

DOE SBIR Grant # DE-FG02-02ER83456
An Improved Liquefaction Process

**Short Residence Time &
Low and High Shear Rate
Coal and Oil Feedstock Test**

Prepared By:

Hydrocarbon Technologies Inc.
Lawrenceville, NJ, U.S.A

April 2003

Table of Contents

1.0 EXECUTIVE SUMMARY	3
2.0 PROGRAM BACKGROUND.....	4
3.0 TEST 245-84.....	5
3.1 RUN PLAN	5
3.2 FEEDSTOCK	5
3.3 CATALYST.....	5
3.4 CATALYST ACTIVATION.....	5
3.5 UNIT CONFIGURATION	5
3.6 UNIT OPERATION	6
3.7 DATA HANDLING	6
3.8 RESULTS	7
4.0 CONCLUSIONS	21
5.0 RECOMMENDATIONS.....	22
APPENDIX A DETAILED RESULTS 245-84	23

1.0 Executive Summary

The original objective of this test program was to study the effect of different catalyst compound forms on coal conversion using HTI's GelCat as the basis. This was later modified to determine the impact of a short resident time highly turbulent tube reactor as the first stage reactor for the liquefaction of coal using HTI's dispersed catalyst. This was not practical to implement within the budget of this program and it was decided to simulate the effect of turbulence using a CSTR reactor operated in both a low shear rate and high shear rate condition. It was also decided to add a condition to the test program to determine the effect of activating GelCat with either sulfur or TNPS.

The test was operated for 13 days and covered 4 conditions. The first condition was with the full reactor volume (850cc each reactor) and high agitation (1200 rpm). The sulfur additive used was elemental sulfur. The second condition was identical to the first except for changing the sulfur additive from elemental sulfur to TNPS. This allowed an evaluation of whether or not the sulfur additive used to activate the GelCat catalyst affected process performance. For the third condition the reactor volume of the first stage was lowered to 140cc's and the agitation was lowered to 300rpm's. This allowed for a low residence time and low shear rate condition to be evaluated that was otherwise identical to the second condition. For the last condition the agitation was increased back to the 1200 rpm's. This allowed a low residence time and high shear rate condition to be evaluated.

The use of sulfur powder versus TNPS as a sulfiding additive has no significant effect on coal conversion, resid conversion, hydrogen consumption or product yield.

The effect of dropping the first stage reactor volume and lowering the shear rate negatively impacts coal conversion, resid conversion, hydrogen consumption and product yield.

Low volume and a high shear rate compared to high volume and high shear rate are surprisingly similar in performance. The low volume and high shear rate condition has nearly the identical coal conversion to the high volume and high shear rate conditions. The reduction in performance as measured by , resid conversion, hydrogen consumption or product yield is slight.

The effect of low volume and a high shear rate compared to low volume and low shear rate is very straightforward. The low volume and high shear rate condition always shows an improvement in performance as measured by coal conversion, resid conversion, hydrogen consumption or product yield. Increased reactor turbulence/agitation improves reaction performance.

Based on the results of this study two questions of interest present themselves:

- 1) Could the performance seen in the first two conditions be further improved by increasing the agitation?
- 2) With a much higher degree of turbulence can the performance of a low volume reactor system be equal to or even surpass that of a high volume reactor system with a fixed degree of turbulence?

2.0 Program Background

The original objective of this test program was to study the effect of different catalyst compound forms on coal conversion using HTI's GelCat as the basis. This was later modified in discussion between HTI and the DOE Project Manager.

The new overall objective of this test program was to determine the impact of a short resident time highly turbulent tube reactor as the first stage reactor for the liquefaction of coal using HTI's dispersed catalyst. This was not practical to implement within the budget of this program due to the very high flowrates required to achieve a turbulent flow in a tube reactor.

The decision was made by HTI and the DOE Project Manager to simulate the effect of turbulence using a CSTR reactor operated in both a low shear rate and high shear rate condition. It was also decided to add a condition to the test program to determine the effect of activating GelCat with either sulfur or TNPS.

3.0 Test 245-84

3.1 Run Plan

The run plan is shown in Table 3.1 and the actual run operation is Shown in Table 3.2. The test was operated for 13 days and covered 4 conditions. The first condition was with the full reactor volume (850cc each reactor) and high agitation (1200 rpm). The sulfur additive used was elemental sulfur. The second condition was identical to the first except for changing the sulfur additive from elemental sulfur to TNPS. This allowed an evaluation of whether or not the sulfur additive used to activate the GelCat catalyst affected process performance. For the third condition the reactor volume of the first stage was lowered to 140cc's and the agitation was lowered to 300rpm's. This allowed for a low residence time and low shear rate condition to be evaluated that was otherwise identical to the second condition. For the last condition the agitation was increased back to the 1200 rpm's. This allowed a low residence time and high shear rate condition to be evaluated. The evaluation of performance is based on coal conversion, resid conversion, hydrogen consumption and product yield.

3.2 Feedstock

In the interest of cost savings, the feedstocks used for this testing was material that HTI already had on-site. Chinese Coal, HTI-7316, approximately 1 year old and Hondo Oil, HTI-6272, stored at HTI for several years were the two fresh feeds. The analysis of each is shown in Table 3-3.

3.3 Catalyst

Approximately 13 kilograms of GelCat from a 230-kilogram batch marked L-1036 was used. The analysis on this batch indicated a 7.31 weight percent iron concentration; therefore, a 68.4 g/hr feedrate was used to obtain a 5,000 ppm Fe loading.

3.4 Catalyst Activation

Sulfur powder was used in the first condition and compared to results of TNPS used in the following conditions. The two forms of sulfur were mixed in with the feed slurry before being added to the unit feed pot. The sulfur feedrate was based on twice the amount required to activate the Fe in the GelCat assuming the active state is FeS_2 .

3.5 Unit Configuration

A simplified flow diagram is shown in Figure 3-1 and a reactor drawing is shown in Figure 3-2. The feed was prepared offline as a batch operation. All the feed material was blended in a charge can for a minimum of 1 hour prior to being charged to the feed tank. From the feed tank the material was sent to two continuous CSTR reactors in series with a maximum capability of approximately 850 cc liquid volumes each and a nominal volume of 1000cc's each. The first stage reactor (K-1) was equipped with an extra exit tube and the valving to allow for a reduction

of liquid volume to approximately 140cc's. The agitator in K-2 was maintained at 1200 rpm for the entire run while the agitator in K-1 was lowered to 300rpm's for Condition 3 but was otherwise also set to 1200 rpm's. The effluent from the second stage reactor was sent to a high temperature high pressure separator (hot separator). The overheads from the hot separator were sent to a low pressure low temperature separator (cold separator) for gas liquid separation where the condensed liquids were recovered and the gases were then sent to a vent meter for volumetric measurement and sampled and analyzed. The hot separator bottoms were let down to atmospheric conditions and collected. The gases from the let down of the hot separator bottoms were included as part of the total gas stream measured, sampled and analyzed.

A sulfiding agent was added to the feed during the entire run.

3.6 Unit Operation

The greatest difficulty encountered during the run was pumping the high *feed rate* into the reactor. During the earlier portion of the run piping changes and pump changes were made in order to successfully deal with the issue. A pre-heater coil was also added early on in the run in order to give additional time to raise the temperature of the feed as well.

After the unit shutdown was complete both reactors were inspected and found to be very clean and free of any solids. All vessels were drained and the unit received a nitrogen purge. No significant deposits were seen throughout the unit.

3.7 Data Handling

This is a fully elementally balanced yield structure based on the process recovery calculated. To perform a fully elementally balanced yield requires that all pertinent streams be analyzed for elemental composition (carbon, hydrogen, nitrogen, sulfur, oxygen, and ash) as well as physical composition (distillation curve, ash, and insoluble organic matter). Elemental and distillation analysis was not done on all Subperiod samples. Where needed an appropriate similar Subperiod analysis was used for purposes of calculations and was indicated on the tables reporting product analysis. Copied analysis is indicated on the tables reporting product analysis. In the event that the gas analysis only done every twelve hours looked incorrect an appropriate gas analysis was substituted from a similar subperiod. To accomplish the objective the following methodology was used:

Ash and Carbon Balance

A forced 100% ash balance was done by correcting the flowrate of the only ash product stream, namely hot separator bottoms. This fixed the hot separator bottoms (O-3Btms) flowrate for future calculations. Then a forced 100% carbon balance was exercised by correcting flowrate of carbon streams, namely hot separator overheads (O-4Btms), knockouts, and vent gases. Mass balances were done on a 12-hour subperiod bases.

Sulfur and Nitrogen Balance

The sulfur and nitrogen are adjusted differently. A significant portion of their products (H_2S and NH_3) are found in both the gas make and the sour water collected. They are balanced by adjusting the quantity of their products to give a 100% balance on each element. The yield presented are those produced by the fresh feed and does not include the contribution of the sulfur agent used to activate the GelCat or the catalyst.

Oxygen Balance

The oxygen content of all feed streams and product streams is calculated by difference taking into account the carbon, hydrogen, nitrogen, sulfur and ash content of the stream. If the calculated oxygen content is negative, as was the case with Subperiod 8B, the other components (carbon, hydrogen, nitrogen, sulfur, oxygen, and ash) were normalized proportionally to give an average oxygen content. If the oxygen content is positive, no adjustment is made to the analysis. The oxygen is balanced by adjusting the water yield such that the oxygen in the feed equals the oxygen in the product streams. This is performed by multiplying the actual water collected by a normalization factor

Hydrogen Consumption

The final element which is calculated is the hydrogen. This is purposely done last, as all the other elements must have a 100% balance. For the other elements, the amount in with the fresh feed must equal the amount out with the products. Hydrogen is different as it is the only element “consumed” in the process. The hydrogen gas in the product gas is less than the hydrogen gas in the feed gas as a portion of the hydrogen in the feed gas has been consumed in the process to form the gas and liquid products. Consequently, the hydrogen in the products is greater than the hydrogen in the fresh feed. This difference is the hydrogen consumption.

3.8 Results

The coal conversion is shown in Figure 3-3. In the case of Conditions 1 & 2 no preference is found for either of the sulfur additives, namely sulfur powder and TNPS. The coal conversion in the first two conditions was better when the total reactor volume was higher than that of the third condition, when the total reactor volume was significantly reduced, and the agitation (shear) rate was low. Conditions 1 and 2 had an average coal conversion rate of 88.7 and 89.1 percent respectively; while, Conditions 3 had an average coal conversion 84.6. What is surprising is that the coal conversion increased in the last condition with the increase in the shear rate returning to nearly the full volume conditions at 87.1 percent. Coal conversion is normally a thermal process and is not strongly affected by catalyst or hydrogen contact. Conditions 3 & 4, the lower total reactor volume cases, show that conversion can be improved by increasing the shear rate, which was done in Condition Four where the first stage reactor was held at roughly 1200 rpm's vs. Condition Three where the first stage reactor was held at 300 rpm's. However, conversion rates comparable to Conditions One and Two were not quite achieved.

Figure 3-4 shows the resid conversion. Here conversion was better in the first two conditions when the total reactor volume was higher than that of the following two conditions when the total reactor volume was significantly reduced. Conditions 1 & 2 had an average resid conversion rate of 76.2 and 76.0 percent, respectively. Conditions 3 & 4 had an average resid conversion of 70.2 and 72.0 percent, respectively. Condition 1 & 2 show no difference in conversion based on the sulfur additive.

Conditions 3 & 4, the lower total reactor volume cases, again show that conversion can be improved by increasing the shear rate, which was done in Condition 4, where the first stage reactor was held at roughly 1200 rpm's, vs. Condition Three, where the first stage reactor was held at 300 rpm's. But the conversion rate on both the final two conditions was lower than that of the first two conditions.

Figure 3-5, showing the hydrogen consumption and IOM yield, lends further support to the conclusions drawn from Figures 3-3 and 3-4. Hydrogen consumption was greatest in the first two conditions and less in the following two. The hydrogen consumption from the first to the fourth condition was 3.75, 3.85, 2.95, and 3.37 W% MAF Fresh Feed, respectively. The IOM yield shows that as conversion and hydrogen consumption goes up the IOM yield, as expected, goes down. Condition 1 had an IOM yield of 2.18. Condition 2's IOM yield was 2.07. Conditions 3 and 4 IOM yields were 3.53 and 2.65, respectively.

In Figure 3-6 the product yields were examined on a C1-C3, C4-C7, IBP-975 °F Oil and 975 °F+ Oil breakdown. Again the two conditions with the least amount of 975 °F+ Oil, indicating the highest conversion, were Conditions 1 and 2 with 13.28 and 13.91 W%, respectively. The 975°F+ W% quantities for Condition 3 was 21.65 and Condition 4 was 18.75. Condition 4, where the shear rate was increased, shows improvement over Condition 3, where the shear rate was lower. All conditions had a W% value between 61.32 and 64.06 for IBP-975°F material. The gas make (C1-C7) was highest in Conditions 1 and 2 (17.13 and 18.23 W% respectively), third highest in Condition 4 (12.22 W%) and fourth in Condition 3 (10.00 W%). These results reiterate the notion that the highest conversion was found when the reactor volume was large during Conditions 1 and 2. For the smaller reactor volume conditions, Condition 4, which had the higher shear rate, showed improvement in conversion over Condition 3.

Figure 3-7 is a clearer indication of the C4-975 °F oil yield of the four conditions. Although in Condition 4 the IBP-975 °F Oil yield is slightly higher than that of Condition 2 when the yields are examined for C4-C7 and IBP-975 °F combined the values showed Condition 1 and 2 have the highest yields. Condition 1 and 2 combined C4-975 °F Oil values were 70.63 and 70.44 W%, respectively, while Condition 3 and 4 were 64.68 and 67.03 W%, respectively. However, this does show the improvement in C4-975 °F oil yield with the increase in the shear rate when all other parameters are the same.

Table 3-1: Run Plan 245-84

Condition	1	2	3	4
Periods	1-7A	7B-9A	9B-11	12-13
Agitator Speeds, rpm's				
K-1	1200	1200	300	1200
K-2	1200	1200	1200	1200
Temperatures, °F				
K-1	825	825	825	825
K-2	840	840	840	840
O-1	650	650	650	650
Unit Backpressure, psig	2500	2500	2500	2500
Feedrates, g/hr				
HTI-6272, Hondo Oil	666.0	666.0	666.0	666.0
HTI-7316, China Coal	333.0	333.0	333.0	333.0
L-1036, GelCat	68.4	68.4	68.4	68.4
HTI-7324, Sulfur Powder	10.0	0.0	0.0	0.0
TNPS	0.0	27.0	27.0	27.0
Total Feedrate	1078.4	1095.4	1095.4	1095.4
Hydrogen, SCFH	66.4	66.4	66.4	66.4
Reactor Volume, nominal cc				
K-1	850	850	140	140
K-2	850	850	850	850

Table 3-2 Actual Operating Conditions

Condition	1	2	3	4
Periods	1-7A	7B-9A	9B-11	12-13
Agitator Speeds, rpm's				
K-1	1189	1212	301	1193
K-2	1217	1207	1208	1209
Temperatures, °F				
K-1	824.7	824.3	825.5	823.7
K-2	840.5	840.7	838.0	838.0
O-1	655.2	652.0	650.4	649.3
Unit Backpressure, psig	2497.6	2478.0	2500	2500
Feedrates, g/hr				
HTI-6272, Hondo Oil	594.3	588.3	598.1	588.9
HTI-7316, China Coal	296.7	293.7	298.6	294.0
L-1036, GelCat	60.9	60.3	61.3	60.4
HTI-7324, Sulfur Powder	8.9	0.0	0.0	0.0
TNPS	0.0	23.8	24.2	23.8
Wash Oil	0.0	36.4	15.2	0.0
H2O	59.0	60.5	58.3	53.7
Hydrogen	175.5	170.8	175.7	175.7
Total Feedrate	1195.3	1233.9	1231.5	1196.4
Hydrogen, SCFH	66.6	65.4	66.7	66.7
Reactor Volume, nominal cc				
K-1	850	850	140	140
K-2	850	850	850	850

Table 3-3 : Feedstock Analysis

Feedstock	Chinese Coal, HTI-7316	Hondo Oil, HTI-6272
API Gravity	-----	6.2
Elemental Analysis, W% dry basis		
Carbon	78.43	83.84
Hydrogen	3.74	10.13
Nitrogen	0.74	0.90
Sulfur	0.45	4.39
Oxygen, calc by difference	10.24	0.59
IR Moisture as-is basis, W%	11.40	-----
Ash, W% dry basis	6.39	0.15
Toluene Insolubles, W%	-----	0.60
Cyclohexane Insolubles, W%	-----	1.25
D-1160 Distillation, F		
IBP		354
5 V%		449
10 V%		476
10 V%		524
Volume %		
IBP-975F		20
975F+		80
Weight %		
IBP-975F		18.6
975F+		81.4

Table 3.4 Operating Conditions & Average Normalized Mass Balance

Average Operating Conditions

Condition	1	2	3	4
Periods for Average	6A-7A	7B-9A	9B-11B	12A-13B
Temperature, F				
First Stage	824.7	824.3	825.5	823.7
Second Stage	840.5	840.7	838.0	838.0
Hot Separator	655.2	652.0	650.4	649.3
Agitator Speed, rpm's				
First Stage	1189	1212	301	1193
Second Stage	1217	1207	1208	1209
Unit Back Pressure, psig	2497.6	2478.0	2500.0	2500.0
Reactor Volume, cc's				
First Stage	850	850	140	140
Second Stage	850	850	850	850
Actual Material Recovery, W% Total Feed	96.9	92.9	95.4	94.7
SV, gms fresh feed / cc reactor volume				
First Stage Only	0.711	0.691	0.114	0.117
Second Stage Only	0.711	0.691	0.691	0.711

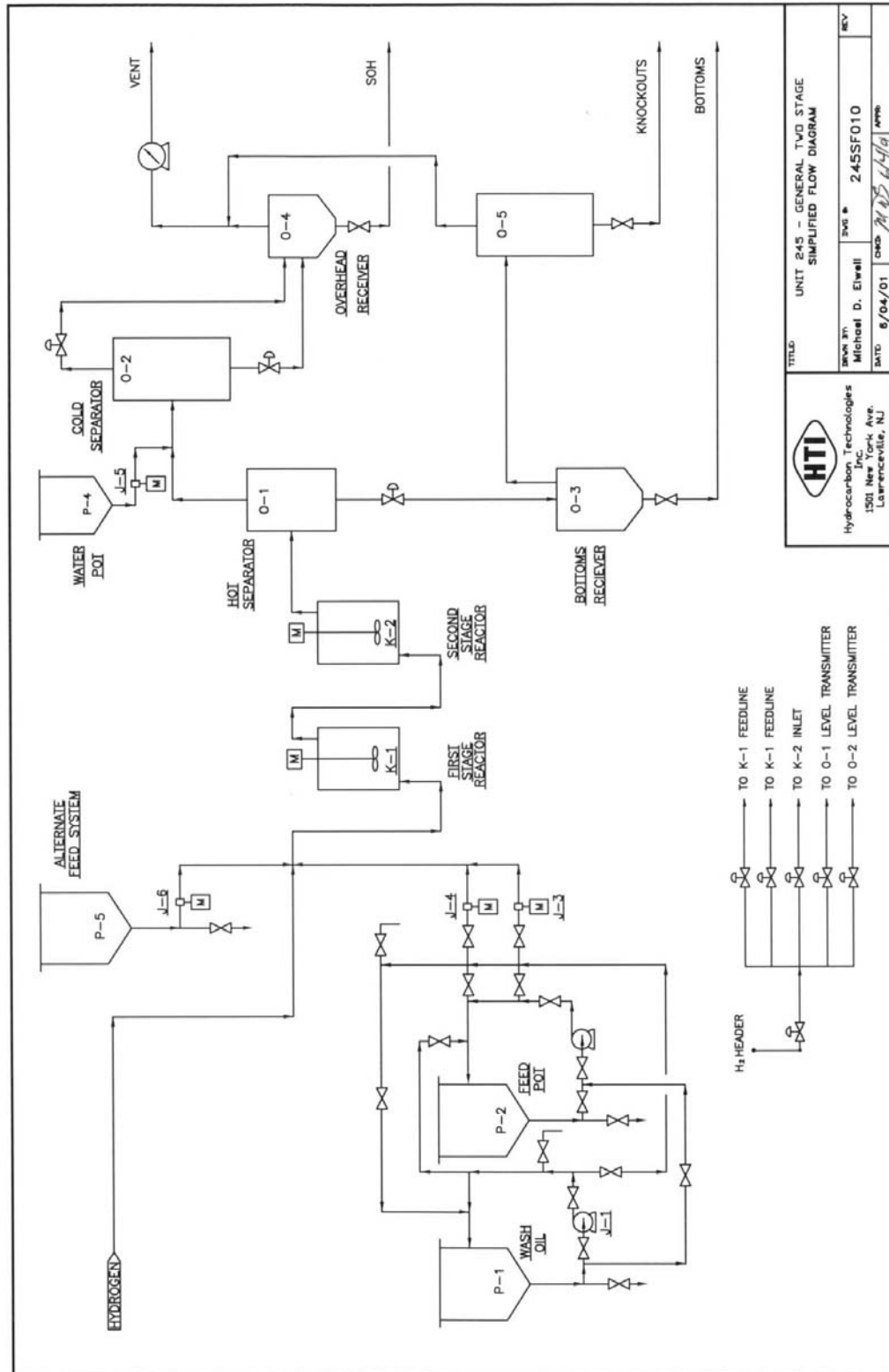
Average Normalized Material Balance

Feeds, gms/hr				
Coal	296.7	293.7	298.6	294.0
Oil	594.3	588.3	598.1	588.9
GelCat	60.9	60.3	61.3	60.4
Sulfur Powder	8.9	0.0	0.0	0.0
TNPS	0.0	23.8	24.2	23.8
Wash Oil	0.0	36.4	15.2	0.0
H2O	59.0	60.5	58.3	53.7
Hydrogen	175.5	170.8	175.7	175.7
TOTAL	1195.3	1233.9	1231.5	1196.4
Products, gms/hr				
Hydrogen	146.0	141.3	152.9	149.6
C1 Gas	32.4	29.2	22.6	26.5
C2 Gas	25.8	23.8	16.8	19.7
C3 Gas	30.2	29.2	18.3	21.5
C4 Gas	25.5	26.4	15.1	18.0
C5 Gas	14.9	18.9	9.4	12.2
C6-C7 Gas	14.7	18.1	3.6	5.8
CO	6.7	9.3	7.2	8.1
CO2	0.4	1.0	2.0	0.7
H2S	29.3	29.5	26.5	27.8
Calculated NH3	4.4	4.0	3.6	3.6
Hot Separator Overhead (O-4)	251.6	250.4	272.9	278.4
Hot Separator Bottoms (O-3)	423.9	453.3	492.8	440.3
KO's	26.2	37.3	27.7	26.9
Sour Water	163.2	162.2	160.1	157.4
TOTAL	1195.3	1233.9	1231.5	1196.4
Material Recovery, W% Total Feed	100.0	100.0	100.0	100.0

Table 3.5 Average Normalized Yields

Condition	1	2	3	4
Periods for Average	6A-7A	7B-9A	9B-11B	12A-13B
Yields, W% maf Fresh Feed				
C1 Gas	3.87	3.63	2.62	3.10
C2 Gas	3.08	2.94	1.92	2.29
C3 Gas	3.61	3.63	2.10	2.51
C4 Gas	3.05	3.35	1.80	2.16
C5 Gas	1.78	2.39	1.14	1.46
C6-C7 Gas	1.74	2.29	0.42	0.69
CO	0.80	1.18	0.84	0.97
CO2	0.05	0.13	0.22	0.08
H2S	2.43	2.42	2.01	2.22
NH3	0.53	0.48	0.43	0.43
IBP-975F Oil	64.06	62.42	61.32	62.71
975F+ Oil	13.28	13.91	21.65	18.75
IOM (Insoluble Organic Matter)	2.18	2.07	3.53	2.65
Water	3.29	3.02	2.94	3.34
Total	103.75	103.85	102.95	103.37
Hydrogen Consumption	3.75	3.85	2.95	3.37

Figure 3-1 : Simplified Flow Diagram




 Hydrocarbon Technologies Inc. 1301 New York Ave. Lawrenceville, NJ	TITLE: UNIT 245 - GENERAL TWO STAGE SIMPLIFIED FLOW DIAGRAM		
	REVISED BY:	DATE:	REV:
	Michael D. Elwell	245SF010	
	DATE: 6/04/01	DESIGNED BY: [Signature]	APP: [Signature]

Figure 3-2 : First Stage Reactor Assembly Diagram

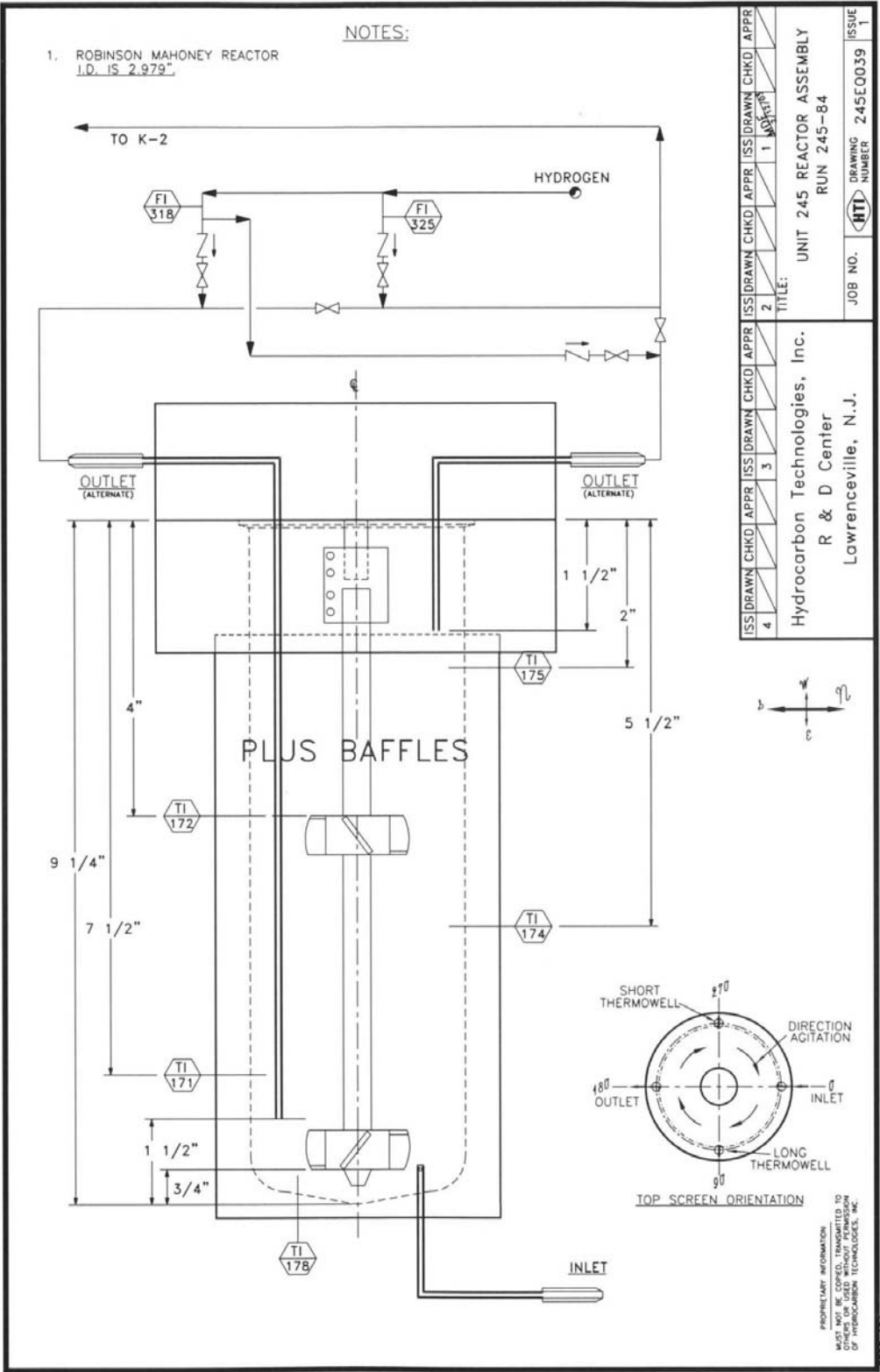


Figure 3-3 : 245-84, Coal Conversion

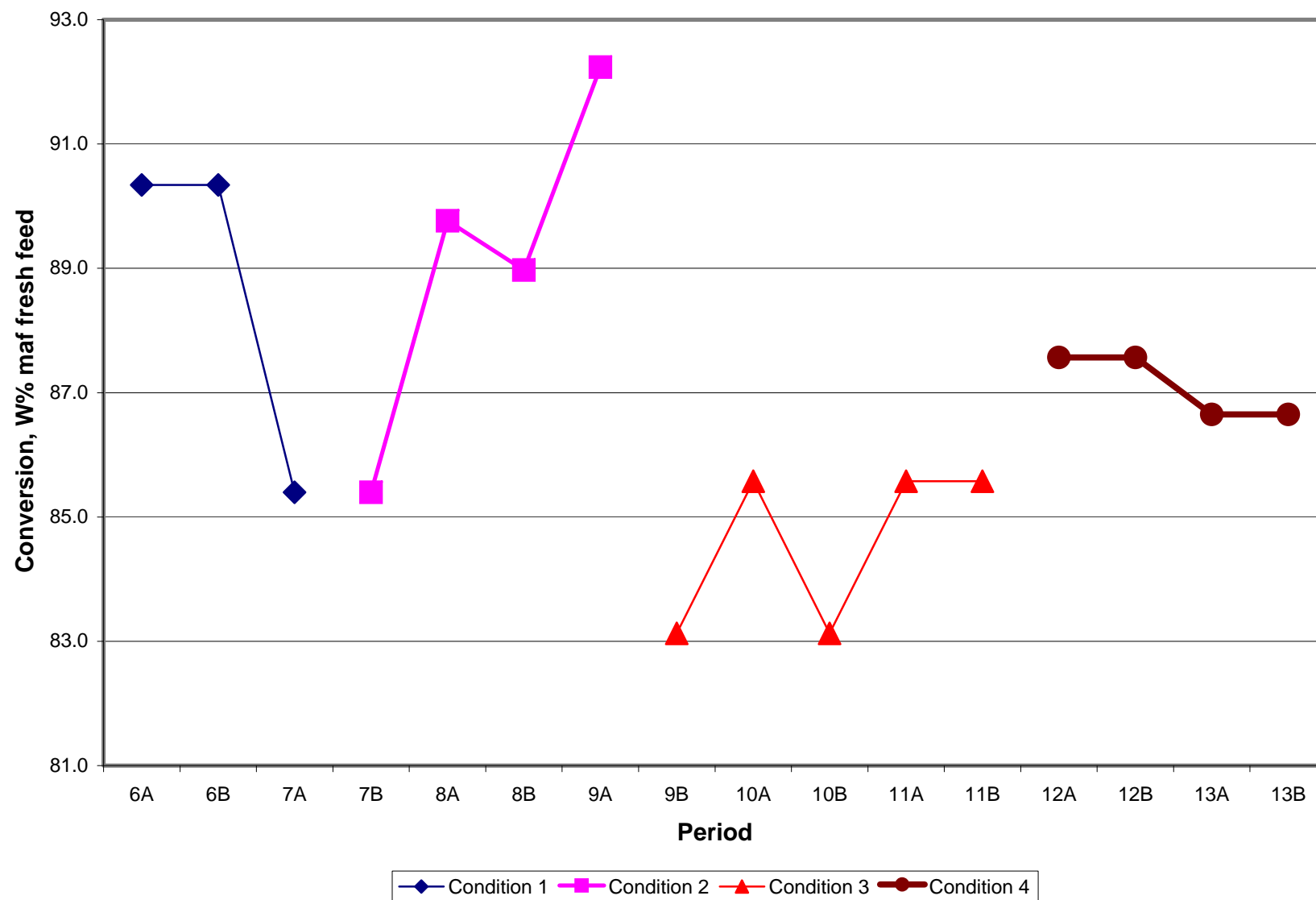


Figure 3-4 : 245-84, Resid Conversion

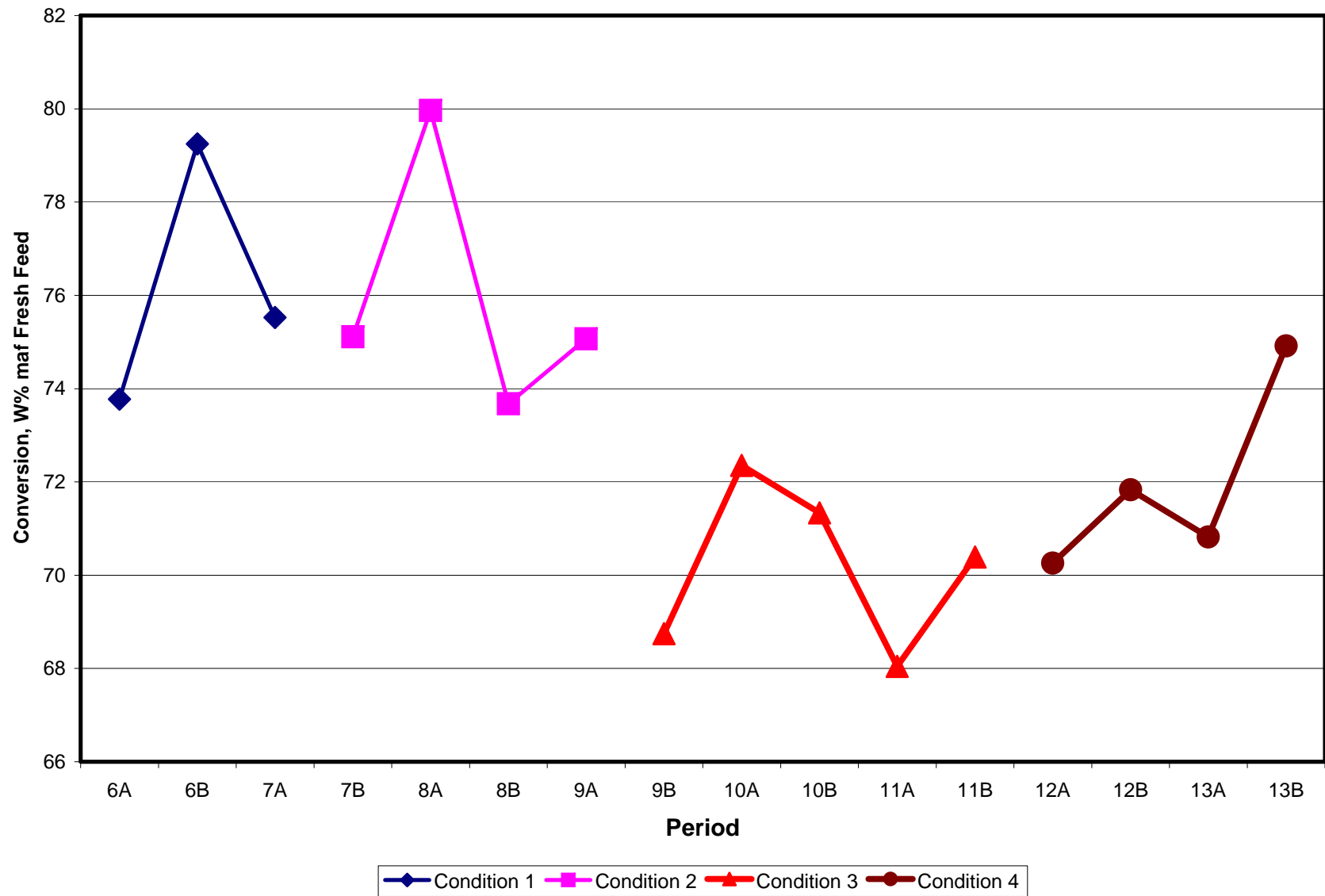


Figure 3-5 : 245-84, Hydrogen Consumption and IOM yield

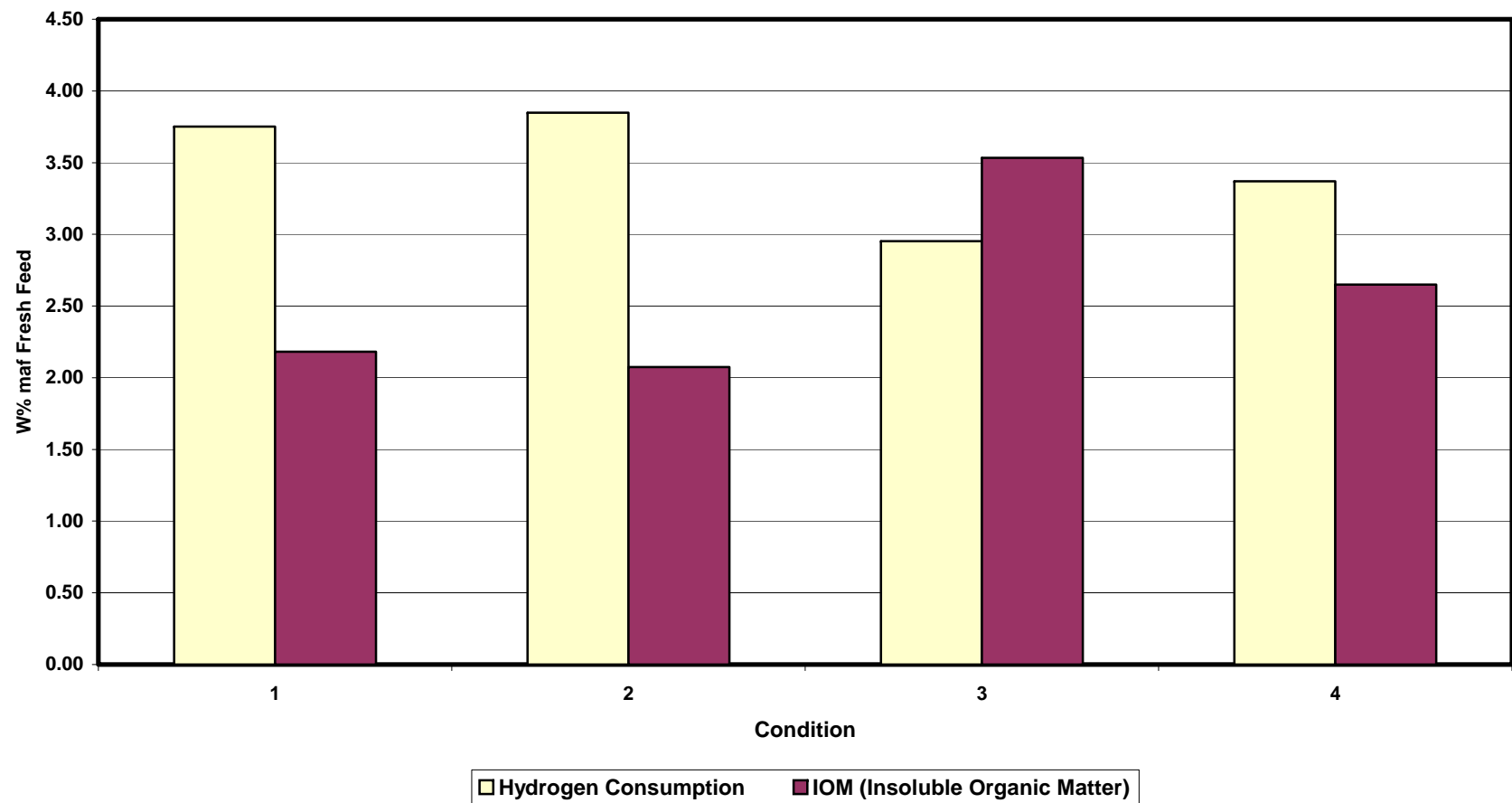


Figure 3-6 : 245-84, Product Yields

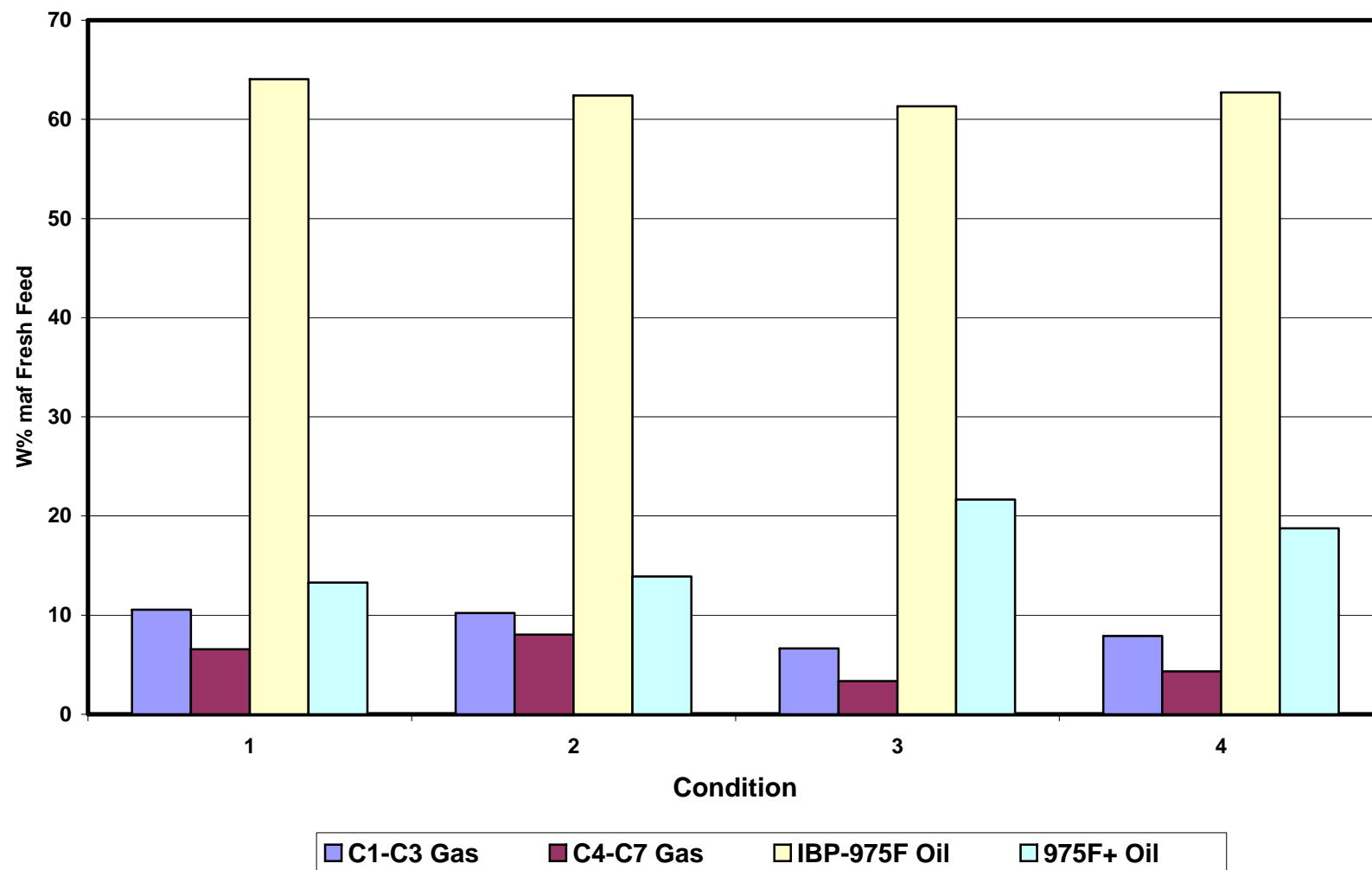
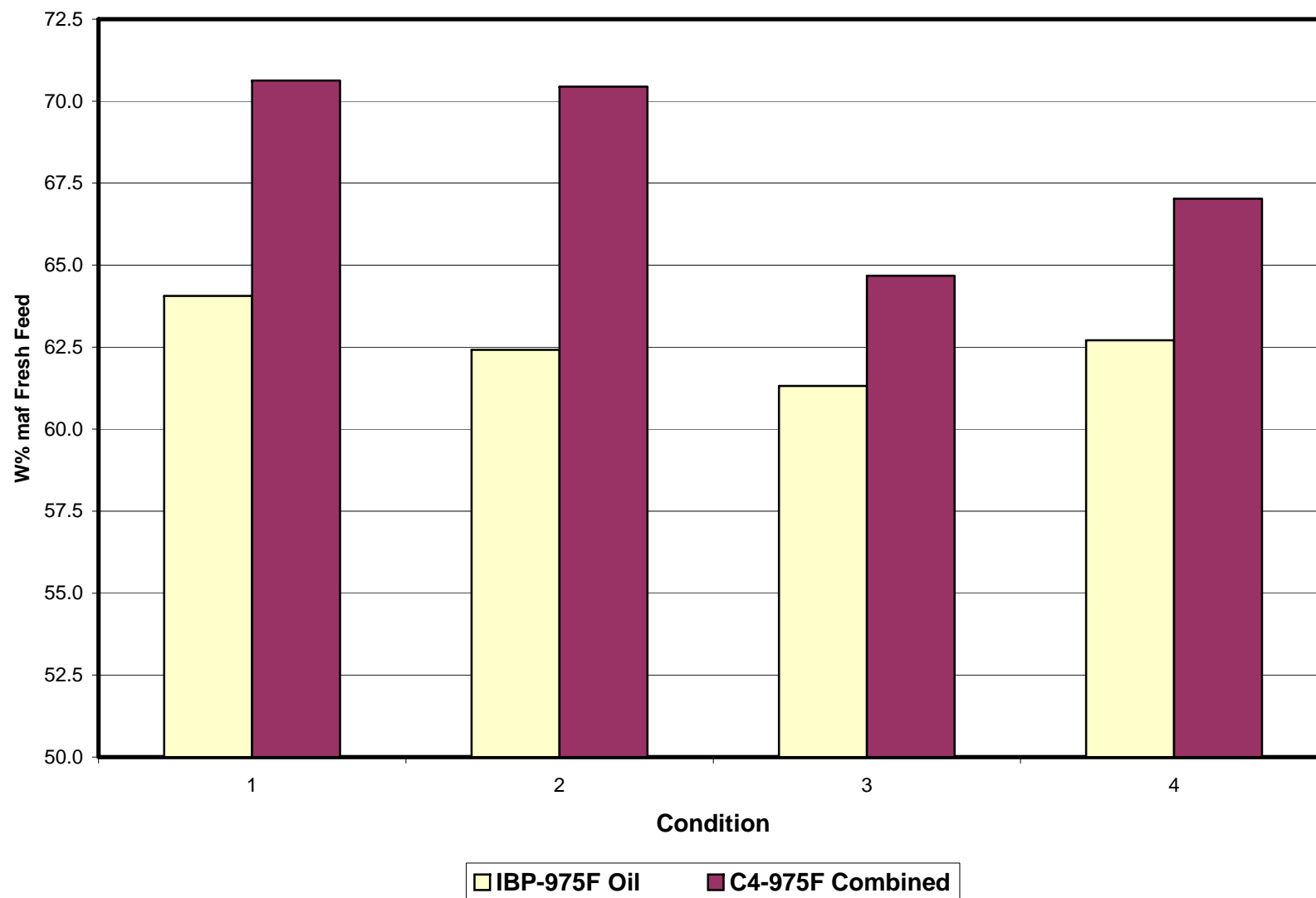


Figure 3-7 : 245-84, C4-975+ Yield Comparison



4.0 Conclusions

The use of sulfur powder versus TNPS as a sulfiding additive has no significant effect on coal conversion, resid conversion, hydrogen consumption or product yield.

The effect of dropping the first stage reactor volume and lowering the shear rate negatively impacts coal conversion, resid conversion, hydrogen consumption or product yield.

Low volume and a high shear rate compared to high volume and high shear rate are surprisingly similar in performance. The low volume and high shear rate condition has nearly the identical coal conversion to the high volume and high shear rate conditions. The reduction in performance as measured by , resid conversion, hydrogen consumption or product yield is slight.

The effect of low volume and a high shear rate compared to low volume and low shear rate is very straightforward. The low volume and high shear rate condition always shows an improvement in performance as measured by coal conversion, resid conversion, hydrogen consumption or product yield. Increased reactor turbulence/agitation improves reaction performance.

5.0 Recommendations

It was demonstrated that the conversion rates were improved by increasing the turbulence (agitation.) As would be expected, the residence times resulting from lowering the reactor volume (Tests 3 & 4) dropped the overall performance of the system.

A valuable future study would be the determination of conversion upon recycle of the individual 975F(+) products. The IBP-975F oil yields (63.2%) (see Table 3.5) for Tests 1 & 2 at high turbulence (agitator RPM) and high reactor volumes were not very different from that for the high RPM agitation used in low volume Test 4...i.e. 62.7%. However, for low reactor volume, high agitation Test 4 the 975F(+) oil yield of 18.8% significantly exceeds that for high volume, high agitation tests 1 & 2 (13.6%.) Prior work has indicated that upon recycle of the 975F(+) a significant portion of the material will convert to 975F(-) material. This would bring the performance of Condition 4 much closer to Conditions 1 & 2.

Another confirmatory study that would be valuable to perform would be to determine the effect of turbulence on system performance when the reactor volumes are high. Could the performance seen in the first two conditions be further improved by increasing the agitation?

Another study that would be valuable to perform would be to determine how much of the decrease in performance from the decrease in reactor volume can be made up by an increase in turbulence. This study definitely showed that a portion of the decrease can be negated by increased turbulence; however, the overall performance was still lower. With a much higher degree of turbulence can the performance of a low volume reactor system be equal to or even surpass that of a high volume reactor system with a fixed degree of turbulence?

Appendix A Detailed Results 245-84

Table A-1, Run 245-84 Analytical Results Hot Separator Overheads (O-4 Bottoms)

Balance Period	6A	6B	7A	7B	8A	8B	9A	9B	10A	10B	11A	11B	12A	12B	13A	13B
Oil / Water Separation																
Oil, gms	3160.5	3151.3	2914.3	1605.2	4471.0	2879.0	2663.9	2606.2	2530.8	2694.1	2248.2	2378.3	2415.9	2418.9	2325.5	2428.8
Water, gms	1102.6	1089.3	1089.7	1025.6	1110.3	1078.1	1045.5	1071.9	1034.9	1061.7	1064.2	994.9	977.7	999.1	960.8	987.0
Low Temp Distillation, °F																
IBP (0.5 W%)		154	154			128	143			149		178		172		172
5 W%		271	271			258	258			267		274		275		276
10 W%		315	314			289	289			289		302		303		304
15 W%		344	344			326	326			325		340		340		340
20 W%		371	369			354	355			356		369		367		367
25 W%		400	399			384	384			388		401		400		400
30 W%		424	422			408	409			417		426		425		425
35 W%		447	447			432	433			442		452		450		449
40 W%		467	466			455	456			463		476		472		472
45 W%		489	489			479	480			488		496		492		492
50 W%		510	509			498	500			510		519		516		516
55 W%		533	531			520	521			534		545		540		540
60 W%		554	553			546	547			559		568		563		563
65 W%		576	576			568	570			581		590		585		585
70 W%		600	600			590	591			605		614		609		609
75 W%		624	625			615	616			631		641		635		635
80 W%		650	652			643	643			660		668		663		664
85 W%		676	678			672	672			690		696		693		693
90 W%		708	713			704	703			723		731		726		727
95 W%		753	757			750	747			770		776		773		774
FBP (99.5 W%)		848	856			846	842			868		875		873		876
Elemental Analysis Oil, W%	6B			8B	8B			10B	10B		11B		12B		13B	
C	85.50	85.50	85.00	85.11	85.11	85.11	85.61	84.85	84.85	84.85	84.70	84.70	84.65	84.65	84.89	84.89
H	12.20	12.20	12.22	12.31	12.31	12.31	12.31	12.35	12.35	12.35	12.24	12.24	12.25	12.25	12.26	12.26
N	0.74	0.74	0.66	0.72	0.72	0.72	0.67	0.63	0.63	0.63	0.82	0.82	0.76	0.76	0.89	0.89
S	0.85	0.85	0.89	0.85	0.85	0.85	0.77	1.19	1.19	1.19	1.24	1.24	1.13	1.13	1.13	1.13
O, by difference	0.71	0.71	1.23	1.01	1.01	1.01	0.64	0.98	0.98	0.98	1.00	1.00	1.21	1.21	0.83	0.83

Table A-2, Run 245-84 Analytical Results Hot Separator Bottoms (O-3 Bottoms)

Balance Period	6A	6B	7A	7B	8A	8B	9A	9B	10A	10B	11A	11B	12A	12B	13A	13B
	6B		7A					10B	10B		11B		12B		13B	
QI, W%	12.23	12.23	12.50	12.50	10.18	12.39	9.75	13.39	13.39	13.39	12.36	12.36	13.34	13.34	12.00	12.00
ASH, W%	6.16	6.16	5.02	5.02	4.98	5.83	5.44	4.92	4.92	4.92	5.00	5.00	5.88	5.88	5.08	5.08
API Gravity	-2.5	-2.5	-3.6	-3.6	-0.5	-1.9	1.0	-3.3	-3.3	-3.3	-2.5	-2.5	-3.5	-3.5	-2.3	-2.3
D-1160 Distillation, °+B5F																
IBP	392.00	392.0	442.0	360.0	429.0	398.0	398.0			503.0		460.0		450.0		440.0
5 V%	523.00	523.0	545.0	488.0	560.0	523.0	512.0			625.0		562.0		590.0		550.0
10 V%	583.00	583.0	603.0	548.0	607.0	590.0	572.0			686.0		645.0		630.0		610.0
20 V%	668.00	668.0	675.0	638.0	675.0	654.0	646.0			770.0		722.0		715.0		680.0
30 V%	725.00	725.0	725.0	700.0	742.0	740.0	716.0			820.0		792.0		774.0		750.0
40 V%	789.00	789.0	774.0	751.0	793.0	783.0	779.0			880.0		845.0		836.0		800.0
50 V%	828.00	828.0	819.0	808.0	837.0	820.0	820.0			910.0		891.0		905.0		870.0
60 V%	900.00	900.0	885.0	860.0	888.0	884.0	886.0									
70 V%																
Volume %																
IBP-975 °F	67.00	67.0	67.0	73.0	66.0	65.0	66.0			54.0		54.0		54.0		50.0
975 °F+	33.00	33.0	33.0	27.0	34.0	35.0	34.0			46.0		46.0		46.0		40.0
Weight %																
IBP-975 °F	58.48	58.48	58.27	66.15	58.52	56.87	59.27			47.11		47.10		46.38		50.00
975 °F+	38.55	38.55	38.83	30.99	38.70	39.65	37.55			50.63		49.30		50.09		46.00
Loss	2.97	2.97	2.90	2.86	2.78	3.48	3.18			2.26		3.60		3.53		3.00
Measured Elemental Analysis, W%	6B		7A					10B	10B		11B		12B		13B	
C	82.24	82.24	82.45	82.45	83.08	83.52	83.24	82.82	82.82	82.82	82.80	82.80	82.62	82.62	83.06	83.06
H	7.73	7.73	7.64	7.64	8.15	7.98	8.50	7.85	7.85	7.85	7.85	7.85	7.87	7.87	8.03	8.03
N	0.75	0.75	0.80	0.80	0.73	0.73	0.83	0.79	0.79	0.79	0.78	0.78	0.74	0.74	0.78	0.78
S	2.26	2.26	2.26	2.26	2.07	2.30	1.81	2.43	2.43	2.43	2.30	2.30	2.40	2.40	2.19	2.19
Sum Elements	99.14	99.14	98.17	98.17	99.01	100.36	99.82	98.81	98.81	98.81	98.73	98.73	99.51	99.51	99.14	99.14
Norm. Elemental Analysis, W%	6B		7A			Norm.		10B	10B		11B		12B		13B	
C	82.24	82.24	82.45	82.45	83.08	82.42	83.24	82.82	82.82	82.82	82.80	82.80	82.62	82.62	83.06	83.06
H	7.73	7.73	7.64	7.64	8.15	7.88	8.50	7.85	7.85	7.85	7.85	7.85	7.87	7.87	8.03	8.03
N	0.75	0.75	0.80	0.80	0.73	0.72	0.83	0.79	0.79	0.79	0.78	0.78	0.74	0.74	0.78	0.78
S	2.26	2.26	2.26	2.26	2.07	2.27	1.81	2.43	2.43	2.43	2.30	2.30	2.40	2.40	2.19	2.19
Ash						5.75										
O, by difference	0.86	0.86	1.83	1.83	0.99	0.96	0.18	1.19	1.19	1.19	1.27	1.27	0.49	0.49	0.86	0.86

**Table A-3, Run 245-84, China Coal/Hondo Oil
Gas Analysis**

Period	6A	6B	7A	7B	8A	8B	9A	9B	10A	10B	11A	11B	12A	12B	13A	13B
Fresh Hydrogen Rate To K-1, scf/hr	66.68	66.50	66.68	63.87	66.68	64.43	66.68	66.68	66.68	66.68	66.68	66.67	66.68	66.67	66.67	66.67
Fresh Hydrogen Rate To Purge, scf/hr	6.19	6.26	6.18	4.59	4.74	6.23	6.33	6.28	6.25	6.25	6.25	6.25	6.25	6.24	6.24	6.25
Vent Gas Rate, scf	788.00	804.58	809.06	770.20	788.58	767.73	786.25	803.60	799.15	816.98	833.97	833.23	825.37	824.28	816.89	818.73
Vent Gas Analysis, V%																
Component	AVG 5&6B		AVG 8B&9A		AVG 8B&9A										AVG 12B&13A	
Hydrogen	92.210	91.396	93.729	92.515	92.515	92.879	92.150	95.606	96.193	95.463	95.246	95.092	95.448	94.696	95.346	95.021
Methane	2.634	3.174	1.900	2.083	2.083	2.016	2.150	1.360	1.309	1.342	1.267	1.340	1.382	1.528	1.409	1.469
Ethylene	0.054	0.060	0.037	0.041	0.041	0.040	0.041	0.037	0.037	0.038	0.033	0.038	0.035	0.039	0.036	0.038
Ethane	1.113	1.270	0.750	0.867	0.867	0.830	0.903	0.499	0.497	0.503	0.447	0.502	0.506	0.573	0.529	0.551
Propene	0.098	0.112	0.067	0.080	0.080	0.079	0.080	0.057	0.059	0.061	0.058	0.068	0.059	0.070	0.060	0.065
N-Propane	0.853	0.943	0.555	0.683	0.683	0.650	0.715	0.319	0.336	0.345	0.287	0.375	0.339	0.400	0.355	0.378
Butenes	0.071	0.084	0.059	0.069	0.069	0.073	0.065	0.036	0.052	0.039	0.042	0.068	0.048	0.063	0.039	0.051
N-Butane	0.415	0.431	0.292	0.347	0.347	0.335	0.359	0.120	0.168	0.140	0.113	0.203	0.150	0.193	0.141	0.167
I-Butane	0.117	0.132	0.086	0.106	0.106	0.104	0.108	0.043	0.050	0.047	0.046	0.061	0.050	0.076	0.051	0.064
Pentenenes	0.034	0.032	0.046	0.046	0.046	0.043	0.049	0.000	0.039	0.000	0.005	0.043	0.036	0.043	0.000	0.022
N-Pentane	0.129	0.122	0.127	0.141	0.141	0.135	0.147	0.037	0.083	0.042	0.037	0.094	0.072	0.093	0.042	0.068
I-Pentane	0.106	0.107	0.097	0.114	0.114	0.110	0.117	0.032	0.062	0.036	0.033	0.071	0.053	0.071	0.037	0.054
MeCyclo C5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cyclo C6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
N-Hexane	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Me-Pentane	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C6 and C7	0.174	0.145	0.249	0.206	0.206	0.241	0.171	0.061	0.019	0.073	0.005	0.017	0.014	0.120	0.006	0.063
CO	0.321	0.305	0.298	0.379	0.379	0.375	0.383	0.247	0.156	0.233	0.273	0.289	0.240	0.259	0.254	0.257
CO2	0.034	0.000	0.000	0.026	0.026	0.000	0.051	0.000	0.000	0.032	0.157	0.000	0.000	0.021	0.015	0.018
H2S	0.789	1.024	0.850	1.116	1.116	1.220	1.012	0.615	0.290	0.640	0.916	0.808	0.722	0.880	0.677	0.779
Nitrogen	0.615	0.452	0.625	0.894	0.894	0.636	1.152	0.682	0.461	0.682	0.723	0.657	0.585	0.611	0.760	0.686
Oxygen	0.237	0.211	0.233	0.291	0.291	0.234	0.347	0.249	0.189	0.284	0.312	0.274	0.261	0.264	0.243	0.254
TOTAL	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table A-4: Normalized Material Balance & Operating Conditions

Operating Conditions

Condition Period	1 6A	1 6B	1 7A	2 7B	2 8A	2 8B	2 9A	3 9B
Temperature, F								
First Stage	825.2	825.5	823.6	819.9	826.5	825.4	825.5	825.1
Second Stage	842.1	841.9	837.6	835.1	839.4	841.7	846.7	838.3
Hot Separator	653.1	655.1	657.5	647.4	654.7	654.1	651.9	658.9
Agitator Speed, rpm's								
First Stage	1183	1188	1196	1206	1217	1211	1212	320
Second Stage	1224	1224	1204	1211	1208	1200	1209	1200
Unit Back Pressure, psig	2492.8	2500	2500	2462.2	2500	2450.8	2498.9	2500.1
Reactor Volume, cc's								
First Stage	850	850	850	850	850	850	850	140
Second Stage	850	850	850	850	850	850	850	850
Actual Material Recovery, W% Total Feed	95.2	98.3	97.2	87.6	94.7	94.3	95.1	97.0
SV, gms fresh feed / cc reactor volume								
First Stage Only	0.706	0.728	0.700	0.758	0.649	0.659	0.699	0.113
Second Stage Only	0.706	0.728	0.700	0.758	0.649	0.659	0.699	0.686

Normalized Material Balance

Feeds, gms/hr								
Coal	298.9	289.5	301.7	229.5	327.5	320.4	297.4	304.1
Oil	598.7	579.9	604.2	459.8	655.9	641.7	595.7	609.2
Gelcat	61.4	59.5	62.0	47.2	67.3	65.8	61.1	62.5
Sulfur Powder	9.0	8.7	9.0	0.0	0.0	0.0	0.0	0.0
TNPS	0.0	0.0	0.0	18.6	26.6	26.0	24.1	24.7
Wash Oil	0.0	0.0	0.0	145.7	0.0	0.0	0.0	0.0
H2O	60.4	54.5	62.1	55.8	60.2	64.8	61.4	62.4
Hydrogen	175.6	175.3	175.6	165.0	172.1	170.3	175.9	175.8
TOTAL	1204.0	1167.4	1214.6	1121.5	1309.5	1289.0	1215.6	1238.6
Products, gms/hr								
Hydrogen	143.8	142.4	151.8	135.8	145.7	139.0	144.7	153.2
C1 Gas	34.8	40.0	22.3	39.4	19.4	28.8	29.4	22.0
C2 Gas	28.8	31.3	17.2	32.0	15.8	23.3	24.1	16.2
C3 Gas	34.4	36.4	19.9	39.4	19.4	28.5	29.7	16.6
C4 Gas	28.7	29.4	18.5	35.6	17.5	26.4	26.2	11.6
C5 Gas	15.9	14.7	14.2	25.4	12.5	18.5	19.1	5.0
C6-C7 Gas	14.4	11.4	18.2	24.3	12.0	21.5	14.6	6.2
CO	7.4	6.7	6.1	12.5	6.2	9.4	9.1	7.0
CO2	1.2	0.0	0.0	1.3	0.7	0.0	1.9	0.0
H2S	30.1	29.3	28.4	21.7	32.4	32.1	31.9	26.9
Calculated NH3	4.6	4.6	4.2	2.5	4.5	4.9	4.2	4.0
Hot Separator Overhead (O-4)	276.1	257.9	220.9	205.5	275.0	279.7	241.4	272.5
Hot Separator Bottoms (O-3)	396.6	384.1	491.1	373.7	537.4	455.1	446.8	505.2
KO's	20.4	20.4	37.9	45.3	35.4	44.9	23.6	24.1
Sour Water	166.8	158.9	163.9	127.0	175.8	177.0	168.9	168.3
TOTAL	1204.0	1167.4	1214.6	1121.5	1309.5	1289.0	1215.6	1238.6
Material Recovery, W% Total Feed	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table A-4 (cont.): Normalized Material Balance & Operating Conditions

Operating Conditions

Condition Period	3 10A	3 10B	3 11A	3 11B	4 12A	4 12B	4 13A	4 13B
Temperature, F								
First Stage	830.9	826.2	820.1	825.4	822.8	824.8	823.9	823.2
Second Stage	838.6	841.1	834.9	837.2	837.1	839.5	836.0	839.3
Hot Separator	650.4	646.7	647.0	648.8	648.5	648.4	651.3	649.0
Agitator Speed, rpm's								
First Stage	289	291	300	304	1191	1190	1194	1196
Second Stage	1200	1215	1213	1213	1192	1219	1211	1214
Unit Back Pressure, psig	2499.9	2500	2499.9	2499.9	2500	2500	2499.9	2500
Reactor Volume, cc's								
First Stage	140	140	140	140	140	140	140	140
Second Stage	850	850	850	850	850	850	850	850
Actual Material Recovery, W% Total Feed	93.5	93.2	95.7	97.3	96.6	95.2	95.1	91.7
SV, gms fresh feed / cc reactor volume								
First Stage Only	0.118	0.111	0.111	0.116	0.116	0.115	0.117	0.119
Second Stage Only	0.713	0.675	0.677	0.701	0.707	0.699	0.713	0.724

Normalized Material Balance

Feeds, gms/hr								
Coal	266.7	312.8	310.6	298.8	296.6	300.5	293.6	285.3
Oil	534.2	626.5	622.1	598.6	594.0	601.9	588.1	571.5
Gelcat	54.8	64.2	63.8	61.4	60.9	61.7	60.3	58.6
Sulfur Powder	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TNPS	21.6	25.4	25.2	24.2	24.0	24.4	23.8	23.1
Wash Oil	76.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H2O	62.2	54.9	58.6	53.3	51.8	51.9	50.7	60.3
Hydrogen	175.7	175.7	175.7	175.7	175.7	175.7	175.7	175.7
TOTAL	1191.3	1259.5	1255.9	1212.0	1203.1	1216.0	1192.1	1174.6
Products, gms/hr								
Hydrogen	152.0	152.7	153.7	152.7	148.0	146.4	151.8	152.1
C1 Gas	23.1	21.2	24.9	22.1	28.1	29.3	25.0	23.5
C2 Gas	17.6	15.9	17.6	16.6	20.5	21.9	18.7	17.6
C3 Gas	19.0	17.5	18.5	20.0	22.1	24.6	20.1	19.3
C4 Gas	17.1	12.8	14.2	19.7	18.2	22.9	14.7	16.2
C5 Gas	14.5	5.5	6.6	15.4	14.6	17.8	6.3	10.2
C6-C7 Gas	2.1	7.2	0.6	1.8	1.8	14.4	0.7	6.3
CO	4.8	6.4	9.4	8.3	8.5	8.7	7.9	7.2
CO2	0.0	1.4	8.5	0.0	0.0	1.1	0.7	0.8
H2S	22.8	27.6	28.2	27.3	28.0	28.6	27.7	27.0
Calculated NH3	3.0	4.1	3.5	3.5	4.0	4.2	3.1	3.1
Hot Separator Overhead (O-4)	291.4	279.4	276.2	245.0	310.3	293.5	262.9	247.0
Hot Separator Bottoms (O-3)	443.0	519.5	507.6	488.4	412.2	417.6	472.3	459.0
KO's	25.7	24.9	28.7	35.1	30.0	27.1	26.3	24.3
Sour Water	155.2	163.2	157.9	156.1	156.9	157.7	154.0	161.0
TOTAL	1191.3	1259.5	1255.9	1212.0	1203.1	1216.0	1192.1	1174.6
Material Recovery, W% Total Feed	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0