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LITERATURE SURVEY OF PROPERTIES OF SYNFUELS DERIVED FROM COAL

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National Aeronautics and Space Administration
Lewis Research Center

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U.S. DEPARTMENT OF ENERGY
Energy Technology
Fossil Fuel Utilization Division

NOTICE

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SUMMARY

This report contains the interim results of a literature survey conducted by the NASA Lewis Research Center. The survey objective was to systematically assemble existing data on the physical, chemical, and elemental composition and structural characteristics of synthetic fuels (liquids and gas) derived from coal. Contained herein are literature survey results compiled to December 1977. The report includes the following:

1. A general description of fuel properties, with emphasis on those properties required for synfuels to be used in gas-turbine systems for industry and utilities
2. Descriptions of the four major concepts for converting coal into liquid fuels (i.e., solvent extraction, catalytic liquefaction, pyrolysis, and indirect liquefaction)
3. Data obtained from the literature on full-range syncrudes, various distillate cuts, and upgraded products for fuels derived by various processes - including H-Coal, Synthoil, Solvent-Refined Coal, COED, Donor Solvent, Zinc Chloride Hydrocracking, Co-Steam, and Flash Pyrolysis (The data are segregated into tables according to the processes by which they were derived, and they are also tabulated by fuel type so that fuels of similar cut can be compared for the various processes.)
4. Data plots illustrating trends in the properties of fuels derived by several processes
5. A source list and bibliography on syncrude production and upgrading programs
6. A listing of some Federal energy contracts for coal-derived synthetic fuels production and upgrading programs

Since information on synfuels is not readily available in the literature, additional information sources were used in compiling the survey, such as monthly contractor reports from ongoing Department of Energy projects and private correspondence. These sources are noted in the data tables where applicable. Since information on these fuels continues to become available, the survey will be updated at the end of fiscal year 1979 to include this new information.

INTRODUCTION

This report evaluates, through a literature survey, the elemental composition, structures, and physical and chemical properties of coal-derived fuels being produced in Department of Energy pilot plant and upgrading programs. Fuel impurity characteristics were tabulated for sodium, potassium, vanadium, lead, chlorides, sulfur, and such easily dissociated nitrogens as ammonia. The fuels that were investigated include low-Btu gas, heavy and light liquid distillates, and residual liquids. Fuels processed or characterized by NASA were not included within the scope of the effort.

Natural gas and no. 2 fuel oil have been used in ground-based gas turbines for industrial and utility applications. Because of the technology base developed through commercial and military research, these fuels are presently in wide use in open-cycle gas turbines for utility peaking service. Natural gas and no. 2 fuel oil are also used in combined gas-turbine/steam-turbine cycles for intermediate duty service. However, these clean fuels are becoming scarce and expensive and may not be available for future ground-based-turbine applications. Viable future fuels for ground-based gas turbines are heavy petroleum oils in the near term and fuels derived from coal in the future. Adapting gas-turbine technology for the use of coal-derived fuels requires the development of key capabilities.

To address this need, NASA and the ERDA Office of Fossil Energy began the Critical Research and Advanced Technology Support (CRT) project with the signing of Interagency Agreement EF-77-A-01-2593 on June 30, 1977. Upon creation of the Department of Energy on October 1, 1977, the project was assigned to the DOE Division of Power Systems, which was renamed the Fossil Fuel Utilization Division. The CRT project will provide a gas-turbine technical data base for the DOE Integrated Coal Conversion and Utilization Systems activities, which are aimed at developing improved central-station utility power-conversion systems that use coal and coal-derived fuels.

The technical objectives of the CRT project are

(1) To develop combustor concepts that will fire coal-derived fuels in an environmentally acceptable manner

(2) To develop a combustion and materials data base to aid in establishing fuel specifications for advanced, fuel-flexible, stationary power-conversion systems

(3) To develop acceptable ceramic coatings for use with coal-derived fuels

(4) To develop a corrosion data base for combustor and turbine materials exposed to combustion products of coal-derived fuels and to correlate the data in a corrosion-life prediction model

(5) To study the trade-offs between various gas-turbine technologies, operating conditions, and component designs

The literature survey, which is the subject of this report, is being conducted under the combustion portion of the CRT project (item 1). Additional combustion efforts include analytical modeling to determine combustor parameters that affect the conversion of fuel-bound nitrogen into oxides of nitrogen (NO_x); flame-tube experiments to evolve fundamental concepts for minimizing the conversion of fuel-bound nitrogen into NO_x; and evaluation of experimental combustors with coal-derived fuels at simulated gas-turbine-combustor operating conditions. Results of these combustion efforts will be reported in forthcoming publications.

In surveying the literature, it became apparent that sufficient information on coal-derived fuels is not readily available. Thus, additional information sources were used in compiling the survey. These additional sources included monthly reports from on-going DOE-sponsored projects and private correspondence. These sources are noted in the data tables where applicable. Since information on coal-derived fuels continues to become available, the survey will be updated to include additional data through fiscal year 1979.

DETAILS OF LITERATURE SURVEY

Since the emphasis of this survey is on fuels from those synthetic fuels processes that are furthest along in development, data on both the processes and the fuels are continually being generated and published in progress reports by the many contractors involved. Accordingly, no survey report can contain all the latest data on the fuels of most interest. However, this report should give the general status of characterization data available to December 1977 and the physical and chemical data needed for the CRT project but currently not being obtained.

This report is arranged in the following general format:

(1) FUEL PROPERTIES - This section includes a discussion of fuel properties of concern to the gas-turbine user and examples of the forms used to compile the data.

(2) COAL LIQUEFACTION PROCESSES - This section describes the four major processes for converting coal into liquid fuels.

(3) FUEL PROPERTIES DATA - This section contains physical and chemical fuel properties data, grouped by process.

(4) DISCUSSION - This section compares the properties of various coal-derived fuels. Also fuels from the different processes are grouped by distillate category.

(5) CONTRACT NUMBERS - This section includes a table of Federal energy contract numbers with author, company affiliation, and contract title. The contractor reports are included in the bibliography.

(6) SOURCES OF FUEL PROPERTIES DATA - This section contains a tabulation of references 1 to 32, from which the properties data were taken.

(7) BIBLIOGRAPHY - The bibliography lists the sources of the citations and all the published citations investigated in the literature study, by year of publication.

FUEL PROPERTIES

Examples of the fuel analysis sheets that were used to collect physical and chemical property data for coal-derived synthetic fuels are shown in table 1 for liquid fuels and in table 2 for low-Btu gases. The lists of properties in these tables were taken from a number of sources that recommended the appropriate fuel properties for applications of advanced gas-turbine systems.

Physical property data such as pourpoint, viscosity, and distillation range are important in determining the pumping, heating, and atomizing characteristics of the fuel. Chemical properties such as elemental composition and trace-metal analyses are important in determining the combustion, emissions, and corrosion characteristics of the fuel. An excellent discussion of the importance of many properties listed in tables 1 and 2 and the use of these fuels in gas-turbine combustion systems is contained in reference 27

Although it would be desirable to know values for all the listed properties for any given fuel, the current specifications placed upon gas-turbine fuels by users are much less comprehensive. Table 3, from reference 27, shows specifications for several types of liquid fuels for advanced gas-turbine industrial engines. The following comments on the importance of some of these specifications draw upon material contained in reference 27.

The ash and trace-metal contaminants, which are most likely to be concentrated in the higher boiling fractions during processing, can lead to turbine corrosion and deposits. Of the trace metals listed in table 1, the more critical ones appear to be vanadium, sodium, potassium, and lead.

Although no specifications are shown for the elemental compositions (C, H, N, S, O), the values of these are important in determining the combustion and emission characteristics of the fuel. Hydrogen content is a critical factor in controlling the smoke emission levels and the radiation properties of the gases in the combustor. The higher the hydrogen content of the fuel, the less tendency it has to smoke and the less tendency it has to radiate heat to the combustor walls. Fuel-bound nitrogen will contribute to the nitrogen oxide pollutant emissions, since varying amounts of fuel-bound nitrogen are converted to NO_x during the combustion process. Sulfur in fuel leads to sulfur oxides in combustion that, when combined with other trace metals, can corrode the turbine. Significant emission problems also occur with fuel-bound sulfur since it is totally converted to sulfur oxides in combustion.

The pourpoint and viscosity-temperature characteristics of the fuel are important in determining

(1) The fuel heating that may be required to pump fuel through the system

(2) The pump pressure requirements

(3) The fuel temperature required at the fuel nozzle for proper atomizing. (Maximum viscosities of 10 to 20 cS, depending on the fuel atomizer used, are set to obtain proper nozzle operation.)

The thermal stability of the fuel - which is the tendency to form deposits in fuel manifolds, fuel nozzles, and fuel heaters - is a most important property for the higher viscosity residual fuels. These fuels may require heating to high temperatures to meet the viscosity requirements.

Table 4, obtained from reference 27, shows some typical ranges of fuel properties applicable to current industrial gas-turbine systems.

COAL LIQUEFACTION PROCESSES

At least four major concepts have been developed for converting coal to liquids: solvent extraction, catalytic liquefaction, pyrolysis, and indirect liquefaction. Each concept is discussed briefly here, and the status of the most important processes that use the concepts is summarized. The technology for coal liquefaction is reviewed in detail in references 33 and 34.

Solvent Extraction

Solvent extraction is a liquefaction process in which coal is mixed with a coal-derived liquid containing relatively loosely bound hydrogen atoms. This liquid is usually called the recycle solvent. The solvent can transfer these loosely bound hydrogen atoms to the coal at temperatures to 500° C (932° F) and pressures to 275 atmospheres absolute. Heating breaks many of the physical interactions in the coal such as van der Waals forces and hydrogen bonding forces. Heating also breaks weak chemical bonds, and the solvent promotes hydrogen transfer to the broken bonds. Three processes have been developed for liquefaction of coal in the presence of a recycle solvent. In the first, the recycle solvent is hydrogenated in a separate step. In the second, hydrogen is added directly to the extraction vessel and the recycle solvent is not hydrogenated. In the third, hydrogen is added to the extraction vessel and the recycle solvent is also hydrogenated. The recycle solvent, usually an oil middle distillate of process-derived liquids, is continuously recovered and recycled to the extraction vessel. The ash in the extraction vessel often acts as a catalyst for the solvation process; its catalytic effectiveness depends on the coal properties.

Identified in these terms, the processes currently under development are

(1) Consol Synthetic Fuel (CSF)

(2) Solvent-Refined Coal (SRC)

(3) Solvent-Refined Lignite (SRL)

(4) Co-Steam

(5) Exxon Donor Solvent (EDS)

Consol Synthetic Fuel. - The CSF process (ref. 34) is under development by the Conoco Coal Development Co. (formerly Consolidation Coal Co.). Bench-scale studies were started in 1963 with support from the Office of Coal Research (OCR). A 20-ton-per-day pilot plant was built at Cresap, West Virginia, to produce gasoline from coal. This activity was halted in 1970. Fluor Engineers and Constructors, Inc., has reactivated the plant, under DOE sponsorship, to produce clean boiler fuel and distillate rather than gasoline and to test critical liquefaction process components. Shakedown operations are scheduled to be completed in fiscal year 1978 and will be followed by test run operations and testing into fiscal year 1981 (ref. 35).

The extraction reactor used in the CSF process is a stirred tank that operates at 400° C (750° F) and 10 to 30 atmospheres absolute. The hydrotreater, to hydrogenate the recycle solvent, operates at 205 atmospheres absolute. A schematic diagram of the CSF process is shown in figure 1. The process yields about 63 percent fuel oil, 25 percent char, and a high-Btu gas.

Solvent-Refined Coal. - The SRC process (ref. 34) was started in 1962 under OCR sponsorship to study the feasibility of coal de-ashing. The initial contract culminated in a 50-pound-per-hour bench-scale unit. The Electric Power Research Institute (EPRI) and Southern Company Services collaborated on a 6-ton-per-day process development unit (PDU) at Wilsonville, Alabama. Success in the PDU led to design, construction, and operation of a 50-ton-per day pilot plant at Fort Lewis, Washington. The Pittsburgh & Midway Coal Co., a subsidiary of the Gulf Oil Corp., operates the pilot plant under DOE sponsorship. A run was completed in 1977 in which 3000 tons of fuel were produced. This fuel was successfully fired in a 22.5-megawatt boiler at the Georgia Power Co. with acceptable emissions. Current plans call for continued testing at both the Fort Lewis pilot plant and the Wilsonville PDU into fiscal year 1981 (ref. 35). Gulf Mineral Resources Co. has prepared a conceptual design of a 6000-ton-per-day model of a full-scale commercial plant. Similarly, Wheelabrator-Frye, Inc., has designed a 2000-ton-per-day unit for DOE.

The original SRC process (now known as SRC-I) converts high-sulfur, high-ash coal to a nearly ash-free, low-sulfur fuel that is solid at room temperatures. A schematic diagram of the SRC-I process is shown in figure 2. Typical product compositions of SRC-I and raw coal are shown in table 5.

The Fort Lewis pilot plant was modified in 1977 to permit recycling of unconverted coal and ash. This recycling resulted in increased hydrogen addition and a product stream with a fluidity about the same as that of a no. 6 oil. A schematic diagram of this processes, called SRC-II, is presented in figure 3. In this process the solidification and solvent recovery unit is not required; the mineral residue slurry is used to produce the additional hydrogen required for the process.

The dissolver reactor in the SRC process - a vertical-tube, plug-flow reactor - operates at about 450° C (850° F) and 69 to 103 atmospheres absolute pressure. In the SRC-I process, about 1400 pounds of fuel are produced for each ton of coal (70 percent conversion efficiency by weight). Small amounts of high-Btu gas and light oil are also produced. In the SRC-II mode, the product streams include (based on weight percentage of coal): 40 to 50 percent residual oil, 6 to 12 percent fuel oil, and 2 to 5 percent naptha. Small amounts of lighter fractions are also produced. Thermal efficiencies for both SRC-I and SRC-II are essentially the same, about 70 percent.

Solvent-Refined Lignite. - The SRL process is being developed by the University of North Dakota under contract to DOE (ref. 34). The process is based on technology derived from both the SRC and Co-Steam processes. The SRL process uses synthesis gas (H_2 + CO) in place of the hydrogen used in the SRC process. A process diagram is shown in figure 4. A 0.5-ton-per-day PDU has been built in Grand Forks, North Dakota. Successful operation of this PDU could lead to a run with lignite in the SRC pilot plant at Fort Lewis, Washington.

Co-Steam. - The Co-Steam process is designed to convert low-ranking subbituminous coals, such as lignite, into a low-sulfur fuel oil by the noncatalytic reaction of a coal - recycle-oil slurry with carbon monoxide or synthesis gas (ref. 34). A schematic of the Co-Steam process is shown in figure 5. The stirred reactor operates at 425° C (800° F) and 275 atmospheres. The water required for the reaction is provided by the moisture contained in the low-rank coal. A 5-pound-per-hour continuous process development unit (PDU) is being built at the Grand Forks Energy Research Center, North Dakota. The PDU should be operating early in fiscal year 1979 and should continue through fiscal year 1982 (ref. 35).

Exxon Donor Solvent. - The EDS process (ref. 34) also liquifies coal in a hydrogen-donor recycle solvent. The recycle solvent is catalytically hydrogenated in a trickle-bed reactor at 260° to 450° C (500° to 850° F) and 80 to 210 atmospheres. A schematic diagram of the EDS process is shown in figure 6. Molecular hydrogen is also added to the liquefaction reactor, which operates at 425° to 480° C (800° to 900° F) and 100 to 140 atmospheres. Products are separated from heavy bottoms by flash distillation. The heavy bottoms are further processed by coking or gasification to produce additional liquids and hydrogen for the process. The process yields about 20 percent char, 54 percent oil, and about 25 percent gas. It is about 60 percent thermally efficient.

The EDS project was begun in 1966 entirely with Exxon funding. Through 1975, a 0.5-ton-per-day PDU operated successfully. With DOE and Exxon sharing the cost, a 250-ton-per-day pilot plant is being designed. Operation is scheduled to start in fiscal year 1980 (ref. 35).

Catalytic Liquefaction

Catalytic liquefaction processes use catalysts other than the mineral matter naturally occurring in ash - ferrous compounds such as ferrous sulfate, $FeSO_4$, $NiClO_2$, $ZnCl_2$, and $SnCl_2$ - to promote hydrogenation of the hydrogen-donor solvent. These processes have the advantage that a separate reactor to rehydrogenate the solvent is not required; catalyst deactivation and separation problems have been encountered, however.

Two main concepts are employed in catalytic liquefaction processes. In the first, the catalyst and the coal are in direct contact in the reactor, hydrogen gas is introduced, and rapid direct hydrogenation is achieved. Examples of these processes are the Bergius, University of Utah, Schroeder, and Liquid-Phase Zinc Chloride (Conoco). In the second concept, the coal and the catalyst are not in direct contact, but the suspended pelletized catalyst promotes hydrogenation of the carrier solvent, which in turn hydrogenates the coal. Examples of these concepts include H-Coal, Synthoil, Gulf-CCL, and CFFC.

Processes with catalyst and coal in direct contact. - A number of these processes have been developed. Some of the more familiar ones are described here.

Bergius: One of the pioneers in coal liquefaction, Bergius first converted coal into oil in 1913 (ref. 34). The process was developed commercially to produce chiefly gasoline. Fifteen plants were operated during World War II and supplied virtually all of Germany's aviation fuel requirements. Costs proved to be prohibitively high for this process, however; and thus none of those plants are now operating.

University of Utah: In the University of Utah process a $ZnCl_2$ catalyst and coal are fed into a preheater and then into the reactor. The high vapor pressure of the catalyst insures direct contact with the coal at reactor conditions. Very short residence times have been achieved. About 60 percent conversion to liquids and 10 percent conversion to gases have been achieved in a 50-pound-per-hour bench-scale PDU. Catalyst recovery remains a primary technical issue (ref. 34).

Schroeder: The Schroeder process is similar to the University of Utah process. The catalyst is ammonium molybdate; residence times are less than 30 seconds. Product yields are about 30 percent distillable liquid, 35 percent residual liquid, 5 percent char, and 30 percent gas. Bench-scale tests of this concept were completed in 1962.

Liquid-Phase Zinc Chlorode: The Liquid-Phase Zinc Chloride process, being developed by the Continental Oil Co., is designed to convert coal into distillates in the gasoline range by severe catalytic cracking under hydrogen pressure (ref. 34). Bench-scale tests were completed in 1977. A 1.2-ton-per-day PDU has been built by the Conoco Coal Development Co. at Library, Pennsylvania. Shakedown testing was scheduled to begin in fiscal year 1978 (ref. 35).

Processes with coal and catalyst not in direct contact. - These processes include H-Coal, Synthoil, Gulf Catalytic Coal Liquids, and Clean Fuel from Coal.

H-Coal: The H-Coal process (fig. 7) is being developed by Hydrocarbon Research, Inc. (HRI) from their H-Oil process, which is used to hydrotreat heavy fuel oils (ref. 2). In the H-Coal process, coal suspended in a recycle solvent is brought into contact with a particulate catalyst in an ebullating-bed reactor (fig. 8). The amount of hydrogen can be varied to produce either a low-sulfur fuel oil or a synthetic crude oil. In the ebullating-bed reactor, which operates at 450° C (850° F) and 150 to 205 atmospheres, the coal and the solvent are forced to flow through the fluidized catalytic bed; both the coal and the solvent are hydrogenated in the reactor. The relative sizes of the catalyst and coal particles are such that the catalyst stays in the reactor. Since catalyst deactivation has been rapid, however, provision is included to withdraw and add catalyst continuously.

The H-Coal process yields about four barrels of oil per ton of coal (about 74 percent conversion efficiency by weight). About 5 percent char is also produced. A self-sufficient plant would be about 64 percent thermally efficient.

Since 1964, HRI has been developing the H-Coal process in a 25-pound-per-day bench-scale unit. The OCR and an industrial consortium funded the building of a 3-ton-per-day PDU. The experimental results and economic feasibility studies were used to complete a detailed design of a 600-ton-per-day pilot plant in 1977. Catlettsburg, Kentucky, has been selected as the location. Procurement and construction is in progress; operations should begin in fiscal year 1979 (ref. 35).

Synthoil: The Synthoil process (ref. 34) being developed by the DOE Pittsburgh Energy Research Center (PERC) reacts coal, recycle liquid, and hydrogen in a fixed-bed catalyst with high throughflow rates (fig. 9). Life of the fixed-bed catalyst has been a problem in tests to date. Product yield and thermal efficiencies are expected to be similar to those in the H-Coal process. The Synthoil process has been developed at PERC in a 5-pound-per-day PDU. Foster-Wheeler has been awarded a contract to design and build a 10-ton-per-day pilot plant at Bruceton, Pennsylvania; operation is expected to begin in fiscal year 1979.

Gulf Catalytic Coal Liquids: The CCL process is a proprietary coal liquefaction development of the Gulf Oil Corp. It is similar to the Synthoil process and features a fixed-bed catalyst in a radial-flow reactor. The catalyst is claimed to have good resistance to deposition, prolonged high activity, and tolerance to metallic compounds in the coal. Bench-scale tests led to a 10-ton-per-day pilot plant at Harmersville, Pennsylvania. Design studies for a demonstration plant are being made.

Clean Fuel from Coal: The CFFC process is being developed by C-E Lummus. The process includes catalytic hydrodesulfurization and dissolution, an anti-solvent-promoted gravity-settling technique, distillation, and product and antisolvent recovery.

C-E Lummus has several patents on the process and has developed it to the small-pilot-plant scale.

Pyrolysis

Pyrolysis, or carbonization, is one of the oldest techniques for obtaining liquids directly from coal. In pyrolysis, coal is heated without air or oxygen to obtain gases, liquid, and char. Pyrolytic processes typically convert about 50 percent of the coal to char, which does not presently have a ready market. Thus, these processes appear to be best suited to multiproduct plants that use char gasification to produce synthesis gas, hydrogen, or fuel gas. Pyrolytic processes include Lurgi-Ruhrgas, COED, Occidental, Toscoal, U.S. Steel Clean-Coke, and rapid hydrocarbonization.

Lurgi-Ruhrgas. - The low-pressure Lurgi-Ruhrgas pyrolytic process was developed for liquefaction of European brown coals and is the only commercialized pyrolytic process (ref. 34). A schematic diagram of the process is shown in figure 10. Pulverized coal is rapidly heated by direct contact with hot, recirculated, partially oxidized char particles. A portion of the carbonized char is withdrawn as product and the balance is rerouted to the entrained-flow reactor. Products of the process (by weight) are 50 percent char, about 18 percent liquids, and about 32 percent gases. A 1600-ton-per-day plant was built in 1963 in Yugoslavia and is still operating.

COED. - The Char Oil Energy Development (COED) process (ref. 34) produces synthetic crude oil by pyrolysis of crushed coal in a series of fluidized beds. Agglomeration is prevented by operating at successively higher temperatures (fig. 11). The process has been under development by FMC Corp. since 1962. Successful operation of a 100-pound-per-hour PDU led to the design, construction, and operation of a pilot plant in Princeton, New Jersey. This plant processed 36 tons of coal per day from which it produced about 6 tons of oil, 18 tons of char, and 4 tons of gas. Design capacities were demonstrated in all parts of the pilot plant except the oil absorber tower. Pilot plant operations have been concluded and demonstrated plants have been designed.

Occidental. - The Occidental Research Corp. has been developing this pyrolytic process (ref. 34) since 1969 with its own funds. A 3.6-ton-per-day pilot plant in La Verne, California, has been operating since 1972. A 250-ton-per-day pilot plant is being designed. The process converts volatile bituminous coal to synthetic crude oil by entrained-flow, low-pressure pyrolysis (fig. 12) with very short residence times and rapid heating rates. The process stream leaves the reactor and passes through a cyclone for gas-solids separation and then to a gas-liquids collection station. The process yields about 57 percent char, 35 percent liquids, and 6 percent gas.

Toscoal. - The Toscoal process (fig 13) is an adaptation of the oil-shale retorting technology developed by Tosco. It produces 5 to 10 weight percent liquids, 5 to 10 percent gas, and the balance char. This process has been demonstrated in a 25-ton-per-day pilot plant; larger scale testing is not believed to be necessary.

U S. Steel Clean-Coke. - The U.S. Steel Clean-Coke process (fig. 14) is a combined pyrolytic and solvent extraction process. Gases, liquids, and metallurgical grade coke are produced. Operation of a 10-inch PDU is under way and design studies have begun for a 240-ton-per-day pilot plant.

Rapid hydrocarbonization. - Occidental Research Corp. is developing the Flash Pyrolysis process (rapid heating to high temperature with short residence times) on the PDU scale. The Rocketdyne Division of Rockwell International Corp. is developing a similar process except that pyrolysis is carried out in the presence of hydrogen. Both processes are in the early development stage.

Indirect Liquefaction

Indirect liquefaction processes first convert coal to synthesis gas ($CO + H_2$) and then use the water-gas shift reaction and catalytic conversion to produce a wide range of liquids, mainly gasolines. Indirect liquefaction processes include Fischer-Tropsch, methanol synthesis, and methanol to gasoline.

Fischer-Tropsch. - In the Fischer-Tropsch process, gasification is done in commercially available reactors (e.g., Lurgi, Winkler, Koppers-Totzek, or Wellman-Galusha). In-situ gasification may also be used. The synthesis gas is converted to liquids over an iron or cobalt catalyst. Total-process thermal efficiencies are about 40 percent. A commercial unit at SASOL in South Africa produces about 2000 barrels of gasoline per day. A new facility is under construction in South Africa that will increase production to 40 000 barrels per day of gasoline and fuel oil, about 30 percent of that country's automobile fuel needs. The process was also used by Germany during World War II.

HRI, Inc., built a 7000-barrel-per-day unit in Brownville, Texas, in which natural gas was used as the feedstock. When natural gas prices increased, however, this plant became uneconomical and was shut down. There has been renewed interest in this process in this country, however; and several development efforts are under way.

Methanol synthesis. - Methanol synthesis occurs according to either

$$CO + H_2 \longrightarrow CH_3OH$$

or

$$CO_2 + 3H_2 \longrightarrow CH_3OH + H_2O$$

Various catalysts are used to promote the reactions. Several commercial-scale plants have been built abroad, and the technology is considered off the shelf.

Methanol to gasoline. - The Mobil Oil Co., with DOE support, is developing a process for the catalytic conversion of methanol to gasoline. This process is in the PDU development stage.

FUEL PROPERTIES DATA

The characterization data obtained from the surveyed literature have been tabulated on the fuel property forms (tables 1 and 2). The fuels are presented according to the process from which they were derived (e.g., H-Coal or Synthoil). Within any one process, characteristics have been tabulated for different boiling-range distillates, as well as for the total crude. For ease of referral to the data, the various distillate cuts have been put into three general categories: light distillates (naphtha, light oil, etc.), middle distillates (diesel fuels), and heavy distillates (heating oils and residual fuels).

All the fuel properties data surveyed are contained in this section. Tabulations are also indexed according to the sources from which the data were obtained.

Characterization data are presented in the following tables:

(1) Data from H-Coal processes in table 6
(2) Data from Synthoil processes in table 7
(3) Data from SRC processes in table 8
(4) Data from COED processes in table 9
(5) Data from the Gulf Catalytic Coal Liquids process in table 10
(6) Data from the Exxon Donor Solvent process in table 11
(7) Data from the Zinc Chloride Hydrocracking process in table 12
(8) Data from the Co-Steam Process in table 13
(9) Data from the Flash Pyrolysis process in table 14
(10) Data from a catalytic liquefaction process in table 15
(11) Data from the Sea Coal process in table 16
(12) Proposed specifications of a typical coal-derived liquid fuel in table 17
(13) Low-Btu gas data in table 18

DISCUSSION

Liquid Fuels

This literature survey emphasizes those processes that are furthest along in development and are still active This criterion could probably have restricted the search to the liquefaction processes of H-Coal, Synthoil, Solvent-Refined Coal, and Exxon Donor Solvent. However, it was felt that including data on other processes could be useful.

It is readily apparent from casual examination of tables 6 to 18 that many of the fuel properties data of interest to this survey have not been determined for the fuels produced to date. In a few specific instances, where the fuel characterization studies were of fuels for gas-turbine engines, many more relevant property data are available. Data of this type can be found in references 5, 13, and 32.

Some of the more important property data on liquid fuels have been summarized in table 19. Plots of these data are shown in figures 15 to 17. Although different boiling ranges of the fuels are shown in table 19, all the data available for each fuel are plotted, irrespective of the type of process or the type of distillate cut.

Figure 15 shows the general trend of increasing weight percentage of hydrogen with increasing API gravity of the product, regardless of the process by which it was produced. Data for only one fuel were significantly different from the general trend.

Figure 16 shows how the weight percentage of nitrogen varied with the weight percentage of hydrogen. As hydrogenation severity is increased in the fuel production process, the fuel-bound nitrogen is decreased, as would be expected, because some fuel-bound nitrogen is converted to ammonia (NH_3). The data for the Zinc Chloride Hydrocracking process (ref. 24), not plotted in figure 16, showed nitrogen levels significantly lower than that of any other process-derived fuel at comparable hydrogen levels. Nitrogen levels for the zinc-chloride-derived fuels were from 0.0018 to 0.0019 weight percent for hydrogen levels of 8.3 to 9.65 weight percent.

Figure 17 shows how heat of combustion varies with weight percentage of hydrogen for those few fuels for which such data were reported. Again, the trend is independent of the processing type.

Gaseous Fuels

The low-Btu gases proposed for use in ground-based power turbine systems would be produced by air-blown gasifiers. As such, they will contain a large percentage (~50 vol %) of nitrogen, as well as some carbon dioxide (CO_2) - neither of which contributes to the heating value of the gas mixture. The primary combustible gases from such a gasifier are hydrogen and carbon monoxide and a small amount of methane.

The heats of combustion of the most probable gases in the low-Btu mixtures are shown in the following table, which is a summary of the heat-of-combustion data in table 18. The gross volumetric heating values of hydrogen (H_2) and carbon monoxide (CO) are nearly identical, about 322 Btu per standard cubic foot. As a result, the heat-

Gas	Molecular weight	Heat of combustion, Btu/lb		Heat of combustion, Btu/std ft^3	
		Gross	Net	Gross	Net
H_2	2	60 958	51 571	322.5	272.9
CO	28	4 344	4 344	321.8	321.8
CO_2	44	0	0	0	0
CH_4	16	23 861	21 502	1010	910
C_2H_6	30	22 304	20 416	1770	1620
N_2	28	0	0	0	0

ing value of a low-Btu gas mixture can be estimated closely if the volume percentage of inert gases (N_2 and CO_2) is known. Thus

$$\text{Gross heat of combustion} = 322 - 3.22 \text{ (vol \% inerts)}, \text{ Btu/std ft}^3$$

A plot of this relationship is shown in figure 18. Also shown in this figure are some of the heat-of-combustion data from table 18.

Most of the references cited in table 18 give "typical" ranges of properties for these gases, rather than actual experimental data. In none of the references cited were there any data on the sulfur, alkali metals, or particulate contamination levels to be expected. These data would undoubtedly be controlled by the cleanup processes used, rather than by the gasifier type or the operating conditions.

CONTRACT CONDITIONS

Federal energy contract numbers relating to coal-derived synthetic fuels production and upgrading programs are listed in the following table:

Fossil energy contract FE -	Author	Company	Process and/or title
628	-------------------------	PAMCO (Merriam, Ka.)	Pilot plant to produce low-Btu gas from coal
1212	Jones, J F , et al	FMC Corp.	COED
1514	Chamberlain, R. M., et al.	Westinghouse	Advanced coal gasification system for electric power generation
1521	-------------------------	Foster-Wheeler	Advanced coal gasification system for electric power from coal
1527	-------------------------	Bituminous Coal Research	Gas generator research and development with clean fuel gas
1529	-------------------------	Atomics International	Molten-salt coal gasification pilot plant
1534	Peters, Bruce	Dow Chemical	Chemicals from coal (characterization and hydroprocessing studies)
1545	Patterson, R. C.	Combustion Engineering, Inc.	C-E low-Btu gasification of coal project· Phases I, II, and III
1730	-------------------------	IGT	Preparation of a coal conversion systems technical data book
1743	Klunder, E. B., et al.	Conoco Coal Development Co.	Zinc Chloride Process; hydrocracking for distillate fuels
2003	Greskovich, E. J.	-------------------------	Chemical characterization· handling and refining of SRC to liquid fuels
2006	Wiser, W. H	Utah University	Applied Research and Evaluation of process concepts for gasification and liquefication of Western coals
2010	de Rosset, et al.,	UOP, Inc.	Characterization of coal liquids
2011	Crynes, B	Oklahoma State University	Catalysts for upgrading coal derivative liquids
2028	Katzer, J P , et al	Deleware University	Kinetics and mechanisms of desulfurization and denitrogenation of coal-derived liquids
2034	Berg, L , et al.	Montana State University	Catalytic hydrogenation of coal-derived liquids
2244	Knell, E W., et al	Occidental Research Corp.	Flash pyrolysis coal liquefication process development
2070	Lewis, H E., et al	Catalytic, Inc.	SRC process operation at Wilsonville, Ala
2286	-------------------------	-------------------------	Preparation of a coal conversion system technical data book
2292	Carlson, N	UTC	Combined-cycle system for low-Btu gas use
2315	Sullivan, R F.	Chevron Research	Refining and upgrading of synfuels from coal and oil shales by advanced catalytic processes
2353	Fant, B T	Exxon Research & Engineering	EDS coal liquefaction process development - Phase IIIa

SOURCES OF FUEL PROPERTIES DATA

Fuel characterization data are listed, by process type, for the various distillate categories in the following table. Reference numbers in the table (1 to 32) refer to the literature where data applicable to this study were found.

The references were obtained from the extensive bibliography that follows it. Many of the citations in the bibliography repeat the data given in the references. Other citations contain no data relevant to this study. Also included in the bibliography is a list of sources.

Syncrude source	Full-range crude	Naphtha, light distillates, and light oil	Heavy naphtha, middle distillates, and wash solvent	Heavy distillates, fuel oil, and process solvent	Miscellaneous and other cuts
	Reference numbers				
H-Coal	1, 5, 6, 7, 32, (a), (b)	1, 2, 4, 6, 32, (b)	1, 2, 4, 6, 32, (a), (b)	1, 2, 6, 32, (b), (c)	3, 5, (a), (d)
Synthoil	5, 8, 9, 10, 12, 13	10	3, 10, 12	3, 10, 12	8, 11, 12
SRC	---------------	5, 16, 17, 32, (e)	(e)	3, 5, 14, 16, 17, 32	14, 15, 16, 17, 32, (e)
COED	6, 18, 19, 20	-------------	---------------	---------------	6, 13, 18, 19
Catalytic liquid (Gulf)	21, 22	-------------	---------------	---------------	21
Donor Solvent (Exxon)	23	-------------	---------------	23	----------------
Zinc Chloride Hydrocracking	24	-------------	---------------	---------------	24
Co-Steam	25	-------------	---------------	---------------	----------------
Flash Pyrolysis	26	-------------	---------------	---------------	----------------
Other liquids	13, (f)	-------------	---------------	---------------	----------------
Low-Btu gases	27 to 37 and (g)				

[a]Memo for record, John S Clark of NASA Lewis Research Center, July 19, 1977

[b]Meeting handout on H-Coal products for gas-turbine combined cycles, Paul H Kydd of General Electric, Schenectady, N Y , Jan. 9, 1976

[c]Letter from G. R Fox of General Electric Research and Development Center to Lloyd I. Shure of NASA Lewis Research Center, Feb. 18, 1977.

[d]Memo for record on trace element analyses of H-Coal hydroclone bottoms sample, Theodore S Mroz of NASA Lewis Research Center, Feb. 26, 1976

[e]Letter from Robert G Sperhac of Pittsburgh & Midway Coal Mining Co to Thaine W. Reynolds of NASA Lewis Research Center, May 16, 1975.

[f]Goodwin, G. G.· Amendment of Solicitation to Prospective Offerors, RFP-EF-77-R-01-2674, June 6, 1977 (Contracting Officer, ERDA)

[g]Hiteshue, Raymond W ; and Eisen, Fred Course notes from "Synthetic Fuels from Coal," Center for Professional Advancement, July 22-24, 1974

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TABLE 1 - LIQUID-FUELS PROPERTY FORM

Property	Test	Distillate categories						
Gravity, °API (specific)								
Boiling range								
Initial boiling point, °F								
5 %								
10 %								
20 %								
30 %								
40 %								
50 %								
60 %								
70 %								
80 %								
90 %								
95 %								
Final boiling point, °F								
Pour point, °F								
Flashpoint, °F								
Viscosity at °F								
at °F								
at °F								
Ash, wt%								
Ash melt temperature, °F								
Heat of combustion, Btu/lb								
Carbon residue								
Carbon ramsbottom, wt%								
Thermal stability								
Electrical conductivity								
Water								
Sediment								
Neutrality								
Corrosion								

Hydrocarbon type								
Saturates								
Olefins								
Aromatics, total								
Aromatics, polynuclear								
Luminometer number								
Analine point, °F								
H/C atom ratio								
Elemental analyses, wt%								
C								
H								
N								
S								
O								
Trace metal analyses, ppm								
V								
Ni								
Na								
K								
Mg								
Ca								
Pb								
Cu								
Fe								
Si								
Zn								
Ba								
Mn								
Mo								
W								
Ti								

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TABLE 2. - LOW-Btu-GAS PROPERTY FORM

Property				
Composition, vol%:				
H_2				
CO				
CO_2				
H_2S				
NH_3				
CH_4				
Other hydrocarbons				
N_2				
COS				
Specific gravity				
Average molecular weight				
Heating value, Btu/ft^3:				
Gross				
Net				
Gross with CO_2, H_2S, and NH_3 removed				
Net with CO_2, H_2S, and NH_3 removed				
Sulfur, ppm				
Alkali metals and sulfur, ppm				
Water, vol.%				
Solids, ppm				
Solids: particle size, μm				
Flammability limit ratio				

TABLE 3 - LIQUID-FUELS PROPERTIES

[Data from ref 27]

Property	Test	Distillate categories						
		Light distillate	Heavy distillate	Crude and blended residuals	Heavy residuals			
Gravity, °API (specific)	D-1298	Report	Report	0.96 max	0 96 max			
Boiling range	D-86							
Initial boiling point, °F								
5 %								
10 %								
20 %								
30 %								
40 %								
50 %								
60 %								
70 %								
80 %								
90 %		650 max	Report	-----	-----			
95 %								
Final boiling point, °F								
Pour point, °F	D-97	0°-20°below sub	Report	Report	Report			
Flashpoint, °F	D-93	Report	Report	Report	Report			
Viscosity at 100°F, cS, min	D-445	0 5	1.8	1 8	1 8			
at 100°F, cS, max	D-445	5 8	30	160	900			
at 210°F, cS, max	D-445							
Ash, wt% max %	D-482	0 0050	0 0050	Report	Report			
Ash melt temperature, °F								
Heat of combustion, Btu/lb								
Carbon residue (10% bottoms max)	D-524	0 25						
Carbon ramsbottom, wt%	D-524	1 0	1.0	1.0	Report			
Thermal stability (tube no , max)	D-1661	---	2 0	2.0	2.0			
Electrical conductivity								
Water, vol % max	D-95	0 1	0 1	Report	0 1			
Sediment								
Neutrality								
Corrosion								

Hydrocarbon type								
Saturates								
Olefins								
Aromatics, total								
Aromatics, polynuclear								
Luminometer number								
Analine point, ^{o}F								
H/C atom ratio								
Elemental analyses, wt%								
C								
H		Report	Report	Report	Report			
N								
S	D-129	Report	Report	Report	Report			
O								
Trace metal analyses, ppm								
V (max)		0 5	0 5	0.5	0 5			
Ni								
Na and K		1 0	1 0	1.0	1 0			
K								
Mg								
Ca		2 0	2 0	10.0	10 0			
Pb		1 0	1 0	1 0	1 0			
Cu								
Fe								
Si								
Zn								
Ba								
Mn								
Mo								
W								
Ti								
Water + sediment, vol % max	D-1796	0 1	0.1	1 0	1 0			
V treated, 3/1 wt% Mg/V		---	---	100 0	500 0			
Other trace metals, > 5 ppm		Report	Report	Report	Report			
Filterable dirt, 1/100 MI max.	D-2276	8 0	10 0	Report	Report			

TABLE 4 - TYPICAL PROPERTIES OF LIQUID FUELS

[Data from ref 27]

Property	Fuel type			
	True distillates		Ash-bearing fuels	
	Kerosene	No. 2 distillate	Blended residuals and crudes	Heavy residuals
Specific gravity at 100° F (38° C)	0.78 - 0.83	0.82 - 0.88	0.80 - 0.92	0.92 - 1.05
Viscosity at 100° F (38° C), cS	1 4 - 2 2	2 0 - 4.0	2 - 100	100 - 1800
Flashpoint, °F (°C)	130 - 160 (55 - 70)	150 - 200 (55 - 95)	50 - 200 (10 - 95)	175 - 265 (80 - 130)
Pourpoint, °F (°C)	-50 (-45)	-10 - 30 (-20 - 0)	15 - 110 (-10 - 45)	15 - 95 (-10 - 35)
Gross heating valve, kcal/kg (Btu/lb)	10 700 - 10 950 (19 300 - 19 700)	10 500 - 10 950 (19 000 - 19 600)	10 500 - 10 900 (19 000 - 19 400)	10 150 - 10 500 (18 300 - 18 900)
Filterable dirt, percent of maximum	0.002	0.005	0.05	0.2
Carbon residue, percent.				
10 Percent bottoms	0.01 - 0.1	0.03 - 0.3	------	-----
100 Percent bottoms	---------	---------	0 3 - 3	2 - 10
Sulfur content, percent	0.01 - 0.1	0.1 - 0.8	0.2 - 3	0.5 - 4
Nitrogen content, percent	0.002 - 0 01	0.005 - 0.06	0.06 - 0.2	0.05 - 0.9
Hydrogen content, percent	12.8 - 14.5	12.2 - 13.2	12.0 - 13.2	10 - 12.5
Ash content, ppm.				
Fuel as delivered	1 - 5	2 - 50	25 - 200	100 - 1000
Inhibited	----	-----	-------	---------
Trace-metal contaminants, ppm				
Sodium plus potassium	0 - 0 5	0 - 1	1 - 100	1 - 350
Vanadium	0 - 0 1	0 - 0 1	0.1 - 80	5 - 400
Lead	0 - 0 5	0 - 1	0 - 1	0 - 25
Calcium	0 - 1	0 - 2	0 - 10	0 - 50

TABLE 5. - TYPICAL PRODUCT COMPOSITION

FROM SOLVENT-REFINED-COAL PROCESS

Component	Raw coal	SRC product
	Typical analysis, wt %	
Carbon	70.7	88.2
Hydrogen	4.7	5.2
Nitrogen	1.1	1.5
Sulfur	3.4	1.2
Oxygen	10.3	3.4
Ash	7.1	.5
Moisture	2.7	0
	100.0	100.0
Volatile matter	38.7	36.5
Fixed carbon	51.5	63.0
Ash	7.1	.5
Moisture	2.7	0
	100.0	100.0
Heating value, Btu/lb	12 821	15 768

TABLE 6 - FUEL DATA FROM H-COAL PROCESS

(a) H-Coal from Illinois #6 coal (fuel oil mode), data from ref 1

Property	Test	Distillate categories						
		Full-range liquid	Naphtha	Middle distillate	Heavy distillate			
Gravity, °API (specific)		27 6	40 6	16 7	5 4			
Boiling range								
Initial boiling point, °F		180	196	452				
5 %			215	452	682			
10 %			228	452	688			
20 %			250	454	699			
30 %			270	470	706			
40 %			292	492	722			
50 %			312	514	737			
60 %			332	534	756			
70 %			350	570	783			
80 %			366	592	843			
90 %			380	616	896			
95 %			394	630	944			
Final boiling point, °F		>944		636				
Pour point, °F								
Flashpoint, °F								
Viscosity at °F								
at °F								
at °F								
Ash, wt%								
Ash melt temperature, °F								
Heat of combustion, Btu/lb								
Carbon residue								
Carbon ramsbottom, wt%								
Thermal stability								
Electrical conductivity								
Water								
Sediment								
Neutrality								
Corrosion								

Hydrocarbon type								
Saturates			70.3					
Olefins			1 1					
Aromatics, total			28 6					
Aromatics, polynuclear								
Luminometer number								
Analine point, °F								
H/C atom ratio								
Elemental analyses, wt%								
C		87 6						
H		7 4						
N		0 81	0 131	0.18	0.36			
S		0 47	0 18	0 0371	0 15			
O		1 93						
Trace metal analyses, ppm								
V			0 2	0 2	0 2			
Ni			0.2	0 2	0.2			
Na								
K								
Mg								
Ca								
Pb								
Cu								
Fe			0 5	1 0	15 3			
Si								
Zn								
Ba								
Mn								
Mo								
W								
Ti								

TABLE 6 - Continued

(b) H-Coal liquids, data from letter of Feb 18, 1977, to Lloyd I Shure, NASA Lewis Research Center, from G R Fox, General Electric Research and Development Center

Property	Test	Distillate categories						
		Light distillate (LO-308)	Residual oil (400°F+, LO-347)	Heavy distillate (LO-317-1)				
Gravity, °API (specific)		19 0	2 0	1 9				
Boiling range								
Initial boiling point, °F		282	358	620				
5 %								
10 %		364	446	650				
20 %		396	490	662				
30 %		418	536	674				
40 %		440	582	688				
50 %		458	620	702				
60 %		482	640	Cracked				
70 %		506	650					
80 %		540	Cracked					
90 %		570						
95 %								
Final boiling point, °F								
Pour point, °F		-50	25	50				
Flashpoint, °F		170	260	375				
Viscosity at 100°F, kin		2 47	272	177/179				
at 122°F, kin			100	67				
at 210°F, kin		0 99	8.8	7 2				
Ash, wt%		77	840	270/292				
Ash melt temperature, °F								
Heat of combustion, Btu/lb		18 415	17 415	17 420				
Carbon residue, wt%		1 0	14 6	2 2				
Carbon ramsbottom, wt%								
Thermal stability, 350°F, 6 hr			Poor st.=3	o k st =1 5				
Electrical conductivity								
Water, percent		nil	0.09	0.11				
Sediment								
Neutrality								
Corrosion								

Hydrocarbon type								
Saturates								
Olefins								
Aromatics, total								
Aromatics, polynuclear								
Luminometer number								
Analine point, °F								
H/C atom ratio		1 4	1 1	1 1				
Elemental analyses, wt%								
C								
H		10.34	8 0	8 1				
N		0.22	0 80	0 77				
S		0.16	0 23	0.15				
O								
Trace metal analyses, ppm								
V	Ash composition	0 7	1 0	0 1, 0 6				
Ni								
Na		0 07	1.9, 2 5	1 0, 0.6				
K		0 12	4 5, 8.6	0 9,0 4,2 1				
Mg		0 5	4 0					
Ca		0 1	40 0	1.1				
Pb		0 03	0 06	Trace, 0 04				
Cu								
Fe			130 0					
Si			190 0					
Zn								
Ba								
Mn								
Mo								
W								
Ti			40 0					
Al			60 0					

TABLE 6 - Continued

(c) H-Coal from Illinois #6 coal, data from ref 2

Property	Test	Distillate categories						
		Naphtha (IBP - 350°F, 19 8 wt%)	Middle distillate (350° - 550°F, 12 1 wt%)	Vac gas oil (450° - 800°F, 11 5 wt%)	Residual (800°F+, 56 6 wt%)			
Gravity, °API (specific)		44 9	25.9	7 9				
Boiling range								
Initial boiling point, °F		-50	217	434				
5 %								
10 %		170	366	552				
20 %		188	378	597				
30 %		217	395	627				
40 %		229	408	655				
50 %		256	417	675				
60 %		282	432	695				
70 %		306	449	716				
80 %		330	471	740				
90 %		353	500	767				
95 %								
Final boiling point, °F								
Pour point, °F								
Flashpoint, °F								
Viscosity at °F								
at °F								
at °F								
Ash, wt%					25 3	unreacted coal		
Ash melt temperature, °F					13 4			
Heat of combustion, Btu/lb								
Carbon residue								
Carbon ramsbottom, wt%								
Thermal stability								
Electrical conductivity								
Water								
Sediment								
Neutrality								
Corrosion								

Hydrocarbon type								
Saturates								
Olefins								
Aromatics, total								
Aromatics, polynuclear								
Luminometer number								
Analine point, ^{o}F								
H/C atom ratio								
Elemental analyses, wt%								
C		86 4	88 0	89 6				
H		12 9	11 2	10 4				
N		0 047	0 044	0 0083				
S		0 26	0 17	0 17				
O		0 039	0 058	0 08				
Trace metal analyses, ppm								
V								
Ni								
Na								
K								
Mg								
Ca								
Pb								
Cu								
Fe								
Si								
Zn								
Ba								
Mn								
Mo								
W								
Ti								

TABLE 6 - Continued

(d) H-Coal residue from Illinois #6 coal (hydroclone bottoms), data from memo for record by John S Clark, NASA Lewis Research Center, July 19, 1977

Property	Test	Distillate categories						
Gravity, °API (specific)		-7 5						
Boiling range								
Initial boiling point, °F		400						
5 %								
10 %								
20 %								
30 %								
40 %								
50 %								
60 %								
70 %								
80 %								
90 %								
95 %								
Final boiling point, °F								
Pour point, °F		115						
Flashpoint, °F		350						
Viscosity at 200°F, cP		465						
at 300°F, cP		22 5						
at 400°F, cP		5 0						
Ash, wt%		0 2						
Ash melt temperature, °F		100 to 200 lower than #6 coal feed						
Heat of combustion, Btu/lb Higher		16 700						
Carbon residue, wt%		32 8						
Carbon ramsbottom, wt%								
Thermal stability (unstable above-)		200°F						
Electrical conductivity, ohms/cm		$3\ 5 \times 10^{9}$						
Water		None						
Sediment								
Neutrality								
Corrosion								

Hydrocarbon type								
Saturates								
Olefins								
Aromatics, total								
Aromatics, polynuclear								
Luminometer number								
Analine point, °F								
H/C atom ratio		1.0						
Elemental analyses, wt%								
C		88 2						
H		7 36						
N		1 3						
S		0 48						
O		2 65						
Trace metal analyses, ppm								
V		2 0						
Ni								
Na		3 1						
K		1 7						
Mg		1 8						
Ca		1 5						
Pb		0 04						
Cu								
Fe								
Si								
Zn								
Ba								
Mn								
Mo								
W								
Ti								

TABLE 6 - Continued

(e) H-Coal hydroclone underflow, data from ref 3

Property	Test	Distillate categories						
		Hydroclone underflow (#3296-87)	Hydroclone underflow filtrate (#3296-153)					
Gravity, °API (specific)		-16 5(1 2307)	17 7(1 2433)					
Boiling range	D-1160							
Initial boiling point, °F		466	493					
5 %		533	538					
10 %		560	567					
20 %		615	621					
30 %		690	680					
40 %		770	752					
50 %		876	822					
60 %			910					
70 %								
80 %								
90 %								
95 %								
Final boiling point, °F								
Pour point, °F (Softening point)		172	240					
Flashpoint, °F								
Viscosity at 250°F, SFS		307 3	161 4					
at 300°F, SFS			154 1					
at °F								
Ash, wt%								
Ash melt temperature, °F								
Heat of combustion, Btu/lb								
Carbon residue (Conradson), wt%		39.43	33 2					
Carbon ramsbottom, wt%								
Thermal stability								
Electrical conductivity								
Water								
Sediment								
Neutrality								
Corrosion								

Hydrocarbon type								
Saturates								
Olefins								
Aromatics, total								
Aromatics, polynuclear								
Luminometer number								
Analine point, °F								
H/C atom ratio								
Elemental analyses, wt%								
C		79 35	87 07					
H		6 35	6 96					
N		1 11	1 30					
S		1 43	0 66					
O		3 92	4 38					
Trace metal analyses, ppm								
V								
Ni								
Na			4					
K								
Mg			14					
Ca			40					
Pb								
Cu								
Fe			208					
Si			24					
Zn								
Ba								
Mn								
Mo								
W								
Ti			164					
Al			52					

TABLE 6 - Continued

(f) H-Coal fuel oil mode, from Illinois #6 coal, data from ref 4

Property	Test	Distillate categories[a]						
		Total overhead	<203°C(397°F), 35 6 percent	>203°C(397°F), 63 7 percent				
Gravity, °API (specific)		19 8 (0 935)	32 3 (0 864)	13 0(0 979)				
Boiling range								
Initial boiling point, °F								
5 %	ERDA routine method	144	144	397				
10 %								
20 %								
30 %								
40 %								
50 %								
60 %								
70 %								
80 %								
90 %								
95 %		687	397	687				
Final boiling point, °F								
Pour point, °F		<5	<5	<5				
Flashpoint, °F								
Viscosity at 77°F, SUS		38						
at 100°F, SUS		35 (2 4cS)		39 (3 8cS)				
at 100°F, cS	D-445		1 08	3 87				
Ash, wt%								
Ash melt temperature, °F								
Heat of combustion, Btu/lb								
Carbon residue (Conradson), wt%	524	0 8	0	2 33				
Carbon ramsbottom, wt%								
Thermal stability								
Electrical conductivity								
Water								
Sediment								
Neutrality								
Corrosion								

Hydrocarbon type								
Saturates		19 56	33.9	12.0				
Olefins		2.1	5.9					
Aromatics, total		52 94	34.2	78.0				
Aromatics, polynuclear		25 98	Trace	46 2				
Luminometer number								
Analine point, °F								
H/C atom ratio								
Elemental analyses, wt%								
C								
H								
N	Kjeldahl	0 44	0 42	0.446				
S	D-129	0 21	0 13	0 29				
O								
Trace metal analyses, ppm								
V								
Ni								
Na								
K								
Mg								
Ca								
Pb								
Cu								
Fe								
Si								
Zn								
Ba								
Mn								
Mo								
W								
Ti								

[a]Distillate, 27 9 percent of crude.

TABLE 6 - Continued

(g) H-Coal syncrude mode, from Illinois #6 coal, data from ref 4

Property	Test	Distillate categories[b]						
		Total overhead	<197°C(387°F), 35 6 wt%	>197°C(387°F), 65 3 wt%				
Gravity, °API (specific)		17 0(0 953)	34 7(0 838)	6 6(1 025)				
Boiling range								
Initial boiling point, °F		138	138	387				
5 %	ERDA							
10 %	routine method							
20 %								
30 %								
40 %								
50 %								
60 %								
70 %								
80 %								
90 %		795						
95 %								
Final boiling point, °F			387	795				
Pour point, °F		<5	<5	<5				
Flashpoint, °F								
Viscosity at 77°F, SUS		59						
at 100°F, SUS		46		77				
at 100°F, cS	D-445	6 1	0 96	14 9				
Ash, wt%								
Ash melt temperature, °F								
Heat of combustion, Btu/lb								
Carbon residue (Conradson), wt%		2 3						
Carbon ramsbottom, wt%								
Thermal stability								
Electrical conductivity								
Water								
Sediment								
Neutrality								
Corrosion								

Hydrocarbon type								
Saturates		19 44	42 6	7 4				
Olefins		1 24	3.6					
Aromatics, total		51 13	31 4	80 9				
Aromatics, polynuclear		32 57	Trace	64 6				
Luminometer number								
Analine point, °F								
H/C atom ratio								
Elemental analyses, wt%								
C								
H								
N	Kjeldahl	0 633	0 212	0 871				
S	D-129	0 27	0 06	0 35				
O								
Trace metal analyses, ppm								
V								
Ni								
Na								
K								
Mg								
Ca								
Pb								
Cu								
Fe								
Si								
Zn								
Ba								
Mn								
Mo								
W								
Ti								

[b]Distillate, 48 2 percent of crude

TABLE 6 - Continued

(h) H-Coal syncrude mode, from Illinois #6 coal, data from meeting handout, Paul H Kydd of General Electric, Schenectady, N Y , Jan 9, 1976

Property	Test	Distillate categories						
		Total crude	180° - 380°F	380° - 650°F	650° - 975°F			
Gravity, °API (specific)		6 4	38 6	14 0	-2 3			
Boiling range								
Initial boiling point, °F		180	180	372	639			
5 %			226	420	652			
10 %			248	440	670			
20 %			264	474	728			
30 %			280	500	737			
40 %			292	510	758			
50 %			306	530	799			
60 %			318	542	823			
70 %			330	568	840			
80 %			338	593	868			
90 %			364	616	932			
95 %			386	670	969			
Final boiling point, °F		975	445	680	975			
Pour point, °F		-5		-100	86			
Flashpoint, °F								
Viscosity at 100°F, SUS		707 (155 cS)		41 (4 4 cS)				
at 210°F, SUS				36 (2 7 cS)	163 (36 cS)			
at °F								
Ash, wt%		0 03						
Ash melt temperature, °F								
Heat of combustion, Btu/lb								
Carbon residue								
Carbon ramsbottom, wt%					4 4			
Thermal stability								
Electrical conductivity								
Water								
Sediment								
Neutrality								
Corrosion								

Hydrocarbon type								
Saturates								
Olefins								
Aromatics, total , percent (Aspheltenes)		12 92		3.07	2 62			
Aromatics, polynuclear								
Luminometer number								
Analine point, °F			86					
H/C atom ratio								
Elemental analyses, wt%								
C		88 3	83 6	88.3	90 0			
H		8 19	12 41	9 73	7.58			
N		0 81	0 19	0 42	1 01			
S		0 22	0 24	0 18	0 22			
O		1 35	0 26	0 94	1.20			
Trace metal analyses, ppm								
V								
Ni								
Na								
K								
Mg								
Ca								
Pb								
Cu								
Fe								
Si								
Zn								
Ba								
Mn								
Mo								
W								
Ti								
Refractive index			1 449	1 514	1 556			

TABLE 6 - Continued

(i) H-Coal, data from ref 5

Property	Test	Distillate categories						
		Sample J-8088	950°F- cut	950°F+ cut				
Gravity, °API (specific)								
Boiling range								
Initial boiling point, °F		482		950				
5 %								
10 %		569						
20 %		620						
30 %		667						
40 %		705						
50 %		759						
60 %		866						
70 %		>963						
80 %								
90 %								
95 %								
Final boiling point, °F			950					
Pour point, °F		>115						
Flashpoint, °F		320						
Viscosity at 21 °F, cS		318 3						
at °F								
at °F								
Ash, wt%	D-482	0 02						
Ash melt temperature, °F								
Heat of combustion, Btu/lb		17 411						
Carbon residue (Conradson), wt%		17 3						
Carbon ramsbottom, wt%								
Thermal stability								
Electrical conductivity								
Water								
Sediment								
Neutrality								
Corrosion								

Hydrocarbon type								
Saturates								
Olefins								
Aromatics, total								
Aromatics, polynuclear								
Luminometer number								
Analine point, ^{o}F								
H/C atom ratio								
Elemental analyses, wt%								
C		89 0	90.33	87.52				
H		7 94	8 85	6 26				
N		0 77	0 39	1 39				
S		0 42	0 19	0.95				
O		2.12	0 53	3 56				
Trace metal analyses, ppm								
V		3 0						
Ni		1 0						
Na		0 8						
K		0 4						
Mg		1 0						
Ca		8 0						
Pb		1 0						
Cu								
Fe		20 0						
Si		2 0						
Zn								
Ba								
Mn								
Mo								
W								
Ti		80 0						
Al		11 0						

TABLE 6 - Continued

(j) H-Coal hydroclone bottoms filtrate, data from memo for record by Theodore S Mroz, NASA Lewis Research Center, Feb 26, 1976[c]

Property	Test	Distillate categories						
		Illinois Geologic Institute			General Electric	Westinghouse	AFAPL	NASA
Gravity, °API (specific)								
Boiling range								
Initial boiling point, °F								
5 %								
10 %								
20 %								
30 %								
40 %								
50 %								
60 %								
70 %								
80 %								
90 %								
95 %								
Final boiling point, °F								
Pour point, °F								
Flashpoint, °F								
Viscosity at °F								
at °F								
at °F								
Ash, wt %								
Ash melt temperature, °F								
Heat of combustion, Btu/lb								
Carbon residue								
Carbon ramsbottom, wt %								
Thermal stability								
Electrical conductivity								
Water								
Sediment								
Neutrality								
Corrosion								

Hydrocarbon type								
Saturates								
Olefins								
Aromatics, total								
Aromatics, polynuclear								
Luminometer number								
Analine point, ^{o}F								
H/C atom ratio								
Elemental analyses, wt%								
C								
H								
N								
S								
O								
Trace metal analyses, ppm		Neut A	X-ray	At abs				
V		13 - 15	12.6		0 8	1 66		1.0
Ni		18		9.08			10 0	
Na		3 1			1 2	10.08		
K		1 7	0.8		0 2	0 95		
Mg		1 8	<4 5	1 89		7.5	2.0	
Ca		1 49	2 3			0 61		
Pb				0 12	0 04			
Cu				3 06			1 0	
Fe		12 1	4 1			35 8	8 0	
Si			5 0				2 0	
Zn		1 5		0 62				
Ba		0 8						
Mn		1 8						
Mo		<0 1						
W								
Ti			2 4				2 0	

[c]Total of 52 trace elements listed in reference Trace elements in filter cake also listed in reference

TABLE 6 - Continued

(k) H-Coal, data from ref 6

Property	Test	Distillate categories						
		Total	Initial/375°F	375° - 650°F	650° - 975°F			
Gravity, °API (specific)								
Boiling range								
Initial boiling point, °F				375	650			
5 %								
10 %								
20 %								
30 %								
40 %								
50 %								
60 %								
70 %								
80 %								
90 %								
95 %								
Final boiling point, °F		975	375	650	975			
Pour point, °F								
Flashpoint, °F								
Viscosity at °F								
at °F								
at °F								
Ash, wt%								
Ash melt temperature, °F								
Heat of combustion, Btu/lb								
Carbon residue								
Carbon ramsbottom, wt%								
Thermal stability								
Electrical conductivity								
Water								
Sediment								
Neutrality								
Corrosion								

Hydrocarbon type								
Saturates								
Olefins								
Aromatics, total								
Aromatics, polynuclear								
Luminometer number								
Analine point, °F								
H/C atom ratio								
Elemental analyses, wt%								
C		87 3	84 5	88 8	89 4			
H		11 9	13 6	11 0	10 2			
N		0 1	0 1	0 1	0 1			
S		0 1	0 1	0 1	0 3			
O		0 6	1 7	---	---			
Trace metal analyses, ppm								
V								
Ni								
Na								
K								
Mg								
Ca								
Pb								
Cu								
Fe								
Si								
Zn								
Ba								
Mn								
Mo								
W								
Ti								

TABLE 6 - Continued

(l) H-Coal (C_4 + liquid), data from ref 7

Property	Test	Distillate categories						
		Syncrude from Illinois coal	Low-sulfur fuel oil from Illinois coal	Syncrude from Wyodak coal				
Gravity, ^{o}API (specific)		15.0	4.4	26.8				
Boiling range								
Initial boiling point, ^{o}F		C_4+	C_4+	C_4+				
5 %								
10 %								
20 %								
30 %								
40 %								
50 %								
60 %								
70 %								
80 %								
90 %								
95 %								
Final boiling point, ^{o}F								
Pour point, ^{o}F								
Flashpoint, ^{o}F								
Viscosity at ^{o}F								
at ^{o}F								
at ^{o}F								
Ash, wt%								
Ash melt temperature, ^{o}F								
Heat of combustion, Btu/lb								
Carbon residue								
Carbon ramsbottom, wt%								
Thermal stability								
Electrical conductivity								
Water								
Sediment								
Neutrality								
Corrosion								

Hydrocarbon type								
Saturates								
Olefins								
Aromatics, total								
Aromatics, polynuclear								
Luminometer number								
Analine point, ^{o}F								
H/C atom ratio								
Elemental analyses, wt%								
C								
H		9 48	8 43	10 54				
N		0 68	1 05	0 64				
S		0 19	0 43	0 16				
O								
Trace metal analyses, ppm								
V								
Ni								
Na								
K								
Mg								
Ca								
Pb								
Cu								
Fe								
Si								
Zn								
Ba								
Mn								
Mo								
W								
Ti								

TABLE 6 - Continued

(m) H-Coal distillate blends, data from ref 32

Property	Test	Distillate categories						
		Sample 76D-1117 (Fuel oil mode)	Sample 76D-3521 (Syncrude mode)					
Gravity, °API (specific)								
Boiling range								
Initial boiling point, °F		271	270					
5 %		333	328					
10 %		349	346					
20 %		372	367					
30 %		397	396					
40 %		413	405					
50 %		441	433					
60 %		467	454					
70 %		498	489					
80 %		540	530					
90 %		626	590					
95 %		697	665					
Final boiling point, °F		885	942					
Pour point, °F								
Flashpoint, °F								
Viscosity at °F								
at °F								
at °F								
Ash, wt%								
Ash melt temperature, °F								
Heat of combustion, Btu/lb								
Carbon residue								
Carbon ramsbottom, wt%								
Thermal stability								
Electrical conductivity								
Water								
Sediment								
Neutrality								
Corrosion								

Hydrocarbon type								
Saturates								
Olefins								
Aromatics, total								
Aromatics, polynuclear								
Luminometer number								
Analine point, ^{o}F								
H/C atom ratio								
Elemental analyses, wt%								
C								
H		10 14	9.80					
N		0.38	0 38					
S		0.11	0 13					
O		1 20	1 50					
Trace metal analyses, ppm								
V		0 3	0 1					
Ni								
Na		0.6						
K		0 2						
Mg								
Ca		0.3						
Pb		4 7						
Cu								
Fe		40 0	12.3					
Si								
Zn								
Ba								
Mn								
Mo								
W								
Ti		40.0						

TABLE 6 - Continued

(n) H-Coal Burning Star (fuel oil mode), data from ref 32

Property	Test	Distillate categories						
		Atmosphere overhead (76D-920)	Atmosphere overhead (76D-921)	Atmosphere bottoms (76D-922)				
Gravity, °API (specific)								
Boiling range								
Initial boiling point, °F		26	20	315				
5 %		160	170	369				
10 %		175	186	391				
20 %		211	213	430				
30 %		262	264	457				
40 %		302	300	486				
50 %		336	332	516				
60 %		363	358	549				
70 %		390	390	581				
80 %		409	409	629				
90 %		446	447	694				
95 %		474	475	740				
Final boiling point, °F		746	548	851				
Pour point, °F								
Flashpoint, °F								
Viscosity at °F								
at °F								
at °F								
Ash, wt%								
Ash melt temperature, °F								
Heat of combustion, Btu/lb								
Carbon residue								
Carbon ramsbottom, wt%								
Thermal stability								
Electrical conductivity								
Water								
Sediment								
Neutrality								
Corrosion								

Hydrocarbon type								
Saturates								
Olefins								
Aromatics, total								
Aromatics, polynuclear								
Luminometer number								
Analine point, °F								
H/C atom ratio								
Elemental analyses, wt%								
C		86 97	87 19	88 67				
H		11.76	11.99	9 43				
N		0 20	0 20	0 42				
S		0 25	0 26	0 12				
O		1 00	1 00	1.20				
Trace metal analyses, ppm								
V								
Ni								
Na								
K								
Mg								
Ca								
Pb								
Cu								
Fe								
Si								
Zn								
Ba								
Mn								
Mo								
W								
Ti								

TABLE 6 - Concluded

(o) H-Coal Burning Star and Wyodak (syncrude mode), data from ref 32

Property	Test	Distillate categories						
		Wyodak atmosphere overhead (76D-1033)	Burning Star atmosphere overhead (76D-3019)	Burning Star atmosphere bottoms (76D-2031/3021)				
Gravity, °API (specific)								
Boiling range								
Initial boiling point, °F		61	71	275				
5 %		162	159	420				
10 %		177	192	440				
20 %		211	251	470				
30 %		249	300	494				
40 %		288	332	516				
50 %		328	361	533				
60 %		358	381	563				
70 %		394	402	588				
80 %		418	432	634				
90 %		468	469	676				
95 %		499	507	722				
Final boiling point, °F		582	608	890				
Pour point, °F								
Flashpoint, °F								
Viscosity at °F								
at °F								
at °F								
Ash, wt%								
Ash melt temperature, °F								
Heat of combustion, Btu/lb								
Carbon residue								
Carbon ramsbottom, wt%								
Thermal stability								
Electrical conductivity								
Water								
Sediment								
Neutrality								
Corrosion								

Hydrocarbon type								
Saturates								
Olefins								
Aromatics, total								
Aromatics, polynuclear								
Luminometer number								
Analine point, °F								
H/C atom ratio								
Elemental analyses, wt%								
C		88.01						
H		11 85	11 27	8 64				
N		0 13	0 44	0 41				
S		0 09	0 24					
O		0 90	1 40	1 10				
Trace metal analyses, ppm								
V								
Ni								
Na								
K								
Mg								
Ca								
Pb								
Cu								
Fe								
Si								
Zn								
Ba								
Mn								
Mo								
W								
Ti								

TABLE 7 - FUEL DATA FROM SYNTHOIL PROCESS

(a) Synthoil off-specification run, data from ref 8

Property	Test	Distillate categories						
		Gross liquified product	Centrifuged liquid product	Centrifuge residue				
Gravity, °API (specific)								
Boiling range								
Initial boiling point, °F								
5 %								
10 %								
20 %								
30 %								
40 %								
50 %								
60 %								
70 %								
80 %								
90 %								
95 %								
Final boiling point, °F								
Pour point, °F								
Flashpoint, °F								
Viscosity at °F								
at °F								
at °F								
Ash, wt%		2.7						
Ash melt temperature, °F								
Heat of combustion, Btu/lb								
Carbon residue								
Carbon ramsbottom, wt%								
Thermal stability								
Electrical conductivity								
Water								
Sediment								
Neutrality								
Corrosion								

Hydrocarbon type								
Saturates								
Olefins								
Aromatics, total								
Aromatics, polynuclear								
Luminometer number								
Analine point, °F								
H/C atom ratio								
Elemental analyses, wt%								
C								
H								
N								
S		0 8						
O								
Trace metal analyses, ppm								
V								
Ni		10	6 6	54				
Na								
K								
Mg								
Ca								
Pb		3.0	1.1	18				
Cu		6 7	2.7	45				
Fe								
Si								
Zn								
Ba								
Mn		31	11	180				
Mo								
W								
Ti								
Cr		15	7.6	84				
Cd		0 19	0.077	1 0				

TABLE 7 - Continued

(b) Synthoil from West Kentucky bituminous coal (5 3 percent sulfur), data from ref 9[a]

Property	Test	Distillate categories						
		4000-psi, 450°C process conditions						
Gravity, °API (specific)								
Boiling range								
Initial boiling point, °F		241						
5 %								
10 %		339						
20 %		413						
30 %		500						
40 %		530						
50 %								
60 %								
70 %								
80 %								
90 %								
95 %								
Final boiling point, °F								
Pour point, °F								
Flashpoint, °F								
Viscosity at °F								
at °F								
at °F								
Ash, wt%		3 4						
Ash melt temperature, °F								
Heat of combustion, Btu/lb								
Carbon residue								
Carbon ramsbottom, wt%								
Thermal stability								
Electrical conductivity								
Water								
Sediment								
Neutrality								
Corrosion								

Hydrocarbon type								
Saturates								
Olefins								
Aromatics, total								
Aromatics, polynuclear								
Luminometer number								
Analine point, °F								
H/C atom ratio								
Elemental analyses, wt%								
C		80.5						
H		7 72						
N		1.190						
S		1.021						
O								
Trace metal analyses, ppm								
V								
Ni								
Na								
K								
Mg								
Ca								
Pb								
Cu								
Fe								
Si								
Zn								
Ba								
Mn								
Mo								
W								
Ti								

[a] Report includes tabulated data on percent S and N in products from many hydrogenation runs. Maximum hydrogenation pressure was only 1500 psi, so S and N reductions were not large. Typical percent reductions are (a) at 1 5 hr^{-1}. max. N reduction, 23 percent, max. S reduction, 74 percent, (b) at 3 hr^{-1}: max. N reduction, 44 percent; max S reduction, 98 percent.

TABLE 7 - Continued

(c) Synthoil (filtered, centrifuged, and upgraded distillate), data from ref 3

Property	Test	Distillate categories						
		Centrifuged (3296-109)	Filtrate (3296-143)	Washed Filtrate (3296-147)	Upgraded distillate (3392-63(p48))			
Gravity, °API (specific)		-5 7 (1 1248)	-3.5 (1.1055)	-4 3 (1.1124)	9.5 (1 0035)			
Boiling range	D-1160							
Initial boiling point, °F		395	407	455	463			
5 %		470	480	519	543			
10 %		510	515	552	565			
20 %		579	518	606	603			
30 %		642	635	665	638			
40 %		700	697	730	670			
50 %		762	760	795	701			
60 %		845	842	865	735			
70 %		945	951	970	774			
80 %					812			
90 %					863			
95 %					901			
Final boiling point, °F					950			
Pour point, °F			70	75				
Flashpoint, °F								
Viscosity at 175 °F, cS		135						
at 210 °F, cS		43 65	34 25	56 20				
at 250 °F, cS		16 84	14 08	18 73				
Ash, wt%		1 40	0 02	0 015	0 06			
Ash melt temperature, °F								
Heat of combustion, Btu/lb								
Carbon residue								
Carbon ramsbottom, wt%								
Thermal stability								
Electrical conductivity								
Water								
Sediment								
Neutrality								
Corrosion								

Hydrocarbon type								
Saturates								
Olefins								
Aromatics, total					87.0			
Aromatics, polynuclear								
Luminometer number								
Analine point, ^{o}F								
H/C atom ratio								
Elemental analyses, wt%								
C			89.70	88 28	89 17			
H			7.58	7.42	9.77			
N			1 46	1 31	0.337			
S			0 55	0.56	0.02			
O			2 18	2.27	0.33			
Trace metal analyses, ppm								
V								
Ni								
Na				0 6				
K								
Mg				<0.08				
Ca				<0.1				
Pb								
Cu								
Fe				4 8				
Si				0 2				
Zn								
Ba								
Mn								
Mo								
W								
Ti				16 0				
Cl			>670 0	<10 0				

TABLE 7 - Continued

(d) Synthoil from West Virginia coal, data from ref 10

Property	Test	Distillate categories						
		Total crude	<207°C(405° F), 4 4 percent of crude	207°-363° C (405°-685° F), 46 2 percent of crude	363°-531° C (685°-988° F), 27 3 percent of crude			
Gravity, °API (specific)		---(1 081)	19 7 (0 936)	11 4 (0 990)	---(1 109)			
Boiling range								
Initial boiling point, °F	Bureau of							
5 %	Mines routine	329	329	405	685			
10 %	method							
20 %								
30 %								
40 %								
50 %								
60 %		795 at 65%						
70 %								
80 %								
90 %								
95 %								
Final boiling point, °F			405	685	988			
Pour point, °F	D-97	40	<5	<5				
Flashpoint, °F								
Viscosity at 100 °F, SUS		2026	34	57				
at 100 °F, kin, cS		~450	2 27	9.56				
at °F								
Ash, wt%								
Ash melt temperature, °F								
Heat of combustion, Btu/lb								
Carbon residue (Conradson), wt%	D-524	11 2	1 29	2 33	7 42			
Carbon ramsbottom, wt%								
Thermal stability								
Electrical conductivity								
Water								
Sediment								
Neutrality								
Corrosion								

Hydrocarbon type								
Saturates			27 1	16	9 7			
Olefins			3 2					
Aromatics, total			30 8	79 0	84 0			
Aromatics, polynuclear			3 2	51.3	79.3			
Luminometer number								
Analine point, °F								
H/C atom ratio								
Elemental analyses, wt%								
C								
H								
N	Kjeldahl	0 786	0 423	0 724	1.187			
S	D-129	0 42	0.20	0.30	0.44			
O								
Trace metal analyses, ppm								
V								
Ni								
Na								
K								
Mg								
Ca								
Pb								
Cu								
Fe								
Si								
Zn								
Ba								
Mn								
Mo								
W								
Ti								

TABLE 7 - Continued

(e) Synthoil I, from West Kentucky bituminous coal (5 3 percent sulfur), data from ref 11[b]

Property	Test	Distillate categories						
		4000-psi, 450° C process conditions						
Gravity, °API (specific)								
Boiling range								
Initial boiling point, °F								
5 %								
10 %								
20 %								
30 %								
40 %								
50 %								
60 %								
70 %								
80 %								
90 %								
95 %								
Final boiling point, °F								
Pour point, °F								
Flashpoint, °F								
Viscosity at °F								
at °F								
at °F								
Ash, wt%								
Ash melt temperature, °F								
Heat of combustion, Btu/lb								
Carbon residue								
Carbon ramsbottom, wt%								
Thermal stability								
Electrical conductivity								
Water								
Sediment								
Neutrality								
Corrosion								

Hydrocarbon type								
Saturates								
Olefins								
Aromatics, total								
Aromatics, polynuclear								
Luminometer number								
Analine point, °F								
H/C atom ratio								
Elemental analyses, wt%								
C		80 5						
H		7 72						
N		1 205						
S		1 057						
O								
Trace metal analyses, ppm								
V								
Ni								
Na								
K								
Mg								
Ca								
Pb								
Cu								
Fe								
Si								
Zn								
Ba								
Mn								
Mo								
W								
Ti								

[b]Results of hydrogenation runs at 500, 1000, and 1500 psi and 650°, 700°, and 800° F with CO-Mo catalyst. Max. N removal, 25 percent, Max S removal, 43 percent No data on products in this report

TABLE 7 - Continued

(f) Synthoil (whole crude, 509°-650° F and 650°-698° F cuts, and residuals (698° F+)), data from ref 12[c]

Property	Test	Distillate categories						
		Whole crude	509°-650° F cut	650°-698° F cut	Residuals (698° F +)			
Gravity, °API (specific)		5 9	15 9	9 4	-4 3			
Boiling range								
Initial boiling point, °F		300	509	650	695			
5 %		440						
10 %		469						
20 %		521						
30 %		573						
40 %		630						
50 %		688						
52 %		698						
70 %								
80 %								
90 %								
95 %								
Final boiling point, °F			650	698				
Pour point, °F		25	-30	20	>120			
Flashpoint, °F								
Viscosity at 80°F, cS		1950						
at 100°F, cS		673	7 29	35 9	2132 at 175° F			
at 210°F, cS			1 85	3.91	359.1			
Ash, wt%								
Ash melt temperature, °F								
Heat of combustion, Btu/lb								
Carbon residue								
Carbon ramsbottom, wt%								
Thermal stability								
Electrical conductivity								
Water } Combined								
Sediment } Combined		0 05						
Neutrality	D-664	0 36						
Corrosion								

Hydrocarbon type								
Saturates								
Olefins								
Aromatics, total								
Aromatics, polynuclear								
Luminometer number								
Analine point, °F			38	40				
H/C atom ratio								
Elemental analyses, wt%								
C								
H								
N		0 79	0 32	0 47	1 22			
S		0 22	0 14	0 12	0 31			
O								
Trace metal analyses, ppm								
V					7 5			
Ni					1.0			
Na								
K								
Mg								
Ca								
Pb								
Cu								
Fe					419 0			
Si								
Zn								
Ba								
Mn								
Mo								
W								
Ti								

[c] Data on other cuts also contained in reference

TABLE 7 - Continued

(g) Synthoil (sample J-7992), data from ref 5

Property	Test	Distillate categories						
		Sample J-7992						
Gravity, °API (specific)		--(1 10)						
Boiling range								
Initial boiling point, °F		341						
5 %								
10 %		473						
20 %		534						
30 %		591						
40 %		654						
50 %		715						
60 %		800						
70 %		>890						
80 %								
90 %								
95 %								
Final boiling point, °F								
Pour point, °F		40						
Flashpoint, °F		222						
Viscosity at 100°F, cS		2509						
at 210°F, cS		28 6						
at °F								
Ash, wt%	D-482	0.68						
Ash melt temperature, °F								
Heat of combustion, Btu/lb		16 891						
Carbon residue (Conradson), wt%		18 9						
Carbon ramsbottom, wt%								
Thermal stability								
Electrical conductivity								
Water } Sediment } Combined, vol%		12						
Neutrality								
Corrosion								

Hydrocarbon type								
Saturates								
Olefins								
Aromatics, total								
Aromatics, polynuclear								
Luminometer number								
Analine point, °F								
H/C atom ratio								
Elemental analyses, wt%								
C		87 62						
H		7 97						
N		0 97						
S		0 43						
O		2 08						
Trace metal analyses, ppm								
V		2						
Ni		1						
Na		79						
K		116						
Mg		33						
Ca		27						
Pb		5						
Cu								
Fe		375						
Si		1348						
Zn								
Ba								
Mn								
Mo								
W								
Ti		150						
Al		886						

TABLE 7 - Concluded

(h) Synthoil (evaluated in T63 combustor), data from ref 13

Property	Test	Distillate categories						
		Synthoil						
Gravity, °API (specific)		4 0						
Boiling range								
Initial boiling point, °F								
5 %								
10 %		409						
20 %								
30 %								
40 %								
50 %		580						
60 %								
70 %								
80 %								
90 %		780						
95 %								
Final boiling point °F								
Pour point, °F		20						
Flashpoint, °F								
Viscosity at 100°F, cS		143 5						
at °F								
at °F								
Ash, wt%		0 26						
Ash melt temperature, °F								
Heat of combustion, Btu/lb		17 245						
Carbon residue		10 2						
Carbon ramsbottom, wt%								
Thermal stability								
Electrical conductivity								
Water								
Sediment								
Neutrality								
Corrosion								

Hydrocarbon type								
Saturates								
Olefins								
Aromatics, total		64						
Aromatics, polynuclear		22						
Luminometer number								
Analine point, °F		Too dark						
H/C atom ratio		1 26						
Elemental analyses, wt%								
C								
H								
N		0 810						
S		0 21						
O								
Trace metal analyses, ppm								
V		<4 8						
Ni								
Na		4 29						
K		1 01						
Mg		2 11						
Ca		3 35						
Pb		<0 48						
Cu								
Fe								
Si								
Zn								
Ba								
Mn								
Mo								
W								
Ti								

TABLE 8 - FUEL DATA FROM SOLVENT-REFINED COAL PROCESS

(a) SRC products from Kentucky high-sulfur bituminous coals, data from ref 14

Property	Test	Distillate categories						
		Solvent-refined coal	Light oil	Wash solvent	Process solvent			
Gravity, °API (specific)								
Boiling range								
Initial boiling point, °F								
5 %								
10 %								
20 %								
30 %								
40 %								
50 %								
60 %								
70 %								
80 %								
90 %								
95 %								
Final boiling point, °F								
Pour point, °F								
Flashpoint, °F								
Viscosity at °F								
at °F								
at °F								
Ash, wt%								
Ash melt temperature, °F								
Heat of combustion, Btu/lb								
Carbon residue								
Carbon ramsbottom, wt%								
Thermal stability								
Electrical conductivity								
Water								
Sediment								
Neutrality								
Corrosion								

		NAA	XRF						
Hydrocarbon type [a]									
Saturates									
Olefins									
Aromatics, total									
Aromatics, polynuclear									
Luminometer number									
Analine point, °F									
H/C atom ratio									
Elemental analyses, wt%									
C									
H									
N									
S									
O									
Trace metal analyses, ppm		NAA	XRF						
V									
Ni		<6 0	2 1						
Na		8 8				1.7			
K									
Mg									
Ca									
Pb			<1 0						
Cu			0 6						
Fe		270	300			14+/-1			
Si									
Zn		8 1	7 2			0 58+/-0 04			
Ba									
Mn									
Mo									
W									
Ti									
Cr		7 5	6 0			0 044+/-0 009			
As		2 1	1 8			0 0013+/-0 001			

[a]Some analysis of hydrocarbon type citing ppm of individual constituents, but not in a manner that can be used to provide numbers in this table.

TABLE 8 - Continued

(b) SRC products from Illinois #6 coal, data from ref 15[b]

Property	Test	Distillate categories						
		92 MB-1	92 MB-2	93 MB-1	93 MB-2			
Gravity, °API (specific)								
Boiling range								
Initial boiling point, °F								
5 %								
10 %								
20 %								
30 %								
40 %								
50 %								
60 %								
70 %								
80 %								
90 %								
95 %								
Final boiling point, °F								
Pour point, °F								
Flashpoint, °F								
Viscosity at °F								
at °F								
at °F								
Ash, wt%		0 19	0 31	0.39	0.25			
Ash melt temperature, °F (SRC melt temp)		312	367	327	354			
Heat of combustion, Btu/lb (unspec)		15 719	15 733	15 857	15 673			
Carbon residue								
Carbon ramsbottom, wt%								
Thermal stability								
Electrical conductivity								
Water								
Sediment								
Neutrality								
Corrosion								

Hydrocarbon type								
Saturates								
Olefins								
Aromatics, total								
Aromatics, polynuclear								
Luminometer number								
Analine point, °F								
H/C atom ratio								
Elemental analyses, wt%								
C		87.12	87.48	86.62	86.29			
H		6 56	6 12	5 62	5 45			
N		1 87	1 89	1 91	1 95			
S		1 07	0 88	1 10	1.09			
O		3 19	3 32	4 36	4.97			
Trace metal analyses, ppm								
V								
Ni								
Na								
K								
Mg								
Ca								
Pb								
Cu								
Fe								
Si								
Zn								
Ba								
Mn								
Mo								
W								
Ti								

[b]Considerable data on streams throughout the pilot plant. However, it is not apparent which are product output streams and which are internal streams only, other than the SRC products contained on this sheet

TABLE 8 - Continued

(c) SRC-II (typical properties from West Kentucky coals with 4 percent sulfur and 2 percent nitrogen), data from refs 16 and 17

Property	Test	Distillate categories						
		SRC solid	Light distillate	Distillate fuel oil				
Gravity, °API (specific)		-18 3	39	5 0				
Boiling range								
Initial boiling point, °F		800+	100	400				
5 %								
10 %								
20 %								
30 %								
40 %								
50 %								
60 %								
70 %								
80 %								
90 %								
95 %								
Final boiling point, °F			400	900				
Pour point, °F								
Flashpoint, °F				168				
Viscosity at 100°F, SUS				50 (7 3 cS)				
at °F								
at °F								
Ash, wt%								
Ash melt temperature, °F								
Heat of combustion, Btu/lb (higher)		16 000	19 048	17 300				
Carbon residue								
Carbon ramsbottom, wt%								
Thermal stability								
Electrical conductivity								
Water								
Sediment								
Neutrality								
Corrosion								

Hydrocarbon type								
Saturates								
Olefins								
Aromatics, total								
Aromatics, polynuclear								
Luminometer number								
Analine point, °F								
H/C atom ratio								
Elemental analyses, wt%								
C			84.0	87.2				
H			11.5	7.9				
N		2 0	0 4	0.9				
S		0.8	0.2	0.3				
O			3.9	3.9				
Trace metal analyses, ppm								
V								
Ni								
Na								
K								
Mg								
Ca								
Pb								
Cu								
Fe								
Si								
Zn								
Ba								
Mn								
Mo								
W								
Ti								

TABLE 8 - Continued

(d) SRC (filtered and upgraded), data from ref 3

Property	Test	Distillate categories						
		Filtered SRC[a]	SRC filtrate[b]	Upgraded SRC[c]				
Gravity, °API (specific)		-5 8 (1 1257)	2 5 (1 0560)	9 6 (1 0028)				
Boiling range								
Initial boiling point, °F		400	385	433				
5 %		520	428	555				
10 %		550	435	600				
20 %		585	450	660				
30 %		620	462	718				
40 %		652	475	780				
50 %		685	498	850				
60 %		740	535	940				
70 %		825	600	1000 at 65%				
80 %		1020	700					
90 %			875 at 89%					
95 %								
Final boiling point, °F								
Pour point, °F		50		55				
Flashpoint, °F								
Viscosity at 100°F, SFS		884 (1900 cS)						
at 210°F, cS		20 45		32 69				
at 250°F, cS				14 43				
Ash, wt%			0 02	0 001				
Ash melt temperature, °F								
Heat of combustion, Btu/lb								
Carbon residue (Conradson), wt%				16 31				
Carbon ramsbottom, wt%								
Thermal stability								
Electrical conductivity								
Water								
Sediment								
Neutrality								
Corrosion								

Hydrocarbon type								
Saturates								
Olefins								
Aromatics, total				91 7				
Aromatics, polynuclear								
Luminometer number								
Analine point, °F								
H/C atom ratio								
Elemental analyses, wt%								
C		86 77		90 85				
H		6 90		8 76				
N		1 28		0 548				
S		0 72		0.02				
O		3 81		0 02				
Trace metal analyses, ppm								
V								
Ni								
Na		0 08						
K								
Mg		0 4						
Ca		0 5						
Pb								
Cu								
Fe		1 8						
Si		8 8						
Zn								
Ba								
Mn								
Mo								
W								
Ti		34 0						
Al		5.0						

[a]Containing 65 percent process solvent (3296-19 p 57)

[b]As received (3296-95 p. 66).

[c]3392-64 p. 79

TABLE 8 - Continued

(e) SRC (light organic liquid and recycle solvent), data from ref 5

Property	Test	Distillate categories						
		Light organic liquid (J-7951)	Recycle solvent (J-7950)					
Gravity, °API (specific)		---- (0.9182)	----(1 039)					
Boiling range								
Initial boiling point, °F		181	326					
5 %								
10 %		284	398					
20 %		325	405					
30 %		335	434					
40 %		348	454					
50 %		365	492					
60 %		375	526					
70 %		397	566					
80 %		407	595					
90 %		415	657					
95 %								
Final boiling point, °F		561	877					
Pour point, °F		65	45					
Flashpoint, °F		90	205					
Viscosity at 100°F, cS		1 441	5 88					
at 210°F, cS		0 647	1 464					
at °F								
Ash, wt%	D-482	18	3					
Ash melt temperature, °F								
Heat of combustion, Btu/lb		17 226	16 715					
Carbon residue (Conradson), wt%		0 01	0 08					
Carbon ramsbottom, wt%								
Thermal stability								
Electrical conductivity								
Water } Combined, vol%		0 05	0					
Sediment }								
Neutrality								
Corrosion								

Hydrocarbon type								
Saturates								
Olefins								
Aromatics, total								
Aromatics, polynuclear								
Luminometer number								
Analine point, °F								
H/C atom ratio								
Elemental analyses, wt%								
C		84 72	87 34					
H		9 98	7 56					
N		0 23	0 59					
S		0 40	0 32					
O		5 00	4 05					
Trace metal analyses, ppm								
V		0 0	0					
Ni		1 2	0 3					
Na		1 9	1 6					
K		0 4	0 4					
Mg		0 1	0 2					
Ca		0 5	0 4					
Pb		0 9	0 3					
Cu								
Fe		17 9	4 4					
Si		0	0					
Zn								
Ba								
Mn								
Mo								
W								
Ti		11 0	11 0					
Al		0 6	1 5					

TABLE 8 - Continued

(f) SRC products from Kentucky #9 coal, data from letter of May 16, 1975, to T W Reynolds, NASA Lewis Research Center, from Robert G Sperhac, Pittsburgh & Midway Coal Mining Co

Property	Test	Distillate categories						
		Solvent-refined coal	Wash solvent	Light oil				
Gravity, °API (specific)			---- (0 984)	---- (0 934)				
Boiling range	D-86							
Initial boiling point, °F			383	155				
5 %			402	219				
10 %			408	280				
20 %			413	310				
30 %			417	322				
40 %			421	332				
50 %			425	342				
60 %			430	350				
70 %			436	357				
80 %			444	366				
90 %			455	380				
95 %			463	400				
Final boiling point, °F			482	402				
Pour point, °F, fusion point, °F		430						
Flashpoint, °F								
Viscosity at 77°F, cS				1 236				
at 100°F, cS			2 75	0 794				
at °F								
Ash, wt%		0.3						
Ash melt temperature, °F								
Heat of combustion, Btu/lb								
Carbon residue								
Carbon ramsbottom, wt%								
Thermal stability								
Electrical conductivity								
Water								
Sediment								
Neutrality								
Corrosion								

Hydrocarbon type								
Saturates								
Olefins								
Aromatics, total								
Aromatics, polynuclear								
Luminometer number								
Analine point, °F								
H/C atom ratio								
Elemental analyses, wt%								
C		87 1	86 2	82 7				
H		5 3	8 6	10 1				
N		2 2	0 6	0 6				
S		0 5	0 2	0.3				
O		4 4	4.4	6.4				
Trace metal analyses, ppm								
V								
Ni								
Na								
K								
Mg								
Ca								
Pb								
Cu								
Fe								
Si								
Zn								
Ba								
Mn								
Mo								
W								
Ti								

TABLE 8 - Continued

(g) SRC (light organic liquids and recycle solvents), data from ref 32

Property	Test	Distillate categories						
		Light organic liquid (76D-1291)	Recycle solvent (76D-3019)	Recycle solvent (76D-1289)	Recycle solvent (76D-1290)			
Gravity, °API (specific)		--- (0 8470)	---(1 0318)	--- (1 0333)	--- (1 0333)			
Boiling range								
Initial boiling point, °F		83	321	306	326			
5 %		149	361	373	367			
10 %		177	375	393	390			
20 %		213	400	409	403			
30 %		250	416	434	441			
40 %		284	443	453	470			
50 %		317	468	483	501			
60 %		339	498	510	550			
70 %		347	537	551	584			
80 %		384	586	594	667			
90 %		399	647	669	771			
95 %		420	688	724	859			
Final boiling point, °F		563	844	902	1007			
Pour point, °F								
Flashpoint, °F		18		180	182			
Viscosity at 100°F, cS			5 56	5.79	10.44			
at 210°F, cS			1 45	1 48	2 25			
at °F								
Ash, ~~wt%~~, ppm	D-482		10	100	100			
Ash melt temperature, °F								
Heat of combustion, Btu/lb		18 148	16 826	16 921				
Carbon residue (Conradson), wt%			0.29	0.19	0.22			
Carbon ramsbottom, wt%								
Thermal stability								
Electrical conductivity								
Water		0		0	0			
Sediment								
Neutrality								
Corrosion								

Hydrocarbon type								
Saturates								
Olefins								
Aromatics, total								
Aromatics, polynuclear								
Luminometer number								
Analine point, °F								
H/C atom ratio								
Elemental analyses, wt%								
C		83 70	88.00	88.40				
H		11.33	7 65	7 43	8 78			
N		0 30	0.59	0.62	0.50			
S		0 60	0 41	0.37	0.35			
O		4 00	4 00	3 90	3.30			
Trace metal analyses, ppm								
V		0 2	0 2	0 9	4 0			
Ni		0	0.2	0	0			
Na		0.4	0.3	0.4	0.4			
K		0.1	0 1	0 2	0 8			
Mg		0	0	0	0			
Ca		0.1	15.0	0.4	0.5			
Pb		7 4	4 0	0	0.9			
Cu								
Fe		2.1	13.0	31.0	56.0			
Si		0	0	1.0	0			
Zn								
Ba								
Mn								
Mo								
W								
Ti		10.0	9 6	20 0	0			
Al		0	1.0	1.0	0			

TABLE 8 - Concluded

(h) SRC (Wilsonville Process Solvent), data from ref 32

Property	Test	Distillate categories						
		Process solvent (76D-1289)	Hydroprocessed process solvent					
			J-8511	J-8512	J-8513			
Gravity, °API (specific)		5 3	13 0	19 5	23 4			
Boiling range								
Initial boiling point, °F	D-2887	324	175	180	172			
5 %		375	303	216	207			
10 %		394	362	268	232			
20 %								
30 %		446	413	402	387			
40 %								
50 %		492	469	463	432			
60 %								
70 %		564	534	525	495			
80 %								
90 %		665	627	602	578			
95 %		709	681	649	630			
Final boiling point, °F		872	857	818	814			
Pour point, °F								
Flashpoint, °F		180	87	48	62			
Viscosity at 100 °F, cS		5 79	3 43	2 20	2 00			
at 210 °F, cS		1 48	1 10	0 93	0 90			
at °F								
Ash, wt%								
Ash melt temperature, °F								
Heat of combustion, Btu/lb		16 921	17 728	18 572	18 903			
Carbon residue								
Carbon ramsbottom, wt%								
Thermal stability								
Electrical conductivity								
Water								
Sediment								
Neutrality								
Corrosion								

Hydrocarbon type								
Saturates								
Olefins								
Aromatics, ~~total~~ Carbon %		74	66	46	34			
Aromatics, polynuclear								
Luminometer number								
Analine point, ^{o}F								
H/C atom ratio								
Elemental analyses, wt%								
C								
H		7 43	8.88	10 32	10 99			
N		0.62	0.44	0.11	0.02			
S		0 37	0 06	0.01	0.01			
O		3 90	2 40	0.60	0.20			
Trace metal analyses, ppm								
V		0 9	<0 1	0 2	<0 1			
Ni								
Na		0 39	1 1	0 08	0 05			
K		0 19	0 22	0 03	0 01			
Mg								
Ca		0 35	0 23	0 12	0.12			
Pb		0 9	0 9	0 6	0 3			
Cu								
Fe		61 0	2 3	1 5	3 4			
Si								
Zn								
Ba								
Mn								
Mo								
W								
Ti		20 0	1 0	1 0	1 0			

TABLE 9 - FUEL DATA FROM COED PROCESS

(a) COED fuel from West Kentucky coal, data from ref 18[a]

Property	Test	Distillate categories						
		Whole crude	Naphtha (22 4 percent)	Middle distillate (46 2 percent)	Gas oil (27 8 percent)			
Gravity, °API (specific)		23 1	44 5	20 7	12 0			
Boiling range								
Initial boiling point, °F	Simulated distillation	97	97	364	217			
5 %			---	---	---			
10 %			144	434	663			
20 %			219	468	693			
30 %			230	499	712			
40 %			257	525	731			
50 %			280	555	750			
60 %			298	581	769			
70 %			325	611	790			
80 %			345	637	811			
90 %		835	367	671	835			
95 %								
Final boiling point, °F								
Pour point, °F								
Flashpoint, °F								
Viscosity at °F								
at °F								
at °F								
Ash, wt%								
Ash melt temperature, °F								
Heat of combustion, Btu/lb								
Carbon residue								
Carbon ramsbottom, wt%								
Thermal stability								
Electrical conductivity								
Water								
Sediment								
Neutrality								
Corrosion								

Hydrocarbon type								
Saturates								
Olefins								
Aromatics, total								
Aromatics, polynuclear								
Luminometer number								
Analine point, °F								
H/C atom ratio								
Elemental analyses, wt%								
C		88 1	86 6	88 3	89 0			
H		11 5	13 0	11 2	10 7			
N		0 125	0 056	0 16	0 09			
S		0 013	0 0049	0 0055	0 0090			
O		0 344	0 342	0 362	0 246			
Trace metal analyses, ppm								
V								
Ni		<0 5						
Na								
K								
Mg		<0 5						
Ca								
Pb		<0 5						
Cu		0 1						
Fe		0 6						
Si								
Zn		<1 0						
Ba								
Mn		<0 2						
Mo		<0 1						
W								
Ti		<0 1						
Cr		<0 2						
Co		<0 1						
Sn		<0 5						
Hg		<0 02						

[a]Report contains detailed hydroprocessing data on COED fractions

TABLE 9 - Continued

(b) COED fuel from West Kentucky coal, data from ref 19[b]

Property	Test	Distillate categories						
		Crude	Distillate (<205°C, 21 percent)	Distillate (205°-380°C, 54 2 percent)	Residuals (>380°C, 24 2 percent)			
Gravity, °API (specific)		24 8 (023)	40 4(823)	18 9 (941)	10 1 (999)			
Boiling range								
Initial boiling point, °F			123	236				
5 %	Percent	212	198	367				
10 %	12 2	302	214	415				
20 %	21 9	392	234	455				
30 %	28 3	437	250	492				
40 %	43 6	527	270	512				
50 %	54	437 at 40 mm	288	532				
60 %	63	482 at 90 mm	314	554				
70 %	73	527 at 40 mm	336	582				
80 %	82 5	572 at 40 mm	362	611				
90 %			400	646				
95 %			435	683				
Final boiling point, °F			495	706				
Pour point, °F		<5	<5	<5	80			
Flashpoint, °F								
Viscosity at 77 °F, SUS		48						
at 100 °F, SUS		43(~5 1 cS)						
at 100 °F, cS	445		0 89	4 51				
Ash, wt%			0	0 002	0			
Ash melt temperature, °F								
Heat of combustion, Btu/lb								
Carbon residue (Conradson)	D-189			0 0	0.36			
Carbon ramsbottom, wt%		0						
Thermal stability								
Electrical conductivity								
Water								
Sediment								
Neutrality, acid number	D-974		0 03	0 08	0 37			
Corrosion								

Hydrocarbon type								
Saturates				25.6	23.4			
Olefins								
Aromatics, total				74 4	76 6			
Aromatics, polynuclear				32 0	51 6			
Luminometer number								
Analine point, °F								
H/C atom ratio								
Elemental analyses, wt%								
C								
H								
N		0 226	0 190	0 248	0 294			
S		0 08	0 05	0 04	0 01			
O								
Trace metal analyses, ppm								
V								
Ni								
Na								
K								
Mg								
Ca								
Pb								
Cu								
Fe								
Si								
Zn								
Ba								
Mn								
Mo								
W								
Ti								

[b]More detailed hydrocarbon analysis contained in report

TABLE 9 - Continued

(c) COED fuel from Utah A-seam and Illinois #6 coal, data from ref 6

Property	Test	Distillate categories						
		Utah A-seam	Illinois #6 seam					
Gravity, °API (specific)		20	22					
Boiling range								
Initial boiling point, °F		280	190					
5 %								
10 %		430	273					
20 %								
30 %		530	390					
40 %								
50 %		660	518					
60 %								
70 %		780	600					
80 %								
90 %		920	684					
95 %								
Final boiling point, °F		950	746					
Pour point, °F		60	0					
Flashpoint, °F		75	60					
Viscosity at 100°F, cS		8	5					
at °F								
at °F								
Ash, wt%		<0 01	<0 01					
Ash melt temperature, °F								
Heat of combustion, Btu/lb								
Carbon residue (10% bottoms)			4 6					
Carbon ramsbottom, wt%								
Thermal stability								
Electrical conductivity								
Water, wt%		0 1	0 1					
Sediment								
Neutrality								
Corrosion								

Hydrocarbon type; liq vol %.								
Saturates		65.9	51.8					
Olefins		0	0					
Aromatics, total		34.1	48.2					
Aromatics, polynuclear								
Luminometer number								
Analine point, °F								
H/C atom ratio								
Elemental analyses, wt%								
C		87 2	87 1					
H		11 0	10 9					
N		0 2	0.3					
S		0 1	0 1					
O		1 4	1 6					
Trace metal analyses, ppm	Total	<10 ppm	<10 ppm					
V								
Ni								
Na								
K								
Mg								
Ca								
Pb								
Cu								
Fe								
Si								
Zn								
Ba								
Mn								
Mo								
W								
Ti								
Paraffins		23 7	10 4					
Naphthenes		42 2	41 4					

TABLE 9 - Continued

(d) COED fuel from Illinois #6 coal (distillate cuts), data from ref 6

Property	Test	Distillate categories						
Gravity, °API (specific)		18 4	22 5	11 2				
Boiling range								
Initial boiling point, °F		354	436	557				
5 %								
10 %		409	459	705				
20 %								
30 %								
40 %								
50 %								
60 %								
70 %								
80 %								
90 %		780	586	870				
95 %								
Final boiling point, °F			613					
Pour point, °F		25	-70	70				
Flashpoint, °F		160	215	400				
Viscosity at 100 °F, SUS		52 5 (8 1 cS)	39 3 (3 9 cS)					
at °F								
at °F								
Ash, wt%		0 007	0 0					
Ash melt temperature, °F								
Heat of combustion, Btu/lb								
Carbon residue	D-189	0 4		1.13				
Carbon ramsbottom, wt%								
Thermal stability								
Electrical conductivity								
Water } Combined		0 10						
Sediment } Combined								
Neutrality								
Corrosion								

Hydrocarbon type								
Saturates								
Olefins								
Aromatics, total								
Aromatics, polynuclear								
Luminometer number								
Analine point, °F								
H/C atom ratio								
Elemental analyses, wt%								
C								
H								
N								
S		0 16	0 004	0 07				
O								
Trace metal analyses, ppm								
V								
Ni								
Na								
K								
Mg								
Ca								
Pb								
Cu								
Fe								
Si								
Zn								
Ba								
Mn								
Mo								
W								
Ti								

TABLE 9 - Continued

(e) COED fuel from Utah light and heavy coal, data from ref 13

Property	Test	Distillate categories						
		Utah light	Utah heavy					
Gravity, °API (specific)		41 9	22 5					
Boiling range								
Initial boiling point, °F		176	<300					
5 %								
10 %		215	314					
20 %		230	416					
30 %								
40 %								
50 %		287	552					
60 %								
70 %		352	680					
80 %								
90 %		439	736					
95 %								
Final boiling point, °F		545	849					
Pour point, °F		-65	60					
Flashpoint, °F		80	120					
Viscosity at 100°F, cS		0.94	6 82					
at °F								
at °F								
Ash, wt%		<0 01	<0 01					
Ash melt temperature, °F								
Heat of combustion, Btu/lb	Lower	18 356	18 020					
Carbon residue		0 05	1 46					
Carbon ramsbottom, wt%								
Thermal stability								
Electrical conductivity								
Water								
Sediment								
Neutrality								
Corrosion								

Hydrocarbon type								
Saturates								
Olefins								
Aromatics, total		32	45					
Aromatics, polynuclear		3	14					
Luminometer number								
Analine point, ^{o}F		84 2	Too dark					
H/C atom ratio		1.86	1.61					
Elemental analyses, wt%								
C								
H								
N		0 193	0 143					
S		<0 01	0 05					
O								
Trace metal analyses, ppm								
V		<6 1	<5 4					
Ni								
Na		0 92	6 13					
K		1 81	0.38					
Mg		2.68	3.21					
Ca		<0 61	28 3					
Pb		0 74	<0 54					
Cu								
Fe								
Si								
Zn								
Ba								
Mn								
Mo								
W								
Ti								

TABLE 9 - Concluded

(f) COED fuel from Utah and West Kentucky coals, data from ref 20

Property	Test	Distillate categories						
		Utah T-460A	W Kentucky T-460C					
Gravity, °API (specific)		19 0	22 3					
Boiling range								
Initial boiling point, °F		198	148					
5 %		340	246					
10 %		412	287					
20 %		485	364					
30 %		510	420					
40 %		520	492					
50 %		635	537					
60 %		697	603					
70 %		755	657					
80 %		803	715					
90 %		860	782					
95 %		910	824					
Final boiling point, °F		950	844					
Pour point, °F		50	-15					
Flashpoint, °F		120	<70					
Viscosity at °F								
at °F								
at °F								
Ash, wt%								
Ash melt temperature, °F								
Heat of combustion, Btu/lb								
Carbon residue								
Carbon ramsbottom, wt%		0 83	0 37					
Thermal stability								
Electrical conductivity								
Water								
Sediment								
Neutrality								
Corrosion								

Hydrocarbon type								
Saturates			7 7					
Olefins			27 4					
Aromatics, total			64 9					
Aromatics, polynuclear								
Luminometer number								
Analine point, °F								
H/C atom ratio								
Elemental analyses, wt%								
C		85 91	86 98					
H		11 97	12 13					
N		0 25	0 18					
S		0 0388	0 0271					
O		1.62	0.60					
Trace metal analyses, ppm								
V								
Ni								
Na								
K								
Mg								
Ca								
Pb								
Cu								
Fe								
Si								
Zn								
Ba								
Mn								
Mo								
W								
Ti								

TABLE 10 - FUEL DATA FROM GULF CATALYTIC LIQUEFACTION PROCESS

[Data from ref 21]

Property	Test	Distillate categories						
		Full-range F1 (Western subbituminous)	Full-range F2 (Bituminous, Pittsburgh seam)	Distillate D from F1				
Gravity, °API (specific)		7 0	10 4	14 0				
Boiling range								
Initial boiling point, °F				266				
5 %								
10 %								
20 %								
30 %								
40 %								
50 %								
60 %								
70 %								
80 %								
90 %								
95 %								
Final boiling point, °F				688				
Pour point, °F								
Flashpoint, °F								
Viscosity at °F		In range of #4 or #5 fuel oils		In range of #2 fuel oil				
at °F								
at °F								
Ash, wt%				0 0030				
Ash melt temperature, °F								
Heat of combustion, Btu/lb								
Carbon residue								
Carbon ramsbottom, wt%								
Thermal stability								
Electrical conductivity								
Water								
Sediment								
Neutrality								
Corrosion								

Hydrocarbon type								
Saturates								
Olefins								
Aromatics, total								
Aromatics, polynuclear								
Luminometer number								
Analine point, ^{o}F								
H/C atom ratio								
Elemental analyses, wt%								
C		89 93	89 0	89.6				
H		8 84	9 44	9.54				
N		0 51	0 50	0 31				
S		0 07		0.04				
O								
Trace metal analyses, ppm								
V								
Ni								
Na								
K								
Mg								
Ca								
Pb								
Cu								
Fe								
Si								
Zn								
Ba								
Mn								
Mo								
W								
Ti								

TABLE 11 - FUEL DATA FROM EXXON DONOR SOLVENT PROCESS

[Data from ref 23]

Property	Test	Distillate categories						
		Heavy naphtha		Fuel oil				
		Raw liquid	Hydrotreated liquid	Raw liquid	Hydrotreated liquid			
Gravity, °API (specific)		----(0 87)	----(0 80)	----(1 08)	----(1 01)			
Boiling range	Nominal	158 - 392	158 - 392	392 - 1000	392 - 1000			
Initial boiling point, °F								
5 %								
10 %		223	198	477	462			
20 %	15/5							
30 %	Distillation							
40 %	D-2892							
50 %		356	315	694	657			
60 %								
70 %								
80 %								
90 %		390	360	811	774			
95 %								
Final boiling point, °F								
Pour point, °F								
Flashpoint, °F								
Viscosity at °F								
at °F								
at °F								
Ash, wt%								
Ash melt temperature, °F								
Heat of combustion, Btu/lb	Higher	18 300	19 300	17 100	18 100			
Carbon residue								
Carbon ramsbottom, wt%								
Thermal stability								
Electrical conductivity								
Water								
Sediment								
Neutrality								
Corrosion								

Hydrocarbon type								
Saturates								
Olefins								
Aromatics, total								
Aromatics, polynuclear								
Luminometer number								
Analine point, °F								
H/C atom ratio								
Elemental analyses, wt%								
C		85 60	86.80	89.40	90 80			
H		10 90	12 90	7.70	8 60			
N		0 21	0 06	0 66	0 24			
S		0 47	0 005	0 41	0 04			
O		2 82	0 23	1.83	0 32			
Trace metal analyses, ppm								
V								
Ni								
Na								
K								
Mg								
Ca								
Pb								
Cu								
Fe								
Si								
Zn								
Ba								
Mn								
Mo								
W								
Ti								

TABLE 12 - FUEL DATA FROM ZINC CHLORIDE PROCESS

[Data from ref 24]

Property	Test	Distillate categories						
		Total distillates			Run 25B data			
		Run 24	Run 26	Run 25B	IBP - 392°F	392° F - 617° F	617° F - 887°F	
Gravity, °API (specific)								
Boiling range								
Initial boiling point, °F				IBP	IBP	392	617	
5 %								
10 %								
20 %								
30 %								
40 %								
50 %								
60 %								
70 %								
80 %								
90 %								
95 %								
Final boiling point, °F				887	392	617	887	
Pour point, °F								
Flashpoint, °F								
Viscosity at °F								
at °F								
at °F								
Ash, wt%								
Ash melt temperature, °F								
Heat of combustion, Btu/lb								
Carbon residue								
Carbon ramsbottom, wt%								
Thermal stability								
Electrical conductivity								
Water								
Sediment								
Neutrality								
Corrosion								

Hydrocarbon type								
Saturates								
Olefins								
Aromatics, total								
Aromatics, polynuclear								
Luminometer number								
Analine point, ^{o}F								
H/C atom ratio								
Elemental analyses, wt%								
C		91 37	90 17	89 74	90 58	89 09	89 40	
H		8 48	8 58	8 65	8 33	9 65	8 98	
N		0 0020	0 0194	0 0023	0 0018	0 0025	0 0060	
S		0 02	0 01	0 0	0 02	0 02	0 03	
O		0 11	1 22	1 61	1 06	1 23	1 58	
Trace metal analyses, ppm								
V								
Ni								
Na								
K								
Mg								
Ca								
Pb								
Cu								
Fe								
Si								
Zn								
Ba								
Mn								
Mo								
W								
Ti								
Cl		161 0	40 0	98 0				
Yields, wt% C_5 - 329° F		34 0	34 55	43 91				
329° - 887° F		18 0	20 57	21 13				
>887° F		3 14	9.60	9 60				
H_2O		15 69	11.85	10.94				
Gases		8.86	10.85	7.14				

TABLE 13 - FUEL DATA FROM CO-STEAM PROCESS[a]

[Data from ref 25]

Property	Test	Distillate categories						
		11th run with 1% HCOOH	11th run with no additive	11th run with aged lignite and H_2O				
Gravity, °API (specific)								
Boiling range								
Initial boiling point, °F								
5 %								
10 %								
20 %								
30 %								
40 %								
50 %								
60 %								
70 %								
80 %								
90 %								
95 %								
Final boiling point, °F								
Pour point, °F								
Flashpoint, °F								
Viscosity at 140°F, cS		190	598	12800				
at 180°F, cS		46.8	110	1030				
at °F								
Ash, wt%		0 05	0.03	0.01				
Ash melt temperature, °F								
Heat of combustion, Btu/lb	Calculated	17 056	16 886	16 906				
Carbon residue								
Carbon ramsbottom, wt%								
Thermal stability								
Electrical conductivity								
Water								
Sediment								
Neutrality								
Corrosion								

Hydrocarbon type								
Saturates								
Olefins								
Aromatics, total								
Aromatics, polynuclear								
Luminometer number								
Analine point, °F								
H/C atom ratio								
Elemental analyses, wt%								
C		88.6	89 8	89.5				
H		7 1	6 8	6.6				
N		1 1	1 1	1.1				
S		0.13	0 10	0 12				
O		3 0	3.2	2.6				
Trace metal analyses, ppm								
V								
Ni								
Na								
K								
Mg								
Ca								
Pb								
Cu								
Fe								
Si								
Zn								
Ba								
Mn								
Mo								
W								
Ti								

[a]Table 7 in reference Operating conditions 1 hr at 430°C and 3000 psig, synthesis gas at 1 1 (H_2O coal oil, 9 30 70)

TABLE 14 - FUEL DATA FROM FLASH PYROLYSIS PROCESS

[Data from ref 26, PDU run 120, 200 lb/hr]

Property	Test	Distillate categories						
		#3912 (startup, 95 5% oil)	#4008 (end of run, 61 9% oil)					
Gravity, °API (specific)								
Boiling range								
Initial boiling point, °F		406	411					
5 %								
10 %		495	540					
20 %		525	595					
30 %		556	660					
40 %		593	710					
50 %		620	745					
60 %								
70 %								
80 %								
90 %								
95 %								
Final boiling point, °F								
Pour point, °F								
Flashpoint, °F								
Viscosity at °F								
at °F								
at °F								
Ash, wt%		0.37	6.04					
Ash melt temperature, °F								
Heat of combustion, Btu/lb								
Carbon residue								
Carbon ramsbottom, wt%								
Thermal stability								
Electrical conductivity								
Water								
Sediment								
Neutrality								
Corrosion								

Hydrocarbon type								
Saturates								
Olefins								
Aromatics, total								
Aromatics, polynuclear								
Luminometer number								
Analine point, °F								
H/C atom ratio								
Elemental analyses, wt%								
C		90 16	80 90					
H		6 15	6.18					
N		1.13	1.43					
S		0 56	0 54					
O	By difference	1 63	2 57					
Trace metal analyses, ppm								
V								
Ni								
Na								
K								
Mg								
Ca								
Pb								
Cu								
Fe								
Si								
Zn								
Ba								
Mn								
Mo								
W								
Ti								

TABLE 15 - FUEL DATA FROM CATALYTIC LIQUEFACTION OF PITTSBURGH SEAM BITUMINOUS AND WYOMING SUBBITUMINOUS COAL

[Data from ref 22]

Property	Test	Distillate categories						
		Pittsburgh seam	Wyoming Big Horn					
Gravity, °API (specific)								
Boiling range								
Initial boiling point, °F		130	130					
5 %								
10 %								
~~20 %~~ 25 2%		470						
~~30 %~~ 28 3%			470					
40 %								
50 %								
60 %								
70 %								
80 %								
90 %								
95 %								
Final boiling point, °F								
Pour point, °F								
Flashpoint, °F								
Viscosity at °F								
at °F								
at °F								
Ash, wt%								
Ash melt temperature, °F								
Heat of combustion, Btu/lb								
Carbon residue								
Carbon ramsbottom, wt%								
Thermal stability								
Electrical conductivity								
Water								
Sediment								
Neutrality								
Corrosion								

Hydrocarbon type [a]		<470	>470	<470	>470					
Saturates		14 2	1 8	14.0	3.6					
Olefins		0 2		0 1						
Aromatics, total		10 8	36 2	14.2	58 3					
Aromatics, polynuclear			30 3		49 3					
Luminometer number										
Analine point, °F										
H/C atom ratio										
Elemental analyses, wt%										
C		89 05		89 18						
H		8 18		8 97						
N		0 82		0 40						
S		0 17		0 04						
O		1 47		1 03						
Trace metal analyses, ppm										
V										
Ni										
Na										
K										
Mg										
Ca										
Pb										
Cu										
Fe										
Si										
Zn										
Ba										
Mn										
Mo										
W										
Ti										

[a]More detailed analyses of various fractions contained in report

TABLE 16 - FUEL DATA FROM SEA COAL PROCESS

[Data from ref 13]

Property	Test	Distillate categories						
		Sea Coal						
Gravity, °API (specific)		18 4						
Boiling range								
Initial boiling point, °F		<300						
5 %								
10 %		<300						
20 %		318						
30 %								
40 %		460						
50 %								
60 %								
70 %		572						
80 %								
90 %		760						
95 %								
Final boiling point, °F		875						
Pour point, °F		55						
Flashpoint, °F		145						
Viscosity at 100 °F, cS		9 78						
at °F								
at °F								
Ash, wt%		0 02						
Ash melt temperature, °F								
Heat of combustion, Btu/lb	Lower	17 782						
Carbon residue		2 59						
Carbon ramsbottom, wt%								
Thermal stability								
Electrical conductivity								
Water								
Sediment								
Neutrality								
Corrosion								

Hydrocarbon type								
Saturates								
Olefins								
Aromatics, total		47 0						
Aromatics, polynuclear		12 0						
Luminometer number								
Analine point, ^{o}F		Too dark						
H/C atom ratio		1.52						
Elemental analyses, wt%								
C								
H								
N		0 403						
S		0 02						
O								
Trace metal analyses, ppm								
V		<5 3						
Ni								
Na		342 0						
K		2 49						
Mg		2.36						
Ca		12 7						
Pb		<0 53						
Cu								
Fe								
Si								
Zn								
Ba								
Mn								
Mo								
W								
Ti								

TABLE 17 - PROPOSED SPECIFICATIONS FOR TYPICAL COAL-DERIVED FUEL[a]

[Data from ERDA RFP-EF-77-R-01-2674, June 6, 1977]

Property	Test	Distillate categories						
Gravity, °API (specific)		17 - 25						
Boiling range								
Initial boiling point, °F								
5 %								
10 %								
20 %								
30 %								
40 %								
50 %								
60 %								
70 %								
80 %								
90 %								
95 %								
Final boiling point, °F								
Pour point, °F		20 - 70						
Flashpoint, °F		140 - 160						
Viscosity at 100 °F, cS		10 - 20						
at °F								
at °F								
Ash, wt%		0 01 - 0 07						
Ash melt temperature, °F		1800 - 1900						
Heat of combustion, Btu/lb		[b]17 500 - 18 500						
Carbon residue		0 05 - 1 50						
Carbon ramsbottom, wt%								
Thermal stability								
Electrical conductivity								
Water		<0 1						
Sediment								
Neutrality								
Corrosion								

Hydrocarbon type								
Saturates								
Olefins								
Aromatics, total		30 - 50						
Aromatics, polynuclear								
Luminometer number								
Analine point, ^{o}F								
H/C atom ratio		1.6 - 1.9						
Elemental analyses, wt%								
C								
H								
N		0 1 - 0 8						
S		<0 9						
O								
Trace metal analyses, ppm								
V		0.1 - 0.20						
Ni		0 2 - 0 3						
Na		1 3 - 2.5						
K		0 9 - 0 6						
Mg								
Ca		1 - 10						
Pb		0 1 - 2						
Cu		0 2 - 0 3						
Fe		3 - 5						
Si		0 50 - 0 60						
Zn		1 - 2						
Ba								
Mn								
Mo								
W								
Ti								

[a]Range of properties assumed to be after water-wash cleanup

[b]Inconsistent with gravity range.

TABLE 18 - FUEL DATA FROM LOW-Btu GAS

(a) Low-Btu coal gas, data from ref 27, p 6

Property	Typical ranges			
Composition, vol%				
H_2	12 - 16			
CO	2 - 32			
CO_2	0 5 - 10			
H_2S				
NH_3				
CH_4	0.5 - 4 5			
Other hydrocarbons				
N_2	30 - 55			
COS				
Specific gravity	0.8 - 0.92			
Average molecular weight				
Heating value, Btu/ft^3				
Gross	110 - 165			
Net				
Gross with CO_2, H_2S, and NH_3 removed				
Net with CO_2, H_2S, and NH_3 removed				
Sulfur, ppm				
Alkali metals and sulfur, ppm				
Water, vol %				
Solids, ppm				
Solids particle size, μm				
Flammability limit ratio				

TABLE 18 - Continued

(b) Typical low-Btu gas, from air-blown gasifiers, data from ref 28

Property				
Composition, vol%				
H_2	17.0			
CO	28.3			
CO_2	4.5			
H_2S				
NH_3				
CH_4	3.0			
Other hydrocarbons				
N_2	47.2			
COS				
Specific gravity				
Average molecular weight				
Heating value, Btu/ft^3				
Gross	176 0			
Net				
Gross with CO_2, H_2S, and NH_3 removed				
Net with CO_2, H_2S, and NH_3 removed				
Sulfur, ppm				
Alkali metals and sulfur, ppm				
Water, vol. %				
Solids, ppm				
Solids particle size, μm				
Flammability limit ratio				

TABLE 18 - Continued

(c) Typical fixed-bed gasifier composition (raw gas out of gasifier); data from ERDA RFP-EF-77-R-01-2674, June 6, 1977

Property				
Composition, vol%				
H_2	19 93			
CO	12.66			
CO_2	13.75			
H_2S	0.57			
NH_3	0.23			
CH_4	4 58			
Other hydrocarbons	0.40			
N_2	37.63			
COS	0 06			
Specific gravity				
Average molecular weight				
Heating value, Btu/ft^3				
Gross	163 8			
Net				
Gross with CO_2, H_2S, and NH_3 removed				
Net with CO_2, H_2S, and NH_3 removed				
Sulfur, ppm				
Alkali metals and sulfur, ppm				
Water, vol.%				
Solids, ~~ppm~~ lb dust/lb gas	~0.049			
Solids particle size, μm	(a)			
Flammability limit ratio				
H_2O	10.19			

[a]Less than 5 percent of solids smaller than 2 μm.

TABLE 18 - Continued

(d) Molten-salt gasification; data from ref 29

Property	Raw fuel gas (p.42)	Hot-wall gasification (p.35)	Cold-wall gasification (p.35)	Study assumption (Illinois #6 coal) (p.17)
Composition, vol%:				
H_2	13.79	13.175-14.337	12.658-13.173	12.57
CO	28.33	27.77-29.413	26.279-27.989	26.398
CO_2	3.08	1.735-2.667	2.599-3.217	3.322
H_2S	0.10	0.007-0.016	0.014-0.028	0.009
NH_3				
CH_4	1.50	1.518-2.028	1.266-2.037	1.850
Other hydrocarbons				
N_2	50.85	50.848-51.905	51.991-52.868	53.01
COS		0.005-0.011	0.010-0.019	0.007
Specific gravity				
Average molecular weight				
Heating value, Btu/ft^3				
Gross				
Net		143.9-149.7	129.6-144.7	
Gross with CO_2, H_2S, and NH_3 removed				
Net with CO_2, H_2S, and NH_3 removed				
Sulfur, ppm				
Alkali metals and sulfur, ppm				
Water, vol. %	2.35	2.041-2.44	2.164-3.130	2.837
Solids, ppm				
Solids particle size, μm				
Flammability limit ratio				

TABLE 18 - Continued

(e) Typical gaseous fuels; data from ref 30

Property	Blast furnace gas	Producer gas (coke)	Producer gas (coal)	
Composition, vol %:				
H_2	2.0	11.0	12.0	
CO	27.0	29.0	29.0	
CO_2	11.0	5.0	4.0	
H_2S				
NH_3				
CH_4	---	0.5	2.6	
Other hydrocarbons	---	---	0.4	
N_2	60.0	54.5	52.0	
COS				
Specific gravity				
Average molecular weight				
Heating value, Btu/ft^3:				
Gross	91.2	131.5	166.4	
Net				
Gross with CO_2, H_2S, and NH_3 removed				
Net with CO_2, H_2S, and NH_3 removed				
Sulfur, ppm				
Alkali metals and sulfur, ppm				
Water, vol. %				
Solids, ppm				
Solids particle size, μm				
Flammability limit ratio				

TABLE 18. - Continued

(f) Data from ref 31

Property	Predicted range not yet verified by test of composition system	Range from tests		
Composition, vol%:				
H_2	14 - 17	11.17-23.5		
CO	9 - 22	6.58-30.95		
CO_2	5 - 11	6.91-19.26		
H_2S				
NH_3				
CH_4	3	1.49-3.66		
Other hydrocarbons				
N_2	48 - 52	34.96-56.7		
COS				
Specific gravity				
Average molecular weight				
Heating value, Btu/ft^3:				
Gross				
Net	100 - 135	90-197		
Gross with CO_2, H_2S, and NH_3 removed				
Net with CO_2, H_2S, and NH_3 removed				
Sulfur, ppm				
Alkali metals and sulfur, ppm				
Water, vol.%	9	0		
Solids, ppm				
Solids: particle size, μm				
Flammability limit ratio				

TABLE 18. - Concluded.

(g) Producer gas; data from course notes on "Synthetic Fuels from Coal," Center for Professional Advancement, July 22-24, 1974, p. 50

Property	Typical			
Composition, vol%:				
H_2	10 - 14			
CO	26 - 32			
CO_2	2 - 5			
H_2S				
NH_3				
CH_4	2 - 3			
Other hydrocarbons	0.1 - 4.0			
N_2	50 - 53			
COS				
Specific gravity				
Average molecular weight				
Heating value, Btu/ft^3:				
Gross	158 - 170			
Net	150 - 160			
Gross with CO_2, H_2S, and NH_3 removed				
Net with CO_2, H_2S, and NH_3 removed				
Sulfur, ppm				
Alkali metals and sulfur, ppm				
Water, vol.%				
Solids, ppm				
Solids: particle size, μm				
Flammability limit ratio				
Oxygen	0.1 - 0.3			

TABLE 19. - SUMMARY OF LIQUID FUEL PROPERTIES

Boiling range, °F	Gravity		Elemental composition, wt %			Viscosity, cP		Heat of combustion, Btu/lb	Reference
	API	Specific	H	N	S	at 100° F	at 210° F		
H-Coal process									
180 - >944	27.6	------	7.4	0.81	0.47	--------	-------	------	1
≥620	1.9	------	8.1	.77	.15	178	7.2	17 420	(a)
≥358	2.0	------	8.0	.80	.23	272	8.8	17 415	(a)
282 - 570 (90%)	19.0	------	10.34	22	.16	2.47	.99	18 415	(a)
-50 - 350	44.9	------	12.9	.047	.26	--------	-------	------	2
217 - 500	25.9	------	11.2	.0044	.17	--------	-------	------	2
434 - 767	7.9	------	10.4	.0083	.17	--------	-------	------	2
400	-7.5	------	7.36	1.3	.48	--------	(465 cP)	16 700	(b)
466 - >876	-16.5	------	6.35	1.11	1.43	--------	-------	------	3
493 - >910	-17.7	------	6.96	1 30	.66	--------	-------	------	3
144 - 689	19.8	------	-----	.44	.21	2.4	-------	------	4
144 - 397	32.3	------	-----	.42	.13	1.08	-------	------	
397 - 687	13.0	------	-----	.446	.29	3 87	-------	------	
138 - 795	17.0	------	-----	683	27	6.1	-------	------	
138 - 387	37.4	------	-----	.212	.06	96	-------	------	
387 - 795	6.6	------	-----	.871	.35	14.9	-------	------	
180 - 975	6.4	------	8.19	.81	.22	155	-------	------	(c)
180 - 445	38.6	------	12.41	.19	.24	--------	-------	------	
372 - 680	14 0	------	9.73	.42	.18	4.45	2.7	------	
639 - 975	-2.3	------	7.58	1.01	.22	--------	36	------	
482 - >963	------	------	7.94	.77	.42	--------	318.3	17 411	5
<950	------	------	8.85	.39	.19	--------	-------	------	5
≥950	------	------	6.26	1.30	.95	--------	-------	------	5
180 - 375	------	------	13.6	.1	.1	--------	-------	------	6
375 - 650	------	------	11.0	.1	.1	--------	-------	------	
650 - 975	------	------	10.2	.1	.3	--------	-------	------	
180 - 975	------	------	11.9	.1	.1	--------	-------	------	
C_4 + Liquids	15.0	------	9.48	.68	.19	--------	-------	------	7
C_4 + Liquids	4.4	------	8.43	1.05	.43	--------	-------	------	7
C_4 + Liquids	26.8	------	10.54	.64	.16	--------	-------	------	7
271 - 885	------	------	10.14	38	.11	--------	-------	------	32
270 - 942	------	------	9.80	.38	.13	--------	-------	------	
26 - 746	------	------	11.76	20	.25	--------	-------	------	
20 - 548	------	------	11.99	.20	.26	--------	-------	------	
315 - 851	------	------	9.43	.42	12	--------	-------	------	
61 - 582	------	------	11.85	.13	.09	--------	-------	------	
71 - 808	------	------	11.27	.44	24	--------	-------	------	
275 - 890	------	------	8.64	.41	------	--------	-------	------	

[a]Letter from G.R. Fox of General Electric Research and Development Center to Lloyd I. Shure of NASA Lewis Research Center, Feb. 18, 1977.

[b]Memo for record, John S. Clark of NASA Lewis Research Center, July 19, 1977.

[c]Meeting handout on H-Coal products for gas-turbine combined cycles, Paul H. Kydd of General Electric Co., Schenectady, N.Y., Jan. 9, 1976

TABLE 19 - Continued

Boiling range, °F	Gravity		Elemental composition, wt %			Viscosity, cP		Heat of combustion, Btu/lb	Reference
	API	Specific	H	N	S	at 100° F	at 210° F		
Synthoil process									
241 - >>530	------	------	7 72	1.190	1 021	--------	-------	------	9
395 - >945	-5 7	1 125	-----	------	------	--------	43 65	------	3
407 - >951	-3 5	1 1055	7 58	1 46	55	--------	34 25	------	
445 - >970	-4 3	1 1124	7 42	1 31	56	--------	56 20	------	
463 - 950	9 5	1 0035	9 77	377	02	--------	-------	------	
329 - >795	- 6	1.081	-----	786	42	450	-------	------	10
329 - 405	19 7	936	-----	423	20	2 27	-------	------	
405 - 685	11 4	950	-----	724	30	9 56	-------	------	
685 - 988	-3 9	1 109	-----	1 187	44	--------	-------	------	
(Full range)	------	------	7.72	1 205	1 057	--------	-------	------	11
300 - >698	5 9	------	-----	79	22	673	-------	------	12
>695	-4 3	------	-----	1 22	31	--------	359.1	------	
509 - 650	15 9	------	-----	32	14	7.23	1 85	------	
650 - 698	9 4	------	-----	47	12	35 9	3 91	------	
341 - >890	-2.9	1 10	7 97	.97	43	2509	28 6	16 891	5
<409 - >780	4 0	------	-----	81	21	143 5	-------	17 245	13
SRC process									
Solid m p 312	------	------	6 56	1 87	1 07	--------	-------	15 719	15
Solid m p 367	------	------	6 12	1 89	88	--------	-------	15 733	
Solid m p 327	------	------	5 62	1 91	1 10	--------	-------	15 857	
Solid m p 354	------	------	5 45	1 95	1 09	--------	-------	15 673	
Solid 800+	-18 3	------	-----	2 0	8	--------	-------	16 000	16,17
400 - 900	5 0	------	7 9	9	3	7 3	-------	17 300	16,17
100 - 400	39 0	------	11 5	4	2	--------	-------	19 048	16,17
400 - >1020	-5 8	------	6 90	1 28	72	1900	20.45	------	3
385 - >875	2 5	------	-----	------	------	--------	-------	------	3
433 - >1000	9 6	------	8 76	548	02	--------	32 69	------	3
181 - 561	22 6	9182	9 98	23	40	1 441	647	17 226	5
326 - 877	4 69	1 039	7 56	59	32	5 88	1 464	16 715	5
383 - 482	12 3	984	8 6	6	2	2 75	-------	------	(d)
155 - 402	20.0	934	10 1	6	3	.794	-------	------	(d)
83 - 563	35 6	847	11 33	30	60	--------	-------	18 148	32
321 - 844	5 64	1 0318	7 65	59	41	5 56	1 45	16 826	
306 - 902	5 48	1 0333	7 43	62	.37	5 79	1 48	16 921	
326 - 1007	5 48	1 0333	8 78	50	35	10 44	2 25	------	
324 - 872	5 3	------	7 43	62	37	5 79	1 48	16 921	

[d]Letter from Robert G Sperhac of Pittsburgh & Midway Coal Mining Co to Thaine W Reynolds of NASA Lewis Research Center, May 16, 1975

TABLE 19 - Continued.

Boiling range, °F	Gravity		Elemental composition, wt %			Viscosity, cP		Heat of combustion, Btu/lb	Reference
	API	Specific	H	N	S	at 100° F	at 210° F		
SRC process (Concluded)									
175 - 857	13.0	------	8.88	0.44	0.06	3.43	1.10	17 728	30
180 - 818	14.5	------	10 32	.11	.01	2.20	.93	18 572	30
172 - 814	23.4	------	10 99	02	01	2.00	90	18 903	30
COED process									
97 - 835	23.1	------	11.5	0.125	0.013	--------	-------	------	18
97 - >367	44.5	------	13.0	.056	0049	--------	-------	------	
364 - >671	20 7	------	11.2	.16	0055	--------	-------	------	
217 - >835	12 0	------	10.7	.09	.0090	--------	-------	------	
212 - >800	21.8	------	-----	226	.08	5.1	-------	------	19
123 - 499	40 4	------	-----	.190	05	89	-------	------	
236 - 706	18.9	------	-----	248	.04	4.51	-------	------	
>716	10.1	------	-----	.294	.01	--------	-------	------	
280 - 950	20	------	11.0	.2	.1	8	-------	------	6
190 - 746	22	------	10.9	.3	.1	5	-------	------	
354 - >780	18.4	------	-----	------	.16	8.1	-------	------	
436 - 613	22.5	------	-----	------	.004	3.9	-------	------	
557 - >870	11.2	------	-----	------	.07	--------	-------	------	
176 - 545	41.9	------	-----	193	<.01	.94	-------	18 356	13
<300 - 849	22.5	------	-----	.143	.05	6.82	-------	18 020	13
198 - 950	19.0	------	11.97	25	.18	--------	-------	------	20
148 - 844	22.3	------	12.13	.0388	.0271	--------	-------	------	20
Gulf Catalytic process									
------------	7.0	------	8.84	0.51	0.07	--------	-------	------	21
------------	10.4	------	9.44	.50	------	--------	-------	------	
266 - 688	14.0	------	9.54	31	.04	--------	-------	------	
>130	------	------	8.97	40	.04	--------	-------	------	
>130	------	------	8.18	.82	.17	--------	-------	------	
Exxon Donor Solvent process									
158 - 392	31.1	0.87	10.90	0.21	0.47	--------	-------	18 300	23
158 - 392	45.4	.80	12.90	.06	.005	--------	-------	19 300	
392 - 1000	-.5	1.08	7.70	.66	41	--------	-------	17 100	
392 - 1000	8.6	1.01	8.60	24	.04	--------	-------	18 100	

TABLE 19. - Concluded.

Boiling range, °F	Gravity		Elemental composition, wt %			Viscosity, cP		Heat of combustion, Btu/lb	Reference
	API	Specific	H	N	S	at 100° F	at 210° F		
$ZnCl_2$ hydrocracking process									
180 - 887	------	------	8.65	0.0023	0	--------	-------	------	24
180 - 392	------	------	8.33	.0018	.02	--------	-------	------	
392 - 617	------	------	9.65	.0025	.02	--------	-------	------	
617 - 887	------	------	8.98	.0060	.03	--------	-------	------	
C_5 - >887	------	------	8 48	0020	.02	--------	-------	------	
C_5 - >887	------	------	8 65	.0023	0	--------	-------	------	
C_5 - >887	------	------	8.58	.0194	.01	--------	-------	------	
Co-Steam process									
------------	------	------	7.1	1.1	0.13	--------	-------	17 056	25
------------	------	------	6.8	1.1	.10	--------	-------	16 886	25
------------	------	------	6.6	1.1	.12	--------	-------	16 906	25
Flash Pyrolysis process									
406 - >620	------	------	6.15	1.13	0.56	--------	-------	------	26
411 - >745	------	------	6.18	1.43	.54	--------	-------	------	26
Sea Coal process									
<300 - 875	18.4	------	-----	0.403	0.02	9.78	-------	17 782	13

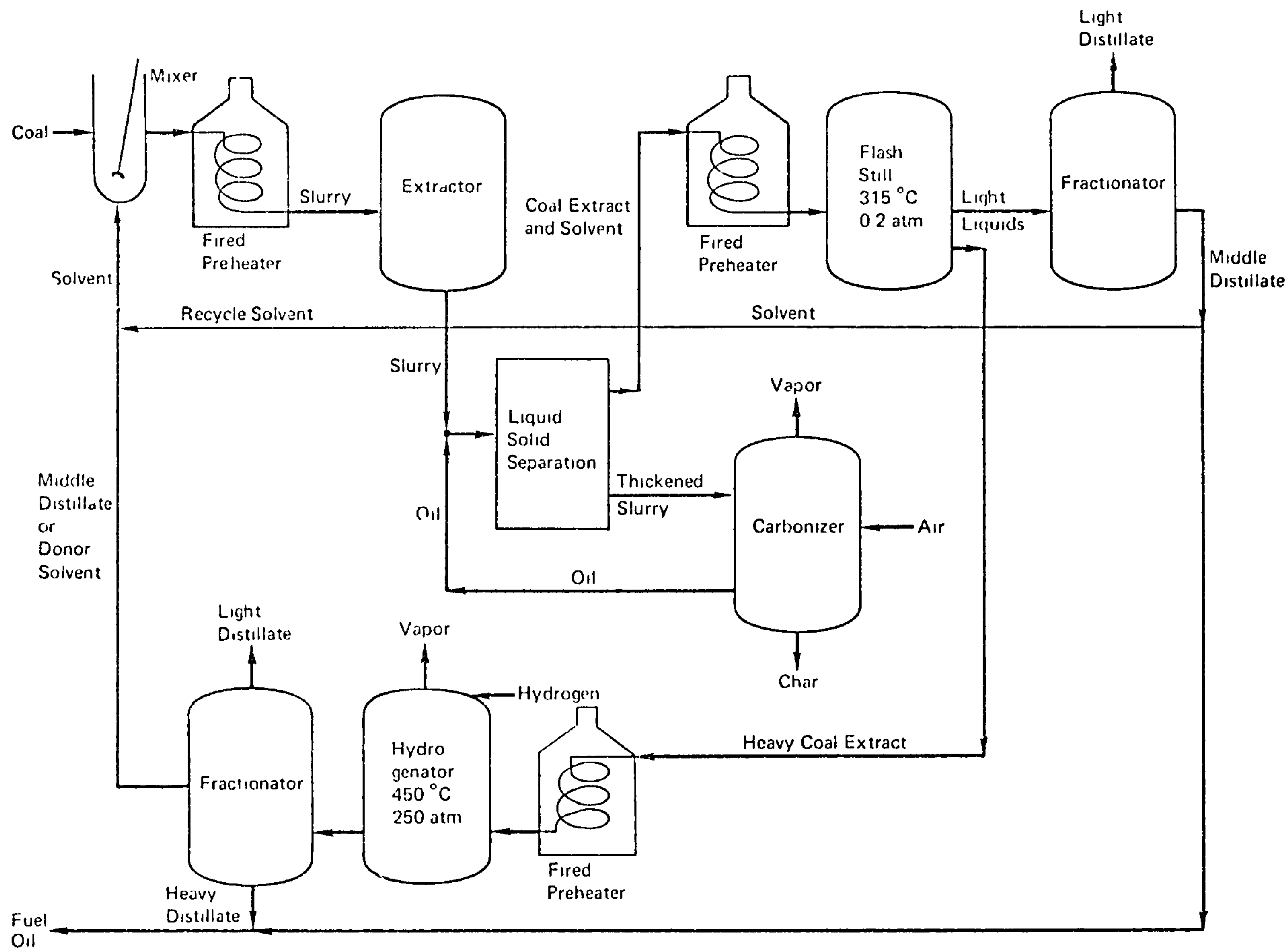

Figure 1. - Schematic of Consol Synthetic Fuel (CSF) process.

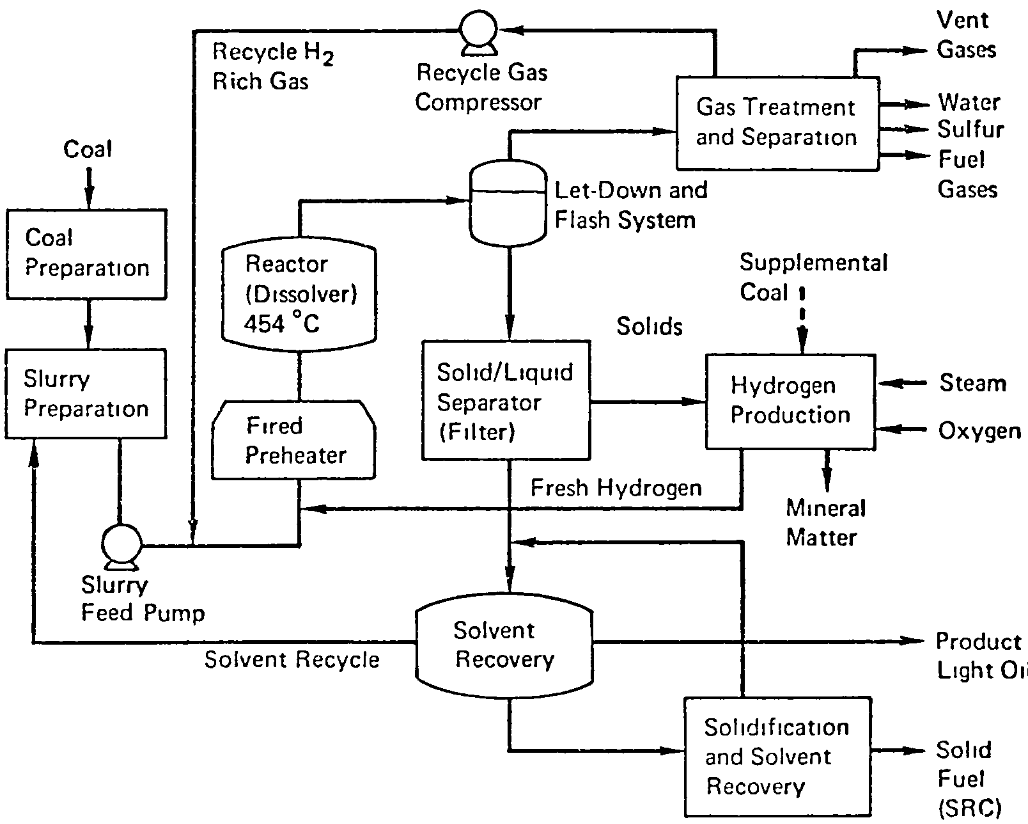

Figure 2. - Schematic of Solvent-Refined Coal (SRC) process.

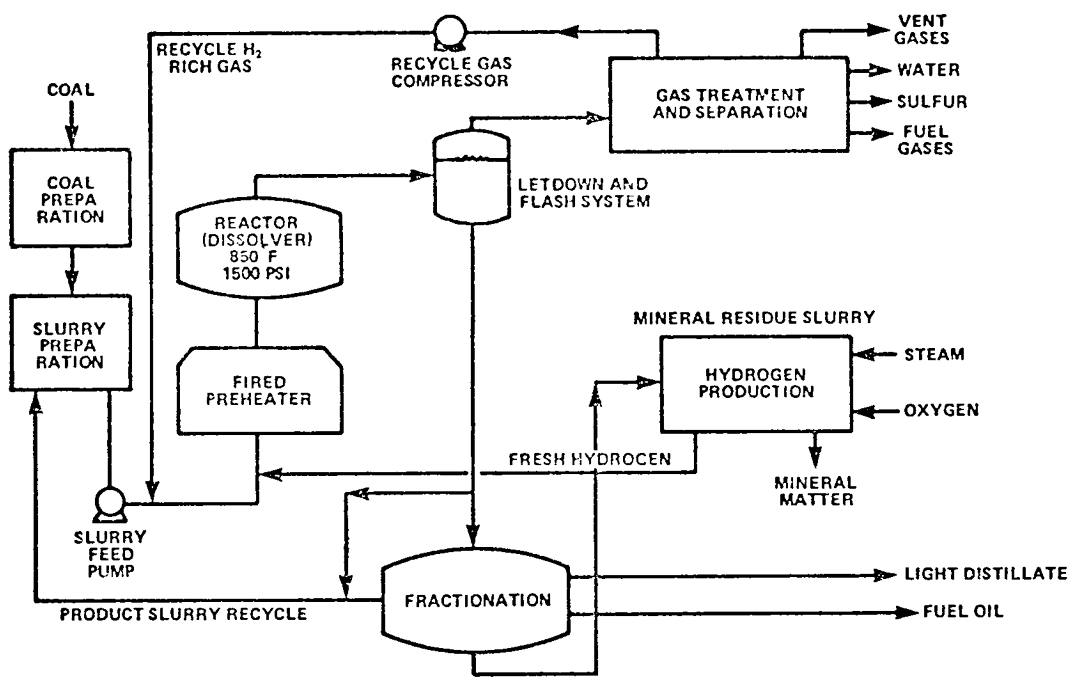

Figure 3. - Schematic of modified SRC process for distillate product.

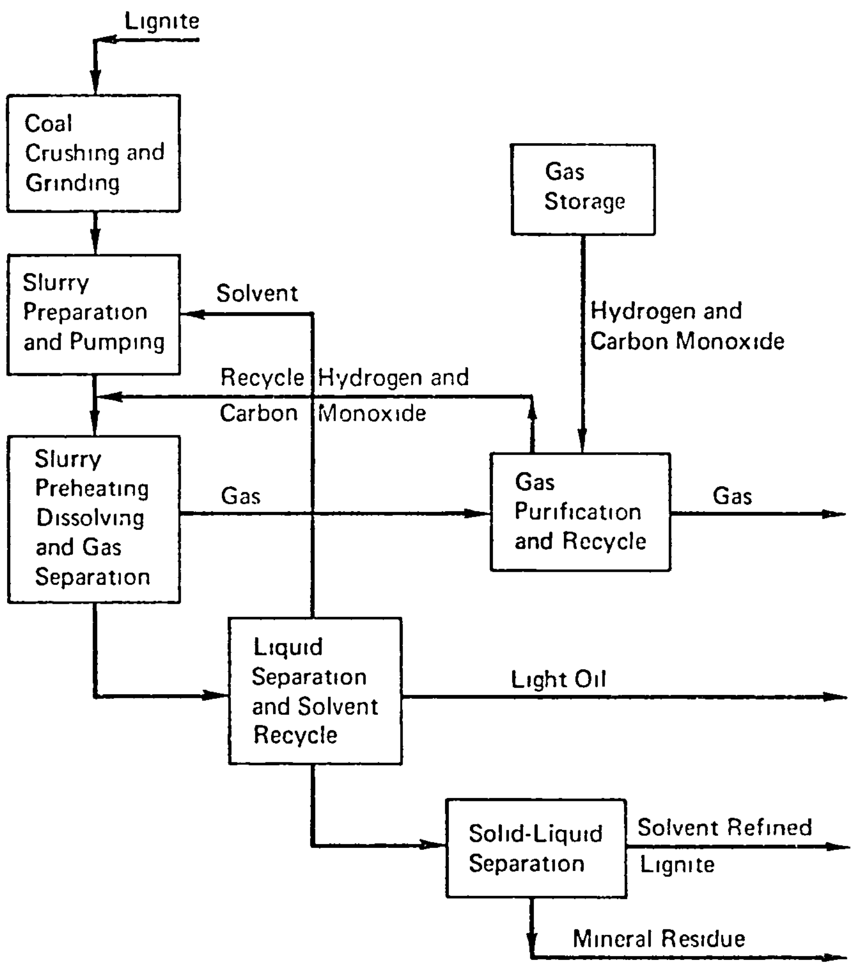

Figure 4. - Schematic of Solvent-Refined Lignite (SRL) process.

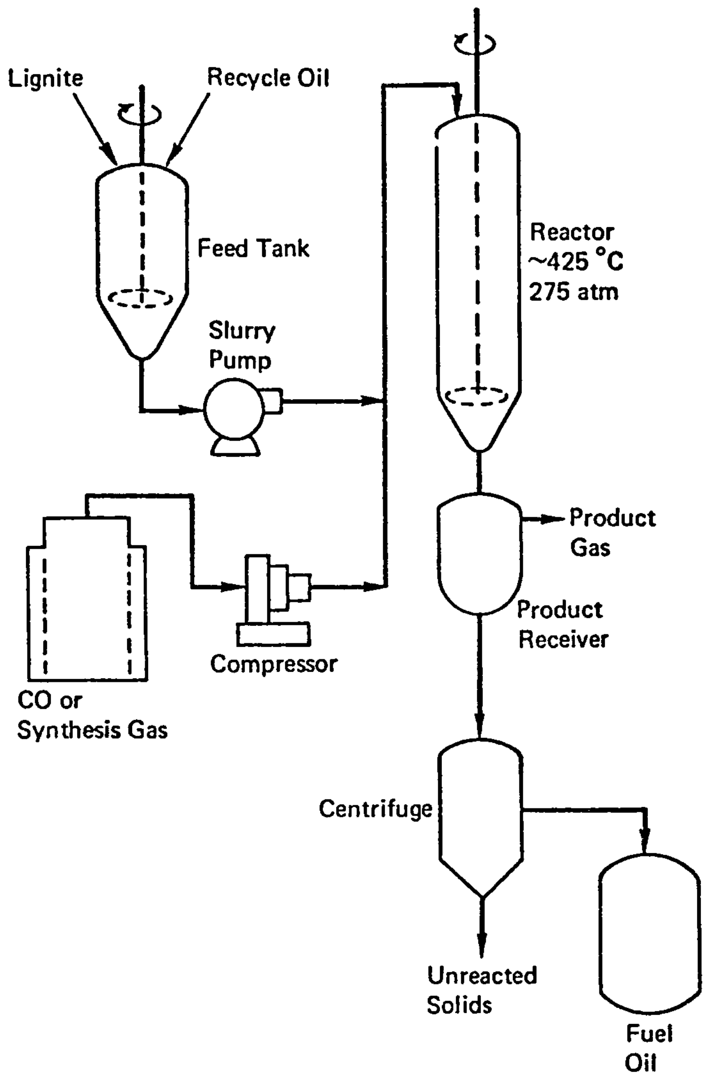

Figure 5. - Schematic of Co-Steam process.

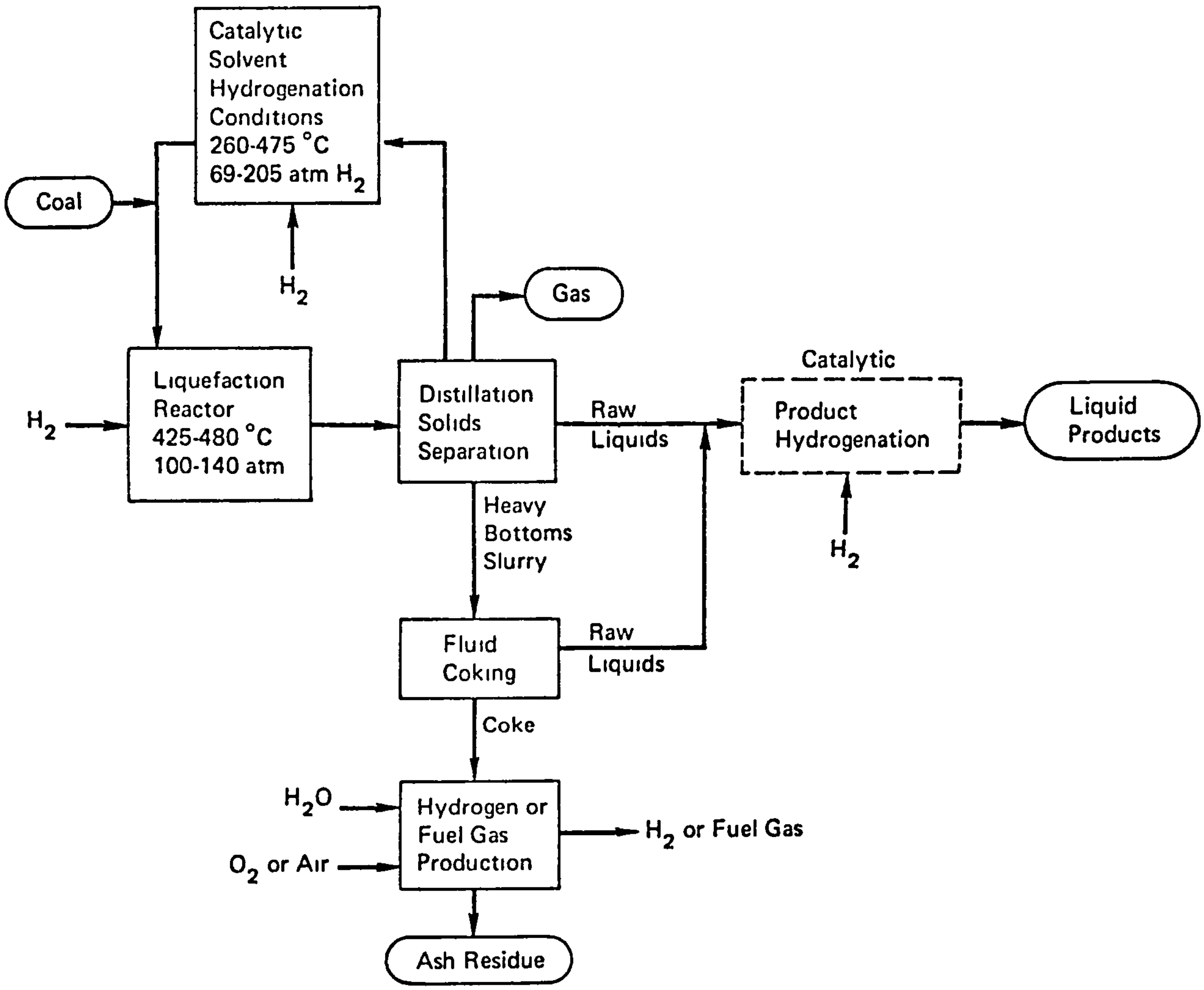

Figure 6. - Schematic of Exxon Donor Solvent (EDS) process.

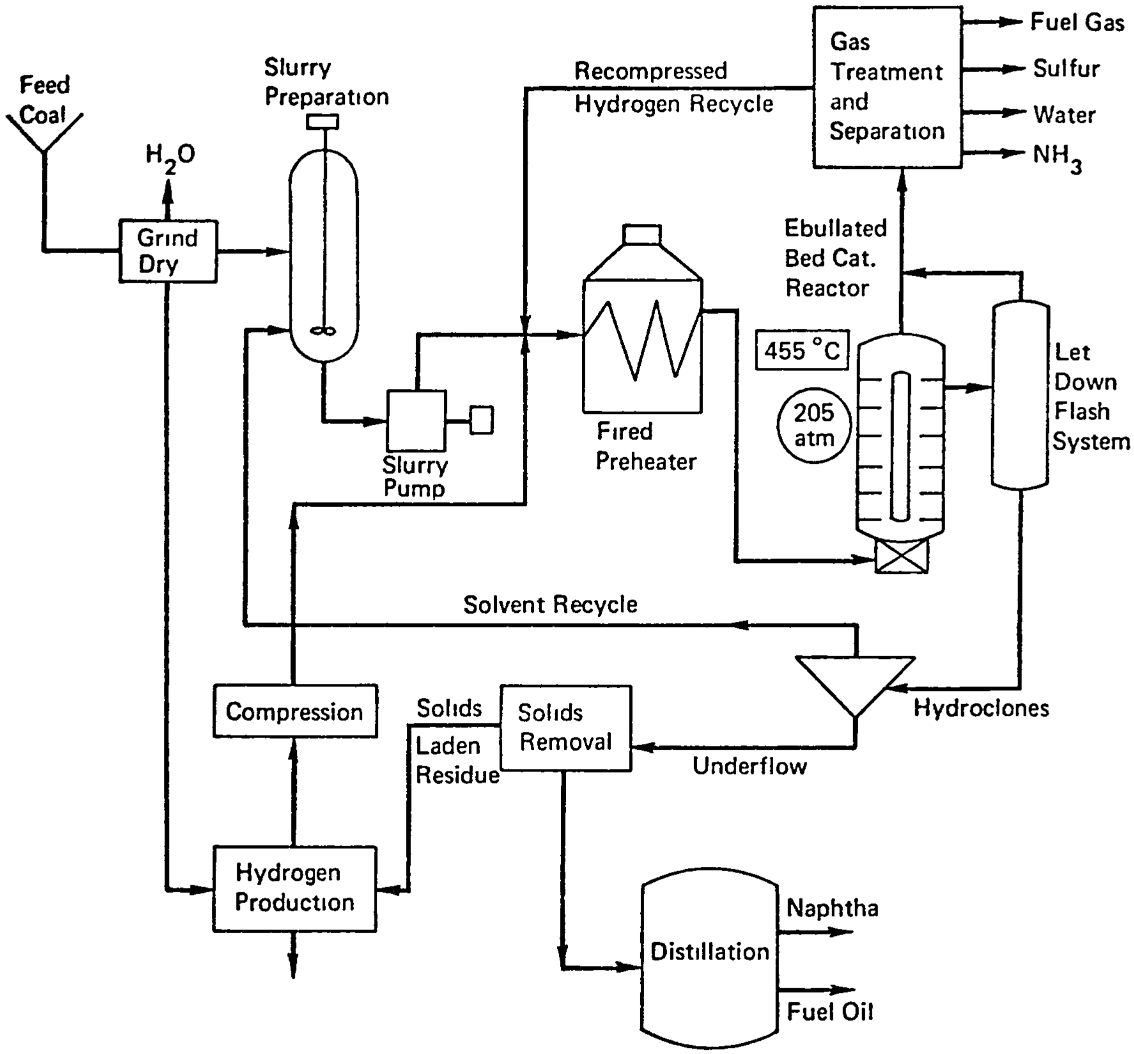

Figure 7. - Schematic of H-Coal process operated in syncrude mode.

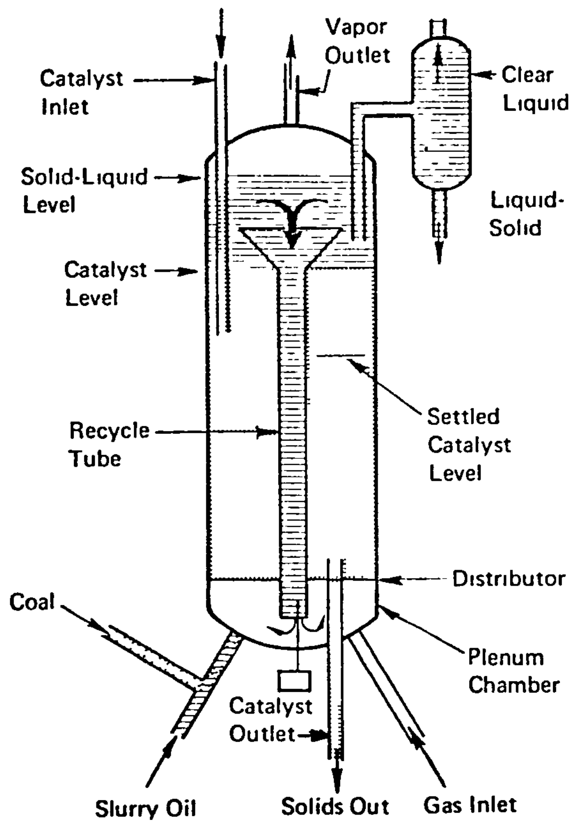

Figure 8. - Ebullating-bed reactor.

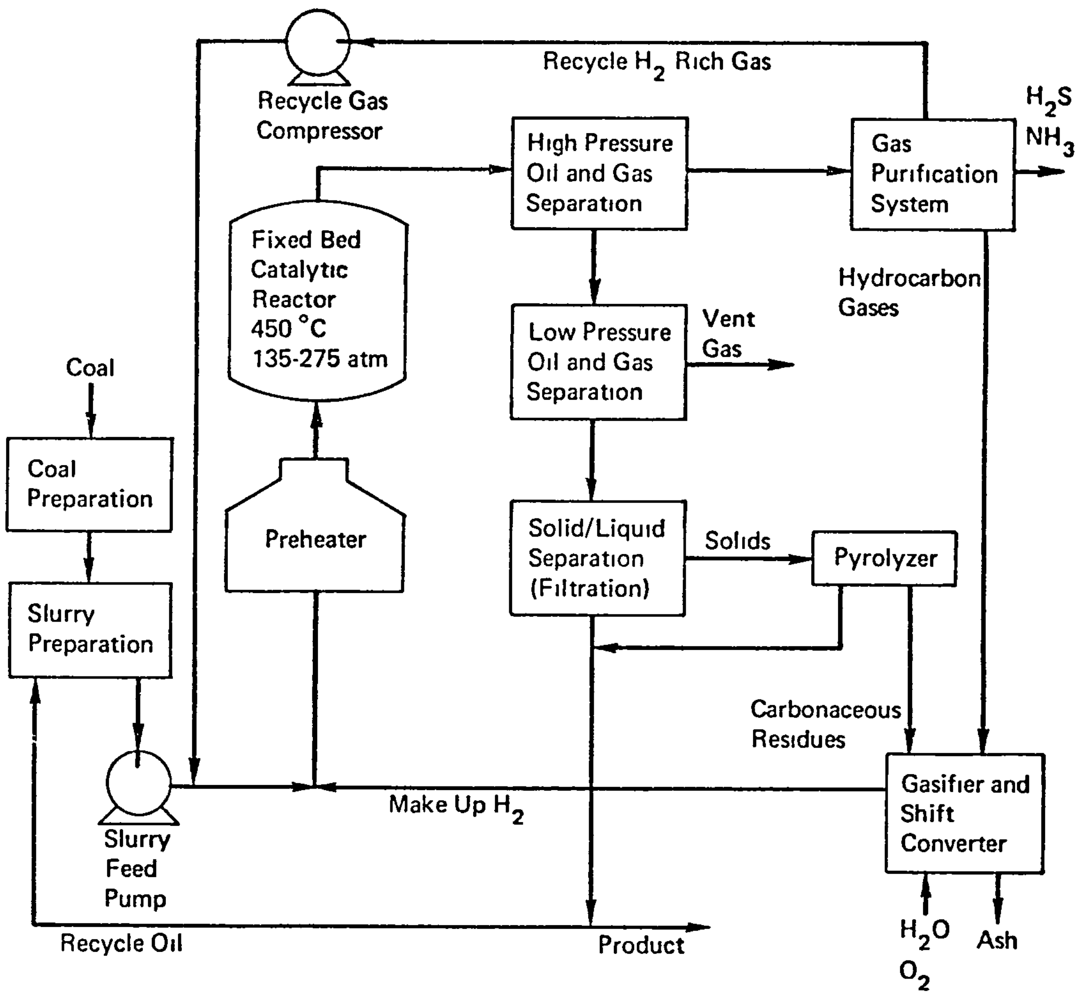

Figure 9. - Schematic of Synthoil process.

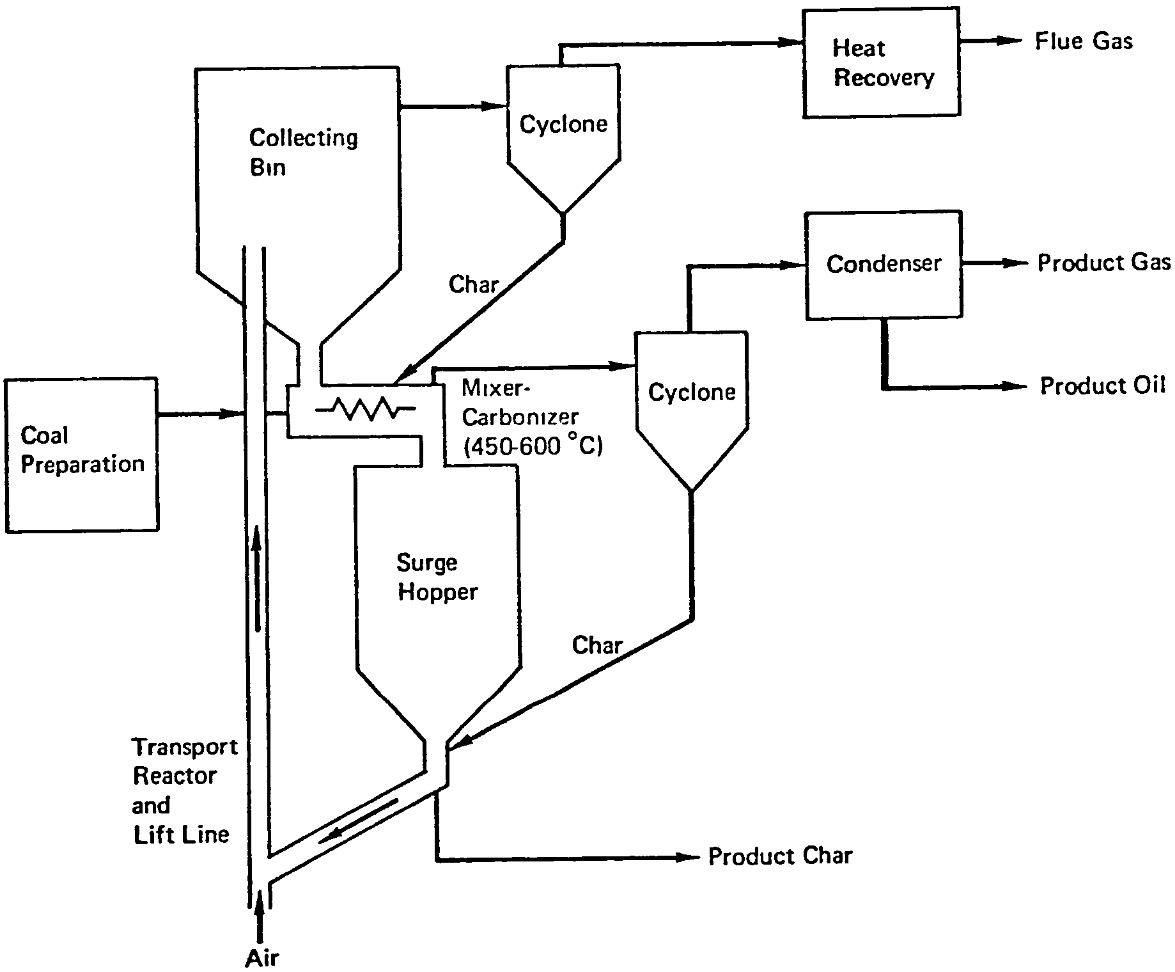

Figure 10. - Schematic of Lurgi-Ruhrgas process.

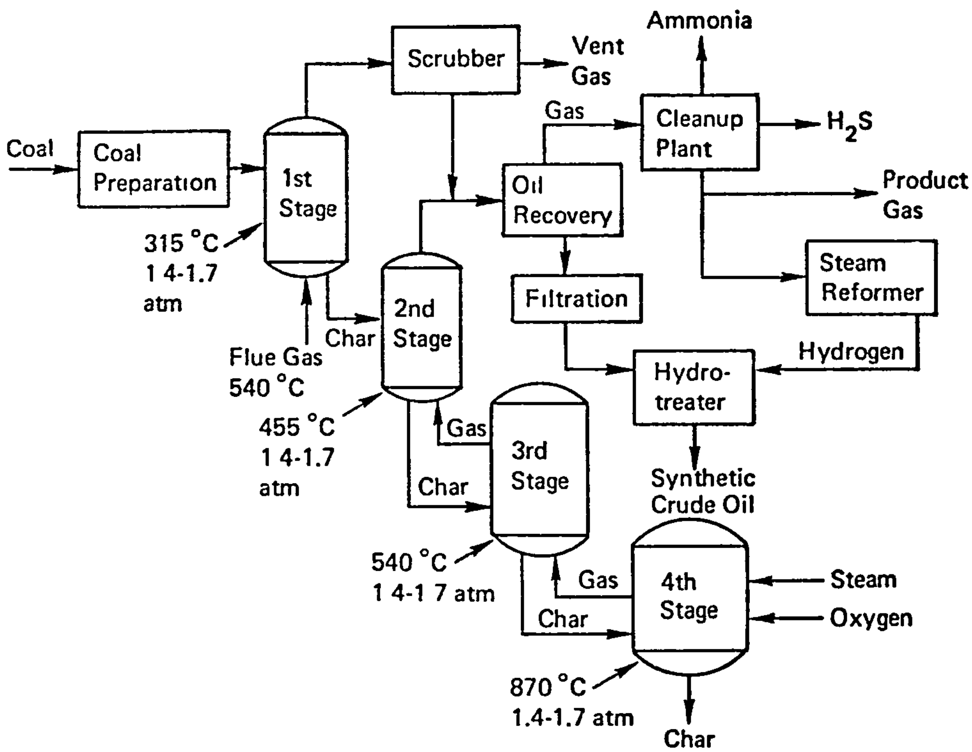

Figure 11. - Schematic of COED (FMC) process.

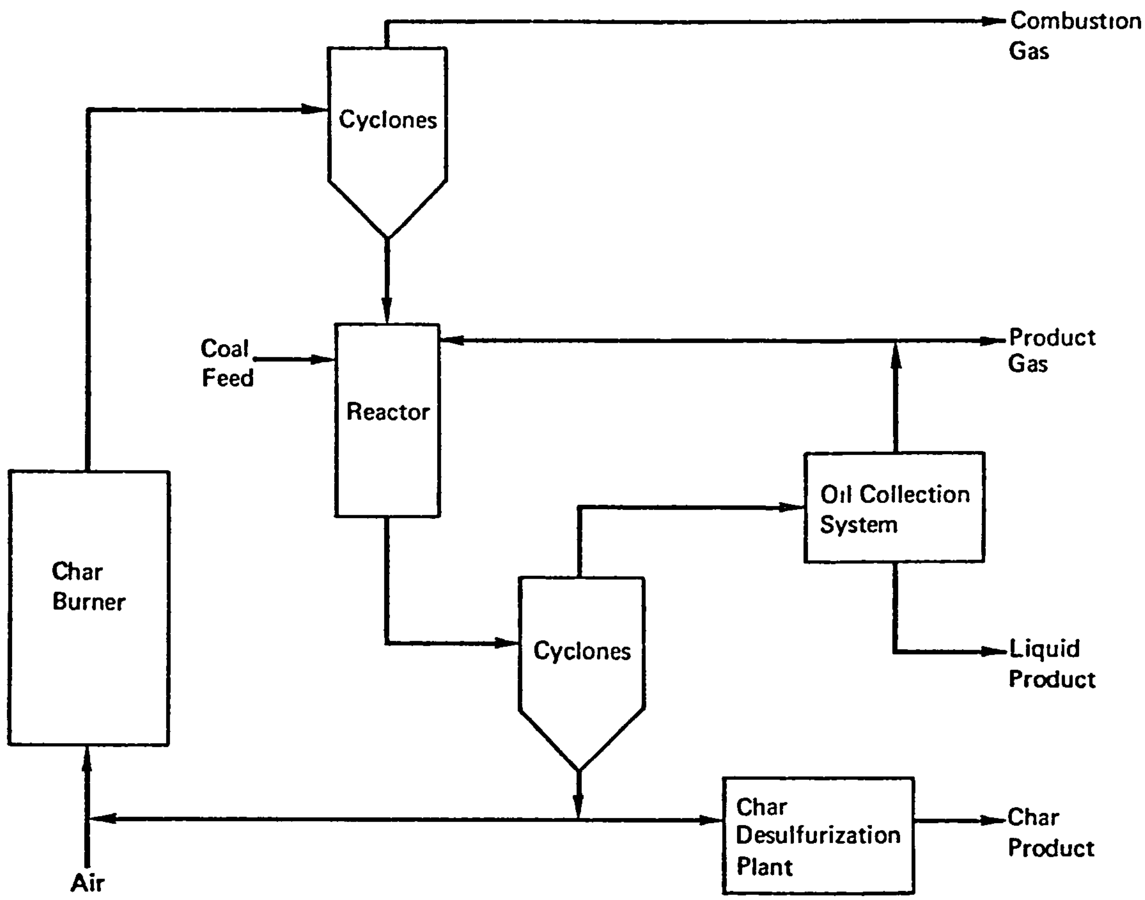

Figure 12. - Schematic of Occidental coal pyrolysis process.

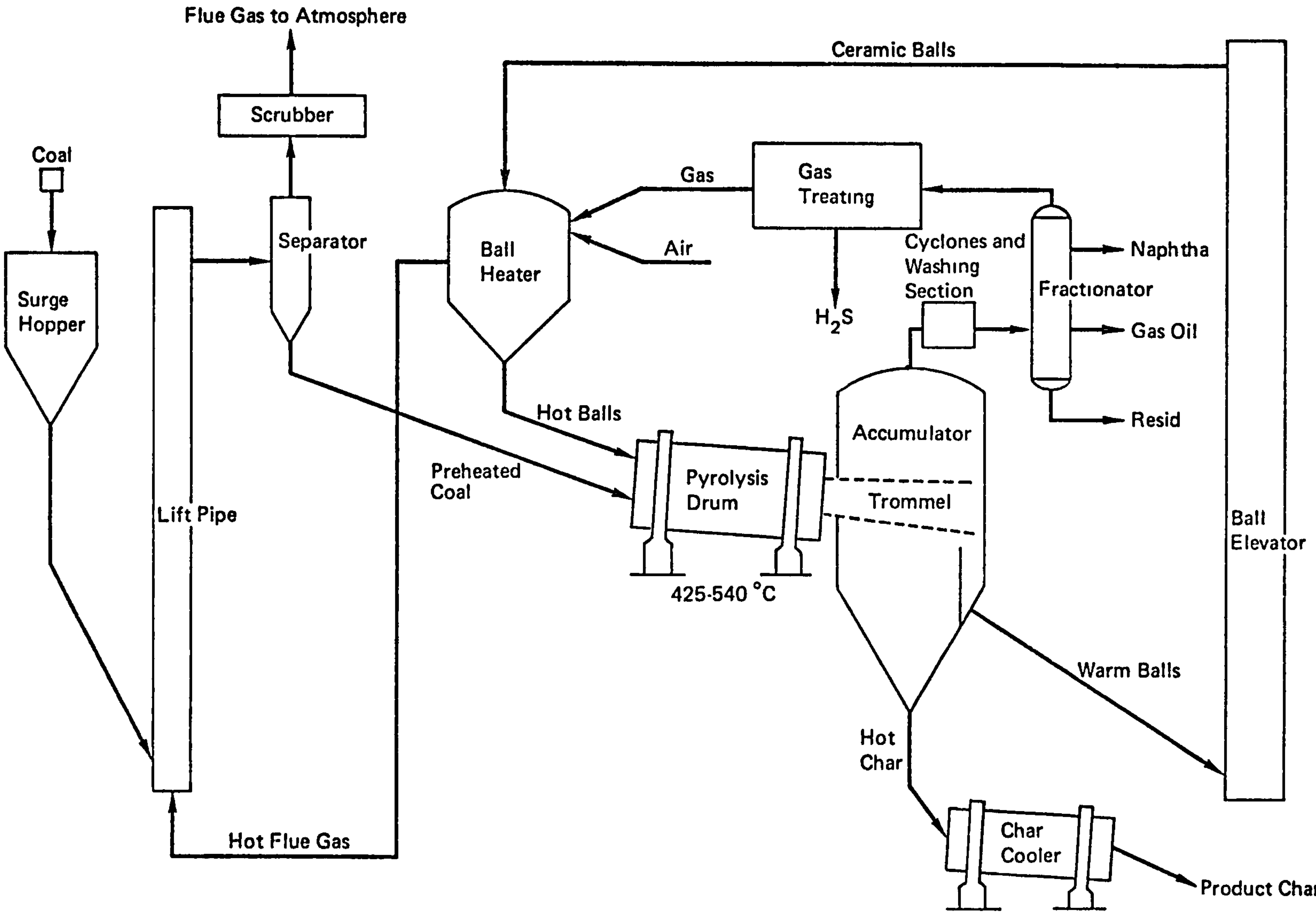

Figure 13. - Schematic of Toscoal process.

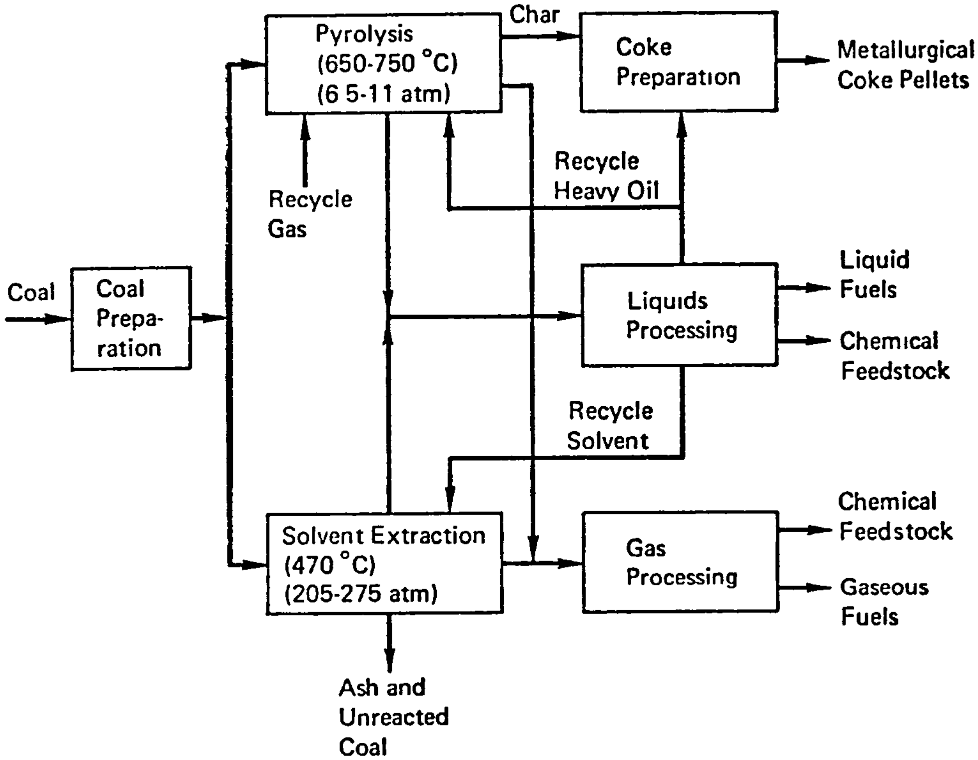

Figure 14. - Schematic of U.S. Steel Clean-Coke process.

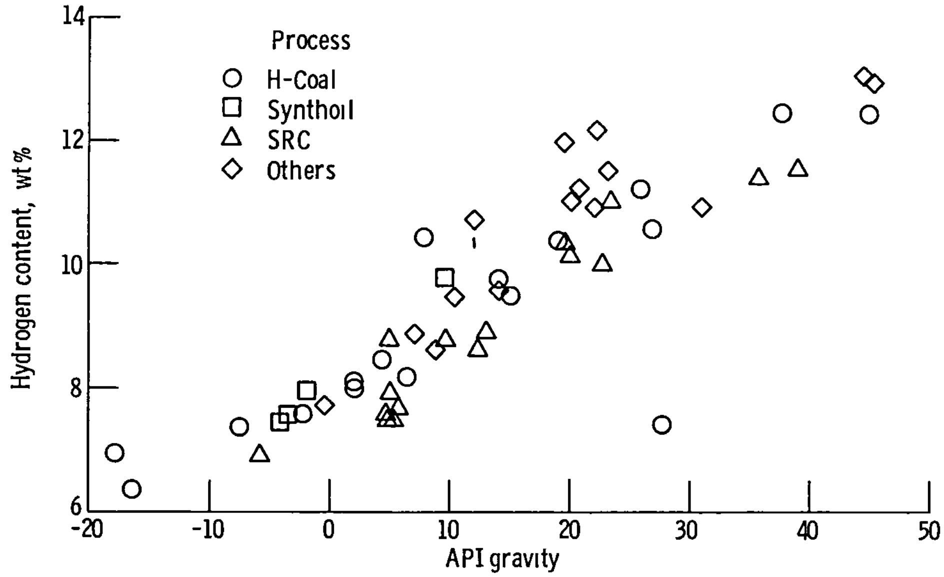

Figure 15. - Variation of hydrogen content of coal-derived fuels with API gravity.

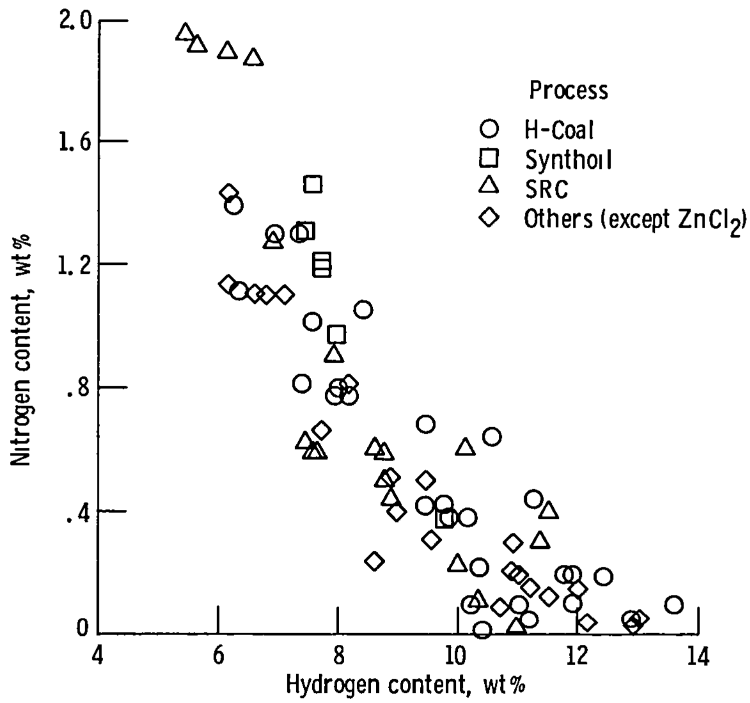

Figure 16. - Relation of fuel-bound nitrogen and hydrogen levels in coal-derived fuels.

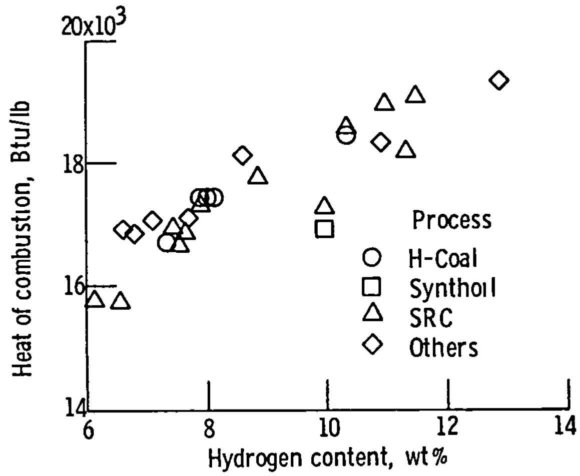

Figure 17. - Variation of heat of combustion of coal-derived fuels with hydrogen content.

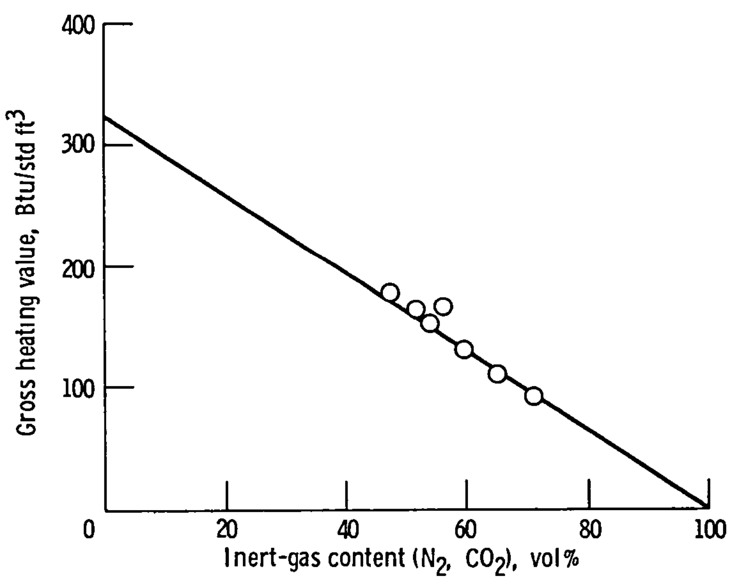

Figure 18. - Variation of gross heating value of low-Btu gases with inert-gas content.

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16. Abstract
This report is an interim literature survey of the properties of synfuels for ground-based gas-turbine applications, compiled to December 1977. Four major concepts for converting coal into liquid fuels are described solvent extraction, catalytic liquefaction, pyrolysis, and indirect liquefaction. Data on full-range syncrudes, various distillate cuts, and upgraded products are presented for fuels derived from various processes, including H-Coal, Synthoil, Solvent-Refined Coal, COED, Donor Solvent, Zinc Chloride Hydrocracking, Co-Steam, and Flash Pyrolysis. Some typical ranges of data for coal-derived low-Btu gases are also presented

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