THE ROLE OF SOLVENT IN THE SOLVENT REFINED COAL PROCESS

Cecilia C. Kang,[1] Govanon Nongbri[1] and Norman Stewart[2]

INTRODUCTION

The coal-derived liquid used to produce a pumpable liquid slurry feed to hydrogeneration systems is commonly referred to as slurry oil or pasting oil. The role of this material, other than as a transport medium, has been neglected until the last few years. The pasting oil used in Bergius Catalytic Hydrogenation consisted of fractions collected at various points in the downstream process. Some of these products of carbonization and/or distillation, were catalytically hydrogenated before being used. No specific analyses were made which provided information about a chemical basis for understanding hydrogen donor capability. Necessary solvent qualities that contribute to or enhance coal conversion, hydrogenation or desulfurization were not quantified. Pott-Broche used a hydroaromatic middle oil generated from coal or tar hydrogenation as their pasting oil and were able to achieve conversions of about 80% at pressures in the 1500-3000 psig range.

More recently processes that depend upon the hydrogen donor capacity of the process solvent have been developed. Among these are the Consol Synthetic Fuel Process (CSF), Pamco Solvent Refined Coal Process (SRC), and Exxon Donor Solvent (EDS) Process.

The CSF and EDS processes depend upon special solvent production through fractionation and subsequent hydrogenation. The SRC process does not employ solvent preparation other than fractionation.

Interest has grown in the role of solvent in these three processes as bench scale and small pilot plant investigations have intensified. The application of analytical techniques toward identifying donatable hydrogen was described by R. P. Anderson (1). More recently donor reactions for desulfurization were described by G. Doyle (2).

The Exxon (EDS) process in operation since 1975 at the one-ton-a-day scale depends heavily upon knowledge of solvent quality and the ability to control it (3). A proprietary solvent quality index was reported by Exxon. A minimum quality index reported to be a function of liquefaction conditions was related to conversion and claimed to improve handling qualities of the products.

This work reports some rather dramatic bench scale coal processing data. Major effects are attributed to identifiable slurry solvent properties.

THE ROLE OF SOLVENT

In conjunction with a process study undertaken at HRI under Electric Power Research Institute Research Project 389 to investigate SRC process operability and product yield structures for several coals of commercial interest, a preliminary analysis of the role of solvent upon coal conversion was carried out. The purpose of this project was to screen coals prior to their testing at the 6 T/D SRC pilot plant at Wilsonville, Alabama. The operation of this plant has been jointly funded by EPRI and Southern Services, Inc. Catalytic, Inc. is

[1] Hydrocarbon Research, Inc. Trenton, New Jersey

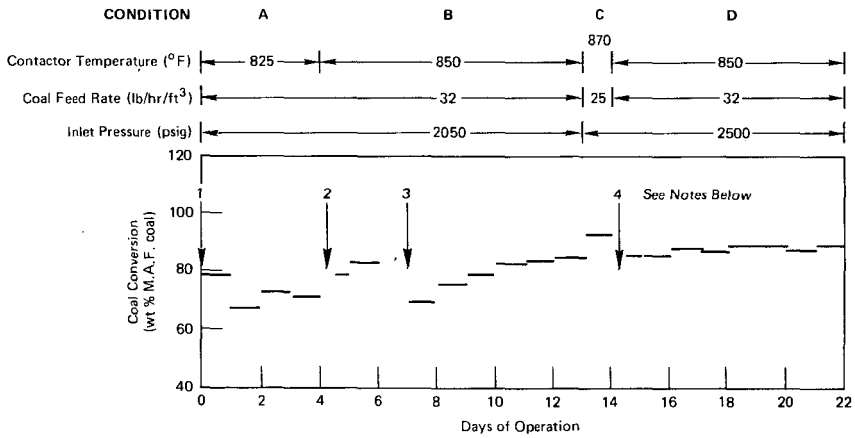
[2] Electric Power Research Institute, Palo Alto, California

the plant operator. The study was undertaken with two sub-bituminous coals, Wyodak coal and Black Mesa coal, and one bituminous coal, Illinois No. 6 coal from the Monterey Mine. The proximate and ultimate analyses of these three coals are summarized in Table 1. All of the work described here was done in a continuous bench-scale noncatalytic unit with a reactor having a volume of 1000 cc. This unit has been described previously in EPRI reports 123-1-0, 123-2, and 389-1 (4, 5, 6, 7).

The solvent was characterized by its tetralin to naphthalene ratio as determined by gas chromatographic analysis, and the H_β value by NMR measurement. H_β represents hydrogen on carbon atom at β-position of the aromatic ring (excluding methyls).

Effect of Tetralin Content of Solvent Upon Coal Conversion - Wyodak Coal Study

During the SRC processing of Wyodak coal it was observed that under steady operating conditions, there was a gradual but persistent change in coal conversion with the operating time. A plot is presented below to show process conditions and coal conversion vs. days of operation. This experimental program was carried out under four conditions as shown. The startup solvent and recycle solvent were characterized by tetralin content and tetralin to naphthalene ratio.



NOTES

1. Startup solvent contained 2.8% tetralin, and 0.24 tetralin to napthalene ratio.
2. About 3000 to 5000 grams of the startup solvent were added during the period of interruption.
3. Wyodak coal operations solvent generated during preceding periods, containing about 1% tetralin, was used for startup.
4. Startup solvent was hydrogenated anthracene oil, containing 1.3% tetralin and 0.76 tetralin to naphthalene ratio.
5. Unconverted coal is defined as the benzene insoluble organic component of dry filter cake. This value is obtained by filtering the slurry product in the bench-scale filter at 300°F, and extracting the cake with benzene to quantify the benzene insoluble content. The dry filter cake value is corrected by subtracting the benzene insolubles present in the 975°F+ oil. Coal conversion in this paper is derived from unconverted coal by using a forced ash balance for bituminous coal or a SO_3 free ash balance for subbituminous coal.

An examination of the operating data revealed that with the startup solvent containing 2.8% tetralin (Condition A), Period 1 gave 79% coal conversion which dropped to 68% during Period 2 as tetralin content decreased to 1.1%. These changes indicate that tetralin content, like coal conversion, is dictated by process conditions. High tetralin content therefore may not by itself sustain good coal conversion under unfavorable process conditions.

The effect of the tetralin content of the startup solvent was more fully demonstrated under Condition B, Periods 5 and 6 which yielded higher conversion, 82%, than Period 8 did. These two intervals were at the same operating conditions, but were interrupted by a shutdown caused by unit plugging. Period 8 was started with the vacuum distillate which comprised the internally generated slurrying oil containing only about 1% tetralin, and Period 5 was preceded with an addition of 3,000 to 5,000 grams of the startup solvent containing 2.8% tetralin to the unit loop with a total holdup of 11,000 grams, resulting in an increase in the tetralin content which, in turn, raised the coal conversion.

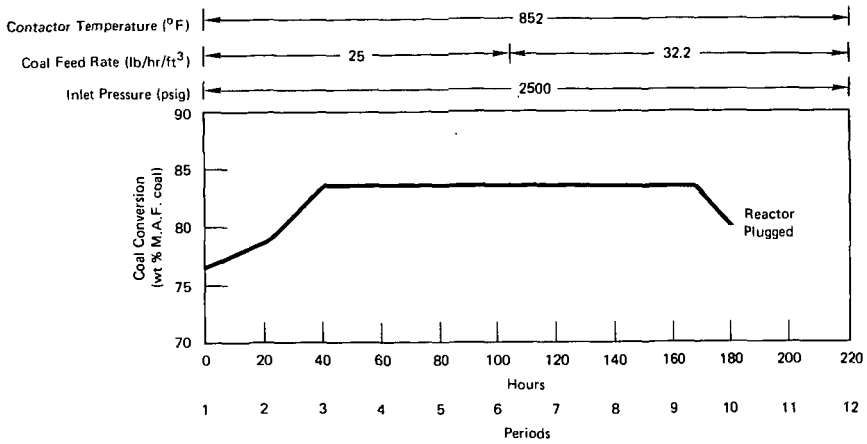
The gradual, but persistent, increase in coal conversion observed during Periods 8 through 13 was rather unique in that it had not been observed before. This was probably caused by the use of a poor startup solvent produced from preceding periods at lower reactor temperatures, which did not contain any tetralin. The solvent from Period 13 had a tetralin content of 1.3%. The bench unit has a rather large holdup capacity; at 15% solvent production, it takes about six days to displace 70% of the startup solvent. These observations further indicate that the hydrogen donor content of the solvent as well as coal conversion is controlled by the process conditions.

Condition D used hydrogenated anthracene oil as the startup solvent. Raw anthracene oil, a coal tar product, was hydrogenated to increase its hydrogen content from 5.5 to 7.2% in a separate operation prior to its use in this work. The hydrogenated anthracene oil has a higher initial boiling point (426°F) than all the other solvents used during this study. Hence, its tetralin (boiling point - 405°F) content is only 1.3%. However, its exceedingly high tetralin to naphthalene ratio, 0.76, indicates that it would be a good donor solvent if it contained other high boiling hydroaromatics with donor capability. Condition D was at higher pressure than Condition B, 2500 psig vs. 2050 psig. Hence, Condition D was expected to yield higher coal conversion than Condition B. The use of hydrogenated anthracene oil as startup solvent did result in a high initial conversion of 86%. The coal conversion only increased slightly to 88% in contrast to the steady increase from 70% to 85% under Condition B which used a poor startup solvent possessing a tetralin to naphthalene ratio of about 0.16. The high initial conversion and slight increase in conversion observed under Condition B leads to a conclusion that the hydrogenated anthracene oil is a better donor solvent than the other startup solvent and recycle solvent because it contains high concentrations of hydrogen donors other than tetralin.

The Effect of Other Hydrogen Donors - Black Mesa Coal Operation

Solvent analyses for the Black Mesa and Monterey coal operations are summarized in Table 2. A plot is presented below to show process conditions and coal conversion.

The Black Mesa coal operations led to a rather significant deduction. The startup solvent obtained from the Wilsonville SRC unit on another coal contained 4.2% tetralin and a tetralin to naphthalene ratio of 0.35. These values were much higher than those of the bench unit recycle solvent, which contained 1.6 to 2.5% tetralin and a tetralin to naphthalene ratio of 0.12 to 0.23. However, the coal conversion steadily increased from 77 to 83.5% and then remained at this level.



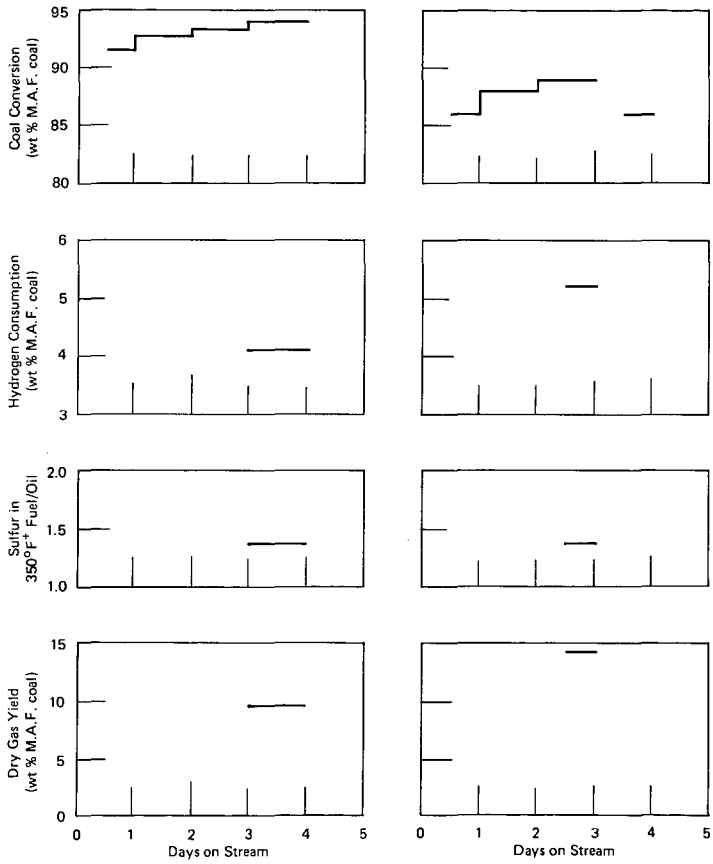
An examination of the H-NMR data in Table 2 discloses that H_β, a measure of the hydroaromatics content of the recycle solvent, increased steadily from 16.5 to 21.6% from Period 1A to Period 7/8. Since the tetralin (one of the hydroaromatics) content of the startup solvent is higher than the recycle solvent, the increase in H_β represents an increase in other hydroaromatics through the displacement of the startup solvent. These observations indicate that the solvent produced from the hydrogenation of Black Mesa coal contains other hydrogen donors which are more reactive towards Black Mesa coal than tetralin.

The Effect of Solvent Quality Upon Coke Formation - Monterey Coal Operation

Wilsonville started operation on Illinois No. 6 Monterey coal in August 1975. Since the Monterey coal had a higher organic sulfur content (2.8%) than the Illinois No. 6 coal from Burning Star Mine which had been used previously, the dissolver temperature was raised from the previous 835°F level to 855-890°F at 1,700 psig in an attempt to produce SRC meeting the sulfur specification of 0.96 weight percent. There was an indication of solids buildup in the dissolver during these runs. This was confirmed by flushing out 400-500 pounds of solids from the dissolver, which has a total volume of 20 cubic feet. Later, extensive plugging of transfer lines around the dissolver occurred with substantial coke accumulation in the lower half of the dissolver. The plugging forced a shutdown of the plant. HRI was retained by EPRI to carry out bench unit SRC experiments under conditions similar to Wilsonville's. Experiments were carried out at 1500 psig, 840 and 868°F contactor temperatures. The coking problem was demonstrated and duplicated in the bench-unit operation at the higher temperatures.

Table 3 summarizes solvent analyses together with certain pertinent operating data. The recycle solvents contained more hydroaromatics than the startup solvent from the Wilsonville SRC plant, as shown by the higher tetralin/naphthalene ratio and higher NMR H measurements of the recycle solvents. Hence, the recycle solvents from these two runs should be better solvents than the Wilsonville solvent. This assumption was supported by the slight, but steady, increase in coal conversion during these two runs. Plots are presented below to show coal conversion, hydrogen consumption, sulfur content of 380°F+ fuel oil, and dry gas production.

Run Number	177-117	177-118
Contactor Temperature (°F)	840	868
Coal Feed Rate (lb/hr/ft^3)	25	25
Inlet Pressure (psig)	1500	1500



The hydrogen consumption was higher at high contactor temperature, 5.1 vs. 4.1 W % as expected. However, the high hydrogen consumption was accompanied by unfavorable product distribution as follows:

1. Low coal conversion, 89.5% at high temperature vs. 94% at low temperature.
2. High C_1-C_3 dry gas production, 13.3% vs. 7.8%.
3. A deterioration in solvent properties, as shown by the low tetralin to naphthalene ratio, 0.36 vs. 0.5, and low H_β value, 16 vs. 19%.
4. High Coke Formation: The run at 840°F was operated for 83 hours without reactor plugging. The run at 868°F was operated for 78 hours then terminated by reactor plugging. The reactor was filled with a hard plug of solids between the middle of preheater to a length of 9 feet out of reactor length of 13 feet. In addition, it was observed that the extensive coke formation was accompanied by a doubling of the filtration rate of the slurry product.

These phenomena lead to the following hypothesis: Coal hydrogenation is promoted by the hydrogen donors present in the solvent. When the process conditions result in a deterioration of donor capability of the solvent, thermal cracking gets ahead of hydrogenation, which can lead to coke formation.

COKE FORMATION

Characterization of Coke

Two coke samples taken from the Wilsonville dissolver after operations on Illinois #6 coal from Monterey Mine (8) were sent to Pennsylvania State University for optical characterization. One was a fine-grained material and the other was a much coarser grain size. Penn State reported (9) that the fine-grained sample was composed of insoluble particles surrounded by a layer of anisotropic carbon. The most common constitutents of the nuclei are semi-coke and calcite, both of which are present in feed coal. The shell of anisotropic carbon is deposited on these nuclei in the SRC process with this coal. Fine-grain anisotropy and extinction characteristics are indicative of a uniform, onion-like deposition, i.e., concentric layers surrounding a nucleus. The coarse-grain sample exhibited agglomeration of the fine-grained deposit and there was a coarsening of anisotropy of the carbonaceous shell. These domains or mosaic structures are recognized as the more traditional optical texture of coalesced mesophase.

The immediate cause of sedimentation of the particles in the reactor was the growth of anisotropic carbon on to the undissolved materials. These insolubles consist of a semi-coke contaminant, mineral matter and undissolved macerals (generally fusinitic material). The resulting adhesion of particles forms a coke-like sediment. Operation conditions and optical texture of the bonding anisotropic carbon suggest that its growth from the solution was by a mechanism of growth of nematic liquid crystals, thus resulting in mesophase formation which then leads to a non-plastic semi-coke.

Coke analyses from both Wilsonville and HRI operations with Illinois No. 6 Monterey coal are summarized in Table 4.

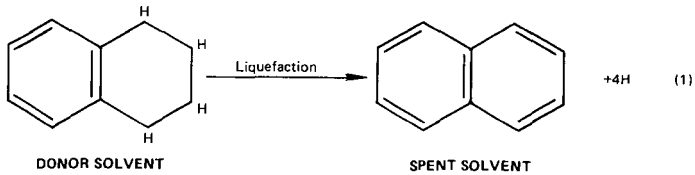
Most of the solids recovered from the dissolver and various parts of the Wilsonville unit such as the high pressure letdown valves and the blowdown tank were similar in composition. These compositions are represented by a UCC (undissolved carbonaceous cresol insolubles) to ash ratio of around 2 with the

exception that the solids which deposited at the vapor-liquid interface contained much more cresol-insoluble carbonaceous material than the others. The solids recovered from the HRI bench units had a much higher ash content than those from the Wilsonville unit. The higher ash content of coke together with the shorter time of HRI operation coincides with Penn State's characterization of coke as a uniform, onion-like carbon deposition surrounding a nucleus of mineral matter.

The H/C atomic ratios of all coke deposits (including the solids deposits at the vapor-liquid interface) were quite consistent, about 0.50. This is significantly lower than the H/C atomic ratio of the Monterey Mine coal, 0.78, and the unconverted coal, 0.73. There was no difference in the H/C atomic ratio between the coke accumulated over short periods of time (three to four days in the HRI unit) and long periods of time (more than one month in the Wilsonville unit). The consistency of the H/C of coke under these circumstances leads to the postulation of a reprecipitation mechanism, without any significant carbonization after the coke deposition.

Mechanism for Coke Formation

The SRC process as practiced at Wilsonville uses a recycle solvent (350° to 750°F) for transporting the coal into the reactor and for promoting the dissolution and the conversion of coal. Reaction (1) illustrates the ability of a donor solvent solvent molecule to release donor hydrogen during liquefaction using tetralin as an example of a donor solvent molecule.



Reaction (2) represents the free radicals formed by thermal cracking of the coal "molecules" accepting donor hydrogen to form liquid product.

$$\text{coal} \xrightarrow{\text{heat}} \underset{\text{coal fragment}}{(A_r\text{-}X)} \xrightarrow{\text{donor H}} \underset{\text{liquid product}}{A_r\text{-}XH} \qquad (2)$$

X = C, O, S, or N

When there is a deficiency of donor hydrogen the coal fragments recombine to form coke.

$$n(A_r\text{-}X) \longrightarrow \underset{\text{coke}}{(A_r\text{-}X)_n} \qquad (3)$$

The presence of solid particles, such as mineral matter, acts as nucleus upon which the reprecipitation of coal fragments occurs.

SUMMARY AND CONCLUSIONS

A preliminary study of the effect of solvent upon SRC process performances was undertaken. The startup solvent and makeup solvent have a significant effect upon coal conversion. However, the use of a good startup solvent does not sustain good process performance under unfavorable process conditions and vice versa. Hydroaromatics, measured in part by H_β from NMR analysis, other than tetralin also possess hydrogen donor capabilities. These hydroaromatics could be better donors than tetralin. This conclusion was reached during a process study of the Black Mesa coal, a subbituminous coal. At the same hydrogen pressure, an increase in reactor temperature resulted in higher hydrogen consumption, lower coal conversion and high dry gas (C_1-C_3) production. The poor process performances were accompanied by a deterioration in solvent properties (as shown by the lower tetralin to naphthalene ratio and lower H_β value) and significant amount of coke formation. These findings support a hypothesis that coke formation results when thermal cracking gets ahead of hydrogenation which is promoted by the hydrogen donors present in the solvent.

ACKNOWLEDGEMENTS

The work described here was done as part of Electric Power Research Institute Research Project (RP) 389. The purpose of the work was to generate process operability, yield structure and hydrogen consumption data for candidate feed coals to the Utility Industry Solvent Refined Coal Test Unit at Wilsonville, Alabama.

The stimulating discussions and solvent analysis provided by Dr. D. D. Whitehurst and Dr. T. O. Mitchell (whose work was carried out as part of EPRI Research Project 410) are sincerely appreciated.

Analysis of coke from the Wilsonville unit was carried out under EPRI Research Project 366 at the Pennsylvania State University.

BIBLIOGRAPHY

1. R. P. Anderson
"Evolution of Steady State Process Solvent in the Pittsburgh & Midway Solvent Refined Coal Process"
Symposium on Coal Processing, American Institute of Chemical Engineers
Salt Lake City, Utah, August 20, 1974.

2. Gerald Doyle
"Desulfurization Via Hydrogen Donor Reactions"
Progress in Processing Synthetic Crudes and Resids
American Chemical Society Chicago Meeting, August 24-29, 1975.

3. L. E. Furlong, E. Effron, L. W. Vernon, E. L. Wilson
"Coal Liquefaction by the Exxon Donor Solvent Process"
The 1975 National AIChE Meeting, Los Angeles November 18, 1975

4. "Solvent Refining of Coal"
Electric Power Research Institute Report, RP123-1-0, August 1974.

5. "Liquefaction of Kapairowits Coal"
Electric Power Research Institute Report, RP123-2, October 1974.

6. "Solvent Refining of Illinois #6 and Pittsburgh #8 Coals"
Electric Power Research Institute Report, EPRI 389, Vol. I, June 1975.

7. "Solvent Refining of Wyoming, Illinois #6 (Monterey Mine) and Black Mesa Coals"
Electric Power Research Institute Report, EPRI 389, Vol. II, May 1976

8. "Solvent Refined Coal Pilot Plant, Wilsonville, Alabama"
SRC Technical Report No. 7, January 1976.

9. "Characterization of Mineral Matter in Coals and Coal Liquefaction Residues"
Pennsylvania State University Report, RP366-1, December 1975.

TABLE 1

ANALYSIS OF FEED COALS

	Wyodak Coal	Black Mesa Coal	Illinois No. 6 Monterey Coal
Proximate Analysis (dry basis) wt.%			
Ash	7.04	10.10	10.11
Volatile Matter	46.48	42.57	40.85
Fixed Carbon	46.48	47.33	49.04
Ultimate Analysis (dry basis) wt.%			
Carbon	67.78	69.81	69.71
Hydrogen	4.97	4.79	4.56
Sulfur	0.80	0.33	4.52
Nitrogen	0.65	1.04	1.17
Ash	7.04	10.10	10.11
Oxygen (by difference)	18.76	13.93	9.89
Sulfur Forms (dry basis) wt.%			
Pyritic Sulfur	0.15	0.17	1.23
Sulfate Sulfur	0.01	0.00	0.14
Organic Sulfur (by difference)	0.51	0.20	2.78
Total Sulfur	0.67	0.37	4.15
Mineral Analysis (ignited Basis) wt.%			
P_2O_5	0.35	0.13	0.34
SiO_2	27.91	46.99	50.25
Fe_2O_3	5.30	5.33	18.66
Al_2O_3	15.75	16.96	18.15
TiO_2	1.10	0.96	0.87
CaO	19.00	18.00	4.25
MgO	5.60	2.24	0.86
SO_3	22.84	6.17	3.29
K_2O	0.48	0.81	1.92
Na_2O	0.72	1.69	1.17
Undetermined	0.95	0.72	0.24

TABLE 2

SRC OPERATIONS ON BLACK MESA COAL AND MONTEREY COAL

SOLVENT ANALYSIS

	Startup Solvent From Wilsonville	Black Mesa Coal Recycle Solvent				Monterey Coal	
Run Number 177-		119-1	-2B	-5	-7/8	117-4	118-3B
Reactor Temperature, °F (estimated)		847	845	838	841	835	863
Inlet Pressure, Psig		2500	2500	2500	2500	1500	1500
Coal Feed Rate, Lbs/Hr/Ft^3		21.4	25	25	32.2	25	25
Coal Conversion, W % of M.A.F. Coal		77.1	79.2	83.0	83.3	94.0	89.5
Hydrogen Consumption W % of M.A.F. Coal				2.94	2.84	4.1	5.1
Simulated Distillation (VPC)							
Boiling Point, °F							
IBP, °F	284	302	293	302	266	320	302
IBP-403°F, W %	10.3	13.3	15.3	11.7	13.2	14.8	15.0
405°F (Tetralin)	4.2	5.1	1.6	2.5	2.5	5.2	4.1
412°F (Naphthalene)	12.1	11.2	13.2	10.9	11.5	10.0	11.3
413-642°F	50.2	50.0	47.8	52.3	48.7	49.3	46.0
644°F (Phenanthrene/Anthracene)	9.9	7.2	7.3	6.6	8.2	5.3	6.3
646°F-EP	13.4	13.2	14.8	16.0	15.9	15.4	17.3
EP, °F	797	806	833	833	824	824	860
Tetralin + Naphthalene	16.3	16.3	14.8	13.4	14.0	15.2	15.4
Tetralin/Naphthalene	0.35	0.46	0.12	0.23	0.22	0.52	0.36
Proton Distribution (H-NMR) /1/							
H_{ar} (9-6 ppm)	52.9	53.5	54.2	50.3	48.2	48.0	54.6
H_{α} (3.5-2 ppm)	24.2	24.3	24.2	23.7	23.9	27.0	24.5
H_{β} (2-1.1 ppm)	17.5	16.5	16.5	20.5	21.6	18.3	16.4
H_r (1.1-0.4 ppm)	5.4	5.7	5.1	5.5	6.3	6.7	4.5

/1/ H_{ar} represents aromatic hydrogens, H_{α} benzylic hydrogens including methyls, H_{β} hydrogens on carbon atoms at β-positions of aromatic rings, and H_r hydrogens in aliphatic methyl groups.

TABLE 3

SRC OPERATIONS ON ILLINOIS NO. 6 MONTEREY MINE COAL

SOLVENT ANALYSIS

	Startup Solvent From Wilsonville	Recycle Solvent 117-4	Recycle Solvent 118-3B
Contactor Temperature, °F (Estimated)		839	863
Inlet Pressure, psig		1500	1500
Coal Feed Rate, Lbs/Hr/Ft^3		25	25
Coal Conversion, W % of M.A.F. Coal		94.0	89.5
Hydrogen Consumption, W % of M.A.F. Coal		4.1	5.1
		0.66	0.57
Simulated Distillation (VPC), Boiling Boiling Point, °F			
IBP, °F	284	320	320
IBO-403°F, W %	10.3	14.8	15.0
405°F (Tetralin)	4.2	5.2	4.1
412°F (Naphthalene)	12.1	10.0	11.3
413-642°F	50.2	49.3	46.0
644°F (Phenanthrene/anthracene)	9.9	5.3	6.3
646°F-End Point	13.4	15.4	17.3
End Point, °F	797	824	860
Tetralin + Naphthalene	16.3	15.2	15.4
Tetralin/Naphthalene	0.35	0.52	0.36
Proton Distribution (H-NMR)*			
H_{ar} (0-6 ppm)	52.9	48.0	54.6
Hα (3.5-2 ppm)	24.2	27.0	24.5
Hβ (2-1.1 ppm)	17.5	18.3	16.4
Hr (1.1-0.4 ppm)	5.4	6.7	4.5

* H_{ar} represents aromatic hydrogen, Hα, benzylic hydrogen including methyls, Hβ, hydrogen on carbon atoms once removed from aromatic rings (excluding methyls), and H_r, hydrogen in aliphatic methyl groups.

TABLE 4

ANALYSIS OF COKE DEPOSITS

Coal Feed	Wilsonville Operation							HRI Operation		
	Monterey					Burning Star		Monterey		
Date Sampled	8/28/75	8/28/75	8/31/75	9/4/75	9/5/76	4/7/75	4/8/75	--	--	
Sample No.	9464	9343	--	9440	9457	--	--	--	--	
Run No.	--	--	--	---	--	--	--	177-117	177-118	
Location	Let Down valve LV-415 550-600°F	Low Pressure Flash at Pump p-136	Flushing-out solids blowdown tank BD-144	Top of dissolver vapor-liquid interface	Bottom of dissolver 6' cone	Dissolver solids flushout	Dissolver solids hydro-	Dissolver	Dissolver Middle section	Dissolver 2'to Bottom Section
Ash, W %	31	34	35	19	33			52.26	28.99	41.37
UCC(1), W %	64	58	63	75	66					
Cresol Soluble, W %	5	8	2	7	1					
UCC/Ash	2.06	1.71	1.80	3.89	2.00					
Benzene Insoluble, W %	--	--	--	--	--			19.18	44.75	44.92
Benzene Soluble, W %	--	--	--	--	--			28.56	26.26	13.71
Benzene Insoluble/Ash	--	--	--	--	--			0.37	1.54	1.09
Sulfur, W %										
Sulfide	1.68	1.41	1.80	0.79	0.55					
Pyritic	0.14	0.10	0.18	0.13	0.33					
Sulfate	0.11	0.50	0.12	0.16	0.09					
Organic	0.64	1.52	0.57	0.62	1.34					
Elemental Analysis, W %								Benzene-Insoluble Solids		
C	60.83	56.12	56.95	73.55		69.09	42.99	34.40	55.26	47.50
H	2.53	2.14	2.27	3.02		2.02	1.86	--	--	--
N	1.03	1.09	1.02	1.15		1.00	0.73	--	--	--
Cl	0.78	0.46	0.96	0.36		0.10	0.05	--	--	--
O (by difference)	0.79	2.06	1.28	0.84		2.95	0.81	5.61	3.55	3.58
S, total	2.57	3.54	2.67	1.70	2.50	0.87	5.24	52.26	28.99	41.37
Ash	31.47	34.63	34.86	19.28		24.07	48.62	0.47	0.48	0.45
H/C Atomic Ratio	0.50	0.46	0.48	0.49		0.51	0.52			

(1) Undissolved carbonaceous cresol insolubles