

## DISTILLATE SELECTIVITY AND QUALITY OF BITUMINOUS COALS IN THE CATALYTIC TWO-STAGE LIQUEFACTION PROCESS

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### INTRODUCTION

The Clean Coal Research Center at Wilsonville, Alabama, has been operating for over 17 years to develop alternate technologies for producing low cost fuels from coal. Process developments of close-coupled integrated (CC-ITSL) configurations using the thermal/catalytic or catalytic/catalytic mode of operation were discussed in an earlier article<sup>1</sup>.

This paper is primarily focused on the high-volatile bituminous coal performance at steady-state operation with catalyst replacement in the catalytic/catalytic mode. Process developments results from eight runs are discussed: Runs 251-I, 252, 253, 254, 256, 257, 259 and 261. Runs 251-I, 252, 253, 257 and 261 processed a normally mine-washed high-ash Illinois No. 6 coal with four bimodal and one unimodal catalysts (Amocat 1A, Amocat 1C, Shell 317, EXP-AO-60 and Shell 324). Runs 254 and 256 processed an additionally cleaned Ohio No. 6 coal with Shell 317 and 324. Run 259 processed an additionally cleaned low-ash Pittsburgh No.8 coal with Shell 324 and Amocat 1C.

The primary objective of this study is to maximize the distillate production with good quality in order to improve the process economics. The distillate production can be enhanced by improving coal reactivity, catalyst conversion activity, and distillate selectivity. Typical analyses of feed coals processed for this study are summarized in Table 1. The coal cleaning procedure was reported elsewhere<sup>2</sup>. Properties of EXP-AO-60, Amocat and Shell Ni-Mo catalysts tested are shown in Table 2.

### PROCESS DESCRIPTION

The current catalytic close-coupled integrated two-stage liquefaction (CC-ITSL) process consists of two H-OIL<sup>®</sup> ebullated-bed reactors and a Residuum Oil Supercritical Extraction-Solids Rejection (ROSE-SR<sup>SM</sup>) unit<sup>3</sup>. Both the reactor designs utilize "H-OIL<sup>®</sup>" technology supplied by Hydrocarbon Research, Inc. The ebullated-bed design helps to maintain a uniform temperature distribution in the reactor. The ROSE-SR<sup>SM</sup> is a proprietary extraction process at conditions close to the critical point of the deashing solvent. It was developed and licensed by the Kerr-McGee Corporation.

### RUN EXPERIMENTS

Key process variables studied are listed below to maximize the distillate yield and production.

- (1) Combined activity of coal and catalyst  
- Illinois, Ohio, Pittsburgh

- unimodal Shell 324
- bimodal EXP-AO-60, Amocat 1C(/1A), Shell 317
- additionally cleaned low-ash coal
- (2) Steady-state operation with catalyst replacement
  - 1.5 to 4 lb/ton MF coal per stage
- (3) Recycle resid concentration in the process solvent
  - 40-50 wt %
- (4) Low/high and high/low thermal severity modes
- (5) Vacuum gas oil recycle
- (6) Coal space velocity
  - 28-76 lb MF coal/hr/cuft-cat per stage
- (7) Reaction temperature
  - 760-835°F in the first stage
  - 750-825°F in the second stage
- (8) Inlet hydrogen partial pressure
  - 2500-2700 psia in the first stage
  - 2400-2600 psia in the second stage
  - 2100 psia in the first stage in 253H
- (9) Slurry composition
  - 29-34 wt % coal (40 wt % in 253C)
  - 12 wt % CI (9 in 251-IA-IB, 4 wt % in 253C)
- (10) No interstage separation
- (11) Catalyst cascading in Run 252
- (12) Reactor operation parameters
  - temperature profiles, exotherms
  - ebullation rate, gas flow, slurry flow
  - slurry viscosity, etc.

Several steady-state operation periods were selected for comparisons of the distillate production, the effect of recycle resid concentration, and the effect of catalyst replacement rate, and are summarized below along with the distillate production projected for the "all-distillate" product slate with resid extinction<sup>4</sup>.

run	catalyst	tempera.	cat. rep.	recycle	projected
		(°F)	(lb/t MF)	resid	distillate
		1st/2nd	1st/2nd	(wt %)	product. <sup>d</sup>
(1) distillate production					
w/ Illinois coal					
257DE	Amo 1C	790/760	3/1.5	50	28.8
257H	Amo 1C	760/810	1.5/3	40	24.8
257J <sup>a</sup>	Amo 1C	810/760	3/1.5	50	42.2
251-IE	Amo 1A/1C	810/760	2 <sup>b</sup> /1 <sup>b</sup>	40	23.6
261B	EXP-AO-60	790/810	3/3	40	37.1
261D	EXP-AO-60	790/810	1.5/1.5	50	29.8
w/ Ohio coal					
254B	She 317	810/760	4 <sup>b</sup> /4 <sup>b</sup>	40	25.3
254G <sup>c</sup>	She 317	810/790	3/3 <sup>b</sup>	50	33.3
w/ Pittsburgh coal					
259H	She 324	825/790	3.6/3.6	50	28.6
259DE <sup>c</sup>	She 324	825/790	4/4	50	23.8
(2) effect of recycle resid concentration					
w/ Illinois coal					
257DE				50	28.8
257F				40	22.3
w/ Pittsburgh coal <sup>c</sup>					
259DE				50	23.8
259F				40	19.3

(3) effect of catalyst replacement			
w/ Illinois coal			
261B	3/3	40	37.1
261D	1.5/1.5	50	29.8
w/ Ohio coal <sup>c</sup>			
254G	3/3 <sup>b</sup>	50	33.3
254H	3/2.1 <sup>b</sup>		28.8
254I	3/1.5 <sup>b</sup>		26.8
254J	3/1.3 <sup>b</sup>		30.4
w/ Pittsburgh coal <sup>c</sup>			
259DE	4/4	50	23.8
259I	3 <sup>b</sup> /3 <sup>b</sup>		19.4
259J	2.5 <sup>b</sup> /2.5 <sup>b</sup>		15.8

<sup>a</sup> Half-volume reactors operation.  
<sup>b</sup> Estimated at steady-state operation from batch aging.  
<sup>c</sup> Additionally cleaned low-ash coal.  
<sup>d</sup> Unit: lb/hr/cuft-cat per stage.  
<sup>e</sup> Runs 254 and 257 operated without interstage separation.

## RESULTS AND DISCUSSION

### DISTILLATE PRODUCTION COMPARISON

#### Combined Activity of Coal and Catalyst

The distillate production was significantly improved in period 261B processing Illinois with EXP-AO-60 (37.1 lb/hr/cuft-cat per stage); 29-57% increases compared to 257DE, 257H and 251-IE. However, the distillate production was 12% lower than 257J. With additional coal cleaning with heavy media the distillate production significantly improved processing Ohio with Shell 317, by 16% in comparison of periods 254G and 257DE, while in contrast lowered 17% processing Pittsburgh with Shell 324 in comparison of periods 259DE, 259H and 257DE.

#### Effect of Recycle Resid Concentration

The effect of recycle resid concentration on distillate production was projected in both Runs 257D-F and 259D-F. Results are illustrated in Figure 1. The recycle resid level increase from 40 to 50 wt % improved 29% distillate production in 257D-F and improved 23% in 259D-F. 257D-F was with Illinois and Amocat 1C and 259D-F was with Pittsburgh and Shell 324. Both runs were in the high/low severity.

#### Effect of Catalyst Replacement Rate

The effect of catalyst replacement rate on distillate production was projected in Runs 261BD, 254G-J, and 259DEIJ. Results are illustrated in Figure 2. If the effect of resid recycle increase from 40 to 50 wt % observed in 257D-F with Illinois and Amocat 1C is considered in comparison of 261B and 261D (29% increase in the distillate production), then the catalyst replacement effect becomes more significant, approximately 61% increase in coal throughput by 3 lb/ton MF coal total replacement increase in 261B compared to 261D with Illinois and EXP-AO-60. The distillate production becomes 48 lb/hr/cuft-cat per stage, higher than that in 257J (42.2). The effect of catalyst replacement increase on coal throughput and distillate production was also significant in 254G-J with Ohio and Shell 317, and in 259DEIJ with Pittsburgh

and Shell 324. Both coals were cleaned with heavy media to lower the ash content and operated at 50 wt % resid recycle level. 254G-J with 1-1.5 lb/ton MF coal total catalyst replacement increase showed 16-24% increase in the distillate production; 259DEIJ with 2-3 lb/ton MF coal total catalyst replacement increase showed 23-51% increase in the distillate production.

Data for 251-IE and 257DEJ in the high/low mode were also included for comparison in Figure 2. Recycle resid concentration was 40 wt % in 251-IE and 50 wt % in 257DEJ. Operating conditions for these runs are listed in the previous section. 257J had the highest distillate production, primarily due to half-volume reactors operation resulting in more isothermal temperature distribution and better mixing, and a higher resid recycle level at 50 wt %, while 251-IE and 257DE with full-volume reactors operation had lower distillate production, because 251-IE operated at a lower resid recycle level, 40 wt % and 257DE operated at a lower first stage reaction temperature, 790°F.

259H with high-ash Pittsburgh and Shell 324 had a similar distillate production to that in 257DE with high-ash Illinois and Amocat 1C (28-29 lb/hr/cuft-cat per stage); 17% higher production than 259DE with low-ash Pittsburgh and Shell 324 (Figure 2). 259H operated at 33°F higher reaction temperature and 60% higher total catalyst replacement than 257DE in the high/low mode. Recycle resid concentration for these periods was same at 50 wt %.

#### EFFECT OF COAL CLEANING ON MAXIMUM DISTILLATE YIELD

Ohio coal was cleaned with heavy media to reduce the ash content from 10 to 6 wt % and Pittsburgh coal was cleaned from 15 to 4-5 wt %. Coal cleaning significantly improved the coal conversion for both Pittsburgh and Ohio coals. As a result, the organic rejection significantly reduced and the C4+ distillate yield significantly increased. Process performance improvements by the coal cleaning are summarized below.

<u>run</u>	<u>254</u>		<u>259</u>	
	<u>Ohio</u>		<u>Pittsburgh</u>	
base period(s)	B	GI	AH <sup>a</sup>	E
cleaning	normal	addit.	normal	addit.
ash in coal (wt%)	10	6	15	5
pyritic sulfur (wt% MF)	1.9	1.5	1.6	0.6
reactives (petrograp.)	94	97	92	93
potential liquid yield				
C4+ resid (wt% MAF)	70	78	69-70	78
coal conversion				
(wt % MAF coal)	94	97	92-93	96
organics rejected to				
solids prod. (wt% MAF)	16	8	19-20	9
C4+ distillate yield				
(projected) (wt% MAF)	68	78	67-70	78
C4+ dist. selectivity				
to resid+UC conv.	0.81	0.84	0.83-0.88	0.85

<sup>a</sup> 259A was unstable.

The coal conversion improvement was probably due to removal of less reactive coal components such as inertinites by cleaning with heavy media<sup>5</sup>. As reported earlier<sup>6</sup>, the linear regression analyses for bituminous coals projected that fully cleaned coals with zero ash content could achieve 100 wt % MAF coal conversion; could produce 83 wt % MAF coal C4+ distillate. The distillate yield higher than 83 wt % is possible, if the distillate selectivity further increases to higher than 0.85, which was observed with the cleaned low-ash coals (4-6 wt % ash content) with heavy media. The effect of coal conversion on organic rejection appeared to be very similar for the three coals. A good linear correlation between organic rejection (Y) and coal conversion (X) was derived for these coals by a linear regression analysis and is shown below.

$$Y = 265.7 - 2.67 X$$

$$r^2 = 0.94 \text{ (determination coefficient)}$$

#### DISTILLATE SELECTIVITY COMPARISON

##### Distillate Selectivity vs Yield

Figure 3 shows that the C4+ distillate selectivity to resid + UC conversion increases, as the distillate yield increases. High-ash Illinois, low-ash Ohio and low-ash Pittsburgh coals are compared. Processing Illinois in Runs 251-I, 252, 253, 257 and 261, the distillate selectivity was not significantly affected by four different catalysts tested (EXP-AO-60, Amocat 1C, Amocat 1A and Shell 317). The variation was 4%. For simplicity of the illustration the linear regression line with Illinois is included without showing the actual data points. Although two different thermal severity modes of low/high and high/low were investigated in runs with Illinois, it seemed that the selectivity was slightly increased by 1-3%, when operated at 790/760°F in the high/low mode (257A-FIK), 760/790-810°F in the low/high mode (257GH) and 790/810°F in the low/high mode with 3 lb/ton MF coal catalyst replacement per stage (261AB). The lower first stage reaction temperature improved the selectivity with less gas make.

Processing additionally cleaned low-ash Ohio and Pittsburgh in Runs 254 and 259, Pittsburgh and Shell 324 had 2% higher selectivity than that with the combination of Illinois and bimodal catalysts, and 4-5% higher than that with Ohio and Shell 317, although operated higher reaction temperatures, 810-825/790°F (Figure 4). Runs 254 with Ohio and Shell 317 and 257 with Illinois and Amocat 1C operated without interstage separation, which might have affected the selectivity. Coal cleaning appeared to improve the selectivity to 0.85-0.86 by producing more distillate about 78 wt % MAF coal (highest). Normally mine-washed high-ash Illinois with bimodal catalysts had a lower selectivity, 0.82-0.83 by producing less distillate about 68-70 wt % (highest). Inconsistent selectivity data were obtained with high-ash Ohio (\*) and Pittsburgh (e), that is, 0.86 in 254A, 0.81 in 254B, 0.83 in 259A and 0.88 in 259H.

##### Distillate Yield vs Hydrogen Consumption

Figure 4 shows with the three coals that the C4+ distillate yield increases, as the hydrogen consumption increases. The effects of catalyst type and reaction temperature were not apparent

processing Illinois. A linear correlation was observed with 4 wt % variation upto 70 wt % MAF coal distillate yield, which is the highest achieved so far with high-ash Illinois at Wilsonville. Required coal conversion and organic rejection to achieve this yield were 94 and 15 wt %, respectively. Processing low-ash Ohio and Pittsburgh, the distillate yield increased to 78 wt % MAF coal due to higher coal conversion (96-97 wt %) and lower organic rejection (7-9 wt %). Hydrogen efficiency (lb distillate/lb hydrogen consumed) in 254 with low-ash Ohio and Shell 317 increased at higher distillate yields above 70 wt %, compared to that with high-ash Illinois at lower distillate yields below 70 wt %. This trend indicated a possibility of two different hydrogenation routes with different reactants and products. Data from low-ash Pittsburgh showed a high scattering, inconclusive trend. Data from high-ash Ohio (\*) and Pittsburgh (o) are also included in the figure for comparison.

#### Hydrogen Efficiency vs Reaction Temperature

Figure 5 compares hydrogen efficiencies from Runs 251-I with high-ash Illinois and Amocat 1A/1C (a regression curve without showing the actual data points), 257 with high-ash Illinois and Amocat 1C, 259 with low-ash Pittsburgh and Shell 324, and 261 with high-ash Illinois and EXP-AO-60. Reaction temperature in the high severity stage was selected as x-coordinate variable. The hydrogen efficiencies for Runs 257, 259 and 261 were significantly higher than that obtained in Run 251-I with high-ash Illinois and Amocat 1A/1C; were similar to that with low-ash Ohio and Shell 317 at 810/790°F (Run 254 data are not included in the figure). Although two different thermal severity modes of low/high and high/low were investigated in these runs, it seemed that the efficiency was increased by 10% processing Illinois coal, when operated at 790/760°F in the high/low mode (257A-FIK), 760/790-810°F in the low/high mode (257GH (•)), and 790/810°F in the low/high mode (261A-D). The lower first stage reaction temperature improved the selectivity with less gas make. Low-ash Pittsburgh and Shell 324 in Run 259 had a higher hydrogen efficiency with wide variation from 10 to 12 compared to Run 251-I, although operated higher reaction temperatures, 810-825/790°F. Coal cleaning with heavy media might be partially contributed to this efficiency improvement by producing more distillate with comparable gas make. Runs 254 with Ohio and Shell 317 and 257 with Illinois and Amocat 1C operated without interstage separation, which might have affected the hydrogen efficiency. Coal cleaning appeared to improve the efficiency by producing more distillate to 78 wt % MAF coal (highest). Two data obtained with high-ash Pittsburgh (o) showed an inconsistent trend, that is, a higher efficiency was observed at a higher temperature operation (12 vs 10.5 lb distillate/lb hydrogen consumed).

#### C<sub>1</sub>-C<sub>3</sub> Gas Selectivity vs Reaction Temperature

Figure 6 compares gas selectivities from Runs 251-I (a regression curve without showing the actual data points), 257, 259, and 261. Reaction temperature in the high severity stage was selected as x-coordinate variable. The gas selectivities for Runs 257 and 261 with high-ash Illinois were significantly lower than those obtained in Run 251-I with high-ash Illinois and Amocat 1A/1C and Run 254 with low-ash Ohio and Shell 317 at 810/790°F (Run 254 data are not included in the figure). The selectivity for Run

259 with low-ash Pittsburgh and Shell 324 was similar to that for Run 254 with low-ash Ohio and Shell 317, although operated at higher reaction temperatures, 810-825/790°F. It seemed that the gas selectivity was decreased with Illinois coal, when operated at 790/760°F in the high/low mode (257A-FIK), 760/790-810°F in the low/high mode (257GH (\*)), and 790/810°F in the low/high mode (261A-D). The lower first stage reaction temperature reduced the gas selectivity with less gas make. Low-ash Pittsburgh and Shell 324 in Run 259 had a higher gas selectivity with wide variation from 11 to 15, when operated at a higher first stage reaction temperature, 825°F. Coal cleaning with heavy media seemed no significant impact on the gas selectivity. Runs 254 with Ohio and Shell 317, and 257 with Illinois and Amocat 1C operated without interstage separation, which might have affected the gas selectivity. Two data with high-ash Pittsburgh (e) showed an inconsistent trend having a similar gas selectivity observed at a higher temperature operation.

#### CATALYST ACTIVITY IN RESID + UC CONVERSION

Catalyst activities were calculated assuming that the resid + UC conversion reaction follows first-order kinetics for a continuous stirred tank reactor<sup>3</sup>. Cracking activity (resid conversion) is not the only function of the catalyst. Hydrogenation activity of the catalyst was not considered in these catalyst activity analyses. Catalyst activity analysis should be considered as the overall activity of combined catalytic and thermal conversion.

Figure 7 compares first stage activities in Runs 261, 257 and 259. Runs 261 and 257 processed Illinois with two different catalysts, EXP-AO-60 and Amocat 1C. The calculated rate constant value at 790°F for 261 with EXP-AO-60 was much higher than that for 257 with Amocat 1C. The rate constant values at 810 and 825°F for 259 processing Pittsburgh with Shell 324 were much lower than those at 790°F for 261 and 257 processing Illinois with EXP-AO-60 and Amocat 1C, respectively. The rate constant value at 810°F for 254 processing Ohio with Shell 317 was higher than those at 810 and 825°F for 259 processing Pittsburgh with Shell 324; lower than those at 790°F for 261 and 257 processing Illinois with EXP-AO-60 and Amocat 1C<sup>2</sup>.

Figure 8 compares second stage activities in Runs 261, 257 and 259. The calculated rate constant value at 810°F for 261 with EXP-AO-60 was higher than those at 760 and 790°F for 257 with Amocat 1C in the high/low mode; similar to that at 810°F for 257H with Amocat 1C in the low/high mode. However, the deactivation rate at 810°F was higher than that at 760°F. The rate constant values became similar for these temperatures at high catalyst ages above 50,000 lb MF coal/cuft-cat. The rate constant values at 760 and 790°F for 259 processing Pittsburgh with Shell 324 were much lower than those at 810°F for 261 and 257H processing Illinois with EXP-AO-60 and Amocat 1C, respectively; similar to those at 760 and 790°F for 257 processing Illinois with Amocat 1C. The rate constant values at 760 and 790°F for 254 processing Ohio with Shell 317 were lower than those at 760 and 790°F for 259 processing Pittsburgh with Shell 324; lower than that at 760°F for 257 processing Illinois with Amocat 1C<sup>2</sup>. The value at 810°F for 254 processing Ohio with Shell 317 appeared to be similar to that at 810°F for 261 processing Illinois with EXP-AO-60, when the deactivation curves were extrapolated for comparison

at similar catalyst ages.

#### COAL REACTIVITY COMPARISON IN RESID + UC CONVERSION

High-ash coal reactivity in the resid + UC conversion reaction was compared and reported in an earlier article<sup>2</sup>, by adjusting the responses measured in Runs 253, 254, 257 and 259. Results are summarized below.

<u>coal</u>	<u>run</u>	<u>C4+dist</u>	<u>resid w/OR=20%</u>	<u>resid+UC conv.</u>
Illinois	257J	66	0	80
Pitts.	259A	50	19	61
Ohio	254B/253D	59	7	73

#### DISTILLATE PRODUCT QUALITY

Table 3 summarizes distillate product qualities in Runs 251-IE, 257FGI, 261BD, 254G and 259DH. During Run 259 with Pittsburgh and Shell 324 which was the first run tested with a better distillation separation system, the distillate product quality improved by reducing the boiling end point of the distillate product (715°F in 259D and 760°F in 259H)<sup>7</sup>. In Run 261BD with Illinois and EXP-AO-60, the boiling end point was 772°F in 261B and 780°F in 261D. 257FGI end point data were estimated by assuming steady recycle of heavy distillate as in Runs 259 and 261. In many respects, the properties of distillates from Illinois, Ohio and Pittsburgh with different Ni-Mo catalysts are similar. This is not unexpected, since they were converted to liquids under similar operating conditions. Hydrogen content was high, 11.3-12.2 wt %. Heteroatom contents were low, 0.1-0.3 wt % nitrogen and <0.1 wt % sulfur. Oxygen content varied 0-2.5 wt %, since it was calculated by the difference. °API gravity was 19-28. Improvements in product quality were recognized by upgrading studies performed with coal-derived liquids by Chevron Oil Company<sup>8</sup>. Reduced boiling end point, lower nitrogen and sulfur contents and increased hydrogen content would make the upgrading task easier for the usage of commercial-type transportation fuels. Some improvements have been made during the past several years and efforts continue at Wilsonville to improve the product quality for the better process economics.

#### CONCLUSIONS

- Processing high-ash Illinois, the distillate production improved by 30-50%. The low/high severity mode with EXP-AO-60, increased catalyst replacement, increased resid recycle, and half-volume reactors operation significantly improved the distillate production.
- Processing low-ash Ohio and Pittsburgh, the distillate yield improved to 78 wt % MAF coal by coal cleaning with heavy media, primarily due to increased coal conversion to 97 wt % and reduced organic rejection to 8 wt %. The distillate production was improved with Ohio and Shell 317 by 16%; was reduced with Pittsburgh and Shell 324 by 17%. The reduction of distillate production with the cleaned Pittsburgh and Shell 324 seemed partly due to a lower pyrite content of the cleaned coal and/or a lower resid conversion activity of the cleaned coal and catalyst.
- The increased gas oil recycle improved the distillate

product quality by reducing the boiling end point of the distillate product. The boiling end point was 715-760°F with Pittsburgh and Shell 324; 770-780°F with Illinois and EXP-AO-60.

- The low/high severity operation seemed improving the distillate selectivity and hydrogen efficiency with less gas make.
- The additional coal cleaning with heavy media seemed improving the distillate selectivity and hydrogen efficiency by increasing the distillate yield to 78 wt % MAF coal.
- The theoretical maximum distillate yield of fully cleaned coals with zero ash content was projected to be 83 wt % MAF coal for high-volatile bituminous coals. The distillate yield higher than 83 wt % is possible, if the distillate selectivity further increases to higher than 0.85, which was observed with the cleaned coals (4-6 wt % ash content) with heavy media.
- Resid derived from Illinois was easier to convert to distillate than from Ohio and Pittsburgh; resid from Pittsburgh was harder to convert than Ohio. Higher reaction temperatures were required to achieve the "all-distillate" product slate with combinations of low-ash Ohio-Shell 317 and Pittsburgh-Shell 324; hydrogen efficiencies were similar with higher gas selectivities due to higher distillate yields.

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TABLE 1

## FEED COAL ANALYSIS

Coal	Illinois No.8	Ohio No.8	Pittsburgh No.8
Mine	Burning Star	Crooksville (cleaned)	Ireland (cleaned)
Runs	251-1,252,253	254,258	259
Rank (ASTM)	257,281		
FC (mf wt %)	hvbB	hvbB	hvaB
HV (Btu/lb mf)	51	53	54
Ultimate (mf wt %)	12,800	13,300	14,200
Carbon	70.8	75.3	78.8
Hydrogen	4.8	5.3	5.7
Nitrogen	1.5	1.4	1.4
Sulfur	3.4	2.8	3.2
Ash	11.5	6.6	4.5
Oxygen (dif.)	8.2	8.8	5.8
Petrographic (mmf vol %)			
Reactive	94	97	93
Pyritic Sulfur	1.1	1.5	0.6

TABLE 2

## WILSONVILLE NI-MO CATALYST PROPERTIES

Catalyst Run	Shell 324 256,259	Amocat 1C 251-253	EXP-AO-60 261	Shell 317 253,254
	281	257,259	258	
Shape	-----Cylindrical-----			Trilobe
Size (in)	1/18	1/18,1/12	1/18	1/20
Ni (wt%)	2.7	2.3	2.5	2.7
Mo	13.2	10.4	10.7	11.8
Surface Area (sqm/g)	185	190,185	241	235
Pore Volume (cc/g)	0.48	0.85,0.88	0.78	0.75
Pore Size Dist.	Unimodal	-----Bimodal-----		
Comp. B. Density (lb/cuft)	54	42,36	33	38

TABLE 3. TOTAL DISTILLATE PRODUCT QUALITY COMPARISON

Run Coal	257F	257G	257I	251-IE	261B	261D	254G	259D	259H
	----- Illinois -----						Ohio	Pitts.	
Wt % C	87.5	87.8	87.4	87.2	87.3	87.5	88.3	86.7	87.0
H	12.2	12.1	12.1	11.6	11.4	11.3	11.3	12.0	11.7
N	0.2	0.1	0.1	0.2	0.2	0.3	0.3	0.2	0.2
S	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
O	0.1	0.0	0.4	1.0	1.1	0.9	0.1	1.1	1.1
									(2.5)
°API	21	21	21	26	23	22	19	28	25
Wt % Naphtha	22	21	18	26	19	14	25	20	19
Mid.D1	11	10	11	12	11	16	9	18	13
Mid.D2	50	53	64	32	40	40	35	43	43
Gas Oil	17	16	7	30	30	30	32	19	25
End point °F (D1160)	680	700	665	-	772	780	-	715	760
	- estimated -								

FIGURE 1  
EFFECT OF RECYCLE RESID CONCENTRATION  
ON DISTILLATE PRODUCTION

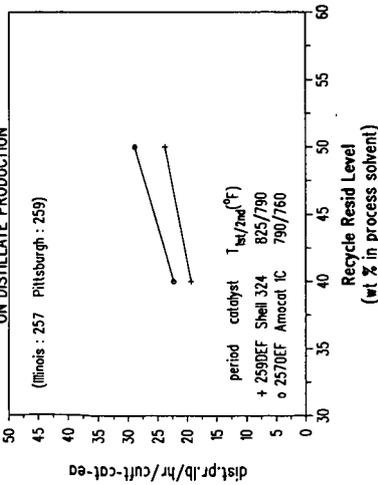


FIGURE 2  
EFFECT OF CATALYST REPLACEMENT  
ON DISTILLATE PRODUCTION

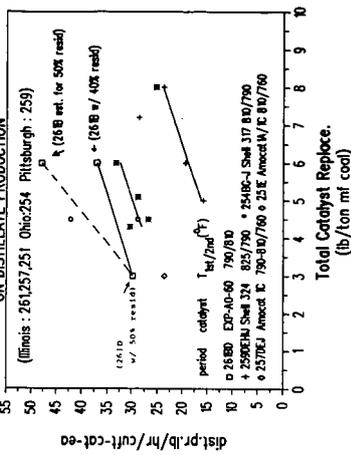


FIGURE 3  
DISTILLATE SELECTIVITY VS YIELD  
(Ohio and Pittsburg Coals - Low Ash)

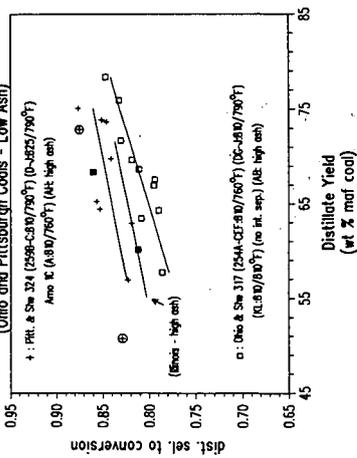


FIGURE 4  
DISTILLATE YIELD VS H2 CONSUMPTION  
(Ohio and Pittsburg Coals - Low Ash)

