LITERATURE SURVEY OF PROPERTIES OF SYNFUELS DERIVED FROM COAL

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION, CLEVELAND, OH. LEWIS RESEARCH CENTER

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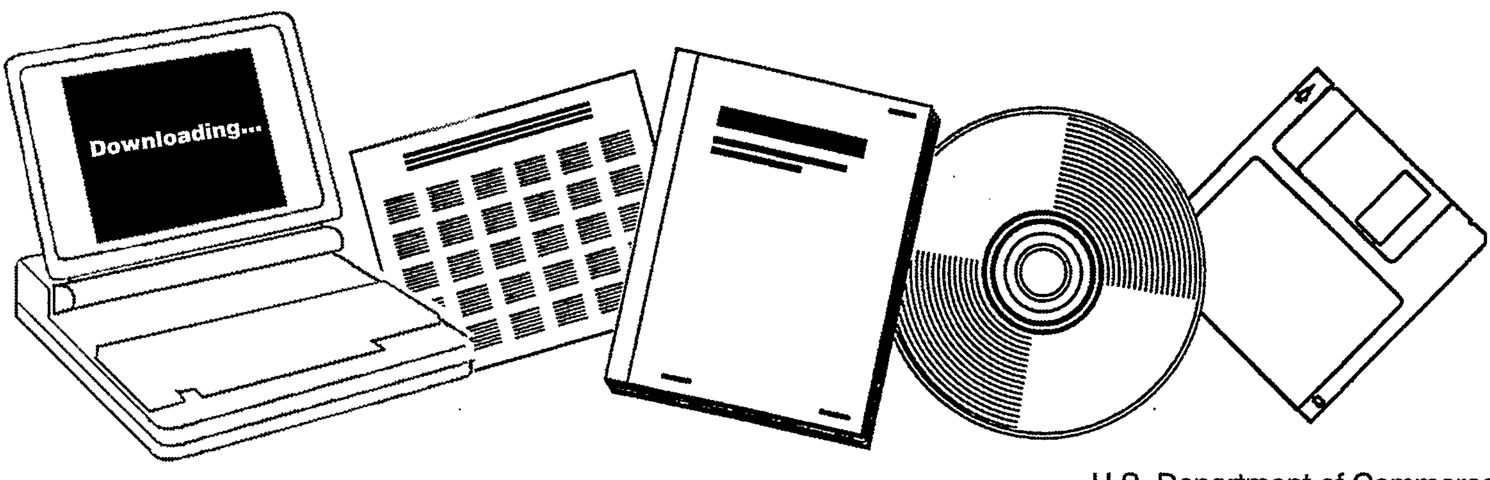

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Literature Survey of Properties of Synfuels Derived from Coal

Francisco Flores
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

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Francisco Flores

National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

SUMMARY

The report contains the results of a literature survey conducted by 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 gases) derived from coal. The report contains the survey results compiled to October 1980. 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) Description of the four major concepts for converting coal into liquid fuels (pyrolysis, solvent extraction, catalytic liquefaction and indirect liquefaction).

(3) Data obtained from the literature on full range syncrudes and certain distillate cuts for fuels derived by various processes - including H-Coal, Synthoil, Solvent Coal, COED, Donor Solvent, Zinc Chloride Hydrocracking Co-Steam, Flash Hydropyrolysis, and Catalytic Liquefaction (These 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) Description of upgrading processes for coal liquids and characterization data for upgraded fuels.

(5) Data plots illustrating trends in the properties of fuels derived by several processes.

(6) Description of the most important concepts in coal gasification (fixed bed, fluidized bed, entrained flow and underground gasification) and characterization data for coal-derived gases.

(7) A source list and bibliography on syncrude production and upgrading programs.

(8) A listing of some Federal energy contracts for coal-derived synthetic fuels production.

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

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*A condensed version of this report was presented at the ASTM symposium on Alternate Fuels and Future Fuels Specifications for Stationary Gas Turbine Applications, Phoenix, Arizona, Dec. 9-10, 1981.

projects and private correspondence. These sources are noted in the data tables where applicable.

INTRODUCTION

The work described in this paper is a part of the Department of Energy/NASA Lewis Research Center (DOE/Lewis) Critical Research and Support Technology (CRT) project. The program is a Lewis in-house effort with funding provided by the DOE and technical program management provided by NASA Lewis.

This report presents a literature survey of information on coal-derived fuels up to October, 1980. It upgrades and replaces a previously published literature survey (ref. 1). The physical and chemical properties of liquid and gaseous fuels being produced in DOE pilot plants and upgrading programs are presented. The report also includes descriptions of some coal liquefaction, upgrading and gasification processes that are at least in the process development unit (PDU) stage. The fuels that are investigated include low and medium-Btu gas, heavy and light liquid distillates, and residual liquids.

Natural gas and No. 2 fuel have been used in industrial and utility applications. These fuels are presently used in open cycle gas turbines for utility peaking service and also in combined gas-turbine/steam-turbine cycle 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. 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 DOE 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 gasturbine technical data base for the DOE Integrated Coal Conversion and Utilization Systems Program, which is 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. Additional combustion efforts include analytical modeling to determine combustor parameters that affect the conversion of fuel-bound nitrogen into oxides of nitrogen (NOx); flame-tube experiments to evolve fundamental concepts for minimizing the conversion of fuel-bound nitrogen into NOx; and evaluation of experimental combustors with coal-derived fuels at simulated gas-turbine combustor operating conditions. Results of these efforts have been previously reported in separate publications (refs. 2 to 4).

In surveying the literature, it becomes apparent that sufficient information on coal-derived fuels is not readily available. Thus, additional information sources included monthly reports from ongoing DOE-sponsored projects and private correspondence. These sources are noted in the data tables where applicable.

DETAILS OF LITERATURE SURVEY

This survey emphasizes synthetic fuels processes that are the furthest along in development. Information on both the processes and the fuels is presented. Since new data are continually generated and published by the contractors involved in synthetic fuels projects, no survey report can contain all the latest data on the fuels of most interest. However, this report gives the general status of characterization data available to October 1980 and some of the physical and chemical data needed for the CRT project.

This report is arranged in the following general format:

(1) Fuel properties discussion - this section includes a discussion of fuel properties of concern to gas turbine users.

(2) Coal liquids
  (a) Liquefaction processes - This section describes the four major concepts for converting coal into liquid fuels.
  (b) Upgrading processes - This section describes the processes (mainly hydroprocessing) used to upgrade coal-derived fuels.
  (c) Liquid fuels property data - This section contains characterization data of coal-derived syncrudes and their distillation cuts, and properties of upgraded streams. It also includes a comparison of properties of different coal-derived liquid fuels.

(3) Coal gases
  (a) Gasification Process - This section describes the four major concepts for converting coal into gaseous fuels.
  (b) Gaseous fuels property data - This section contains characterization data for coal-derived gases and discussion of this data.

FUEL PROPERTIES DISCUSSION

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 18 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 pour-point, 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 18 and the use of these fuels in gas-turbine combustion systems is contained in reference 5.

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 2, from reference 5, 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 5.

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, and 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 NOx 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 pour-point 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. The heating required for these fuels may lead to deposit formation.

Table 3, obtained from reference 27, shows some typical ranges of fuel properties applicable to current industrial gas-turbine systems.

COAL LIQUEFACTION PROCESSES

Four major concepts have been developed for converting coal to liquids (fig. 1): pyrolysis and hydrocarbonization, solvent extraction, catalytic liquefaction, and indirect liquefaction. Each concept is discussed briefly here, and the status of the most important processes that use each concept are summarized. The technology for coal liquefaction is reviewed in detail in references 6 to 9.

Pyrolysis and Hydrocarbonization

Pyrolysis, or carbonization, takes place when coal is heated in the absence of air or oxygen to obtain heavy oil, light liquids, gases and char. When pyrolysis is carried out in the presence of hydrogen it is called hydrocarbonization. Pyrolytic processes typically convert about 50 percent of the coal to char, which presently does not have a ready market. Thus, these processes appear to be best suited to plants that use char gasification to produce synthesis gas, hydrogen, or fuel gas. Using short residence times or pyrolyzing coal in a fluidized bed at high pressures in the presence of hydrogen improves liquid yields but may require additional processing to reduce the sulfur in the products. Pyrolytic processes include Lurgi-Ruhrgas, COED, U.S. Steel Clean Coke, Coalcon, and Flash Hydropyrolysis.

Lurgi-Ruhrgas. - This low pressure process was developed for the liquefaction of European brown coals and is the only pyrolysis process presently in commercial use (ref. 7). A schematic diagram of the process is shown in figure 2. Pulverized coal is rapidly heated to about 450 to 600°C by direct contact with recirculated char particles previously heated by combustion with air in an entrained flow reactor. A portion of the carbonized char is withdrawn as product; the rest is recycled to the entrained flow reactor. Products of the process (by weight) are 50 percent char, 18 percent liquids, and 32 percent gases. A 1600 ton/day plant was built in Yugoslavia in 1963 and is still operating.

COED. - The Char Oil Energy Development (COED) process (refs. 7, 10, and 11) was developed by FMC corporation. It produces synthetic crude oil by pyrolysis of crushed coal in a series of fluidized bed reactors (fig. 3). Agglomeration is prevented by operating at successively higher temperatures. Some of the char is gasified by steam and burned with oxygen in the fourth stage to maintain the bed temperature and to provide hot gases for heating and fluidizing the second and third stages. A 36 ton/day (TPD) pilot plant in Princeton, New Jersey started operation in 1970. It produced about 6 tons of oil, 18 tons of char, and 4 tons of gas. Pilot plant operations have been concluded and demonstration plants have been designed.

U.S. Steel clean coke. - The Clean Coke process (ref. 12) developed by U.S. Steel Corporation combines pyrolysis and solvent extraction processes. A schematic of the process is shown in figure 4. This process produces metallurgical coke, and gaseous and liquid fuels. A portion of the coal is sent to a pyrolysis unit. The char produced is used to make metallurgical coke. The rest of the coal is sent to a solvent extraction unit. The liquid product from this unit is combined with the liquid stream from the pyrolysis unit and treated to obtain product fuels. Part of this liquid is recycled and used as a solvent in the solvent extraction unit. The gaseous streams from both units are also combined and treated to produce gaseous fuels.

Coalcon. - The Coalcon process (refs. 7 and 11) developed by Union Carbide utilizes heavy fuel oils and gases. A flow diagram of the process is shown in figure 5. Average yields from subbituminous coal are 40 wt % char, 30 wt % liquids, 20 wt % gases, and the remainder ash.

Flash hydropyrolysis. - In flash hydropyrolysis processes (refs. 13 and 14), coal is contacted with hot hydrogen at high pressure in an entrained flow reactor. The reaction is terminated by rapid quenching of the products, thus preventing dehydrogenation, repolymerization, decomposition, and carbonization. There are two major flash hydropyrolysis processes (ref. 15): the Cities Services (fig. 6) and the Schroeder Spencer Chemical Co. processes (fig. 7). The two processes are very similar and the main difference between them is that the Schroeder process uses catalytic hydropyrolysis and hydrogenation of the liquid products.

Solvent Extraction

In solvent extraction processes, coal is mixed with a solvent containing relatively loosely bound hydrogen atoms. This solvent can transfer those hydrogen atoms to the coal at temperatures of about 500° C (932° F) and pressures of about 275 atm. Heating breaks many of the physical interactions in the coal such as van der Waals forces and hydrogen bonding forces. It also breaks weak chemical bonds and the solvent promotes hydrogen transfer to the broken bonds. The recycle solvent, usually a mid-distillate of process-derived liquids, is continuously recovered and recycled to the extraction vessel. The ash in the extraction vessel can act as a catalyst for the solvation process. The solvent extraction processes included in this report are: Consol Synthetic Fuel (CSF), Solvent-Refined Coal (SRC), Co-Steam, and Exxon Donor Solvent (EDS).

Consol synthetic fuel. - The CSF process (refs. 7 and 11) was developed by Conoco Coal Development Co. (formerly Consolidation Coal Co.). In this process coal is slurried with a process-derived solvent in a stirred extraction vessel that operates at a temperature of approximately 400° C (750° F) and at pressures of 11 to 30 atm. The recycle solvent is hydrotreated in a catalytic reactor at pressures of about 205 atm and temperatures of 425 to 250° C (800 to 845° F). A schematic diagram of the CSF process is shown in figure 8. The process yields about 63 wt % fuel oil, 25 wt % char and the rest is high-Btu gas.

A 20 ton/day pilot plant was built at Cresap, West Virginia to produce gasoline from coal. The plant was closed in 1970. It was reactivated in 1976 by the Fluor Corporation for operation to produce boiler and distillate fuels (ref. 16).

Solvent-refined coal. - The SRC process (refs. 7, 10, 11, and 17 to 19) was developed by the Pittsburgh and Midway Coal Mining Co. (PAMCO), a subsidiary of Gulf Oil Corp. The original SRC process (known as SRC-I) converts high-sulfur, high-ash coal to a nearly ash-free, low-sulfur fuel that is solid at room temperatures. Typical composition of SRC-I and raw coal is shown in table 4.

In the SRC-I process, crushed coal is slurried with a process-derived solvent. Gaseous hydrogen is added to the slurry and the mixture is heated to about 450° C (850° F) and pressurized to about 100 atm, and fed to a dissolver where extraction and hydrogenation take place. The liquid/solid mix is separated to obtain recycle solvent, a product light oil, and a solid fuel. A schematic of the SRC-I process is shown in figure 9.

In a modified SRC (known as SRC-II), the solidification and solvent recovery unit is not required. In this process, a portion of the unfiltered dissolver liquid product (containing undissolved coal particles and ash) is used for recycle to slurry the feed coal. This results in a higher ash content in the dissolver providing a pseudocatalytic effect, a longer retention time and a higher H/C ratio in the liquid with a lower sulfur content. A schematic diagram of the SRC-II process is shown in figure 10. In the SRC-II mode, the product streams include (based on wt % of coal): 40 to 50 percent residual oil, 6 to 12 percent fuel oil, and 2 to 5 percent naphtha. Small amounts of lighter fractions are also produced.

The Electric Power Research Institute and Southern Company services collaborated on a 6 ton/day PDU at Wilsonville, Alabama (refs. 20 and 21). Success in the PDU led to design construction and operation of a 50 ton/day pilot plant at Fort Lewis, Washington. Current plans call for continued testing at both the Fort Lewis pilot plant and the Wilsonville PDU into fiscal year 1981 (ref. 16).

The Solvent-Refined Lignite (SRL) process is being developed by the University of North Dakota under contract to DOE. This process is based on technology derived from the SRC process. The SRL process uses synthesis gas (H_2 + CO) in place of the hydrogen used in the SRC process. Synthesis gas is used since low-rank high moisture coal provides the necessary steam for the in situ production of hydrogen by the water-gas shift reaction. A process diagram is shown in figure 11. A 0.5 ton/day PDU has been built in Grand Forks, North Dakota.

Co-Steam. - The Co-Steam process is designed to liquify low ranking subbituminous coals which have high reactivities and high moisture content. Coal is liquified by treatment with CO and water by way of a noncatalytic reaction with hydrogen formed in the gas shift reaction (ref. 6). A schematic of the Co-Steam process is shown in figure 12. A coal-recycle-oil slurry is fed to a stirred reactor which operates at about 425° C (800° F) and 275 atm. The water required for the reaction is provided by the moisture contained in the low-rank coal. A 5 lb/hr continuous PDU was built at the Grand Forks Energy Research Center, North Dakota. The PDU started operation early in fiscal year 1979 and should continue through fiscal year 1982 (ref. 7).

Exxon donor solvent. - The EDS process involves the liquefaction of coal in a hydrogen donor solvent (refs. 6, 7, 22, and 23). The hydrogen donor solvent is a catalytically hydrogenated recycle stream fractionated from the midboiling range (205 to 455° C) of the liquid product. A process diagram is shown in figure 13. After hydrogenation, the solvent is mixed with coal and fed to the liquefaction reactor. Molecular hydrogen is also added to the reactor which operates at 425 to 480° C (800 to 900° F) and 100 to 140 atm. The slurry leaving the reactor is separated into gas, naphtha, distillates, and heavy bottoms. The bottoms are fed to a "Flexicoking" unit to produce additional liquids and low-Btu gas. The process yields about 20 percent char, 54 percent oil and 25 percent gas. The thermal efficiency is about 60 percent.

Catalytic Liquefaction

Catalytic liquefaction includes those hydrogenation processes in which catalysts other than the mineral matter naturally occurring in ash are used to promote hydrogenation of the hydrogen donor solvent. The catalysts usually used are Lewis acids such as FeO, MoO, $ZnCl_2$ and $NiClO_2$. These processes have the advantage that a separate reactor to rehydrogenate the solvent is not required. However, catalyst deactivation and separation problems have been encountered.

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 hydrogenation is achieved. Examples of these processes are the Schroeder and Liquid-Phase Zinc Chloride. 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 processes include H-Coal, Synthoil, and Clean Fuel From Coal.

Schroeder. - In the Schroeder process, coal is impregnated with an ammonium molybdate catalyst and fed to a hydrogenation reactor along with gaseous hydrogen (ref. 7). Residence times of 30 sec are used in the reactor. Products from the reactor are cooled and separated; heavy oil is further hydrotreated to distillable oils and gas. A schematic of the process is shown in figure 14. Product yields are about 30 percent distillable liquids, 35 percent residual liquids, 5 percent char, and 30 percent gas. Bench-scale tests of this concept were completed in 1962.

Liquid-phase zinc chloride. - The liquid-phase $ZnCl_2$, developed by Continental Oil Co., is designed to convert coal into distillates in the gasoline range by severe catalytic cracking under hydrogen pressure (refs. 6 and 7). In this process coal is mixed with molten $ZnCl_2$ and fed to a hydrocracking reactor (fig. 15). The products are collected and separated from the catalyst which is regenerated and recycled. A 1.2 ton/day PDU has been built by the Conoco Coal Development Co. at Library, Pennsylvania. Shakedown testing began in 1978 (ref. 24).

H-Coal. - The H-Coal process is being developed by Hydrocarbon Research Inc. (HRI). This is a liquid phase process in which coal suspended in a recycle solvent is contacted with particulate catalyst in an ebullating-bed reactor (refs. 6 and 7). A schematic of the H-Coal process is shown in figure 16 and the ebullating-bed reactor is shown in figure 17. A slurry of coal and solvent is forced upward through the reactor which operates at 450° C (850° F) and 150 to 205 atm. The relative sizes of the catalyst and the coal particles are such that the catalyst stays in the reactor. Since catalyst deactivation has been rapid, 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 will be about 64 percent thermally efficient.

The Office of Coal Research (OCR) and an industrial consortium funded the building of a 3 ton/day PDU. The experimental results and the economic feasibility studies were used to complete the design of a 600 ton/day pilot plant (ref. 25). The plant was built in Cattlesburg, Kentucky and is presently in operation.

Synthoil. - The Synthoil process is being developed by the DOE Pittsburgh Energy Research Center (PERC). In this catalytic process, coal is mixed with a recycle liquid and passed through a fixed bed catalytic reactor at high flowrates (refs. 6, 7, 10, 11, and 18). The solid dissolves in the liquid solvent and the mixture undergoes hydrogenation in the reactor. A schematic of the process is shown in figure 18. Projected overall thermal efficiency of a self-sufficient plant is about 70 percent. The Synthoil process has been developed at PERC in a 5 lb/day PDU. Foster-Wheeler has been awarded a contract to design and build a 10 ton/day pilot plant at Bruceton, Pennsylvania.

Clean fuel from coal. - The Clean Fuel from Coal (CFFC) process, developed by C-E Lummus, is designed to convert coal into low-sulfur liquid fuel. The main features of this process are: (a) catalytic hydrodesulfurization of coal integrated with dissolution to produce a refined liquid product containing 0.5 percent sulfur or less, and (b) special ash separation to produce a product containing less than 0.1 percent ash (refs. 6 and 7). A schematic flow diagram of the CFFC process is shown in figure 19.

Gulf catalytic coal liquids. - The Catalytic Coal Liquids (CCL) process is a proprietory coal-liquefaction development of the Gulf Oil Corp. This process involves the fixed-bed catalytic hydrogenation of a coal slurry with gaseous hydrogen. A schematic of the CCL process is shown in figure 20. It includes a fixed-bed radial flow reactor containing a hydrogenation catalyst such as cobalt molybdate. This 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/day pilot plant at Hammersville, Pennsylvania. Design studies for a demonstration plant are being made.

Indirect Liquefaction

Indirect liquefaction involves gasification of coal to produce synthesis gas ($H_2 + CO$) followed by water-gas shift and catalytic conversion to produce liquid hydrocarbons and oxygenated compounds. Indirect liquefaction processes include Fischer-Tropsch, methanol synthesis, and methanol to gasoline (ref. 7).

Fischer-Tropsch. - In the Fischer-Trospch process, a synthesis gas is initially produced via the steam and oxygen gasification of coal. Gasification can be accomplished in commercially available reactors (Lurgi, Winkler, Koppers-Totzek or Wellman-Galusha). In situ gasification may also be used. The synthesis gas is then converted to liquid hydrocarbons, waxes, and smaller quantities of alcohol and ketones over an iron or cobalt catalyst. The reaction may be carried out in fixed-bed or entrained-bed reactors. Total process thermal efficiency including gasification is about 40 percent. A commercial unit at SASOL in South Africa produces about 2000 bbl/day of gasoline. A new facility is under construction in South Africa that will increase production to 40 000 bbl/day of gasoline and fuel oil.

Methanol synthesis. - Methanol synthesis occurs according to either

$$CO + H_2 \rightarrow CH_3OH$$

or

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

The synthesis gas is obtained by coal gasification similar to the Fischer-Tropsch process. Several commercial-scale plants have been built abroad, and the technology is considered off the shelf. A feasibility study for the conceptual design of a commercial plant was performed by Badger, Inc. for DOE (ref. 26).

Methanol to gasoline. - The Mobil Oil Co., with DOE support, is developing a process for the catalytic conversion of methanol to gasoline (ref. 27). This process involves the dehydration of methanol over a zeolite catalyst to form hydrocarbons that are highly aromatic.

UPGRADING OF COAL LIQUIDS

Existing technologies for upgrading coal liquids come largely from petroleum refining. Upgrading of coal liquids includes removal of oxygen, nitrogen, and sulfur by catalytic hydrotreating, and boiling range conversion by fluid catalytic cracking (FCC) and hydrocracking. Coal liquids are highly aromatic and most of the contaminants (O, N, and S) are contained in these aromatic structures making their removal more difficult in comparison to petroleum (ref. 28). Concentration of heavy metals (which deactivate the catalysts) is also much higher in coal liquid than in petroleum.

Studies of catalytic hydrotreating have been performed using mainly liquids derived from the Synthoil, SRC, and H-Coal processes (refs. 29 to 33). Hydrotreating was performed on the whole crude and on fractions like naphtha and mid-distillate. Fixed-bed and expanded-bed reactors were used in these studies.

Very little work has been done on boiling range conversion processes for coal-derived liquids. Gulf Research a Development Co., under contract to DOE, performed a study on the processing of coal liquid residuals by coking followed by FCC (ref. 34). Problems were found due to catalyst deactivation by heavy metals present in the coal liquid residue.

LIQUID FUELS PROPERTY DATA

The characterization data obtained for the coal-derived liquids from the surveyed literature have been tabulated on the liquid fuel property form (table I). The fuels are presented according to the process from which they were derived. Within any process, characteristics have been tabulated for different boiling-range fractions, as well as for the total crude. Property data for some hydroprocessed coal-derived liquids are also included. For ease of referral to the data, the various distillation 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 5

(2) Data from Synthoil processes in table 6

(3) Data from SRC processes in table 7

(4) Data from COED processes in table 8

(5) Data from the Gulf CCL process in table 9

(6) Data from the EDS process in table 10

(7) Data from the $ZnCl_2$ Hydrocracking process in table 11

(8) Data from the Co-Steam Process in table 12

(9) Data from the Flash Pyrolysis process in table 13

(10) Data from a catalytic liquefaction process in table 14

(11) Data from the Sea Coal process in table 15

(12) Summary of liquid fuel properties in table 16

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, SRC, EDS, and COED. However, it was felt that including data on newer processes like the CCL and the Liquid-Phase $ZnCl_2$, could be useful.

It is readily apparent from casual examination of tables 5 to 16 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 38, 47, and 41.

Some of the more important property data on liquid fuels have been summarized in table 16. Plots of these data are shown in figures 21 to 23. Although different boiling ranges of the fuels are shown in table 16, all the data available for each fuel are plotted, irrespective of the type of process or the type of distillate cut. Table 17 shows proposed specifications for typical coal-derived liquid fuels to be used in gas-turbine engines.

Figure 21 shows the general trend of increasing wt % 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 22 shows how the wt % of nitrogen varied with the wt % 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 $ZnCl_2$ Hydrocracking process (ref. 58), not plotted in figure 22, showed nitrogen levels significantly lower than that of any other process-derived fuel at comparable hydrogen levels. In the hydrocracking process, the bonds between carbon and heteroatoms (O, N, and S) are usually broken resulting in a higher conversion to NH_3 and a lower nitrogen content in the product fuel. Nitrogen levels for the $ZnCl_2$-derived fuels were from 0.0018 to 0.0019 wt % for hydrogen levels of 8.3 to 9.65 wt %.

Figure 23 shows how heat of combustion for liquid fuels varies with wt % of hydrogen for those few fuels for which such data were reported. Again, the trend is independent of the processing type.

COAL GASIFICATION PROCESSES

The primary purpose of gasification processes is to provide clean fuels in gaseous form that will meet existing emission standards. These processes are based on thermal decomposition of coal and gasification or combustion of the resulting char. The products of gasification are classified as low- and intermediate-Btu gases. Low-Btu gas (heating value below 200 Btu/scf) is made by gasifying coal with air and steam. Four major concepts for coal gasification have been developed: fixed bed, fluidized bed, entrained flow, and underground gasification. The technology for coal gasification is reviewed in detail in reference 62.

Fixed Bed

In fixed-bed gasifiers, coal is fed into the top of the gasifier and moves slowly downward in a bed through which air or oxygen flows upward. The countercurrent contact permits both the coal and gaseous reactants to be preheated before gasification, thus increasing the overall thermal efficiency. Relatively long residence time of the fuel in the reaction vessel permits high carbon conversion. The long residence time reduces gasification rates, but because of higher carbon conversions, thermal efficiencies are high (ref. 63). Fixed-bed gasifiers have certain disadvantages, mainly the softening, thickening, and swelling behavior of certain bituminous coals in the upper region of the bed can cause serious problems with solids caking and gas channeling (ref. 62).

The Lurgi gasification process was developed by Lurgi Mineratoltechnik of West Germany to make synthesis gas from noncaking coals in a gasifier blown with steam and oxygen. A schematic configuration of the process is shown in figure 24.

Five Lurgi gasifiers began operation in a SteinkolenElektriziat AG plant in Lunen, West Germany in 1972. This plant uses steam, air, and coal to produce 160 MM scfd of low-Btu gas for a combined cycle generating plant. The plant was still operational in the late 1970's. Continental Oil Company was awarded a contract to design, construct and operate a 250 MM scfd in Montgomery, Illinois. This plant uses a modified Lurgi process followed by methanation to produce pipeline quality gas (refs. 64 and 65).

Fluidized Bed

In fluidized-bed gasification, the particle size is much smaller than in fixed-bed operation and the gas is passed up through the bed with a velocity high enough to fluidize the particles. Fluidized-bed gasifiers have more carryover of solids than fixed-bed gasifiers, which can lead to fuel loss and make solids removal more difficult. They also have less soot and tar production which facilitates gas cleanup and lower gas heating values due to smaller yield of hydrocarbon gases. Fluidized-bed gasifiers can use a wide range of coals but some pretreatment may be necessary for caking coals that can agglomerate in the bed and lead to loss in fluidization. This pretreatment usually consists of mild oxidation with oxygen or air.

Fluidized-bed gasification processes included in this survey are: Synthane, Exxon, U-Gas, Westinghouse, and CO_2 Acceptor processes.

Synthane. - The Synthane process (refs. 62, 18, 65) was developed by the U.S. Bureau of Mines for the production of pipeline quality gas. This process uses a two-zone gasifier consisting of a dense fluid bed in the top section and a dilute fluid bed in the bottom section. Steam and oxygen are injected at the bottom of the gasifier to fluidize and gasify the coal. The synthesis gas exits from the top of the gasifier and goes to a water-gas shift reactor followed by catalytic methanation. A schematic of the process is shown in figure 25.

A 72 ton/day pilot plant has been constructed at Bruceton, Pennsylvania for the study of pipeline gas production using steam and oxygen in the gasifier followed by catalytic methanation. Testing of the plant began early in 1976.

Exxon. - The Exxon Catalytic Gasification process was developed by the Exxon Research and Engineering Co. to produce intermediate-Btu gas from coal. This process uses alkali metal gasification catalysts to increase the rate of steam gasification. The synthesis gas produced is recycled to the gasifier so that the only net products are CH_4, CO_2, and small quantities of H_2S and NH_3. The product composition closely approaches that of gas-phase methanation equilibrium. The resulting overall gasification reaction is Coal + $H_2O \rightarrow CH_4 + CO_2$. A schematic of the process is shown in figure 26.

A 0.5 ton/day integrated PDU at Baytown, Texas has been operated by Exxon for several years (ref. 66).

U-Gas. - The U-Gas process, developed by the Institute of Gas Technology (IGT), is used to produce low- or intermediate-Btu gas from coals of any rank. Coal overflows into the fluidized-bed gasifier where it reacts with steam and air (or oxygen) at about 1040° C. As carbon is gasified at the top of the gasifier, ash agglomerates grow at the bottom. When they become heavy enough, the agglomerates fall countercurrent to the high velocity gas and are separated from the bed. The dust is removed from the product gas and the gas is subsequently desulfurized. A schematic configuration of the U-Gas process is shown in figure 27.

Westinghouse. - The Westinghouse process is designed to operate in conjunction with a combined cycle power plant. Coal is dried and sent to a fluidized-bed reactor where devolatilization, desulfurization with added lime, and hydrogasification take place. The reactor operates at 700 to 930° C and 20 to 30 atm. The coal is diluted with large quantities of recycled solids (char and lime sorbent) which control the agglomeration of coal. The devolatilized char is further gasified in a fluidized bed in which char is burned with air to provide gasification heat. After removing the particulates, the clean fuel gas goes to a turbine plant. A schematic diagram of the process is shown in figure 28.

CO_2 acceptor. - The CO_2 acceptor process (ref. 67) was developed by Conoco Coal Development Co. to process western coals into pipeline gas. This process uses two fluidized-bed reactors (a gasifier bed with steam and a regenerator fed with air) and a circulating lime bearing material called the acceptor which is fed initially as limestone or dolomite. Coal is initially gasified by the reactions:

$$C + H_2O_{(g)} \rightarrow CO + H_2$$

and

$$2C + H_2O_{(g)} \rightarrow CH_4 + CO$$

Carbon is formed by the water-gas shift reaction:

$$CO + H_2O_{(g)} \rightarrow CO_2 + H_2.$$

The three reactions mentioned above are endothermic. The required heat of reaction is supplied by the CO_2 acceptor reaction:

$$CaO + CO_2 \rightarrow CaCO_3.$$

The limestone is calcined in the regenerator and recycled to the gasifier. A schematic of the CO_2 acceptor process is shown in figure 29, and the two fluidized-bed reactor system is shown in figure 30.

A 40 ton/day pilot plant has been operated by Conoco Coal Development with DOE support, at Rapid City, South Dakota since 1972 (ref. 68).

Entrained Flow

In entrained-flow gasifiers (ref. 69), pulverized coal is carried through the gasifier in concurrent flow by a mixture of air (or oxygen and steam). The reactants are usually premixed and fed to the gasifiers through burners or nozzles. Since the flow is concurrent, the reaction rate decreases as the particles pass through the reactor and high temperatures are required to achieve necessary conversion with a reasonable reactor size. High exit temperatures make it necessary to use a heat recovery system.

The main advantages of entrained flow gasifiers are:

(a) They can use all types of coal since there is little or no agglomeration

(b) Reaction rate is much higher and, because of particle size, coal throughput per unit volume of gasifier is higher than in fixed beds or fluidized beds

(c) There is little tar production in steam-air or steam-oxygen systems

The main disadvantages are: large carryover of fine particles, short refractory life and unreliable coal feeding, and the need for a heat recovery system.

Entrained-flow gasification processes include Bi-Gas, Combustion Engineering, and Koppers-Totzek processes.

Bi-Gas. - The Bi-Gas process, developed by Bituminous Coal Research (BCR), uses a vertical-axis, two-stage gasifier that operates at 68 to 102 atm (1000 to 1500 psi) on coals of any rank (refs. 62 and 70). A schematic of the process is shown in figure 31. Coal and steam are fed to the upper reactor where they come in contact with synthesis gas from the lower section. Coal devolatilization and hydrogasification take place in this stage. The products gas and char exit in the gasifier overhead and are then separated. The char is returned to the bottom stage where it is contacted with steam and oxygen for fixed carbon gasification.

A 120 ton/day pilot plant has been constructed at Homer City, Pennsylvania by BCR with DOE funding. This plant includes catalytic methanation of the synthesis gas. The development work is directed toward high-Btu gas production (ref. 71).

Combustion engineering. - The Combustion Engineering process was developed by Combustion Engineering, Inc., with support from DOE and EPRI to convert coal into clean fuel gas for electric power generation (refs. 62 and 72). This process is very similar to the Bi-Gas process. It uses a two-section, airblown gasifier operating at atmospheric pressure. Coal and recycle char are burned with air in the lower (combustion) section of the gasifier. Steam and coal are fed into the upper (reducing) section of the gasifier where they encounter hot gases leaving the combustion zone. Coal is devolatilized and gasified by reaction with steam. Raw gases are then scrubbed and desulfurized. A schematic of the process is shown in figure 32.

Koppers-Totzek. - The Koppers-Totzek process (refs. 18 and 62) was developed by Heinrich Koppers GmbH of West Germany. This process uses an oxygen-blown atmospheric pressure gasifier. Coal is suspended in a steam and oxygen stream and fed at atmospheric pressure to the gasifier where partial oxidation takes place. The high operating temperature minimizes the formation of organic compounds. The gas is then cleaned by conventional methods to remove the ash, CO_2, and H_2S.

Underground Gasification

Underground gasification (refs. 62, 73, and 74) is achieved by partially burning the coal in situ in the presence of steam-air or steam-oxygen mixtures introduced into the steam through boreholes or shafts. Underground gasification consists of the same basic steps (devolatilization of coal to form char, reaction of char with steam and combustion of the remaining char) as other types of gasification. This process permits recovery of gas from coals that are technically or economically unattractive to recover by conventional mining techniques.

The present U.S. program is being conducted primarily by DOE and includes the following concepts: longwall generator, linked verticle wells, and packed-bed reactor.

Longwall generator. - The Longwall Generator concept, developed by the DOE Morgantown Energy Research Center (MERC), is specifically designed for use in thin seams of eastern bituminous coals (refs. 70, 75, and 76). The concept makes use of directionally drilled holes placed horizontally in the coal seam. Vertical holes are drilled to intersect the ends of the horizontal holes. In the linking phase, the coal is ignited along the length of the horizontal hole and reverse combustion is achieved by injection of oxygen or air in front of the combustion wave via a second parallel borehole. A simplified drawing of the Longwall Generator Concept is shown in figure 33.

Linked vertical wells. - The Linked Vertical Wells (LVW) concept is being developed by DOE Laramie Energy Research Center (LERC) to gasify thick seams of subbituminous coals (refs. 75 and 76). The process is carried out in two stages. In the first stage, gasification paths are formed by means of high-pressure air injection between the vertical boreholes. This is followed by reverse combustion linkage between two adjacent boreholes. To accomplish linkage of the wells, a fire is ignited in the borehole from which product gas is to be withdrawn, and air is injected in the adjacent well. The combustion front moves toward the injection well advancing in the direction opposite to that of the gas flow (reverse gasification). Once linkage of the boreholes is completed, the second stage begins as the combustion front changes direction and proceeds along the channel formed during the reverse linkage step. Gasification now occurs in the same direction as the injection and gas flow. A simplified drawing of the LVW concept is shown in figure 34.

Packed bed. - The Packed Bed concept, developed by Lawrence Livermore Laboratory, is intended for application in thick, subbituminous coal seams.

In this process, natural coal permeability is enhanced by explosive fracturing to create a well defined, permeable reaction zone. After the coal is fractured, wells are drilled to the bottom of the fractured zone around its perimeter. Process gas injection takes place through wells previously used for explosive fracturing. Gasification begins at the top and moves downward and outward (forward mode) toward the collection well. Essentially the gasification process takes place in an underground packed bed reactor. A simplified drawing of the Packed Bed concept is shown in figure 35.

GASEOUS FUELS PROPERTY DATA

The low-Btu gases proposed for use in ground-based power turbine systems would be produced by airblown gasifiers. As such, they will contain a large percentage (50 vol. %) of nitrogen, as well as some carbon-dioxide, 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. To produce medium-Btu gases, oxygen-blown gasifiers (which will eliminate the nitrogen in the product) can be used or methanation of the synthesis gas can be incorporated into the process.

The characterization data for the coal-derived gases have been tabulated on the syngas property form (table 18). Characterization data for gaseous fuels are presented in the following tables:

(1) Data for low-Btu gas in table 19

(2) Data from the Lurgi process in table 20

(3) Data from the Koppers-Totzek process in table 21

(4) Data from the Hygas process in table 22

(5) Data from the Synthane process in table 23

(6) Data from the Exxon Catalytic process in table 24

(7) Data from the CO_2 acceptor process in table 25

Figure 36 shows the relationship between gross heat of combustion and vol. % of inerts (N_2, CO_2) in the gas. These data were obtained from tables 19 to 25. This relationship is not linear but can be roughly approximated for low-Btu gas as

Gross heat of combustion = 466 - 5.48 (vol. % of inerts) Btu/scf

Some of the references cited in table 19 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.

REFERENCES

1. Reynolds, T. W.; Niedzwiecki, R. W.; and Clark, J. S.: Literature Survey of Properties of Synfuels Derived from Coal. NASA TM-79243, 1980

2. Bittker, D. A.: An Analytical Study of Nitrogen Oxides and Carbon Monoxide Emissions in Hydrocarbon Combustion with Added Nitrogen-Preliminary Results. NASA TM-79296, 1979.

3. Schultz, D. F.; and Wolfbrandt, G.: Flame Tube Parametric Studies for Control of Fuel Bound Nitrogen Using RichLean Two-Stage Combustion. NASA TM-81472, 1980.

4. Bittker, D. A.; and Wolfbrandt, G.: Effect of Fuel Nitrogen and Hydrogen Content on Emissions in Hydrocarbon Combustion. NASA TM-81612, 1981.

5. Foster, A. D.; Doering H. von E.; and Hickey, J. W.: Fuel Flexibility in G. E. Gas Turbines. General Electric, GER-2222L, 1977.

6. Assessment of Technology for Liquefaction of Coal: Summary. FE-1216-2, U.S. Dept. of Energy, 1977.

7. Assessment of Technology for Liquefaction of Coal. FE-1216-3, U.S. Dept. of Energy. 1977.

8. Ahmed, M. M.: Solvent Refined Coal (SRC) Process: Development of a Process for producing an Ashless, Low-Sulfur Fuel from Coal. Vol. IV. Product Studies. Part 9: An Investigation of the Activity of Two Cobalt-Molybdenum-Alumina Catalysts for Hydrodesulfurization of a Coal-Derived Liquid. FE-0496-T9, U.S. Dept. of Energy, 1979 .

9. Environmental Development Plan (EDP) - Coal Liquefaction Program (FY 1977). DOE/EDP-0012, U.S. Dept. of Energy, 1978.

10. Weinstein, N.J. : Fundamental Data Needs for Coal Conversion Technology. COO/4059-1, U.S. Dept. of Energy.

11. O'Hara, J. B.; et al: Project POGO: Total Coal Utilization COG Refining Design Criteria. FE-1775-11, U.S. Dept. of Energy, 1977.

12. Clean Coke Process: Process Development Studies. FE-1220-39, vol. 1 to 3, pts. 1 and 2. U.S. Dept. of Energy, 1978.

13. Epstein, M.; Chen, T. P.; and Ghaly, M. A.: Analysis of Coal Hydrogasification Processes. FE-2565-14, U.S. Dept. of Energy, 1978.

14. Fallon, P.; and Steinberg, M.: Flash Hydropyrolsis of Coal; The Design, Construction, Operation and Initial Results of a Flash Hydropyrolysis Experimental Unit. BNL 50698, Energy Research and Development Administration, 1977.

15. Singh, L. P.: Scoping Study on Two Flash Hydropyrolsis Processes. ORNL/TM-6265, U.S. Dept. of Energy, 1978.

16. Fossil Energy Research and Development Program of the U.S. Department of Energy, 1979. DOE/ET-0013(78), U.S. Dept. of Energy, 1978.

17. Moh, T. T. L.: Solvent Refined Coal (SRC) Process: Development of a Process for Producing an Ashless, Low-Sulfur Fuel from Coal. FE-496-T11, U.S. Dept. of Energy, 1978.

18. Oldham, R. G.; and Wetherold, R. G.: Assessment, Selection and Development of Procedures for Determining the Environmental Acceptability of Synthetic Fuel Plants Based on Coal. FE-1795-3, U.S. Dept. of Energy, 1977.

19. Grimes, W. R. L.; et al: ORNL Coal Chemistry Report - 1979. Executive Summary ORNL-5629 U.S. Dept. of Energy, 1980.

20. Lewis, H. E.; et al: Solvent Refined Coal (SRC) Process. Operation of Solvent Refined Coal Pilot Plant at Wilsonville, Alabama. FE-2270-19, U.S. Dept. of Energy, 1977.

21. Lewis, H. E.; et al: Solvent Refined Coal (SRC) Process. Operation of Solvent Refined Coal Pilot Plant at Wilsonville, Alabama. EPRI AF-585, Electric Power Research Institute, 1977.

22. Epperly, W. R.: EDS Coal Liquefaction Process Development-Phase III B. FE-2893-7, U.S. Dept. of Energy, 1977.

23. Computer-Aided Industrial Process Design - The Aspen Project. MIT-2295T9-2, Massachusetts Institute of Technology, 1976.

24. Lindahl, D. R.; et al: Design and Construction of the PDU for Zinc Halide Hydrocracking of Coal. FE-1743-61, U.S. Dept. of Energy, 1978.

25. H-Coal Integrated Pilot Plant. HCP/T-1544/1. U.S. Dept. of Energy, 1977.

26. Conceptual Design of a Coal to Methanol Commercial Plant. Executive Summary. FE-2416-24, U.S. Dept. of Energy, 1978.

27. Schreiner, M.: Research Guidance Studies to Assess Gasoline from Coal by Methanol-to-Gasoline and SASOL-Type Fischer-Tropsch Technologies. FE-2447-9. U.S. Dept. of Energy, 1978.

28. Lanning, W. C.: The Denitrogenation of Coal Liquids. BETC/IC-78/1. U.S. Dept. of Energy, 1978.

29. Schneider, A.; Hollstein, E. J.; and Janoski, E. J.: Research and Development of an Advanced Process for the Conversion of Coal to Synthetic Gasoline and Other Distillate Fuels. TID-28447. Energy Research and Development Administration, 1976.

30. Tan, G.; and de Rosset, A. J.: Upgrading of Coal Liquids. FE-2566-12. U.S. Dept. of Energy, 1978.

31. deRosset, A. J.; et al.: Characterization of Coal Liquids. FE-2010-09. U.S. Dept. of Energy, 1977.

32. Potts, J. D.; Hastings, K. E.; and Wysocki, E. D.: Commercial Scale Expanded Bed Hydroprocessing of Solvent Refined Coal (SRC) Extract. FE-2038-17. U.S. Dept. of Energy, 1977.

33. Givens, E. N.; et al.: Chemical Characterization, Handling and Refining all Solvent Refined Coal to Liquid Fuels. FE-2003-27. U.S. Dept. of Energy, 1977.

34. Sinnet, C. E.; and Wynne, F. E.: Research and Development of an Advanced Process for Conversion of Coal to Synthetic Gasoline and Other Distillate Motor Fuels. FE-1800-24. U.S. Dept. of Energy, 1978.

35. Jewitt, C. H.; and Wilson, G. D.: Comparative Characterization and Hydrotreating Response of Coal, Shale and Petroleum Liquids. Am. Chem. Soc., Div. Pet. Chem., Prepr., vol. 22, no. 2, Mar. 1977, pp. 785-792.

36. Peters, B. C.: Chemicals from Coal: Interim Report on HRI H-Coal. FE-1534-48, U.S. Dept. of Energy, 1977.

37. Holmes, S. A.; et al.: Characterization of Coal Liquids Derived from the H-Coal Process. BERC/RI-76/10, Energy Research and Development Admin., 1976.

38. Callen, R. B.; et al.: Upgrading Coal Liquids to Gas Turbine Fuels. 1. Analytical Characterization of Coal Liquids. Ind. Eng. Chem., Prod. Res. Dev., vol. 15, no. 4, 1976, pp. 222-233.

39. Shaw, H.; et al.: Evaluation of Methods to Produce Aviation Turbine Fuels from Synthetic Crude Oils. Phase I - Coal Utilization in the Manufacturing of Jet Engine Fuels. GRU-1PEA-75, Exxon Research and Engineering Co., 1975 (AFAPL-TR-75-10, AD-A016456).

40. Johnson, Clarence A.; Stotler, Harold H.; and Winter, Olaf : H-Coal Prototype Program. Symposium on Project Plants for Production of Clean Fuels from Coal, Paper 55C, 1973.

41. Stein, T. R.; et al.: Upgrading of Coal Liquids for Use as Power Generation Fuels. EPRI AF-444, Electric Power Research Institute, 1977.

42. Schultz, H.; et al.: A Study of Some Trace Elements in the Half Ton Per Day Synthoil PDU. Am. Chem. Soc., Div. Pet. Chem., Prepr., vol. 22, no. 2, Mar. 1977, pp. 588-592.

43. Crynes, B. L.: Catalysts for Upgrading Coal-Derived Liquids. FE-2011-7, Energy Research and Development Admin., 1977.

44. Woodward, P. W.; et al.: Compositional Analysis of Synthoil from West Virginia Coal. BERC/RI-76/2, Energy Research and Development Admin., 1976.

45. Crynes, B. L.: Catalysts for Upgrading Coal-Derived Liquids. FE-2011-3, Energy Research and Development Admin., 1976.

46. Kalfadelis, C. D.: Evaluation of Methods to Produce Aviation Turbine Fuels from Synthetic Crude Oils - Phase II, Vol. 2. GRU-2PEA-76-VOL-2, Exxon Research and Engineering Co., 1976 (AFAPL-TR-75-10, Vol. 2, AD-A036190).

47. Hardin, M. C.: Evaluation of Three Coal-Derived Liquid Fuels in a Standard T63 Combustor. Detroit Diesel Allison. RN-74-28, 1974.

48. Preparation of a Coal Conversion Systems Technical Data Book. FE-2286-28, U.S. Dept. of Energy. 1978.

49. Frutcher, J. S.; et al.: High Precision Trace Element and Organic Constituent Analysis of Oil Shale and Solvent-Refined Coal Materials. Am. Chem. Soc., Div. Pet. Chem., Prepr., vol. 22, no. 2, Mar. 1977, pp. 793-807.

50. Schmid, B. K.; and Jackson, D. M.: The SRC-II Process. Presented at the 2nd Pacific Chemical Engineering Congress (PAChEC '77). AIChE, 1977, vol.2, pp. 908-915.

51. Schmid, B. K.; and Jackson, D. M.: Recycle SRC Processing for Liquid and Solid Fuels. Presented at 4th Annual International Conference on Coal Gasification, Liquefaction and Conversion to Electricity, (Pittsburgh, PA.), Aug. 2-4, 1977.

52. Solvent Refined Coal (SRC) Process. FE 496-143, U.S. Dept. of Energy, 1978.

53. Peters, B. C.: Chemicals from Coal. FE-1534-44, Energy Research and Development Admin., 1977.

54. Sturm, G. P., Jr.; et al.: Analyzing Syncrude from Western Kentucky Coal. BERC/RI-75/12, Energy Research and Development Admin., 1975.

55. Eisen, F. S.: Preparation of Gas Turbine Engine Fuel from Synthetic Crude Oil Derived from Coal. Final Report, Sun Oil Co., Feb. 1975 (AD-A007923).

56. Haebig, J. E.; Davis, B. E.; and Dzuna, E. R.: Preliminary Small-Scale Combustion Tests of Coal Liquids. Am. Chem. Soc., Div. Fuel Chem., Prepr., vol. 20, no. 1, Apr. 1975, pp. 203-214.

57. Furlong, L. E.; et al.: The Exxon Donor Solvent Process. Chem. Eng. Prog., Vol. 72 no. 8, Aug. 1976, pp. 69-75 (Also Coal Processing Technology. Vol. 3. AIChE, 1977, pp. 145-151).

58. Klunder, E. B.; et al.: Zinc Halide Hydrocracking Process for Distillate Fuels from Coal. FE-1743-37, Energy Research and Development Admin., 1977.

59. Appell, H. R.; Moroni, E. C.; and Miller, R. D.: Co-Steam Liquefaction of Lignite.
Am. Chem. Soc., Div. Fuel Chem., Prepr., vol. 20, no. 1, Apr. 1975, pp. 58-65.

60. Knell, E. W.; et al.: Flash Pyrolysis Coal Liquefaction Process Development. FE-2244-8 Energy Research and Development Admin., 1977.

61. Ruberto, R. G.; et al.: Characterization of Synthetic Liquid Fuels. Am. Chem. Soc., Div. Fuel Chem., Prepr., vol. 19, no. 2, 1974, pp. 258-290 (Also Shale Oil, Tar Sands, and Related Fuel Sources, T. F Yen, ed., Advances in Chemistry Series 151, ACS, 1976, pp. 28-47).

62. Assessment of Low and Intermediate-Btu Gasification of Coa.. FE/1216-4, U.S. Dept. of Energy, 1977.

63. Fixed Bed Coal Gasification for Production of Industrial Fuel Gas. FE-2220-26. U.S. Dept. of Energy, 1977.

64. Aul, E. F.; et al.: Phase I: The Pipeline Gas Demonstration Plant (Technical Support Program Report). FE-2542-13. U.S. Dept. of Energy, 1978.

65. Prototype Pilot Plant Operation Synthane Process. COO-0003-14. U.S. Dept. of Energy, 1977.

66. Exxon Catalytic Coal Gasification Process: Predevelopment Program. FE-2369-20. U.S. Dept. of Energy, 1978.

67. CO_2 Acceptor Process Gasification Pilot Plant, Commercial Plant Conceptual Design and Cost Estimate. FE-1734-43 (Vol. 10, Book 1-2-3). U.S. Dept. of Energy, 1977.

68. Curron, G. P.; et al.: CO_2 Acceptor Process Gasification Pilot Plant; Operations FE-1734-40 (Vol. 7), U.S. Atomic Energy Commission, 1974.

69. Su, F. Y.; et al: Analysis and Interpretation of Laboratory Coal Gasification Simulation Data. MERC/CR-78/2. U.S. Dept. of Energy, 1978.

70. Nakles, D. V.; Walters, R. W.; and Massey, M.J.: Characterization of Effluents from the Bi-Gas Pilot Plant. FE-2496-21, U.S. Dept. of Energy, 1978.

71. Gas Generator Research and Development: Bi-Gas Process. FE-1207-33. Energy Research and Development Administration, 1977.

72. Simon, J. J.: The Test Program for Low-Btu Gasification of Coal for Electric Power Generation. FE-1545-47. U.S. Dept of Energy, 1977.

73. Underground Gasification for Steeply Dipping Coal Beds. SAN-1472-9. U.S. Dept. of Energy, 1978.

74. Aiman, W. R.; and Fisher, W. T.: In Situ Coal Gasification Program. UCRL-50026-78-1. U.S. Dept. of Energy, 1978.

75. Lee, K. Y.: Thermo-Mechanical Responses for PorousPermeable Media with Application to Underground Coal Gasification. METC/CR-78/17. U.S. Dept. of Energy, 1978.

76. Ulrich, W. C.: Evaluation of In Situ Coal Gasification Processes on Regional Basis. ORNL-5279. U.S. Dept. of Energy, 1977.

77. McCaleb, T. L.; and Chen, C. L.: Low Btu Gas as on Industrial Fuel. Chem. Eng. Prog., vol. 73, no. 6, June 1977, pp. 82-88.

78. Carlson, N. G.: Development of High Temperature Subsystem Technology to a Technology Readiness State: Phase I. Topical Report, Baseline Combined-Cycle System for Operation with Coal-Derived Gaseous Fuel. FE-2292-15. Energy Research and Development Admin., 1977.

79. Littlewood, K.: Gasification: Theory and Application. Prog. Energy Combust. Sci., vol. 3, no. 1, 1977, pp. 35-71.

80. Pillsbury, P. W.; and Lin, S. S.: Advanced Coal Gasification System for Electric Power Generation. Development of Full-Size Turbine Combustors Using Synthetic Low-Btu Fuel Gas at 350° F. FE-1514-52 Energy Research and Development Admin., 1976.

81. Walsh, P. M.: A Review of Ammonia and Hydrogen Cyanide Concentrations in Low and Medium-Btu Coal Gases. FE-2762-2. U.S. Dept. of Energy, 1978.

BIBLIOGRAPHY

Bibliography Sources

Coal Liquefaction Process Research Process Survey; Data Source Book. ORNL/Sub-7186/13, U.S. Dept. of Energy, 1977.

Coal Conversion Applications; Collected Works, 1972-1977. FE-1775-15, U.S. Dept. of Energy, 1978.

McKee, C. R. and Serafini, A.: Bibliography of Subsidence and Related Topics for In Situ Coal Gasification. LETC/BL-71316-1, U.S. Dept. of Energy, 1978.

Cavagnaro, Diane M.: Coal Gasification and Liquefaction Technology, Vo. 3, June 1976 - Apr. 1978, A Bibliography with Abstracts. NTIS/PS-77/0305, National Technical Information Service, 1978.

Mathison, Ruby L., compiler: Synthetic Fuels Research, A Bibliography 1945-1976. Third ed., American Gas Association, 1977.

ERDA Energy Research Abstracts. Energy Research and Development Administration, 1976- .

Coal Processing; Gasification, Liquefaction, Desulfurization: A Bibliography 1930-1974. TID-3349, U.S. Atomic Energy Commission, 1974.

Coal Processing, Production, and Properties: A Bibliography; Citations. TID-3349-S1P1, Energy Research and Development Admin., 1976.

Coal Processing, Production, and Properties: A Bibliography; Indexes. TID-3349-S1P2, Energy Research and Development Admin., 1976.

Citations from 1979

Walsh, P. M.: A Review of Ammonia and Hydrogen Cyanide Concentrations in Low and Medium-Btu Coal Gases. FE-2762-2, U.S. Dept. of Energy, 1979.

Curran, G. P.; et al.: CO_2 Acceptor Process Gasification Pilot Plant; Operations FE-1734-40, (Vol. 7), U.S. Atomic Energy Commission, 1974.

Citations from 1978

Filby, R. H.: Solvent Refined Coal (SRC) Process. FE-496-143, U.S. Dept. of Energy, 1978.

Epperly, W. R.: EDS Coal Liquefaction Process Development Phase III-B: FE-2893-7, U.S. Dept. of Energy, 1978.

Tan, G.; and deRosset, A. J.: Upgrading of Coal Liquids. FE-2566(-05 to -26), U.S. Dept. of Energy, 1977-1979.

Preparation of a Coal Conversion Systems Technical Data Book. FE-2286-28, U.S. Dept. of Energy, 1978.

Nahas, N. C.: Exxon Catalytic Coal Gasification Process - Predevelopment Program. FE-2369-21, U.S. Dept. of Energy, 1978.

Citations from 1977

Cabal, Albert V.; Voltz, Sterling E.; and Stein, Thomas R.: Upgrading Coal Liquids to Gas Turbine Fuels. 2. Compatibility of Coal Liquids with Petroleum Fuels. Ind. Eng. Chem., Prod. Res. Dev., vol. 16, no. 1, Mar. 1977, pp. 58-61.

Callen, R. B.; Simpson, C. A.; and Bendoraitis, J. G.: Analytical Characterization of Solvent Refined Coal. Comparison with Petroleum Residua. Am. Chem. Soc., Div. Pet. Chem., Prepr., vol. 22, no. 2, Mar. 1977, pp. 656-664.

Carlson, Nils G.: Development of High-Temperature Subsystem Technology to a Technology Readiness State: Phase I. Topical Report. Baseline Combined-Cycle System for Operation with Coal-Derived Gaseous Fuel. FE-2292-15, Energy Research and Development Admin., 1977.

Clark, Bruce R.; Ho, C.-H.; and Jones, A. Russell: Approaches to Chemical Class Analysis of Fossil Derived Materials. Am. Chem. Soc., Div. Pet. Chem., Prepr., vol. 22, no. 2, Mar. 1977, pp. 811-822. Technique is illustrated, but samples used are not identified; therefore, of no use in this project.

Crynes, B. L.: Catalysts for Upgrading Coal-Derived Liquids. FE-2011-7, Energy Research and Development Admin., 1977. Progress summary table indicates characterization of synfuels; started early 1975.

deRosset, A. J.; et al.: Characterization of Coal Liquids. FE-2010-09, Energy Research and Development Admin., 1977.

Fant, B. T.: EDS Coal Liquefaction Process Development: Phase IIIA. FE-2353-1, Energy Research and Development Admin., 1977.

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
496	Ahmed, M. M.	Oklahoma State University	Solvent-Refined Coal (SRC) process
628		PAMCO	Pilot Plant to Produce Low-Btu Gas from Coal
1207		Bituminous Coal Research	Gas Generator Research and Development
1212	Jones, J. F., et al.	FMC Corp.	COED
1220		USS Engineers and Consultants, Inc.	Clean Coke Process
1224	Severson, D. E.	University of North Dakota	Process Development for Solvent-Refined Lignite
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, B.	Dow Chemical	Chemicals from Coal
1545	Patterson, R. C.	Combustion Engineering, Inc.	C-E Low-Btu Gasification of Coal Project: Phases I, II, and III
1734	Curran, G. P., et al.	Conoco Coal Development Co.	CO_2 Acceptor Process
1743	Klunder, E. B., et al.	Conoco Coal Development Co.	$ZnCl_2$ Process: Hydrocracking for Distillate Fuels
1775	O'Hara, J. B., et al.	Ralph M. Parsons Co.	Project POGO: Total Coal Utilization

Fossil energy Contract FE	Author	Company	Process and/or title
1800	Sinnet, C. E. Wynne, F. E.	Gulf Research a Development Co.	Conversion of Coal to Synthetic Gasoline and Other Distillate Motor Fuels
2003	Gresbovich, E. J.		Chemical Characterization: Handling and Refining SRC to Liquid Fuels
2006	Wiser, W. H.	Utah University	Applied Research and Evaluation of Process Concepts for Gasification and Liquefaction of Western Coals
2010	de Rosset, et al.	UOP, Inc.	Characterization of Coal Liquids
2028	Katzer, J. P., et al.	Delaware University	Kinetics and mechanisms of Desulfurization and Denitrogenation of Coal-Derived Liquids
2030	Nsakala, N., et al.	Penn State University	Characteristics of Chars Produced by Pyrolysis Following Rapid Heating of Pulverized Coal
2034	Berg, S., et al.	Montana State University	Catalysts for Upgrading Coal-Derived Liquids
2038	Potts, J. D., et al.	Cities Service Co.	Commercial Scale Expanded Bed Hydroprocessing of Solvent
2070	Lewis, H. E., et al.	Catalytic, Inc.	SRC Process Operation at Wilsonville, Alabama
2202		SRI International	Homogenous Catalytic Hydro-cracking Process for Conversion of Coal to Liquid Fuels
2206	Starkovich, J. A., et al.	TRW	Catalytic Conversion of Coal Energy to Hydrogen
2220		Gilbert/Commonwealth	Fixed Bed Coal Gasification for Production of Industrial

Fossil energy Contract FE	Author	Company	Process and/or title
Fuel Gas			
2240	Kertamus, N. G.	C. F. Braun and Co.	Combined Shift-Methanation Processes
2270	Lewis, H. E., et al.	Catalytic, Inc.	Solvent Refined Coal
2292	Calison, 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 Advance Catalytic Processes
2353	Fant, B.	Exxon Research and Engineering	EDS Coal Liquefaction Process Development-Phase III
2361	Moluyen, B.	Hydrocarbon Research, Inc.	Development of a Fast Fluid Bed Gasifier
2369	Kalina, T.	Exxon Research and Engineering	Exxon Catalytic Coal Gasification Process: Predevelopment Program
2416		Badger Plants, Inc.	Conceptual Design of a Coal to Methanol Commercial Plant
2434		Institute of Gas Technology	Pipeline Gas from Coal Hydrogenation
2447	Schreiner, M.	Mobil Research and Development Corp.	Research Guidance Studies to Assess Gasoline and Sasol-Type Fischer-Tropsch Technologies
2542	Watson, W. B. Sweany, G. A.	Continental Oil Co.	The Pipeline Gas Demonstration Plant
2566	Ton, G., de Rosset, A.	UOP, Inc.	Upgrading of Coal Liquids
2893	Epperly, W. R.	Exxon Research and Engineering	EDS Coal Liquefaction Process Development

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								
Aniline 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								
-								

TABLE 2. - SPECIFICATIONS FOR LIQUID FUELS USED IN ADVANCED GAS-TURBINE INDUSTRIAL ENGINES

[Data from ref. 5.]

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 [illegible]	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								
Aniline point, °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								
Hg								
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 ml max.	D-2276	3.0	10.0	Report	Report			

TABLE 3. - 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 4. - 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 5. - FUEL DATA FROM H-COAL PROCESS

(a) H-coal from Illinois #6 coal (fuel oil mode); data from ref. 35.

Property	Test	Distillate categories						
		Full-range liquid	Naphtha	Middle distillate	Heavy distillate			
Gravity, °API (specific)		27.6	40.6	16.7	[illegible]			
Boiling range:								
Initial boiling point, °F		180	196	432				
5%			215	442	682			
10%			228	452	688			
20%			250	456	699			
30%			270	470	706			
40%			292	492	722			
50%			312	514	737			
60%			332	536	756			
70%			350	570	783			
80%			366	592	84			
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								
Aniline point, °F								
H/C atom ratio								
Elemental analyses, wt%:								
C		83.6						
H		3.4						
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 5. - Continued.

(b) H-Coal liquids; data from letter of Feb. 16, 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.		2.41	222	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		10.14	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		0.01	0.06	trace; 0.04				
Cu								
Fe			110.0					
Si			190.0					
Zn								
Ba								
Mn								
Mo								
W								
Ti			40.0					
Al			60.0					

TABLE 5. - Continued.

(c) H-Coal from Illinois #6 coal; data from ref. 36.

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	621				
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								
Aniline point, °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	0.0031				
S		0.26	0.17	0.17				
O		0.039	0.038	0.03				
Trace metal analyses, ppm:								
V								
Ni								
Na								
K								
Mg								
Ca								
Pb								
Cu								
Fe								
Si								
Zn								
Ba								
Mn								
Mo								
W								
Ti								

TABLE 5. - 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)		-2.5						
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%		3[illegible].8						
Carbon ramsbottom, wt%								
Thermal stability (unstable above-)		200°F						
Electrical conductivity, ohms/cm		0.5×10^9						
Water		None						
Sediment								
Neutrality								
Corrosion								

Hydrocarbon type:								
Saturates								
Olefins								
Aromatics, total								
Aromatics, polynuclear								
Luminometer number								
Aniline point, °F								
H/C atom ratio		1.0						
Elemental analyses, wt%:								
C		88.2						
H		7.36						
N		1.1						
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 5. - Continued.

(e) H-Coal hydroclone underflo.., data from ref. 31.

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 5. - Continued.

(f) H-Coal fuel oil mode, from Illinois #6 coal; data from ref. 37.

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)	32.1 (0.864)	13.0(0.979)				
Boiling range:								
Initial boiling point, °F								
5 %	ERDA	144	144	397				
10 %	routine method							
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	2.31				
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								
Aniline point, °F								
H/C atom ratio								
Elemental analyses, wt%:								
C								
H								
N	Kjeldahl	0.44	0.47	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 5. - Continued.

(g) H-Coal syncrude mode, from Illinois #6 coal; data from ref. 37.

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%	coal liq. 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 72°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 5. - 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)		6.6	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 (Asphalteres)		12.92		3.07	2.62			
Aromatics, polynuclear								
Luminometer number								
Analine point, ^{o}F		.	66					
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	0.13	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 5. - Continued.

(i) H-Coal; data from ref. 38.

Property	Test	Distillate categories						
		Sample 3-8088	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								
Aniline point, °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	1.56				
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		70.0						
Si		2.0						
Zn								
Ba								
Mn								
Mo								
W								
Ti		80.0						
Al		11.0						

TABLE 5. - 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								
Aniline point, °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	2.1			0.61		
Pb				0.12	0.04			
Cu				1.06			1.0	
Fe		12.1	4.1			35.0	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 5. - Continued.

(k) H-Coal; data from ref. 39.

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								
Lamtrometer number								
Aniline 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	0.1			
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 5. - Continued.

(l) H-Coal (C_4 + liquid); data from ref. 40.

Property	Test	Distillate categories						
		Syncrude from Illinois coal	Low-sulfur fuel oil from Illinois coal	Syncrude from Wyodak coal				
Gravity, °API (specific)		15.0	4.4	26.8				
Boiling range:								
Initial boiling point, °F		C_4+	C_4+	C_4+				
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		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 5. - Continued.

(m) H-Coal distillate blends; data from ref. 41.

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								
Aniline point, °F								
H/C atom ratio								
Elemental analyses, wt%:								
C								
H		10.14	9.80					
N		0.18	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 5. - Continued.

(n) H-Coal Burning Star (fuel oil mode); data from ref. 41.

Property	Test	Distillate categories						
		Atmosphere overhead (760-920)	Atmosphere overhead (760-921)	Atmosphere bottoms (760-922)				
Gravity, °API (specific)								
Boiling range:								
Initial boiling point, °F		26	20	315				
5 %		160	170	369				
10 %		175	186	391				
20 %		211	213	436				
30 %		262	284	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 5. - Continued.

(o) H-Coal Burning Star and Wyodak (syncrude mode); data from ref. 41.

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 %		320	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 5 - Concluded.

(p) H-Coal; data from ref. 30.

Property	Test	Distillate categories						
		Straight Run Naphtha	Hydro-treated Naphtha					
Gravity, °API (specific)		43.7	46.8					
Boiling range:	D-86							
Initial boiling point, °F		132	153					
5 %		170	185					
10 %		189	199					
20 %		215	217					
30 %		233	231					
40 %		251	246					
50 %		260	263					
60 %		292	284					
70 %		312	306					
80 %		328	329					
90 %		351	352					
95 %		373	367					
Final boiling point, °F		396	393					
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		70.1	81.1					
Olefins		5.2	0.6					
Aromatics, total		24.7	18.9					
Aromatics, polynuclear								
Luminometer number								
Analine point, °F								
H C atom ratio								
Elemental analyses, wt%:								
C		85.90	86.45					
H		12.80	13.59					
N		0.193	nil					
S		0.128	nil					
O		0.594	0.003					
Trace metal analyses, ppm:								
V								
Ni								
Na								
K								
Mg								
Ca								
Pb								
Cu								
Fe								
Si								
Zn								
Ba								
Mn								
Mo								
W								
Ti								

TABLE 6. - FUEL DATA FROM SYNTHOIL PROCESS

(a) Synthoil off-specification run; data from ref. 42.

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								
Aniline 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	56				
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 6. - Continued.

(b) Synthoil from West Kentucky bituminous coal (5.3 percent sulfur); data from ref. 45.

Property	Test	Distillate categories						
		4000-psi, 450°C process conditions						
Gravity, °API (specific)								
Boiling range:								
Initial boiling point, °F		241						
5 %								
10 %		339						
20 %		411						
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, 93 percent.

TABLE 6. - Continued.

(c) Synthoil (filtered, centrifuged, and upgraded distillate);data from ref. 31

Property	Test	Distillate categories						
		Centrifuged (3296-109)	Filtrate (3296-143)	Washed Filtrate (3296-147)	Upgraded distillate (3392-6)(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	710	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		15.84	14.08	18.71				
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, °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 6. - Continued.

(d) Synthoil from West Virginia coal; data from ref. 44.

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)	--- (1.104)			
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	52				
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	2.42			
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	3.42	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 6. - Continued.

(e) Synthoil I, from West Kentucky bituminous coal (5.3 percent sulfur); data from ref. 45(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								
Aniline point, °F								
H/C atom ratio								
Elemental analyses, wt%:								
C		[illegible]						
H		[illegible]						
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 6. - Continued.

(f) Synthoil (whole crude, 509° - 650° F and 650° - 698° F cuts, and residuals (698° F+)); data from ref. 4a(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[c]								
Saturates								
Olefins								
Aromatics, total								
Aromatics, polynuclear								
Luminometer number								
Aniline 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 6. - Continued.

(g) Synthoil (sample J-7992); data from ref. 38.

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 } Combined, vol%								
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		81.62						
H		7.97						
N		0.97						
S		0.43						
O		2.08						
Trace metal analyses, ppm:								
V		2						
Ni		1						
Na		19						
K		116						
Mg		11						
Ca		27						
Pb		5						
Cu								
Fe		175						
Si		1158						
Zn								
Ba								
Mn								
Mo								
W								
Ti		150						
Al		836						

TABLE 6. - Continued.

(h) Synthoil (evaluated in T63 combustor); data from ref. 42.

Property	Test	[illegible] 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		17 345						
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								
Aniline 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								
Pt								

TABLE 6. - Continued.

(i) H-Coal; data from ref. 38.

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								
Aniline point, °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 5. - Continued.

(j) H-Coal hydroclone bottoms filtrate; data from memo for record by Theodore S. Mroz, NASA Lewis Research Center, Feb. [illegible]6, 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								
Aniline point, °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		2.08			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		2.5	2.0	
Ca		1.49	2.3			0.61		
Pb				0.12	0.04			
Cu				3.06			1.0	
Fe		12.1	4.1			15.6	8.0	
Si			5.0				2.0	
Zn		1.5		0.62				
Ba		0.6						
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 - Concluded

(k) Synthoil from West Va. coal; data from ref. 48.

Property	Test	Distillate categories						
		Whole crude						
Gravity, °API (specific)		1.08						
Boiling range:	D-86							
Initial boiling point, °F								
5 %								
10 %		440						
20 %								
30 %		572						
40 %								
50 %		705						
60 %								
70 %		835						
80 %								
90 %		965						
95 %								
Final boiling point, °F								
Pour point, °F	D-97	40						
Flashpoint, °F								
Viscosity at 100 °F		2.03						
545 at °F								
at °F								
Ash, wt%								
Ash: melt temperature, °F								
Heat of combustion, Btu/lb								
Carbon residue	D-524	11.2						
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								
H								
N								
S	Kjeldahl	0.786						
O	D-129	0.42						
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 SOLVENT-REFINED COAL PROCESS

(a) SRC products from Kentucky high-sulfur bituminous coals; data from ref. 49.

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								

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 7. - Continued.

(b) SRC products from Illinois #6 coal; data from ref. 21(b).

Property	Test	Distillate categories						
		92 HB-1	92 HB-2	93 HB-1	93 HB-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	356			
Heat of combustion, Btu/lb (unspec.)		15 719	15 733	15 657	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								
Aniline point, °F								
H/C atom ratio								
Elemental analyses, wt%:								
C		87.12	87.68	85.62	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 7. - Continued.

(c) SRC-II (typical properties from West Kentucky coals with 4 percent sulfur and 2 percent nitrogen); data from refs. 50 and 51.

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	0.1				
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 7. - Continued.

(d) SRC (filtered and upgraded); data from ref. 31.

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, SUS		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		0.8						
Zn								
Ba								
Mn								
Mo								
W								
Ti		16.0						
Al		5.0						

[a]Containing 65 percent process solvent (1296-19 p. 57).

[b]As received (3775-95 p. 65).

[c]3192-64 p. 79.