

FLUID-BED CARBONIZATION/DESULFURIZATION
OF ILLINOIS COAL BY THE CLEAN COKE
PROCESS: PDU STUDIES*

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Introduction

The CLEAN COKE Process combines both fluid-bed carbonization and hydrogenation/liquefaction to convert high-sulfur coal to low-sulfur metallurgical coke, chemical feedstocks, and to a lesser extent, liquid and gaseous fuels. The overall processing scheme, which has previously been described in detail (1), is illustrated by the sketch in Figure 1.

Briefly, run-of-mine coal is beneficiated and classified by conventional means and split into two feed portions: a sized fraction suited for fluid-bed processing and a fines fraction suited for high-pressure hydrogenation. The sized feed is dried and subjected to a mild surface oxidation in a nonpressurized bed fluidized with air-enriched flue gas. The dry, preoxidized feed is then carbonized in two stages, at 820°F (440°C) and 1400°F (760°C), in fluid-bed reactors operated at pressures up to 150 psig, to produce low-sulfur char, tar, and gas rich in methane and hydrogen. The fines fraction of the beneficiated coal, combined with run-of-mine coal, is dried, pulverized, and slurried with a process-derived oil. The slurry is then pumped to a pressure reactor and liquefied at 850 to 900°F (455 to 480°C) and a pressure of 3000 to 4000 psig to produce liquids and C₁-to-C₄ hydrocarbon gases. Liquids from both operations are distilled to produce a light chemical oil, a middle oil for recycle to the hydrogenation reaction, and a heavy oil. The heavy oil, a soft pitch, is combined with the carbonization char and processed to make a low-sulfur metallurgical formcoke, currently in the form of pellets. Similarly, product gases from all operations are combined and processed to produce hydrogen for the hydrogenation operation, fuel, ethylene and propylene, sulfur, and ammonia. A detailed description of yield of chemical products and process economics has been presented previously (2).

This paper presents the results obtained from sustained operation of the carbonization PDU (process-development unit). These results confirm and extend the data obtained previously in bench studies (3). All tests were run with Illinois No. 6 seam coal con-

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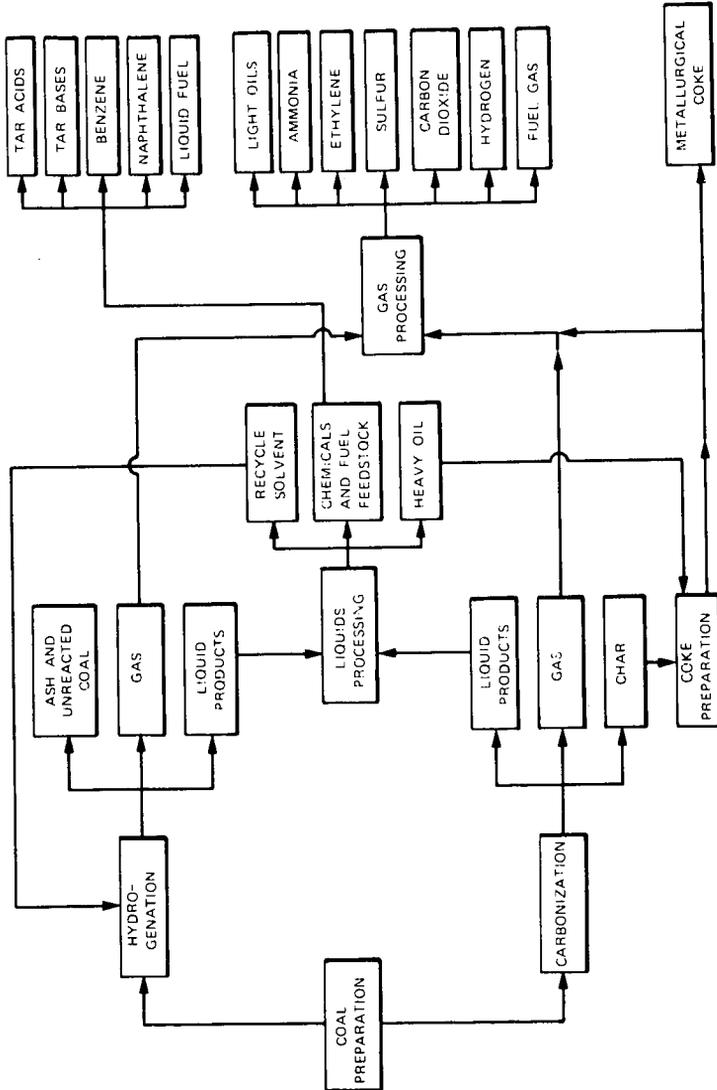


Figure 1. CLEAN COKE PROCESS

taining 2 to 2.5 percent sulfur after preparation. From this were produced chars containing, generally, 0.6 to 0.7 percent sulfur; char containing as little as 0.2 percent sulfur was produced under the more severe reaction conditions. Reaction conditions investigated for their effect on char sulfur content included residence time, temperature, pressure, and H₂S concentration in the fluidizing gas. Data are also presented to show the weight distribution of materials into and out of the PDU system. The scale of the tests discussed in this paper is best illustrated by a description of the design and operation of the carbonization PDU.

The Carbonization PDU

Figure 2 is a photograph of the carbonization PDU, in which the fluid-bed reactor occupies the second level; feed vessels are on the top level; the char receivers are at floor level. Two other vessels visible at floor level in the picture are liquid catchpots attached to the gas-to-gas heat exchanger (on the right) and the water-cooled exchanger (on the left). Construction details of the fluid-bed carbonizer are illustrated by the diagram in Figure 3. The vessel, including top and bottom closures, is 9 feet 3 inches tall and is fabricated from 1-inch-thick Incoloy Alloy 800 to permit operation at 1500°F (815°C) and 150 psig. The lower 36-inch section of the reactor is the 10-inch-ID fluid-bed area; the expanded upper 36-inch section has a 20-inch ID, to facilitate deentrainment of fine solids from the fluidizing gas. Feed enters the fluid bed by gravity flow through the feed pipe, positioned about 1 inch above the gas-distributor plate; char exits the fluid bed through the overflow pipe at 30 inches above the distributor plate. The vessel also contains an internal cyclone, which removes char fines from the exiting gas and returns them to the fluid bed.

The major components and stream flows of the complete PDU are illustrated in the simplified diagram in Figure 4. Feed is metered by rotary feeders from either of two lock hoppers to the fluid-bed carbonizer, from which product char overflows and falls into one of the two receivers, also lock hoppers. Residence time in the reactor is controlled by varying the solids feed rate.

Gas derived from carbonization of the feed is recycled through the system to fluidize the bed. Carbonization gases, along with recycle gas, leave the fluid bed, pass through the internal cyclone in the expanded section, and leave the vessel. The gas then passes through an external cyclone and into the gas-to-gas interchanger (shell and tube design), where it is partially cooled by heat exchange with clean recycle gas returning to the main gas heater. In the interchanger, the carbonization gas is also contacted with a spray of wash oil to remove tar mist and char dust, which collect in the interchanger pot. The gas then passes to a water-cooled exchanger for final cooling to about 110°F (45°C), after which it passes in series through a wash-oil scrubber and a caustic scrubber for final

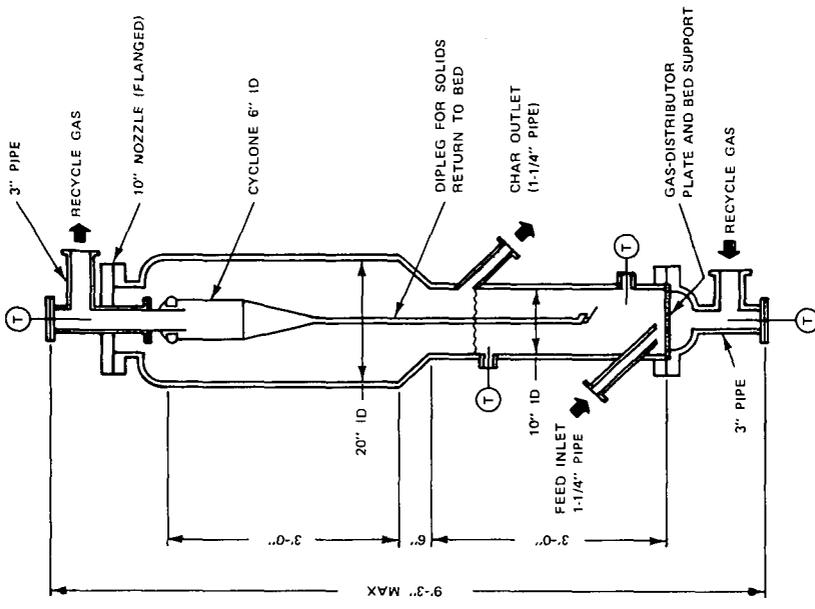


Figure 3. FLUID-BED CARBONIZER

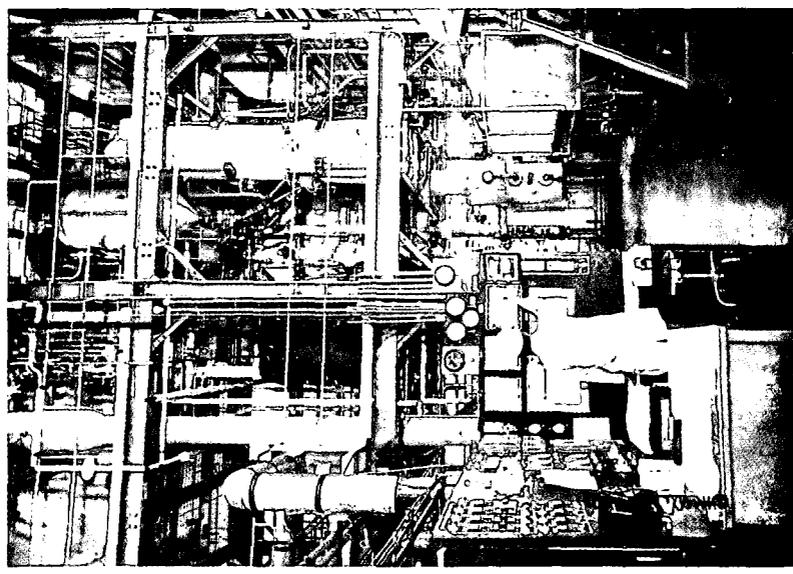


Figure 2. CARBONIZATION PDU FOR CLEAN COKE PROCESS

cleanup of tar mist, char dust, and acid gases—particularly H_2S . The clean gas is then recycled by a compressor through the shell side of the interchanger to the main electric heater, where it is reheated to the temperature desired to maintain the fluid bed at design temperature. Actual temperature of gas from the heater varies with operating conditions in the reactor, but the temperature of gas exiting the heater is on the order of $100^\circ F$ ($55^\circ C$) higher than bed temperature. Net product gas is vented by a pressure regulator-controller through a wet-test meter and sampled for analysis.

The function of the water-injection system, Figure 4, is to maintain a concentration of about 8 volume percent water vapor in the recycle gas while the gas is in contact with the hot alloy-metal surfaces of the main gas heater during second-stage carbonization. The presence of 8 volume percent water vapor, along with 50 ppm H_2S , prevents formation of carbon deposits on the hot metal surfaces, which attain temperatures above about $1500^\circ F$ during second-stage carbonization. Previous experience has shown that, without the water vapor, carbon deposits grew to sufficient size to significantly impede gas flow through the heater. Moreover, the carbon resulted in catastrophic carburization of the metal and destroyed the original recycle-gas heater. With water vapor and H_2S present, carbon formation is controlled, at least up to metal wall temperatures of $1550^\circ F$ ($845^\circ C$). Water is injected as a liquid into the interchanger shell-side gas inlet, where it is vaporized by external electric heaters. Most of the injected water condenses in the wash-oil quench in the interchanger pot and in the gas cooler. The remainder of the water condenses into the caustic-scrubber solution.

It should be noted that the wash-oil spray system is operated in different modes for the two stages of carbonization. For first-stage carbonization at $820^\circ F$, wash-oil quench of the gas occurs at the top of the interchanger to provide a washed-tube flow, which prevents plugging of the tubes by tar/char agglomerates. For second-stage carbonization at 1300 to $1400^\circ F$ (705 to $760^\circ C$), wash-oil quench of the gas occurs below the interchanger tube bundle. In this mode, tube-exit gas temperature is controlled at about $900^\circ F$ ($480^\circ C$) to prevent condensation of tar within the tubes.

Fresh wash oil, at about 2 gallons per hour, is metered continuously into the wash-oil scrubber to maintain a low concentration of tar and char fines in the oil system. Overflow from the level-controlled scrubber flows into the gas-cooler pot, from which the wash oil is pumped to the spray nozzle in the gas/gas interchanger. Wash-oil blowdown, including dissolved tar and suspended water and char, is removed from the interchanger pot. Wash-oil blowdown is screened to remove plus 50-mesh solids, heated to boil off contained water, and flash-distilled to separate heavy oil boiling above $540^\circ F$ ($280^\circ C$), which is used as part of the binder for coke production. The flash distillate is processed through a continuous distillation column at atmospheric pressure to separate a chemical oil distilling

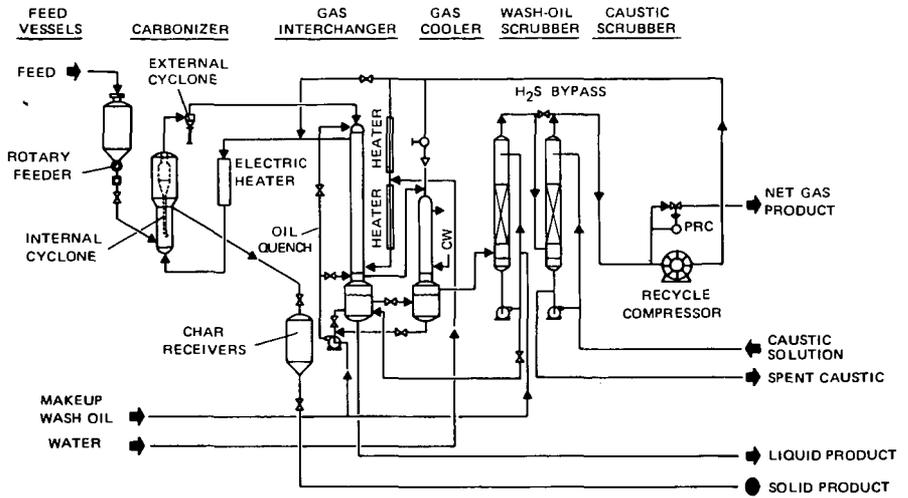


Figure 4. SCHEMATIC OF CLEAN COKE PROCESS CARBONIZATION PDU

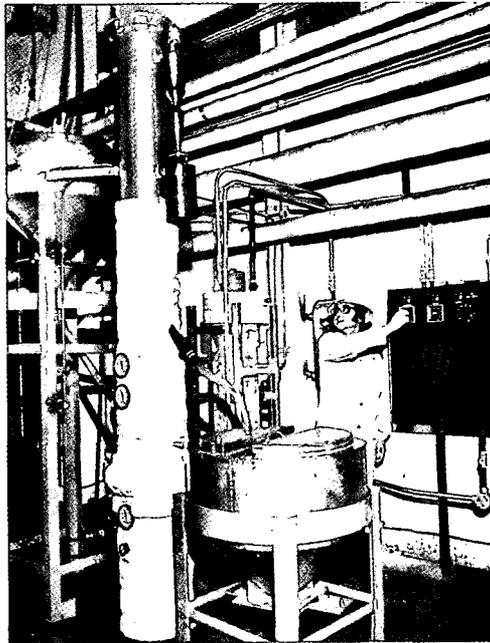


Figure 5.
CONTINUOUS 10-INCH
COAL OXIDIZER

to 445°F (230°C) as overhead and fresh wash oil as bottoms. The wash oil consists essentially of mono- and dimethylnaphthalenes, acenaphthene, and quinoline bases.

The final system is caustic scrubbing, which is used to control H₂S concentration in the recycle gas. Normally, H₂S concentration in the gas is maintained in the range 50 to 100 ppm, which aids in controlling carbon deposition from the catalytic decomposition of the carbon components in the gas. Control of H₂S concentration may be effected by means of partial bypass of gas around the caustic scrubber and by varying the rate of metering fresh caustic solution (about 7% NaOH) into the scrubber. Generally, the PDU operators prefer to use the latter method.

The Continuous Coal Oxidizer

An important adjunct to the carbonization PDU, the continuous coal oxidizer dries and preoxidizes the sized coal feed. The need for preoxidation of Illinois coal was discussed in the previous paper (3) on bench-scale studies, which showed that a mild surface oxidation of the coal diminishes its caking tendency sufficiently to prevent its agglomeration when it is heated at 800°F (425°C) in first-stage carbonization. Mild surface oxidation in this use refers to oxidation so slight that petrographic examination reveals virtually no change in the surface of the treated coal (4).

In practice, sized coal feed is heated at 350°F (177°C) for a 20-minute residence time in a bed fluidized with air at atmospheric pressure. The continuous coal oxidizer, shown in Figure 5, is similar in design and operation to the carbonizer reactor. The unit consists of a 10-inch-ID carbon-steel fluid-bed reactor with a coal-feed and product-overflow system and an electrically heated air supply. As in the PDU, the fluid bed of the coal oxidizer is heated to and maintained at design temperature by the heated fluidizing air. This unit is capable of oxidizing up to 1 ton of coal per 24 hours of operation, and it is normally operated at a coal feed rate of about 60 pounds per hour.

Heated air is used in the existing coal oxidizer for convenience only. In a larger operation, the oxidizer can be operated with waste flue gas containing about 2 percent oxygen to achieve adequate preoxidation of the feed coal.

Because the effluent gas from the coal oxidizer contains only moisture and dust from the fluid bed, waste-gas cleanup is accomplished by a small external cyclone and dust filters in the vent system. The yield of dry, oxidized coal is essentially a function of moisture content in the coal charged, which is generally about 8 percent by weight.

Experimental Results From First-Stage Carbonization

Carbonization of the oxidized coal in the PDU is conducted in two separate stages to avoid agglomeration of feed in the fluid bed. Initial carbonization is effected at temperatures in the range 800 to 840°F (425 to 450°C) to partially devolatilize the coal and produce a semichar, which can be fed subsequently into a fluid bed at 1400°F without agglomeration. The operating limits on temperature for the first stage were determined by bench-scale studies on the agglomeration problem. A nonagglomerating semichar was obtained at 800°F and incipient agglomeration was observed at about 850°F.

Although the primary function of first-stage carbonization is reduction of the agglomerating property of the coal, about two thirds of the carbonization tar is produced in this stage. Gas production is low in the first stage, amounting to about 15 weight percent of the total gas produced. Analysis of the recycle gas shows its composition (in mole %) to be methane, 71; ethane, 13; carbon monoxide, 10; hydrogen, 2; and C₂-to-C₄ hydrocarbons, 4.

Tests were made in the PDU to study the effect upon volatile-matter and sulfur contents in the semichar of bed temperature, residence time, system pressure, and H₂S concentration in the recycle gas. The variation in volatile-matter content with temperature and residence time is illustrated in Figure 6, which shows that volatile-matter content varies inversely with temperature and residence time and is independent of pressure over the range 15 to 160 psia. In the figure, a few data points from a 1-inch continuous bench-scale unit were included to extend the pressure range to 15 psia. Generally, about half the volatiles were eliminated from the coal in first-stage carbonization, and all the semichar products were processed through second-stage carbonization without agglomeration.

Response of sulfur content to residence time and temperature of first-stage carbonization is shown graphically in Figure 7. Sulfur content of the semichar product also varies inversely with temperature and residence time and is independent of pressure over the ranges studied; conditions included temperatures of 800 and 840°F, residence times of 20 to 80 minutes, and pressures of 80 to 160 psia. In these tests, H₂S concentration was controlled in the range 50 to 100 ppm. However, a test was run at 800°F, 52 minutes residence time, 120 psia, and H₂S concentrations varying from 300 to 2000 ppm. The semichar product from this test contained 1.77 percent sulfur, which is in the range normally attained with low H₂S concentration in the recycle gas.

Temperature and residence time thus appear to be the only variables having an effect on volatiles and sulfur remaining in the semichar product. The data in Figures 6 and 7 indicate that, at the temperatures deemed feasible, first-stage devolatilization/desulfurization is essentially complete in about 20 minutes residence time. To provide a consistent data base for process design, first-stage car-

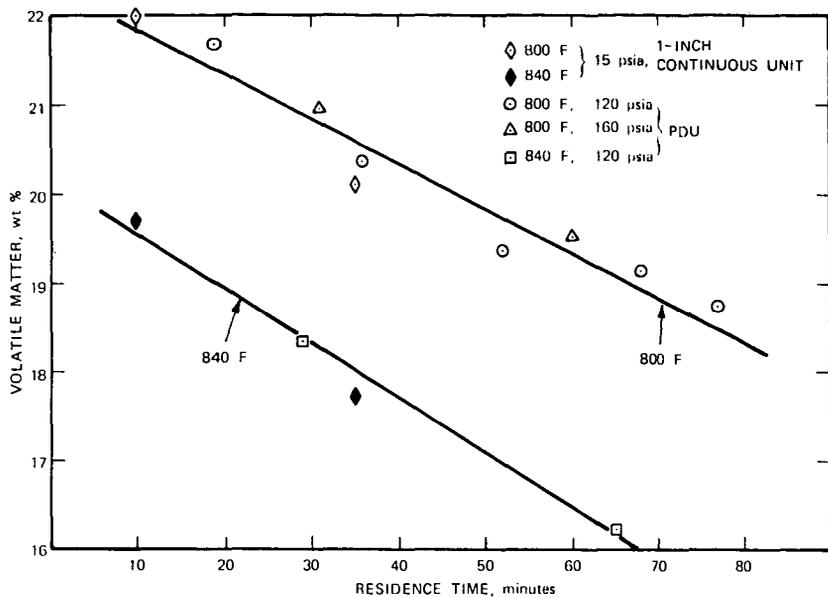


Figure 6. EFFECT OF TEMPERATURE AND RESIDENCE TIME ON COAL DEVOLATILIZATION

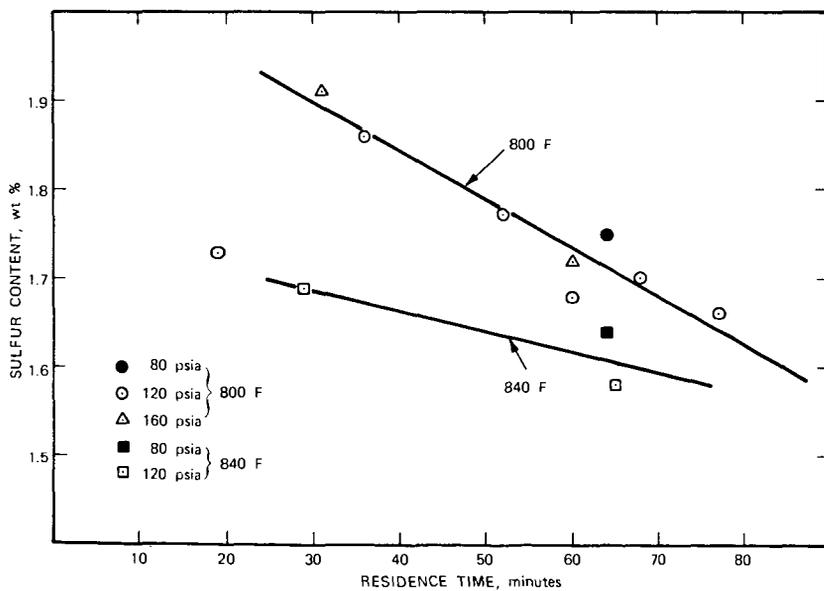


Figure 7. EFFECT OF TEMPERATURE AND RESIDENCE TIME ON SEMICHAR SULFUR CONTENT

bonizations in the PDU are now routinely run at 820°F, 25 minutes residence time, 165 psia, and 100 ppm H₂S in the recycle gas. Under these conditions, coal containing 35 percent volatile matter and about 2.2 percent sulfur is converted to semichar containing 20 percent volatile matter and 1.7 to 1.8 percent sulfur.

Experimental Results From Second-Stage Carbonization

Tests were made in the PDU to study effects of temperature and residence time in the fluid bed upon sulfur content of the char produced in second-stage carbonization. The ranges for these variables were 1250 to 1410°F (675 to 765°C) and 40 to 200 minutes. System pressure was generally 165 psia, although other tests were run at pressures of 80, 120, and 150 psia. Concentration of H₂S in the recycle gas was controlled in the range 50 to 100 ppm, but concentrations as high as 1000 ppm H₂S were studied in special tests.

Results from the studies of temperature and residence-time effects are shown graphically in Figure 8, which for clarity were limited to data obtained at temperatures of 1250, 1325, and 1400°F. Sulfur content of the semichar feed for the test series ranged from 1.65 to 1.80 percent and averaged about 1.70 percent. The quantity of char produced at a single set of conditions was usually about 600 pounds, and more than 1600 pounds of char was produced during the longest test. Sulfur content of the char products ranged from 1.1 percent at the mildest conditions to 0.2 percent at 1400°F and 190 minutes residence time.

Temperature exerted the greatest effect on desulfurization of the char, as indicated in Figure 8; a temperature increase of 75°F provided a lower char sulfur content than increasing residence time threefold or even fourfold. For example, 40 minutes residence at 1400°F was the equivalent of 157 minutes at 1325°F in producing char containing 0.64 percent sulfur. It is apparent from the data that desulfurization of the feed occurred rapidly during the initial period of heating and devolatilization. Chars having sulfur contents in the range 0.7 to 0.8 percent were obtained in 40 to 50 minutes residence time at fluid-bed temperatures greater than about 1300°F. Desulfurization below about 0.8 percent sulfur proceeded at a much slower rate, and the rate then appeared to be almost completely linear with time.

All the data in Figure 8 were obtained at a system pressure of 165 psia, except for the one point, indicated on the 1325°F line, which was obtained at a pressure of 100 psia. This point was included to show that the effect of pressure over the range 100 to 165 psia is not discernible in the sulfur content of the char from the continuous fluid-bed reactor. Other tests in the PDU gave similar results; for example, at 1370°F and about 90 minutes residence time, the sulfur contents of the char products were 0.67 and 0.66 percent at pressures of 120 and 150 psia, respectively.

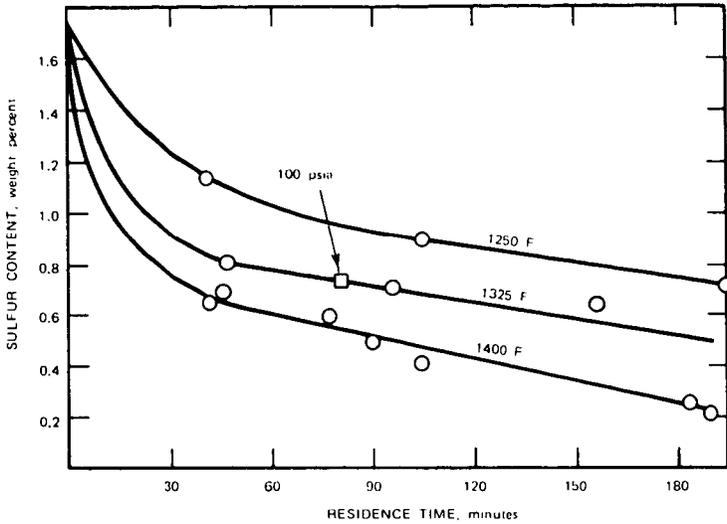


Figure 8. EFFECT OF TEMPERATURE AND RESIDENCE TIME ON CHAR SULFUR CONTENT (165 psia)

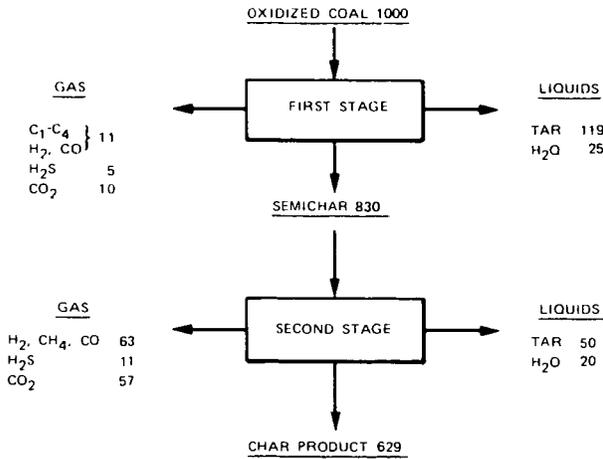


Figure 9. MATERIAL FLOW AND WEIGHT DISTRIBUTION DURING STAGED CARBONIZATION

The inability to demonstrate a pressure effect in the continuous reactor of the PDU results from the interdependence of variables in the system. For example, intentionally changing the pressure results in automatically changing the mole fraction of hydrogen in the gas, which changes the hydrogen-to-sulfur ratio in the fluid bed. In addition, a greater volume of lower-pressure (lower density) gas must be recirculated through the bed to maintain the same degree of fluidization, and lower-pressure gas must be hotter to effect the desired heat transfer to maintain bed temperature. Because of this, char particles near the bottom of the bed are contacting hotter gas and are momentarily heated to temperatures greater than the average bed temperature. These competing forces combine to mask the pressure effect in the continuous reactor. However, the effect of increased pressure is known to be beneficial in decreasing the sulfur content of the product char. This has been demonstrated by numerous investigations and by our bench-scale tests in batch reactors (3), which were suited for studying the pressure effect separately from the other variables.

An important dependent variable, for which a continuous reactor is best suited, is average sulfur content of the bed. In a batch unit, the sulfur content of the bed declines throughout the reaction time, but in a continuous unit, the average sulfur content of the fluid bed remains essentially constant, because of the continuous addition of sulfur with the feed, and is dependent upon the sulfur content of the feed and upon the feed rate. This factor contributes significantly to the observed benefit of very long residence times, which were achieved in the PDU by greatly reduced feed rates. The consequent reduction in rate of sulfur addition to the bed resulted merely in a lower average sulfur content in the bed. From these considerations, it may be concluded that the important variables in desulfurization of char in the PDU are temperature and average sulfur content of the bed, provided there is a significant concentration of hydrogen in the fluidizing gas.

Composition of the fluidizing gas was not a controllable variable, except for H_2S concentration, because process-derived gas was recycled in the system. The gas was composed almost entirely of methane, hydrogen, and carbon monoxide. Carbon dioxide was present only in tenths of a percent because of caustic scrubbing to control H_2S concentration. At 165-psia pressure, hydrogen concentration in mole percent varied from the low 20's at 1250°F to the low 40's at 1400°F; methane concentration ranged from the low 70's to the mid 50's; carbon monoxide concentration was nearly independent of reaction temperature but varied from a high of about 6 percent at the shorter residence times to about 2 percent at the longer times. Hydrogen concentration was also sensitive to residence time, and increased 3 to 5 percentage points between the shortest and longest times.

The effect of several H_2S concentrations in the recycle gas was studied in tests conducted at 1400°F, Table I. The tests were

run primarily to generate data relevant to the design of larger fluid-bed reactors, in which bed height would be significantly greater than the 30-inch bed height in the existing PDU. Concentration of H₂S increases in the fluidizing gas as it passes up through the bed, and at bed depths envisioned for reactors designed for 100 tons or more of feed per day, average H₂S concentration within the fluid bed might easily reach 1000 ppm.

Table I

Effect of H₂S Concentration in Fluidizing Gas on
Char Sulfur Content
(1400°F, 165 psia, 190 minutes residence time)

<u>H₂S Concentration, ppm</u>	<u>Char Product, wt % S</u>
50-100	0.21
500	0.71
1000	0.69

The data in Table I show a significant deterioration in char sulfur content from 0.2 percent to 0.7 percent, when the H₂S level in the gas entering the fluid bed was increased from the normal 50 to 100 ppm to the 500-ppm level. Interestingly, increasing the H₂S level to 1000 ppm did not have any perceptible additional effect. However, design for larger scale fluid-bed carbonizers will have to provide for minimizing the average H₂S concentration within the fluid-bed region.

To provide an indication of the reproducibility of data points, Table II presents analyses of the consecutive receivers of char produced during 10-day runs at 1400°F, 165 psia, and residence times of 46 and 190 minutes. The total quantities of feed for the tests were 2170 and 875 pounds, respectively. The data show excellent reproducibility, considering that observed variations in the products are the cumulative effects of variations in the semichar feed and process conditions, plus the repeatability of sampling and analysis.

Of interest also are the incremental changes in concentration of the various forms of sulfur originally present in the raw coal. These changes are illustrated by the analytical results in Table III for the feed and products involved in the CLEAN COKE Process. Forms of sulfur are shown simply as organic and inorganic, because the inorganic sulfur was nearly all pyritic and contained at most 0.05 percent sulfate sulfur. Coals from several mines in central Illinois were evaluated and all samples were quite similar. However, only coal from No. 24 mine of the Old Ben Coal Mining Company was processed

in the carbonization PDU, and the data in Table III were obtained with this coal.

Table II

Uniformity of Product Char From Carbonization PDU
(1400°F, 165 psia)

<u>Receiver</u>	<u>Char Sulfur Content, wt %</u>	
	<u>46 min</u>	<u>190 min</u>
1	0.69	0.26
2	0.70	0.21
3	0.68	0.18
4	0.61	0.18
5	0.68	0.18
6	0.66	0.25
7	0.68	--
<u>8</u>	<u>0.71</u>	<u>--</u>
Average	0.68	0.21

Table III

Incremental Change in Forms of Sulfur

<u>Processing Step</u>	<u>Sulfur Forms, wt %</u>	
	<u>Organic</u>	<u>Inorganic</u>
As-mined coal	1.00	2.50*
Cleaned and sized carbonization feed	1.13	1.00
Semichar (First-stage product)	0.91	0.81
Char (Second-stage product, 1400°F)	0.13	0.08

* Inorganic sulfur is pyritic sulfur plus about 0.05% sulfate sulfur in the as-mined coal.

Typically, the run-of-mine coal sample contained about 1 percent organic sulfur and 2 percent or so inorganic sulfur. Conventional

wet cleaning of this coal by gravity separation and tabling operations removed inorganic sulfur selectively and produced a clean coal feed, which contained about 1 percent inorganic and 1.1 percent organic sulfur. Devolatilization and desulfurization in first-stage carbonization at 820°F removed about one third of the sulfur in each form, and the ratio of organic to inorganic remained about the same in the semichar product as in the feed coal. (The coal-drying and preoxidation treatment did not affect either the amount or the forms of sulfur.) Final devolatilization and desulfurization in second-stage carbonization at 1400°F removed about 90 percent of each form of sulfur in the semichar feed, and the lowest sulfur char made contained only slightly more organic than inorganic sulfur.

It is also of interest that both forms of sulfur contributed substantially to the production of H₂S during carbonization. This fact is illustrated by the data in Table IV, which show the quantity of sulfur in each form that was converted and the quantity recovered as H₂S in the caustic scrubbing solution.

Table IV
Conversion of Forms of Sulfur to H₂S

	<u>Distribution of Sulfur, pounds</u>			<u>Recovered as H₂S</u>
	<u>Organic</u>	<u>Inorganic</u>	<u>Total</u>	
Coal feed	26.6	31.7	58.3	--
Converted sulfur (at 820°F)	8.4	12.3	20.7	18.2
Semichar feed	18.2	19.4	37.6	--
Converted sulfur (at 1400°F)	12.8	12.2	25.0	23.8
Char product	5.4	7.2	12.6	--

The pyritic sulfur converted contributed about two thirds of the H₂S produced by first-stage carbonization at 820°F, and the inorganic sulfur remaining in the semichar contributed about half of the H₂S produced during second-stage carbonization at 1400°F. Assuming that all the reacting inorganic sulfur is converted to H₂S, Table IV data show that about 70 percent of the organic sulfur reacting at 820°F was converted to H₂S and about 95 percent was converted to H₂S at 1400°F. Thus, it is apparent that reaction conditions in both stages are adequate to convert both types of sulfur compounds to easily recoverable H₂S. The remainder of the sulfur liberated from the coal during

pyrolysis is recovered as organic compounds in the liquid products, which contain 1.1 to 1.3 percent sulfur.

Material Flow During Staged Carbonization

Material flows and weight distribution through the two stages of carbonization of oxidized Illinois coal are shown in the simplified flow diagram of Figure 9. The products of first-stage carbonization of the coal are, in weight percent, semichar, 83.0; tar, 11.9; water, 2.5; fuel gas, 1.1; and acid gases, 1.5. The products of second-stage carbonization of the semichar (at 1400°F and 77 minutes residence time) are, in weight percent of the coal, low-sulfur char, 62.9; tar, 5.0; water, 2.0; process gas, 6.3; and acid gases, 6.8. The yield of CO₂ shown in Figure 9 is actual, but the high value results from the use of aqueous-caustic scrubbing to control H₂S levels in the carbonization PDU. Removal of CO₂ in the scrubber prevents this component from reaching a normal steady-state concentration in the recycle gas. In a larger system using conventional means for H₂S recovery, such as the use of Benfield scrubbers,* CO₂ would not be continuously removed from the gas, and its concentration in and yield from the process gas are expected to be substantially less.

Conclusions

The carbonization PDU of the CLEAN COKE Process has proved to be a valuable research tool in demonstrating, on a substantial scale, the efficient desulfurization of Illinois coal in a continuous, pressurized, fluid-bed carbonizer. After conventional cleaning and sizing, coal was processed during sustained operation of up to 10 days through two separate stages of carbonization, which together removed more than 90 percent of the coal sulfur and produced char containing as little as 0.2 percent sulfur. First-stage carbonization at a temperature of about 820°F served primarily to produce a nonagglomerating semichar feed for high-temperature carbonization, but the first-stage carbonization removed about one third of the sulfur from the coal and produced about two thirds of the total tar. Second-stage carbonization removed up to 90 percent of the remaining sulfur and produced low-sulfur char, hydrogen-rich fuel gas, and tar. Both forms of sulfur, organic and inorganic, were shown to be removed with equal facility by the carbonization process.

In addition to the data on desulfurization and process yields and chemistry, the PDU has provided much useful engineering information, which was needed for the design of a 100-ton-per-day pilot plant. The pilot-plant process-design work is currently in progress, and continued testing in the PDU will generate data needed for the design. Concurrently, studies are in progress on carbonization of high-sulfur

* Use of trade names or company names is for identification only and does not imply endorsement by ERDA.

coals from other major seams of national interest. Coal from the Kentucky No. 9 seam is being processed at present, and this will be followed by testing of a Pittsburgh seam coal.

Acknowledgments

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