95.482	96.891	98.316
T	1380.0	1385.0	1390.0	1395.0	1400.0	1405.0	1410.0	1415.0
H	249.081	250.437	251.793	253.151	254.509	255.868	257.228	258.589
P	99.757	101.216	102.691	104.183	105.693	107.220	108.765	110.327
T	1420.0	1425.0	1430.0	1435.0	1440.0	1445.0	1450.0	1455.0
H	259.951	261.314	262.678	264.043	265.408	266.774	268.142	263.510
P	111.907	113.505	115.122	116.756	118.410	120.081	121.772	123.482
T	1460.0	1465.0	1470.0	1475.0	1480.0	1485.0	1490.0	1495.0
H	270.879	272.249	273.620	274.992	276.364	277.738	279.112	280.487
P	125.211	126.959	128.726	130.514	132.321	134.148	135.995	137.863
T	1500.0	1505.0	1510.0	1515.0	1520.0	1525.0	1530.0	1535.0
H	281.864	283.241	284.618	285.997	287.377	288.757	290.139	291.521
P	139.751	141.669	143.589	145.539	147.511	149.504	151.519	153.555

P	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	M/DA
52.552	29.400	.11216	.12569	.03070	.00114	.71751	.01281	.05450	.00640

T	1540.0	1545.0	1550.0	1555.0	1560.0	1565.0	1570.0	1575.0
H	292.904	294.288	295.673	297.059	298.445	299.833	301.221	302.610
P	155.617	157.694	159.796	161.922	164.069	166.240	168.433	170.650
T	1580.0	1585.0	1590.0	1595.0	1600.0	1605.0	1610.0	1615.0
H	304.000	305.391	306.782	308.175	309.568	310.962	312.357	313.753
P	172.893	175.154	177.441	179.753	182.088	184.448	186.833	189.242
T	1620.0	1625.0	1630.0	1635.0	1640.0	1645.0	1650.0	1655.0
H	315.150	316.547	317.945	319.345	320.745	322.145	323.547	324.949
P	191.676	194.135	196.620	199.130	201.666	204.228	206.816	209.430
T	1660.0	1665.0	1670.0	1675.0	1680.0	1685.0	1690.0	1695.0
H	326.352	327.757	329.161	330.567	331.973	333.381	334.789	336.198
P	212.071	214.738	217.433	220.155	222.904	225.681	228.485	231.318
T	1700.0	1705.0	1710.0	1715.0	1720.0	1725.0	1730.0	1735.0
H	337.607	339.018	340.429	341.841	343.254	344.667	346.082	347.497
P	234.178	237.068	239.986	242.932	245.908	248.914	251.948	255.013
T	1740.0	1745.0	1750.0	1755.0	1760.0	1765.0	1770.0	1775.0
H	348.913	350.329	351.747	353.165	354.584	356.004	357.424	358.846
P	258.108	261.232	264.388	267.574	270.790	274.038	277.318	280.629
T	1780.0	1785.0	1790.0	1795.0	1800.0	1805.0	1810.0	1815.0
H	360.268	361.691	363.114	364.538	365.963	367.389	368.816	370.243
P	283.972	287.346	290.754	294.193	297.666	301.171	304.710	308.282
T	1820.0	1825.0	1830.0	1835.0	1840.0	1845.0	1850.0	1855.0
H	371.671	373.100	374.529	375.959	377.390	378.822	380.254	381.687
P	311.889	315.529	319.203	322.912	326.655	330.434	334.247	338.096
T	1860.0	1865.0	1870.0	1875.0	1880.0	1885.0	1890.0	1895.0
H	383.121	384.556	385.991	387.427	388.863	390.301	391.739	393.177
P	341.981	345.902	349.859	353.853	357.884	361.951	366.056	370.198

P	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
52.562	29.400	.11216	.12563	.03079	.00114	.71751	.01281	.05450	.00649

T	1900.0	1905.0	1910.0	1915.0	1920.0	1925.0	1930.0	1935.0
H	394.617	396.057	397.498	398.939	400.381	401.824	403.268	404.712
P	374.378	378.596	382.852	387.147	391.481	395.854	400.267	404.719
T	1940.0	1945.0	1950.0	1955.0	1960.0	1965.0	1970.0	1975.0
H	406.157	407.602	409.049	410.495	411.943	413.391	414.840	416.289
P	409.211	413.743	418.315	422.929	427.584	432.280	437.017	441.796
T	1980.0	1985.0	1990.0	1995.0	2000.0	2005.0	2010.0	2015.0
H	417.739	419.190	420.642	422.094	423.546	425.000	426.454	427.909
P	446.619	451.482	456.389	461.338	466.331	471.368	476.449	481.573
T	2020.0	2025.0	2030.0	2035.0	2040.0	2045.0	2050.0	2055.0
H	429.364	430.820	432.276	433.733	435.191	436.650	438.109	439.568
P	486.742	491.956	497.215	502.520	507.870	513.266	518.708	524.197
T	2060.0	2065.0	2070.0	2075.0	2080.0	2085.0	2090.0	2095.0
H	441.029	442.489	443.951	445.413	446.876	448.339	449.803	451.267
P	529.732	535.315	540.945	546.623	552.350	558.124	563.947	569.820
T	2100.0	2105.0	2110.0	2115.0	2120.0	2125.0	2130.0	2135.0
H	452.732	454.198	455.664	457.131	458.598	460.066	461.535	463.004
P	575.741	581.712	587.734	593.805	599.927	606.100	612.325	618.601
T	2140.0	2145.0	2150.0	2155.0	2160.0	2165.0	2170.0	2175.0
H	464.474	465.944	467.415	468.886	470.358	471.831	473.304	474.777
P	624.929	631.308	637.[illegible]41	644.226	650.765	657.357	664.003	670.704
T	2180.0	2185.0	2190.0	2195.0	2200.0	2205.0	2210.0	2215.0
H	476.252	477.726	479.202	480.678	482.154	483.631	485.108	486.587
P	677.458	684.268	691.133	698.054	705.030	712.063	719.152	726.298
T	2220.0	2225.0	2230.0	2235.0	2240.0	2245.0	2250.0	2255.0
H	488.065	489.544	491.024	492.504	493.985	495.466	496.948	498.430
P	733.502	740.763	748.082	755.460	762.896	770.391	777.946	785.560

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
52.562	29.400	.11216	.12569	.03070	.00114	.71751	.01281	.05450	.00640

T	2260.0	2265.0	2270.0	2275.0	2280.0	2285.0	2290.0	2295.0
H	499.913	501.396	502.880	504.364	505.849	507.335	508.821	510.307
P	793.235	800.970	808.766	816.623	824.542	832.523	840.566	848.672
T	2300.0	2305.0	2310.0	2315.0	2320.0	2325.0	2330.0	2335.0
H	511.794	513.282	514.769	516.258	517.747	519.236	520.726	522.217
P	856.841	865.073	873.369	881.730	890.155	898.645	907.200	915.821
T	2340.0	2345.0	2350.0	2355.0	2360.0	2365.0	2370.0	2375.0
H	523.708	525.199	526.691	528.183	529.676	531.170	532.664	534.158
P	924.508	933.262	942.032	950.970	959.926	968.949	978.041	987.202
T	2380.0	2385.0	2390.0	2395.0	2400.0	2405.0	2410.0	2415.0
H	535.653	537.148	538.644	540.140	541.637	543.134	544.632	546.130
P	996.432	1005.732	1015.102	1024.543	1034.054	1043.636	1053.291	1063.017
T	2420.0	2425.0	2430.0	2435.0	2440.0	2445.0	2450.0	2455.0
H	547.629	549.128	550.628	552.128	553.628	555.129	556.631	558.133
P	1072.815	1082.688	1092.633	1102.652	1112.746	1122.914	1133.157	1143.475
T	2460.0	2465.0	2470.0	2475.0	2480.0	2485.0	2490.0	2495.0
H	559.635	561.138	562.642	564.145	565.650	567.154	568.660	570.165
P	1153.869	1164.340	1174.888	1185.512	1196.215	1206.995	1217.854	1228.792
T	2500.0	2505.0	2510.0	2515.0	2520.0	2525.0	2530.0	2535.0
H	571.671	573.178	574.685	576.193	577.701	579.209	580.718	582.227
P	1239.810	1250.907	1262.085	1273.343	1284.683	1296.104	1307.607	1319.193
T	2540.0	2545.0	2550.0	2555.0	2560.0	2565.0	2570.0	2575.0
H	583.737	585.247	586.758	588.269	589.781	591.293	592.805	594.318
P	1330.862	1342.615	1354.452	1366.373	1378.379	1390.470	1402.648	1414.911
T	2580.0	2585.0	2590.0	2595.0	2600.0	2605.0	2610.0	2615.0
H	595.832	597.346	598.860	600.375	601.890	603.406	604.922	606.438
P	1427.262	1439.700	1452.226	1464.640	1477.543	1490.335	1503.217	1516.189

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
52.562	29.400	.11215	.12569	.03070	.00114	.71751	.01281	.05450	.00640

T	2620.0	2625.0	2630.0	2635.0	2640.0	2645.0	2650.0	2655.0
H	607.955	609.473	610.991	612.510	614.028	615.548	617.068	618.588
P	1529.[illegible]	1542.406	1555.652	1568.991	1582.422	1595.946	1609.585	1623.277
T	2660.0	2665.0	2670.0	2675.0	2680.0	2685.0	2690.0	2695.0
H	620.109	621.630	623.151	624.674	626.196	627.719	629.243	630.767
P	1637.[illegible]	1650.988	1664.987	1679.082	1693.275	1707.565	1721.953	1736.439
T	2700.0	2705.0	2710.0	2715.0	2720.0	2725.0	2730.0	2735.0
H	632.[illegible]	633.816	635.341	636.867	638.394	639.920	641.448	642.975
P	1751.[illegible]	1765.711	1780.495	1795.383	1810.371	1825.461	1840.653	1855.949
T	2740.0	2745.0	2750.0	2755.0	2760.0	2765.0	2770.0	2775.0
H	644.504	646.032	647.561	649.091	650.621	652.152	653.683	655.214
P	1871.349	1886.851	1902.459	1918.172	1933.992	1949.917	1965.950	1982.091
T	2780.0	2785.0	2790.0	2795.0	2800.0	2805.0	2810.0	2815.0
H	656.746	658.279	659.812	661.346	662.880	664.414	665.949	667.485
P	1998.349	2014.698	2031.165	2047.742	2064.431	2081.230	2098.141	2115.165
T	2820.0	2825.0	2830.0	2835.0	2840.0	2845.0	2850.0	2855.0
H	669.021	670.557	672.094	673.632	675.170	676.709	678.248	679.787
P	2132.[illegible]	2149.553	2166.919	2184.399	2201.996	2219.708	2237.538	2255.485
T	2860.0	2865.0	2870.0	2875.0	2880.0	2885.0	2890.0	2895.0
H	681.327	682.868	684.409	685.951	687.493	689.036	690.579	692.123
P	2273.551	2291.735	2310.039	2328.464	2347.009	2365.677	2384.466	2403.379
T	2900.0	2905.0	2910.0	2915.0	2920.0	2925.0	2930.0	2935.0
H	693.669	695.213	696.758	698.304	699.851	701.398	702.946	704.494
P	2422.415	2441.576	2460.862	2480.273	2499.812	2519.477	2539.278	2559.192
T	2940.0	2945.0	2950.0	2955.0	0.0	0.0	0.0	0.0
H	706.043	707.592	709.143	710.693	0.000	0.000	0.000	0.000
P	2579.244	2599.426	2619.738	2640.182	0.000	0.000	0.000	0.000

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
52.882	29.222	.15041	.08502	.02282	.00077	.72797	.01301	.03630	.00640

T	460.0	465.0	470.0	475.0	480.0	485.0	490.0	495.0
H	14.458	15.665	16.872	18.080	19.288	20.497	21.706	22.915
P	1.641	1.705	1.772	1.839	1.909	1.981	2.054	2.130
T	500.0	505.0	510.0	515.0	520.0	525.0	530.0	535.0
H	24.125	25.335	26.546	27.757	28.968	30.180	31.392	32.605
P	2.208	2.287	2.369	2.453	2.539	2.627	2.717	2.810
T	540.0	545.0	550.0	555.0	560.0	565.0	570.0	575.0
H	33.819	35.031	36.245	37.460	38.674	39.890	41.106	42.322
P	2.905	3.002	3.101	3.203	3.308	3.414	3.524	3.636
T	580.0	585.0	590.0	595.0	600.0	605.0	610.0	615.0
H	43.539	44.756	45.973	47.192	48.410	49.629	50.849	52.069
P	3.750	3.867	3.987	4.109	4.234	4.362	4.493	4.627
T	620.0	625.0	630.0	635.0	640.0	645.0	650.0	655.0
H	53.290	54.511	55.733	56.955	58.178	59.401	60.625	61.850
P	4.763	4.903	5.045	5.191	5.339	5.491	5.646	5.804
T	660.0	665.0	670.0	675.0	680.0	685.0	690.0	695.0
H	63.075	64.300	65.527	66.753	67.981	69.209	70.437	71.666
P	5.965	6.130	6.299	6.469	6.644	6.822	7.004	7.189
T	700.0	705.0	710.0	715.0	720.0	725.0	730.0	735.0
H	72.896	74.126	75.357	76.588	77.821	79.053	80.287	81.521
P	7.378	7.570	7.767	7.967	8.171	8.378	8.590	8.805
T	740.0	745.0	750.0	755.0	760.0	765.0	770.0	775.0
H	82.755	83.991	85.227	86.463	87.701	88.939	90.177	91.417
P	9.025	9.249	9.475	9.708	9.944	10.185	10.430	10.679
T	780.0	785.0	790.0	795.0	800.0	805.0	810.0	815.0
H	92.657	93.897	95.139	96.381	97.623	98.867	100.111	101.356
P	10.932	11.190	11.453	11.720	11.992	12.268	12.549	12.835

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	W/DA
52.892	29.222	.15041	.08532	.02282	.00077	.72797	.01301	.03630	.00640

T	820.0	825.0	830.0	835.0	840.0	845.0	850.0	855.0
H	102.601	103.848	105.095	106.342	107.591	108.840	110.090	111.341
P	13.126	13.422	13.723	14.029	14.340	14.657	14.978	15.305
T	860.0	865.0	870.0	875.0	880.0	885.0	890.0	895.0
H	112.592	113.844	115.097	116.351	117.605	118.861	120.117	121.373
P	15.637	15.975	16.319	16.666	17.020	17.380	17.746	18.118
T	900.0	905.0	910.0	915.0	920.0	925.0	930.0	935.0
H	122.631	123.889	125.148	126.408	127.669	128.930	130.193	131.456
P	18.495	18.878	19.267	19.663	20.064	20.472	20.886	21.306
T	940.0	945.0	950.0	955.0	960.0	965.0	970.0	975.0
H	132.719	133.984	135.250	136.516	137.783	139.051	140.319	141.589
P	21.733	22.167	22.606	23.053	23.506	23.966	24.433	24.907
T	980.0	985.0	990.0	995.0	1000.0	1005.0	1010.0	1015.0
H	142.859	144.130	145.402	146.675	147.949	149.223	150.499	151.775
P	25.388	25.875	26.370	26.873	27.382	27.899	28.424	28.956
T	1020.0	1025.0	1030.0	1035.0	1040.0	1045.0	1050.0	1055.0
H	153.052	154.330	155.608	156.888	158.168	159.449	160.731	162.014
P	29.495	30.042	30.598	31.161	31.731	32.310	32.897	33.493
T	1060.0	1065.0	1070.0	1075.0	1080.0	1085.0	1090.0	1095.0
H	163.298	164.583	165.868	167.154	168.442	169.730	171.019	172.308
P	34.096	34.708	35.329	35.957	36.595	37.241	37.896	38.560
T	1100.0	1105.0	1110.0	1115.0	1120.0	1125.0	1130.0	1135.0
H	173.599	174.890	176.183	177.476	178.770	180.065	181.361	182.658
P	39.233	39.915	40.606	41.307	42.017	42.736	43.465	44.203
T	1140.0	1145.0	1150.0	1155.0	1160.0	1165.0	1170.0	1175.0
H	183.955	185.254	186.553	187.854	189.155	190.457	191.760	193.063
P	44.951	45.709	46.477	47.255	48.043	48.841	49.650	50.468

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
52.882	29.222	.15041	.08502	.02282	.00077	.72797	.01301	.03630	.00640

T	1180.0	1185.0	1190.0	1195.0	1200.0	1205.0	1210.0	1215.0
H	194.368	195.674	196.980	198.287	199.595	200.905	202.214	203.525
P	51.298	52.138	52.989	53.850	54.723	55.606	56.501	57.407
T	1220.0	1225.0	1230.0	1235.0	1240.0	1245.0	1250.0	1255.0
H	204.837	206.150	207.463	208.777	210.093	211.409	212.726	214.044
P	58.324	59.252	60.192	61.144	62.108	63.083	64.071	65.070
T	1260.0	1265.0	1270.0	1275.0	1280.0	1285.0	1290.0	1295.0
H	215.363	216.682	219.003	219.324	220.647	221.970	223.294	224.619
P	66.082	67.106	68.143	69.192	70.254	71.328	72.416	73.516
T	1300.0	1305.0	1310.0	1315.0	1320.0	1325.0	1330.0	1335.0
H	225.945	227.272	228.599	229.928	231.257	232.588	233.919	235.251
P	74.630	75.756	76.897	78.050	79.218	80.399	81.594	82.802
T	1340.0	1345.0	1350.0	1355.0	1360.0	1365.0	1370.0	1375.0
H	236.584	237.917	239.252	240.588	241.924	243.262	244.600	245.939
P	84.025	85.263	86.514	87.780	89.061	90.356	91.667	92.992
T	1380.0	1385.0	1390.0	1395.0	1400.0	1405.0	1410.0	1415.0
H	247.279	248.620	249.961	251.304	252.647	253.992	255.337	256.683
P	94.332	95.688	97.059	98.445	99.848	101.266	102.699	104.149
T	1420.0	1425.0	1430.0	1435.0	1440.0	1445.0	1450.0	1455.0
H	258.030	259.378	260.726	262.076	263.426	264.777	266.129	267.482
P	105.616	107.098	108.597	110.113	111.645	113.194	114.761	116.344
T	1460.0	1465.0	1470.0	1475.0	1480.0	1485.0	1490.0	1495.0
H	268.836	270.191	271.546	272.903	274.260	275.618	276.977	278.337
P	117.945	119.563	121.199	122.853	124.524	126.214	127.921	129.648
T	1500.0	1505.0	1510.0	1515.0	1520.0	1525.0	1530.0	1535.0
H	279.697	281.059	282.421	283.784	285.148	286.513	287.878	289.245
P	131.392	133.156	134.939	136.739	138.559	140.398	142.257	144.136

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
52.882	29.222	.15041	.08502	.02282	.00077	.72797	.01301	.03630	.00640

T	1540.0	1545.0	1550.0	1555.0	1560.0	1565.0	1570.0	1575.0
H	290.612	291.980	293.349	294.719	296.090	297.461	298.833	300.206
P	146.074	147.952	149.890	151.848	153.827	155.826	157.846	159.887
T	1580.0	1585.0	1590.0	1595.0	1600.0	1605.0	1610.0	1615.0
H	301.580	302.955	304.330	305.707	307.084	308.462	309.841	311.220
P	161.949	164.032	166.135	168.262	170.410	172.579	174.771	176.984
T	1620.0	1625.0	1630.0	1635.0	1640.0	1645.0	1650.0	1655.0
H	312.601	313.982	315.364	316.746	318.130	319.514	320.899	322.285
P	179.220	181.479	183.760	186.065	188.392	190.742	193.116	195.514
T	1660.0	1665.0	1670.0	1675.0	1680.0	1685.0	1690.0	1695.0
H	323.672	325.059	326.448	327.837	329.226	330.617	332.008	333.400
P	197.935	200.380	202.850	205.343	207.862	210.405	212.972	215.565
T	1700.0	1705.0	1710.0	1715.0	1720.0	1725.0	1730.0	1735.0
H	334.793	336.187	337.581	338.976	340.372	341.769	343.166	344.565
P	218.183	220.827	223.496	226.191	228.911	231.659	234.432	237.232
T	1740.0	1745.0	1750.0	1755.0	1760.0	1765.0	1770.0	1775.0
H	345.964	347.363	348.764	350.165	351.567	352.969	354.373	355.777
P	240.055	242.912	245.793	248.701	251.637	254.601	257.592	260.612
T	1780.0	1785.0	1790.0	1795.0	1800.0	1805.0	1810.0	1815.0
H	357.181	358.587	359.993	361.400	362.808	364.216	365.625	367.035
P	263.660	266.736	269.841	272.975	276.139	279.331	282.553	285.805
T	1820.0	1825.0	1830.0	1835.0	1840.0	1845.0	1850.0	1855.0
H	368.446	369.857	371.269	372.682	374.095	375.509	376.924	378.339
P	289.087	292.399	295.742	299.115	302.519	305.954	309.421	312.918
T	1860.0	1865.0	1870.0	1875.0	1880.0	1885.0	1890.0	1895.0
H	379.755	381.172	382.589	384.008	385.426	386.846	388.216	389.687
P	316.448	320.009	323.603	327.228	330.887	334.578	338.302	342.059

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	M/DA
52.882	29.222	.15041	.08502	.02282	.00077	.72797	.01301	.03630	.00640

T	1900.0	1905.0	1910.0	1915.0	1920.0	1925.0	1930.0	1935.0
H	391.108	392.530	393.953	395.377	396.801	398.226	399.651	401.077
P	345.850	349.675	353.533	357.426	361.353	365.314	369.310	373.342
T	1940.0	1945.0	1950.0	1955.0	1960.0	1965.0	1970.0	1975.0
H	402.504	403.931	405.359	406.788	408.217	409.647	411.078	412.509
P	377.408	381.511	385.648	389.822	394.032	398.279	402.562	406.[illegible]92
T	1980.0	1985.0	1990.0	1995.0	2000.0	2005.0	2010.0	2015.0
H	413.941	415.373	416.806	418.240	419.674	421.109	422.545	423.981
P	411.240	415.635	420.067	424.537	429.046	433.593	438.178	442.803
T	2020.0	2025.0	2030.0	2035.0	2040.0	2045.0	2050.0	2055.0
H	425.417	426.855	428.293	429.731	431.170	432.610	434.050	435.491
P	447.465	452.169	456.912	461.694	466.517	471.380	476.283	481.228
T	2060.0	2065.0	2070.0	2075.0	2080.0	2085.0	2090.0	2095.0
H	436.933	438.375	439.817	441.260	442.704	444.149	445.593	447.039
P	486.214	491.241	496.309	501.420	506.573	511.768	517.007	522.288
T	2100.0	2105.0	2110.0	2115.0	2120.0	2125.0	2130.0	2135.0
H	448.485	449.932	451.379	452.826	454.275	455.724	457.173	458.623
P	527.612	532.980	538.392	543.847	549.347	554.892	560.481	566.116
T	2140.0	2145.0	2150.0	2155.0	2160.0	2165.0	2170.0	2175.0
H	460.073	461.524	462.976	464.428	465.881	467.334	468.788	470.242
P	571.796	577.522	583.294	589.112	594.976	600.888	606.846	612.852
T	2180.0	2185.0	2190.0	2195.0	2200.0	2205.0	2210.0	2215.0
H	471.697	473.152	474.608	476.064	477.521	478.978	480.436	481.895
P	618.905	625.007	631.156	637.354	643.601	649.897	656.243	662.638
T	2220.0	2225.0	2230.0	2235.0	2240.0	2245.0	2250.0	2255.0
H	483.354	484.813	486.273	487.733	489.194	490.656	492.118	493.580
P	669.083	675.578	682.124	688.720	695.368	702.067	708.818	715.621

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
52.982	29.222	.15041	.08502	.02282	.00077	.72797	.01301	.03630	.00640

T	2260.0	2265.0	2270.0	2275.0	2280.0	2285.0	2290.0	2295.0
H	495.043	496.507	497.971	499.435	500.900	502.365	503.831	505.298
P	722.477	729.385	736.346	743.360	750.428	757.550	764.726	771.956
T	2300.0	2305.0	2310.0	2315.0	2320.0	2325.0	2330.0	2335.0
H	506.765	508.232	509.700	511.168	512.637	514.106	515.576	517.046
P	779.241	786.582	793.977	801.429	808.937	816.501	824.121	831.799
T	2340.0	2345.0	2350.0	2355.0	2360.0	2365.0	2370.0	2375.0
H	518.517	519.988	521.460	522.932	524.404	525.877	527.351	528.825
P	839.534	847.327	855.178	863.087	871.055	879.082	887.168	895.314
T	2380.0	2385.0	2390.0	2395.0	2400.0	2405.0	2410.0	2415.0
H	530.299	531.774	533.249	534.725	536.201	537.678	539.155	540.633
P	903.520	911.786	920.113	928.501	936.951	945.461	954.034	962.670
T	2420.0	2425.0	2430.0	2435.0	2440.0	2445.0	2450.0	2455.0
H	542.111	543.589	545.068	546.547	548.027	549.508	550.968	552.470
P	971.368	980.129	988.954	997.842	1006.795	1015.812	1024.894	1034.041
T	2460.0	2465.0	2470.0	2475.0	2480.0	2485.0	2490.0	2495.0
H	553.951	555.433	556.916	558.399	559.882	561.366	562.850	564.335
P	1043.253	1052.532	1061.877	1071.288	1080.767	1090.313	1099.926	1109.608
T	2500.0	2505.0	2510.0	2515.0	2520.0	2525.0	2530.0	2535.0
H	565.820	567.306	568.792	570.278	571.765	573.253	574.740	576.229
P	1119.358	1129.177	1139.066	1149.024	1159.052	1169.150	1179.319	1189.559
T	2540.0	2545.0	2550.0	2555.0	2560.0	2565.0	2570.0	2575.0
H	577.717	579.206	580.696	582.186	583.677	585.167	586.659	588.151
P	1199.871	1210.255	1220.711	1231.240	1241.842	1252.517	1263.266	1274.090
T	2580.0	2585.0	2590.0	2595.0	2600.0	2605.0	2610.0	2615.0
H	589.643	591.135	592.629	594.122	595.616	597.110	598.605	600.101
P	1284.988	1295.961	1307.010	1318.135	1329.336	1340.614	1351.969	1363.402

P	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	M/DA
52.892	29.222	.15041	.08502	.02282	.00077	.72797	.01301	.03630	.00640

T	2620.0	2625.0	2630.0	2635.0	2640.0	2645.0	2650.0	2655.0
H	601.595	603.093	604.589	606.086	607.584	609.082	610.580	612.079
P	1374.912	1386.501	1398.169	1409.916	1421.743	1433.650	1445.638	1457.706
T	2660.0	2665.0	2670.0	2675.0	2680.0	2685.0	2690.0	2695.0
H	613.579	615.078	616.579	618.079	619.581	621.082	622.584	624.087
P	1469.856	1482.088	1494.402	1506.799	1519.279	1531.843	1544.491	1557.224
T	2700.0	2705.0	2710.0	2715.0	2720.0	2725.0	2730.0	2735.0
H	625.590	627.093	628.597	630.102	631.606	633.112	634.618	636.124
P	1570.041	1582.944	1595.933	1609.009	1622.171	1635.420	1648.758	1662.184
T	2740.0	2745.0	2750.0	2755.0	2760.0	2765.0	2770.0	2775.0
H	637.631	639.138	640.646	642.154	643.662	645.172	646.681	648.191
P	1675.698	1689.302	1702.996	1716.779	1730.654	1744.620	1758.677	1772.827
T	2780.0	2785.0	2790.0	2795.0	2800.0	2805.0	2810.0	2815.0
H	649.702	651.213	652.725	654.237	655.750	657.263	658.776	660.291
P	1787.070	1801.405	1815.835	1830.358	1844.977	1859.691	1874.500	1889.406
T	2820.0	2825.0	2830.0	2835.0	2840.0	2845.0	2850.0	2855.0
H	661.805	663.320	664.836	666.352	667.869	669.386	670.904	672.423
P	1904.409	1919.509	1934.707	1950.004	1965.400	1980.895	1996.490	2012.186
T	2860.0	2865.0	2870.0	2875.0	2880.0	2885.0	2890.0	2895.0
H	673.942	675.461	676.981	678.502	680.023	681.544	683.066	684.589
P	2027.984	2043.883	2059.884	2075.989	2092.196	2108.508	2124.925	2141.447
T	2900.0	2905.0	2910.0	2915.0	2920.0	2925.0	2930.0	2935.0
H	686.113	687.636	689.161	690.686	692.212	693.738	695.265	696.792
P	2158.075	2174.809	2191.650	2208.599	2225.656	2242.822	2260.098	2277.483
T	2940.0	2945.0	2950.0	2955.0	0.0	0.0	0.0	0.0
H	698.320	699.849	701.378	702.908	0.000	0.000	0.000	0.000
P	2294.979	2312.587	2330.307	2348.139	0.000	0.000	0.000	0.000

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	M/DA
53.045	29.132	.16999	.06421	.01879	.00058	.73332	.01311	.02720	.00640

T	460.0	465.0	470.0	475.0	480.0	485.0	490.0	495.0
H	14.453	15.659	16.866	18.072	19.279	20.486	21.694	22.902
P	1.678	1.702	1.768	1.835	1.905	1.976	2.049	2.124
T	500.0	505.0	510.0	515.0	520.0	525.0	530.0	535.0
H	24.110	25.319	26.528	27.737	28.947	30.157	31.367	32.578
P	2.201	2.280	2.361	2.444	2.530	2.617	2.707	2.798
T	540.0	545.0	550.0	555.0	560.0	565.0	570.0	575.0
H	33.789	35.000	36.212	37.424	38.637	39.850	41.063	42.277
P	2.892	2.989	3.087	3.188	3.292	3.398	3.506	3.616
T	580.0	585.0	590.0	595.0	600.0	605.0	610.0	615.0
H	43.491	44.706	45.921	47.136	48.352	49.569	50.785	52.003
P	3.730	3.846	3.964	4.085	4.209	4.335	4.465	4.597
T	620.0	625.0	630.0	635.0	640.0	645.0	650.0	655.0
H	53.221	54.439	55.657	56.877	58.096	59.317	60.537	61.758
P	4.732	4.869	5.010	5.154	5.300	5.450	5.603	5.759
T	660.0	665.0	670.0	675.0	680.0	685.0	690.0	695.0
H	62.980	64.202	65.425	66.648	67.872	69.097	70.322	71.547
P	5.918	6.080	6.246	6.415	6.587	6.762	6.942	7.124
T	700.0	705.0	710.0	715.0	720.0	725.0	730.0	735.0
H	72.773	74.000	75.227	76.454	77.683	78.912	80.141	81.371
P	7.310	7.500	7.693	7.890	8.090	8.295	8.503	8.715
T	740.0	745.0	750.0	755.0	760.0	765.0	770.0	775.0
H	82.602	83.833	85.065	86.298	87.531	88.764	89.999	91.234
P	8.931	9.151	9.375	9.603	9.835	10.071	10.311	10.556
T	780.0	785.0	790.0	795.0	800.0	805.0	810.0	815.0
H	92.470	93.706	94.943	96.180	97.419	98.658	99.897	101.138
P	10.805	11.058	11.316	11.578	11.845	12.116	12.392	12.672

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	M/DA
53.045	29.132	.16999	.06421	.01879	.00058	.73332	.01311	.02720	.00640

T	820.0	825.0	830.0	835.0	840.0	845.0	850.0	855.0
H	102.379	103.620	104.862	106.106	107.349	108.594	109.839	111.085
P	12.958	13.248	13.543	13.843	14.147	14.457	14.772	15.092
T	860.0	865.0	970.0	875.0	880.0	885.0	890.0	895.0
H	112.331	113.578	114.826	116.075	117.325	118.575	119.826	121.077
P	15.417	15.748	16.084	16.425	16.771	17.124	17.481	17.845
T	900.0	905.0	910.0	915.0	920.0	925.0	930.0	935.0
H	122.339	123.583	124.837	126.091	127.347	128.603	129.860	131.117
P	18.214	18.588	18.969	19.355	19.747	20.146	20.550	20.961
T	940.0	945.0	950.0	955.0	960.0	965.0	970.0	975.0
H	132.376	133.635	134.895	136.156	137.417	138.679	139.942	141.206
P	21.378	21.801	22.230	22.666	23.108	23.557	24.012	24.474
T	980.0	985.0	990.0	995.0	1000.0	1005.0	1010.0	1015.0
H	142.471	143.737	145.003	146.270	147.538	148.806	150.076	151.346
P	24.943	25.419	25.901	26.391	26.887	27.391	27.902	28.420
T	1020.0	1025.0	1030.0	1035.0	1040.0	1045.0	1050.0	1055.0
H	152.617	153.889	155.162	156.435	157.710	158.985	160.261	161.538
P	28.946	29.479	30.019	30.567	31.123	31.686	32.257	32.837
T	1060.0	1065.0	1070.0	1075.0	1080.0	1085.0	1090.0	1095.0
H	162.815	164.094	165.373	166.653	167.934	169.216	170.499	171.782
P	33.424	34.019	34.622	35.233	35.853	36.481	37.118	37.763
T	1100.0	1105.0	1110.0	1115.0	1120.0	1125.0	1130.0	1135.0
H	173.067	174.352	175.638	176.925	178.212	179.501	180.790	182.081
P	38.417	39.079	39.750	40.430	41.120	41.818	42.525	43.242
T	1140.0	1145.0	1150.0	1155.0	1160.0	1165.0	1170.0	1175.0
H	183.372	184.664	185.956	187.250	188.545	189.840	191.136	192.433
P	43.967	44.703	45.448	46.202	46.966	47.740	48.524	49.317

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
53.045	29.132	.16999	.06421	.01879	.00058	.73332	.01311	.02720	.00640

T	1180.0	1185.0	1190.0	1195.0	1200.0	1205.0	1210.0	1215.0
H	193.731	195.030	196.330	197.630	198.932	200.234	201.537	202.841
P	50.121	50.935	51.759	52.594	53.439	54.294	55.161	56.038
T	1220.0	1225.0	1230.0	1235.0	1240.0	1245.0	1250.0	1255.0
H	204.146	205.451	206.758	208.065	209.374	210.683	211.993	213.304
P	56.925	57.824	58.734	59.655	60.587	61.531	62.486	63.452
T	1260.0	1265.0	1270.0	1275.0	1280.0	1285.0	1290.0	1295.0
H	214.616	215.928	217.242	218.556	219.871	221.187	222.504	223.822
P	64.430	65.420	66.422	67.436	68.462	69.500	70.551	71.614
T	1300.0	1305.0	1310.0	1315.0	1320.0	1325.0	1330.0	1335.0
H	225.141	226.460	227.780	229.102	230.424	231.747	233.071	234.395
P	72.689	73.777	74.878	75.992	77.119	78.259	79.412	80.578
T	1340.0	1345.0	1350.0	1355.0	1360.0	1365.0	1370.0	1375.0
H	235.721	237.047	238.375	239.703	241.032	242.361	243.692	245.024
P	81.758	82.951	84.158	85.379	86.614	87.863	89.126	90.403
T	1380.0	1385.0	1390.0	1395.0	1400.0	1405.0	1410.0	1415.0
H	246.356	247.689	249.024	250.359	251.694	253.031	254.369	255.707
P	91.695	93.001	94.322	95.657	97.008	98.373	99.754	101.150
T	1420.0	1425.0	1430.0	1435.0	1440.0	1445.0	1450.0	1455.0
H	257.046	258.386	259.727	261.069	262.412	263.755	265.099	266.444
P	102.561	103.988	105.431	106.889	108.363	109.854	111.360	112.883
T	1460.0	1465.0	1470.0	1475.0	1480.0	1485.0	1490.0	1495.0
H	267.790	269.137	270.485	271.833	273.183	274.533	275.884	277.236
P	114.423	115.978	117.551	119.141	120.747	122.371	124.012	125.670
T	1500.0	1505.0	1510.0	1515.0	1520.0	1525.0	1530.0	1535.0
H	278.588	279.942	281.295	282.651	284.007	285.364	286.721	288.080
P	127.346	129.040	130.751	132.481	134.228	135.994	137.779	139.582

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
53.045	29.132	.15999	.06421	.01879	.00958	.73332	.01311	.02720	.00640

T	1540.0	1545.0	1550.0	1555.0	1560.0	1565.0	1570.0	1575.0
H	289.439	290.799	292.161	293.522	294.884	296.247	297.611	298.976
P	141.403	143.244	145.103	146.982	148.880	150.797	152.734	154.691
T	1580.0	1585.0	1590.0	1595.0	1600.0	1605.0	1610.0	1615.0
H	300.342	301.708	303.076	304.444	305.812	307.182	308.553	309.924
P	156.667	158.664	160.681	162.718	164.776	166.855	168.954	171.075
T	1620.0	1625.0	1630.0	1635.0	1640.0	1645.0	1650.0	1655.0
H	311.296	312.669	314.042	315.417	316.792	318.168	319.544	320.922
P	173.216	175.379	177.563	179.769	181.997	184.247	186.519	188.813
T	1660.0	1665.0	1670.0	1675.0	1680.0	1685.0	1690.0	1695.0
H	322.300	323.679	325.059	326.439	327.820	329.202	330.585	331.969
P	191.130	193.470	195.832	198.217	200.625	203.057	205.512	207.991
T	1700.0	1705.0	1710.0	1715.0	1720.0	1725.0	1730.0	1735.0
H	333.353	334.738	336.124	337.510	338.898	340.286	341.674	343.064
P	210.493	213.020	215.571	218.146	220.746	223.370	226.019	228.693
T	1740.0	1745.0	1750.0	1755.0	1760.0	1765.0	1770.0	1775.0
H	344.454	345.845	347.237	348.629	350.022	351.416	352.811	354.206
P	231.393	234.118	236.869	239.645	242.447	245.276	248.131	251.012
T	1780.0	1785.0	1790.0	1795.0	1800.0	1805.0	1810.0	1815.0
H	355.607	356.998	358.396	359.794	361.193	362.592	363.993	365.393
P	253.920	256.855	259.817	262.806	265.823	268.867	271.940	275.040
T	1820.0	1825.0	1830.0	1835.0	1840.0	1845.0	1850.0	1855.0
H	366.795	368.197	369.600	371.004	372.408	373.813	375.219	376.625
P	278.168	281.325	284.511	287.725	290.968	294.241	297.543	300.874
T	1860.0	1865.0	1870.0	1875.0	1880.0	1885.0	1890.0	1895.0
H	378.032	379.440	380.849	382.258	383.667	385.078	386.489	387.900
P	304.236	307.627	311.049	314.501	317.983	321.496	325.041	328.616

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	M/DA
53.045	29.132	.16999	.06421	.01879	.00058	.73332	.01311	.02720	.00640

T	1900.0	1905.0	1910.0	1915.0	1920.0	1925.0	1930.0	1935.0
H	389.313	390.726	392.139	393.554	394.968	396.384	397.800	399.217
P	332.223	335.862	339.533	343.235	346.970	350.737	354.537	358.370
T	1940.0	1945.0	1950.0	1955.0	1960.0	1965.0	1970.0	1975.0
H	400.634	402.053	403.471	404.891	406.311	407.731	409.152	410.574
P	362.236	366.136	370.069	374.035	378.036	382.071	386.140	390.244
T	1980.0	1985.0	1990.0	1995.0	2000.0	2005.0	2010.0	2015.0
H	411.997	413.420	414.843	416.267	417.692	419.118	420.544	421.970
P	394.383	398.556	402.765	407.010	411.291	415.607	419.960	424.349
T	2020.0	2025.0	2030.0	2035.0	2040.0	2045.0	2050.0	2055.0
H	423.398	424.825	426.254	427.683	429.112	430.542	431.973	433.404
P	428.774	433.237	437.737	442.274	446.849	451.461	456.112	460.800
T	2060.0	2065.0	2070.0	2075.0	2080.0	2085.0	2090.0	2095.0
H	434.836	436.269	437.702	439.135	440.569	442.004	443.439	444.875
P	465.529	470.294	475.099	479.943	484.827	489.751	494.714	499.718
T	2100.0	2105.0	2110.0	2115.0	2120.0	2125.0	2130.0	2135.0
H	446.311	447.748	449.185	450.623	452.062	453.501	454.940	456.381
P	504.762	509.847	514.973	520.140	525.348	530.598	535.890	541.224
T	2140.0	2145.0	2150.0	2155.0	2160.0	2165.0	2170.0	2175.0
H	457.821	459.262	460.704	462.146	463.589	465.032	466.476	467.920
P	546.601	552.020	557.482	562.988	568.537	574.129	579.766	585.446
T	2180.0	2185.0	2190.0	2195.0	2200.0	2205.0	2210.0	2215.0
H	469.365	470.811	472.256	473.703	475.150	476.597	478.045	479.493
P	591.172	596.942	602.756	608.617	614.522	620.474	626.471	632.515
T	2220.0	2225.0	2230.0	2235.0	2240.0	2245.0	2250.0	2255.0
H	480.942	482.391	483.841	485.292	486.743	488.194	489.646	491.098
P	638.606	644.743	650.928	657.160	663.439	669.767	676.142	682.567

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	M/DA
53.045	29.132	.16999	.06421	.01879	.00058	.73332	.01311	.02720	.00640

T	2260.0	2265.0	2270.0	2275.0	2280.0	2285.0	2290.0	2295.0
H	492.551	494.004	495.459	496.912	498.367	499.822	501.278	502.734
P	689.040	695.562	702.133	708.754	715.425	722.146	728.917	735.739
T	2300.0	2305.0	2310.0	2315.0	2320.0	2325.0	2330.0	2335.0
H	504.190	505.647	507.105	508.563	510.021	511.480	512.940	514.400
P	742.613	749.537	756.513	763.542	770.622	777.754	784.940	792.178
T	2340.0	2345.0	2350.0	2355.0	2360.0	2365.0	2370.0	2375.0
H	515.860	517.321	518.782	520.244	521.706	523.168	524.631	526.095
P	799.470	806.916	814.215	821.669	829.177	836.741	844.359	852.033
T	2380.0	2385.0	2390.0	2395.0	2400.0	2495.0	2410.0	2415.0
H	527.559	529.023	530.489	531.953	533.419	534.885	536.352	537.819
P	859.762	867.548	875.390	883.288	891.244	899.257	907.327	915.456
T	2420.0	2425.0	2430.0	2435.0	2440.0	2445.0	2450.0	2455.0
H	539.286	540.754	542.222	543.691	545.161	546.630	548.100	549.571
P	923.642	931.888	940.192	948.555	956.978	965.461	974.004	982.608
T	2460.0	2465.0	2470.0	2475.0	2480.0	2485.0	2490.0	2495.0
H	551.042	552.513	553.985	555.457	556.930	558.403	559.877	561.351
P	991.272	999.997	1008.784	1017.633	1026.544	1035.517	1044.554	1053.653
T	2500.0	2505.0	2510.0	2515.0	2520.0	2525.0	2530.0	2535.0
H	562.825	564.300	565.775	567.251	568.727	570.204	571.681	573.158
P	1062.816	1072.043	1081.334	1090.689	1100.110	1109.595	1119.147	1128.764
T	2540.0	2545.0	2550.0	2555.0	2560.0	2565.0	2570.0	2575.0
H	574.636	576.115	577.593	579.073	580.552	582.032	583.513	584.994
P	1138.447	1148.197	1158.014	1167.899	1177.851	1187.871	1197.960	1208.117
T	2580.0	2585.0	2590.0	2595.0	2600.0	2605.0	2610.0	2615.0
H	586.475	587.957	589.439	590.922	592.405	593.888	595.372	596.857
P	1218.344	1228.640	1239.006	1249.443	1259.950	1270.528	1281.177	1291.899

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	M/DA
53.045	29.132	.16999	.06421	.01879	.00058	.73332	.01311	.02720	.00640

T	2620.0	2625.0	2630.0	2635.0	2640.0	2645.0	2650.0	2655.0
H	598.342	599.827	601.313	602.799	604.285	605.773	607.260	608.748
P	1302.692	1313.559	1324.498	1335.510	1346.596	1357.757	1368.991	1380.301
T	2660.0	2665.0	2670.0	2675.0	2680.0	2685.0	2690.0	2695.0
H	610.236	611.725	613.215	614.704	616.194	617.685	619.176	620.668
P	1391.686	1403.147	1414.684	1426.298	1437.988	1449.756	1461.602	1473.525
T	2700.0	2705.0	2710.0	2715.0	2720.0	2725.0	2730.0	2735.0
H	622.150	623.652	625.145	626.639	628.133	629.627	631.122	632.617
P	1485.524	1497.609	1509.770	1522.011	1534.332	1546.734	1559.218	1571.782
T	2740.0	2745.0	2750.0	2755.0	2760.0	2765.0	2770.0	2775.0
H	634.113	635.609	637.106	638.603	640.101	641.599	643.098	644.597
P	1584.429	1597.158	1609.971	1622.866	1635.846	1648.910	1662.058	1675.292
T	2780.0	2785.0	2790.0	2795.0	2800.0	2805.0	2810.0	2815.0
H	646.097	647.597	649.097	650.599	652.100	653.603	655.105	656.608
P	1688.611	1702.017	1715.509	1729.089	1742.756	1756.510	1770.354	1784.286
T	2820.0	2825.0	2830.0	2835.0	2840.0	2845.0	2850.0	2855.0
H	658.112	659.616	661.121	662.627	664.132	665.639	667.146	668.653
P	1798.308	1812.420	1826.623	1840.916	1855.301	1869.778	1884.347	1899.009
T	2860.0	2865.0	2870.0	2875.0	2880.0	2885.0	2890.0	2895.0
H	670.161	671.670	673.179	674.689	676.199	677.710	679.221	680.733
P	1913.765	1928.615	1943.559	1958.599	1973.734	1988.965	2004.293	2019.718
T	2900.0	2905.0	2910.0	2915.0	2920.0	2925.0	2930.0	2935.0
H	682.246	683.759	685.272	686.787	688.302	689.817	691.333	692.850
P	2035.241	2050.862	2066.582	2082.402	2098.321	2114.341	2130.462	2146.685
T	2940.0	2945.0	2950.0	2955.0	0.0	0.0	0.0	0.0
H	694.367	695.885	697.404	698.923	0.000	0.000	0.000	0.000
P	2163.010	2179.438	2195.969	2212.605	0.000	0.000	0.000	0.000

Table A 4.1.5 - Properties of the Products of Combustion of Direct Fired Montana Subbituminous Coal with 20% Moisture

R	MOL.WGT	PCT.O2	PCT CO2	PCT.H2O	PCT SO2	PCT.N2	PCT.A	F/DA	H/DA
52.[illegible]34	29.699	.[illegible] 88	24943	.[illegible]6997	[illegible]259	.66572	01190	.1400[illegible]	0[illegible]640

T	460.0	465 0	470.0	475 0	480 0	485 0	490.0	495 0
H	14.668	15 897	17.127	18.358	19.590	20.823	22.057	23 292
P	1.667	1 734	1 804	1.875	1 949	2.025	2.1[illegible]3	2.184
T	500.0	505 0	510.0	515 0	520 0	525 0	530.0	535.0
H	24.528	25.765	27.003	28.242	29.482	30.722	31.964	33.207
P	2.265	2 3[illegible]1	2.438	2.528	2 620	2.715	2.812	2 912
T	540.0	545 0	550.0	555 [illegible]	56[illegible] 0	565.0	5[illegible]0.0	575 0
H	34.[illegible]	35.695	36.941	38.187	39.434	40.683	41.932	43.182
P	3.015	3.120	3 228	3.339	3 452	3.569	3.688	3.811
T	580.0	585 0	590.0	595.0	600 0	605.0	610.0	615 0
H	44.434	45 686	46.939	48.193	49 448	50.7[illegible]3	51.963	53.218
P	3.936	4 065	4.196	4.331	4 469	4.611	4.756	4.904
T	620.0	625 0	630.0	635 0	640 0	645.0	650.0	655.0
H	54.477	55 736	56.997	58.258	59.521	60.784	62.048	63 313
P	5.056	5 211	5.370	5.533	5.699	5.869	6.043	6.220
T	660.0	665 0	670.0	675.0	680.0	685.0	690.0	695.0
H	64.580	65.847	67.115	68.384	69.654	70.925	72.197	73.470
P	6.402	6.588	6.778	6.972	7 170	7.372	7.579	7.790
T	700.0	705 0	710.0	715 [illegible]	720 0	725.0	730.0	735 0
H	74.744	76.018	77.294	78.571	79.849	81.127	82.407	83.688
P	8.006	8.226	8.451	8.680	8.915	9.154	9.398	9 647
T	740.0	745 0	750.0	755 0	760 0	765.0	770.0	775.0
H	84.969	86.252	87.536	88.820	90 106	91.392	92.680	93.969
P	9.900	10.160	10.424	10.693	10.968	11.248	11.534	11.825
T	780.0	785 0	790.0	795 0	800 0	805 0	810.0	815 0
H	95.259	96.549	97.841	99.133	100.427	101.722	103.017	104.314
P	12.122	12.425	12.733	13.048	13.368	13.695	14.027	14.366

R	MOL.WGT	PCT.O2	PCT.CO2	PCT.H2O	PCT SO2	PCT.N2	PCT.A	F/DA	M/DA
52.034	29.699	.00288	24943	.06997	.00209	.66572	.01190	.14000	00640

T	820.0	825.0	830.0	835.0	840.0	845.0	850.0	855.0
H	105.612	106.911	108.210	109.511	110.813	112.116	113.420	114.725
P	14.711	15.062	15.420	15.785	16.156	16.534	16.919	17.310
T	860.0	865.0	870.0	875.0	880.0	885.0	890.0	895.0
H	116.031	117.338	118.646	119.955	121.266	122.577	123.889	125.203
P	17.709	18.115	18.528	18.948	19.376	19.811	20.254	20.705
T	900.0	905.0	910.0	915.0	920.0	925.0	930.0	935.0
H	126.517	127.832	129.149	130.467	131.785	133.105	134.426	135.748
P	21.163	21.630	22.104	22.586	23.077	23.576	24.083	24.599
T	940.0	945.0	950.0	955.0	960.0	965.0	970.0	975.0
H	137.071	138.395	139.720	141.046	142.373	143.701	145.031	146.361
P	25.124	25.657	26.199	26.750	27.310	27.880	28.458	29.046
T	980.0	985.0	990.0	995.0	1000.0	1005.0	1010.0	1015.0
H	147.693	149.025	150.359	151.694	153.030	154.367	155.705	157.044
P	29.644	30.251	30.869	31.496	32.133	32.780	33.437	34.105
T	1020.0	1025.0	1030.0	1035.0	1040.0	1045.0	1050.0	1055.0
H	158.384	159.725	161.067	162.411	163.755	165.101	166.448	167.796
P	34.783	35.472	36.172	36.882	37.604	38.337	39.081	39.836
T	1060.0	1065.0	1070.0	1075.0	1080.0	1085.0	1090.0	1095.0
H	169.144	170.494	171.845	173.198	174.551	175.905	177.261	178.617
P	40.603	41.382	42.173	42.975	43.790	44.617	45.456	46.308
T	1100.0	1105.0	1110.0	1115.0	1120.0	1125.0	1130.0	1135.0
H	179.975	181.334	182.693	184.054	185.416	186.779	188.143	189.509
P	47.172	48.050	48.940	49.843	50.760	51.690	52.633	53.591
T	1140.0	1145.0	1150.0	1155.0	1160.0	1165.0	1170.0	1175.0
H	190.875	192.242	193.611	194.981	196.351	197.723	199.096	200.470
P	54.562	55.547	56.546	57.560	58.588	59.631	60.689	61.762

R	MOL.WGT	PCT.O2	PCT CO2	PCT.H2O	PCT SO2	PCT.N2	PCT.A	F/DA	M/DA
52.634	29.699	.1[illegible]88	24943	.06997	.00209	.66572	.01190	.14000	00640

T	1180.0	1185.0	1190.0	1195.0	1200.0	1205.0	1210.0	1215.0
H	201.845	203.221	204.598	205.977	207.356	208.737	210.118	211.501
P	62.850	63.9[illegible]3	65.071	66.206	67.356	68.522	69.704	70.903
T	1220.0	1225.0	1230.0	1235.0	1240.0	1245.0	1250.0	1255.0
H	212.885	214.269	215.655	217.042	218.430	219.820	221.210	222.601
P	72.118	73.3[illegible]0	74.599	75.865	77.148	78.448	79.766	81.102
T	1260.0	1265.0	1270.0	1275.0	1280.0	1285.0	1290.0	1295.0
H	223.993	225.387	226.781	228.177	229.574	230.971	232.370	233.770
P	82.456	83.828	85.219	86.627	88.055	89.502	90.968	92.453
T	1300.0	1305.0	1310.0	1315.0	1320.0	1325.0	1330.0	1335.0
H	235.171	236.573	237.976	239.380	240.786	242.192	243.599	245.008
P	93.957	95.482	97.026	98.591	100.176	101.781	103.407	105.054
T	1340.0	1345.0	1350.0	1355.0	1360.0	1365.0	1370.0	1375.0
H	246.417	247.827	249.239	250.652	252.065	253.480	254.896	256.313
P	106.723	108.412	110.124	111.857	113.612	115.390	117.190	119.013
T	1380.0	1385.0	1390.0	1395.0	1400.0	1405.0	1410.0	1415.0
H	257.730	259.149	260.569	261.990	263.412	264.835	266.259	267.684
P	120.858	122.727	124.620	126.536	128.476	130.440	132.428	134.441
T	1420.0	1425.0	1430.0	1435.0	1440.0	1445.0	1450.0	1455.0
H	269.111	270.538	271.966	273.395	274.825	276.257	277.689	279.122
P	136.478	138.541	140.629	142.743	144.882	147.048	149.239	151.458
T	1460.0	1465.0	1470.0	1475.0	1480.0	1485.0	1490.0	1495.0
H	280.557	281.992	283.428	284.866	286.304	287.744	289.184	290.625
P	153.703	155.975	158.274	160.601	162.956	165.339	167.750	170.190
T	1500.0	1505.0	1510.0	1515.0	1520.0	1525.0	1530.0	1535.0
H	292.068	293.511	294.955	296.401	297.847	299.295	300.743	302.192
P	172.659	175.156	177.684	180.241	182.828	185.445	188.093	190.772

R	MOL.WGT	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
52.034	29.699	.00088	24943	.06997	00209	.66572	01190	.14000	00640

T	1540.0	1545 0	1550.0	1555.0	1560 0	1565.0	1570.0	1575 0
H	303.643	305.094	306.546	307.999	309.454	310.909	312.365	313.822
P	193.481	196.222	198.995	201.800	204.637	207.506	210.409	213.344
T	1580.0	1585 0	1590.0	1595 0	1600.0	1605.0	1610.0	1615 0
H	315.280	316.739	318 199	319.660	321.122	322.585	324.049	325.514
P	216.313	219.316	222.353	225.424	228.529	231.670	234.846	238.058
T	1520.0	1625 0	1630.0	1635.0	1640.0	1645.0	1650.0	1655 0
H	326.980	328.446	329.914	331.383	332.852	334.323	335.794	337.266
P	241.305	244 589	247 909	251.266	254.660	258.092	261.561	265.069
T	1560.0	1665 0	1670.0	1675.0	1680.0	1685.0	1690.0	1695.0
H	338.740	340.214	341.689	343.165	344.642	346.120	347.598	349.078
P	268.615	272 200	275.825	279.488	283.192	286.936	290.720	294 545
T	1700.0	1705 0	1710.0	1715.0	1720.0	1725.0	1730.0	1735.0
H	350.559	352.040	353.523	355.006	356.490	357.975	359.461	360.948
P	298.411	302.319	306.269	310.261	314.296	318.374	322.495	326.660
T	1740.0	1745 0	1750.0	1755 0	1760 0	1765.0	1770.0	1775.0
H	362.436	363.924	365.414	366.904	368.396	369.888	371.381	372.875
P	331.869	335.122	339.421	343.764	348.153	352.588	357.070	361.598
T	1780.0	1785 0	1790.0	1795.0	1800.0	1805.0	1810.0	1815 0
H	374.369	375.865	377.361	378.859	380.357	381.856	383.356	384.857
P	366.173	370.796	375.467	380.186	384.953	389.770	394.636	399.552
T	1820.0	1825.0	1830.0	1835.0	1840.0	1845.0	1850.0	1855.0
H	386.358	387.861	389.364	390.868	392.373	393.879	395.385	396.893
P	404.518	409.535	414.603	419.723	424.894	430.118	435.395	440.724
T	1860.0	1865 0	1870.0	1875.0	1880.0	1885.0	1890.0	1895.0
H	398.401	399.910	401.420	402.931	404.442	405.955	407.468	408.982
P	445.108	451.545	457.037	462.584	468.186	473.843	479.557	485.328

R	MOL.WGT	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
52.034	29.699	.00388	24943	.06937	00209	.66572	01190	.14000	00640

T	1540.0	1545 0	1550.0	1555.0	1560 0	1565 0	1570.0	1575 0
H	303.643	305.094	306.546	307.999	309.454	310.909	312.365	313.822
P	193.481	196.222	198.995	201.800	204.637	207.506	210.409	213.344
T	1580.0	1585 0	1590.0	1595 0	1600.0	1605.0	1610.0	1615 0
H	315.280	316.739	318 199	319.660	321.122	322.585	324.049	325.514
P	215.313	219.316	222.353	225.424	228 529	231.670	234.846	238.058
T	1520.0	1625 0	1630.0	1635.0	1640.0	1645.0	1650.0	1655 0
H	325.980	328.446	329.914	331.383	332.852	334.323	335.794	337.266
P	241.305	244 589	247 909	251.266	254.660	258.092	261.561	265.069
T	1560.0	1665 0	1670.0	1675.0	1680.0	1685.0	1690.0	1695.0
H	338.740	340.214	341.689	343.165	344.642	346.120	347.598	349.078
P	268.615	272 200	275.825	279.488	283.192	286.936	290.720	294 545
T	1700.0	1705 0	1710.0	1715.0	1720.0	1725.0	1730.0	1735.0
H	350.559	352.040	353.523	355.006	356.490	357.975	359.461	360.948
P	298.411	302.319	306.269	310.261	314.296	318.374	322.495	326.660
T	1740.0	1745 0	1750.0	1755 0	1760 0	1765.0	1770.0	1775.0
H	362.436	363.924	365.414	366.904	368.396	369.888	371.381	372.875
P	330.869	335.122	339.421	343.764	348.153	352.588	357.070	361.598
T	1780.0	1785 0	1790.0	1795.0	1800.0	1805.0	1810.0	1815 0
H	374.369	375.865	377.361	378.859	380.357	381.856	383.356	384.857
P	365.173	370.796	375.467	380.186	384.953	389.770	394.636	399.552
T	1320.0	1825.0	1830.0	1835.0	1840 0	1845.0	1850.0	1855 0
H	386.358	387.851	389.364	390.868	392.373	393.879	395.385	396.893
P	404.518	409.535	414.603	419.723	424.894	430.118	435.395	440.724
T	1860.0	1865 0	1870.0	1875.0	1880 0	1885.0	1890.0	1895.0
H	398.401	399.910	401.420	402.931	404.442	405.955	407.468	408.982
P	445.108	451.545	457.037	462.584	468.186	473.843	479.557	485.328

R	MOL.WGT	PCT.O2	PCT CO2	PCT H2O	PCT SO2	PCT.N2	PCT.A	F/DA	M/DA
52.034	29.699	.03088	.24943	.06997	.00209	.66572	.01190	.14000	.00640

T	1900.0	1905.0	1910.0	1915.0	1920.0	1925.0	1930.0	1935.0
H	410.497	412.012	413.529	415.046	416.564	418.083	419.602	421.122
P	491.155	497.040	502.984	508.985	515.045	521.165	527.345	533.584
T	1940.0	1945.0	1950.0	1955.0	1960.0	1965.0	1970.0	1975.0
H	422.643	424.165	425.688	427.211	428.736	430.261	431.786	433.313
P	539.885	546.246	552.669	559.155	565.702	572.313	578.988	585.726
T	1980.0	1985.0	1990.0	1995.0	2000.0	2005.0	2010.0	2015.0
H	434.840	436.368	437.897	439.427	440.957	442.488	444.020	445.552
P	592.529	599.397	606.331	613.330	620.396	627.529	634.729	641.997
T	2020.0	2025.0	2030.0	2035.0	2040.0	2045.0	2050.0	2055.0
H	447.085	448.619	450.154	451.690	453.226	454.763	456.301	457.839
P	649.334	656.740	664.215	671.760	679.376	687.063	694.821	702.652
T	2060.0	2065.0	2070.0	2075.0	2080.0	2085.0	2090.0	2095.0
H	459.378	460.918	462.458	464.000	465.542	467.084	468.628	470.172
P	710.555	718.531	726.581	734.705	742.904	751.178	759.528	767.954
T	2100.0	2105.0	2110.0	2115.0	2120.0	2125.0	2130.0	2135.0
H	471.717	473.262	474.808	476.355	477.903	479.451	481.000	482.549
P	775.458	785.038	793.697	802.435	811.251	820.148	829.125	838.182
T	2140.0	2145.0	2150.0	2155.0	2160.0	2165.0	2170.0	2175.0
H	484.100	485.651	487.202	488.755	490.308	491.861	493.416	494.971
P	847.321	856.542	865.846	875.233	884.703	894.258	903.898	913.624
T	2180.0	2185.0	2190.0	2195.0	2200.0	2205.0	2210.0	2215.0
H	496.526	498.083	499.640	501.197	502.756	504.315	505.874	507.434
P	923.435	933.334	943.320	953.393	963.556	973.807	984.148	994.580
T	2220.0	2225.0	2230.0	2235.0	2240.0	2245.0	2250.0	2255.0
H	508.995	510.557	512.119	513.682	515.245	516.809	518.374	519.939
P	1005.103	1015.717	1026.424	1037.223	1048.117	1059.104	1070.186	1081.364

R	MOL.WGT	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
52.034	29.699	.00088	24943	.06997	.00209	.66572	.01190	.14000	00640

T	2260.0	2265 0	2270.0	2275.0	2280.0	2285.0	2290.0	2295 0
H	521.505	523.072	524.639	526.207	527 775	529.344	530.914	532.484
P	1092.638	1104.009	1115.477	1127.043	1138.708	1150.472	1162.337	1174.302
T	2300.0	2305 0	2310.0	2315 0	2320.0	2325.0	2330.0	2335 0
H	534.055	535.627	537.199	538.772	540.345	541.919	543.493	545.068
P	1185.369	1198.537	1210.809	1223.184	1235.663	1248.247	1260.937	1273.733
T	2340.0	2345 0	2350.0	2355 0	2360 0	2365.0	2370.0	2375 0
H	545.644	548.220	549.797	551.375	552.953	554.531	556.111	557.691
P	1285.636	1299.6-7	1312.765	1325.993	1339.331	1352.779	1366.339	1380.010
T	2380.0	2385.0	2390.0	2395.0	2400.0	2405.0	2410.0	2415.0
H	559.271	560.852	562.433	564.016	565.598	567.181	568.765	570.350
P	1393.795	1407.692	1421.704	1435.831	1450 073	1464.432	1478.907	1493.501
T	2420.0	2425 0	2430.0	2435 0	2440 0	2445.0	2450.0	2455.0
H	571.93?	573.520	575.106	576.693	578.280	579.868	581.456	583.045
P	1508.214	1523.045	1537.997	1553.070	1568.265	1583.582	1599.022	1614.587
T	2460.0	2465 0	2470.0	2475.0	2480.0	2485.0	2490.0	2495.0
H	584.634	586.224	587.815	589.406	590.998	592.590	594.183	595.776
P	1630.275	1646.091	1662.033	1678.101	1694.298	1710.623	1727.079	1743.664
T	2500.0	2505 0	2510.0	2515.0	2520.0	2525.0	2530.0	2535 0
H	597.370	598.964	600.559	602.154	603.750	605.347	606.944	608.541
P	1761.381	1777.230	1794.212	1811.328	1828.578	1845.964	1863.486	1881.146
T	2540.0	2545 0	2550.0	2555.0	2560 0	2565.0	2570.0	2575 0
H	610.139	611.738	613.337	614.937	616.537	618.137	619.739	621.340
P	1898.943	1916.879	1934.955	1953.171	1971.529	1990.029	2008.672	2027.459
T	2580.0	2585.0	2590.0	2595.0	2600.0	2605.0	2610.0	2615.0
H	622.943	624.545	626.149	627.753	629.357	630.962	632.567	634.173
P	2046.392	2065.470	2084.694	2104.067	2123.588	2143.258	2163.079	2183.051

R	MOL.WGT	PCT.O2	PCT CO2	PCT.H2O	PCT SO2	PCT.N2	PCT.A	F/DA	W/DA
52.134	29.699	.10 88	24943	.06997	00209	.66572	01190	.14000	00640

T	2620.0	2625 0	2630.0	2635 0	2640 0	2645.0	2650.0	2655 0
H	635.779	637.386	638.994	640.502	642.210	643.819	645.429	647.038
P	2203.175	2223 452	2243.884	2264.470	2285.212	2306.111	2327.168	2348.383
T	2660.0	2665 0	2670.0	2675 0	2680.0	2685.0	2690.0	2695.0
H	648.649	650.250	651.871	653.483	655.096	656.709	658.322	659.936
P	2369.758	2391 294	2412.992	2434.8[illegible]2	2456 875	2479.053	2501.417	2523.937
T	27[illegible].0	2705 0	2710.0	2715.0	272[illegible].0	2725.0	2730.0	2735 0
H	661.551	663.165	664 781	666.397	668.014	669.631	671.248	672.866
P	2545.625	2569.481	2592.507	2615.7[illegible]3	2639.071	2662.611	2686.325	2710.213
T	2740 0	2745 0	2750.0	2755.0	2760 0	2765 0	2770.0	2775 0
H	674.485	676.1 3	677.723	679.343	680 963	682.584	684.206	685.828
P	2734.277	2758.518	2782.936	2807.533	2832.310	2857.258	2882.408	2907.731
T	2780.0	2785 0	2790.0	2795 0	2800.0	2805.0	2810.0	2815 0
H	687.459	689.073	690.696	692.320	693.945	695.570	697.195	698.821
P	2933.238	2958.930	2984.808	3010.874	3037.128	3063.571	3090.205	3117.031
T	2820.0	2825 0	2830.0	2835.0	2840.0	2845.0	2850.0	2855 0
H	701.447	702.074	703.701	705.329	706 958	708.586	710.216	711.846
P	3144.050	3171.263	3198.671	3226.275	3254 077	3282.077	3310.277	3338.678
T	2860.0	2865 0	2870.0	2875.0	2880.0	2885.0	2890.0	2895.0
H	713.476	715.107	716.738	718.370	720.002	721.635	723.268	724.902
P	3367.280	3396.086	3425.097	3454.312	3483.735	3513.366	3543.205	3573.255
T	2900.0	2905 0	2910.0	2915.0	2920.0	2925.0	2930.0	2935.0
H	726.536	728.171	729.806	731.442	733.078	734.715	736.352	737.990
P	3603.517	3633.991	3664.680	3695.583	3726.703	3758.041	3789.598	3821.374
T	2940.0	2945 0	2950.0	2955.0	0.0	0 0	0.0	0 0
H	739.628	741.267	742.906	744.546	0.000	0.000	0.000	0.000
P	3853.373	3885.594	3918.039	3950.710	0.000	0.000	0.000	0.000

R	MOL.WGT	PCT.O2	PCT.CO2	PCT.H2O	PCT SO2	PCT.N2	PCT.A	F/DA	H/DA
52.746	29.297	.10373	13222	.04038	.00111	.70524	01262	.07000	00640

T	460.0	465 0	470.0	475 0	480.0	485.0	490.0	495 0
H	14.561	15.777	16.994	18.212	19.431	20.650	21.869	23.090
P	1.649	1.714	1.781	1.851	1.921	1.994	2.069	2.146
T	500.0	505 0	510.0	515 0	520.0	525.0	530.0	535 0
H	24.310	25 532	26.754	27.976	29.199	30.423	31.647	32.872
P	2.225	2 3 7	2.390	2.476	2.564	2.654	2.746	2.841
T	540.0	545 0	550.0	555.0	560 0	565.0	570.0	575 0
H	34.097	35 323	36.550	37.777	39.005	40.233	41.462	42.692
P	2.938	3 038	3 140	3.244	3 351	3.461	3.573	3.688
T	580.0	585 0	590.0	595.0	600.0	605.0	610.0	615.0
H	43.922	45.153	46.384	47.616	48.849	50.082	51.316	52.550
P	3.806	3 927	4.050	4.176	4.305	4.437	4.572	4.710
T	620.0	625.0	630.0	635.0	640 0	645.0	650.0	655 0
H	53.786	55.021	56.258	57.495	58.733	59.971	61.211	62.450
P	4.851	4.995	5.142	5.293	5.447	5.604	5.764	5.928
T	660.0	665 0	670.0	675 0	680.0	685.0	690.0	695.0
H	63.691	64.932	66.174	67.416	68.660	69.904	71.148	72.394
P	6.095	6.266	6.441	6.618	6.800	6.985	7.174	7.367
T	700.0	705 0	710.0	715 0	720.0	725.0	730.0	735 0
H	73.640	74.886	76 134	77.382	78.631	79.881	81.131	82.382
P	7.564	7.765	7.969	8.178	8.390	8.607	8.828	9.054
T	740.0	745 0	750.0	755.0	760.0	765.0	770.0	775.0
H	83.634	84.887	86.140	87.394	88.649	89.905	91.161	92.419
P	9.283	9.517	9.755	9.998	10.245	10.497	10.754	11.015
T	780.0	785 0	790.0	795.0	800.0	805.0	810.0	815.0
H	93.677	94.936	96.195	97.455	98.717	99.979	101.241	102.505
P	11.281	11.552	11.828	12.109	12.394	12.685	12.981	13.282

R	MOL.WGT	PCT.O2	PCT.CO2	PCT.H2O	PCT SO2	PCT.N2	PCT.A	F/DA	M/DA
52.745	29.297	.10873	13222	.04008	.00111	.70524	.01262	.07000	.00640

T	820.0	825 0	830.0	835 0	840 0	845.0	850.0	855 0
H	103.769	105.035	106.301	107.567	108.835	110.104	111.373	112.643
P	13.589	13.931	14.218	14.541	14 869	15.233	15.542	15.888
T	860.0	855 0	870.0	875.0	880.0	885.0	890.0	895.0
H	113.914	115.186	116.458	117.732	119.006	120.282	121.558	122 835
P	16.239	16.596	16.959	17.328	17 703	18.085	18.472	18.866
T	900.0	905 0	910.0	915 0	920.0	925.0	930.0	935 0
H	124.112	125.391	126.671	127.951	129.232	130.514	131.797	133.081
P	19.267	19.674	20.087	20.507	20.934	21.367	21.808	22.255
T	940.0	945 0	950.0	955 0	960 0	965 0	970.0	975.0
H	134.366	135.652	136.938	138.226	139.514	140.803	142.093	143.384
P	22.710	23.171	23.640	24.116	24.599	25.090	25.589	26.095
T	980.0	985 0	990.0	995 0	1000.0	1005.0	1010.0	1015.0
H	144.676	145.969	147.263	148.557	149.853	151.149	152.447	153.745
P	26.608	27.130	27.659	28.196	28.742	29.295	29.857	30.427
T	1020.0	1025 0	1030.0	1035.0	1040.0	1045.0	1050.0	1055.0
H	155.044	156.344	157.645	158.947	160.250	161.554	162.859	164.164
P	31.006	31.593	32.188	32.792	33.415	34.027	34.658	35.298
T	1060.0	1065 0	1070.0	1075.0	1080.0	1085.0	1090.0	1095.0
H	165.471	166.778	168.087	169.396	170.706	172.018	173.330	174.643
P	35.947	36.606	37.274	37.951	38.638	39.334	40.041	40.757
T	1100.0	1105 0	1110.0	1115.0	1120 0	1125.0	1130.0	1135 0
H	175.957	177.272	178.588	179.905	181.222	182.541	183.861	185.181
P	41.483	42.219	42.966	43.722	44.490	45.257	46.055	46.854
T	1140.0	1145 0	1150.0	1155.0	1160.0	1165.0	1170.0	1175.0
H	186.503	187.825	189.149	190.473	191.798	193.125	194.452	195.780
P	47.664	48.485	49.317	50.160	51.014	51.880	52.757	53.646

R	MOL.WGT	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	W/DA
52.745	29.297	.10873	13222	04018	00111	.70524	01262	.07000	.00640

T	1180.0	1185 0	1190.0	1195.0	120[illegible].0	12[illegible]5.0	1210.0	1215 0
H	197.139	198.439	199.770	201.102	202 435	203.769	205.104	206.439
P	54.547	55.459	56.384	57.320	58.269	59.230	60.204	61.190
T	1220.0	1225 0	1230.0	1235 0	1240.0	1245 0	1250.0	1255 0
H	207.776	209.114	210.452	211.792	213.132	214.474	215.816	217.159
P	62.189	63.211	64 226	65.264	66 315	67.379	68.457	69.549
T	1260.0	1265 0	1270.0	1275.0	1280 0	1285.0	1290.0	1295 0
H	218.504	219 849	221.195	222.542	223 890	225.239	226.589	227.940
P	70.654	71.773	72.906	74.054	75.215	76.391	77.582	78.787
T	1300.0	1335 0	1310.0	1315.0	1320.0	1325.0	1330.0	1335 0
H	229.292	230.644	231 998	233.353	234 708	236.065	237.422	238.781
P	80.027	81.242	82.492	83.758	85 039	86.335	87.647	88 975
T	1340.0	1345 0	1350.0	1355 0	1360 0	1365.0	1370.0	1375 0
H	240.140	241.500	242.861	244.224	245.587	246.951	248.316	249.681
P	90.319	91.679	93.055	94.448	95.857	97.283	98.725	100.185
T	1380.0	1385 0	1390.0	1395 0	1400.0	1405.0	1410.0	1415.0
H	251.048	252.416	253.784	255.154	256.525	257.896	259.268	260.641
P	101.662	103.157	104.668	106.198	107.745	109.311	110.894	112.496
T	1420.0	1425 0	1430.0	1435 0	1440.0	1445.0	1450.0	1455 0
H	262.016	263.391	264.767	266.144	267.521	268.900	270.280	271.660
P	114.116	115.754	117.412	119.088	120.784	122.499	124.233	125.987
T	1460.0	1465 0	1470.0	1475 0	1480.0	1485.0	1490.0	1495 0
H	273.042	274.424	275.808	277.192	278.577	279.963	281.350	282.738
P	127.761	129.555	131.368	133.203	135.057	136.933	138.829	140.746
T	1500.0	1505 0	1510.0	1515.0	1520.0	1525.0	1530.0	1535.0
H	284.126	285.516	286.906	288.298	289.690	291.083	292.477	293.872
P	142.684	144.644	146.625	148.528	150 653	152.700	154.770	156.862

R	MOL.WGT	PCT.O2	PCT.CO2	PCT.H2O	PCT SO2	PCT.N2	PCT.A	F/DA	H/DA
52.745	29.297	.1[illegible]873	13222	.14006	.00111	.70524	01262	.07000	00640

T	1540.0	1545.0	1550.0	1555.0	1560.0	1565.0	1570.0	1575.0
H	295.268	296.6[illegible]4	298.062	299.460	300.8[illegible]	302.260	303.661	305.063
P	153.976	161.114	163.274	165.458	167.665	169.896	172.150	174.429
T	1580.0	1585.0	1590.0	1595.0	1600.0	1605.0	1610.0	1615.0
H	306.465	307.869	309.273	310.679	312.085	313.492	314.900	316.309
P	175.732	179.0[illegible]9	181.411	183.788	186.190	188.517	191.069	193.547
T	1620.0	1625.0	1630.0	1635.0	1640.0	1645.0	1650.0	1655.0
H	317.718	319.129	320.540	321.952	323.365	324.779	326.194	327.609
P	195.051	198.541	201.137	203.720	206.330	208.966	211.629	214.320
T	1660.0	1665.0	1670.0	1675.0	1680.0	1685.0	1690.0	1695.0
H	328.025	330.443	331.861	333.279	334.699	336.119	337.541	338.963
P	217.038	219.784	222.559	225.361	228.191	231.051	233.939	236.856
T	1700.0	1705.0	1710.0	1715.0	1720.0	1725.0	1730.0	1735.0
H	340.386	341.839	343.234	344.659	346.085	347.512	348.940	350.368
P	239.803	242.779	245.785	248.821	251.887	254.984	258.111	261.269
T	1740.0	1745.0	1750.0	1755.0	1760.0	1765.0	1770.0	1775.0
H	351.798	353.228	354.659	356.090	357.523	358.956	360.390	361.825
P	264.459	267.679	270.932	274.216	277.533	280.882	284.263	287.677
T	1780.0	1785.0	1790.0	1795.0	1800.0	1805.0	1810.0	1815.0
H	363.260	364.697	366.134	367.572	369.010	370.450	371.890	373.331
P	291.125	294.6[illegible]6	298.120	301.658	305.250	308.867	312.518	316.205
T	1820.0	1825.0	1830.0	1835.0	1840.0	1845.0	1850.0	1855.0
H	374.772	376.215	377.658	379.102	380.546	381.992	383.438	384.885
P	319.926	323.682	327.475	331.303	335.167	339.068	343.005	346.979
T	1860.0	1865.0	1870.0	1875.0	1880.0	1885.0	1890.0	1895.0
H	385.332	387.781	389.230	390.679	392.130	393.581	395.033	396.486
P	351.991	355.0[illegible]0	359.126	363.251	367.414	371.616	375.856	380.136

R	MOL.WGT	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
52.745	29.297	.10873	.13222	.04008	.00111	.70524	.01262	.07000	.01640

T	1900.0	1905.0	1910.0	1915.0	192[illegible]	1925.0	1930.0	1935.0
H	397.939	399.393	400.848	402.303	403.760	405.216	406.674	408.132
P	384.454	388.813	393.211	397.650	402.129	406.549	411.210	415.813
T	1940.0	1945.0	1950.0	1955.0	1960.0	1965.0	1970.0	1975.0
H	409.591	411.0[illegible]1	412.511	413.972	415.434	416.896	418.359	419.823
P	423.457	425.1[illegible]3	429.871	434.5[illegible]2	439.465	444.312	449.212	454.156
T	1980.0	1985.0	1990.0	1995.0	2000.0	2005.0	2010.0	2015.0
H	421.287	422.752	424.218	425.684	427.151	428.619	430.088	431.557
P	459.144	464.1[illegible]6	469.253	474.374	479.541	484.753	490.011	495.315
T	2020.0	2025.0	2030.0	2035.0	2040.0	2045.0	2050.0	2055.0
H	433.[illegible]26	434.496	435.967	437.439	438.911	440.384	441.858	443.332
P	500.6[illegible]	506.064	511.508	517.000	522.539	528.127	533.763	539.447
T	2060.0	2055.0	2070.0	2075.0	2080.0	2085.0	2090.0	2095.0
H	444.806	446.282	447.758	449.235	450.712	452.190	453.668	455.147
P	545.181	550.953	556.796	562.578	568.611	574.594	580.628	586.713
T	2100.0	2105.0	2110.0	2115.0	2120.0	2125.0	2130.0	2135.0
H	455.627	458.107	459.588	461.070	462.552	464.035	465.518	467.002
P	592.850	599.039	605.280	611.574	617.921	624.320	630.774	637.281
T	2140.0	2145.0	2150.0	2155.0	2160.0	2165.0	2170.0	2175.0
H	465.486	469.971	471.457	472.943	474.430	475.918	477.406	478.894
P	643.843	650.460	657.131	663.858	670.640	677.479	684.374	691.326
T	2180.0	2185.0	2190.0	2195.0	2200.0	2205.0	2210.0	2215.0
H	480.383	481.873	483.363	484.854	486.346	487.838	489.330	490.823
P	698.335	705.4[illegible]1	712.525	719.7[illegible]7	726.948	734.248	741.607	749.026
T	2220.0	2225.0	2230.0	2235.0	224[illegible].0	2245.0	2250.0	2255.0
H	492.317	493.811	495.306	496.801	498.297	499.794	501.291	502.788
P	755.505	764.044	771.644	779.305	787.028	794.813	802.660	810.569

R	MOL.WGT	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
52.745	29.297	.10373	.13222	.04008	.00111	.70524	.01262	.07005	.00640

T	2260.0	2265.0	2270.0	2275.0	2280.0	2285.0	2290.0	2295.0
H	504.285	505.785	507.284	508.783	510.284	511.784	513.286	514.787
P	818.542	826.578	834.678	842.842	851.071	859.365	867.724	876.149
T	2300.0	2305.0	2310.0	2315.0	2320.0	2325.0	2330.0	2335.0
H	516.290	517.793	519.296	520.800	522.304	523.809	525.314	526.820
P	884.640	893.198	901.822	910.514	919.274	928.102	936.999	945.964
T	2340.0	2345.0	2350.0	2355.0	2360.0	2365.0	2370.0	2375.0
H	528.327	529.834	531.341	532.849	534.358	535.867	537.376	538.886
P	954.999	964.104	973.279	982.525	991.842	1001.231	1010.691	1020.224
T	2380.0	2385.0	2390.0	2395.0	2400.0	2405.0	2410.0	2415.0
H	540.397	541.908	543.419	544.931	546.444	547.957	549.470	550.984
P	1029.829	1039.508	1049.260	1059.086	1068.987	1078.963	1089.014	1099.141
T	2420.0	2425.0	2430.0	2435.0	2440.0	2445.0	2450.0	2455.0
H	552.498	554.013	555.529	557.045	558.561	560.078	561.595	563.113
P	1109.344	1119.624	1129.981	1140.416	1150.929	1161.520	1172.190	1182.940
T	2460.0	2465.0	2470.0	2475.0	2480.0	2485.0	2490.0	2495.0
H	564.632	566.150	567.670	569.189	570.710	572.230	573.752	575.273
P	1193.769	1204.679	1215.669	1226.741	1237.895	1249.130	1260.449	1271.850
T	2500.0	2505.0	2510.0	2515.0	2520.0	2525.0	2530.0	2535.0
H	576.795	578.318	579.841	581.365	582.889	584.413	585.938	587.464
P	1283.335	1294.904	1306.558	1318.297	1330.121	1342.031	1354.028	1366.112
T	2540.0	2545.0	2550.0	2555.0	2560.0	2565.0	2570.0	2575.0
H	588.990	590.516	592.043	593.570	595.098	596.627	598.155	599.685
P	1378.283	1390.542	1402.890	1415.327	1427.853	1440.469	1453.176	1465.973
T	2580.0	2585.0	2590.0	2595.0	2600.0	2605.0	2610.0	2615.0
H	601.214	602.744	604.275	605.806	607.338	608.870	610.402	611.935
P	1478.863	1491.844	1504.918	1518.085	1531.345	1544.700	1558.149	1571.694

R	MOL.WGT	PCT.O2	PCT CO2	PCT.H2O	PCT SO2	PCT.N2	PCT.A	F/DA	W/DA
52.746	29.297	.13873	13222	.04038	.00111	.70524	.01262	.07000	.00640

T	2520.0	2625 0	2630.0	2635.0	2640.0	2645.0	2650.0	2655.0
H	613.469	615.013	616.537	618.072	619 607	621.143	622.679	624 216
P	1585.334	1599.070	1612 904	1626.834	1640.863	1654.990	1669.216	1683.541
T	2560.0	2665 0	2670-0	2675.0	2680.0	2685.0	2690.0	2695.0
H	625.753	627.291	628.829	630.368	631.907	633.447	634.987	636.527
P	1697.967	1712.493	1727.120	1741.855	1756 681	1771.616	1786.654	1801 796
T	2700.0	2715 0	2711.0	2715 0	2720 0	2725.0	2730.0	2735 0
H	639.068	639.610	641.152	642.594	644.237	645.781	647.325	648.869
P	1817.043	1832.395	1847.852	1863.417	1879.088	1894.857	1910.754	1926 750
T	2740.0	2745 0	2750.0	2755 0	2760 0	2765.0	2770.0	2775 0
H	651.414	651.959	653.505	655.052	656.599	658.146	659.694	661.242
P	1942.855	1959.071	1975.397	1991.834	2008 383	2025.045	2041.820	2058.709
T	2780.0	2785 0	2790.0	2795 0	2800 0	2805.0	2810.0	2815 0
H	662.791	664.340	665.890	667.441	668.991	670.543	672.095	673.647
P	2075.712	2092.830	2110.063	2127.414	2144.881	2162.465	2180.160	2197.990
T	2320.0	2825 0	2830.0	2835 0	2840 0	2845.0	2850.0	2855 0
H	675.200	676.753	678 307	679.862	681.417	682.972	684.[illegible]28	686.085
P	2215.932	2233.994	2252.177	2270.481	2288.9[illegible]8	2307.458	2326.132	2344.930
T	2360.0	2865 0	2870.0	2875.0	2880.0	2885.0	2890.0	2895.0
H	687.642	689.200	690.758	692.316	693.876	695.435	696.996	698.557
P	2363.853	2382.902	2402.077	2421.380	2440.810	2460.359	2480.058	2499.877
T	2900.0	2915 0	2910.0	2915.0	2920 0	2925.0	2930.0	2935.0
H	700.118	701.680	703.243	704.806	706.369	707.934	709.498	711.064
P	2519.826	2539.907	2560.121	2580.467	2600.948	2621.563	2642.313	2663.200
T	2340.0	2945 0	2950.0	2955.0	0 0	0.0	0.0	0.0
H	712.630	714.196	715.763	717.331	0.000	0.000	0.000	0.000
P	2684.223	2705.384	2726.684	2748.123	0.000	0.000	0.000	0.000

R	MOL.WGT	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	M/DA
53.003	29.156	.14756	.09002	.02932	.00076	.71947	.01288	.04670	.00640

T	460.0	465.0	470.0	475.0	480.0	485.0	490.0	495.0
H	14.521	15.734	16.946	18.160	19.373	20.587	21.802	23.017
P	1.643	1.7[illegible]7	1.774	1.842	1.912	1.984	2.058	2.133
T	500.0	505.0	510.0	515.0	520.0	525.0	530.0	535.0
H	24.232	25.4[illegible]8	26.664	27.880	29.[illegible]97	30.315	31.533	32.751
P	2.211	2.291	2.373	2.457	2.544	2.532	2.723	2.816
T	540.0	545.0	550.0	555.0	560.0	565.0	570.0	575.0
H	33.970	35.189	36.409	37.529	38.850	40.071	41.293	42.515
P	2.911	3.0[illegible]9	3.1[illegible]9	3.211	3.316	3.424	3.534	3.646
T	580.0	585.0	590.0	595.0	600.0	605.0	610.0	615.0
H	43.737	44.961	46.184	47.408	48.633	49.858	51.084	52.310
P	3.761	3.879	3.999	4.123	4.248	4.377	4.509	4.643
T	620.0	625.0	630.0	635.0	640.0	645.0	650.0	655.0
H	53.537	54.764	55.992	57.220	58.449	59.679	60.909	62.140
P	4.781	4.921	5.064	5.211	5.360	5.513	5.669	5.828
T	660.0	665.0	670.0	675.0	680.0	685.0	690.0	695.0
H	63.371	64.603	65.835	67.068	68.302	69.536	70.771	72.006
P	5.991	6.156	6.325	6.498	6.674	6.853	7.037	7.223
T	700.0	705.0	710.0	715.0	720.0	725.0	730.0	735.0
H	73.242	74.479	75.716	76.954	78.193	79.432	80.672	81.912
P	7.414	7.6[illegible]8	7.805	8.007	8.213	8.422	8.635	8.853
T	740.0	745.0	750.0	755.0	760.0	765.0	770.0	775.0
H	83.153	84.395	85.638	86.881	88.125	89.369	90.615	91.861
P	9.074	9.3[illegible]0	9.529	9.763	10.0[illegible]1	10.244	10.491	10.742
T	780.0	785.0	790.0	795.0	800.0	805.0	810.0	815.0
H	93.107	94.355	95.603	96.851	98.101	99.351	100.602	101.854
P	10.998	11.258	11.523	11.793	12.067	12.346	12.630	12.919

R	MOL.WGT	PCT.O2	PCT.CO2	PCT.H2O	PCT SO2	PCT.N2	PCT.A	F/DA	H/DA
53.003	29.156	.14756	.09[illegible]2	.02932	.00078	.71947	.01288	.04670	.00540

T	820.0	825.0	830.0	835.0	840.0	845.0	850.0	855.0
H	103.106	104.359	105.613	106.867	108.123	109.379	110.636	111.893
P	13.213	13.512	13.816	14.125	14.439	14.758	15.083	15.413
T	860.0	865.0	870.0	875.0	880.0	885.0	890.0	895.0
H	113.152	114.411	115.671	116.931	118.193	119.455	120.718	121.982
P	15.749	16.090	16.437	16.789	17.147	17.511	17.881	18.256
T	900.0	905.0	910.0	915.0	920.0	925.0	930.0	935.0
H	123.246	124.512	125.778	127.045	128.313	129.581	130.851	132.121
P	18.638	19.025	19.419	19.819	20.225	20.637	21.056	21.481
T	940.0	945.0	950.0	955.0	960.0	965.0	970.0	975.0
H	133.392	134.664	135.937	137.210	138.484	139.759	141.036	142.312
P	21.913	22.351	22.796	23.248	23.707	24.172	24.645	25.124
T	980.0	985.0	990.0	995.0	1000.0	1005.0	1010.0	1015.0
H	143.593	144.868	146.148	147.428	148.709	149.991	151.274	152.557
P	25.611	26.1 5	26.606	27.115	27.631	28.154	28.685	29.224
T	1020.0	1025.0	1030.0	1035.0	1040.0	1045.0	1050.0	1055.0
H	153.842	155.127	156.413	157.700	158.988	160.277	161.566	162.857
P	29.771	30.325	30.887	31.458	32.036	32.623	33.218	33.821
T	1060.0	1065.0	1070.0	1075.0	1080.0	1085.0	1090.0	1095.0
H	164.148	165.440	166.733	168.027	169.322	170.618	171.914	173.212
P	34.432	35.053	35.681	36.319	36.965	37.621	38.285	38.958
T	1100.0	1105.0	1110.0	1115.0	1120.0	1125.0	1130.0	1135.0
H	174.510	175.809	177.109	178.410	179.712	181.015	182.318	183.623
P	39.640	40.332	41.033	41.743	42.463	43.193	43.932	44.681
T	1140.0	1145.0	1150.0	1155.0	1160.0	1165.0	1170.0	1175.0
H	184.929	186.235	187.542	188.850	190.159	191.459	192.780	194.091
P	45.440	46.209	46.989	47.778	48.578	49.388	50.208	51.040

R	MOL.WGT	PCT.O2	PCT.CO2	PCT.H2O	PCT SO2	PCT.N2	PCT.A	F/DA	M/DA
53.003	29.156	.14756	.09002	.02932	.00076	.71947	.01288	.04670	.01640

T	1180.0	1185.0	1190.0	1195.0	1200.0	1205.0	1210.0	1215.0
H	195.4[illegible]4	196.717	198.032	199.347	200.663	201.980	203.298	204.617
P	51.882	52.735	53.598	54.473	55.359	56.256	57.165	58.085
T	1220.0	1225.0	1230.0	1235.0	1240.0	1245.0	1250.0	1255.0
H	205.937	207.257	208.579	209.901	211.224	212.549	213.874	215.200
P	59. 15	59.960	60.915	61.882	62.861	63.852	64.855	65.871
T	1260.0	1265.0	1270.0	1275.0	1280.0	1285.0	1290.0	1295.0
H	215.527	217.855	219.183	220.513	221.843	223.175	224.507	225.840
P	65.899	67.940	68.993	70.060	71.139	72.231	73.337	74.456
T	1300.0	1305.0	1310.0	1315.0	1320.0	1325.0	1330.0	1335.0
H	227.174	228.509	229.845	231.182	232.520	233.858	235.198	236.538
P	75.588	76.734	77.893	79.066	80.254	81.455	82.670	83.900
T	1340.0	1345.0	1350.0	1355.0	1360.0	1365.0	1370.0	1375.0
H	237.880	239.222	240.565	241.909	243.254	244.599	245.946	247.293
P	85.144	86.403	87.676	88.964	90.267	91.586	92.919	94.268
T	1380.0	1385.0	1390.0	1395.0	1400.0	1405.0	1410.0	1415.0
H	248.642	249.991	251.341	252.592	254.044	255.397	256.751	258.105
P	95.632	97.012	98.408	99.819	101.247	102.690	104.150	105.627
T	1420.0	1425.0	1430.0	1435.0	1440.0	1445.0	1450.0	1455.0
H	259.461	260.817	262.174	263.532	264.891	266.251	267.612	268.973
P	107.121	108.630	110.156	111.700	113.261	114.839	116.434	118.047
T	1460.0	1455.0	1470.0	1475.0	1480.0	1485.0	1490.0	1495.0
H	270.336	271.699	273.063	274.428	275.794	277.161	278.529	279.897
P	119.678	121.327	122.994	124.579	126.382	128.104	129.845	131.604
T	1500.0	1505.0	1510.0	1515.0	1520.0	1525.0	1530.0	1535.0
H	281.266	282.637	284.008	285.380	286.752	288.126	289.500	290.876
P	133.383	135.180	136.997	138.833	140.689	142.564	144.460	146.375

R	MOL.WGT	PCT.O2	PCT.CO2	PCT.H2O	PCT SO2	PCT.N2	PCT.A	F/DA	W/DA
53.[illegible]3	29.156	.14756	.09032	.02932	.00076	.71947	.01288	.04670	.00640

T	1540.0	1545.0	1550.0	1555.0	1560.0	1565.0	1570.0	1575.0
H	292.252	293.629	295.007	296.385	297.765	299.145	300.526	301.908
P	148.311	150.267	152.244	154.241	156.260	158.299	160.360	162.442
T	1580.0	1585.0	1590.0	1595.0	1600.0	1605.0	1610.0	1615.0
H	303.291	304.675	306.059	307.444	308.831	310.217	311.605	312.994
P	164.546	166.671	168.818	170.988	173.179	175.394	177.630	179.890
T	1520.0	1625.0	1630.0	1635.0	164[illegible]	1645.0	1650.0	1655.0
H	314.383	315.773	317.164	318.556	319.949	321.342	322.736	324.132
P	182.172	184.478	186.807	189.159	191.535	193.935	196.360	198.808
T	1560.0	1655.0	1670.0	1675.0	1680.0	1685.0	1690.0	1695.0
H	325.527	326.924	328.321	329.720	331.119	332.518	333.919	335.320
P	201.281	203.778	206.300	208.847	211.419	214.017	216.640	219.289
T	1700.0	1705.0	1710.0	1715.0	1720.0	1725.0	1730.0	1735.0
H	335.722	338.125	339.529	340.933	342.338	343.744	345.151	346.559
P	221.964	224.665	227.393	230.146	232.927	235.735	238.569	241.431
T	1740.0	1745.0	1750.0	1755.0	1760.0	1765.0	1770.0	1775.0
H	347.967	349.376	350.786	352.196	353.607	355.019	356.432	357.846
P	244.321	247.238	250.183	253.156	256.158	259.188	262.246	265.334
T	1780.[illegible]	1785.0	1790.0	1795.0	1800.0	1805.0	1810.0	1815.0
H	359.260	360.675	362.091	363.507	364.924	366.342	367.761	369.180
P	268.451	271.597	274.773	277.979	281.215	284.480	287.777	291.104
T	1320.0	1825.0	1830.0	1835.0	1840.0	1845.0	1850.0	1855.0
H	371.6[illegible]	372.021	373.442	374.865	376.287	377.711	379.135	380.560
P	294.461	297.850	301.271	304.722	308.206	311.721	315.269	318.849
T	1360.0	1855.0	1870.0	1875.0	1880.0	1885.0	1890.0	1895.0
H	381.986	383.413	384.840	386.268	387.696	389.125	390.555	391.986
P	322.461	326.1[illegible]7	329.785	333.497	337.243	341.022	344.835	348.683

R	MOL.WGT	PCT.O2	PCT.CO2	PCT.H2O	PCT SO2	PCT.N2	PCT.A	F/DA	M/DA
53.003	29.156	.14756	09032	.02932	.00076	.71947	01288	.04670	00640

T	1900.0	1935 0	1910 0	1915 0	1920 0	1925..	1930 0	1935 0
H	393.417	394.849	396.281	397.715	399.149	400.583	402.018	403.454
P	352.564	356.481	360 433	364.419	368.442	372.499	376.593	380.723
T	1940.0	1945 0	1950.0	1955 0	1960 0	1965 0	1970 0	1975 0
H	404.891	406.328	407 766	409.204	410 644	412.083	413.524	414.965
P	384.889	389.092	393.332	397.608	401 922	406.274	410.664	415.091
T	1980.0	1985 0	1990.0	1995 0	2000 0	2005.0	2010 0	2015 0
H	416.407	417.849	419 292	420.736	422.180	423.625	425.070	426.517
P	419.557	424.062	428 606	433.188	437.810	442.472	447.173	451.915
T	2020.0	2025 0	2030.0	2035.0	2040.0	2045.0	2050.0	2055 0
H	427.963	429.411	430.059	432.307	433 756	435.206	436.657	438.108
P	455.697	461 519	466 383	471.287	476.233	481.221	486.251	491.323
T	2160.0	2065 0	2070.0	2075.0	2080 0	2085.0	2090 0	2095 0
H	439.559	441 011	442.464	443.917	445 371	446.826	448.281	449 737
P	495.437	501.595	506.795	512.039	517.326	522.657	528.032	533.452
T	2100.0	2105 0	2110 0	2115 0	2120 0	2125.0	2130.0	2135 0
H	451.193	452.650	454.107	455.565	457.024	458.483	459.943	461.403
P	538.916	544.425	549.980	555.580	561.226	566.918	572.656	578.441
T	2140.0	2145 0	2150.0	2155 0	2160.0	2165.0	2170.0	2175 0
H	462.864	464.325	465 787	467.250	468.713	470.176	471.640	473.105
P	584.273	590.152	596.078	602.053	608.075	614.146	620.266	626.435
T	2180.0	2185 0	2190.0	2195 0	2200.0	2205.0	2210.0	2215 0
H	474.570	476.036	477.502	478.969	480 436	481.904	483.373	484.842
P	632.653	638.920	645.237	651.605	658.023	664.492	671.012	677.583
T	2220.0	2225 0	2230.0	2235.0	2240.0	2245.0	2250.0	2255.0
H	485.311	487.781	489.251	490.722	492.194	493.666	495.139	496.612
P	684.206	690.881	697.608	704.388	711.221	718.107	725.047	732.040

R	MOL.WGT	PCT.O2	PCT CO2	PCT.H2O	PCT SO2	PCT.N2	PCT.A	F/DA	W/DA
53.023	29.156	.14756	.09002	.02932	.00076	.71947	.01288	.04670	.00640

T	2260.0	2265.0	2270.0	2275.0	2280.0	2285.0	2290.0	2295.0
H	498.085	499.559	501.034	502.509	503.985	505.461	506.937	508.415
P	739.088	746.190	753.347	760.559	767.827	775.150	782.530	789.966
T	2300.0	2305.0	2310.0	2315.0	2320.0	2325.0	2330.0	2335.0
H	509.892	511.370	512.849	514.328	515.807	517.287	518.768	520.249
P	797.459	805.008	812.616	820.281	828.004	835.786	843.626	851.525
T	2340.0	2345.0	2350.0	2355.0	2360.0	2365.0	2370.0	2375.0
H	521.731	523.213	524.695	526.178	527.661	529.145	530.630	532.114
P	859.484	867.503	875.582	883.721	891.921	900.182	908.505	916.889
T	2380.0	2385.0	2390.0	2395.0	2400.0	2405.0	2410.0	2415.0
H	533.600	535.086	536.572	538.059	539.546	541.033	542.522	544.010
P	925.335	933.846	942.418	951.053	959.752	968.515	977.343	986.235
T	2420.0	2425.0	2430.0	2435.0	2440.0	2445.0	2450.0	2455.0
H	545.499	546.989	548.479	549.969	551.460	552.951	554.443	555.935
P	995.192	1004.215	1013.303	1022.458	1031.679	1040.967	1050.322	1059.745
T	2460.0	2465.0	2470.0	2475.0	2480.0	2485.0	2490.0	2495.0
H	557.428	558.921	560.415	561.909	563.404	564.899	566.394	567.890
P	1069.236	1078.795	1088.423	1098.121	1107.887	1117.724	1127.631	1137.609
T	2500.0	2505.0	2510.0	2515.0	2520.0	2525.0	2530.0	2535.0
H	569.386	570.883	572.380	573.878	575.376	576.875	578.374	579.874
P	1147.658	1157.778	1167.970	1178.235	1188.572	1198.982	1209.466	1220.024
T	2540.0	2545.0	2550.0	2555.0	2560.0	2565.0	2570.0	2575.0
H	581.374	582.874	584.375	585.876	587.378	588.880	590.383	591.886
P	1230.656	1241.362	1252.144	1263.001	1273.935	1284.944	1296.031	1307.194
T	2580.0	2585.0	2590.0	2595.0	2600.0	2605.0	2610.0	2615.0
H	593.390	594.894	596.398	597.903	599.408	600.914	602.421	603.927
P	1318.435	1329.754	1341.152	1352.628	1364.184	1375.820	1387.536	1399.332

R	MOL.WGT	PCT.O2	PCT CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	M/DA
53.003	29 156	.14756	09002	.02932	.00076	.71947	.01288	.04670	0.0640

T	2520 0	2625 0	2630.0	2635 0	2640 0	2645.0	2650 0	2655 0
H	605.434	606.942	608.450	609.959	611 468	612.977	614.487	615.998
P	1411.209	1423.158	1435.209	1447.333	1459.539	1471.828	1484.201	1496.659
T	2560.0	2665 0	2670.0	2675 0	2680 0	2685.0	2690 0	2695 0
H	617.509	619.020	620.532	622.044	623 557	625.070	626.583	628.098
P	1509.201	1521.828	1534.541	1547.340	1560.225	1573.198	1586.258	1599.405
T	2700.0	2705 0	2710 0	2715 0	2720 0	2725.0	2730 0	2735 0
H	629.612	631.127	632.643	634.159	635.675	637.192	638.710	640.228
P	1612.642	1625 967	1639 381	1652.886	1666.481	1680.166	1693.944	1707.813
T	2740.0	2745 0	2750.0	2755 0	2760.0	2765.0	2770.0	2775 0
H	641.746	643.265	644.784	646.304	647 825	649.345	650.867	652.389
P	1721.774	1735.828	1749.976	1764.217	1778.553	1792.984	1807.510	1822.133
T	2780.0	2785 0	2790.0	2795 0	2800 0	2805.0	2810.0	2815 0
H	653.911	655.434	656.957	658.481	660.005	661.530	663.056	664.582
P	1835.851	1851.667	1866.581	1881.592	1896.702	1911.912	1927.221	1942.630
T	2820 0	2825 0	2830.0	2835.0	2840.0	2845.0	2850.0	2855.0
H	665.108	667.635	669.163	670.691	672.219	673.748	675.278	676.808
P	1958.140	1973.752	1989.465	2005.281	2021.201	2037.223	2053.351	2069.582
T	2860.0	2865 0	2870.0	2875 0	2880.0	2885.0	2890.0	2895.0
H	678.339	679.870	681.402	682.934	684.467	686.001	687.535	689.069
P	2085.920	2102.353	2118.913	2135.570	2152.335	2169.208	2186.191	2203.283
T	2900.0	2905 0	2910 0	2915 0	2920 0	2925.0	2930.0	2935 0
H	690.604	692.140	693.677	695.214	696.751	698.289	699.828	701.367
P	2221.485	2237.798	2255.222	2272.759	2290.408	2308.171	2326.048	2344.039
T	2940.0	2945 0	2950.0	2955.0	0.0	0.0	0.0	0.0
H	702.907	704.448	705.989	707.531	0.000	0.000	0.000	0.000
P	2362.146	2380.369	2398.7[illegible]8	2417.165	0.000	0.000	0.000	0.000

R	MOL.WGT	PCT.O2	PCT.CO2	PCT.H2O	PCT SO2	PCT.N2	PCT.A	F/DA	M/DA
65.502	23.592	.1[illegible]14	04234	39354	00036	.45145	00808	.03500	64000

T	460.0	465.0	470.0	475.0	480.0	485.0	490.0	495.0
H	19.061	20.6[illegible]1	22.241	23.832	25.424	27.015	28.608	30.200
P	1.694	1.7[illegible]5	1.838	1.913	1.990	2.070	2.151	2.236
T	500.0	505.0	510.0	515.0	520.0	525.0	530.0	535.0
H	31.793	33.387	34.981	36.576	38.171	39.757	41.363	42.960
P	2.322	2.412	2.503	2.597	2.694	2.794	2.896	3.001
T	540.0	545.0	550.0	555.[illegible]	56[illegible].[illegible]	565.0	570.0	575.0
H	44.557	45.1[illegible]5	47.753	49.353	50.952	52.553	54.154	55.755
P	3.109	3.220	3.333	3.450	3.569	3.692	3.818	3.947
T	580.0	585.0	590.0	595.0	600.0	605.0	610.0	615.0
H	57.358	58.961	60.565	62.169	63.775	65.[illegible]0	66.987	68.595
P	4.079	4.215	4.354	4.496	4.642	4.791	4.944	5.100
T	620.0	625.0	630.0	635.0	640.0	645.0	650.0	655.0
H	70.203	71.812	73.422	75.032	76.644	78.256	79.869	81.483
P	5.261	5.425	5.592	5.764	5.940	6.119	6.303	6.491
T	660.0	665.0	670.0	675.0	680.0	685.0	690.0	695.0
H	83.097	84.713	86.329	87.947	89.565	91.184	92.804	94.425
P	6.683	6.880	7.080	7.286	7.495	7.709	7.928	8.152
T	700.0	705.0	710.0	715.0	720.0	725.0	730.0	735.0
H	95.047	97.659	99.293	100.918	102.543	104.170	105.797	107.426
P	8.380	8.613	8.851	9.094	9.342	9.595	9.854	10.117
T	740.0	745.0	750.0	755.0	760.0	765.0	770.0	775.0
H	109.055	110.686	112.317	113.950	115.583	117.218	118.853	120.490
P	10.386	10.661	10.941	11.226	11.518	11.815	12.118	12.426
T	780.0	785.0	790.0	795.0	800.0	805.0	810.0	815.0
H	122.128	123.766	125.406	127.047	128.689	130.332	131.976	133.621
P	12.741	13.062	13.389	13.723	14.062	14.408	14.761	15.120

R	MOL.WGT	PCT.O2	PCT.CO2	PCT.H2O	PCT SO2	PCT.N2	PCT.A	F/DA	M/DA
65.502	23.592	.10414	04234	39354	00036	.45145	.00808	.03500	64000

T	820.0	825.0	830.0	835.0	840.0	845.0	850.0	855.0
H	135.267	136.915	138.563	140.213	141.863	143.515	145.168	146.822
P	15.486	15.859	16.239	16.626	17.019	17.420	17.829	18.244
T	860.0	865.0	870.0	875.0	880.0	885.0	890.0	895.0
H	148.478	150.134	151.792	153.451	155.111	156.772	158.434	160.097
P	18.668	19.098	19.537	19.983	20.437	20.899	21.369	21.847
T	900.0	905.0	910.0	915.0	920.0	925.0	930.0	935.0
H	161.762	163.428	165.095	166.753	168.433	170.103	171.775	173.449
P	22.334	22.829	23.333	23.845	24.366	24.896	25.434	25.982
T	940.0	945.0	950.0	955.0	960.0	965.0	970.0	975.0
H	175.123	176.799	178.475	180.154	181.833	183.513	185.195	186.878
P	26.539	27.106	27.681	28.267	28.862	29.467	30.081	30.706
T	980.0	985.0	990.0	995.0	1000.0	1005.0	1010.0	1015.0
H	188.563	190.248	191.935	193.624	195.313	197.004	198.696	200.389
P	31.341	31.986	32.642	33.308	33.985	34.673	35.371	36.081
T	1020.0	1025.0	1030.0	1035.0	1040.0	1045.0	1050.0	1055.0
H	202.084	203.780	205.477	207.175	208.875	210.576	212.279	213.983
P	36.802	37.534	38.277	39.033	39.800	40.579	41.370	42.173
T	1060.0	1065.0	1070.0	1075.0	1080.0	1085.0	1090.0	1095.0
H	215.688	217.394	219.102	220.811	222.521	224.233	225.946	227.660
P	42.988	43.816	44.657	45.510	46.376	47.255	48.148	49.053
T	1100.0	1105.0	1110.0	1115.0	1120.0	1125.0	1130.0	1135.0
H	229.376	231.093	232.812	234.531	236.253	237.975	239.699	241.424
P	49.973	50.906	51.853	52.814	53.789	54.778	55.782	56.800
T	1140.0	1145.0	1150.0	1155.0	1160.0	1165.0	1170.0	1175.0
H	243.151	244.879	246.608	248.339	250.071	251.804	253.539	255.275
P	57.834	58.882	59.945	61.024	62.118	63.228	64.354	65.496

R	MOL.WGT	PCT.O2	PCT.CO2	PCT.H2O	PCT SO2	PCT.N2	PCT.A	F/DA	M/DA
65.5[illegible]2	23.592	.10414	04234	.39354	.00036	45145	.00808	.03500	64000

T	1180.0	1185 0	1190.0	1195.0	1200 0	1205.0	1210.0	1215 0
H	257.012	258.751	260.492	262.233	263 976	265.721	267.466	269.214
P	65.654	67.828	69.019	70.227	71.452	72.593	73.953	75.229
T	1220 0	1225 0	1230.0	1235.0	1240.0	1245.0	1250.0	1255.0
H	270.962	272.712	274.464	276.216	277.971	279.726	281.483	283.241
P	75.523	77.836	79.166	80.514	81.082	83.267	84.672	86 096
T	1260 0	1255 0	1270.0	1275.0	1280 0	1285.0	1290.0	1295 0
H	285.001	286.762	288.525	290.289	292.054	293.821	295.589	297.359
P	87.539	89.001	90.483	91.985	93.508	95.050	96.613	98.197
T	1300.0	1305 0	1310.0	1315 0	1320 0	1325 0	1330 0	1335 0
H	299.130	300.932	302.676	304.451	306.228	308.006	309.785	311.566
P	99.802	101.428	103.076	104.745	106.436	108.150	109.885	111.643
T	1340.0	1345 0	1350.0	1355.0	1360 0	1365.0	1370.0	1375 0
H	313.348	315.132	316.917	318.704	320.491	322.281	324.072	325.864
P	113.424	115.229	117.056	118.9 7	120.782	122.660	124.603	126.551
T	1380.0	1385.0	1390.0	1395.0	1400.0	1405.0	1410.0	1415.0
H	327.657	329.452	331.249	333.046	334.846	336.646	338.448	340.252
P	128.523	130.521	132.543	134.592	136.665	138.766	140.892	143.045
T	1420.0	1425 0	1430.0	1435 0	1440 0	1445.0	1450.0	1455.0
H	342.057	343.863	345.671	347.480	349.291	351.102	352.916	354.731
P	145.225	147.431	149.666	151.928	154.218	156.536	158.882	161.258
T	1460.0	1465 0	1470.0	1475.0	1480 0	1485.0	1490.0	1495 0
H	355.547	358.365	360.184	362.004	363.826	365.649	367.474	369.300
P	163.662	166.096	168.560	171.053	173.577	176.131	178.716	181.332
T	1500.0	1505 0	1510.0	1515 0	1520.0	1525.0	1530.0	1535 0
H	371.127	372.956	374.787	376.618	378.452	380.286	382.122	383.959
P	183.979	186.659	189.370	192.114	194.890	197.699	200.542	203.418

R	MOL.WGT	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	M/DA
65.502	23.592	.10414	04234	.3935-	.00336	.45145	.00808	.03500	64000

T	1540.0	1545.0	1550.0	1555.0	1560.0	1565.0	1570.0	1575.0
H	385.798	387.638	389.480	391.323	393.167	395.013	396.860	398.709
P	205.328	209.273	212.252	215.265	218.315	221.399	224.520	227.677
T	1580.0	1585.0	1590.0	1595.0	1600.0	1605.0	1610.0	1615.0
H	400.559	402.4[illegible]0	4[illegible]4.263	406.117	4[illegible]7.973	409.830	411.688	413.548
P	230.870	23[illegible]	237.369	240.574	244.017	247.399	250.820	254.279
T	1620.0	1625.0	1630.0	1635.0	1640.0	1645.0	1650.0	1655.0
H	415.409	417.271	419.135	421.001	422.867	424.735	426.605	428.476
P	257.778	261.317	264.896	268.515	272.175	275.877	279.620	283.406
T	1660.0	1665.0	1670.0	1675.0	1680.0	1685.0	1690.0	1695.0
H	430.348	432.221	434.096	435.973	437.850	439.730	441.610	443.492
P	287.234	291.1[illegible]4	295.018	298.975	302.977	307.023	311.113	315.249
T	1700.0	1705.0	1710.0	1715.0	1720.0	1725.0	1730.0	1735.0
H	445.375	447.260	449.146	451.033	452.921	454.811	456.703	458.596
P	319.431	323.658	327.932	332.253	336.621	341.037	345.500	350.013
T	1740.0	1745.0	1750.0	1755.0	1760.0	1765.0	1770.0	1775.0
H	460.493	462.385	464.282	466.180	468.079	469.980	471.883	473.786
P	354.574	359.185	363.846	368.556	373.318	378.131	382.996	387.912
T	1780.0	1785.0	1790.0	1795.0	1800.0	1805.0	1810.0	1815.0
H	475.691	477.597	479.505	481.414	483.324	485.235	487.148	489.062
P	392.881	397.9[illegible]3	402.979	408.108	413.292	418.531	423.825	429.175
T	1820.0	1825.0	1830.0	1835.0	1840.0	1845.0	1850.0	1855.0
H	490.978	492.895	494.813	496.733	498.653	500.575	502.499	504.424
P	434.581	440.044	445.565	451.143	456.779	462.474	468.229	474.043
T	1860.0	1865.0	1870.0	1875.0	1880.0	1885.0	1890.0	1895.0
H	506.350	508.277	510.[illegible]6	512.136	514.067	516.000	517.934	519.869
P	479.917	485.852	491.849	497.907	504.028	510.211	516.458	522.769

R	MOL.WGT	PCT.O2	PCT CO2	PCT H2O	PCT SO2	PCT.N2	PCT.A	F/DA	H/DA
65.5.2	23.592	.10414	04234	.39364	00036	.45145	.00808	.03500	.64000

T	1300.0	1935 0	1910.0	1915 0	1920 0	1925.0	1930.0	1935 0
H	521.805	523.743	525.682	527.523	529 564	531.507	533.452	535.397
P	523.145	535.585	542.091	548.663	555.302	562.038	568.781	575.623
T	1340.0	1945 0	1950.0	1955 0	1960.0	1965.0	1970.0	1975.0
H	537.344	539.292	541.241	543.192	545.144	547.097	549.051	551.007
P	582.534	589.515	596.565	603.586	610.878	618.142	625.478	632 888
T	1380.0	1985 0	1990.0	1995 0	200[illegible]	2005.0	2010.0	2015 0
H	552.964	554.922	556.882	558.842	560.804	562.758	564.732	566.698
P	641.370	647.927	655.559	663.266	671.049	678.909	686.846	694.860
T	2020.0	2025 0	2030.0	2035 0	2040 0	2045 0	2050.0	2055 0
H	568.665	570.633	572.602	574.573	576.545	578.518	580.492	582.468
P	702.953	711.126	719 377	727.710	736.123	744.618	753.195	761.855
T	2060.0	2055 0	2070.0	2075.0	2080 0	2085.0	2090 0	2095.0
H	584.445	586.423	588.402	590.382	592.364	594.347	596.331	598.316
P	770.599	779.427	788.340	797.338	806.423	815.595	824.854	834.202
T	2100.0	2105 0	2110.0	2115.0	2120.0	2125.0	2130.0	2135.0
H	600.303	602.290	604.279	606.269	608.261	610.253	612.247	614.242
P	843.639	853.165	862.782	872.490	882.290	892.183	902.168	912.248
T	2140 0	2145 0	2150.0	2155 0	2160.0	2165.0	2170.0	2175.0
H	616.238	618.235	620.233	622.233	624.234	626.235	628.239	630.243
P	922.423	932.692	943.058	953.521	964.082	974.741	985.499	996.350
T	2180.0	2185 0	2190.0	2195.0	2200.0	2205.0	2210.0	2215 0
H	632.248	634.255	636.263	638.272	640.282	642.293	644.305	646.319
P	1007.317	1018.377	1029.539	1040.805	1052.175	1063.649	1075.228	1086.913
T	2220.0	2225 0	2230.0	2235 0	2240 0	2245.0	2250.0	2255 0
H	648.333	650.349	652.366	654.384	656.4 4	658.424	660.446	662.468
P	1098.706	1110.606	1122.615	1134.733	1146.962	1159.301	1171.753	1184.317

R	MOL.WGT	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	M/DA
65.502	23.592	.10-14	04234	.39354	.00036	.45145	.00808	.03500	64000

T	2260.0	2265.0	2270.0	2275.0	2280.0	2285.0	2290.0	2295.0
H	664.492	666.517	668.543	670.570	672.598	674.528	676.658	678.690
P	1196.995	1209.787	1222.694	1235.717	1248.858	1262.116	1275.493	1288.989
T	2300.0	2305.0	2310.0	2315.0	2320.0	2325.0	2330.0	2335.0
H	680.722	682.756	684.791	686.827	688.864	690.903	692.942	694.982
P	1302.6[illegible]5	1316.344	1330.205	1344.188	1358.296	1372.528	1386.886	1401.371
T	2340.0	2345.0	2350.0	2355.0	2360.0	2365.0	2370.0	2375.0
H	697.024	699.066	701.110	703.155	705.201	707.248	709.296	711.345
P	1415.984	1430.725	1445.596	1460.598	1475.737	1490.995	1506.394	1521.926
T	2380.0	2385.0	2390.0	2395.0	2400.0	2405.0	2410.0	2415.0
H	713.395	715.446	717.498	719.552	721.606	723.662	725.718	727.776
P	1537.594	1553.398	1569.343	1585.419	1601.638	1617.996	1634.496	1651.138
T	2420.0	2425.0	2430.0	2435.0	2440.0	2445.0	2450.0	2455.0
H	729.835	731.894	733.955	736.017	738.080	740.144	742.209	744.275
P	1667.923	1684.853	1701.927	1719.148	1736.516	1754.032	1771.698	1789.514
T	2460.0	2465.0	2470.0	2475.0	2480.0	2485.0	2490.0	2495.0
H	746.342	748.410	750.479	752.549	754.620	756.693	758.766	760.840
P	1807.482	1825.602	1843.875	1862.303	1880.887	1899.628	1918.527	1937.585
T	2500.0	2505.0	2510.0	2515.0	2520.0	2525.0	2530.0	2535.0
H	762.915	764.992	767.069	769.147	771.227	773.307	775.389	777.471
P	1956.813	1976.182	1995.723	2015.428	2035.298	2055.333	2075.535	2095.906
T	2540.0	2545.0	2550.0	2555.0	2560.0	2565.0	2570.0	2575.0
H	779.555	781.639	783.724	785.811	787.898	789.987	792.076	794.167
P	2116.445	2137.155	2158.036	2179.190	2200.318	2221.721	2243.301	2265.058
T	2580.0	2585.0	2590.0	2595.0	2600.0	2605.0	2610.0	2615.0
H	796.258	798.351	800.444	802.539	804.634	806.730	808.828	810.926
P	2286.993	2309.129	2331.405	2353.884	2376.547	2399.394	2422.428	2445.649

R	MOL.WGT	PCT.O2	PCT.CO2	PCT.H2O	PCT SO2	PCT.N2	PCT.A	F/DA	M/DA
65.502	23.592	.13414	.34234	.39364	.00036	.45145	.00808	.03500	.64000

T	2620.0	2625.0	2630.0	2635.0	2640.0	2645.0	2650.0	2655.0
H	813.026	815.126	817.227	819.330	821.433	823.537	825.643	827.749
P	2469.058	2492.658	2516.448	2540.431	2564.608	2588.980	2613.549	2638.315
T	2660.0	2665.0	2670.0	2675.0	2680.0	2685.0	2690.0	2695.0
H	829.855	831.964	834.073	836.184	838.295	840.407	842.520	844.634
P	2663.280	2688.445	2713.812	2739.382	2765.157	2791.137	2817.324	2843.720
T	2700.0	2705.0	2710.0	2715	272[illegible]	2725.0	2730.0	2735.0
H	845.749	848.865	850.982	853.099	855.218	857.338	859.459	861.580
P	2871.326	2897.1[illegible]3	2924.173	2951.417	2978.876	3006.552	3034.447	3062.561
T	2740.0	2745.0	2750.0	2755.0	2760.0	2765.0	2770.0	2775.0
H	863.7[illegible]3	865.827	867.951	870.077	872.203	874.331	876.459	878.588
P	3091.897	3119.456	3148.238	3177.246	3206.482	3235.946	3265.640	3295.566
T	2780.0	2785.0	2790.0	2795.0	2800.[illegible]	2805.0	2810.0	2815.0
H	881.719	882.850	884.982	887.115	889.249	[illegible]1.384	893.520	895.657
P	3325.725	3356.118	3386.748	3417.516	3448.722	34[illegible].070	3511.660	3543.494
T	2820.0	2825.0	2830.0	2835.0	2840.0	2845.0	2850.0	2855.0
H	897.795	899.934	902.074	904.214	906.356	908.499	910.642	912.787
P	3575.574	3607.901	3640.477	3673.3[illegible]3	37[illegible]6.381	3739.713	3773.301	3807.145
T	2860.0	2865.0	2870.0	2875.0	2880.0	2885.0	2890.0	2895.0
H	914.932	917.078	919.226	921.374	923.523	925.673	927.825	929.977
P	3841.248	3875.611	3910.236	3945.125	3980.279	4015.700	4051.390	4087.351
T	2900.0	2905.0	2910.0	2915.0	2920.0	2925.0	2930.0	2935.0
H	932.130	934.284	936.438	938.594	940.751	942.909	945.067	947.227
P	4123.584	4160.091	4196.874	4233.934	4271.274	4308.894	4346.798	4384.987
T	2940.0	2945.0	2950.0	2955.0	0.0	0.0	0.0	0.0
H	949.388	951.549	953.712	955.875	0.000	0.000	0.000	0.000
P	4423.462	4462.225	4501.279	4540.625	0.000	0.000	0.000	0.000

Table A 4.1.6 - Properties of the Products of Combustion of Direct Fired North Dakota Lignite with 27% Moisture

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
52.517	29.425	.00155	.24843	.08503	.00200	.6513	.0110	.1666	.0064

T	460.0	465.0	470.0	475.0	480.0	485.0	490.0	495.0
H	14.849	16.093	17.338	18.584	19.831	21.079	22.328	23.578
P	1.669	1.737	1.807	1.879	1.953	2.029	2.108	2.189
T	500.0	505.0	510.0	515.0	520.0	525.0	530.0	535.0
H	24.829	26.081	27.334	28.588	29.843	31.099	32.355	33.613
P	2.272	2.357	2.445	2.535	2.628	2.723	2.821	2.921
T	540.0	545.0	550.0	555.0	560.0	565.0	570.0	575.0
H	34.872	36.132	37.392	38.654	39.917	41.180	42.445	43.710
P	3.025	3.130	3.239	3.350	3.465	3.582	3.702	3.825
T	580.0	585.0	590.0	595.0	600.0	605.0	610.0	615.0
H	44.977	46.244	47.512	48.781	50.052	51.323	52.595	53.868
P	3.952	4.081	4.214	4.350	4.489	4.631	4.777	4.927
T	620.0	625.0	630.0	635.0	640.0	645.0	650.0	655.0
H	55.142	56.417	57.693	58.969	60.247	61.526	62.806	64.086
P	5.080	5.236	5.395	5.560	5.728	5.899	6.074	6.253
T	660.0	665.0	670.0	675.0	680.0	685.0	690.0	695.0
H	65.368	66.651	67.934	69.219	70.504	71.791	73.078	74.367
P	6.437	6.624	6.815	7.011	7.211	7.415	7.624	7.837
T	700.0	705.0	710.0	715.0	720.0	725.0	730.0	735.0
H	75.656	76.946	78.238	79.530	80.824	82.118	83.413	84.710
P	8.054	8.276	8.503	8.735	8.971	9.213	9.459	9.710
T	740.0	745.0	750.0	755.0	760.0	765.0	770.0	775.0
H	86.007	87.306	88.605	89.905	91.207	92.509	93.813	95.117
P	9.966	10.228	10.495	10.767	11.044	11.327	11.616	11.910
T	780.0	785.0	790.0	795.0	800.0	805.0	810.0	815.0
H	96.423	97.729	99.037	100.345	101.655	102.965	104.277	105.590
P	12.210	12.516	12.828	13.145	13.469	13.799	14.135	14.477

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
52.517	29.425	.00155	.24843	.08503	.00206	.65134	.01104	.16506	.00[illegible]

T	820.0	825.0	830.0	835.0	840.0	845.0	850.0	855.0
H	105.904	108.218	109.534	110.851	112.169	113.458	114.808	116.123
P	14.826	15.182	15.543	15.912	16.287	16.669	17.059	17.455
T	860.0	865.0	870.0	875.0	880.0	885.0	890.0	895.0
H	117.452	118.775	120.099	121.425	122.751	124.079	125.407	126.737
P	17.858	18.269	18.686	19.112	19.544	19.985	20.433	20.889
T	900.0	905.0	910.0	915.0	920.0	925.0	930.0	935.0
H	128.068	129.399	130.732	132.066	133.401	134.737	136.075	137.413
P	21.353	21.825	22.305	22.793	23.290	23.795	24.309	24.831
T	940.0	945.0	950.0	955.0	960.0	965.0	970.0	975.0
H	138.752	140.093	141.435	142.777	144.121	145.465	146.812	148.159
P	25.362	25.902	26.451	27.010	27.577	28.154	28.740	29.335
T	980.0	985.0	990.0	995.0	1000.0	1005.0	1010.0	1015.0
H	149.507	150.856	152.207	153.558	154.911	156.264	157.619	158.975
P	29.941	30.557	31.182	31.818	32.463	33.119	33.785	34.462
T	1020.0	1025.0	1030.0	1035.0	1040.0	1045.0	1050.0	1055.0
H	160.332	161.690	163.049	164.410	165.771	167.134	168.497	169.862
P	35.150	35.848	36.558	37.278	38.010	38.753	39.508	40.274
T	1060.0	1065.0	1070.0	1075.0	1080.0	1085.0	1090.0	1095.0
H	171.228	172.595	173.963	175.332	176.702	178.074	179.446	180.821
P	41.052	41.842	42.644	43.458	44.285	45.124	45.975	46.840
T	1100.0	1105.0	1110.0	1115.0	1120.0	1125.0	1130.0	1135.0
H	182.195	183.570	184.947	186.325	187.705	189.085	190.466	191.849
P	47.717	48.607	49.511	50.428	51.358	52.302	53.260	54.232
T	1140.0	1145.0	1150.0	1155.0	1160.0	1165.0	1170.0	1175.0
H	193.233	194.617	196.003	197.390	198.778	200.167	201.558	202.949
P	55.218	56.219	57.234	58.263	59.307	60.367	61.441	62.531

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
52.517	29.425	.00155	.24843	.03503	.00200	.65134	.01164	.16660	.00646

T	1180.0	1185.0	1190.0	1195.0	1200.0	1205.0	1210.0	1215.0
H	204.342	205.735	207.133	208.526	209.923	211.321	212.720	214.120
P	63.636	64.757	65.893	67.046	68.215	69.400	70.601	71.819
T	1220.0	1225.0	1230.0	1235.0	1240.0	1245.0	1250.0	1255.0
H	215.522	216.924	218.328	219.732	221.138	222.545	223.953	225.362
P	73.055	74.307	75.575	76.863	78.167	79.490	80.830	82.188
T	1260.0	1265.0	1270.0	1275.0	1280.0	1285.0	1290.0	1295.0
H	226.772	228.184	229.595	231.009	232.424	233.840	235.256	236.674
P	83.565	84.960	86.374	87.808	89.260	90.731	92.223	93.733
T	1300.0	1305.0	1310.0	1315.0	1320.0	1325.0	1330.0	1335.0
H	238.093	239.513	240.934	242.356	243.780	245.204	246.629	248.055
P	95.264	96.815	98.387	99.979	101.592	103.225	104.881	106.557
T	1340.0	1345.0	1350.0	1355.0	1360.0	1365.0	1370.0	1375.0
H	249.484	250.912	252.342	253.773	255.205	256.638	258.072	259.507
P	108.256	109.976	111.718	113.483	115.270	117.080	118.913	120.769
T	1380.0	1385.0	1390.0	1395.0	1400.0	1405.0	1410.0	1415.0
H	260.943	262.380	263.819	265.258	266.698	268.140	269.582	271.025
P	122.649	124.553	126.480	128.432	130.408	132.409	134.434	136.485
T	1420.0	1425.0	1430.0	1435.0	1440.0	1445.0	1450.0	1455.0
H	272.471	273.916	275.363	276.811	278.260	279.710	281.161	282.613
P	138.561	140.663	142.791	144.945	147.126	149.333	151.567	153.828
T	1460.0	1465.0	1470.0	1475.0	1480.0	1485.0	1490.0	1495.0
H	284.066	285.520	286.975	288.431	289.888	291.345	292.805	294.265
P	156.117	158.433	160.777	163.150	165.551	167.981	170.440	172.928
T	1500.0	1505.0	1510.0	1515.0	1520.0	1525.0	1530.0	1535.0
H	295.727	297.189	298.652	300.117	301.582	303.049	304.516	305.984
P	175.446	177.994	180.572	183.181	185.820	188.490	191.192	193.925

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/OA	H/OA
52.517	29.425	.0[illegible]155	24843	.03503	.00200	.00134	.01104	.10566	.00646

T	1540.0	[illegible]	[illegible]	1555.0	1560.0	1565.0	1570.0	1575.0
H	307.454	308.924	310.395	311.868	313.341	314.816	316.291	317.767
P	195.690	199.437	202.317	205.166	208.075	211.004	213.967	216.964
T	1580.0	1585.0	1590.0	1595.0	1600.0	1605.0	1610.0	1615.0
H	319.245	320.723	322.202	323.683	325.164	326.646	328.130	329.614
P	219.995	223.061	226.161	229.297	232.469	235.675	238.920	242.205
T	1620.0	1625.0	1630.0	1635.0	1640.0	1645.0	1650.0	1655.0
H	331.099	332.585	334.072	335.560	337.049	338.539	340.030	341.522
P	245.517	248.871	252.263	255.692	259.160	262.666	266.212	269.795
T	1660.0	1665.0	1670.0	1675.0	1680.0	1685.0	1690.0	1695.0
H	343.015	344.509	346.004	347.499	348.996	350.494	351.992	353.492
P	273.420	277.084	280.788	284.532	288.318	292.145	296.014	299.924
T	1700.0	1705.0	1710.0	1715.0	1720.0	1725.0	1730.0	1735.0
H	354.992	356.493	357.995	359.499	361.003	362.508	364.014	365.521
P	303.877	307.873	311.912	315.995	320.121	324.291	328.506	332.767
T	1740.0	1745.0	1750.0	1755.0	1760.0	1765.0	1770.0	1775.0
H	367.029	368.537	370.047	371.557	373.069	374.581	376.094	377.608
P	337.072	341.423	345.821	350.264	354.755	359.293	363.879	368.513
T	1780.0	1785.0	1790.0	1795.0	1800.0	1805.0	1810.0	1815.0
H	379.123	380.639	382.155	383.674	385.192	386.711	388.232	389.753
P	373.195	377.927	382.707	387.538	392.418	397.349	402.331	407.364
T	1820.0	1825.0	1830.0	1835.0	1840.0	1845.0	1850.0	1855.0
H	391.275	392.798	394.322	395.846	397.372	398.898	400.425	401.953
P	412.449	417.587	422.777	428.020	433.316	438.667	444.071	449.531
T	1860.0	1865.0	1870.0	1875.0	1880.0	1885.0	1890.0	1895.0
H	403.482	405.012	406.542	408.074	409.606	411.139	412.673	414.208
P	455.046	460.616	466.243	471.926	477.666	483.454	489.320	495.234

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
52.517	29.425	.00155	24843	.08503	.00200	.65134	.01164	.16666	.00646

T	1900.0	1905.0	1910.0	1915.0	1920.0	1925.0	1930.0	1935.0
H	415.743	417.280	418.817	420.355	421.894	423.434	424.974	426.515
P	501.207	507.239	513.331	519.483	525.696	531.970	538.306	544.704
T	1940.0	1945.0	1950.0	1955.0	1960.0	1965.0	1970.0	1975.0
H	428.058	429.601	431.144	432.689	434.234	435.780	437.327	438.875
P	551.165	557.669	564.275	570.928	577.644	584.425	591.272	598.185
T	1980.0	1985.0	1990.0	1995.0	2000.0	2005.0	2010.0	2015.0
H	440.423	441.973	443.523	445.074	446.625	448.178	449.731	451.285
P	605.164	612.211	619.325	626.508	633.759	641.079	648.469	655.929
T	2020.0	2025.0	2030.0	2035.0	2040.0	2045.0	2050.0	2055.0
H	452.839	454.395	455.951	457.508	459.066	460.624	462.184	463.744
P	663.460	671.062	678.735	686.483	694.302	702.195	710.161	718.202
T	2060.0	2065.0	2070.0	2075.0	2080.0	2085.0	2090.0	2095.0
H	465.304	466.866	468.429	469.991	471.555	473.119	474.684	476.250
P	726.319	734.511	742.779	751.124	759.546	768.046	776.624	785.282
T	2100.0	2105.0	2110.0	2115.0	2120.0	2125.0	2130.0	2135.0
H	477.817	479.384	480.952	482.521	484.091	485.651	487.232	488.803
P	794.019	802.836	811.734	820.714	829.775	838.919	848.146	857.457
T	2140.0	2145.0	2150.0	2155.0	2160.0	2165.0	2170.0	2175.0
H	490.376	491.949	493.523	495.097	496.672	498.248	499.825	501.402
P	866.852	876.332	885.897	895.549	905.287	915.113	925.027	935.029
T	2180.0	2185.0	2190.0	2195.0	2200.0	2205.0	2210.0	2215.0
H	502.980	504.558	506.139	507.718	509.298	510.879	512.461	514.044
P	945.121	955.302	965.574	975.937	986.392	996.939	1007.580	1018.314
T	2220.0	2225.0	2230.0	2235.0	2240.0	2245.0	2250.0	2255.0
H	515.628	517.212	518.796	520.382	521.968	523.554	525.141	526.729
P	1029.142	1040.066	1051.085	1062.200	1073.413	1084.723	1096.132	1107.639

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/OA	H/OA
52.517	29.425	.00155	.24843	.08563	.00260	.65134	.01164	.16600	.00640

T	2260.0	2265.0	2270.0	2275.0	2280.0	2285.0	2290.0	2295.0
H	528.318	529.907	531.497	533.088	534.679	536.271	537.863	539.455
P	1119.246	1130.954	1142.763	1154.673	1166.686	1178.803	1191.023	1203.347
T	2300.0	2305.0	2310.0	2315.0	2320.0	2325.0	2330.0	2335.0
H	541.050	542.645	544.240	545.835	547.432	549.028	550.626	552.224
P	1215.777	1228.313	1240.955	1253.705	1266.564	1279.531	1292.607	1305.794
T	2340.0	2345.0	2350.0	2355.0	2360.0	2365.0	2370.0	2375.0
H	553.823	555.422	557.022	558.623	560.224	561.825	563.428	565.031
P	1319.092	1332.502	1346.024	1359.660	1373.409	1387.274	1401.254	1415.353
T	2380.0	2385.0	2390.0	2395.0	2400.0	2405.0	2410.0	2415.0
H	566.635	568.239	569.844	571.450	573.056	574.662	576.270	577.877
P	1429.564	1443.895	1458.345	1472.915	1487.604	1502.415	1517.347	1532.402
T	2420.0	2425.0	2430.0	2435.0	2440.0	2445.0	2450.0	2455.0
H	579.486	581.095	582.704	584.315	585.925	587.537	589.149	590.761
P	1547.580	1562.883	1578.310	1593.863	1609.543	1625.350	1641.286	1657.353
T	2460.0	2465.0	2470.0	2475.0	2480.0	2485.0	2490.0	2495.0
H	592.374	593.988	595.602	597.217	598.832	600.448	602.065	603.682
P	1673.545	1689.870	1706.325	1722.915	1739.638	1756.494	1773.486	1790.513
T	2500.0	2505.0	2510.0	2515.0	2520.0	2525.0	2530.0	2535.0
H	605.299	606.918	608.535	610.156	611.776	613.395	615.017	616.638
P	1807.877	1825.278	1842.818	1860.497	1878.316	1896.276	1914.378	1932.623
T	2540.0	2545.0	2550.0	2555.0	2560.0	2565.0	2570.0	2575.0
H	618.261	619.883	621.505	623.130	624.754	626.379	628.005	629.631
P	1951.012	1969.545	1988.224	2007.050	2026.022	2045.143	2064.413	2083.834
T	2580.0	2585.0	2590.0	2595.0	2600.0	2605.0	2610.0	2615.0
H	631.257	632.884	634.512	636.140	637.768	639.398	641.027	642.658
P	2103.405	2123.128	2143.005	2163.035	2183.220	2203.560	2224.058	2244.713

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
52.517	29.425	.00155	.24843	.03363	.00200	.69134	.01104	.15600	.00040

T	2620.0	2625.0	2630.0	2635.0	2640.0	2645.0	2650.0	2655.0
H	644.288	645.920	647.552	649.184	650.817	652.450	654.084	655.719
P	2265.527	2286.560	2307.635	2328.930	2350.389	2372.011	2393.797	2415.750
T	2660.0	2665.0	2670.0	2675.0	2680.0	2685.0	2690.0	2695.0
H	657.354	658.989	660.625	662.262	663.899	665.537	667.175	668.814
P	2437.868	2460.155	2482.610	2505.235	2528.030	2550.997	2574.137	2597.451
T	2700.0	2705.0	2710.0	2715.0	2720.0	2725.0	2730.0	2735.0
H	670.453	672.093	673.733	675.374	677.015	678.657	680.299	681.942
P	2620.939	2644.604	2668.445	2692.465	2716.663	2741.042	2765.602	2790.345
T	2740.0	2745.0	2750.0	2755.0	2760.0	2765.0	2770.0	2775.0
H	683.566	685.229	686.874	688.519	690.164	691.810	693.457	695.104
P	2815.270	2840.381	2865.677	2891.159	2916.830	2942.689	2968.739	2994.980
T	2780.0	2785.0	2790.0	2795.0	2800.0	2805.0	2810.0	2815.0
H	696.751	698.399	700.048	701.697	703.346	704.995	706.647	708.298
P	3021.413	3048.040	3074.861	3101.878	3129.092	3156.504	3184.116	3211.928
T	2820.0	2825.0	2830.0	2835.0	2840.0	2845.0	2850.0	2855.0
H	709.950	711.602	713.254	714.907	716.561	718.215	719.870	721.525
P	3239.941	3268.158	3296.578	3325.204	3354.036	3383.075	3412.324	3441.783
T	2860.0	2865.0	2870.0	2875.0	2880.0	2885.0	2890.0	2895.0
H	723.181	724.837	726.494	728.151	729.809	731.467	733.126	734.785
P	3471.453	3501.335	3531.431	3561.743	3592.270	3623.016	3653.980	3665.164
T	2900.0	2905.0	2910.0	2915.0	2920.0	2925.0	2930.0	2935.0
H	736.445	736.105	739.766	741.427	743.089	744.751	746.414	748.078
P	3716.569	3748.197	3780.049	3812.127	3844.431	3876.953	3909.724	3942.715
T	2940.0	2945.0	2950.0	2955.0	0.0	0.0	0.0	0.0
H	749.742	751.406	753.071	754.736	0.000	0.000	0.000	0.000
P	3975.939	4009.395	4043.085	4077.014	0.000	0.000	0.000	0.000

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
52.997	29.159	.10783	.1333[illegible]	.04850	.00107	.69703	.01247	.083[illegible]	.0064[illegible]

T	460.0	465.0	470.0	475.0	480.0	485.0	490.0	495.0
H	14.658	15.863	17.103	18.335	19.551	20.769	22.017	23.245
P	1.651	1.716	1.763	1.853	1.924	1.997	2.072	2.150
T	500.0	505.0	510.0	515.0	520.0	525.0	530.0	535.0
H	24.474	25.704	26.934	28.165	29.396	30.628	31.860	33.093
P	2.229	2.311	2.394	2.480	2.568	2.659	2.752	2.847
T	540.0	545.0	550.0	555.0	560.0	565.0	570.0	575.0
H	34.327	35.561	36.795	38.032	39.268	40.505	41.742	42.980
P	2.944	3.044	3.147	3.252	3.359	3.470	3.582	3.698
T	580.0	585.0	590.0	595.0	600.0	605.0	610.0	615.0
H	44.219	45.458	46.698	47.938	49.179	50.421	51.663	52.905
P	3.816	3.937	4.061	4.188	4.318	4.450	4.586	4.725
T	620.0	625.0	630.0	635.0	640.0	645.0	650.0	655.0
H	54.156	55.394	56.639	57.885	59.131	60.378	61.626	62.874
P	4.866	5.011	5.159	5.311	5.465	5.623	5.785	5.949
T	660.0	665.0	670.0	675.0	680.0	685.0	690.0	695.0
H	64.123	65.373	66.624	67.875	69.127	70.379	71.633	72.887
P	6.118	6.289	6.465	6.644	6.827	7.013	7.203	7.397
T	700.0	705.0	710.0	715.0	720.0	725.0	730.0	735.0
H	74.141	75.397	76.653	77.910	79.167	80.425	81.685	82.945
P	7.595	7.797	8.003	8.213	8.427	8.645	8.868	9.094
T	740.0	745.0	750.0	755.0	760.0	765.0	770.0	775.0
H	84.206	85.467	86.729	87.992	89.256	90.520	91.786	93.052
P	9.326	9.561	9.801	10.046	10.295	10.548	10.807	11.070
T	780.0	785.0	790.0	795.0	800.0	805.0	810.0	815.0
H	94.319	95.586	96.855	98.124	99.394	100.665	101.937	103.209
P	11.338	11.611	11.889	12.171	12.459	12.752	13.051	13.354

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R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	M/DA
52.997	29.159	.10783	.13305	.04850	.00107	.69705	.01247	.08300	.00640

T	820.0	825.0	830.0	835.0	840.0	845.0	850.0	855.0
H	104.483	105.757	107.032	108.308	109.584	110.862	112.140	113.419
P	13.663	13.977	14.297	14.622	14.953	15.290	15.632	15.960
T	860.0	865.0	870.0	875.0	880.0	885.0	890.0	895.0
H	114.700	115.980	117.262	118.545	119.828	121.113	122.398	123.684
P	16.334	16.694	17.061	17.433	17.811	18.195	18.587	18.984
T	900.0	905.0	910.0	915.0	920.0	925.0	930.0	935.0
H	124.971	126.259	127.547	128.837	130.128	131.419	132.711	134.004
P	19.388	19.798	20.215	20.639	21.070	21.507	21.952	22.403
T	940.0	945.0	950.0	955.0	960.0	965.0	970.0	975.0
H	135.298	136.593	137.889	139.186	140.484	141.782	143.082	144.382
P	22.862	23.327	23.801	24.281	24.769	25.254	25.767	26.275
T	980.0	985.0	990.0	995.0	1000.0	1005.0	1010.0	1015.0
H	145.683	146.985	148.289	149.593	150.897	152.203	153.510	154.818
P	26.797	27.323	27.858	28.400	28.951	29.510	30.077	30.653
T	1020.0	1025.0	1030.0	1035.0	1040.0	1045.0	1050.0	1055.0
H	156.127	157.436	158.747	160.058	161.371	162.684	163.998	165.313
P	31.237	31.830	32.432	33.042	33.661	34.290	34.927	35.574
T	1060.0	1065.0	1070.0	1075.0	1080.0	1085.0	1090.0	1095.0
H	166.629	167.947	169.265	170.584	171.903	173.224	174.546	175.869
P	36.230	36.895	37.570	38.254	38.948	39.652	40.366	41.093
T	1100.0	1105.0	1110.0	1115.0	1120.0	1125.0	1130.0	1135.0
H	177.193	178.517	179.843	181.169	182.497	183.825	185.155	186.485
P	41.824	42.568	43.323	44.088	44.864	45.650	46.447	47.255
T	1140.0	1145.0	1150.0	1155.0	1160.0	1165.0	1170.0	1175.0
H	187.817	189.149	190.482	191.816	193.151	194.487	195.825	197.163
P	48.074	48.904	49.745	50.598	51.462	52.337	53.225	54.124

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
52.997	29.159	.10783	.13305	.04850	.00107	.69703	.01247	.08300	.00640

T	1180.0	1185.0	1190.0	1195.0	1200.0	1205.0	1210.0	1215.0
H	198.562	199.84[illegible]	201.182	202.524	203.867	205.211	206.556	207.901
P	55.035	55.928	56.894	57.841	58.801	59.774	60.755	61.757
T	1220.0	1225.0	1230.0	1235.0	1240.0	1245.0	1250.0	1255.0
H	209.248	210.595	211.944	213.294	214.644	215.995	217.348	218.702
P	62.768	63.792	64.829	65.880	66.944	68.021	69.112	70.218
T	1260.0	1265.0	1270.0	1275.0	1280.0	1285.0	1290.0	1295.0
H	220.056	221.411	222.768	224.125	225.483	226.842	228.202	229.563
P	71.337	72.470	73.617	74.779	75.955	77.146	78.352	79.572
T	1300.0	1305.0	1310.0	1315.0	1320.0	1325.0	1330.0	1335.0
H	230.925	232.288	233.652	235.017	236.383	237.750	239.117	240.485
P	80.808	82.059	83.325	84.607	85.904	87.218	88.547	89.892
T	1340.0	1345.0	1350.0	1355.0	1360.0	1365.0	1370.0	1375.0
H	241.856	243.226	244.598	245.970	247.344	248.718	250.093	251.469
P	91.254	92.631	94.026	95.437	96.865	98.310	99.772	161.252
T	1380.9	1385.0	1390.0	1395.0	1400.0	1405.0	1410.0	1415.0
H	252.847	254.225	255.604	255.984	258.365	259.747	261.130	262.513
P	102.749	104.264	105.795	107.346	108.915	110.502	112.107	113.731
T	1420.0	1425.0	1430.0	1435.0	1440.0	1445.0	1450.0	1455.0
H	263.898	265.284	266.670	268.058	269.446	270.835	272.226	273.617
P	115.374	117.035	118.715	120.416	122.136	123.875	125.634	127.413
T	1460.0	1465.0	1470.0	1475.0	1480.0	1485.0	1490.0	1495.0
H	275.009	276.402	277.795	279.191	280.586	281.983	283.381	284.779
P	129.212	131.031	132.871	134.732	136.613	138.515	140.439	142.385
T	1500.0	1505.0	1510.0	1515.0	1520.0	1525.0	1530.0	1535.0
H	286.179	287.579	288.980	290.382	291.785	293.189	294.594	296.000
P	144.351	146.340	148.350	150.383	152.438	154.516	156.616	118.739

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
52.997	29.159	.10783	.13305	.04850	.00167	.69735	.01247	.08300	.00040

T	1540.0	1545.0	1550.0	1555.0	1560.0	1565.0	1570.0	1575.0
H	297.406	298.814	300.222	301.632	303.042	304.453	305.865	307.273
P	150.886	163.035	165.248	167.465	169.706	171.971	174.260	176.574
T	1580.0	1585.0	1590.0	1595.0	1600.0	1605.0	1610.0	1615.0
H	308.691	310.106	311.521	312.938	314.355	315.773	317.192	318.612
P	178.912	181.275	183.663	186.077	188.516	190.981	193.472	195.989
T	1620.0	1625.0	1630.0	1635.0	1640.0	1645.0	1650.0	1655.0
H	320.033	321.454	322.875	324.300	325.724	327.149	328.575	330.001
P	198.533	201.132	203.699	206.323	208.974	211.652	214.359	217.093
T	1660.0	1665.0	1670.0	1675.0	1680.0	1685.0	1690.0	1695.0
H	331.429	332.857	334.286	335.716	337.147	338.579	340.011	341.445
P	219.855	222.645	225.464	228.312	231.189	234.095	237.030	239.995
T	1700.0	1705.0	1710.0	1715.0	1720.0	1725.0	1730.0	1735.0
H	342.879	344.314	345.750	347.186	348.624	350.062	351.501	352.941
P	242.991	246.016	249.072	252.158	255.276	258.424	261.604	264.815
T	1740.0	1745.0	1750.0	1755.0	1760.0	1765.0	1770.0	1775.0
H	354.382	355.823	357.265	358.709	360.153	361.597	363.043	364.489
P	268.058	271.333	274.641	277.981	281.354	284.760	288.199	291.672
T	1780.0	1785.0	1790.0	1795.0	1800.0	1805.0	1810.0	1815.0
H	365.936	367.384	368.833	370.282	371.732	373.183	374.635	376.087
P	295.179	298.720	302.295	305.905	309.549	313.229	316.944	320.695
T	1820.0	1825.0	1830.0	1835.0	1840.0	1845.0	1850.0	1855.0
H	377.541	378.995	380.450	381.905	383.361	384.819	386.276	387.735
P	324.481	328.304	332.163	336.059	339.992	343.962	347.969	352.015
T	1860.0	1865.0	1870.0	1875.0	1880.0	1885.0	1890.0	1895.0
H	389.194	390.654	392.115	393.577	395.039	396.502	397.966	399.430
P	356.098	360.220	364.380	368.580	372.818	377.095	381.413	385.771

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
52.997	29.159	.10783	.13306	.04856	.00107	.69706	.01247	.08300	.00640

T	1900.0	1905.0	1910.0	1915.0	1920.0	1925.0	1930.0	1935.0
H	400.896	402.361	403.828	405.296	406.764	408.232	409.702	411.172
P	390.169	394.607	399.087	403.607	408.169	412.773	417.416	422.105
T	1940.0	1945.0	1950.0	1955.0	1960.0	1965.0	1970.0	1975.0
H	412.643	414.115	415.587	417.060	418.534	420.008	421.483	422.959
P	426.837	431.611	436.428	441.288	446.192	451.141	456.133	461.171
T	1980.0	1985.0	1990.0	1995.0	2000.0	2005.0	2010.0	2015.0
H	424.436	425.913	427.391	428.869	430.348	431.828	433.309	434.790
P	465.253	471.361	476.555	481.775	487.041	492.353	497.713	503.113
T	2020.0	2025.0	2030.0	2035.0	2040.0	2045.0	2050.0	2055.0
H	436.272	437.754	439.238	440.721	442.206	443.691	445.177	446.663
P	508.574	514.076	519.625	525.225	530.873	536.570	542.317	548.113
T	2060.0	2065.0	2070.0	2075.0	2080.0	2085.0	2090.0	2095.0
H	448.151	449.638	451.127	452.616	454.105	455.595	457.086	458.578
P	553.960	559.857	565.805	571.804	577.855	583.958	590.112	596.320
T	2100.0	2105.0	2110.0	2115.0	2120.0	2125.0	2130.0	2135.0
H	460.070	461.563	463.056	464.550	466.045	467.540	469.036	470.533
P	602.580	608.894	615.261	621.682	628.157	634.687	641.272	647.912
T	2140.0	2145.0	2150.0	2155.0	2160.0	2165.0	2170.0	2175.0
H	472.030	473.527	475.025	476.525	478.024	479.524	481.025	482.525
P	654.608	661.361	668.159	675.034	681.957	688.937	695.975	703.071
T	2180.0	2185.0	2190.0	2195.0	2200.0	2205.0	2210.0	2215.0
H	484.028	485.530	487.033	488.537	490.041	491.546	493.051	494.557
P	710.226	717.440	724.713	732.046	739.439	746.892	754.407	761.982
T	2220.0	2225.0	2230.0	2235.0	2240.0	2245.0	2250.0	2255.0
H	496.064	497.571	499.078	500.586	502.095	503.605	505.114	506.625
P	769.620	777.319	785.081	792.905	800.793	808.744	816.760	824.839

R	HOL.HGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	M/DA
52.997	29.159	.10783	.13306	.04550	.00107	.69705	.01247	.08300	.00640

T	2260.0	2265.0	2270.0	2275.0	2280.0	2285.0	2290.0	2295.0
H	509.136	509.647	511.159	512.672	514.185	515.699	517.213	518.729
P	832.984	841.193	849.469	857.813	866.217	874.692	883.233	891.842
T	2300.0	2305.0	2310.0	2315.0	2320.0	2325.0	2330.0	2335.0
H	520.243	521.759	523.276	524.793	526.310	527.823	529.347	530.865
P	900.520	909.205	918.079	926.963	935.917	944.940	954.034	963.199
T	2340.0	2345.0	2350.0	2355.0	2360.0	2365.0	2370.0	2375.0
H	532.365	533.905	535.425	536.947	538.469	539.991	541.514	543.037
P	972.435	981.743	991.124	1000.577	1010.103	1019.702	1029.376	1039.124
T	2380.0	2385.0	2390.0	2395.0	2400.0	2405.0	2410.0	2415.0
H	544.561	546.085	547.610	549.135	550.661	552.187	553.714	555.242
P	1048.947	1058.845	1068.819	1078.869	1088.996	1099.199	1109.481	1119.840
T	2420.0	2425.0	2430.0	2435.0	2440.0	2445.0	2450.0	2455.0
H	556.769	558.298	559.827	561.356	562.886	564.415	565.947	567.478
P	1130.278	1140.795	1151.391	1162.067	1172.823	1183.660	1194.579	1205.573
T	2460.0	2465.0	2470.0	2475.0	2480.0	2485.0	2490.0	2495.0
H	569.010	570.542	572.075	573.609	575.142	576.677	578.211	579.747
P	1216.661	1227.826	1239.074	1250.406	1261.822	1273.322	1284.908	1296.579
T	2500.0	2505.0	2510.0	2515.0	2520.0	2525.0	2530.0	2535.0
H	581.282	582.819	584.355	585.893	587.430	588.959	590.507	592.045
P	1308.337	1320.180	1332.111	1344.130	1356.237	1368.432	1380.716	1393.090
T	2540.0	2545.0	2550.0	2555.0	2560.0	2565.0	2570.0	2575.0
H	593.586	595.126	596.667	598.208	599.750	601.292	602.834	604.377
P	1405.554	1418.109	1430.755	1443.493	1456.323	1469.245	1482.261	1495.370
T	2580.0	2585.0	2590.0	2595.0	2600.0	2605.0	2610.0	2615.0
H	605.921	607.465	609.009	610.554	612.100	613.646	615.192	616.739
P	1508.574	1521.873	1535.267	1548.757	1562.344	1576.027	1589.809	1603.688

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
52.997	29.159	.10783	.13336	.04651	.00107	.69738	.01247	.08366	.006[illegible]

T	2620.0	2625.0	2630.0	2635.0	2640.0	2645.0	2650.0	2655.0
H	618.286	619.834	621.382	622.931	624.481	626.031	627.581	629.131
P	1617.666	1631.743	1645.920	1660.198	1674.576	1689.055	1703.638	1718.322
T	2660.0	2665.0	2670.0	2675.0	2680.0	2685.0	2690.0	2695.0
H	630.683	632.234	633.787	635.339	636.893	638.445	640.000	641.555
P	1733.110	1748.002	1762.998	1778.099	1793.305	1808.618	1824.038	1839.564
T	2700.0	2705.0	2710.0	2715.0	2720.0	2725.0	2730.0	2735.0
H	643.110	644.666	646.222	647.779	649.336	650.893	652.451	654.013
P	1855.199	1870.943	1886.795	1902.758	1918.831	1935.014	1951.310	1967.713
T	2740.0	2745.0	2750.0	2755.0	2760.0	2765.0	2770.0	2775.0
H	655.569	657.129	658.689	660.249	661.811	663.372	664.934	666.497
P	1984.238	2000.873	2017.621	2034.465	2051.463	2068.558	2085.770	2103.093
T	2780.0	2785.0	2790.0	2795.0	2800.0	2805.0	2810.0	2815.0
H	668.060	669.624	671.188	672.753	674.318	675.883	677.450	679.015
P	2120.546	2138.112	2155.795	2173.593	2191.530	2209.577	2227.747	2246.043
T	2820.0	2825.0	2830.0	2835.0	2840.0	2845.0	2850.0	2855.0
H	680.584	682.151	683.720	685.289	686.858	688.428	689.998	691.569
P	2264.456	2282.997	2301.662	2320.453	2339.370	2358.415	2377.587	2396.887
T	2860.0	2865.0	2870.0	2875.0	2880.0	2885.0	2890.0	2895.0
H	693.141	694.713	696.285	697.859	699.433	701.007	702.582	704.157
P	2416.317	2435.877	2455.567	2475.389	2495.343	2515.431	2535.650	2556.005
T	2900.0	2905.0	2910.0	2915.0	2920.0	2925.0	2930.0	2935.0
H	705.733	707.309	708.887	710.464	712.042	713.621	715.201	716.781
P	2576.495	2597.121	2617.884	2638.784	2659.823	2681.000	2702.318	2723.775
T	2940.0	2945.0	2950.0	2955.0	0.0	0.0	0.0	0.0
H	718.361	719.942	721.524	723.106	0.000	0.000	0.000	0.000
P	2745.375	2767.117	2789.002	2811.031	0.000	0.000	0.000	0.000

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	M/DA
53.172	29.063	.14660	.09696	.03517	.00073	.71377	.01277	.05540	.00640

T	450.0	455.0	470.0	475.0	480.0	485.0	490.0	495.0
H	14.588	15.807	17.025	18.244	19.463	20.683	21.903	23.124
P	1.644	1.709	1.775	1.843	1.914	1.986	2.060	2.136
T	500.0	505.0	510.0	515.0	520.0	525.0	530.0	535.0
H	24.345	25.566	26.789	28.010	29.233	30.455	31.680	32.904
P	2.214	2.294	2.375	2.461	2.547	2.636	2.727	2.820
T	540.0	545.0	550.0	555.0	560.0	565.0	570.0	575.0
H	34.128	35.353	36.579	37.805	39.031	40.258	41.485	42.714
P	2.916	3.014	3.114	3.217	3.322	3.430	3.540	3.653
T	580.0	585.0	590.0	595.0	600.0	605.0	610.0	615.0
H	43.942	45.171	46.400	47.630	48.861	50.092	51.323	52.555
P	3.789	3.887	4.008	4.131	4.258	4.357	4.519	4.554
T	520.0	625.0	630.0	635.0	640.0	645.0	650.0	655.0
H	53.788	55.021	56.255	57.489	58.724	59.960	61.196	62.432
P	4.792	4.933	5.077	5.224	5.374	5.527	5.684	5.844
T	660.0	665.0	670.0	675.0	680.0	685.0	690.0	695.0
H	63.669	64.907	66.145	67.385	68.624	69.864	71.105	72.347
P	6.007	6.173	6.343	6.516	6.693	6.873	7.057	7.245
T	700.0	705.0	710.0	715.0	720.0	725.0	730.0	735.0
H	73.589	74.831	76.075	77.319	78.563	79.808	81.054	82.301
P	7.436	7.631	7.830	8.033	8.239	8.450	8.664	8.882
T	740.0	745.0	750.0	755.0	760.0	765.0	770.0	775.0
H	83.548	84.796	86.045	87.294	88.544	89.795	91.046	92.298
P	9.105	9.332	9.563	9.798	10.037	10.281	10.529	10.782
T	780.0	785.0	790.0	795.0	800.0	805.0	810.0	815.0
H	93.551	94.805	96.059	97.314	98.570	99.825	101.083	102.341
P	11.039	11.301	11.567	11.838	12.114	12.395	12.681	12.971

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
53.172	29.063	.14660	.09095	.03517	.00073	.71377	.01277	.05540	.00640

T	820.0	825.0	830.0	835.0	840.0	845.0	850.0	855.0
H	103.600	104.859	106.119	107.380	108.641	109.904	111.167	112.431
P	13.267	13.567	13.873	14.184	14.500	14.821	15.148	15.480
T	860.0	865.0	870.0	875.0	880.0	885.0	890.0	895.0
H	113.696	114.961	116.227	117.494	118.762	120.031	121.300	122.570
P	15.818	16.161	16.510	16.865	17.225	17.591	17.963	18.341
T	900.0	905.0	910.0	915.0	920.0	925.0	930.0	935.0
H	123.841	125.113	126.385	127.659	128.933	130.208	131.484	132.761
P	18.725	19.115	19.511	19.914	20.323	20.738	21.159	21.588
T	940.0	945.0	950.0	955.0	960.0	965.0	970.0	975.0
H	134.038	135.316	136.596	137.876	139.156	140.438	141.721	143.004
P	22.022	22.464	22.912	23.367	23.829	24.298	24.773	25.255
T	980.0	985.0	990.0	995.0	1000.0	1005.0	1010.0	1015.0
H	144.288	145.573	146.859	148.146	149.433	150.722	152.011	153.301
P	25.747	26.244	26.749	27.261	27.781	28.308	28.843	29.385
T	1020.0	1025.0	1030.0	1035.0	1040.0	1045.0	1050.0	1055.0
H	154.592	155.884	157.177	158.471	159.765	161.060	162.357	163.654
P	29.937	30.495	31.062	31.637	32.220	32.811	33.410	34.018
T	1060.0	1065.0	1070.0	1075.0	1080.0	1085.0	1090.0	1095.0
H	164.952	166.251	167.551	168.851	170.153	171.455	172.758	174.063
P	34.635	35.260	35.893	36.536	37.188	37.848	38.518	39.195
T	1100.0	1105.0	1110.0	1115.0	1120.0	1125.0	1130.0	1135.0
H	175.368	176.674	177.981	179.288	180.597	181.907	183.217	184.528
P	39.884	40.581	41.288	42.005	42.730	43.466	44.212	44.967
T	1140.0	1145.0	1150.0	1155.0	1160.0	1165.0	1170.0	1175.0
H	185.841	187.154	188.468	189.783	191.099	192.415	193.733	195.052
P	45.733	46.508	47.294	48.090	48.897	49.714	50.542	51.380

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
53.172	29.063	.14660	.09095	.03517	.00073	.71377	.01277	.05540	.00640

T	1180.0	1185.0	1190.0	1195.0	1200.0	1205.0	1210.0	1215.0
H	196.371	197.691	199.013	200.335	201.658	202.982	204.307	205.633
P	52.230	53.090	53.961	54.844	55.738	56.643	57.560	58.488
T	1220.0	1225.0	1230.0	1235.0	1240.0	1245.0	1250.0	1255.0
H	206.959	208.287	209.615	210.945	212.275	213.606	214.939	216.272
P	59.428	60.380	61.343	62.319	63.307	64.308	65.320	66.345
T	1260.0	1265.0	1270.0	1275.0	1280.0	1285.0	1290.0	1295.0
H	217.606	218.941	220.275	221.613	222.951	224.289	225.629	226.969
P	67.383	68.434	69.497	70.574	71.663	72.765	73.882	75.012
T	1300.0	1305.0	1310.0	1315.0	1320.0	1325.0	1330.0	1335.0
H	228.310	229.652	230.995	232.339	233.684	235.030	236.377	237.724
P	76.155	77.312	78.483	79.667	80.866	82.079	83.307	84.548
T	1340.0	1345.0	1350.0	1355.0	1360.0	1365.0	1370.0	1375.0
H	239.073	240.422	241.772	243.124	244.476	245.829	247.182	248.537
P	85.805	87.076	88.362	89.663	90.980	92.311	93.656	95.021
T	1380.0	1385.0	1390.0	1395.0	1400.0	1405.0	1410.0	1415.0
H	249.893	251.249	252.607	253.965	255.325	256.685	258.046	259.408
P	96.399	97.793	99.203	100.629	102.071	103.530	105.005	106.497
T	1420.0	1425.0	1430.0	1435.0	1440.0	1445.0	1450.0	1455.0
H	260.770	262.134	263.499	264.864	266.231	267.598	268.966	270.335
P	108.006	109.531	111.074	112.634	114.212	115.807	117.419	119.050
T	1460.0	1465.0	1470.0	1475.0	1480.0	1485.0	1490.0	1495.0
H	271.705	273.075	274.447	275.820	277.193	278.567	279.942	281.318
P	120.698	122.365	124.050	125.753	127.475	129.216	130.976	132.755
T	1500.0	1505.0	1510.0	1515.0	1520.0	1525.0	1530.0	1535.0
H	282.695	284.073	285.451	286.831	288.211	289.592	290.974	292.357
P	134.553	136.370	138.207	140.064	141.940	143.837	145.754	147.691

R	HOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	M/DA
53.172	29.063	.14660	.09395	.03517	.00073	.71377	.01277	.05546	.00046

T	1540.0	1545.0	1550.0	1555.0	1560.0	1565.0	1570.0	1575.0
H	293.741	295.126	296.511	297.897	299.284	300.672	302.061	303.451
P	149.648	151.627	153.626	155.646	157.688	159.751	161.835	163.942
T	1580.0	1585.0	1590.0	1595.0	1600.0	1605.0	1610.0	1615.0
H	304.841	306.233	307.625	309.018	310.412	311.806	313.202	314.598
P	166.070	168.220	170.392	172.587	174.804	177.045	179.308	181.594
T	1620.0	1625.0	1630.0	1635.0	1640.0	1645.0	1650.0	1655.0
H	315.995	317.393	318.792	320.192	321.592	322.993	324.395	325.798
P	183.904	186.237	188.594	190.974	193.379	195.808	198.261	200.739
T	1660.0	1665.0	1670.0	1675.0	1680.0	1685.0	1690.0	1695.0
H	327.202	328.606	330.011	331.417	332.824	334.232	335.640	337.050
P	203.242	205.770	208.323	210.901	213.505	216.135	218.791	221.472
T	1700.0	1705.0	1710.0	1715.0	1720.0	1725.0	1730.0	1735.0
H	338.460	339.870	341.282	342.694	344.107	345.521	346.936	348.351
P	224.181	226.915	229.677	232.465	235.281	238.124	240.994	243.892
T	1740.0	1745.0	1750.0	1755.0	1760.0	1765.0	1770.0	1775.0
H	349.768	351.185	352.602	354.021	355.440	356.860	358.281	359.703
P	246.818	249.773	252.755	255.767	258.807	261.875	264.974	268.102
T	1780.0	1785.0	1790.0	1795.0	1800.0	1805.0	1810.0	1815.0
H	361.125	362.548	363.972	365.395	366.822	368.248	369.674	371.102
P	271.259	274.446	277.664	280.911	284.189	287.498	290.838	294.209
T	1820.0	1825.0	1830.0	1835.0	1840.0	1845.0	1850.0	1855.0
H	372.530	373.959	375.389	376.819	378.250	379.682	381.115	382.548
P	297.611	301.045	304.511	308.009	311.539	315.101	318.696	322.325
T	1860.0	1865.0	1870.0	1875.0	1880.0	1885.0	1890.0	1895.0
H	383.982	385.416	386.852	388.288	389.725	391.162	392.600	394.039
P	325.986	329.681	333.410	337.172	340.969	344.800	348.665	352.565

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
53.172	29.063	.14660	.09095	.03517	.00073	.71377	.01277	.05540	.00040

T	1900.0	1905.0	1910.0	1915.0	1920.0	1925.0	1930.0	1935.0
H	395.479	396.919	398.360	399.801	401.244	402.687	404.130	405.575
P	356.501	360.472	364.478	368.520	372.598	376.713	380.864	365.051
T	1940.0	1945.0	1950.0	1955.0	1960.0	1965.0	1970.0	1975.0
H	407.019	408.465	409.911	411.358	412.806	414.254	415.703	417.153
P	389.276	393.538	397.838	402.175	406.550	410.964	415.416	419.907
T	1980.0	1985.0	1990.0	1995.0	2000.0	2005.0	2010.0	2015.0
H	418.553	420.054	421.505	422.957	424.410	425.864	427.318	428.772
P	424.437	429.006	433.615	438.264	442.953	447.682	452.452	457.262
T	2020.0	2025.0	2030.0	2035.0	2040.0	2045.0	2050.0	2055.0
H	430.228	431.684	433.140	434.597	436.055	437.513	438.972	440.432
P	462.114	467.007	471.942	476.919	481.938	486.999	492.103	497.250
T	2060.0	2065.0	2070.0	2075.0	2080.0	2085.0	2090.0	2095.0
H	441.892	443.353	444.815	446.277	447.739	449.202	450.666	452.131
P	502.441	507.675	512.953	518.275	523.642	529.053	534.509	540.013
T	2100.0	2105.0	2110.0	2115.0	2120.0	2125.0	2130.0	2135.0
H	453.596	455.061	456.527	457.994	459.462	460.929	462.398	463.867
P	545.557	551.150	556.789	562.475	568.207	573.986	579.812	585.585
T	2140.0	2145.0	2150.0	2155.0	2160.0	2165.0	2170.0	2175.0
H	465.337	466.807	468.278	469.749	471.221	472.693	474.166	475.640
P	591.608	597.577	603.596	609.663	615.779	621.945	628.160	634.425
T	2180.0	2185.0	2190.0	2195.0	2200.0	2205.0	2210.0	2215.0
H	477.114	478.588	480.064	481.539	483.016	484.493	485.970	487.445
P	640.740	647.106	653.523	659.991	666.510	673.082	679.705	686.381
T	2220.0	2225.0	2230.0	2235.0	2240.0	2245.0	2250.0	2255.0
H	488.926	490.405	491.885	493.365	494.845	496.325	497.808	499.290
P	693.169	699.891	706.725	713.615	720.557	727.554	734.606	741.713

R	HOL.HGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	M/DA
53.172	29.063	.14660	.09395	.03517	.00073	.71377	.01277	.03546	.00040

T	2260.0	2265.0	2270.0	2275.0	2280.0	2285.0	2290.0	2295.0
H	500.773	502.256	503.743	505.224	506.708	508.194	509.679	511.165
P	748.875	756.092	763.365	770.695	778.082	785.525	793.026	800.584
T	2300.0	2305.0	2310.0	2315.0	2320.0	2325.0	2330.0	2335.0
H	512.652	514.140	515.627	517.115	518.604	520.094	521.583	523.074
P	808.201	815.875	823.608	831.401	839.252	847.163	855.134	863.165
T	2340.0	2345.0	2350.0	2355.0	2360.0	2365.0	2370.0	2375.0
H	524.564	526.055	527.547	529.039	530.532	532.025	533.519	535.013
P	871.258	879.411	887.625	895.902	904.241	912.642	921.145	929.632
T	2380.0	2385.0	2390.0	2395.0	2400.0	2405.0	2410.0	2415.0
H	536.508	538.003	539.498	540.994	542.491	543.988	545.465	546.983
P	938.223	946.877	955.595	964.379	973.227	982.141	991.120	1000.165
T	2420.0	2425.0	2430.0	2435.0	2440.0	2445.0	2450.0	2455.0
H	548.482	549.981	551.480	552.980	554.480	555.981	557.482	558.984
P	1009.278	1018.457	1027.703	1037.016	1046.398	1055.848	1065.367	1074.955
T	2460.0	2465.0	2470.0	2475.0	2480.0	2485.0	2490.0	2495.0
H	560.486	561.989	563.492	564.996	566.500	568.004	569.509	571.014
P	1084.612	1094.339	1104.137	1114.006	1123.945	1133.956	1144.039	1154.194
T	2500.0	2505.0	2510.0	2515.0	2520.0	2525.0	2530.0	2535.0
H	572.520	574.027	575.534	577.041	578.549	580.057	581.565	583.075
P	1164.422	1174.723	1185.097	1195.545	1206.068	1216.665	1227.338	1238.085
T	2540.0	2545.0	2550.0	2555.0	2560.0	2565.0	2570.0	2575.0
H	584.584	586.094	587.605	589.116	590.627	592.139	593.651	595.164
P	1248.910	1259.811	1270.788	1281.842	1292.975	1304.185	1315.474	1326.841
T	2580.0	2585.0	2590.0	2595.0	2600.0	2605.0	2610.0	2615.0
H	596.677	598.191	599.705	601.220	602.735	604.251	605.767	607.283
P	1338.289	1349.816	1361.423	1373.111	1384.880	1396.731	1408.663	1420.679

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	W/DA
53.172	29.063	.14660	.09035	.03517	.00673	.71377	.01277	.05540	.00640

T	2620.0	2625.0	2630.0	2635.0	2640.0	2645.0	2650.0	2655.0
H	608.800	610.317	611.835	613.354	614.872	616.392	617.911	619.432
P	1432.777	1444.958	1457.224	1469.574	1482.028	1494.528	1507.134	1519.825
T	2660.0	2665.0	2670.0	2675.0	2680.0	2685.0	2690.0	2695.0
H	620.952	622.473	623.995	625.517	627.040	628.563	630.086	631.610
P	1532.604	1545.469	1558.422	1571.463	1584.593	1597.812	1611.120	1624.519
T	2700.0	2705.0	2710.0	2715.0	2720.0	2725.0	2730.0	2735.0
H	633.135	634.660	636.185	637.711	639.238	640.764	642.292	643.820
P	1638.008	1651.588	1665.259	1679.023	1692.879	1706.828	1720.871	1735.008
T	2740.0	2745.0	2750.0	2755.0	2760.0	2765.0	2770.0	2775.0
H	645.348	646.877	648.406	649.936	651.466	652.997	654.529	656.061
P	1749.239	1763.565	1777.987	1792.506	1807.121	1821.833	1836.643	1851.551
T	2780.0	2785.0	2790.0	2795.0	2800.0	2805.0	2810.0	2815.0
H	657.593	659.126	660.659	662.193	663.727	665.262	666.798	668.334
P	1866.558	1881.664	1896.871	1912.177	1927.583	1943.095	1958.706	1974.421
T	2820.0	2825.0	2830.0	2835.0	2840.0	2845.0	2850.0	2855.0
H	669.870	671.407	672.945	674.403	676.022	677.561	679.100	680.641
P	1990.238	2006.160	2022.186	2038.317	2054.553	2070.896	2087.346	2103.903
T	2860.0	2865.0	2870.0	2875.0	2880.0	2885.0	2890.0	2895.0
H	682.182	683.723	685.265	686.807	688.350	689.894	691.438	692.983
P	2120.568	2137.341	2154.224	2171.217	2188.320	2205.534	2222.860	2240.298
T	2900.0	2905.0	2910.0	2915.0	2920.0	2925.0	2930.0	2935.0
H	694.528	696.074	697.621	699.168	700.716	702.264	703.813	705.362
P	2257.849	2275.514	2293.293	2311.187	2329.196	2347.322	2365.564	2383.924
T	2940.0	2945.0	2950.0	2955.0	0.0	0.0	0.0	0.0
H	706.913	708.463	710.013	711.567	0.000	0.000	0.000	0.000
P	2402.402	2420.999	2439.716	2458.553	0.000	0.000	0.000	0.000

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
53.263	29.013	.16685	.05898	.02820	.00056	.72245	.01293	.04150	.00640

T	460.0	465.0	470.0	475.0	480.0	485.0	490.0	495.0
H	14.552	15.767	16.981	18.195	19.412	20.628	21.844	23.063
P	1.641	1.705	1.771	1.839	1.908	1.980	2.053	2.129
T	500.0	505.0	510.0	515.0	520.0	525.0	530.0	535.0
H	24.277	25.494	26.712	27.930	29.148	30.365	31.585	32.805
P	2.206	2.286	2.367	2.451	2.536	2.624	2.714	2.807
T	540.0	545.0	550.0	555.0	560.0	565.0	570.0	575.0
H	34.025	35.245	36.465	37.686	38.908	40.130	41.352	42.574
P	2.901	2.998	3.097	3.199	3.303	3.410	3.519	3.630
T	580.0	585.0	590.0	595.0	600.0	605.0	610.0	615.0
H	43.798	45.021	46.245	47.470	48.695	49.920	51.146	52.372
P	3.744	3.861	3.980	4.102	4.227	4.354	4.484	4.617
T	620.0	625.0	630.0	635.0	640.0	645.0	650.0	655.0
H	53.599	54.827	56.054	57.283	58.512	59.741	60.971	62.201
P	4.753	4.892	5.034	5.179	5.327	5.478	5.632	5.789
T	660.0	665.0	670.0	675.0	680.0	685.0	690.0	695.0
H	53.432	64.664	65.895	67.128	68.362	69.599	70.830	72.065
P	5.950	6.114	6.281	6.451	6.625	6.802	6.983	7.167
T	700.0	705.0	710.0	715.0	720.0	725.0	730.0	735.0
H	73.300	74.536	75.773	77.010	78.248	79.485	80.725	81.965
P	7.355	7.546	7.742	7.940	8.143	8.350	8.560	8.774
T	740.0	745.0	750.0	755.0	760.0	765.0	770.0	775.0
H	83.205	84.446	85.688	86.930	88.173	89.416	90.660	91.905
P	8.992	9.215	9.441	9.671	9.906	10.145	10.388	10.635
T	780.0	785.0	790.0	795.0	800.0	805.0	810.0	815.0
H	93.150	94.396	95.643	96.891	98.139	99.388	100.637	101.887
P	10.887	11.143	11.404	11.669	11.939	12.213	12.492	12.775

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
53.263	29.013	.16685	.05898	.02820	.00056	.72248	.01293	.04150	[illegible]

T	820.0	825.0	830.0	835.0	840.0	845.0	850.0	855.0
H	103.138	104.390	105.642	106.895	108.149	109.403	110.659	111.915
P	13.065	13.359	13.657	13.961	14.270	14.583	14.902	15.227
T	860.0	865.0	870.0	875.0	880.0	885.0	890.0	895.0
H	113.171	114.429	115.687	116.946	118.205	119.465	120.727	121.989
P	15.556	15.891	16.231	16.577	16.928	17.285	17.647	18.015
T	900.0	905.0	910.0	915.0	920.0	925.0	930.0	935.0
H	123.251	124.515	125.779	127.044	128.309	129.575	130.843	132.111
P	18.390	18.769	19.155	19.547	19.945	20.349	20.759	21.175
T	940.0	945.0	950.0	955.0	960.0	965.0	970.0	975.0
H	133.380	134.650	135.920	137.191	138.463	139.736	141.010	142.284
P	21.598	22.028	22.463	22.906	23.354	23.810	24.272	24.741
T	980.0	985.0	990.0	995.0	1000.0	[illegible]	1010.0	1015.0
H	143.560	144.836	146.113	147.390	148.669	149.949	151.228	152.509
P	25.217	25.700	26.190	26.687	27.192	27.703	28.222	28.749
T	1020.0	1025.0	1030.0	1035.0	1040.0	1045.0	1050.0	1055.0
H	153.791	155.074	156.357	157.642	158.927	160.213	161.500	162.787
P	29.283	29.824	30.373	30.930	31.495	32.067	32.648	33.237
T	1060.0	1065.0	1070.0	1075.0	1080.0	1085.0	1090.0	1095.0
H	164.076	165.365	166.655	167.947	169.238	170.531	171.825	173.119
P	33.834	34.439	35.052	35.674	36.304	36.943	37.591	38.247
T	1100.0	1105.0	1110.0	1115.0	1120.0	1125.0	1130.0	1135.0
H	174.415	175.711	177.008	178.306	179.605	180.905	182.205	183.505
P	38.912	39.586	40.269	40.961	41.662	42.373	43.093	43.822
T	1140.0	1145.0	1150.0	1155.0	1160.0	1165.0	1170.0	1175.0
H	184.809	186.112	187.416	188.721	190.027	191.333	192.641	193.949
P	44.561	45.310	46.058	46.837	47.615	48.403	49.201	50.010

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
53.263	29.013	.16685	.05898	.02926	.00056	.72243	.01293	.04150	.0064[illegible]

T	1180.0	1185.0	1190.0	1195.0	1200.0	1205.0	1210.0	1215.0
H	195.258	196.569	197.880	199.191	200.504	201.818	203.132	204.448
P	50.829	51.658	52.498	53.348	54.209	55.081	55.964	56.853
T	1220.0	1225.0	1230.0	1235.0	1240.0	1245.0	1250.0	1255.0
H	205.764	207.081	208.399	209.718	211.038	212.359	213.680	215.003
P	57.763	58.679	59.607	60.546	61.497	62.459	63.433	64.419
T	1260.0	1265.0	1270.0	1275.0	1280.0	1285.0	1290.0	1295.0
H	216.326	217.650	218.975	220.301	221.628	222.956	224.285	225.614
P	65.417	66.426	67.449	68.483	69.530	70.589	71.661	72.746
T	1300.0	1305.0	1310.0	1315.0	1320.0	1325.0	1330.0	1335.0
H	226.945	228.276	229.608	230.941	232.275	233.610	234.945	236.282
P	73.844	74.955	76.079	77.216	78.366	79.530	80.707	81.899
T	1340.0	1345.0	1350.0	1355.0	1360.0	1365.0	1370.0	1375.0
H	237.619	238.958	240.297	241.637	242.978	244.320	245.662	247.005
P	83.104	84.323	85.556	86.803	88.064	89.340	90.631	91.935
T	1380.0	1385.0	1390.0	1395.0	1400.0	1405.0	1410.0	1415.0
H	248.350	249.696	251.042	252.389	253.737	255.085	256.435	257.785
P	93.256	94.591	95.941	97.306	98.687	100.083	101.495	102.922
T	1420.0	1425.0	1430.0	1435.0	1440.0	1445.0	1450.0	1455.0
H	259.137	260.489	261.843	263.197	264.551	265.907	267.264	268.621
P	104.365	105.824	107.300	108.792	110.300	111.824	113.365	114.924
T	1460.0	1465.0	1470.0	1475.0	1480.0	1485.0	1490.0	1495.0
H	269.979	271.338	272.698	274.059	275.421	276.763	278.147	279.511
P	116.499	118.091	119.700	121.327	122.971	124.633	126.313	128.011
T	1500.0	1505.0	1510.0	1515.0	1520.0	1525.0	1530.0	1535.0
H	280.876	282.242	283.609	284.976	286.345	287.714	289.084	290.455
P	129.727	131.461	133.213	134.984	136.774	138.583	140.410	142.257

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	H/DA
53.263	29.013	.16685	.05893	.0282[illegible]	.00056	.72245	.01293	.0415[illegible]	.006[illegible]

T	1540.0	1545.0	1550.0	1555.0	1560.0	1565.0	1570.0	1575.0
H	291.827	293.199	294.573	295.947	297.322	298.698	300.075	301.452
P	144.123	146.009	147.[illegible]1[illegible]	149.839	151.783	153.748	155.734	157.739
T	1580.0	1585.0	1590.0	1595.0	1600.0	1605.0	1610.0	1615.0
H	302.831	304.210	305.590	306.971	308.352	309.735	311.118	312.502
P	159.765	161.812	163.880	165.968	168.078	170.210	172.363	174.537
T	1620.0	1625.0	1630.0	1635.0	1640.0	1645.0	1650.0	1655.0
H	313.887	315.273	316.659	318.046	319.434	320.823	322.213	323.603
P	175.733	178.952	181.193	183.456	185.741	188.049	190.381	152.735
T	1660.0	1665.0	1670.0	1675.0	1680.0	1685.0	1690.0	1695.0
H	324.994	326.386	327.779	329.173	330.567	331.962	333.358	334.754
P	195.112	197.513	199.938	202.366	204.858	207.354	209.875	212.420
T	1700.0	1705.0	1710.0	1715.0	1720.0	1725.0	1730.0	1735.0
H	336.152	337.550	338.949	340.349	341.749	343.150	344.552	345.955
P	214.989	217.564	220.203	222.848	225.518	228.213	230.935	233.682
T	1740.0	1745.0	1750.0	1755.0	1760.0	1765.0	1770.0	1775.0
H	347.358	348.762	350.157	351.573	352.980	354.387	355.795	357.203
P	236.455	239.255	242.081	244.934	247.814	250.721	253.655	256.617
T	1780.0	1785.0	1790.0	1795.0	1800.0	1805.0	1810.0	1815.0
H	358.613	360.023	361.434	362.845	364.257	365.670	367.084	368.498
P	259.606	262.623	265.669	268.742	271.844	274.974	278.134	261.322
T	1820.0	1825.0	1830.0	1835.0	1840.0	1845.0	1850.0	1855.0
H	369.914	371.329	372.745	374.163	375.581	377.000	378.419	379.839
P	284.540	287.787	291.064	294.371	297.707	301.075	304.472	307.900
T	1860.0	1865.0	1870.0	1875.0	1880.0	1885.0	1890.0	1895.0
H	381.260	382.681	384.103	385.526	386.949	388.374	389.798	391.224
P	311.359	314.850	318.371	321.924	325.509	329.126	332.775	336.455

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	M/DA
53.263	29.013	.16685	.06898	.02820	.00056	.72249	.01293	.04150	.00640

T	1900.0	1905.0	1910.0	1915.0	1920.0	1925.0	1930.0	1935.0
H	392.650	394.077	395.504	396.932	398.361	399.791	401.221	402.651
P	340.171	343.917	347.697	351.511	355.357	359.238	363.152	367.101
T	1940.0	1945.0	1950.0	1955.0	1960.0	1965.0	1970.0	1975.0
H	404.083	405.515	406.947	408.361	409.815	411.249	412.685	414.123
P	371.083	375.101	379.153	383.241	387.364	391.522	395.716	399.945
T	1980.0	1985.0	1990.0	1995.0	2000.0	2005.0	2010.0	2015.0
H	415.557	416.994	418.432	419.870	421.309	422.749	424.189	425.630
P	404.212	408.515	412.854	417.231	421.644	426.095	430.584	435.113
T	2020.0	2025.0	2030.0	2035.0	2040.0	2045.0	2050.0	2055.0
H	427.071	428.513	429.955	431.399	432.843	434.287	435.732	437.178
P	439.675	444.277	448.919	453.599	458.319	463.078	467.876	472.714
T	2060.0	2065.0	2070.0	2075.0	2080.0	2085.0	2090.0	2095.0
H	438.624	440.071	441.519	442.966	444.415	445.864	447.314	448.764
P	477.593	482.511	487.471	492.471	497.512	502.594	507.719	512.885
T	2100.0	2105.0	2110.0	2115.0	2120.0	2125.0	2130.0	2135.0
H	450.215	451.666	453.118	454.571	456.024	457.477	458.931	460.385
P	518.093	523.343	528.636	533.972	539.351	544.774	550.240	555.750
T	2140.0	2145.0	2150.0	2155.0	2160.0	2165.0	2170.0	2175.0
H	461.841	463.297	464.754	466.211	467.668	469.125	470.585	472.044
P	561.305	566.963	572.547	578.236	583.970	589.749	595.574	601.445
T	2180.0	2185.0	2190.0	2195.0	2200.0	2205.0	2210.0	2215.0
H	473.503	474.963	476.424	477.885	479.347	480.809	482.272	483.735
P	607.363	613.328	619.339	625.397	631.503	637.657	643.859	650.109
T	2220.0	2225.0	2230.0	2235.0	2240.0	2245.0	2250.0	2255.0
H	485.199	486.663	488.128	489.593	491.059	492.526	493.993	495.460
P	656.408	662.755	669.152	675.598	682.094	688.640	695.236	701.883

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	M/DA
53.263	29.013	.16685	.06893	.02820	.00056	.72245	.01293	.04150	.00640

T	2260.0	2265.0	2270.0	2275.0	2280.0	2285.0	2290.0	2295.0
H	496.928	498.396	499.865	501.334	502.804	504.274	505.745	507.217
P	708.581	715.330	722.131	728.983	735.888	742.845	749.854	756.917
T	2300.0	2305.0	2310.0	2315.0	2320.0	2325.0	2330.0	2335.0
H	508.688	510.161	511.633	513.107	514.580	516.055	517.529	519.004
P	764.033	771.202	778.425	785.703	793.035	800.422	807.864	815.362
T	2340.0	2345.0	2350.0	2355.0	2360.0	2365.0	2370.0	2375.0
H	520.480	521.956	523.433	524.910	526.387	527.865	529.344	530.823
P	822.915	830.524	838.190	845.912	853.692	861.529	869.423	877.376
T	2380.0	2385.0	2390.0	2395.0	2400.0	2405.0	2410.0	2415.0
H	532.302	533.782	535.262	536.743	538.224	539.706	541.188	542.671
P	885.387	893.456	901.585	909.772	918.020	926.327	934.695	943.123
T	2420.0	2425.0	2430.0	2435.0	2440.0	2445.0	2450.0	2455.0
H	544.154	545.638	547.122	548.606	550.091	551.575	553.062	554.548
P	951.612	960.163	968.775	977.449	986.185	994.984	1003.846	1012.772
T	2460.0	2465.0	2470.0	2475.0	2480.0	2485.0	2490.0	2495.0
H	556.035	557.522	559.010	560.498	561.986	563.475	564.965	566.455
P	1021.761	1030.814	1039.932	1049.114	1058.361	1067.674	1077.053	1086.498
T	2500.0	2505.0	2510.0	2515.0	2520.0	2525.0	2530.0	2535.0
H	567.945	569.436	570.927	572.418	573.910	575.403	576.896	578.389
P	1095.009	1105.587	1115.233	1124.946	1134.727	1144.577	1154.495	1164.462
T	2540.0	2545.0	2550.0	2555.0	2560.0	2565.0	2570.0	2575.0
H	579.883	581.378	582.872	584.368	585.863	587.359	588.856	590.353
P	1174.539	1184.666	1194.863	1205.130	1215.469	1225.879	1236.360	1246.914
T	2580.0	2585.0	2590.0	2595.0	2600.0	2605.0	2610.0	2615.0
H	591.850	593.348	594.847	596.345	597.845	599.344	600.845	602.345
P	1257.541	1268.240	1279.013	1289.869	1300.780	1311.775	1322.845	1333.993

R	MOL.WGT.	PCT.O2	PCT.CO2	PCT.H2O	PCT.SO2	PCT.N2	PCT.A	F/DA	M/DA
53.263	29.013	.16685	.05898	.02820	.00055	.72248	.01293	.04156	.00646
T	2620.0	2625.0	2630.0	2635.0	2640.0	2645.0	2650.0	2655.0	
H	603.846	605.348	606.853	608.352	609.855	611.358	612.862	614.365	
P	1345.212	1356.529	1367.853	1379.333	1390.862	1402.468	1414.152	1425.915	
T	2660.0	2665.0	2670.0	2675.0	2680.0	2685.0	2690.0	2695.0	
H	615.871	617.376	618.882	620.388	621.895	623.402	624.969	626.417	
P	1437.757	1449.678	1461.680	1473.762	1485.924	1498.158	1510.494	1522.901	
T	2700.0	2705.0	2710.0	2715.0	2720.0	2725.0	2730.0	2735.0	
H	627.926	629.435	630.944	632.454	633.964	635.475	636.986	638.495	
P	1535.392	1547.965	1560.522	1573.302	1586.167	1599.097	1612.092	1625.173	
T	2740.0	2745.0	2750.0	2755.0	2760.0	2765.0	2770.0	2775.0	
H	640.010	641.523	643.037	644.550	646.065	647.579	649.095	650.610	
P	1638.340	1651.594	1664.935	1678.364	1691.880	1705.485	1719.180	1732.964	
T	2780.0	2785.0	2790.0	2795.0	2800.0	2805.0	2810.0	2815.0	
H	652.127	653.644	655.161	656.679	658.197	659.716	661.235	662.755	
P	1746.838	1760.803	1774.858	1789.006	1803.245	1817.575	1832.001	1846.520	
T	2820.0	2825.0	2830.0	2835.0	2840.0	2845.0	2850.0	2855.0	
H	664.276	665.797	667.318	668.840	670.363	671.885	673.410	674.934	
P	1861.132	1875.839	1890.542	1905.540	1920.534	1935.625	1950.813	1966.093	
T	2860.0	2865.0	2870.0	2875.0	2880.0	2885.0	2890.0	2895.0	
H	676.459	677.984	679.510	681.036	682.563	684.091	685.619	687.148	
P	1981.483	1996.966	2012.549	2028.231	2044.014	2059.899	2075.885	2091.973	
T	2900.0	2905.0	2910.0	2915.0	2920.0	2925.0	2930.0	2935.0	
H	688.677	690.207	691.739	693.269	694.801	696.333	697.866	699.400	
P	2108.164	2124.459	2140.857	2157.360	2173.969	2190.683	2207.503	2224.431	
T	2940.0	2945.0	2950.0	2955.0	0.0	0.0	0.0	0.0	
H	700.934	702.469	704.005	705.541	0.000	0.000	0.000	0.000	
P	2241.466	2258.610	2275.862	2293.224	0.000	0.000	0.000	0.000	

Appendix A 4.2

DESCRIPTION OF WESTINGHOUSE FLUIDIZED BED LOW-BTU GASIFICATION SUBSYSTEM

A schematic of the Westinghouse Fluidized Bed Gasifiers is shown in Figure A 4.2.1. The major subsystems are described in the following text.

A 4.2.1 Coal Sizing and Drying System

This will consist of a grinding mill, heater, air classifier, blowers, and so on. The coal will be fed by the coal mill feeder to the air-swept coal-grinding mill. Once ground to size in the latter, the coal will be swept out by a flow of gas from the blower through the air classifier,where size classification will be made. This will allow the product-sized coal to be conveyed to a cyclone collector and coal silo, while oversize coal will be returned for further grinding. Most of the product-sized coal will be removed from the air stream by the cyclone collector and discharged via the screw conveyor to the coal silo.

Airborne coal fines that remain entrained in the exhaust gas from the cyclone collector will be recycled through the blower and the grinding mill. A side stream of this basic circuit, large enough to remove the dust and moisture given off by the drying coal, will exit through the dust collector, which will be designed to ensure conformance with environmental codes. The coal fines will be discharged from the bottom of the dust collector to the screw conveyor. The screw conveyor will be driven by a reversible motor which will enable coke, as required, to by-pass the coal silo and be transferred directly to process, as described below.

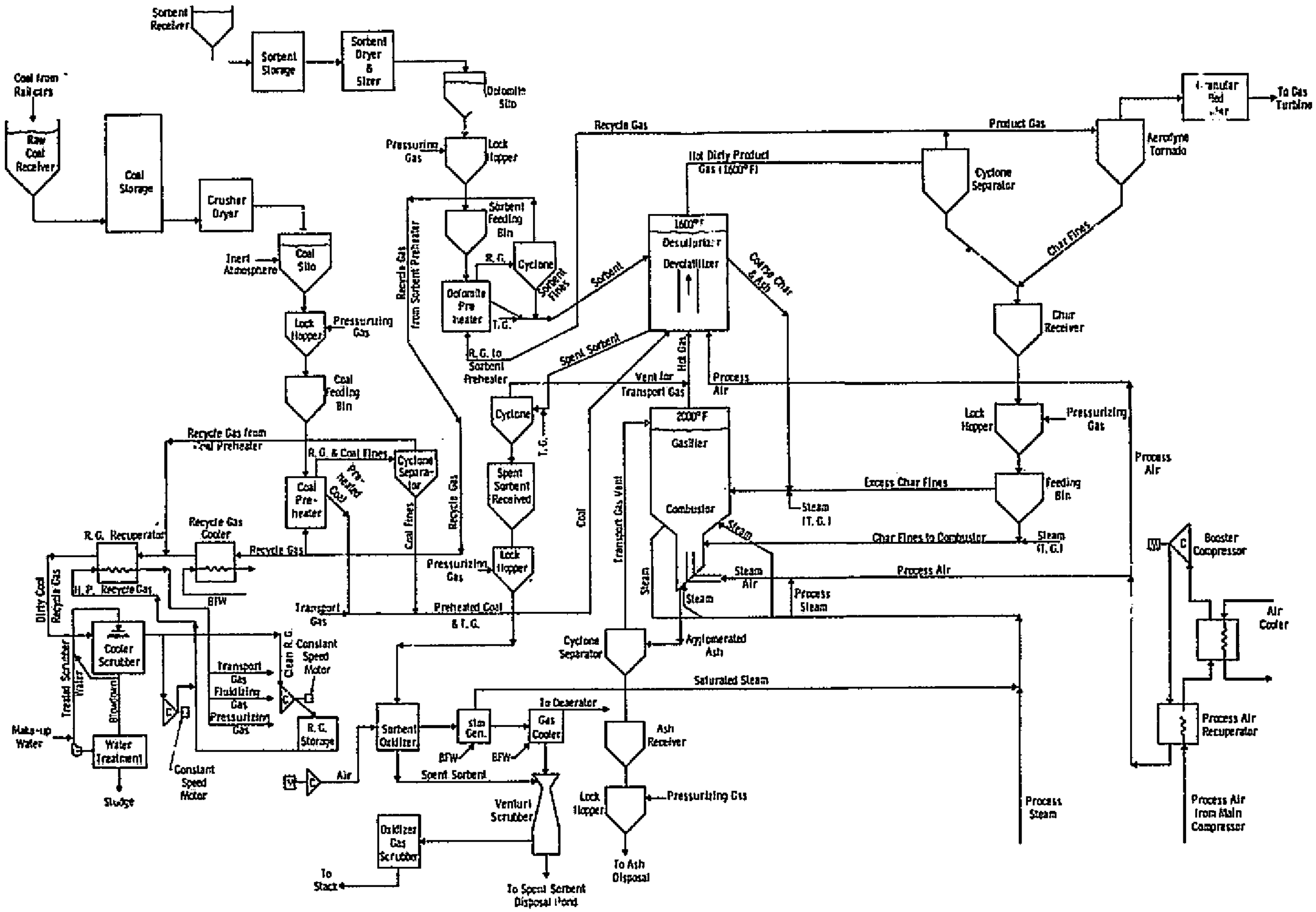

Fig. A 4.2.1—Westinghouse coal gasification subsystem

The necessary heat for drying the coal will be provided by burning lockhopper vent gas supplied by a fuel gas blower, or by No. 2 fuel oil for start-up, supplied by a fuel oil pump with air supplied by a combustion blower in the heater. The products of combustion will provide the necessary inert atmosphere for drying, crushing, and classifying the coal. To further permit the coal-grinding mill to process hazardous coal dust in a controlled, low-oxygen atmosphere, a recycle blower and a recycle line from the dust collector to the heater will be provided to enable a further reduction in oxygen level.

A 4.2.2 Coal Silo

The coal silo [storage capacity about 36 ks (10 hr)] will be made of concrete with a self-supporting skirt and with the bottom of the storage compartment a 60-degree steel cone ending about 9.14 m (30 ft) above grade.

The coal silo will be maintained under a blanket of lockhopper gas. Coal from the storage compartment will discharge to a scalping screen. Any agglomerated coal that is too large to pass through the scalping screen will discharge via rotary valve to a portable bin. Any coal collected in the latter will be dumped, as required, into the existing coal hopper for retreatment, grinding, and so on. Coal of product size passing through the scalping screen will discharge by gravity to the pneumatic transfer vessels of the coal transfer system, which will be located within the silo's supporting skirt under the storage compartment.

A 4.2.3 Coal Transfer System

This will consist of two pneumatic transfer vessels equipped with piping, flanges, valves, and controls. They will be mounted on weigh cells with the capability to control and vary the rate of discharge, which will be essentially continuous, to process. The system controls will be essentially continuous, to process. The system controls will include printout of product batch weights and continuous digital indication of material movement rate. Recycle gas will be provided as necessary for operation of this system. The gas vented from pneumatic transfer vessels will discharge via a vent line to the coal-bag filter, which will be located on top of the coal silo. The coal bag filter, equipped with a rotary valve, will be sized to handle gas venting from the coal pneumatic transfer vessels as well as from the dolomite pneumatic transfer vessels prior to discharging to the lockhopper gas storage tank.

A 4.2.4 Coke-Handling Facilities

When there is a temporary need for nonvolatile carbon for the coal gasification process, such as at start-up, it is proposed to bring in coke [bulk density 800.9 kg/m^3 (50 lb/ft^3)] using the same existing belt conveyor, and treat it using the same tramp iron removal, dewatering, sizing, and drying facilities as described for coal, except that it will be necessary to by-pass the coal silo in order to transfer coke to process. Similarly, as proposed for coal above, after treatment in the sizing and drying facility, the coke from the cyclone collector and the dust collector will be discharged to the screw conveyor. The conveyor, however, will operate in the opposite direction to its normal coal direction. This will enable the sized coke to go directly via the scalping screen to the transfer vessels and be transferred pneumatically to process via the same pneumatic transfer system as described for coal.

A 4.2.5 Dolomite Sizing and Drying System

This will include the classifying screen, the grinding mill, the rotary dryer, the combustion air blower, the cyclone dust collector, the exhaust fan and the stack.

Dolomite too large to pass through the classifying screen (i.e., not to product size) will be ground by the grinding mill and returned back to the classifying screen by the classifier bucket elevator. The burner of the rotary dryer will burn recycle gas, supplied by fuel gas blower, or No. 2 fuel oil, supplied by the fuel oil pump for start-up. The dolomite dryer will process wet dolomite to a moisture content of between 0.002 and 0.010 kg water/kg stone. The exit temperature of the dolomite and vent discharge will be about 422°K.

The exhaust fan will be located in the system so gases and fines will pass through the cyclone dust collector where fines will be removed and be discharged through the rotary valve. The dolomite from the dryer and the cyclone dust collector will discharge to the dolomite rotary feeder, which will be part of the dolomite transfer system.

A 4.2.6 Dolomite Transfer System A

This will consist of a rotary feeder and a rotary blower which will circulate gas from and to the dolomite silo. It will be protected against inlet temperature of the gas by a precooling using water as the cooling medium. The rotary feeder will discharge dolomite at a controlled rate, into a stream of lockhopper gas provided by the rotary blower and will be discharged into the dolomite silo.

A 4.2.7 Dolomite Silo

The dolomite silo (storage capacity about 36 ks (10 hr) will be made of concrete with a self-supporting skirt and with the bottom of the storage compartment a 60-degree steel cone ending about 9.14 m (30 ft) above grade. The dolomite silo will be maintained under a blanket of lockhopper gas. Dolomite from the storage compartment will discharge to a scalping screen.

Any agglomerated dolomite too large to pass through the latter will discharge via a rotary valve to a portable bin. Any dolomite collected in the latter will be dumped, as required, into the above ground hopper for retreatment, grinding, etc. Dolomite of product size passing through the scalping screen will discharge by gravity to the pneumatic transfer vessels of Dolomite Transfer System B, which will be located within the silo's supporting skirt under the storage compartment.

A 4.2.8 Dolomite Transfer System B

This will consist of two pneumatic transfer vessels equipped with various controls and mounted on weigh cells with the capability to control and vary the rate of discharge, which will be essentially continuous to process. The system controls will include batch printout of product batch weights, and continuous digital indication of material movement rate.

Recycle gas at up to 2.068 MPa (300 psig) pressure will be provided as necessary for operation of the system.

The gas vented from the pneumatic transfer vessels will discharge to lockhopper gas storage via the coal bag filter located on top of the coal silo.

A 4.2.9 Solids Feed and Preheat

Sized, dried, coal and dolomite will be introduced into their respective feed heaters by means of pressurized pneumatic systems using recycle gas. These systems will be capable of essentially continuous flow, turndown from 110 to 30% of rated flow, and will also provide an inventory record of coal and dolomite used.

Coal entering the fluidized bed in the coal feed heater will be heated to about 533°K (500°F). It is believed that most of the chlorine in the coal will be released into the recycle gas stream. Dolomite entering the dolomite feed heater will be heated to about 941°K (1235°F).

From the feed heaters coal and dolomite will be individually pneumatically conveyed into the devolatilizer/desulfurizer fluidized bed in the upper portion of the vessel. Since the operating pressure of the preheaters is less than that of the devolatilizer/desulfurizer, hydrostatic-type lift legs of solids-gas are established to force the solids into the conveying gas streams. In the case of the coal, which has a lower density than the dolomite, a second lift leg and a coal lift leg surge drum are required.

A 4.2.10 Devolatilizer

The coal and recycle gas entering the devolatilizer/desulfurizer/gasifier will be directed into the center of a central draft tube which, together with output gas of the lower gasification section, establishes a rapidly circulating, fluidized bed of 1144°K (1600°F) gas, char, and dolomite. With a turnover rate of 50 to 100 times the entering coal rate, the coal will be quickly diluted and dispersed. The coal will be heated, devolatilized, and converted to char.

As the coal is heated, its surface will pass through a sticky phase. It is theorized that large agglomerates will not form in the highly diluted condition since the sticky particles will tend to be separated from each other.

A 4.2.11 Desulfurization

The volatile sulfur compounds which are released upon heating the coal to 1144°K (1600°F) will combine with the calcium carbonate portion of the dolomite, releasing carbon dioxide.

A 4.2.12 Fines Removal

The hot product gas at close to 1127°K (1570°F) from the devolatilizer/desulfurizer passes through the devolatilizer cyclone, where most of the char fines are removed. The gas then goes to an Aerodyne gas cleaner, where particles down to about 6 μm in size are removed. All of these devices operate at the hot gas temperature.

A 4.2.13 Dolomite Removal and Cooling

The fluidized bed in the devolatilizer/desulfurizer zone will actually be separated into two distinct levels: a lower bed which consists principally of dolomite, circulating through and around a central draft tube, and an upper bed consisting principally of char. Dolomite will be removed and cooled in a separate vessel by a countercurrent stream of cool recycle gas. Discharge letdown is by means of a rate-controlled rotary valve into pressurized lockhoppers.

A 4.2.14 Combustion and Ash Agglomeration

The lower portion of the main reactor vessel devolatilizer/desulfurizer/gasifier is a bed of char and ash which is fluidized by a flow of air, steam, and hot combination gases. In the bottom section of this bed steam, char fines, and air are brought together in an agglomerating combustor zone where the fines burn at about 1478°K (2200°F) producing carbon dioxide. In this very hot zone the ash residue reaches its sticky point and tends to agglomerate. As the ash particles grow in size they are removed from the gasifier in contact with a stream of cooling steam. A rate-controlled rotary valve discharges the ash into one of a pair of pressurized lockhopper-transfer tanks.

A 4.2.15 Gasification

Char flows from the devolatilizer/desulfurizer portion of vessel down to the gasifier section by gravity, under level control.

The main portion of the fluid bed of char in the gasifier is maintained about 1366°K (2000°F). At this temperature steam reacts with the carbon in the char to product carbon monoxide and hydrogen. Carbon dioxide from the combustor/agglomerator zone reacts with the carbon to form carbon monoxide. As the ash is formed it tends to be agglomerated in the agglomerating combustor in the lower zone.

A 4.2.16 Fines Recirculation

The amount of char fines removed from the hot product gas stream by the devolatilizer cyclone and the aerodyne gas cleaner is greater than the weight of carbon required in the agglomerating combustor. Due to the relatively low density of the char fines and the pressure difference between the gasifier and the devolatilizer/desulfurizer, a total of three lift legs are needed to generate the pressure required to recycle the fines to the gasifier.

There will be two streams of char fines to the gasifier, one corresponding to the amount needed to maintain the combustion in the agglomerating zone, the balance will go into the gasification zone.

A 4.2.17 Recycle Gas System

A portion of the product gas stream is cooled, scrubbed, and compressed to serve various heat exchange and fluid transport functions in the unit.

The first stage of cooling is accomplished in the dolomite feed heater where the dolomite is heated 941°K (1235°F). The gas mixes with cooler recycle transport gas and it drops in temperature from 1113 to 890°K (1543 to 1142°F). One portion of gas exiting from the dolomite feed heater is tempered with cooler recycle gas and continues to the coal feed heater. The current projected top temperature for this stream is 811°K (1000°F). In the coal feed heater the incoming coal is heated to 533°K (500°F) the recycle gas mixes with cooler transport recycle gas and leaves the coal heater at 483°K (410°F).

It has been assumed that the stream leaving the coal feed heater will contain some chlorine picked up in heating the coal, which we anticipate will be removed in the scrubbing system. The portion of gas leaving the dolomite feed heater which is not used for coal heating passes through the recycle gas cooler steam generator, where it generates process steam and is cooled to 589°K (600°F).

The various streams of recycle gas going to the scrubber and compressor are gathered together before entering the recycle gas recuperator, where they exchange heat with the stream from the recycle gas compressor.

The final cooling of the recycle gas, prior to scrubbing in the recycle gas jet scrubber, is done in the recycle gas-makeup water heater. The recycle gas jet scrubber is designed to remove any particles that have been carried with the gas. The recycle gas scrubber will further clean and cool the gas stream.

A 4.2.18 Lockhopper Gas

During the cyclic operation of the lockhopper-transfer tank unit, recycle gas must be released to essentially atmospheric pressure. This gas will be used to provide heat for the coal and dolomite drying operation.

A 4.2.19 Venting Start-up and Shutdown Gas

During start-up of the gasification module, the gas turbine will be operating on liquid fuel until the gas production rate reaches about 40% of design flow. At this point it is estimated that the various gas cleanup devices will have achieved a satisfactory operating condition, and the gas may be admitted to the gas turbine combustor. The gas produced during this period will be cooled to about 811°K (1000°F) to allow reasonable handling and sent to a thermal oxidizer where it will be consumed.

On normal shutdowns the reverse procedure will be followed; in other words, gas will go to the turbine until the flow rate falls to about 40% of design flow. At that point the gas turbine will be switched from gas to liquid fuel and the gas output of the plant will be diverted to the thermal oxidizer.

A 4.2.20 Sulfided Dolomite Disposal

The sulfided dolomite disposal module will consist of a dolomite oxidizer, air compressor, waste heat recovery exchangers, venturi contactor, and gas scrubber. Sulfided dolomite will be fed into the spent dolomite lockhoppers. The oxidizer will contain a fluidized bed of dolomite suppended in a stream of compressed air supplied by the oxidizer air blower. The bed will operate at 1072°K (1470°F). A start-up heater will supply heated air to initiate the reaction and to maintain temperature during low sulfur load conditions.

Hot product gases will pass through two stages of heat recovery, the dolomite oxidizer steam generator, and the dolomite oxidizer gas cooler to produce steam and to heat boiler makeup water for use in the process. Cooled gas and oxidized dolomite will be contacted with water in the Venturi scrubber. Gases and steam from the Venturi will be scrubbed and cooled in the oxidizer gas scrubber before being vented to the atmosphere via the stack.

A slurry of spent dolomite in water will be pumped to a disposal pond by the scrubber disposal pump.

A 4.2.21 Waste Disposal - Ash Disposal

In general, ash from the coal gasification process will be conveyed pneumatically to an elevated storage hopper, from which the ash will be discharged by gravity, as required, into a railway gondola and transported to a dump. The state highway department has been using the ash from the existing boiler plant on slippery roads during winter.

The facilities involved will include safety provisions, as required by the Occupational Safety and Health Act regulations, and will conform with environmental codes, where applicable. Ash [bulk density 800.93 kg/m^3 (50 lb/ft^3)] will be conveyed pneumatically and stored in the ash storage hopper, which will be located over the pipeway of the gasification plant. The hopper will be made of steel, 3.048 m (10 ft) in diameter by 9.75 m (32 ft) high, with an eccentric cone bottom to permit dumping of ashes through a pipe chute into a railway gondola running on a spur track alongside the pipeway. The pipe chute will have a Chiksan joint to permit raising or lowering it by means of a hoist.

A 4.2.22 Other Support Facilities

Off-site support facilities included in this task definition include a boiler feedwater deaerator, thermal oxidizer, lockhopper gas storage tank, and air booster compressor. The boiler feedwater deaerator will be sized to handle all of the makeup water required to satisfy the requirements of the process boiler. The thermal oxidizer will be sized to handle a flow of gas equal to 40% of the plant output. On normal start-up and shutdown procedure the product gas will be sent to the gas turbine only when its volumetric flow rate is greater than about 40% of plant design output. At flows lower than 40%, where the gas-cleaning cyclones will be operating at reduced efficiency, the product gas will be sent to the thermal oxidizer. Under emergency shutdown conditions, when it may be necessary to vent some portion of the product gas, the thermal oxidizer will also be available.

A lockhopper gas storage tank will be provided to assist in the salvage of lockhopper vent gas which would otherwise be wasted. This tank will have a capacity of 1.8 ks (30 min) average production of this gas. This gas will be used to augment the recycle gas for the coal and dolomite drying operations. Lockhopper gas will be cooled in the lock-hopper gas cooler prior to storage.

An air booster compressor will be provided, complete with condensing steam turbine drive, to raise the air pressure at the discharge of the gas turbine air compressor. That portion of the turbine air supply required for gasification (less than 20% of the air available) will be raised in pressure to allow for a pressure drop through the gasification system and that required for the combustor.

Appendix A 4.3

CALCULATIONS OF PARTICULATE REMOVAL EQUIPMENT PERFORMANCE FOR FLUIDIZED BED COMBUSTION APPLICATIONS

The particulate removal equipment for fluidized bed combustion applications consists of a cyclone (Ducon) separator and a tornado (Aerodyne) separator in series and a low-efficiency electrostatic precipitator in the flue gas. The performance calculations of each component are contained in this appendix.

Table A 4.3.1 C_1, C_2 - Ducon Cyclone Calculations[a]

D_p (μ)	Wt in gr/scf	$(1 - \eta^{mid})$	Wt out (gr/scf)	%	Σ %
(0-1)	(0.02) L_i	0.865	0.0173 L_i	46.7	46.7
(1-2)	(0.01) L_i	0.645	0.00645 L_i	17.4	64.1
(2-3)	(0.01) L_i	0.465	0.00465 L_i	12.6	76.7
(3-4)	(0.01) L_i	0.300	0.00300 L_i	8.1	84.8
(4-7)	(0.024) L_i	0.160	0.00384 L_i	10.4	95.2
(7-10)	(0.021) L_i	0.055	0.00116 L_i	3.1	98.3
(10-20)	(0.065) L_i	0.010	0.00065 L_i	1.7	100.0
(20-50)	(0.130) L_i				
> 50	(0.71) L_i				
	Total L_i		0.03705 L_i	100.0	

[a] η = 96.3%

Inlet loading (i) = L_1 = 12.38 gr/scf - outlet loading 0.458

L_2 = 9.85 gr/scf - outlet loading 0.365.

Curve 680108-A

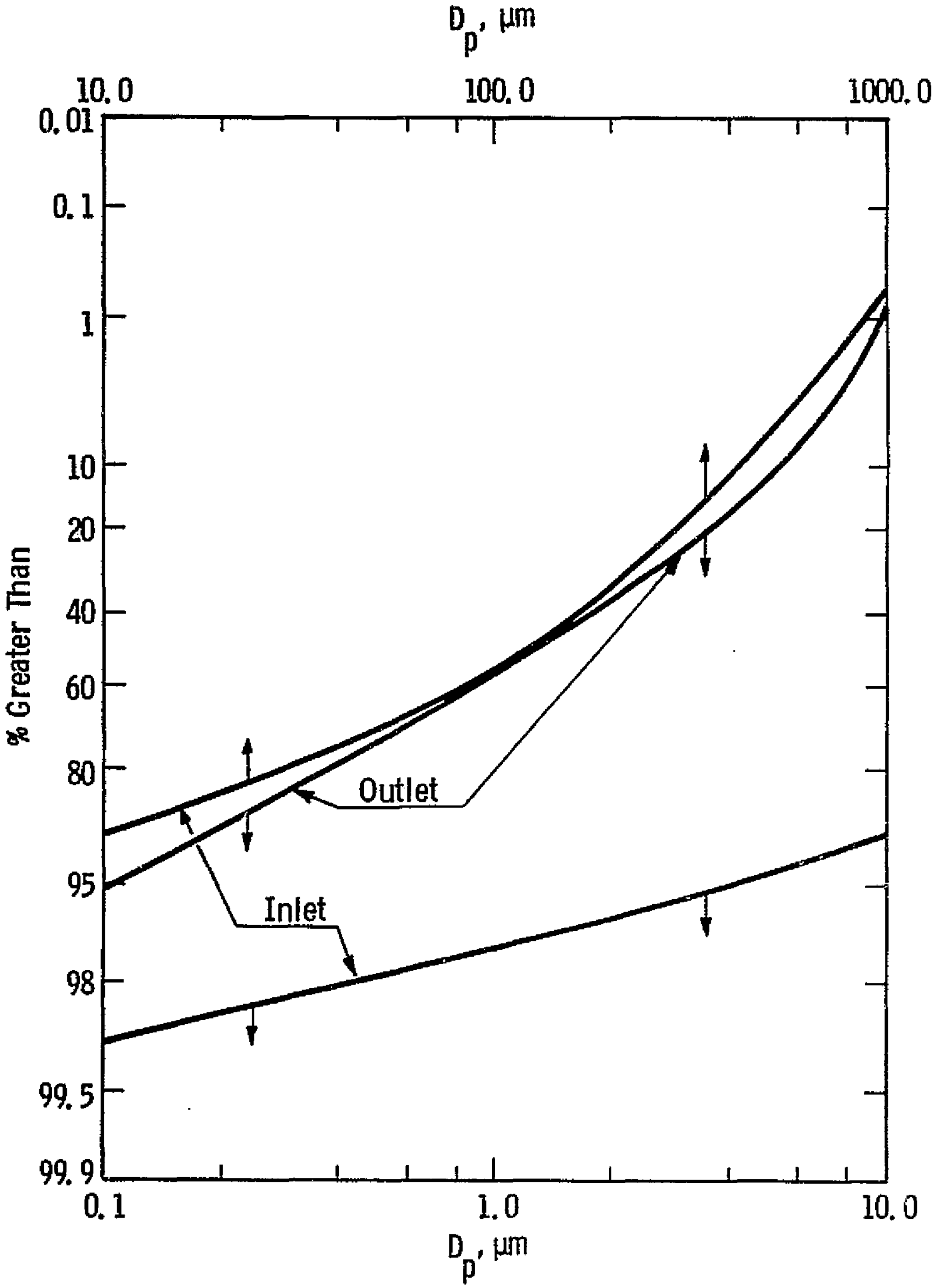

Fig. A 4.3.1—Inlet and outlet size distributions of primary cyclones

Table A 4.3.2 C_2 - Aerodyne Calculations

$D_p(\mu)$	Wt in gr/scf	$(1-\eta)^a$	Wt out (gr/scf)	%	Σ %
(0-0.2)	(0.11)(0.365)= 0.0402	0.85	0.0341	27.3	27.3
(0.2-0.5)	(0.26-0.11)(0.365)= 0.0547	0.74	0.0405	32.5	59.8
(0.5-1)	(0.42-0.26)(0.365)= 0.0584	0.47	0.0274	22.0	81.8
(1-2)	(0.64-0.42)(0.365)= 0.0803	0.21	0.0169	13.5	95.3
(2-3)	(0.77-0.64)(0.365)= 0.0474	0.08	0.0038	3.0	98.3
(3-5)	(0.895-0.77)(0.365)= 0.0456	0.04	0.0018	1.44	99.74
(5-7)	(0.95-0.895)(0.365)= 0.0201	0.01	0.0002	0.16	99.9
(7-10)	(0.982-0.95)(0.365)= 0.0117	0.005	0.0006		
TOTAL	0.365		0.125 gr/scf		

[a] η = 65.8%

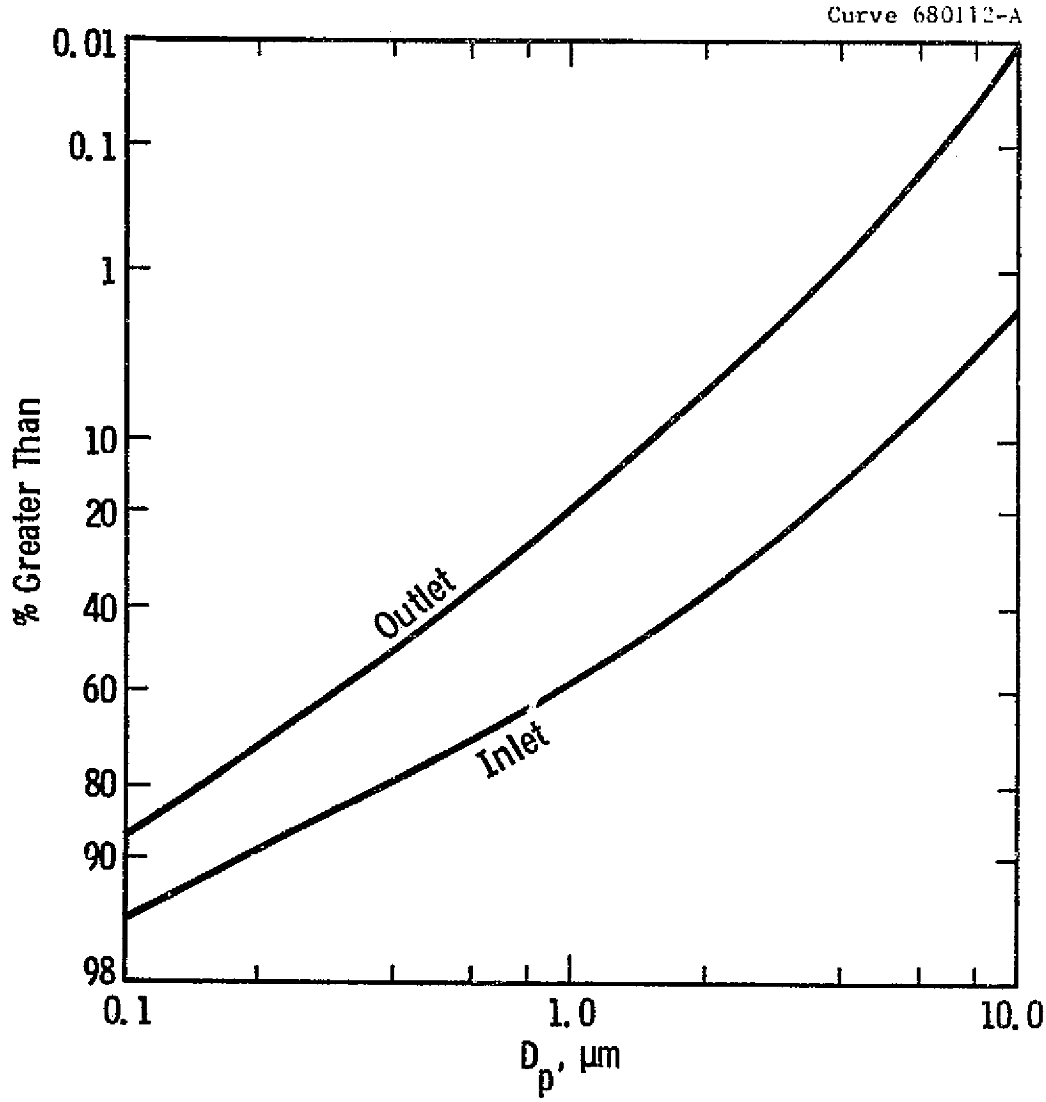

Fig. A 4.3.2—Inlet and outlet size distributions of Aerodyne unit

Table 4.3.3 - High Efficiency ESP Calculations

$D_p (\mu)$	Wt in (gr/scf)	$(1-\eta)^a$	Wt out (gr/scf)	%	Σ %
(0-0.1)	(0.125-0)(0.125)= 0.0156	0.13	0.00203	23.2	23.2
(0.1-0.5)	(0.58-0.125)(0.125)= 0.0569	0.08	0.00455	51.9	75.1
(0.5-1)	(0.81-0.58)(0.125)= 0.0287	0.06	0.00173	19.7	94.8
(1-2)	(0.945-0.81)(0.125)= 0.0169	0.025	0.00042	4.8	99.6
(2-5)	(0.997-0.945)(0.125)= 0.0065	0.005	0.00003	0.4	100.0
(5-10)	(0.9999-0.997)(0.125)= 0.00036	0.001	- -		
TOTAL	0.125		0.00876		

[a] η = 93%

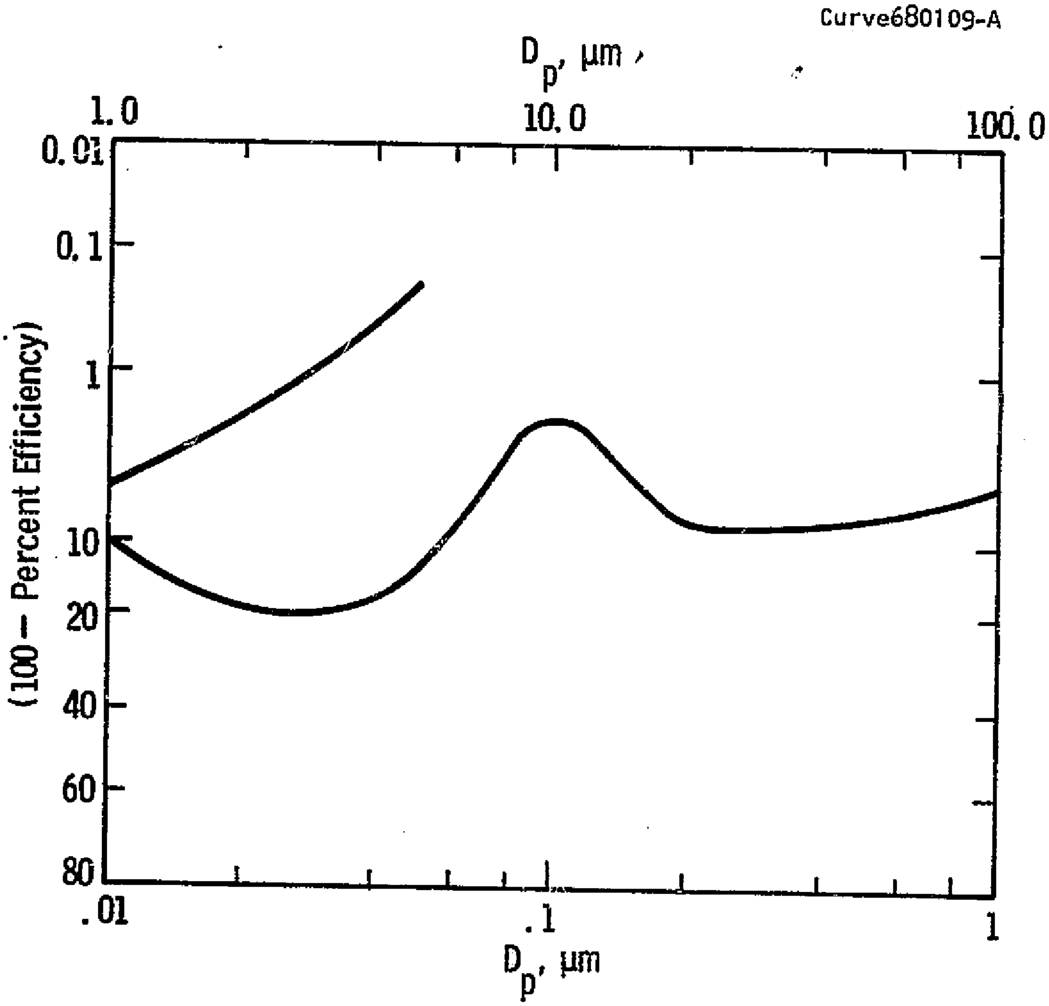

Fig. A 4.3.3—Grade efficiency curve for high-efficiency electrostatic precipitator

Table A 4.3.4 - Low Efficiency ESP

D_p (μ)	Wt in (gr/scf)	$(1-\eta^{mid})^a$	Wt out (gr/scf)	%	Σ %
0-0.1	0.0156	(1-0.19) = 0.81	0.0126	0.2206	22.06
0.1-0.5	0.0569	(1-0.48) = 0.52	0.0296	0.5182	73.88
0.5-1	0.0287	(1-0.65) = 0.35	0.0100	0.1751	91.39
1-2	0.0169	(1-0.76) = 0.24	0.0041	0.0718	98.57
2-5	0.0065	(1-0.87) = 0.13	0.0008	0.0140	99.97
5-10	0.00036	(1-0.83) = 0.07	0.000025	0.0003	100.00
	0.125		0.0571		

[a] η = 54.28%

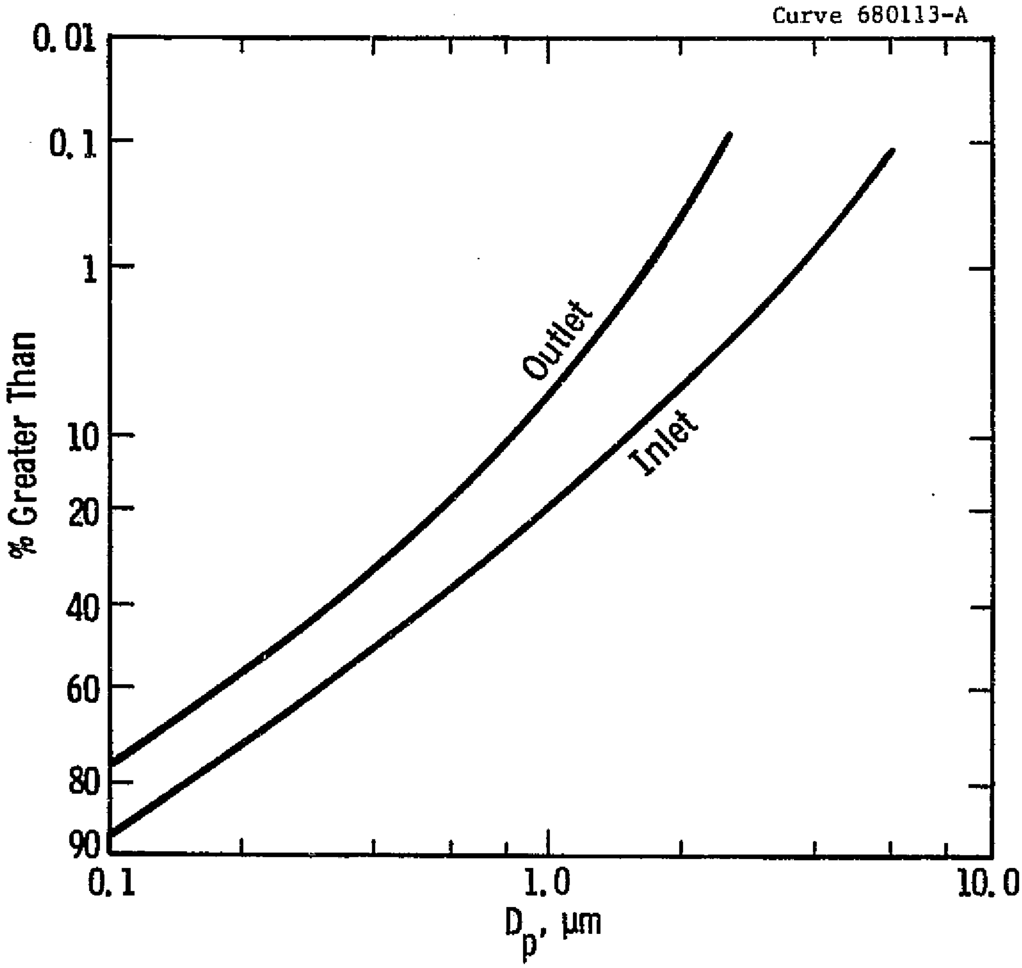

Fig. A 4.3.4 – Inlet and outlet size distributions of precipitator

Appendix A 4.4

PARTICULATE REMOVAL EQUIPMENT PERFORMANCE FOR FLUIDIZED BED GASIFICATION APPLICATIONS

The particulate removal equipment for fluidized bed gasification applications consists of a cyclone (Ducon) separator, a tornado (Aerodyne) separator, and a high-efficiency granular bed filter in series. The performance calculations of each component are contained in this appendix.

Table A 4.4.1 - Ducon First-Stage Cyclone (1600°F and 75 lb/ft^3)

D_p(μ)	Wt in	$(1 - \eta)^a$	Wt out	%	Σ %
(0 - 1)	(0.02) (27.8)	0.91	0.506	0.378	0.378
(1 - 2)	(0.01) (27.3)	0.74	0.205	0.153	0.531
(2 - 3)	(0.01) (27.8)	0.60	0.167	0.125	0.656
(3 - 4)	(0.01) (27.3)	0.47	0.131	0.098	0.754
(4 - 7)	(0.024) (27.3)	0.29	0.193	0.144	0.898
(7 - 10)	(0.021) (27.8)	0.14	0.082	0.062	0.960
(10 - 20)	(0.065) (27.8)	0.02	0.036	0.027	0.987
(20 - 50)	(0.130) (27.8)	0.005	0.018	0.013	1.000
TOTAL	27.8		1.33		

$^a\eta = 95.2\%$

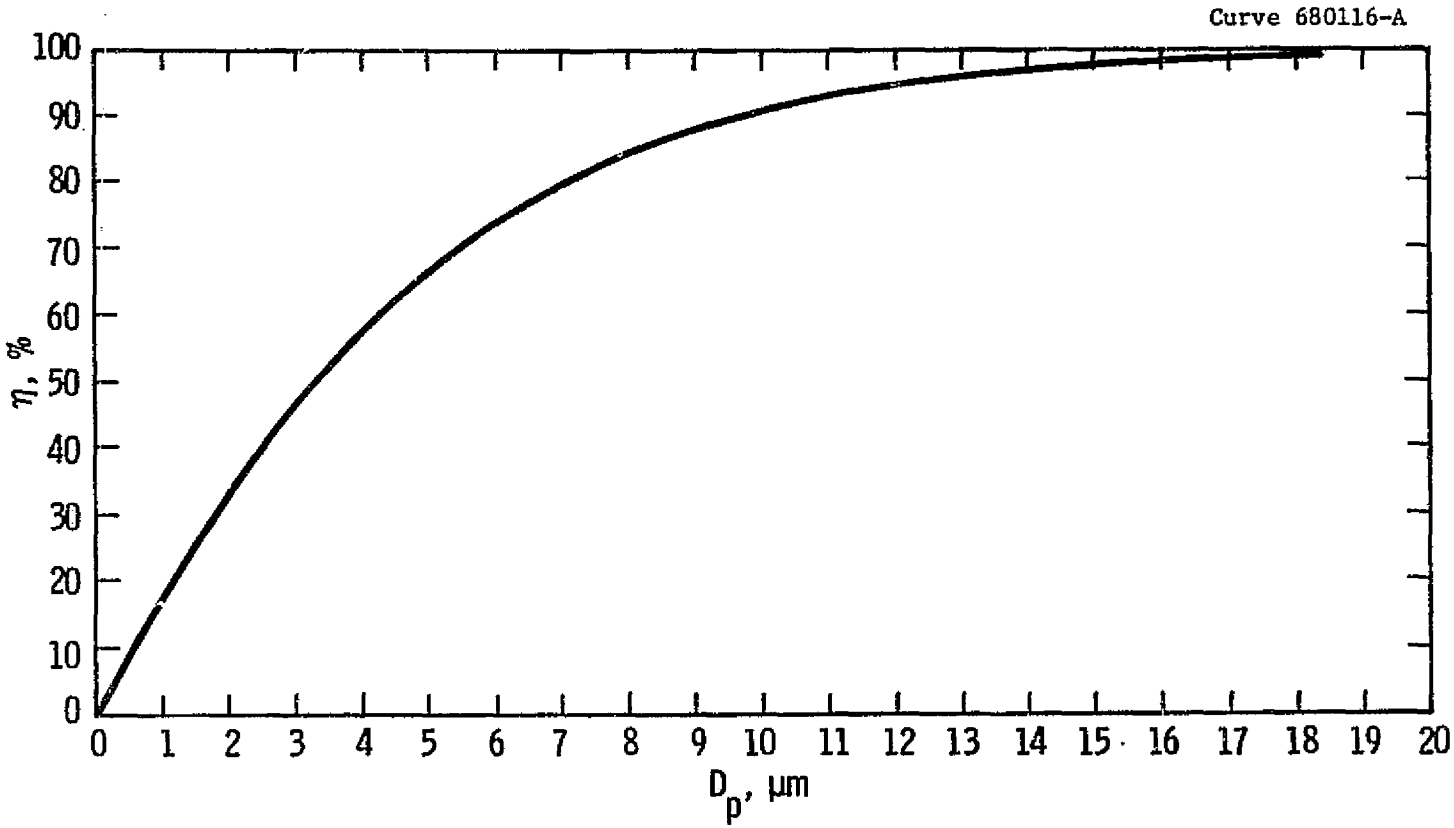

Fig. A 4.4.1—Grade efficiency curves of Ducon cyclone (1600°F and ρ_p = 75 lb/ft^3)

Table A 4.4.2 - Aerodyne Unit (1600°F and 75 lb/ft^3)

D_p(μ)	Wt in (gr/scf)	$(1 - \eta)^a$	Wt out (gr/scf)	%	Σ %
(0 - 0.2)	(0.165 - 0) (1.33)	0.97	0.215	0.415	0.415
(0.2 - 0.5)	(0.26 - 0.165)(1.33)	0.83	0.105	0.203	0.618
(0.5 - 1)	(0.37 - 0.26) (1.33)	0.60	0.088	0.169	0.787
(1 - 2)	(0.53 - 0.37) (1.33)	0.34	0.072	0.139	0.926
(2 - 3)	(0.65 - 0.53) (1.33)	0.16	0.026	0.050	0.976
(3 - 5)	(0.81 - 0.65) (1.33)	0.045	0.010	0.020	0.996
(5 - 7)	(0.89 - 0.81) (1.33)	0.010	0.002	0.004	1.000
(7 - 10)	(0.96 - 0.89) (1.33)	0.005	---		
(10 - 20)	(0.987 - 0.96) (1.33)	---	---		
TOTAL	1.33		0.518		

$^a\eta$ = 61.3%

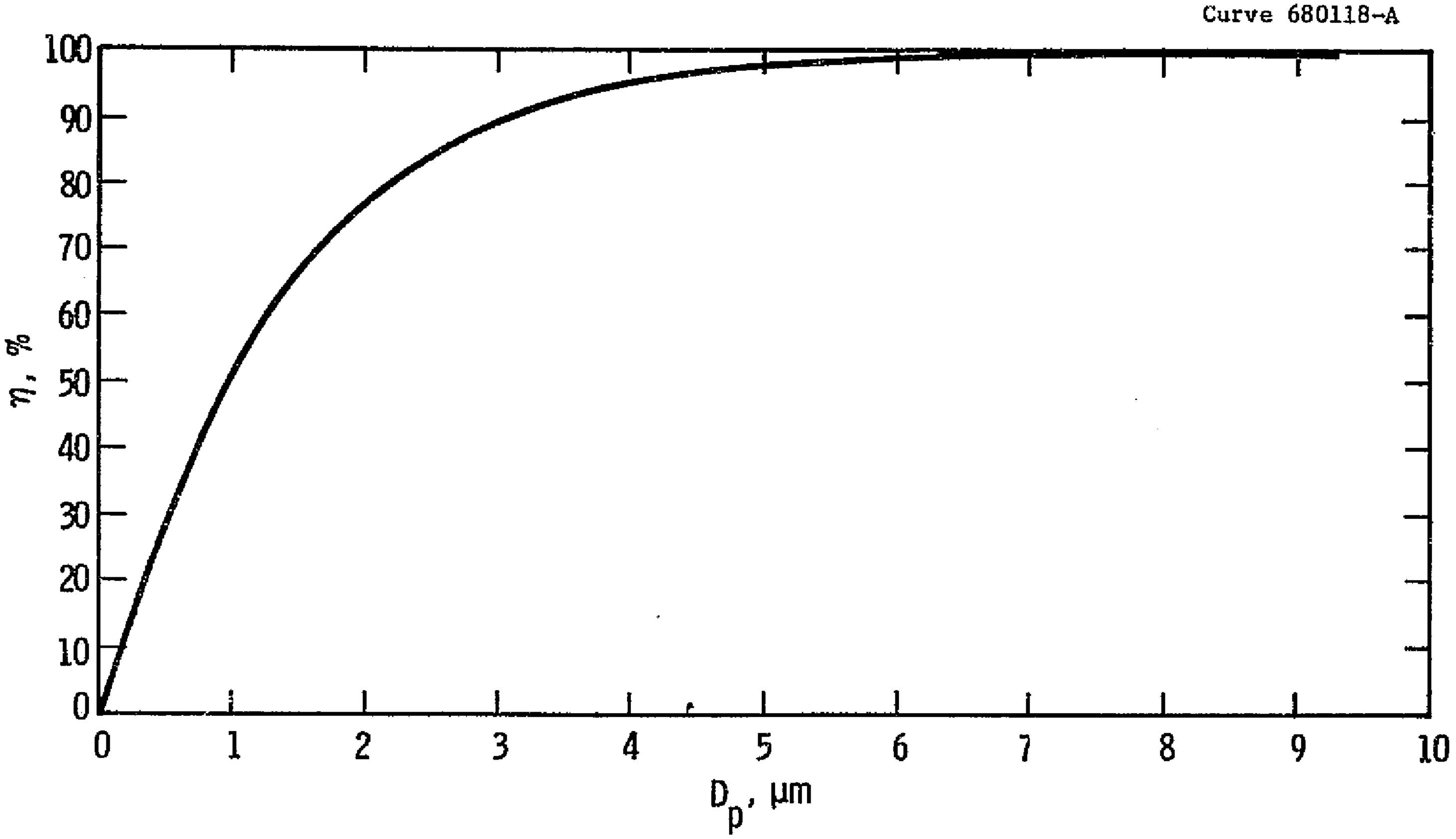

Fig. A 4.4.2—Grade efficiency curve of Aerodyne (1600°F and 75 lb/ft^3)

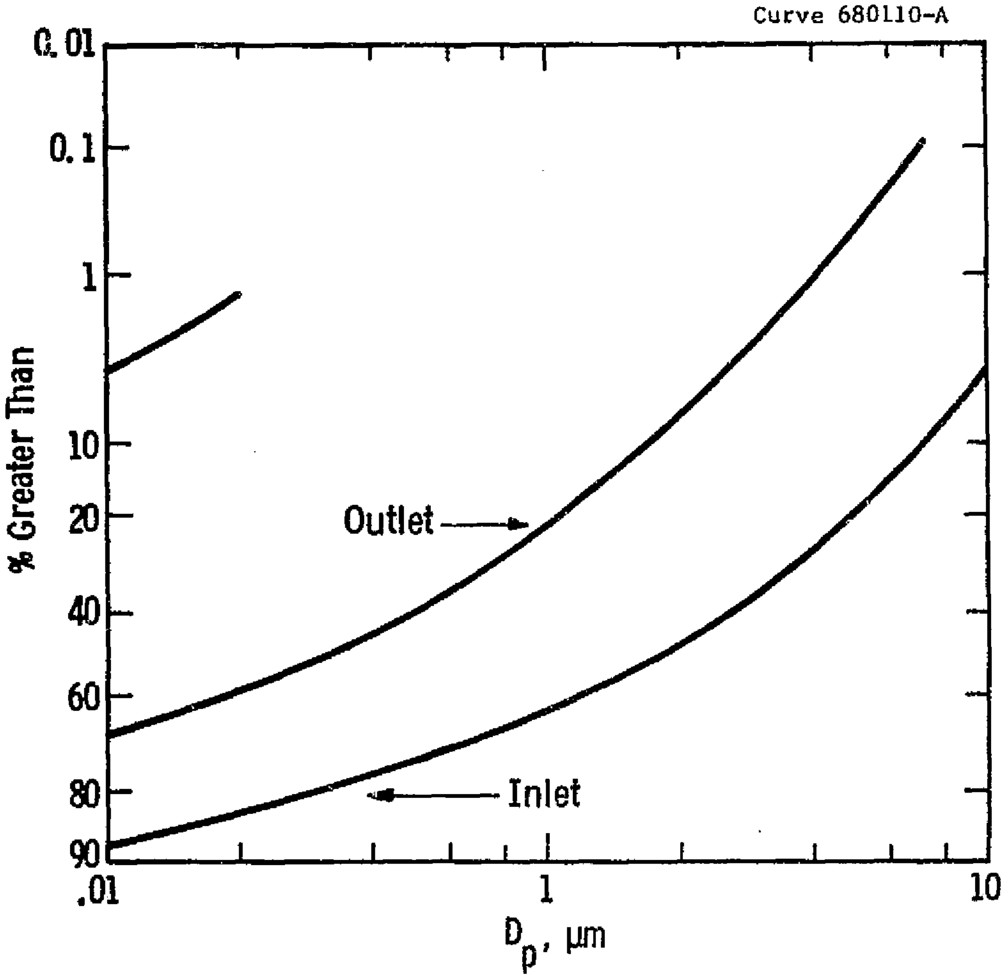

Fig. A 4.4.3—Aerodyne inlet and outlet size distributions

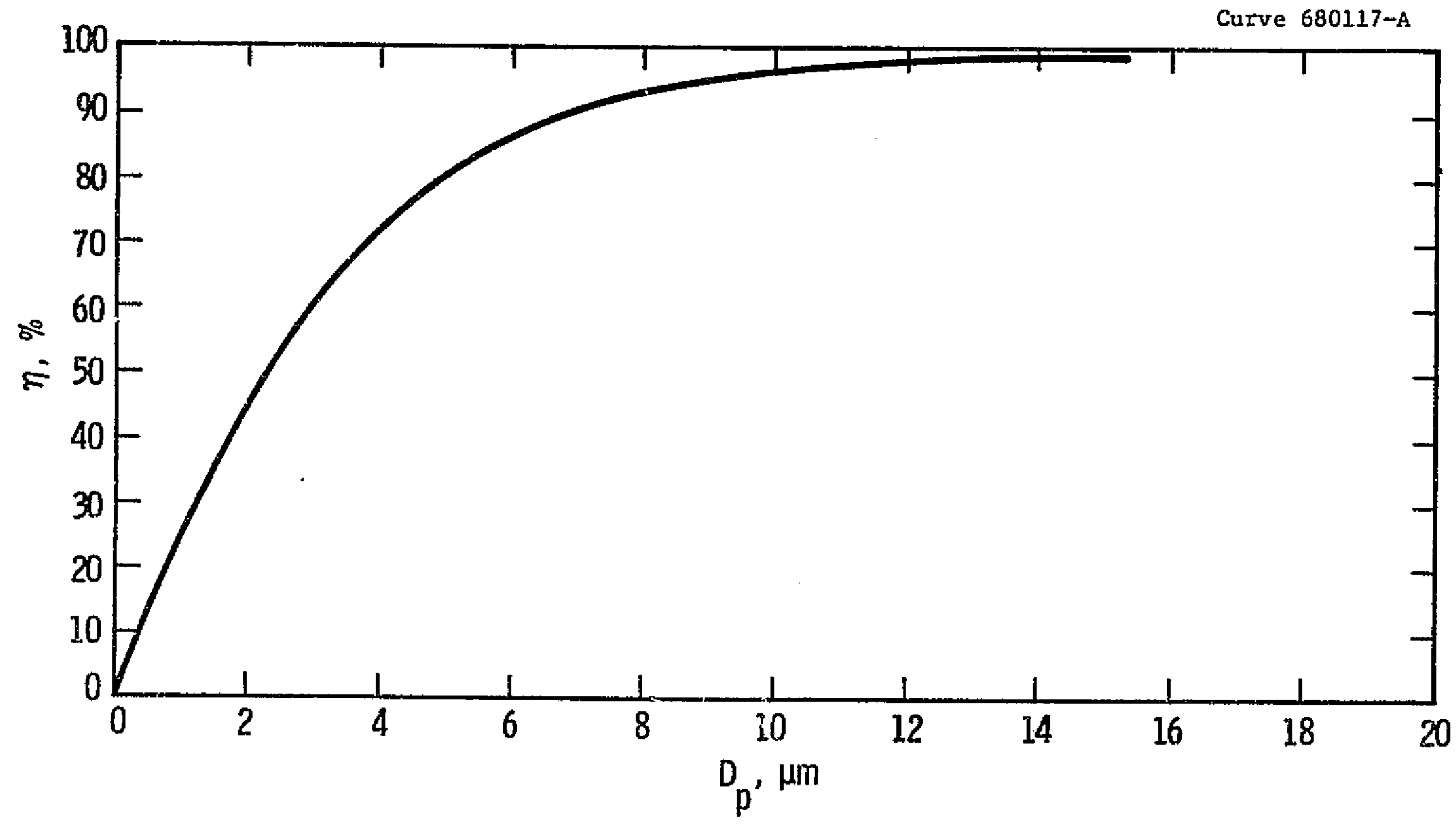

Fig. A 4.4.4—Grade efficiency of Ducon primary cyclone (1600 °F) C_1 and C_2

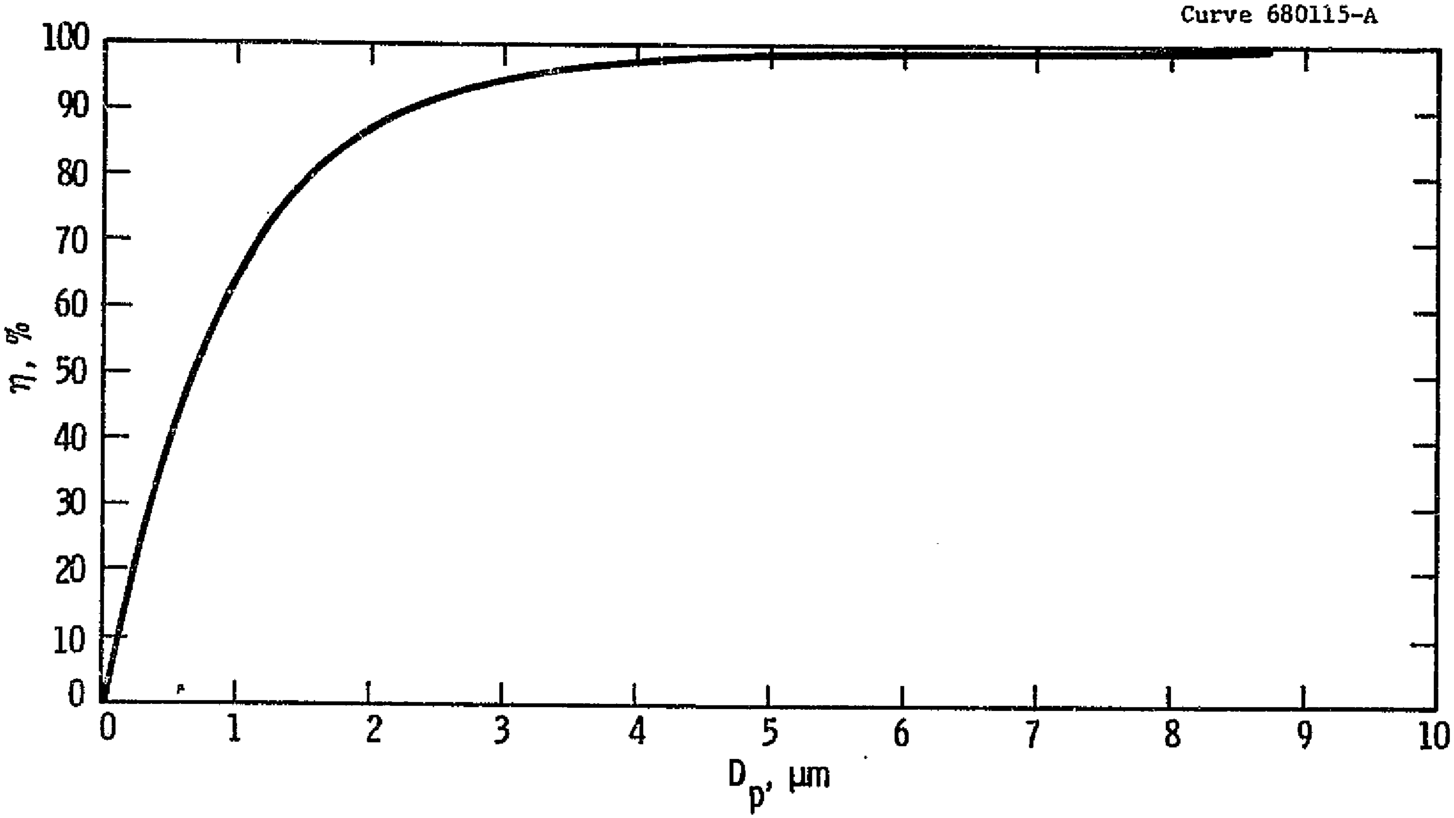

Fig. A 4.4.5—Grade efficiency for Aerodyne (1600 °F)

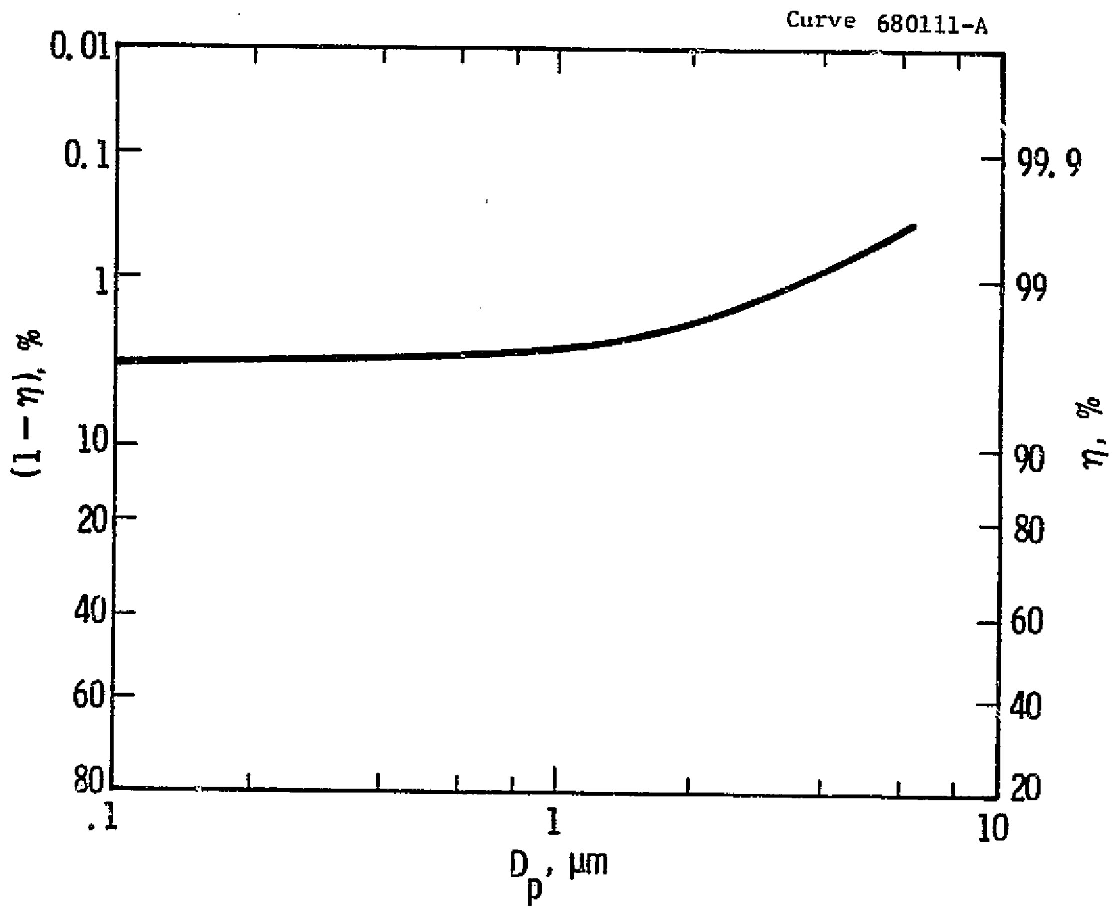

Fig. A 4.4.6—Grade efficiency for granular bed

From Aerodyne unit $C_{in} = 0.518$ gr/scf = 7.53 gr/lb gas

$$\left(\frac{W_f}{W_a}\right)_{st} = 0.7$$

$$\phi = \frac{(W_a/W_f)_{ACT}}{(W_a/W_f)_{ST}} \qquad \text{(A 4.4.1)}$$

$$W_a = (1/.7)\, W_f\phi = 1.429\, W_f\phi$$

Concentration after dilution with combustion air

$$C_{out} = \left(\frac{C_{in}}{1 + 1.429\,\phi}\right)\left(\frac{29}{359}\right) = \frac{0.0808\, C_{in}\ (\text{gr/lb fuel})}{1 + 1.429\,\phi}\left\{\frac{\text{gr}}{\text{scf}}\right\}$$

for $\phi = 1$ $C_{out} = 0.025$ gr/scf → need granular bed

$\phi = 2$ $C_{out} = 0.158$ gr/scf → need granular bed (A 4.4.2)

$\phi = 3$ $C_{out} = 0.115$ gr/scf with $0.0085 > 2\mu$

Table A 4.4.3 - Granular Bed Filter

D_p (μ)	Wt in (gr/scf)	$(1 - \eta)^a$	Wt out (gr/scf)	%	Σ %
(0 - 0.2)	0.215	0.035	0.0075	0.482	0.482
(0.2 - 0.5)	0.105	0.031	0.0033	0.206	0.688
(0.5 - 1)	0.088	0.030	0.0026	0.166	0.854
(1 - 2)	0.072	0.025	0.0018	0.113	0.967
(2 - 3)	0.026	0.016	0.0004	0.028	0.995
(3 - 5)	0.010	0.008	0.0001	0.005	1.000
(5 - 7)	0.002	0.004	---		
(7 - 10)	---	---	---		
TOTAL	0.518		0.0157		

[a] η = 97%

Appendix A 4.5

DETAILED COST ESTIMATES OF ADVANCED FLUE GAS DESULFURIZATION PROCESS

A 4.5.1 Description of Processes (Reference 4.33)

A 4.5.1.1 Limestone Slurry Scrubbing

Stack gas is washed with a recirculating slurry (pH of 5.8 to 6.4) of limestone and reacted calcium salts in water using a two-stage (venturi and mobile bed) scrubber system for particulate and sulfur dioxide removal. Limestone feed is wet ground prior to addition to the scrubber effluent hold tank. Calcium sulfite and sulfate salts are withdrawn to a disposal area for discard. Reheat of the stack gas to 353°K (175°F) is provided. The design is based on data taken from EPA-TVA-Bechtel Shawnee test program.

A 4.5.1.2 Lime Slurry Scrubbing

Stack gas is washed with a recirculating slurry (pH of 6.0 to 8.0) of calcined limestone (lime) and reacted calcium salts in water using two stages of venturi scrubbing. Lime is purchased from "across the fence" calcination operation, slaked, and added to both circulation streams. Calcium sulfite and sulfate are withdrawn to a disposal area for discard. Reheat of the stack gas to 353°K (175°F) is provided in the design is based on data provided by Chemical Construction Corporation (Chemico).

A 4.5.1.3 Magnesia Slurry Scrubbing - Regeneration to H_2SO_4

The stack gas is washed in two separate stages of venturi scrubbing -- the first utilizing water for removal of particulates and the second utilizing a recirculating slurry (pH 7.5 to 8.5) of magnesia (MgO) and reacted magnesium-sulfur salts in water for removal of sulfur dioxide. Makeup magnesia is slaked and added to cover only handling losses, since the sulfates formed are reduced during regeneration. Slurry from the sulfur dioxide scrubber is dewatered, dried, calcinated, and recycled, during which processes concentrated sulfur dioxide is evolved to a contact sulfuric acid plant producing 98% acid. The design is based on data supplied by Chemico-Basic Corporation

A 4.5.1.4 Sodium Solution Scrubbing - SO_2 Regeneration and Reduction to Sulfur

The stack gas is washed with water in a venturi scrubber for removal of particulates and then washed in a valve tray scrubber with a recirculating solution of sodium salts in water for sulfur dioxide removal. Makeup sodium carbonate is added to cover losses due to handling and oxidation of sodium sulfite to sulfate. Sodium sulfate crystals are purged from the system, dried, and sold. Water is evaporated from the scrubbing solution using a single-effect evaporator to crystallize and thermally decompose sodium bisulfite, driving off concentrated sulfur dioxide. The resulting sodium sulfite is recycled to the scrubber, and sulfur dioxide is reacted with methane for reduction to elemental sulfur. The regeneration and reduction areas are designed for 100% of power unit load. Design for the scrubbing-evaporator-crystallizer system is provided by Davy Powergas Inc. (Wellman-Lord process), and data for the sulfur dioxide reduction unit are provided by Allied Chemical Corporation.

A 4.5.1.5 Catalytic Oxidation

The stack gas is first cleaned of particulates by a high-temperature elestrostatic precipitator; then, the sulfur dioxide is catalytically converted to sulfur trioxide and the available excess heat is recovered. The sulfur trioxide reacts with moisture in the stack gas to form sulfuric acid mist which is scrubbed in a packed tower using a recirculating acid stream to yield 80% acid. The mist is removed by a Brink mist eliminator and the clean 397° K (254 °F) gas is exhausted to the stack. The design is based on data supplied by Monsanto Company, developers of the Cat-Ox process.

A 4.5.2 Major Cost Factors

In the TVA-EPA study the following factors were considered. For the purpose of the Westinghouse-NASA coal study contract, FGD data relating to oil-fired plants have been eliminated.

1. Project schedule and location. Project assumed to start in mid-1972 with 94.608 Ms (3 yr) construction period ending mid-1975. Midpoint of construction costs mid-1974; Chemical Engineering Cost Index - 160.2. Start-up - mid-1975. A midwestern plant location is assumed.

2. Power unit size. Costs for 200,500, and 1000 MW are projected.

3. Fuel type. Coal 27.906 MJ/kg (12,000 Btu/lb), 12% ash.

4. Sulfur content of fuel. Costs for three coal sulfur levels are evaluated - 2.0, 3.5, and 5.0%.

5. Plant status. New units designed for a 946 Ms (30 yr) life, 459 Ms (127,500 hr) of operation.

6. Sulfur dioxide removal. Since all five processes are capable of 90% sulfur dioxide removal and future demands for emission control may exceed present standards, 90% removal is specified as the base value. For those processes in which cost-effective design changes could be identified, 80% removal is also projected.

7. Particulate removal. Costs are included for 98.7% particulate removal [to meet EPA standard of kg/MJ (0.1 lb/10^6 Btu) heat input] on coal-fired systems except Cat-Ox, which required 99.9% removal for process reasons [restricted to g/m^3 (0.005 gr/scf) prior to entering converter].

8. Raw materials and catalysts. Assuming start-up in 1975, midwestern 1975 delivered prices are projected.

9. Labor. 1975 midwestern operating labor rates are projected.

10. Utilities. Recent energy cost escalation is recognized, and 1975 values are projected. Values used in operating cost estimates for utilities supplied by power plant cover all costs for generation, including return on investment, depreciation, and income taxes.

11. Maintenance. Various levels are analyzed.

12. Capital charges. Regulated (profit and taxes included) economic basis is used. Annual operating cost estimates utilize a base value of 14.9% of fixed investment (10% cost of money).

13. On-stream time. Annual operating costs are projected for 80, 57, 40, and 17% of full-time operation (7000,5000, 3500, and 1500 hr/yr). These values are used to project a lifetime cost over a predefined 946 Ms (30 yr) declining operating schedule.

14. Solids disposal. On-site ponding for limestone and lime processes includes prorated costs for calcium solids to cover pumping and piping to and from the pond, plus a 12.19 m (40-ft) deep, clay-lined pond, sized to meet requirements over the remaining life of the power unit.

15. Net sales revenue. Base values -- \$8.64/Mg (\$7.84/ton) 98% sulfuric acid, \$5.29/Mg (\$4.80/ton) 80% sulfuric acid, \$27.56/Mg (\$25.00/ton) for sulfur, \$22.09/Mg (\$20.00/ton) for sodium sulfate are used.

A 4.5.3 Capital Cost

Figures A 4.5.1 and A 4.5.2 summarize the TVA-EPA study results on FGD system capital cost as a function of power plant size and sulfur content of the coal. In these data the lime slurry process does not include the cost of calcining the limestone and includes only minimal facilities for storage of calcined limestone.

Figures A 4.5.1 and A 4.5.2 are for 90% sulfur dioxide removal as indicated. For an 80% removal system the cost would run 3.2 to 4.5% less according to TVA's findings. Costs given are for on-site disposal systems for the limestone and lime slurry processes.

Curve 683307-A

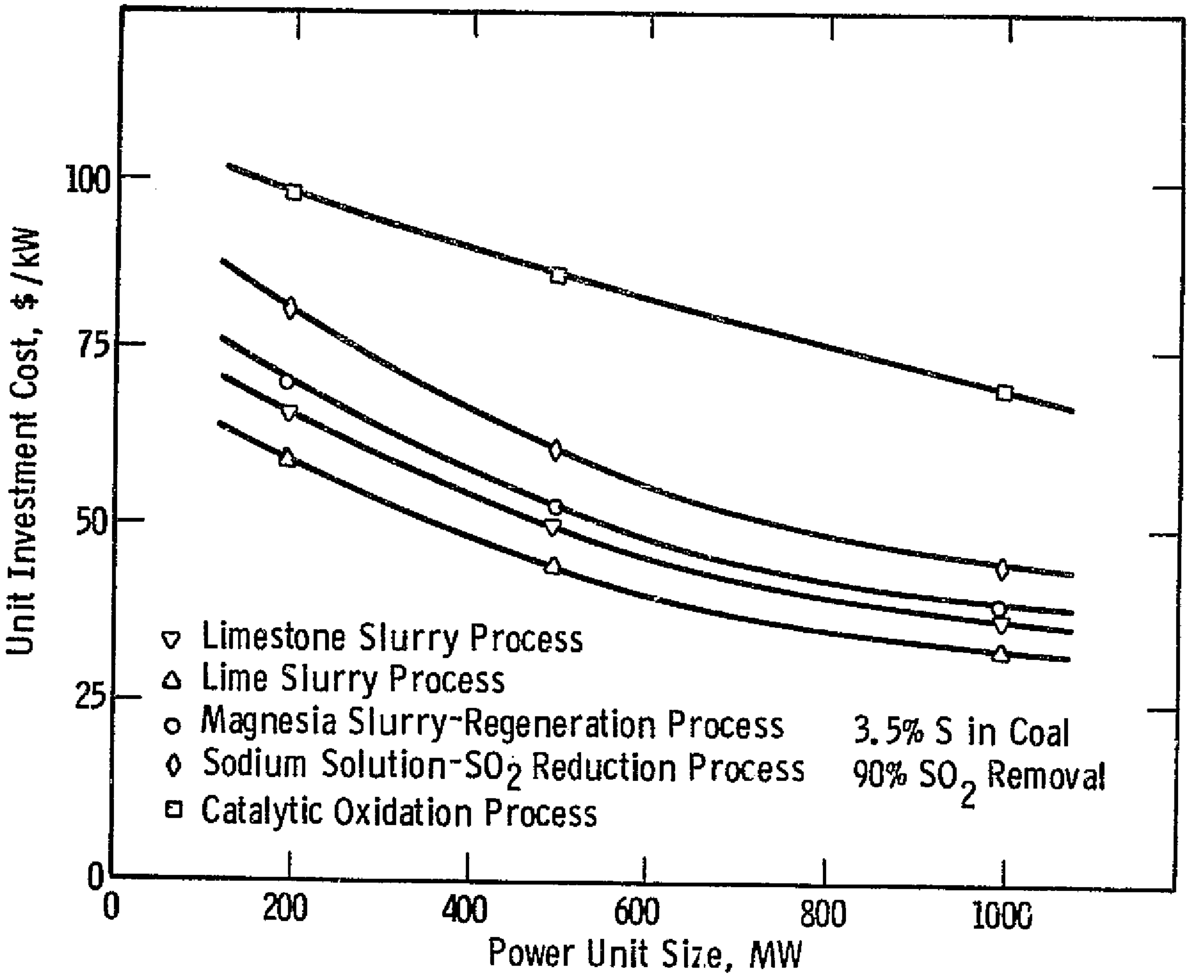

Fig. A 4.5.1—New coal-fired units - the effect of power unit size on unit investment cost,

Curve 683308-A

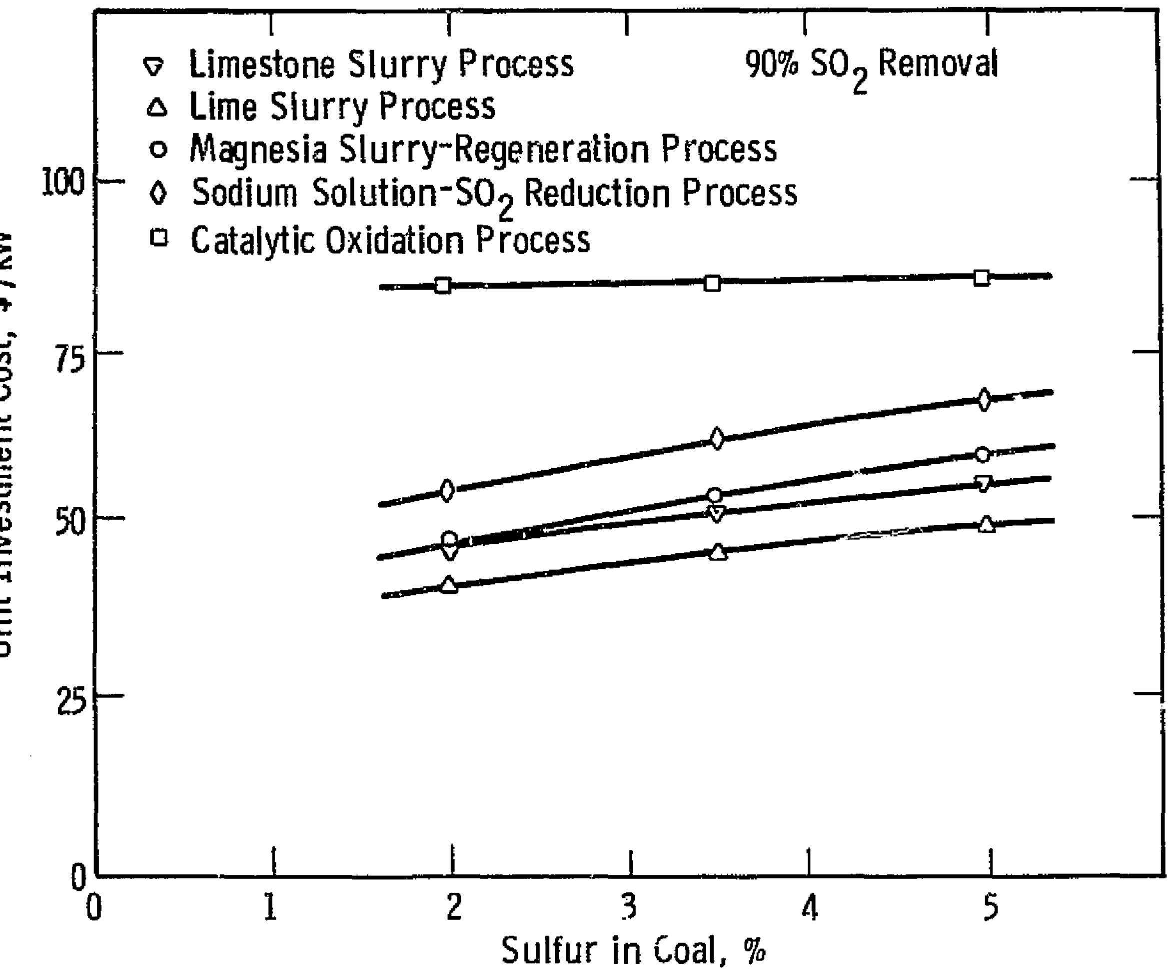

Fig. A 4.5.2—500-MW new coal-fired units - effect of sulfur content of coal on unit investment cost (Source TVA - Ref. 4.33)

Curve 683309-A

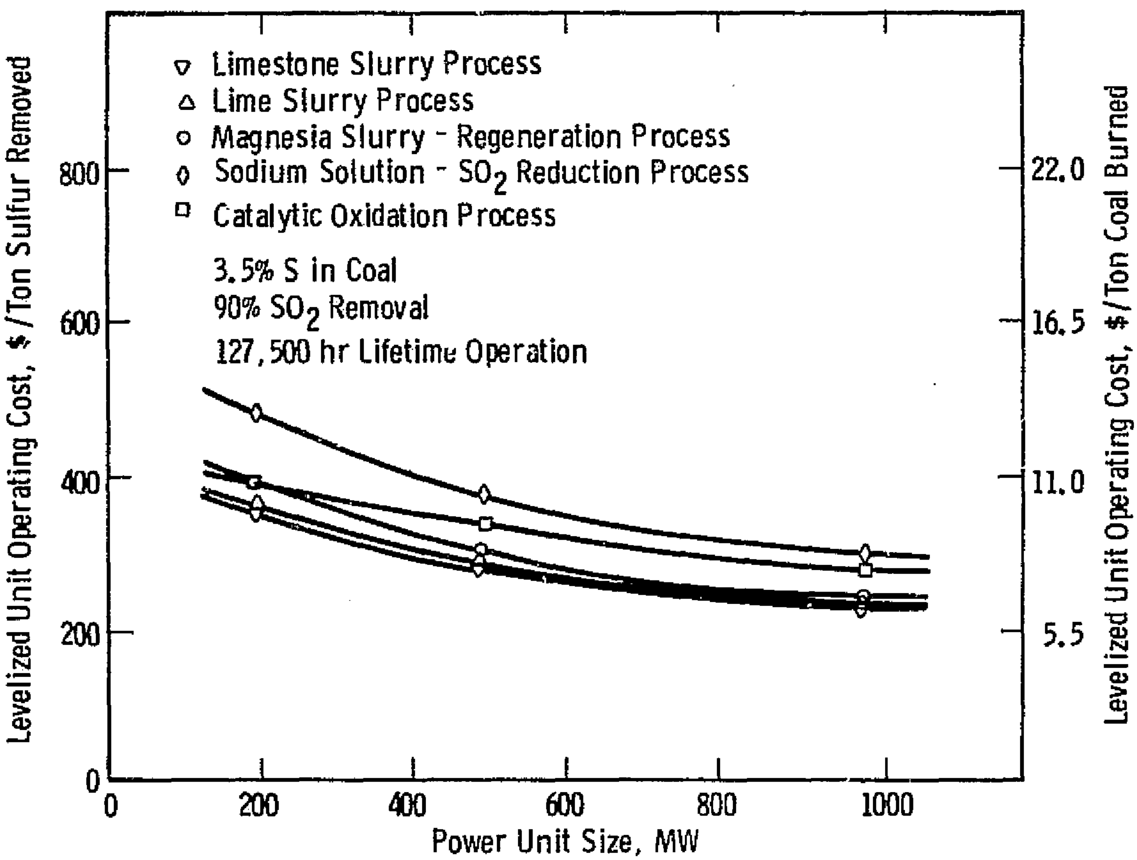

Fig. A 4.5.3—New coal-fired units - the effect of power unit size on levelized unit operating cost - regulated economics (Source TVA-Ref. 4.33)

A 4.5.4 Levelized Operating Cost

Figures A 4.4.3 and A 4.4.4 show the levelized operating cost over a 946 Ms (30 yr) period with the following operating profile: 80% first 315.3 Ms (10 yr), 57% next 158 Ms (5 yr), 40% next 158 Ms (5 yr), 17% last 315.3 Ms (10 yr). Credits are taken for by-product sale based on the following prices: \$8.64/Mg (\$7.84/ton) 98% sulfuric acid, \$5.29/Mg (\$4.80/ton) 80% sulfuric acid, \$27.56/Mg (\$25/ton) elemental sulfur, \$22.04/Mg (\$20/ton) sodium sulfate. With recent and forecast inflation, however, it is anticipated that prices of these products may rise sharply, making the regenerative FGD systems much more attractive. TVA is currently making a study of projected by-product prices. (Reference 4.34.)

A 4.5.5 Space Requirements

Space requirements for the FGD systems as well as for the disposal pond of the limestone and lime slurry processes are indicated in Table 4.5.1. For the regenerative by-product recovery process the acreage indicated includes space for the FGD apparatus as well as for the by-product recovery equipment for sulfuric acid, sulfur or sodium sulfate, as applicable.

Table A 4.5.1 - MW Rating vs Space Requirements/Acres (Reference 4.34 and 4.35)

Unit Size		Limestone Slurry	Lime Slurry	Magnesia Slurry	Sodium Solution	Calalytic Oxidation
200 MW	Equip	3.3	2.5	3.2	3.1	3.0
	Pond*	53.6	45.8	-	-	-
	TOTAL ACRES	56.9	48.3	3.2	3.1	3.0
500 MW	Equip	8.0	5.5	7.8	7.7	7.4
	Pond*	131.2	112.8	-	-	-
	TOTAL ACRES	139.2	118.3	7.8	7.7	7.4
1000 MW	Equip	15.5	11.6	15.1	14.8	14.3
	Pond*	253.3	216.5	-	-	-
	TOTAL ACRES	268.8	228.1	15.1	14.8	14.3

*Pond acreage is prorated for limestone and lime disposal only and does not include area for normal fly-ash disposal.

Curve 683310-A

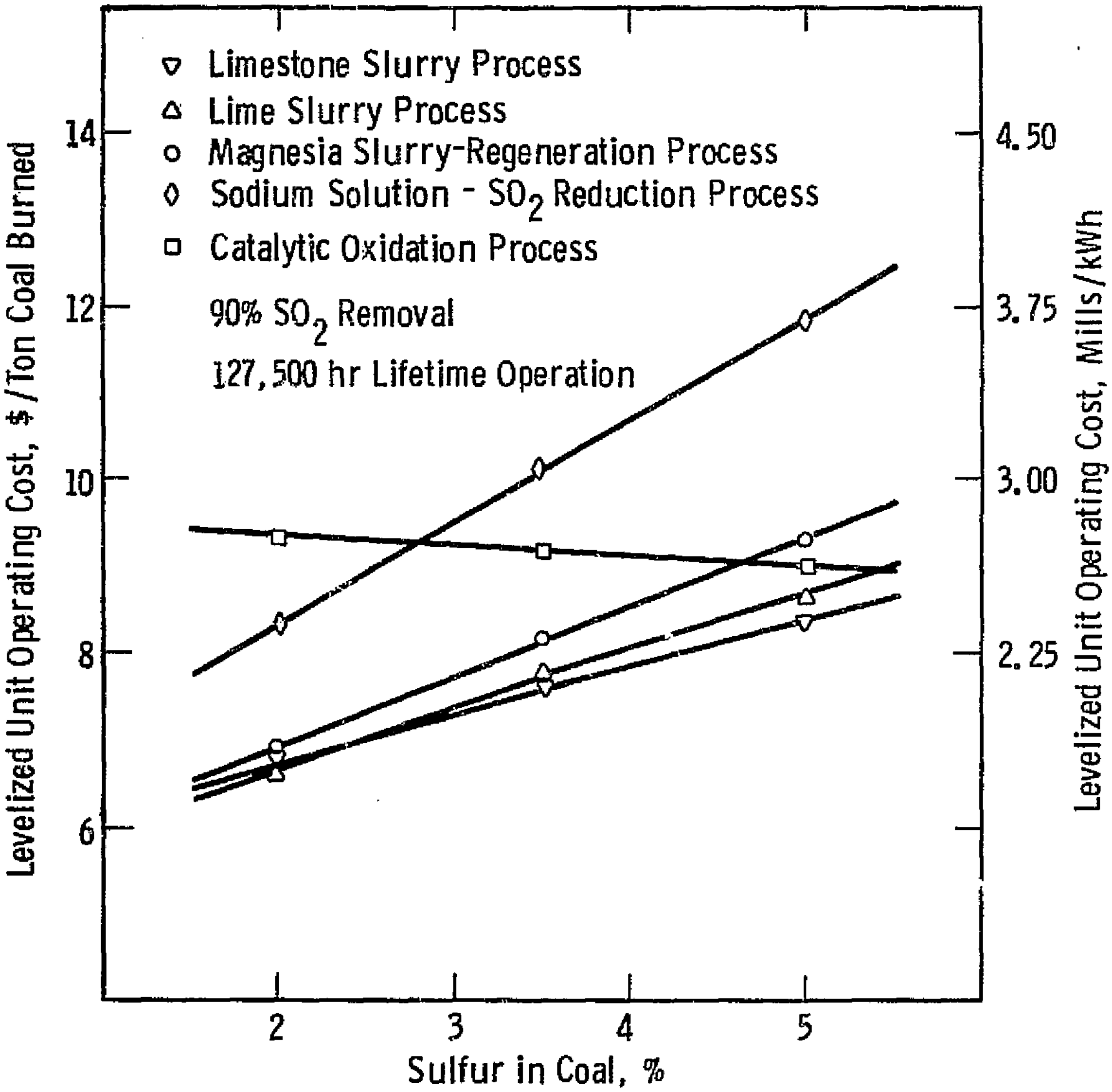

Fig. A 4.5.4—500-MW new coal-fired units - effect of sulfur content of coal on levelized unit operating cost - regulated economics

Appendix A 4.6

ASH UTILIZATION SYMPOSIUM HELD IN PITTSBURGH, PA. (MARCH 13, 14, 1973)

A 4.6.1 Production and Utilization (References 4.85, 4.86, 4.87, 4.99, and 4.103)

A 4.6.1.1 Coal ash production and utilization in the U.S. can be assessed by data from electrical utilities. In 1970, 469 x 10^{12} Mg (517 x 10^{12} tons) of bituminous coal was consumed as follows:

62% Electrical utilities
20% Coke and steel
16% Other manufacturers
2% Retail market

A 4.6.1.2 Electrical utilities are thus producing 80% of the coal ash; they are also consuming 80% of the ash-containing oil fuels.

A 4.6.1.3 Three kinds of ash are made: fly ash, bottom ash, and boiler slag. Fly ash is recovered from flue gas. Bottom ash is also known as dry bottom ash and is obtained by water quenching heavy ash from pulverized coal. Boiler slag is also known as wet-bottom ash and is obtained by water quenching molten ash from combustion of pulverized or crushed coal. It is black, extremely hard and brittle, and usually rather fine and uniform (4 to 16 mesh).

A 4.6.1.4 In 1971, a total of 39 x 10^{12} Mg (43 x 10^{12} tons) of coal, oil, and lignite ash was produced, distributed as follows:

	% of Total	% Utilized	Estimated 1976 Production x 10^{-12}, tons
Fly Ash	64	12	37
Bottom Ash	24	16	117
Boiler Slag	12	75	3
	100%	20%	157

The 80% not utilized was removed to disposal areas at company expense. The increase by 1976 in bottom ash is due to additives for SO_x control.

Note: At 1602 kg/m^3 (100 lb/ft^3), the total 1971 ash production amounted to about 7.82 m^3/s (200,000 acre-ft/yr) or 0.6798 m^3/Tg (500 acre-ft/10^6 tons) coal. This means a 250 MW station operating at full load would produce ash at the rate of 0.0143 m^3/s (1.0 acre-ft/day), assuming an average ash content of 15%.

Alternatively, if this coal ash were used in concrete to the extent of 20% by weight, 195 Mg (215 x 10^{12} tons) of concrete could be produced, which is about 3.248 m^3/s (134 x 10^6 yd^3/yr). This is enough to pave 666.7 km^2 (257 mi^2) with 15.24 cm (6 in) concrete, or 43,774 km (27,200 mi) of road 15.24 m (50 ft) wide.

A 4.6.1.5 Ash will increase because a) coal consumption is increasing, b) ash content is increasing, c) efficiency of ash collection is increasing, and d) additives will be used for SO_x removal.

A 4.6.1.6 Countries represented in the United Nations Economic Commission for Europe account for 70% of the energy, 75% of the electric power and 75% of the solid fuels consumption of the world. These countries include the U.S. and Russia.

A 4.6.1.7 In 1971, the European countries produced 5.443 x 10^{12} Mg (6.0 x 10^{12} tons) of total ash from hard coal and utilized 27% of it; West Germany utilized 79% of its coal ash; France, the United Kingdom, Finland, Belgium, and Poland showed utilizations of 65 to 34%. Principal uses were road construction, construction site fill, prepared concrete, concrete blocks, cement replacement, and cellular concrete.

A 4.6.1.8 The same countries produced 32.6 x 10^{12} Mg (36 x 10^{12} tons) of lignite ash but were able to utilize only 5% of it. France had the highest utilization rate (30%), mostly as replacement for cement. Turkey used 26%, essentially all in dam construction.

A 4.6.1.9 Various research projects are under way to increase utilization of fly ash. Utilization still is hampered by lack of laboratory and field data on properties, construction methods, and performance of coal ash materials.

A 4.6.2 Methods of Utilization of Coal Ash

A 4.6.2.1 Dumping in Disposal Areas (Reference 4.85, 4.106, and 4.88)

Ocean Dumping. Dumping in the ocean is a possibility but is limited to those sources near coastlines. There is also a growing internation concern about long-range effects which might lead to restrictions on such dumping.

Land dumping. Overall, 80% of the coal ash production is being transported to disposal areas and simply dumped. This can be taken as the ground-level disposal method, with the following economic characteristics:

- The ash produced at the power plant site has zero time and place value
- It acquires a negative value due to the cost of transporting it to a disposal area.

Most disposal systems either pump a slurry to a settling lagoon or truck it away after conditioning it by moistening with not less than 10% water. In one case in England the transportation cost was $7.72/Mg ($7.00/ton) for a 128.7 km (80 mi) haul.

When a lagoon is full, it is allowed to dry out. The ash can be excavated and transported to a final reclamation site, such as old mineral workings or quarries. It is also possible to cultivate the dried surface.

Lagooning incidentally results in washing away some salts harmful to plant life.

A 4.6.2.2 Fill Material

Sanitary Landfill (References 4.107, 4.109)

World population is increasing by 1.736 people/s (150,000 people/day). Urbanization is increasing; in the U.S., since 1800, the proportion of people living in cities has increased from 6 to 85%. Solid waste generation in the U.S. is 26 to 52 Mg/s/person (5 to 10 lb/day/person) and is projected to 42 Mg/s/person (8 lb/day/person) by 1980. At least 90% of the solid waste is merely dumped on open land; only a small fraction is properly handled. Problems common to marginal soils and landfills are:

- Low load-bearing capacity
- Large long-term settlements
- Differential settlements.

Problems peculiar to landfills and dumps are:

- Possibility of toxic and explosive gas
- Presence of sulfates
- Presence of organic compounds and acids.

Problems peculiar to dumps are:

- Large differential settlements
- Poor underdrainage and surface drainage
- Large uneven pockets of material saturated with water
- Minimum compaction.

Typical values for bearing capacity are 23.94 to 95.76 kPa (500 to 2000 lb/ft^2), depending on the age of the landfill and the amount of soil over the fill.

Settlement may be elastic, plastic, or consolidative. If elastic, removal of the load may result in spring-back; this is present in only a small percentage of the settlements. Plastic settlements occur by ravelling, which is the movement of finer materials in or out of voids. Decomposition, which is usually a volume reduction along with generation of gaseous and liquid by-products, produces consolidation.

The average sanitary landfill settles 90% of its expected total within 63.07 Ms (2 yr).

Differential settlements are very likely to occur during reclamation.

True in-place densities in the top layers of refuse in a landfill cannot be expected to exceed 415 kg/m^3 (700 lb/yd^3) with a normal moisture content and loading of 2.154 kPa (45 lb/ft^3). Compaction by loading with 15.24 to 45.72 cm (6 to 18 ft)earth can result in densities of 415 to 474 kg/m^3(700 to 800 lb/yd^3) from initial values of 237 to 356 kg/m^3 (400 to 600 lb/yd^3), and ultimately 593 kg/m^3 (1000 lb/yd^3).

Management of water run-off from the dump is necessary to avoid environmental contamination. Covering with 15.24 cm (6 in) earth 0.224 Mg/m^3 (1000 ton/acre) would cost about $1.10/Mg ($1.00/ton). The same results can be had with 0.0448 Mg/m^3 (200 ton/acre) of fly ash at the same unit cost. This also avoids the problem of borrowing earth from another location.

Mine Subsidence and Fire Control

This application was described in the 1970 Conference. Fly ash is blown dry or pumped as a slurry through bore holes drilled from the surface into the mid area.

Old coal-mining practices create a honeycomb structure underground consisting of combustible fuel under relatively shallow cover with numerous surface openings. Typically, 50% of the coal was left behind as pillars to support the overburden. Two problems developed: fire and subsidence. Fires can be initiated by an external source of heat, such as rubbish fires near exposed coal. Subsidence can result from failure of the arch of overburden between pillars and from the eventual crushing out or erosion of the coal pillars.

Fly ash is well suited for sealing large voids because of its low angle of repose (8°), excellent roofing characteristics, low density, nonsettling property, and tendency to become firm when exposed to moisture. It can also be injected at high rates [7.56 kg/s (0.5 tons/min)] without special nozzles, and in all kinds of weather.

Thus far, mine application has not developed into a major consumer of fly ash. There is evidence that fly-ash injection has been successful in controlling and smothering underground fires. It is too early to tell how successful it is in subsidence control.

A 4.6.2.3 Agricultural Uses

Mined-Land Reclamation (Reference 4.106, 4.107)

Surface mining methods disturb large areas of land and produce spoil banks that do not support plant life. If fly ash were used in reclamation, more than half the annual production could be used for this purpose.

Factors restricting plant life are acidity and compacted surface, coarse texture, and dark color. The latter two relate to the ability of the material to absorb and retain moisture and the equilibrium temperature during hot summer months.

Fly ash contains elements taken up by plants millions of years ago: calcium, magnesium, potassium, phosphorus, sulfur, boron, zinc, copper, and molybdenum.

Treatment of surface mine spoils by 33,630 to 179,300 Mg/km^2 (150 to 800 tons/acre) of fly ash increased pH from 2.54 to 4.7 to 4 to 8. The pH gradually decreases with time, but 252.2 ms (8 yr) later, at 5.1, it was still above the untreated level.

Benefits realized by reclamation with fly ash are:

- Increase in pH
- Lightened soil texture
- Increase in resistance holding capacity
- Increase in pore volume
- Reduction of erosion through immediate establishment of soil cover of grains and legumes

- Utilization of large tonnages of fly ash
- Addition of some macro- and micronutrients
- Forage yields comparable to undisturbed land.

Cost of reclamation by normal methods is \$172,900 to \$247,100/km^2 (\$700 to \$1000/acre), of which \$123,600/km^2 (\$500/acre) is for earth moving and the balance for seeding, fertilizer, and soil conditioning.

Assuming \$0.275/Mg (\$0.25/ton) for loading fly ash at the power station and \$0.0685/Mg-km (\$0.10/ton-mi) for delivery to a site 16.09 km (10 mi) away, fly ash treatment would cost \$31.63/Mg/km^2 (\$1.25/ton/acre). At 33,630 Mg/km^2 (150 tons/acre), this is \$46,456/km^2 (\$188/acre). A credit of \$3.85/Mg (\$3.50/ton), however, can be ascribed to the market value of the components of the fly ash.

When fly ash is used for land reclamation, some protection of the surface is needed. Minimum treatment is spraying to keep dust from blowing away.

Spraying can be with water for short-term control, or with emulsions and polymers for longer-term control. Overlaying with 30.48 cm (12 in) topsoil will permit growth of a variety of crops, but is usually impracticable and costly.

<u>Source of Plant Nutrients</u> (References 4.106, 4.108)

Alfalfa yields were apparently increased by fly ash additions. The increase was attributed to the effective addition of boron at the rate of 0.168 and 3.36 Mg/km^2 (1.5 and 3.0 lb/acre). Addition of sodium borate produced comparable increases in yield at the rate of 3.36 Mg/km^2 (3.0 lb/acre) in 1971 followed by 2.24 Mg/km^2 (2.0 lb/acre) in 1972.

The yield increase in 1971 was from the level of 151.3 Mg/km^2 (1350 lb/acre) alfalfa for untreated plots to the level of 319 to 358.7 Mg/km^2 (2850 to 3200 lb/acre). The yield from the untreated plots, however, increased in 1972 to the level of 919.1 Mg/km^2 (8200 lb/acre). The treated plots in 1972 produced 1042.4 to 1120.9 Mg/km^2 (9300 to 10,000 lb/acre). Thus, the year-to-year variation for untreated plots were 4-to-6 times the increases attributed to boron addition. The within-years variations were reported to be statistically significant at the 95% confidence level. Soil amendments were used to increase pH to 6.5.

Yield increases were also obtained by treating acidic soil with fly ash to raise pH. Additions of as much as 14,347 Mg/km^2 (64 ton/acre) of fly ash in two successive years did not adversely affect corn yields. CEGB research concluded soluble boron was the major plant toxin in ash. Available boron from ash was 20 times the normal level of 1 to 2 ppm in soil. Nitrogen is essentially absent, and phosphorus is generally insufficient in coal ash.

Soil Conditioner

Coal ash without any soil covering can support some plant life: clover, grasses, beets, cabbage, and rye,for example. Weathered coal ash will give acceptable crops of carrots, radishes, parsnips, celery, onions.

Pulverized fly ash (PFA) is very susceptible to formation of hardpan (a dense impermeable layer) a few inches below the surface.

7.62 cm (3 in) of subsoil mixed with fly ash provides colloidal particles to aid in fertilizer retention. Ash is superior to most soils in moisture retention.

A 4.6.2.4 Construction Uses

Stabilizer for Road Bases (References 4.89, 4.101, 4.102, 4.93, 4.98)

In new boiler plants, a trend is appearing of eliminating fly ash electrostatic precipitators in favor of collecting fly ash simultaneously with lime scrubbing for SO_x removal.

Billions of tons of granular materials are used annually in base and subbase construction for roads and airports. Materials derived from fly ash could be used in these markets, but lack of acceptance by the engineering profession has limited their use.

In 1971, nearly 1.8144 x 10^{12} Mg (2 x 10^{6} ton) of lime-fly ash aggregate (LFA) were placed in the U.S. with over 0.9072 x 10^{12} Mg (1 x 10^{12} ton) in the Chicago area alone. Newark Airport used over 1.8144 x 10^{12} Mg (2 x 10^{12} ton) of LFA and lime-cement-fly ash aggregate (LCFA). These were used on primary runway and taxi systems and serve modern jumbo aircraft such as the 747 and DC-10. A recent survey shows the systems to be in excellent condition. Both high-calcium dolomitic and monohydrated dolomitic limes are commonly used.

Fly ash is classed as a pozzolan. ASTM defines this as a siliceous or siliceous-and-aluminous material, which in itself possesses little or no cementitious value but which will, when in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds having cementitious properties. Natural pozzolans include pumice, volcanic ash, tuffs, clays, and shales.

LFA mixtures range from 2% lime/8% fly ash to 5% lime/36% fly ash, with 3% lime/10-to-25% fly ash, being typical. Fly ash content is not important in the development of compressive strength. LCFA mixtures may have lime/cement ratios of 3 or 4. Pozzolanic reactions will not occur unless sufficient moisture is present. They also nearly stop at temperatures below 277.6°K (40 F).

The two most important properties of paving materials are durability and dimensional stability. Strength and stiffness are also important but can be designed around. LFA and LCFA materials show gains in compressive strength during alternating freeze-thaw test cycles, which favors durability. Good pavement performance requires that dimensional changes be limited to strains not over 10^{-5}. Hardened LFA and LCFA materials give coefficients of linear thermal expansion of 0.2743 m/°K (6 x 10^{-6} in/°F), about the same as portland cement concrete. LFA/LCFA mixtures show long-term increases in compressive strength. Values approach 17.237 MPa (2500 psi) after 252.19 to 315.36 ms (8 to 10 yr) service. Ultimate strength increases with curing temperature.

LFA mixtures have the characteristic of autogeneous healing: they can recement across a crack by a self-generating mechanism. Like all paving materials, though, they are susceptible to deterioration when subjected to repeated loading. Compacted density is the most important single factor in producing quality LFA/LCFA materials. Relatively small reductions in compacted density can reduce strength by 40 to 60%. LFA/LCFA mixtures have had an excellent performance record as paving materials. Failures are traceable to poor construction techniques and inadequate quality control.

Waste calcium sulfate is generated by several industrial processes. There is evidence that it will react with lime-fly ash mixtures at normal temperatures to form stable compounds which contribute to strength development.

A chance to show the use of such mixtures occurred in the construction of a 0.4046 km^2 (100 acre) parking area for the Transpo '70 International Transportation Exposition at Dulles Airport, Washington, D.C. during the week of May 27, 1972. The area was needed for only a week, so funding was low. This, plus adverse weather, prevented proper compaction of the subgrade. Also, various factors operated to cause the surface asphaltic seal coat to be inadequate. Overall, the mixtures do not appear suitable as the riding surface, but do appear useable as a base course. Shrinkage cracks did not develop in any of the compositions. The Federal Highway Administration is sponsoring basic research on lime-fly ash-sulfate mixtures.

The sulfate waste products used were anhydrous calcium sulfate from HF production, acid mine drainage sludge, and sulfur dioxide scrubber sludge. Lime added was both dolomitic monohydrated lime with a calcium oxide content of 58% and a 95% calcium oxide hydrated lime.

The synthetic aggregates were prepared in a pugmill. It was concluded that the mixtures could be stockpiled for future use.

The low density of fly ash is advantageous for construction of embankments over poor ground, such as alluvial silt or clay, where excessive loading might cause settlement beyond allowable limits or even complete failure of the subsoil. Fly ash in England is marketed as PFA, pulverized fly ash. PFA has more slope stability than clayey soils. It has been shown in the laboratory, and also on site, that there is little or no buildup of pore pressure in PFA bucause pressure is borne by the strong skeleton of particles of cemented PFA; whereas in clay, the pressure is largely borne by moisture in the soil pores.

PFA stabilized with cement,either alone or blended with sand or granulated slag or mixtures of PFA, chalf, gypsum, and lime,have been used on major roadworks in France for subbases, bases, and hard shoulders. PFA soaks up soil moisture, which reduces plasticity of the base and permits compaction operation to proceed.

Fill Material

Fly ash has been used as a structural fill material in Europe for many years. Applications include highway embankments, and dikes to retain slurry fly ash. Prcblems associated with fly ash fills include:

- Internal erosion - controlled by proper drainage.
- External erosion due to wind, rain, and wave action -- controlled by vegetative cover on downstream side and slope protection on upstream side via impervious clay, shale, or rock.
- Liquefaction, which is the sudden decrease in shearing resistance to almost zero, caused by the collapse of the structure of the material associated with a sudden but temporary increase in the pore pressure.

  Conditions leading to liquefaction are the presence of material in the fine sand/coarse silt range, loose material with a high percentage of voids, high water table or excess pore water pressure, and shock loading. Only the middle two conditions can be controlled.

Filler in Asphalt Mix (References 4.103, 4.105)

In 1972, Highway Materials Co. of Bridgeport, W.Va., was able to get the West Virginia Department of Highways (DOH) to use PFA in their secondary road improvement program. About 117,936 Mg (130,000 tons) of PFA was used in a mix to resurface 127.1 km (79 mi) of road in eight counties. It was a combination of bottom ash and 5 to 7% anionic cold emulsified asphalt and was applied as a cold mix. The material was called Ashphalt. It was placed over untreated soil base as well as over surfaces such as gravel, limestone, and deteriorated hot-mix asphalt.

Ashphalt proved more economical to mix and place than conventional hot mixes or cement-treated bases, and:

- It can be pugged or mixed and stockpiled in advance.
- It can be placed in cold or inclement weather.
- It can be blended with sand, gravel, limestone, or blast furnace slag to any desired gradation.

The DOH figures show stockpile cost of $5.62/Mg ($5.10/ton) and in-place figures of $9.92 to $11.02/Mg ($9 to $10/ton), including 56.32 to 64.37 km (35 to 40 mi) hauls.

Lightweight Aggregate

There are enough miles of road in West Virginia in which coal ash marketed as power plant aggregate (PPA) has been used to serve as evidence of its suitability for this purpose, but specifications for road building materials will have to be modified to permit fuller use of PPA.

PPA results in a compacted density of 2082.4 kg/m^3 (130 lb/ft^3) vs 2883.3 kg/m^3 (180 lb/ft^3) for competitive materials.

A sintering plant at the Scholven power station near Essen, West Germany is producing lightweight aggregate as an alternate utilization method during winter months when construction activity is low.

Fly ash is blended with powdered coal or high-carbon fly ash to 5 to 6% carbon, pelletized with the aid of 2 to 3% water, and sintered. The aggregate is crushed and sized into three fractions: 0 to 4 mm, 4 to 8 mm, and 8 to 16 mm (0 to 0.157 in, 0.157 to 0.315 in, and 0.315 to 0.630 in).

Partial Replacement of Cement (References 4.91, 4.92, 4.93)

Fly ash is utilized in Portland cement mixtures as:

- An admixture in the mortar
- A component of a blended hydraulic cement
- A raw material in manufacture of Portland cement.

Benefits obtained include:

- Reduced water requirement
- Enhanced workability
- Improved finishing qualities
- Increased crusher capacity
- Increased grinding efficiency
- Lower cost
- Reduced shrinkage on drying
- Lower heat of hydration
- Improved chemical resistance
- Improved flexural strength
- Lower permeability.

Adverse reports include:

- Difficulcy in control of air content
- Slow strength gain of concrete, especially at low ambient temperature or with less than optimum curing
- Reduced freezing and thawing resistance
- Quality control problems due to variation of fineness, moisture content, and requirements for air entrainment
- Handling difficulties -- dust control, conveyance, and segregation of carbon particles.

Proper utilization requires use of:

- Suitable specifications and quality control
- Proper handling techniques
- Fly ash from one source for a given job
- Special quality control procedures to deal with variations due to variable plant load
- Proportions of components of concrete to meet the requirements of the job.

Fly ash can be used to replace 30 to 50% of the Portland cement required for a given strength and durability. This usually results in delayed setting and reduced early strength. The main application is in mass concrete where these properties are not objectionable, and economy and lower heat generation are desired.

Fly ash can also be used as a pozzolan to reduce the cement content while improving working qualities and cementitious value of the concrete. The total of fly ash and cement will be greater than the cement in the normal formulation. Such concrete will show high early strength and freeze-thaw durability equal to normal concrete design for structural or pavement construction. It is possible to use 59.328 to 103.8 kg/m^3 (100 to 175 lb/yd^3) of fly ash in concrete.

Fly ash concrete appears to have the following properties:

- Lower coefficient of variation for compressive strength
- Freeze-thaw resistance of properly air-entrained concrete is independent of the ratio of cement to fly ash.

Fly ash concrete is useful as a protective cover for steel reinforcement rods.

Since 1940, the Bureau of Reclamation has used 244,944 Mg (270,000 tons) of fly ash in 542,833.10 m^3 (7.1 x 106 yd^3) of concrete.

More than 50 dams have been built using fly ash concrete in the last 630.7 Ms (20 yr):

- 1942 - Repair of tennel spillway for Hoover Dam
- 1953 - Hungry Horse Dam
- 1966 Yellowtail Dam
- 1972 - Dworshak Dam, Idaho - 226,800 Mg (250,000 tons) fly ash in 5.734×10^{12} m^3 (7.5×10^{12} yd^3) concrete.

Fly ash concrete was used in:

- 243.8 m (800 ft) flue gas stacks at the J.M. Stuart generating plant at Aberdeen, Ohio
- 16-story Landmark Office Building in Bloomington, Ohio, for which concrete was pumped as high as 59.44 m (195 ft) above grade.

Pumpable Concrete (Reference 4.94)

Particle size distribution, especially in the sand fraction, is most important in pumpable concrete.

The total surface area of the particles in a mix can be decreased by adjusting sizes and proportions of aggregate and sand. The effect is to permit the cement paste to function more efficiently as a lubricant in transit and later as the major factor in concrete quality.

Fly ash improves the ultimate strength and other qualities of concrete, improving workability more than an equivalent extra amount of cement, and is cheaper.

A 4.6.2.5 Minerals Recovery (Reference 4.104)

Minerals Content

In Portland, fly ash is a source for industrial production of magnetite and aluminum oxide. In 1970, about 7.258×10^{12} Mg (8×10^{12} ton) of fly ash and slag were produced by power plants.

Ash from bituminous coal contained 8 to 16% ferrous oxide and 18 to 28% aluminum oxide; that from subbituminous coal has only 7% ferrous oxide but 34% aluminum oxide.

Magnetic separation of iron to the extent of 85 to 95% was possible for ash from bituminous coal because its combustion process leads to ferrous oxide. In 1970, 9,979.2 Mg (11,000 ton) of artificial magnetite was produced. All of it was used as a dense (flotation) medium for coal preparation plants.

Processes

Two processes are available for extraction of alumina: the sintering-disintegration method of Grzymek and the acid method of Bretsznajder. In the former, aluminiferous materials are sintered with limestone and allowed to disintegrate from 5 to 20 cm (1.968 to 7.874 in) lumps into 20 μm (0.787 mil) dust. This takes about 1.8 ks (30 min). The operating principle is stated as polymorphis of the β-phase of calcium orthosilicate. The calcium aluminates are leached with sodium carbonate solution, and the residual calcium orthosilicate dust is mixed with ground limestone to make Portland cement.

In the acid method, aluminiferous materials are leached by recirculated brines, sulfuric acid is added, and the suspension heated. Basic aluminum sulfate is crystallized from the filtered solution and decomposed in a rotary kiln to produce alumina and sulfur dioxide. The latter is sent to a sulfuric acid plant.

4.6.2.6 Miscellaneous (References 4.90, 4.110)

Adsorbent

Fly ashes in general do not have conventional absorptive properties comparable to commercial-grade activated carbon.

Ashes with a high lime content have a definite potential for removal of color bodies from pulp and paper mill effluents. This appears to be a chemical precipitation within the waste rather than a true absorption.

Ferrocement

Boats of various types from 3.048 m (10 ft) rowboats to steamers have been constructed from ferrocement. This consists of a skeleton of 0.476 or 0.635 cm (3/16 or 1/4 in) rebar plus 4 to 12 layers of chicken wire, plus concrete to overall thicknesses up to 5.71 cm (2.25 in).

Qualities required for the cement are high strength, high workability, impermeability, and sulfate resistance.

Small amounts of fly ash -- 4.536 kg/bag (10 lb/bag) of cement -- improve workability and sulfate resistance. Pozzolanic activity produces long-term increase in strength.

Cenospheres (Reference 4.88)

Cenospheres are hollow spheres. In fly ash, they average 20 to 200 μm (0.787 to 7.87 mil) in diameter. The shell is coherent, nonporous silicate glass with a thickness of about 10% of the radius. True particle density is 0.4 to 0.6 g/cm^3 (24.96 to 37.44 lb/ft^3); bulk density is 0.25 to 0.40 g/cm^3 (15.6 to 24.96 lb/ft^3).

The gas in the cenospheres is mainly carbon dioxide and nitrogen. At room temperature, the internal pressure is 20.265 kPa (0.2 atm).

Cenospheres are formed at about 1673°K (2552°F) and freeze at 1273°K (1832°F). On heating to 573°K (572°F), they decrepitate, indicating release of water dissolved in the glassy material. They begin to sinter at 1473°F (2192°F) and collapse above 1573°K (2372°F). Chemically, they are principally silica and alumina (80 to 90%), with the balance being mainly ferrous oxide.

Cenospheres have been used as a filler in sprayable vinyl mastic for fire protection of power plant high-voltage cables and as a wall filler for noise attenuation. A syntactic foam of cenospheres in an epoxy binder was used to achieve buoyancy in the deep ocean; and lightweight turf has been produced by floating cenospheres on water in a shallow pond, covering them with a carrier sheet, and adding fertilizer and grass seed. The root system ties the whole layer together.

A 4.6.3 Properties of Coal Ash

A 4.6.3.1 Fly Ash (Reference 4.100, 4.95)

Fly ash consists mainly of glass spheres and, in soil terminology, falls into the class of a sandy silt.

The particle size distribution of ash from a single boiler will normally be consistent.

The specific gravity of fly ash particles is 1.9 to 2.4. Bulk densities vary greatly. Compacted dry density is 1121 to 1441.6 kg/m^3 (70 to 90 lb/ft^3). Maximum density is obtained at optimum water contents in the range of 18 to 30%.

Field compaction characteristics vary with ash source, so field tests are recommended to determine what equipment and compactive effort will produce the desired density.

Undrained shear strength decreases substantially at water contents significantly wetter than optimum. The permeability of compacted fly ash is low: (10^{-4} to 10^{-6} ft/min). This range is adequate for a homogeneous, compacted, water-retaining structure.

Fly ash is slightly soluble in water but otherwise chemically stable. Pozzolanic activity* on contact with water tends to fix the small soluble content, and therefore environmental pollution potential is low.

Fly ashes have been found to be less than sufficiently consistent for commercial use.

Ash from Australian lignite was found to contain 18% magnesium oxide and 15% sulfur trioxide.

*See Section A 4.6.2.4.

A 4.6.3.2 Bottom Ash and Boiler Slag (Reference 4.99)

Properties of bottom ash and boiler slag were examined at West Virginia University for samples from West Virginia, Ohio, and Pennsylvania. The comments in the following sections apply to these samples.

Particles of bottom ash are angular and have a very porous surface. Slag tends to be angular/subangular and have a glassy surface.

Particle size distribution tends to be more uniform for boiler slag. The coefficient of uniformity is 3.8 to 4.7 vs 4.8 to 26 for bottom ash. Bottom ash tends to have a lower specific gravity (2.2 to 2.4) vs 2.5 to 2.7 for slag. Most of the samples would meet ASTM specifications for aggregates.

The angle of internal friction for ash and slag in loose condition was 38 to 42°.

Bottom ash loses its stability when it dries out, but blends of bottom ash and fly ash show good initial density and improved dry stability.

A 4.6.3.3 Power Plant Sludges (Reference 4.97)

In conventional lime-scrubbing process sludges, the major component besides fly ash is calcium sulfite hemihydrate.

The surface area of sludge particles as measured by the Blaine Index is more variable than would be expected from the particle size distribution.

A 4.6.4 Requirements and Specifications (Reference 4.91, 4.105)

A 4.6.4.1 Fly Ash in Portland Cement

- ASTM C 618-72 Standard Specifications for Fly Ash and Raw or Calcined Natural Pozzolans for Use in Portland Cement Concrete (Nov., 1972)

- Federal Specifications SS-P-570B (4/18/69) Pozzolan (For Use in Portland Cement Concrete)
- CRD-C 262-63 Corps of Engineers Specifications for Pozzolans for Use in Portland Cement Concrete (3/1/63).
- The most significant difference in the above three specification is that the allowable loss on ignition, which relates to carbon content, is 12.0% in ASTM vs 6.0% in the other two. Another difference is a 5.0% limit on magnesium oxide in the government specifications vs no specification in ASTM.

A 4.6.4.2 Fly Ash in Portland - Pozzolan Cement

ASTM C 595 Standard Specification for Blended Hydraulic Cement (Nov. 1972). Covers Type IP (general concrete construction), Type P (high). Early strength not required, Type IP-MS (moderate sulfate resistance and Type IP-LH (moderate heat of hydration).

Federal Specification SS-C-208C Cement, Portland-Pozzolan (11/21/60).

A 4.6.4.3 The Blaine Test

The Blaine test for specific surface is given in ASTM C 204-55 (Reapproved 1967) Standard Method of Test for Fineness of Portlant Cement by Air Permeability Apparatus.

A 4.6.5 Marketing

A 4.6.5.1 General Considerations (References 4.103, 4.96, 4.95)

Coal ash materials must be available in sufficient tonnages to permit developing markets. Markets must be pursued aggressively, cultivated, and given continuing attention to help solve the problems of the customer. These problems often have nothing to do with the performance of the ash, but nevertheless could result in a loss of markets if not attended to.

Selling fly ash is a full-time job. It is doubtful if an electrical utility would have the staff or the inclination to take on this task. A marketing company independent of the utility makes sense. It also has a legal advantage insofar as the marketer assumes responsibility for the material in application.

Transportation is the major cost in marketing fly ash. In Australia it was necessary to design and develop a bulk pneumatic tanker fleet capable of economically delivering fly ash over considerable distances. The tanker fleet has expanded into transportation of other bulk commodities.

A 4.6.5.2 Specific Recommendations

- The utility should use fly ash in all its own construction.
- Fly ash should not be designated as a waste product.
- Loading facilities should be readily accessible.
- Loading practices should be carefully worked out.
- Good housekeeping must be evident to assure the customer that trash and scrap materials are not being dumped into the ash.
- The marketer should not be charged a fixed price for every ton he sells. This encourages unscrupulous marketers to come in, make the easy sales, and depart, leaving no one responsible for follow-up.

Appendix A 4.7

SPENT STONE DISPOSAL-ASSESSMENT OF ENVIRONMENTAL IMPACT

The pressurized fluid bed combustion process results in the production of partially utilized dolomite or limestone material in the form of calcium sulfate ($CaSO_4$). This sorbent material may be regenerated for recycling to the fluid bed boiler for repeated sulfur dioxide (SO_2) removal or disposed of in its partially utilized form in a once-through system. Although the regenerative process has the advantage of decreased solid waste for disposition (Reference 4.111), there is still much uncertainty about it. In either case, the spent stone is composed of magnesium oxide (MgO), calcium sulfate, calcium oxide (CaO) [or calcium carbonate ($CaCO_3$)] when dolomite is used, and calcium sulfate, calcium oxide (or calcium carbonate) when limestone is used. The waste stone has particle size ranges of 0 to 0.635 mm (0 to 1/4 in). Factors affecting the final composition include composition of the fuel, composition of the limestone or dolomite, and operating conditions. The spent sorbent may be utilized as road-base aggregates, concrete and block fillers, neutralizing agents for acid mine drainage, and so on; or marketed for chemical recovery — sulfur recovery or magnesium oxide extraction. In this discussion, the environmental impact of the spent stone when it is dumped or used as a landfill is assessed.

A 4.7.1 Chemical Stability - References 4.112 and 4.113

Of the above compounds, calcium sulfate and calcium carbonate are most likely to be environmentally stable and suitable for direct disposal without further processing, as the abundance of naturally occurring limestone and gypsum deposits will attest. Calcium oxide will hydrate readily to form calcium hydroxide ($Ca[OH]_2$) with release of heat [64.041 J/g-mole (15,300 cal/g-mole)] on contact with water unless it is dead-burned. Recarbonation of calcium oxide will also occur with carbon dioxide in the ambient air in the presence of water or water vapor.

Magnesium oxide is virtually insoluble (0.0086 g/l) and does not hydrate under atmospheric pressure except in the case of commercially prepared reactive grades. When most types of dolomite quicklimes are hydrated under atmospheric conditions, all calcium oxide components readily hydrate, but very little of magnesium oxide slakes. As a result, high-calcium quicklime slakes much more readily than does dolomitic, which usually requires pressure or long retention periods for complete hydration because of its hard-burned magnesium oxide component.

Magnesium oxide occurs infrequently in nature as the mineral periclase; it is also the end product of the thermal decomposition of numerous magnesium compounds. The physical and chemical properties of magnesium oxides vary greatly with the nature of the initial material, time and temperature of calcination, and trace impurities. The increase in density which results from increasing calcination temperature is paralleled by a decrease in reactivity. Magnesium oxide, prepared in the temperature range of 673 to 1173°K (752 to 1652°F) from magnesium hydroxide or basic magnesium carbonate, is readily soluble in dilute acids and hydrates rapidly, even in cold water. Fused magnesium oxides are virtually insoluble in concentrated acids and are indifferent to water unless very finely pulverized. The oxides prepared below 1173°K (1652°F), which are easily hydrated with water, are known as caustic-burned magnesias. The unreactive magnesias, prepared at higher temperatures, are called dead-burned or sintered magnesias. The hydration rate of various magnesium oxides is determined by the active surface area and may vary from a few hours, in the case of the reactive oxides obtained at low temperatures, to months or even years for the dead-burned grades.

It is generally recognized that the dissociation temperature for calcite is 1171°K (1648°F) under atmospheric pressure in a 100% carbon dioxide atmosphere. The temperature of dolomite, however, is not nearly as explicit. Magnesium carbonate ($MgCO_3$) dissociates at a much lower temperature -- 675 to 753°K (756 to 896°F). Since the proportion of magnesium carbonate to calcium carbonate differs in the many species of dolomites, the dissociation temperature also varies. Differences in the crystallinity of stone also appear to add to the disparity of data. The magnesium carbonate component of dolomite decomposes at higher temperatures than do natural magnesites. A good average value for complete dissociation of magnesium carbonate in dolomite at 101.3 kPa (760 mm) pressure in a 100% carbon dioxide atmosphere is 998°K (1337°F); the calcium carbonate component of dolomite would, of course, adhere to the above higher value representing dual-stage decomposition. As a result of these differences in dissociation points, the magnesium oxide is usually hard-burned before the calcium oxide is formed.

From the above discussion it follows that there may be some question about the environmental stability of the magnesium oxide component of the spent sorbent mixtures calcium carbonate/calcium sulfate/magnesium oxide. With the fluid bed boiler conditions approaching 1228°K (1750°F) and 1.013 MPa (10 atm), it is expected that the magnesium oxide component is hard-burned and, therefore, suitable for disposal without further processing. Activity and leaching tests have been performed on the waste stone from the Argonne National Laboratory (ANL) 15.24 cm (6 in) fluid bed boiler and the Exxon Research and Engineering (Exxon) batch unit and miniplant and will be discussed in a later section of this appendix.

A 4.7.2 <u>Environmental Impact</u>

The environmental impact of any disposed material is a function of its physical and chemical properties and of the quantity involved. Potential water pollution problems can, in many cases, be predicted by chemical properties such as solubility, the presence of toxic metals, and the pH of leachates. Disposal of the spent stone from the fluid bed combustion system may create air pollution or an odor nuisance such as hydrogen sulfide, depending on the amount of calcium sulfide present, although it is not expected in significant quantities. Heat may be released on hydration of calcium oxide when the calcium in the spent stone exists in the calcined state if the combustion temperature is high enough to produce fully calcined dolomite.

The first consideration when looking at potential water pollution from the solid waste disposal is the volume of leachate that will be produced. This is a direct function of the amount of water reaching the landfill. There are two possible sources of this water: rainfall and naturally occurring subsurface flow through the landfill site. Subsurface flow is a natural phenomenon which can seriously interfere with safe operation of landfills in two ways. First, it is a source of additional, potentially harmful leachate. Second, it can serve as a direct means of groundwater contamination. Prevention can be effected by a thorough geological study of the site beforehand and, if needed, installation of rerouting devices for the groundwater flow. In a similar vein, coverage of the landfill area when complete will greatly reduce, if not eliminate, the amount of leachate produced.

In order to predict leachate characteristics of a landfill, it is first necessary to describe the general features of water movement and geological considerations for this disposal method. Due to the recent surge of ecological interest in sanitary landfills for solid waste disposal, there is an abundance of information available. Emrich's review of research in this field presents an overall perspective of progress on this subject (References 4.114 and 4.115). Research is being conducted to define and solve this problem, but results available to date are not sufficient to assess it fully (Reference 4.116).

A 4.7.3 <u>Experiments</u>

Under EPA contract 68-02-0605 leaching experiments and activity tests were performed in order to assess the potential environmental impact of the spent stone from the pressurized fluid bed combustion process and its suitability for disposal as a landfill material. The samples used in these experiments were the spent sorbents from the ANL and Exxon pressurized fluid bed combustion pilot plants [partially sulfated Tymochtee dolomite from ANL run C2 and C3 (Reference 4.117) and partially sulfated Grove limestone 1359 from Exxon run 8.4 (Reference 4.118)]. As calcium sulfate was a major constituent of the waste stone from the pressurized fluid bed combustion processes, a naturally occurring calcium sulfate (ground gypsum 114 of -20 mesh from Fort Dodge, Iowa) was selected to undergo similar leaching conditions for comparative purposes. Table A 4.7.1 summarizes the chemical compositions of the ANL and Exxon spent stones as well as the Iowa gypsum.

Table A 4.7.1 - Chemical Compositions of Spent Stone from ANL and Exxon Pressurized Fluid Bed Combustion Pilot Plants and Iowa Ground Gypsum 114

Composition, %	ANL Spent Stone	Exxon Spent Stone	Gypsum 114
$CaSO_4$	57	26	74.0
$CaCO_3$	9	58	1.8
CaO	2	7.6	--
CaS	<0.05	<0.05	--
MgO	20	0.8	0.2
H_2O (combined)	--	--	19.0
Others	12	7.6	5.0

A 4.7.3.1 Leaching Tests

Procedures

A series of leaching experiments was designed to study leachate characteristics as functions of the varying parameters and procedures to induce leachates, as follows:

1. Mixing time - 250 ml of deionized water was mixed with 25 g of waste stone in a 500 ml Erlenmeyer flask. The mixture was agitated for various lengths of time using an automatic shaker (Eberback) at 70 excursions per minute and room temperature. The supernatant resulting from this operation was passed through

a Whatman No. 42 filter. The filtrate was used for determination of pH, specific conductance, calcium, magnesium, sulfate, sulfide, and trace metal concentrations.

2. Stone load - 250 ml of deionized water was mixed with different amounts of spent stone and shaken for 24 hours. The supernatant was filtered and analyzed.
3. Mixing mode - shaking versus nonshaking: 250 ml of deionized water was mixed with 25 g of waste stone. The mixture was allowed to sit for 86.4 ks (24 hr) at room temperature with and without shaking. The supernatant was filtered and analyzed.
4. Sample compaction - 25 g of sample stone, either in its original size or ground to fine powder, was isostatically pressed at 68.95 to 344.74 MPa (10,000 to 50,000 psi) into pellet form and then immersed in 250 ml for 86.4 ks (24 hr) for nonshaking leaching time. The supernatant was filtered and analyzed.
5. Run-off tests - Deionized water was dripped at a constant rate onto 25 g ANL waste stone which was packed manually in a cylindrical column of 1.1 cm (0.43 in) diameter and 21.3 cm (8.375 in) height. Successive 250 ml leachates were collected and monitored for pH, specific conductance, calcium, magnesium, and sulfate.

Results

Table A 4.7.2 summarizes the chemical characteristics (pH, specific conductance, calcium, magnesium, sulfate, sulfide, and trace metal concentrations) of leachates induced from the ANL waste stone under conditions corresponding to the severest cases and compares them with leachates from a natural gypsum and with water quality standards set by the Commonwealth of Pennsylvania (Reference 4.119), the U.S. Public Health Service, and the World Health Organization (Reference 4.129)

Table A 4.7.3 presents results from leaching tests on the ANL waste stone and Iowa gypsum No. 114 using the procedures described previously. Calcium and sulfate concentration, pH, and specific conductance of the leachates were shown as functions of batch mixing time, between 1 and 96 hours, in Figure A 4.7.1. Leaching Procedure 1 was used for inducing the leachates. In Figure A 4.7.2 calcium, sulfate, pH, and specific conductance were plotted as functions of stone loading from 1 to 50 g of sample stone in 250 ml deionized water using Procedure 2. Characteristics of leachates from a natural gypsum induced under identical conditions are also shown in Figures A 4.7.1 and A 4.7.2 for comparison. A shaking versus nonshaking mode of leaching was studied using Procedure 3 and results summarized in Table A 4.7.3. Procedure 4 was used in an attempt to compact sample stone into dense pellets so that water permeability might be reduced, but the pellets crumbled on contact with water and resulted in leachates similar to those from the unpressed samples. Finally, a run-off test was carried out on ANL waste stone using Procedure 5. Figure A 4.7.3 shows the calcium concentration, sulfate, pH, and specific conductance for successive 250 ml leachates collected. Such data would be useful in cases where stone washing before disposal or leachate treatment was needed.

Conclusions

Results from leaching tests on ANL spent stone from the pressurized fluid bed combustion process indicated that:

- In both the leaching-time experiment (Figure A 4.7.1) and the stone-loading experiment (Figure A 4.7.2), calcium and sulfate dissolution plateaued at concentrations limited by the calcium sulfate solubility.
- The equilibrium calcium and sulfate concentrations were high, exceeding the water quality criteria. Since calcium sulfate occurs abundantly in nature as gypsum, leachates induced from a natural gypsum offers a good reference for its calcium and sulfate concentrations. Iowa ground gypsum No. 114 was selected to undergo parallel leaching tests with the ANL waste stone. Results indicated that gypsum leachates contained approximately the same amounts of dissolved calcium and sulfate ions as the ANL leachates.

Both agreed relatively well with the calcium sulfate solubility, and both exceeded the water quality standards, 75 mg/l for calcium and 250 mg/l for sulfate.

- There was negligible dissolution of magnesium ions.
- Insignificant amounts of heavy metal ions were found in the leachates.
- ANL leachates were alkaline, with pH = 10.6 to 12.1. It is interesting to note, however, that the run-off leachates showed a gradual decrease in pH with the amount of leachates passing through.

Results from the leaching experiments on ANL spent stone agreed well with those reported by the British Coal Utilization Research Association (BCURA) (Reference 4.121) and Pope, Evans and Robbins (PER) (Reference 4.122) in that the leachates had high pH, calcium, and sulfate, and negligible magnesium ions. The difference between the PER and BCURA findings in the extent of calcium and sulfate extraction was, in the light of the Westinghouse stone-loading and mixing-time studies, largely due to the difference in the stone-to-water ratio and the leaching time of their experiments. The Westinghouse results also indicated that it is unlikely that the heavy metal ions in the leachates from pressurized fluid bed combustion processes will cause water pollution. The solutions were alkaline, but the run-off tests showed a gradual decrease in pH with the amount of water passing through. Superficially, the calcium and sulfate concentrations in the leachates might suggest the possibility of a water pollution hazard from these ions, but it must be emphasized that the conditions in these experiments were much more extreme than those that would exist in actual cases, where water percolation is minimized. The fact that equally high calcium sulfate dissolution was found in gypsum leachates under identical conditions offers a useful comparison. Further tests using much larger quantities of material and taking into consideration geocriteria such as topography, geology, hydrology, and soil conditions of the actual landfill site are needed to determine fully the environmental impact of spent stone disposal.

Activity Test

Heat release experiments were carried out on the following samples to determine their reactivity toward water:

1. Spent sorbent from ANL pressurized fluidized bed combustion process of run C2/C3 (Reference 4.91) - sulfated Tymochtee dolomite, -14 mesh
2. Tymochtee dolomite, -16 +18 mesh
3. Spent sorbent from Exxon pressurized fluidized bed combustion process of run No. 8.4 (Reference 4.92) - sulfated limestone 1359, -8 +80 mesh
4. Limestone 1359, -16 +18 mesh
5. Limestone 1359, -18 +35 mesh
6. Calcined limestone 1359 at 1233°K (1760°F) -18 +35 mesh.

In each of the above tests, 3 g of stone was added to 20 ml of deionized water in a Dewar flask which had been thermally equilibrated. Iron-constantan thermocouples were used to monitor the temperature rise in the stone/water system with an Omega cold junction compensator and a digital voltmeter readout. Table A 4.7.4 summarizes the maximum temperature rise and time required for reaching the temperature. Less than 0.2°K (0.36°F) temperature rise was found for the above samples 1 to 5 but a temperature rise of 55°K (99°F) was found for sample 6. The great contrast between the calcined limestone and the other samples indicated the validity of the experiment as well as the lack of reactivity of the ANL and Exxon spent stones with water. Although it can be safely assumed that no heat pollution will result if these particular batches of spent stone are subjected to rainfall after disposal, it must be pointed out that the activity and heat release properties of the spent sorbent are functions of the operating conditions of the fluid bed combustion process.

Table A 4.7.4 - Summary of Stone Activity Tests

Samples	Stone/H_2O	ΔT_{max}, °C (°F)	t_{max}
ANL Spent Stone -14 mesh	3 g/20 ml	0.1 (0.18)	--
Tymochtee Dolomite -16 +18 mesh	3 g/20 ml	0.1 (0.18)	--
Exxon Spent Stone -8 +80 mesh	3 g/20 ml	0.2 (0.36)	5 s
Limestone 1359 -16 +18 mesh	3 g/20 ml	0.1 (0.18)	--
Limestone 1359 -18 +35	3 g/20 ml	0.1 (0.18)	--
Calcined Limestone 1359 -18 +35 mesh	3 g/20 ml	55 (99)	4 to 20 s

A. 4.7.4 Conclusions and Recommendations

The pressurized fluid bed combustion process results in the production of spent solids in the form of partially sulfated limestone or dolomite. The long-term stability and the suitability for its disposal into the environment have been discussed. Laboratory leaching and activity tests have been initiated. Preliminary results indicate that it would probably not cause water and heat pollution. It must be remembered, however, that the physical and chemical properties of the spent sorbent are functions of the operating conditions of the pressurized fluid bed process and that the physical characteristics of the specific disposal site must be judged individually in evaluating the leaching properties of the spent stone.

To assess fully the environmental impact of spent sorbent, further tests on stone analyses, leaching properties, heat release properties, landfill properties, and air emission should be performed.

Appendix A 4.8

PRESSURIZED COMBUSTOR SUBSYSTEM PROGRAMS

The calculations of the performance of the pressurized combustor subsystem were done by the program PCOMB, written in BASIC. A series of subroutine files were also created which, when merged with PCOMB, supplied properties of the combustion products for the various fuels. GASPROP 3 is included here to demonstrate the form which these subroutine files take. The polynomial coefficients for the other fuels are given in Appendix A 4.1, Table A 4.1.1.

For cases with integrated low-Btu gasifiers, some additional logic is required. GASPROP 15 is merged with PCOMB and any of the combustion product subroutine files in order to provide the means of calculating the performance of the integrated low-Btu gasifier-combustor sybsystems. GASPROP 15 also has the capability, in cases where process steam for the gasifier is not available externally, of calculating the required utilization waste heat for process steam generation. This includes the determination of whether cooling of the product fuel gas is required for steam generation and if so, to what temperature the fuel must be cooled. Redundant statements replace statements in the main program or in the subroutine files.

```
40 REM        THIS PROGRAM CALCULATES THE PERFORMANCE OF A PRESSURIZED
41 REM        COMBUSTOR SUB-SYSTEM.  IN ORDER TO USE, MERGE WITH ANY
42 REM        OF THE SUB-ROUTINE FILES FOR PROPERTIES OF AIR AND PROD-
43 REM        UCTS OF COMBUSTION.
44 REM
45 REM         GASPROP1 DIRECT FIRED ILL#6 BITUMINOUS
46 REM         GASPROP2 DIRECT FIRED MONTANA SUB-BIT.
47 REM         GASPROP3 DIRECT FIRED NORTH DAKOTA LIGNITE
48 REM         GASPROP4 LOW-BTU FUEL GAS, FLUIDIZED BED, T-750
49 REM         GASPROP5 SYNCRUDE DISTILLATE
50 REM         GASPROP6 HIGH-BTU FUEL GAS
51 REM         GASPROP7 LOW BTU FUEL GAS, FLUIDIZED BED, T=550
52 REM         GASPROP8 DIRECT-FIRED ILL #6 BIT., ISO CONDITIONS
53 REM         GASPROP9 DIRECT-FIRED ILL#6 BIT., ISO AIR, NON-ISO PROD.
54 DIM D(10),K(30),P(30),R(30),T(30),G(10),C(10),B(10),O(10),A(10)
55 DATA 59,290
65 DATA 14.7,.0075,.0039
70 DATA 1,.98,.985
80 PRINT "COMPLETE OUTPUT? (1=YES,2=NO)"
85 INPUT H1
100 READ T(1),T(10)
102 READ H1,L
105 READ P0,D(1),D(6)
109 READ E(1),E(6),E(7)
112 READ S0
114 PRINT"INPUT TURB INLET TEMP"
116 INPUT T(5)
117 PRINT "INPUT COMP PR"
118 INPUT X
120 Z=(T(5)-1280)/6400
125 IF Z<0 THEN Z=0
126 Z1=Z
130 E(1)=.8847-(.00317*X)
140 IF X=5 THEN E(5)=.911
141 IF X=10 THEN E(5)=.919
142 IF X=15 THEN E(5)=.924
143 IF X=20 THEN E(5)=.927
145 PRINT "INPUT RECUP EFFECT"
147 INPUT E(3)
150 IF E(3)=0 THEN D(2)=0
155 IF E(3)=0 THEN D(4)=0
160 IF E(3)>0 THEN D(2)=.015
165 IF E(3)>0 THEN D(4)=.015
172 PRINT "INPUT FUEL EQUIV"
175 INPUT V
176 PRINT "INPUT D(3)"
177 INPUT D(3)
178 PRINT "INPUT D(5)"
179 INPUT D(5)
180 T=T(1)+460
190 GOSUB 9000
200 K(1)=H
210 GOSUB 9050
220 R(1)=R
225 P(1)=P0*(1-D(1))
230 P(2)=X*P(1)
240 R(2)=X*R(1)
250 R=R(2)
260 GOSUB 9140
270 K(2)=H
280 K(3)=K(1)+(K(2)-K(1))/E(1)
290 H=K(3)
300 GOSUB 9270
310 T(3)=T
320 GOSUB 8000
330 T=T(5)+460
340 GOSUB 9320
350 K(5)=H
360 GOSUB 9410
370 R(5)=R
380 P(5)=P(2)*(1-D(2))*(1-D(3))
390 P(6)=P0/((1-D(6))*(1-D(5))*(1-D(4)))
400 Y=P(6)/P(5)
410 R(6)=Y*R(5)
420 R=R(5)
430 GOSUB 9570
```

```
440 K(6)=H
450 K(7)=K(5)-((K(5)-K(6))*E(5))
455 K(8)=((1-Z)*(1+(V*S0))*K(7)+Z*K(3))/((1-Z)*(1+(V*S0))+Z)
456 V=V*(1-Z)
457 GOSUB 3000
460 H=K(8)
470 GOSUB 3300
480 T(8)=T
481 V=V/(1-Z)
482 GOSUB 8000
484 IF E(3)=0 THEN 490
485 IF T(8)>T(3) THEN 490
487 PRINT "RECUPERATION IS NEGATIVE...RUN IS INVALID"
488 GO TO 1025
490 T(4)=E(3)*(T(8)-T(3))+T(3)
500 T=T(4)
510 GOSUB 9000
520 K(4)=H
530 Q(1)=((1/(V*S0))*K(4))+(L+H1)-(((1/(V*S0))+1)*K(5))
540 Q(2)=Q(1)*(1-Z)*V*S0
550 PRINT "Q1=";Q(1);"BTU/LB FUEL"
555 PRINT "Q1=";Q(2);"BTU/LB COMP AIR"
557 V=V*(1-Z)
560 PRINT "COOLING AIR FRACTION=";Z1
561 K(11)=(K(4)/(1+(V*S0)))+(((V*S0)/(1+(V*S0)))*(H1+L))
562 IF K(11)>700 GO TO 568
563 H=K(11)
564 GOSUB 9900
565 T(11)=T
566 PRINT "ADIABATIC FLAME TEMPERATURE=";T(11)-460;"DEG F"
567 GO TO 570
568 PRINT "ADIAB. FLAME TEMP EXCEEDS RANGE OF ACCURACY"
570 K(9)=K(6)-((1-Z)/(1+((1-Z)*V*S0)))*(K(4)-K(3))
571 V=V*(1-Z)
572 GOSUB 8000
580 H=K(9)
590 GO SUB 9900
600 T(9)=T
605 PRINT "T(4)=";T(4)-460;"DEG F"
610 PRINT "T(9)=";T(9)-460;"DEG F"
615 IF D(5)=0 THEN T(10)=T(9)
616 IF D(5)=0 THEN K(10)=K(9)
617 IF D(5)=0 THEN 660
620 T(10)=T(10)+460
630 T=T(10)
640 GOSUB 9300
650 K(10)=H
651 V=V/(1-Z)
660 Q(3)=(K(9)-K(10))*((1+V*S0)*(1-Z)+Z)
670 PRINT "Q2=";Q(3);"BTU/LB COMP AIR"
675 P1=(K(3)-K(1))*(3600/3413)
677 P2=(1-Z)*(1+V*S0)*(K(5)-K(7))*(3600/3413)
680 P=P2-P1
685 PRINT "COMPRESSOR POWER=";P1;"KW/LB COMP AIR/SEC"
686 PRINT "TURBINE POWER   =";P2;"KW/LB COMP AIR/SEC"
687 PRINT "TOTAL POWER     =";P;"KW/LB COMP AIR/SEC"
688 PRINT "NET POWER       =";P*E(6)*E(7);"KW/LB COMP AIR/SEC"
700 IF M1=2 THEN 705
701 PRINT TAB(4);"STAGE";TAB(15);"P";TAB(27);"T";TAB(39);"R";TAB(51);"K"
702 FOR I=1 TO 10
703 PRINT TAB(6);I;TAB(10);P(I);TAB(22);T(I);TAB(34);R(I);TAB(46);K(I)
704 NEXT I
705 T(10)=290
1025 GO TO 114
10100 END

END PRINT ON      072375  110024
```

```
60 DATA 2228.89,2060.0
62 DATA .4346,0,.1594,.2152,.0837,.0757,0,.0315,0
65 DATA 14.7,.0075,.0039,24.08
75 DATA .699,.552,4.28,2.86
90 PRINT "NEED STEAM GENERATION? (1=YES,2=NO)"
95 INPUT M3
101 READ L,T(17)
102 FOR I=1 TO 9
103 READ A(I)
104 NEXT I
105 READ PO,O(1),D(6),M
106 T=T(17)
107 GOSUB 9981
108 H1=H3
112 READ SO,F3,F4,F5
191 F6=F4/F5
193 F2=Z+((1-Z)/(1+(V*SO/F6)))
195 Z=Z/F2
205 Z=Z*(1+V*SO/F6)
277 PRINT "FOR LOW BTU FUEL GAS,FL. BED,T=550"
521 T=T(17)
522 GOSUB 9981
535 Q(1)=Q(1)*F2
665 Q(3)=Q(3)*F2
678 P2=P2*F2
710 T(15)=1010
715 T=T(15)
720 GOSUB 9000
725 K(15)=H
730 T(12)=610
735 T=T(12)
740 GOSUB 9000
745 K(12)=H
750 GOSUB 9050
755 R(12)=R
760 R(13)=1.5*R(12)
765 R=R(13)
770 GOSUB 9140
775 K(13)=H
780 K(14)=K(12)+((K(13)-K(12))/0.8)
785 K(11)=K(3)+K(13)-K(14)
790 H=K(11)
800 GOSUB 9270
805 T(11)=T
810 Q(4)=(K(11)-K(12))*((1-Z)/(1+(F6/V*SO)))
812 PRINT "FOR THE GASIFIER SUBSYSTEM"
815 PRINT "Q3=";Q(4);"BTU/LB COMP AIR"
817 PRINT "T(11)=";T(11)-460;"DEG F"
820 W5=(F3/F4)*V*SO*F2
823 H1=H3
825 W6=V*SO*F2/F4
830 PRINT "STEAM REQUIRED=";W5;"LB/LB COMP AIR"
835 PRINT "COAL REQUIRED=";W6;"LB/LB COMP AIR"
840 P3=(K(13)-K(12))*((1-Z)/(1+(F6/V*SO)))
842 P3=P3*(3600/3413)
845 PRINT "BOOSTER COMPRESSOR POWER=";P3;"KW/LB COMP AIR/SEC"
850 P4=14.4*V*SO*F2
855 PRINT "GASIFIER AUX. PWR=";P4;"KW/LB COMP AIR/SEC"
860 PRINT "TOTAL POWER DEBIT=";P3+P4;"KW/LB COMP AIR/SEC"
862 PRINT "NET POWER (AFTER DEBIT) =";P*E(6)*E(7)-P3-P4;"KW/LB COMP AIR/SEC"
865 IF M1=2 THEN 890
870 PRINT TAB(4);"STAGE";TAB(15);"P";TAB(27);"T";TAB(39);"R";TAB(51);"K"
875 FOR I=11 TO 15
880 PRINT TAB(6);I;TAB(10);P(I);TAB(22);T(I);TAB(34);R(I);TAB(46);K(I)
885 NEXT I
890 T(20)=391.6
891 IF M3=2 THEN 1025
895 T(21)=T(20)+50+460
900 T=T(21)
905 GOSUB 9320
910 K(21)=H
912 K5=1175*W5
913 K6=349.1*W5
915 Q5=F2*(1+(V*SO*(1-Z)))*(K(9)-K(21))
916 Q9=Q5+K6
917 IF Q9>=K5 THEN Q5=K5-K6
```

```
920 T(22)=T(21)-(16.0/Q5)*(T(9)-T(21))
925 IF T(22)>750 THEN 940
930 PRINT "PATCH UNSUCCESSFUL"
935 GO TO 1025
940 IF Q9>=K5 THEN 1000
941 T=T(21)
945 GOSUB 9000
950 K(21)=H
955 Q6=(K(11)-K(21))*((1-Z)/(1+(F6/V*S0)))
960 Q7=16.0+Q5+Q6
961 IF Q7>=K5 THEN Q6=K5-Q5-K6
962 IF Q7>=K5 THEN 1000
965 Q8=K5-Q7
966 W9=F4*W6
970 K(17)=H1-Q8/W9
975 T(17)=T(17)-(Q8/W9)/.265
980 T=T(17)
985 GOSUB 9981
990 K1=H3
995 K2=K(17)-K1
996 IF K2>1 THEN 998
997 IF K2>-1.0 THEN 1000
998 T(17)=T(17)-K2/.265
999 GO TO 980
1000 PRINT "FUEL TEMP=";T(17)-460;"DEG F"
1001 PRINT "Q(2) USED=";Q5+16.0;"BTU/LB COMP AIR"
1005 PRINT "Q(3) USED=";Q6;"BTU/LB COMP AIR"
1010 PRINT "Q(4) USED=";Q8;"BTU/LB COMP AIR"
1011 PRINT "FUEL ENTHALPY=";K1
1015 PRINT "FINAL STACK GAS TEMP=";T(22)-460;"DEG F"
1016 T(17)=2060.0
1017 Q6=0
1018 Q8=0
1019 T(22)=750
1020 T=T(17)
1021 GOSUB 9981
1022 H1=H3
1025 GO TO 114
9981 REM SUB FOR FUEL ENTHALPY = F(T)
9982 B(1)=5.09960263E-07+T*(-1.95674801 4E-10+2.541732919E-14*T)
9983 B(1)=4.167925117E+02+T*(6.973862801+T*(-1.599350656E-04+T*B(1)))
9984 B(2)=9.240212044E-07+T*(-5.684665209E-10+1.091519372E-13*T)
9985 B(2)=4.145273717E+02+T*(7.030265516+T*(1.408905755E-05+T*B(2)))
9986 B(3)=-2.706914462E-07+T*(1.675255134E-10-3.000034225E-14*T)
9987 B(3)=4.014249577E+02+T*(6.867783058+T*(2.509019251E-04+T*B(3)))
9988 B(4)=5.14452134E-07+T*(-2.176529747E-10+3.041974531E-14*T)
9989 B(4)=4.174267924E+02+T*(6.953798593+T*(-7.077733279E-05+T*B(4)))
9990 B(5)=-1.083524666E-06+T*(2.347004966E-10-2.319432625E-14*T)
9991 B(5)=4.903788263E+02+T*(8.409138611+T*(3.180226902E-03+T*B(5)))
9992 IF T>1000 THEN 9996
9993 B(6)=6.006657161E-07+T*(-2.904377262E-10+5.794580715E-14*T)
9994 B(6)=4.785562712E+02+T*(7.980869961+T*(1.87543267E-04+T*B(6)))
9995 GO TO 9998
9996 B(6)=4.824960665E-07+T*(-1.397136194E-10+1.364115701E-14*T)
9997 B(6)=4.199317293E+02+T*(8.150824784+T*(8.78278704E-05+T*B(6)))
9998 B(7)=2.20416235E-06+T*(-1.44518297E-09+1.957051164E-13*T)
9999 B(7)=5.616395226E+02+T*(8.289967068+T*(-4.892433851E-04+T*B(7)))
10000 B(8)=3.498819056E-06+T*(-1.849749429E-09+2.935054065E-13*T)
10001 B(8)=5.305596817E+02+T*(8.4[illegible]5646145+T*(1.148635708E-03+T*B(8)))
10002 B(9)=3.[illegible]27246185E-06+T*(-2.[illegible]25351399E-09+4.706916953E-13*T)
10003 B(9)=5.[illegible]36403625E+02+T*(1.0[illegible]38195E+01+T*(3.475398257E-03+T*B(9)))
10004 FOR I=1 TO 9
10005 C(I)=A(I)*B(I)+C(I-1)
10006 NEXT I
10007 H3=C(I)/N
10008 RETURN

END PRINT ON      072375  105855
```

```
60 DATA 30.7365
75 DATA .166
112 READ S0
276 DATA .9,.88,.886,.9,.9,.98,.985,.166
277 PRINT *FOR DIRECT-FIRED N. DAKOTA LIGNITE*
8000 REM SUB FOR INTERPOLATION ON V
8010 IF V<.25 THEN 8140
8020 IF V>.33 THEN 8060
8030 J1=(V-.25)/(.33-.25)
8040 J=1
8050 GO TO 8180
8060 IF V>.5 THEN 8100
8070 J1=(V-.33)/(.5-.33)
8080 J=2
8090 GO TO 8180
8100 IF V>1. THEN 8160
8110 J1=(V-.5)/(1.-.5)
8120 J=3
8130 GO TO 8180
8140 PRINT *V IS TOO LOW*
8150 STOP
8160 PRINT *V IS TOO HIGH*
8170 STOP
8180 RETURN
9000 REM SUB FOR H=F(T) AIR
9010 H2=2.93445O411E-08*T*(-8.586883109E-12+9.039401158E-16*T)
9020 H2=-9.908467607E+01+T*(2.558042349E-01+T*(-3.087323016E-05+T*H2))
9030 H=H2
9040 RETURN
9050 REM SUB FOR PR=F(T) AIR
9060
9070 R1=2.697160644E-08*T*(3.450982192E-12+4.736244672E-15*T)
9080 R1=-3.430639434+T*(1.333399018E-02+T*(-1.945354143E-05+T*R1))
9090
9100
9110
9120 R=R1
9130 RETURN
9140 REM SUB FOR H=F(PR) AIR
9150 IF R>90 THEN 9190
9160 H2=3.262238919E-03*R*(-2.572566624E-05+7.996310265E-08*R)
9170 H2=2.130205861E+01+R*(8.585680893+R*(-2.098648054E-01+R*H2))
9180 GO TO 9250
9190 IF R>600 THEN 9230
9200 H2=1.777639515E-05+R*(-2.242293201E-08+1.125635622E-11*R)
9210 H2=1.154049837E+02+R*(2.0373070 76+R*(-7.387609014E-03+R*H2))
9220 GO TO 9250
9230 H2=5.486871982E-07+R*(-2.072015101E-10+3.179185049E-14*R)
9240 H2=2.155097006E+02+R*(7.661480303E-01+R*(-7.830672271E-04+R*H2))
9250 H=H2
9260 RETURN
9270 REM SUB FOR T=F(H) AIR
9280 T1=-2.762396916E-06+H*(4.832237733E-09-2.604227588E-12*H)
9290 T1=3.994612345E+02+H*(4.146688522+H*(-2.050110336E-04+H*T1))
9300 T=T1
9310 RETURN
9320 REM SUB FOR H=F(T) COAL-GAS
9325
9330 A(4)=1.712189743E-08+T*(-5.415360064E-12+5.660302159E-16*T)
9335 A(4)=-9.842567749E+01+T*(2.443774459E-01+T*(-2.293959583E-05+T*A(4)))
9336
9340 A(3)=3.006228438E-08+T*(-9.430675665E-12+1.046895349E-15*T)
9345 A[3]=-9.982854936E+01+T*(2.549849935E-01+T*(-2.485043933E-05+T*A(3)))
9350 A(2)=2.430305061E-08+T*(-7.255393729E-12+7.608810061E-16*T)
9355 A(2)=-9.870519111E+01+T*(2.510239665E-01+T*(-1.954370323E-05+T*A(2)))
9360
9370 A(1)=2.552502979E-08+T*(-7.578505203E-12+7.956290841E-16*T)
9375 A(1)=-5.879708355E+01+T*(2.521810541E-01+T*(-2.228607309E-05+T*A(1)))
9380
9390 H=J1*(A(J+1)-A(J))+A(J)
9400 RETURN
9410 REM SUB FOR PR=F(T) COAL-GAS
9420
9425
9430 A(4)=1.55159975E-07+T*(-6.168420 34E-11+2.619187288E-14*T)
9436 A(4)=-1.487418083E+01+T*(7.494754957E-02+T*(-1.472253998E-04+T*A(4)))
```

```
9435
9440 A(3)=6.157772318E-08+T*(-1.436724156E-11+1.22041088E-14*T)
9445 A(3)=-6.188032689+T*(2.877854879E-02+T*(-5.293546621E-05+T*A(3)))
9450 A(2)=4.460577052E-08+T*(-5.706223136E-12+9.097134124E-15*T)
9455 A(2)=-4.694318201+T*(2.369723791E-02+T*(-3.60773468E-05+T*A(2)))
9460
9470 A(1)=-1.670215005E-07+T*(7.153313833E-11-1.846720613E-15*T)
9475 A(1)=2.171642933E+01+T*(-1.176106722E-01+T*(2.215028824E-04+T*A(1))).
9480
9490
9495
9500
9505
9506
9510
9515
9520
9530
9540
9550 R=J1*(A(J+1)-A(J))+A(J)
9560 RETURN
9570 REM SUB FOR H=F(PR) COAL-GAS
9580 IF R>30 THEN 9650
9590 A(4)=1.278499932E-03+R*(-6.951104801E-06+1.458413058E-08*R)
9595 A(4)=3.049682188E+01+R*(5.572820811+R*(-1.173141502E-01+R*A(4)))
9600 A(3)=2.031800428E-03+R*(-1.324540322E-05+3.341964569E-08*R)
9605 A(3)=2.590173541E+01+R*(7.501812383+R*(-1.565467203E-01+R*A(3)))
9610 A(2)=2.361192274E-03+R*(-1.635572493E-05+4.392554149E-08*R)
9615 A(2)=2.446223456E+01+R*(7.828956324+R*(-1.717768638E-01+R*A(2)))
9620 A(1)=2.552971457E-03+R*(-1.824779596E-05+5.062065175E-08*R)
9625 A(1)=2.370211304E+01+R*(8.005957269+R*(-1.802965232E-01+R*A(1)))
9630
9640 GO TO 9750
9650 IF R>600 THEN 9710
9660 A(4)=3.905108511E-06+R*(-2.790737374E-09+7.930192379E-13*R)
9665 A(4)=1.398677737E+02+R*(1.278624963+R*(-2.803105557E-03+R*A(4)))
9670 A(3)=7.433896749E-06+R*(-6.971521419E-09+2.524678502E-12*R)
9675 A(3)=1.304340984E+02+R*(1.555498324+R*(-4.203942735E-03+R*A(3)))
9680 A(2)=1.026451436E-05+R*(-1.054866470E-08+4.292048665E-12*R)
9685 A(2)=1.245228852E+02+R*(1.719874179+R*(-5.197357721E-03+R*A(2)))
9690 A(1)=6.305448942E-06+R*(-3.518250955E-09+2.398495466E-13*R)
9695 A(1)=1.197404413E+02+R*(1.75189940 3+R*(-4.504631425E-03+R*A(1)))
9700 GO TO 9750
9710 A(4)=7.367857149E-08+R*(-1.354279115E-11+9.987521004E-16*R)
9715 A(4)=2.608206024E+02+R*(4.037349159E-01+R*(-2.120556309E-04+R*A(4)))
9720 A(3)=1.432566838E-07+R*(-3.441659063E-11+3.277750099E-15*R)
9725 A(3)=2.516944958E+02+R*(4.980325398E-01+R*(-3.229659323E-04+R*A(3)))
9730 A(2)=2.667593193E-07+R*(-7.774661132E-11+9.164164355E-15*R)
9735 A(2)=2.318761418E+02+R*(6.088042391E-01+R*(-4.893610113E-04+R*A(2)))
9740 A(1)=3.17887458E-07+R*(-9.866669382E-11+1.239944714E-14*R)
9745 A(1)=2.279099438E+02+R*(6.438275274E-01+R*(-5.491522497E-04+R*A(1)))
9750 H=J1*(A(J+1)-A(J))+A(J)
9760 RETURN
9770 REM SUB FOR PR=F(H) COAL-GAS
9780
9790 A(4)=3.07202925E-06+H*(4.179776129E-09+4.29730213E-12*H)
9795 A(4)=9.080646578E-01+H*(4.03662429E-02+H*(4.483737799E-04+H*A(4)))
9800 A(3)=2.276752257E-06+H*(4.539582184E-09+1.853021734E-12*H)
9805 A(3)=1.005933459+H*(3.379731839E-02+H*(5.43007845 7E-04+H*A(3)))
9810 A(2)=2.483717795E-06+H*(3.679833816E-09+1.750367117E-12*H)
9815 A(2)=1.025738778+H*(3.510065149E-02+H*(4.915086082E-04+H*A(2)))
9820 A(1)=4.213979446E-07+H*(8.608102319E-09-2.105729702E-12*H)
9825 A(1)=-3.990026172E-01+H*(5.99157797E-02+H*(5.277292908E-04+H*A(1)))
9830
9840
9845
9850
9855
9860
9870
9880 R=J1*(A(J+1)-A(J))+A(J)
9890 RETURN
9900 REM SUB FOR T=F(H) COAL-GAS
9905
9910 A(4)=-2.944403648E-08+H*(1.107908426E-09-6.783374095E-13*H)
9915 A(4)=3.998671927E+02+H*(4.03330927+H*(-1.203319527E-03+H*A(4)))
```

```
A(3)=-1.46C313441E-C6+H*(3.227552345E-C9-1.832212149E-12*H)
A(3)=3.996360038E+C2+H*(4.C84985847+H*(-7.375219906E-G4+H*A(3)))
A(2)=-1.542872984E-C6+H*(3.113747465E-C9-1.686962C89E-12*H)
A(2)=3.995424427E+C2+H*(4.1C8C41832+d*(-6.363554878E-C4+H*A(2)))
A(1)=-1.816179912E-C6+H*(3.492545594E-C9-1.88563CC18E-12*H)
A(1)=3.995175972E+02+H*(4.117591727+H*(-5.384752416E-C4+H*A(1)))


T=J1*(A(J+1)-A(J))+A(J)
RETURN
```

END PRINT ON C72375 1128C1

*USGPO: 1976 — 660-301