COAL FEED COMPONENT TESTING FOR CDIF

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The significantly higher temperatures, pressures and power densities of magnetohydrodynamic (MHD) combustors, along with the need to utilize low-sulfur, high moisture content coals in very dry form, makes preparation and injection for this type of electric power system quite different from that of current commercial electric power plants. In addition, "seed" material must also be injected at high pressure to enhance electrical conductivity of the high temperature gases.

Investigations conducted during the conceptual design of the Montana MHD Component Development and Integration Facility (CDIF) identified commercially available processing and feeding equipment potentially suitable for use in a reference design. Tests on sub-scale units of this equipment indicated that they would perform as intended.

Studies on open-cycle MHD topping cycle, steam bottom cycle electric power generating plants indicate such systems have the potential of achieving a 50 percent efficiency (coal-pile-to-busbar) at a competitive cost of electricity.

Accordingly, a national goal for MHD has been established that calls for the "Development of a commercially acceptable system for conversion of coal to electric power by a combined MHD-Steam cycle by 1989."

In order to achieve this goal, two major objectives have been established by ERDA:

1. <u>Near-Term Objective</u> (1985)

Design and test MHD components and sub-systems and to integrate these into system tests to be conducted in the pilot scale Engineering Test Facility (ETF) which could be available as early as 1982.

2. <u>Mid-Term Objective</u> (1990)

To develop and operate a commercial scale demonstration MHD electric power plant before 1990, fueled by coal, in an environmentally acceptable manner.

Continue development, after 1990, of MHD technology to improve the performance, reliability and benefits of commercialization of MHD. This will make more efficient use of coal as commercial plants begin to come on line.

The inherently higher temperatures, pressures and power densities of MHD combustors, however, will require new approaches to coal preparation and injection. Utilization of lower rank, low-sulfur, high-moisture-content coals will influence system design.

The coal-feed system development studies presented in this paper are the result of investigations conducted during the conceptual design of the Montana MHD Component Development and Integration Facility (CDIF), the first of the essential facilities in the MHD program of the Energy Research and Development Administration.

The CDIF located in Montana near the Industrial Park 5 miles south of Butte, occupies approximately 50 acres of a 93-acre site. The facility specifications call for a highly flexible 50 thermal megawatt size, multiple test train facility for (1) MHD component developmental testing and (2) determination of the component and subsystem interactions. Coal and seed processing and injection are an important aspect of the major design development program required to develop MHD to a viable commercial status.

The CDIF conceptual design project established a set of requirements for prepared coal characteristics as a result of several MHD combustor design studies. Existing coal processing and injecting systems for commercial power plants were investigated and found to be inherently inapplicable to MHD requirements.

The coal fired combustor designs proposed for CDIF employed a coal combustion process residence time of the order of 50-70 millisec. Seed vaporization residence time is less than 50 millisec. Variations in feed rate with respect to time and space in the short residence system will adversely affect combustor performance. The net result is to require that the coal and seed feed systems be dependable, extremely uniform in their dense phase feed injection rates and be able to be closely controlled.

Studies by AVCO, Westinghouse, General Electric, UTSI, and others have shown that optimum cycle efficiency for plants employing near-term technical feasibility require combustor conditions of 5-8 atmospheres combustion pressure, and plasma discharge temperatures greater than 4600°F. If air only is used (i.e. no oxygen additive) the combustor air inlet temperature must exceed 2500°F, (depending upon the type of coal used) in order to achieve the 4600°F flame temperature. In the case of the CDIF, Montana Rosebud, a sub-bituminous coal, is the reference fuel and the inlet temperature of the combustion air must exceed 2900°F.

Figure 1 shows the coal combustor proposed for initial tests in CDIF. Table I lists the characteristics of the Rosebud Coal. Figure 2 shows a block diagram of the subsystems making up the CDIF conceptual system.

Early in the evaluation of the status of technology of dry power feed system it became obvious that mechanical metered feed systems could not be used and that gas conveyance and injection appeared to be the only technically feasible method for feeding the K_2CO_3 seed material, and powdered coal fuel into the plug-flow MHD combustors.

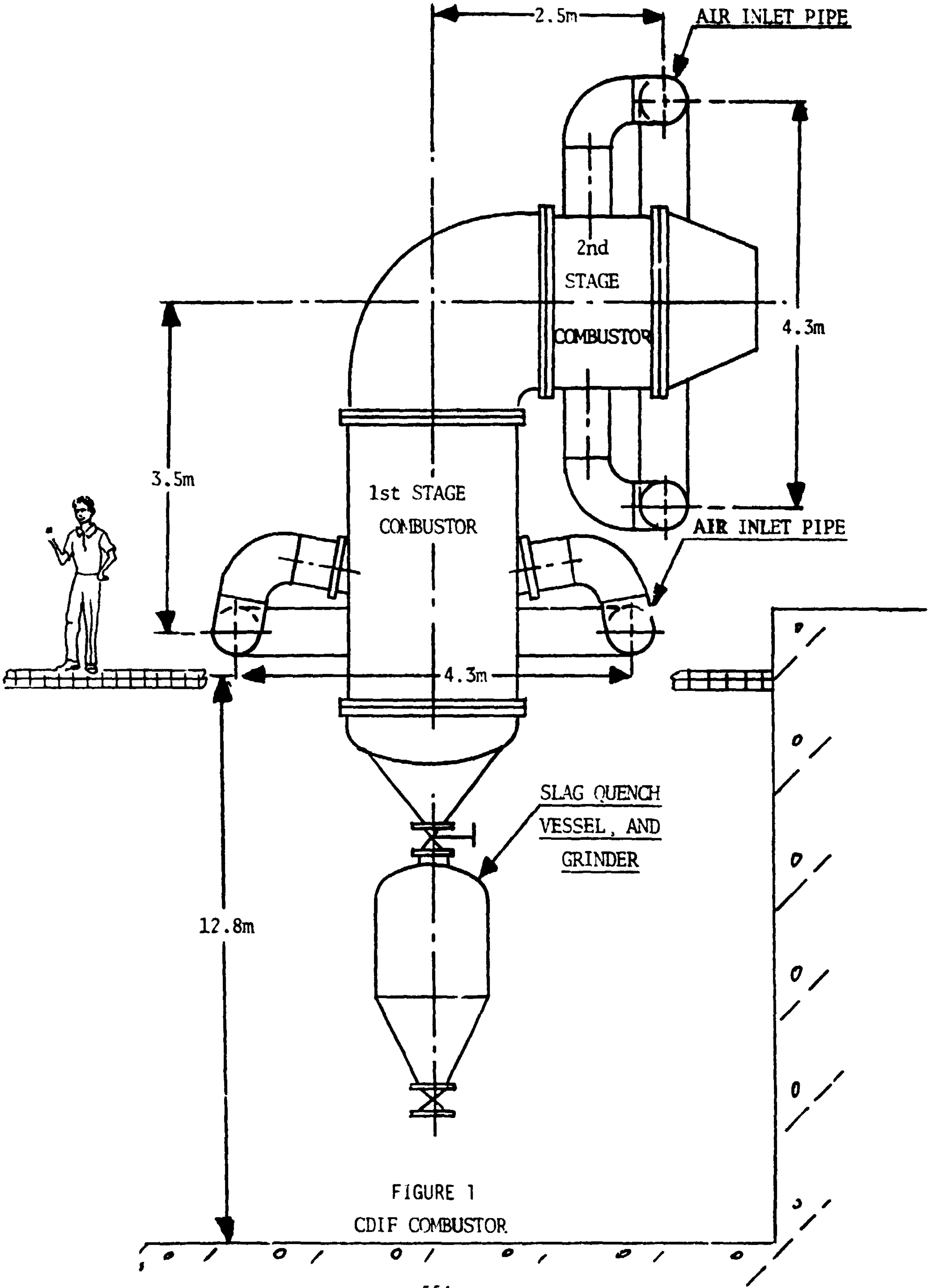


FIGURE 1
CDIF COMBUSTOR

Table 1

CDIF Reference Coals

	Montana Rosebud Nominal (3)	Montana Rosebud Range (1, 2, 3)	Illinois #6 Nominal (4)	Illinois #6 Range (2)
1.0 Ultimate Analysis				
%, Moisture Free				
Hydrogen	4.6	2.8-6.4	4.8	-
Carbon	65.6	61.8-69.4	68.5	-
Nitrogen	1.0	0.9-1.1	1.3	-
Oxygen	14.4	12.4-16.4	9.2	-
Sulfur	1.1	0.4-5.0	3.6	1.0-6.7
Ash	13.0	6.0-17.0	12.5	7.9-17.5
2.0 Ash Analysis, %				
SiO_2	47.5	22-55	44.7	38-5[illegible]
Al_2O_3	21.1	12-25	20.9	13-26
CaO	14.5	5-20	5.8	2-8.5
Fe_2O_3	7.8	2-20	24.1	9-30
MgO	4.6	2.2-7.0	1.8	0.4-2.3
TiO_2	0.8	0.2-1.4	1.0	0.5-1.5
K_2O	0.7	0-1.5	2.3	0.8-2.7
Na_2O	0.4	0-1.2	0.6	0.2-0.8
P_2O_5	0.4	0.1-0.7	0.12	0.06-0.24
3.0 Proximate Analysis, moisture free				
Volatile	37.7	34-42	41.7	30-42
Fixed Carbon	47.6	43-52	45.8	40-52
4.0 Moisture, as received, %	25.5	20-35	9.0	4-9
5.0 Heating Value				
Dry BTU/lb	11,300	10,650-11,950	12,400	11,700-12,800
6.0 Fusions				
Initial Deformation Temp, °F	2244	1960-2420	1960	1890-2040
Softening Temp, °F	2278	1990-2470	2030	1960-2100
Fluid Temp, °F	2362	2040-2520	2260	2060-2460

References:

(1) Reserves and Properties of Rosebud McKay Coal Seams in SE. Montana, D. Brelsford, MERDI, March 1976, ERDA Contract E(49-18)-1811, Task J2.

(2) Coal Conversion Systems Technical Data Book, Institute of Gas Techology, February 1976, ERDA Contract E(49-18)-1730.

(3) Data from (163) full seam, core samples. Colstrip mine, Rosebud seam area C & D, Private communication from Montana Power Company.

(4) Nominal PERC supplied data.

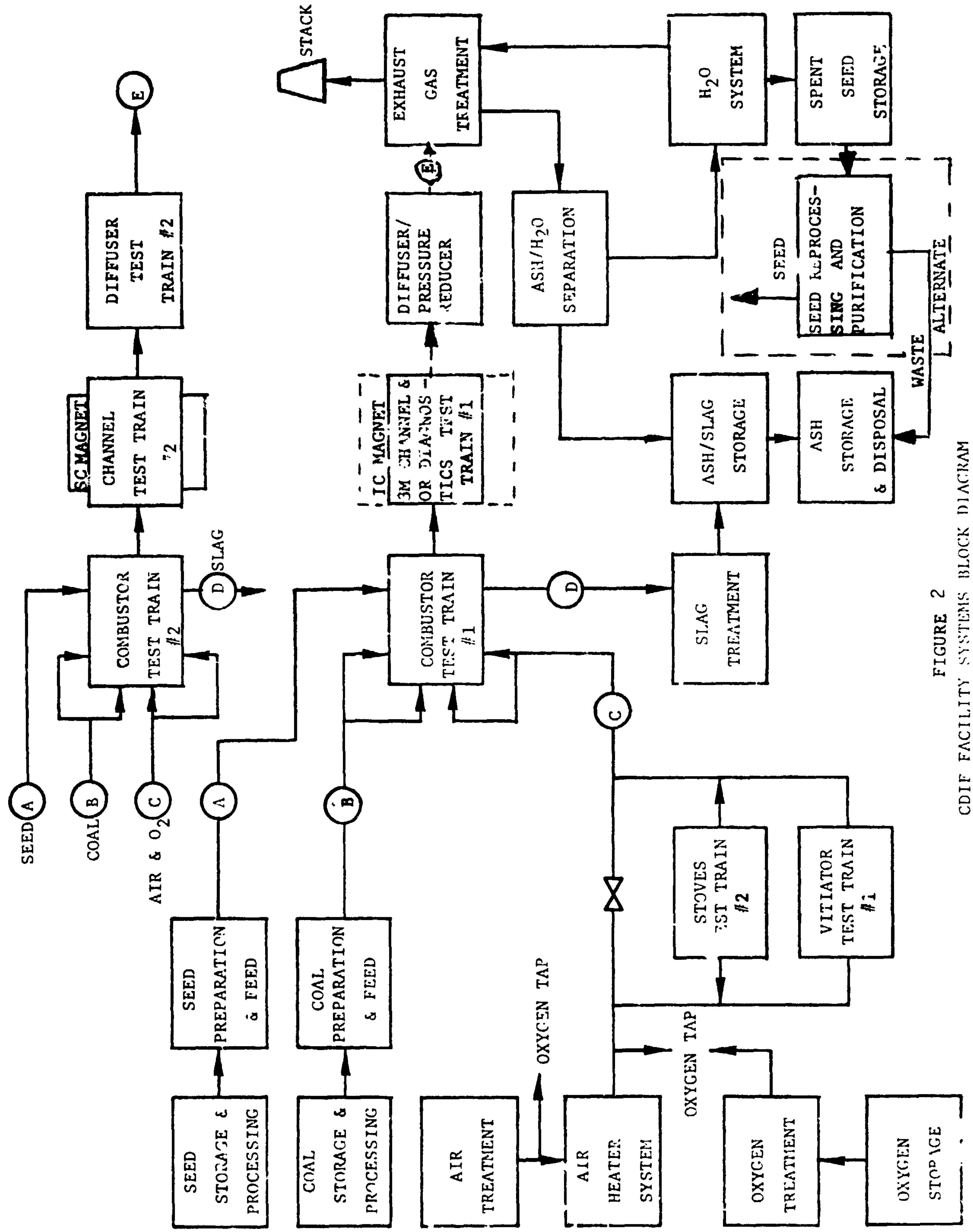


FIGURE 2
CDIF FACILITY SYSTEMS BLOCK DIAGRAM

The limited study conducted in connection with the CDIF conceptual design included assessment of utility experience with handling and preparation of Montana sub-bituminous coals, survey of existing technology for applicability to the preparation, feeding of sub-bituminous coals under MHD requirements and proof testing to verify design assumptions and commercial vendor assertions. Because of the tight schedule for development of the conceptual design, the program could not afford the luxury of an extensive evaluative program. Instead, due to the expediency of time, reference systems were selected based on proven experience in other applications. The individual components were selected on an engineering judgment basis and then tested to assure that they would work as intended. Those components having large commercial usage under conditions closest to the MHD requirements were given first consideration.

The CDIF conceptual design specified dense phase coal injection (as high as 35 pounds of coal per actual cubic foot of transport gas, or more), at high pressures (up to 10 standard atmospheres). This is considerably different from typical commercial power plant feed practices that use the primary air to convey dilute-phase, pulverized coal directly into the furnace at essentially atmospheric pressure.

In conventional commercial plants moisture is removed from the coal only for the purpose of improving its Hardgrove grindability. The moisture thus removed from the coal ultimately goes back into the furnace with the primary air. Dilute-phase feed and high moisture content fuel are inappropriate for

MHD for several reasons. The need for dense phase coal injection for the sake of achieving extremely high plasma temperatures precludes the use of the relatively cool pulverizer sweep air for coal transport and injection into the furnace. Instead, the MHD system requires separation of the coal from the pulverizer sweep air. This ultimately complicates the coal preparation system by introducing the need for bag filters, cyclones and/or other coal and air separation means.

An additional requirement is imposed by the use of low rank western coals having high moisture contents, (as high as 20% to 30%). In the MHD system moisture imposes a penalty on flame temperature and plasma conductivity, thus requiring the drying of coal to as low as 1% to 2% total moisture content for greatest advantage. Accomplishment of this degree of moisture removal requires higher drying temperatures which, coupled with the high pyrophoricity of sub-bituminous and lignite coals, greatly enhances the probability of explosion and fire and demands the need for oxygen control in the pulverizing and injecting gas systems.

Evaluation of the effects of these commercial application conditions on the MHD combustor performance indicated that certain penalties for less than optimum performance would be incurred. The net effect of inability of the commercially available components to meet all the MHD system requirements was assessed in terms of effect on combustor-power channel performance and total system response to the anomalies generated. In the final analysis, a trade-off was made to determine which off-design conditions created by the use of commercial state-of-the-art feed system components could be tolerated most in this test facility. Of all the off-design conditions, those tending to reduce combustor flame temperature appeared to [illegible] the easiest compensated for (i.e.. add oxygen to raise the flame temperature). Uniformity of flow and feed rate was considered to be the most critical. Consequently, all system design features were optimized in order to produce optimum uniform air, coal and seed flow conditions.

Figures 3 and , show the effect of air inlet temperature and coal moisture content on flame temperature.

The CDIF conceptual design verification tests for the coal and seed feed systems included processing and feeding Montana Rosebud coal and K_2CO_3 powder through equipment considered to be best capable of meeting the CDIF requirements. These tests also gave the manufacturer the necessary experimental data that in turn could be used to recommend the proper size equipment for the conceptual design.

Ten barrels of coal were obtained by the Montana Energy Research Development Institute from the Peabody mines and shipped to Williams Patent Crusher Co., St. Louis to be roller milled to the size and dryness necessary for safe and dependable storage, handling and feeding in an inert gas storage and lock hopper feed injection system. Both McKay and Rosebud seam coals were tested in these preliminary assessments of commercial capability.

A roller type mill was selected because of its ability to be adjusted to produce uniform size over a wide range of preselected gradations. Since CDIF is to test different types of combustors, the flexibility of the roller mill over other types of mill became an important consideration. Tests were run to determine ability to produce pulverized coal ranging from a coarse 75% - 10, + 100 mesh; and less than 15% fines, down to 95% through - 200 mesh. Moisture content in the dried coal was to be less than 2% (mine-mouth water content is normally in excess of 25% for combined surface and bound moisture.) The tests indicated that with proper adjustment, the coarse coal size range

FIGURE 3
EFFECT OF COMBUSTION
AIR TEMPERATURE ON FLAME
TEMPERATURE

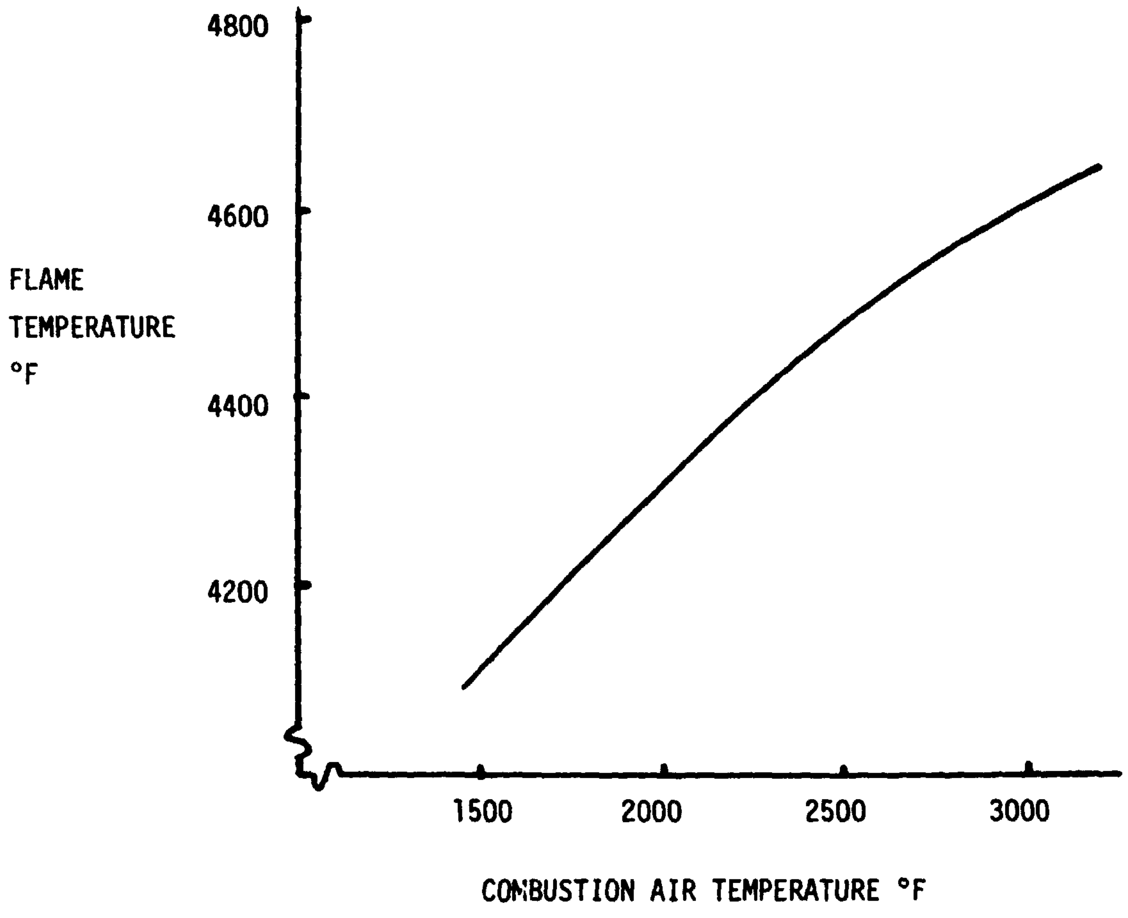
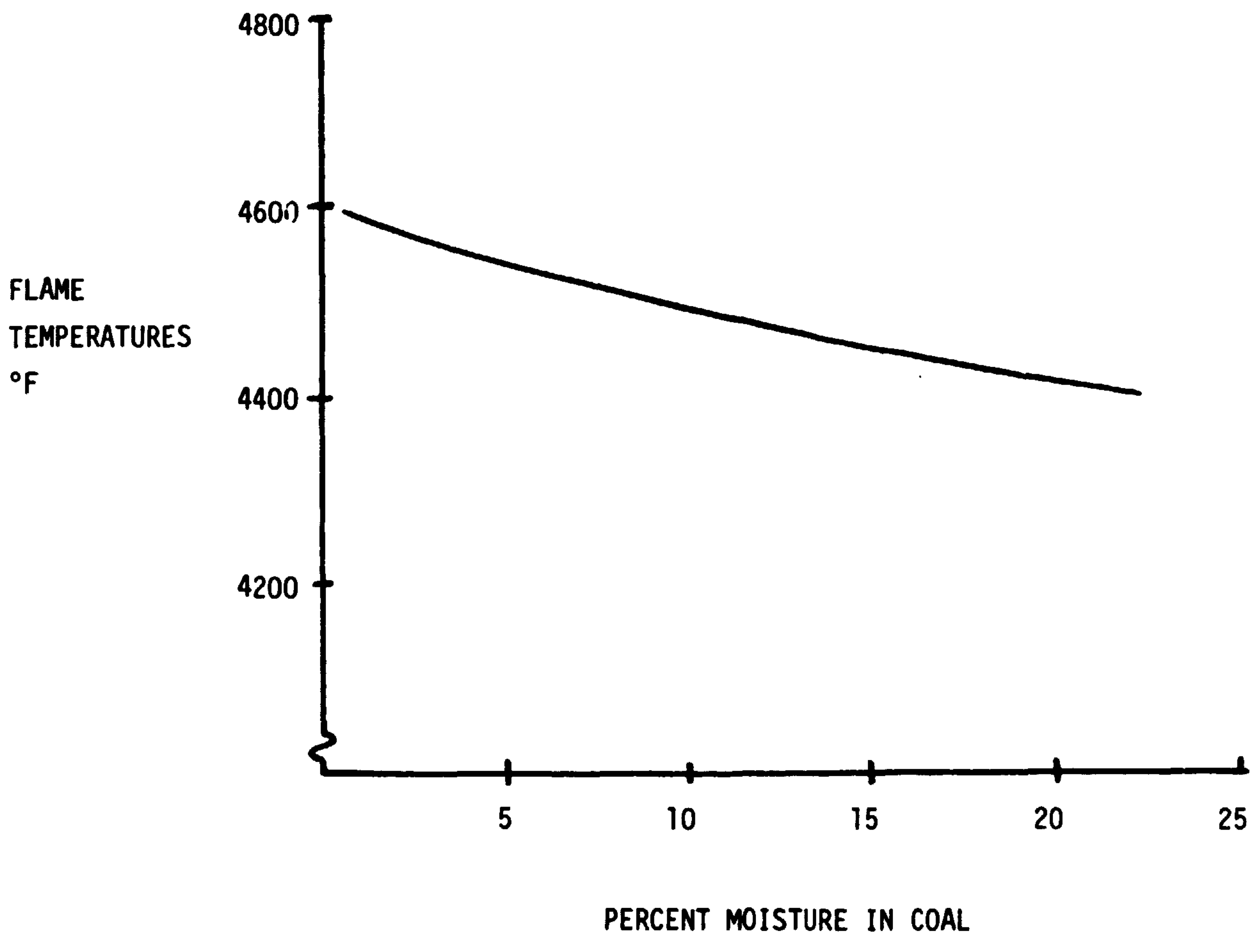


FIGURE 4
EFFECT OF MOISTURE IN ROSEBUD
COAL ON FLAME TEMPERATURE



could be dried to 4% total moisture and the fine size range could be dried to 2%, in a single drying stage without using excessive drier temperatures or complicated additional equipment. Based on the tests to determine how the Montana Coal pulverized and dried, the manufacturer determined the recommended size and capacity of the roller mill, separator, air heater, bag house and fan to process the 25 tons/hour of moist coal for CDIF.

The 10 barrels of coal supplied to the Williams Patent Crusher Co. for the processing tests were then reloaded into the barrels and three barrels of 90%-325 mesh pulverized and dried (~2% moisture) coal was sent to Petrocarb Inc. for feed flow tests. The fine material was used because previous experience in the industry had indicated that fine material was more difficult to feed than coarse material. Also, since one of the CDIF combustor study designers had specified a fineness down to 80%-325 mesh, this particular size was used in the tests.

The Petrocarb tests consisted of two distinct feed flow tests on a special mini-injector. The first series were designed to determine whether a sample of dried Rosebud Coal sized 90% minus 325 mesh could be injected at controlled rates between 15 and 42 pounds per minute when feeding into a receiver pressurized to 100 psig and at atmospheric pressure.

The second series was intended to determine whether calcined, pulverized potassium carbonate could be fed at rates between 5 and 15 pounds per minute when feeding into a receiver pressurized to 100 psig.

The experimental test equipment used included a special "Mini Injector" which has a storage capacity of approximately two cubic feet and which is capable of feeding at rates consistent with a one-half inch Mix-Tee and transport line (or smaller). This unit is normally used by Petrocarb for preliminary evaluations to obtain data on characteristics of materials to be injected. The unit was arranged for feeding through a 25 foot length of 0.5 inch diameter reinforced rubber hose into the receiver maintained at atmospheric pressure.

A special Petrocarb Model 24 Injector that can be equipped to feed from a few pounds to several hundred pounds per minute into a receiving vessel that can be operated at pressures up to 100 psig was used for the high pressure receiver tests.

The test procedure involved manually filling the injectors after screening through a 1/8 inch mesh sieve to remove any tramp material. The receiving vessel was mounted on a platform scale used to measure the weight of material transported from the injector to the receiver. Material was fed for timed intervals designed to demonstrate repeatability and rate control as a function of differential pressure between the two vessels. Dry nitrogen gas was used for pressurizing and transport of the dried coal. The pressure and gas flow rates were manually controlled with regulating valves and monitored by flow indicating rotameters and pressure gages.

The "mix-tee" and transport line each were 1/2 inch diameter. The transport line consisted of 40 feet of horizontal and 21 feet of vertical 1/2 inch Schedule 80 pipe followed by a 180° bend and about 15 feet of 0.88 inch ID hose into the top of a pressurized receiver injector. The outlet vent of the pressurized receiver was equipped with a cotton dust bag.

The test to determine coal flowability and controllability consisted of filling the injector hopper and pressurizing to 15 psig. The coal was observed to flow smoothly and the injector ran completely empty without interruption.

The injector hopper was then refilled and the time for feeding 5 pounds of coal was measured. Each of eight consecutive five-pound batches took 18 seconds which corresponds to 16.6 pounds per minute. This was regarded by Petrocarb as good repeatability.

A series of runs were then made at pressures varying from 5 to 35 psig injector pressure and two different transport gas flow rates. These data are presented in Figure 5. The curves are plotted with pressure as the ordinate and solids rate as the abscissa. The curves illustrate the effect of the volumetric flow rate of transport gas on solids flow rate as well as the pressure in the injector. The preliminary result with the "Mini" Injector fully justified continuing the test with the larger scale equipment to demonstrate the capability of the Petrocarb Injector to feed controllably and uniformly against elevated back pressures.

A second series of tests was made with the Special Model 24 Injector feeding into a receiver which was maintained at atmospheric pressure. A third series of tests were made with the receiver maintained at 100 psig. Three high pressure runs were made using 15.2 SCFM, 12.8 SCFM, and 10.1 SCFM transport gas additions, respectively. The resulting test data are plotted in the set of curves shown in Figure 6. Two of the curves were observed to cross at approximately 40 pounds per minute coal flow rate. This is due to the fact that 10.1 SCFM additional transport gas is slightly inadequate at the higher rates and thus the flow rate dropped off. This indicated that the test was not at the optimum minimum gas flow rate (i.e., the rate which will result in the maximum solids flow for a given injector pressure). This phenomenon will occur even though the solids flow is smooth and reproducible but would normally be avoided in practice by adding slightly more transport gas.

FIGURE 5

TEST WITH PETROCARB MINI INJECTOR

(1/2" MIX-TEE WITH 25' OF 0.5" DIAMETER HOSE - ATMOSPHERIC PRESSURE RECEIVER)

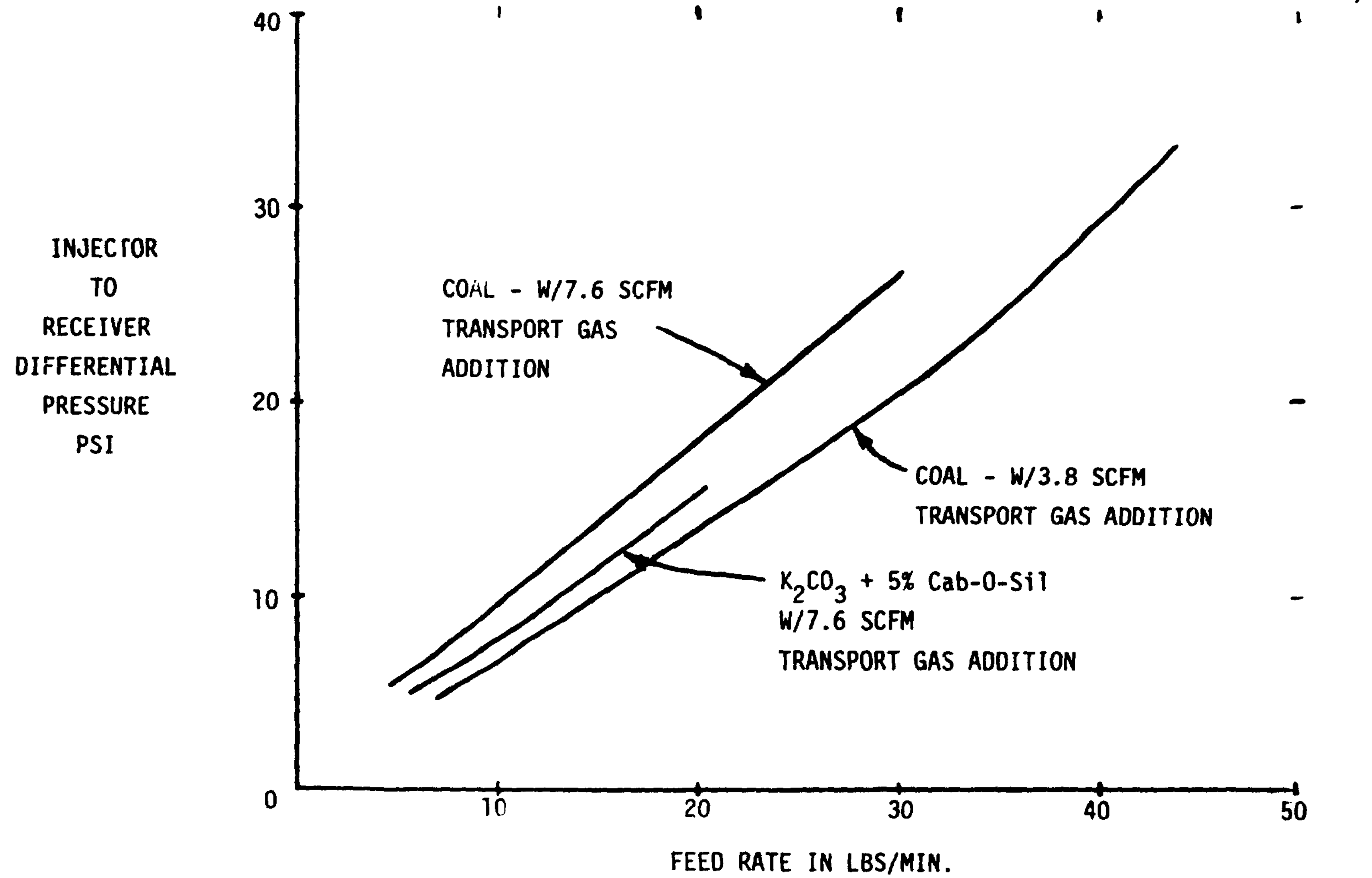
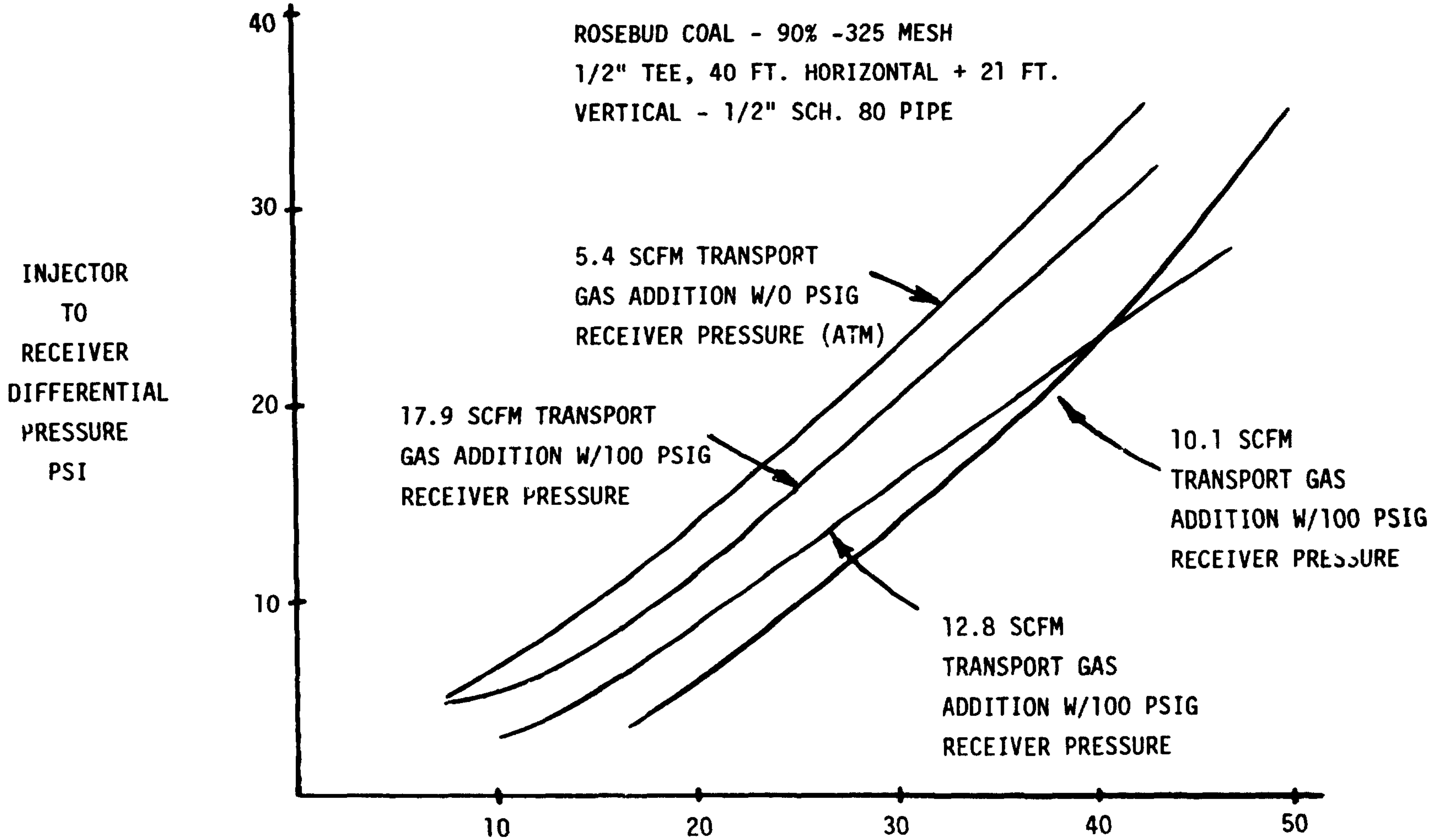


FIGURE 6
TEST DATA FOR PETROCARB
SPECIAL MODEL 24 INJECTOR



Based on the data obtained in the coal feed tests it was concluded that if the coal sample tested was truly representative, there should be no major problem in designing the system to feed coal uniformly at the flow rates of 15 to 42 pounds per minute for the CDIF in a system utilizing a number of 1/2 inch Schedule 80 pipe feed lines. The low end of the feed rate (15 lb/min) could be reduced further to 10 pounds per minute but the solids/gas ratio would have to be decreased somewhat. The feed mass flow rate ratio of 7 lbs coal/1 lb of air results in some dilution of the net gas inlet temperature, but the resulting decrease of approximately 60°F in the flame temperature was considered acceptable.

Two drums of calcined pulverized potassium carbonate (-325 mesh K_2CO_3 powder)were supplied for the seed feed tests. Even though the containers were sealed and the inner contents protected by plastic bags, the anhydrous solids were noticeably lumpy and agglomerated. The angle of repose was negative and the material very difficult to handle.

An attempt was made to inject this material in the "Mini Injector" but flow was sporadic and non-uniform. The equipment was very difficult to clean up and all valves and fittings required complete dismantling, cleaning, and drying.

Petrocarb recommended that consideration be given to adding a flow promoting reagent such as Cab-O-Sil (a fumed silica) to determine whether the potassium carbonate could be made flowable. However, several other small tests were made to study means of converting the K_2CO_3 to a more flowable form for feeding.

In one test the K_2CO_3 was heated in a small fluidizer to +300°F with the intent that moisture would be driven off and the solids converted into a flowable condition. The capability of feeding hot materials up to a temperature of about 1000°F were considered not to be unduly difficult if the properties of the solids were improved. However, preliminary tests indicate no improvement at temperatures up to 300°F, so the test was discontinued.

A similar test was made in a fluidizer to study the change in properties caused by additions of Cab-O-Sil. A marked improvement was obtained by the use of the flow agent. However, it was evident that because the carbonate on hand was lumpy, each mass of agglomerate required intimate hand mixing of the two materials. Had the carbonate been freshly pulverized, it is believed that a simple mixing would have sufficed. However, because of the encouraging results of Cab-O-Sil addition, a small test was conducted to prove that the treated carbonate could be injected reliably. About 75 pounds of carbonate was carefully mixed in small batches with 5% by weight of Cab-O-Sil. This work was done by manually rubbing materials together in plastic bags. Obviously, it is not practical to produce large samples for test by this means, but since this was a small batch test conducted in the "Mini Injector", this proved to be a practical expediency and provided a good feed material. Petrocarb indicated they could predict with good reliability extrapolation to large scale equipment based on these small scale tests.

The sample of 5% Cab-O-Sil and carbonate was fed at three different feed rates and the results are included on the plot in Figure 5 with the coal tests. Excellent correlations were developed that were then used as the basis for sizing and selection of a Petrocarb seed injector as a reference design for the CDIF concept. The injection work was thereupon terminated. Further testing will be necessary to establish long-term performance and reliability of this, or other MHD seed feed concepts.

One additional test was made which involved the mixing of incremental quantities of raw carbonate to the sample containing 5% Cab-O-Sil. This indicated that the Cab-O-Sil ratio to K_2CO_3 could be reduced to 2.5% without noticeably changing the flow properties of the mixture. As lesser percentages of Cab-O-Sil addition were made, the flow properties were noticeably poorer.

Conclusion

The coal and seed processing and feeding investigations conducted in connection with the CDIF Conceptual design identified commercially available equipment suitable for use in a reference design and established reference operation conditions for the desired performance of the coal and seed processing and feed systems. This information became a part of the conceptual design description and was provided to the Architect Engineer for his consideration in the preparation of the Title I design. Figure 7 shows the flow schematic of the 50 MW CDIF, coal feed system developed as a result of this preliminary coal feed system design development program for the CDIF.

Since this was a preliminary evaluation, it is recommended that further development be conducted to improve the processing and feed system components design and operation to improve the reliability, uniformity, and quality of performance. Special emphasis should be placed on improving flow measurement instrumentation and reduction of the conveyance air weight fraction.

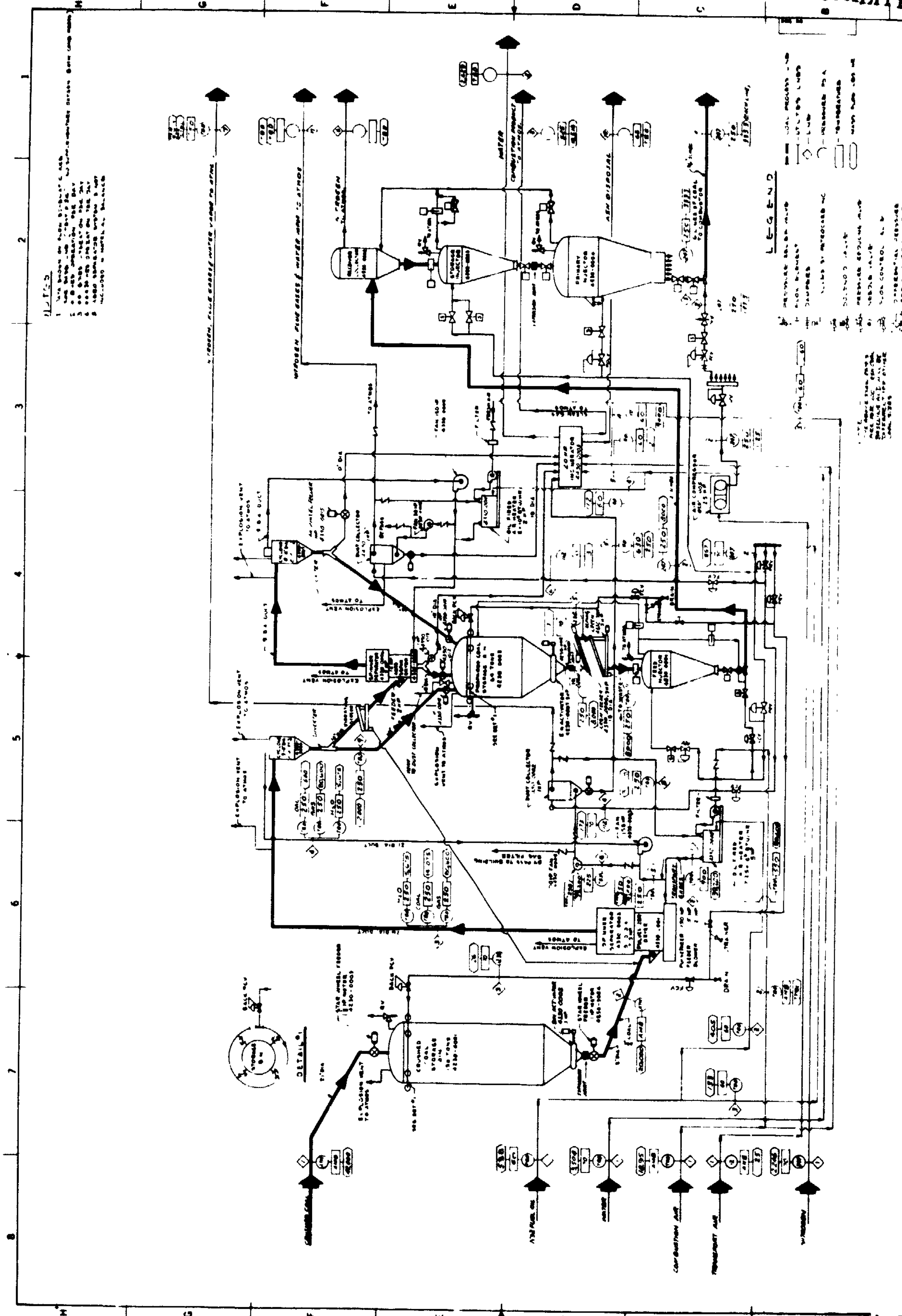


FIGURE 7. CDIF CONCEPTUAL DESIGN COAL FEED SYSTEM