U.S. Department of Energy
Federal Energy Technology Center

Refining and End Use Study of Coal Liquids

Contract No. DE-AC22-93PC91029

Quarterly Report
July - September 1997

Section 1

Introduction and Summary

This report is Bechtel's sixteenth quarterly technical progress report and covers the period of July 1, 1997 through September 30, 1997.

1.1 Introduction

Bechtel National Inc, with Southwest Research Institute, Amoco Oil R&D, and the M.W. Kellogg Co. as subcontractors, initiated a study on November 1, 1993, for the U.S. Department of Energy's (DOE's) Federal Energy Technology Center (FETC) to determine the most cost effective and suitable combination of existing petroleum refinery processes needed to make specification transportation fuels or blending stocks, from direct and indirect coal liquefaction product liquids. This 47-month study, with an approved budget of $4.4 million dollars, is being performed under DOE Contract Number DE-AC22-93PC91029.

A key objective is to determine the most desirable ways of integrating coal liquefaction liquids into existing petroleum refineries to produce transportation fuels meeting current and future, e.g. year 2000, Clean Air Act Amendment (CAAA) standards. An integral part of the above objectives is to test the fuels or blends produced and compare them with established ASTM fuels. The comparison will include engine tests to ascertain compliance of the fuels produced with CAAA and other applicable fuel quality and performance standards.

The final part of the project includes a detailed economic evaluation of the cost of processing the coal liquids to their optimum products. The cost analyses is for the incremental processing cost; in other words, the feed is priced at zero dollars. The study reflects costs for operations using state of the art refinery technology; no capital costs for building new refineries is considered. Some modifications to the existing refinery may be required. Economy of scale dictates the minimum amount of feedstock that should be processed.

To enhance management of the study, the work has been divided into two parts, the Basic Program and Option 1.

The objectives of the Basic Program are to:

- Characterize the coal liquids
- Develop an optimized refinery configuration for processing indirect and direct coal liquids
- Develop a LP refinery model with the Process Industry Modeling System (PIMS) software.

The work has been divided into six tasks.

Task 1 - Development of a detailed project management plan for the Basic Program
Task 2 - Characterization of four coal liquid feeds supplied by DOE
Task 3 - Optimization of refinery processing configurations by linear programming
Task 4 - Pilot plant analysis of critical refinery process units to determine yield, product quality and cost assumptions. Petroleum cuts, neat coal liquids, and coal liquids/petroleum blends will be processed through the following process units: reforming, naphtha and distillate hydrotreating, catalytic cracking and hydrocracking.
Task 5 - Development of the project management plan for Option 1

Task 6 - Project management of the Basic Program and Option 1

The objectives of Option 1 are to:

- Confirm the validity of the optimization work of the Basic Program
- Produce large quantities of liquid transportation fuel blending stocks
- Conduct engine emission tests
- Determine the value and the processing costs of the coal liquids

This will be done by processing the coal liquids as determined by the optimization work, blending and characterizing the product liquids, and running engine emission tests of the blends. Option 1 has been divided into three tasks.

Task 1 - Based on the pilot plant and linear programming optimization work of the Basic Program, production runs of pilot plants (hydrotreating, reforming, catalytic cracking, and hydrocracking) will be conducted to produce sufficient quantities for blending and engine testing.
Task 2 - The pilot plant products will be blended, characterized, and engine tested
Task 3 - An economic analysis will be conducted to determine the costs of processing the coal liquids through the existing refinery

Table 1-1 shows which organization has the primary responsibility for each task.

1.2 Summary

The major efforts conducted during the third quarter of 1997 was in the area of:

- Basic Program reforming pilot plant testing

Table 1-1 Project Task Primary Responsibility Chart

Task	Description	Bechtel	SwRI	Amoco	Kellogg
1	Project Management Plan (PMP) development	x			
2	Feed characterization		x		
3	Linear programming	x			
4	Pilot plant analysis -				
	Cat cracking of DL liquids				x
	Cat cracking of indirect wax			x	
	Hydrocracking of wax			x	
	Fractionation, reforming, hydrotreating, etc.		x		
5	Option 1 PMP development	x			
6	Project management	x			
Option 1 - Task 1	Pilot plant production -				
	Cat cracking of DL liquids and wax				x
	All other production work		x		
Option 1 - Task 2	Fuel blending, characterizing, engine testing		x		
Option 1 - Task 3	Economic analysis	x			

- x = key participant

Section 2

SwRI Activities

2.0 Pilot Plant, 450 Psi Reformer Experiments Run 13 (RR13)

2.0.1 Background

The reforming experiments were made using two coal-derived liquids, a petroleum liquid and a blend of a coal and petroleum-derived liquid. The coal-derived liquids were naphthas previously distilled from the DL1 and DL2 “full-range” coal liquids, then hydrotreated. The hydrotreating experiments and the hydrotreating for test fuel production were described in previous reports. The petroleum liquid was a sample of a commercial refinery reformer feed. The main emphasis in these experiments was the difference between the DL2 naphtha and the petroleum naphtha, and the most complete sets of experimental data were obtained for those two feeds. The SwRI designation for this set of experiments was “RR13".

Table 2-1 shows the properties of the feeds. The high concentration of naphthenes in the coal-derived liquids contrasts with the concentration in the petroleum liquid. The previous hydrotreating had made all of the feeds high in hydrogen concentration, but the coal-derived liquids had higher specific gravities in agreement with the high concentration of naphthenes. Naphthenes have a higher density than non-cyclic hydrocarbons. The naphthenes convert to aromatics readily during the reforming operation and contribute to high octane number in the product, so the highly naphthenic coal-derived liquids provide a desirable reformer feed.

During earlier reforming experiments (SwRI designation RR9), significant amounts of cracking and catalyst deactivation occurred resulting in data of limited value. In light of the earlier experience, the catalyst bed was replaced for RR13, and two significant changes were made in the operating procedures to enable the completion of the reforming experiments with only minor catalyst deactivation. Those changes were:

- The operating pressure was raised from 250 to 450 psi in accordance with the catalyst manufacturer’s recommendation.
- The severity of the overall matrix was reduced, and the order of the experiments was changed, scheduling the high-temperature conditions for the end.

The catalyst, Englehard #-302, is a familiar, standard variety of monometallic platinum catalyst. It is typically used at higher pressures than more specialized reforming catalysts commonly found today. For this catalyst, higher hydrogen pressure suppresses coke formation and extends catalyst life.

The modified matrix encompassed the processing variables in the range of 820 F to 920 F, and liquid hourly space velocity (LHSV) from 1 to 3 Hr^{-1} A high severity excursion was added during the run. The selected order of experiments placed the high-temperature points toward the end, so any catalyst deactivation due to high-temperature operation would not affect most of the lower temperature experiments. Repeat experiments with petroleum liquid indicated a small decline in catalyst activity during the processing, but no major, precipitous drops.

SwRI Activities

The reforming experiments were accomplished in three, week-long processing sessions. Figure 2-1 shows the experimental matrix with the temperatures and space velocities used to produce each sample. A one-liter reactor and associated small equipment of the pilot plant was used for the reforming. The reactor contained 0.2686 gallons (1.657 pounds) of equilibrium reforming catalyst.

The special catalyst packing used for these experiments distributed the heat load. The endothermic reaction requires heat, supplied by heaters surrounding the reactor, in proportion to the amount of feed undergoing reaction. Ideally, for both ease of control and interpretation of results, a flat temperature profile is preferred with no significant variation from place to place within the reactor. With the reaction temperature constant, the feed composition and catalyst activity largely determine the reaction rate. Near the entrance, the feed is high in saturates and low in aromatics, which, with all other factors equal, would cause a higher reaction rate than would occur toward the exit of the reactor where the relative quantities of saturates and aromatics are closer to the equilibrium values. The catalyst was diluted with tabular alumina, and it was packed with a dilution gradient so the catalyst was most diluted near the reactor entrance and most concentrated near the reactor exit. The diluted catalyst near the entrance slowed the reaction where it would otherwise have been high, and the concentrated catalyst near the exit increased the rate where it otherwise would have been slow. The net result provided reaction at a fairly uniform rate over the catalyst bed making the heat load more evenly distributed with the reactor temperature easier to control.

The pilot plant experiment involved changing the reforming reactor operating conditions and measuring the changes in product properties and yields. Changes to the temperature and the reactor residence time, or space velocity, provided products with varying octane quality, hydrogen and aromatics concentrations. Space velocity is an inverse measure of residence time equal to the feed flowrate divided by the catalyst volume (undiluted) in the reactor in consistent units. The pressure was maintained at 450 psi throughout the run except for two points at the end, where the effect of lower pressure was explored. Sample point W was made at 300 psi and sample X at 200 psi. Samples U and V were run at a higher, 950 F, to further define the effect of severity on yield.

2.0.2 Product Properties

Table 2-2 contains a summary of the product sample properties. The specific gravity was measured with a Paar densitometer, ASTM method D 4052, and the hydrogen concentration was measured by ASTM method D 4808, a nuclear magnetic resonance (NMR) procedure. The aromatics concentrations were measured with a fourier-transform infrared (FTIR) Petrospec instrument, and selected points were confirmed with GC speciation analyses.

Table 2-3 shows the octane quality of the feeds and products. The octane numbers were measured using ASTM methods D 2699 (Research Octane Number, RON) and D 2700 (Motor Octane Number, MON) on the whole bottoms product liquid. Adjustments for butane not having been removed by the stripper and hence having remained in the liquid product were made, although the effect was insignificant in most cases.

SwRI Activities

Figures 2-2 through 2-5 show three-dimensional “drop-line” charts of the product aromatic concentrations. The bottom plane of the box shown in the chart represents the processing severity, varying from least severe (high Liquid Hourly Space Velocity, LHSV, and low temperature) in the lower left corner to highest severity in the back, or upper right corner. This plane is analogous to Figure 2-1, the experimental matrix. The height of the “drop-line” or “stick-pin” indicates the aromatics concentration as a height above the process severity plane. The lighter shaded points without a line extending beneath them are the projections onto the temperature vs aromatics concentration plane at the back, left of the box, or the LHSV vs aromatics concentration plane at the right of the box.

The most pronounced differences in aromatics concentrations resulting from the different feeds occurred at low processing severity. Both of the coal liquids, DL1 and DL2, produced significantly higher aromatics concentrations at low severity than did the petroleum liquid. The results for the blend were intermediate in aromatics concentration, as expexcted. At high severity, both DL1 and DL2 products were higher in aromatics concentrations than the petroleum products, but the differences were smaller. The DL2 aromatics concentrations were slightly higher than DL1. All the samples fit the pattern of increasing aromatics concentration with increasing severity of processing conditions. The variation among several petroleum samples taken at low severity conditions shows the effect of catalyst deactivation, which occurred mostly during the highest temperature portion of the experimental series.

Figures 2-6 through 2-9 show “drop-line” charts of the octane number results. The effect of varying severity resembles the pattern of the aromatics results. The octane numbers for both coal liquids, processed at low severity, were much higher than for petroleum processed at low severity. For the high severity points, both coal liquids gave octane numbers a little higher than the petroleum, but the difference between DL1 and DL2 does not seem to be significant. The blend results were intermediate between its constituent petroleum and DL2 liquids results, but were higher than would be expected based on linear blending. That is, although the petroleum constituted two-thirds of the blends, the blend products had octane numbers closer to the DL2 values than to the petroleum values.

Figure 2-10 shows the octane number-aromatics concentration relationship for all the feeds. The line is a least squares fit with a variance (r^2) of 0.97. Despite the differences in feed properties, there were no apparent differences in the products octane number-aromatics concentration relationships.

Except for the somewhat non-linear octane results of the blend with respect to its components, the changes in aromatics and octane numbers are consistent with the feed properties shown in Table 2-1. The ease of reforming the highly naphthenic coal liquids was readily apparent. With the coal liquids, results were achieved in the mid-range of severity which were comparable or better than the results with petroleum in the high-severity corner of the matrix.

2.0.3 Mass Balances

During the run, process conditions were measured and reported to an automated data collection system. The data included temperatures, pressures, flow rates, weight scale readings and liquid flow rates based on the weight scale readings. Analytical data recorded separately included gas chromatographic (GC) analyses of the product gas streams, aromatics by FTIR, specific gravity, and octane number. The data from all the sources were imported into spreadsheets for calculation of the mass balances for each experimental point. The flow-based values included the liquid feed and products, which were weighed continuously to determine the flow rates. This method avoided interruptions in the data caused by refilling or pumping out the weigh tanks. Tables 2-4 through 2-6 show summaries of the mass balance results for each of the three, week-long processing sessions. Note the following abbreviations:

Ga	Gain (loss if negative),
Gal.	Gallons
SCF	Standard Cubic Feet
Sp. Gr.	Specific Gravity
Btms	Bottoms liquid from the stripper
Ovhd	Overhead liquid from the stripper
HPV	High-pressure vent
LPV	Low-pressure vent
SV	Stripper vent

The input to the process was the feed naphtha while reformate and light gases were produced. The boundaries for the mass balance are shown in Figure 2-11. The product percents are all based on the amount of feed used during the period of time designated for the mass balance, the “mass balance period”. The bottoms liquid was the reformate and constituted the principal product. The amount of overhead liquid recorded was insignificantly small. Most of the produced gas left the system through the high-pressure vent. A smaller quantity of gas was measured in the stripper vent, and the amount leaving through the low-pressure vent was insignificantly small. The total apparent weight gain represents the mass balance closure, that is, a negative number represents the loss as a percent of feed not accounted for in any of the products, and a positive number represents the calculated quantity of products recorded in excess of the feed quantity. The total closure was less than ±5% of the feed for most of the experimental points. Yields were also calculated for hydrogen and other light gases through the hexanes. Separately, a “chemical” hydrogen balance was calculated, which compares the hydrogen in the liquid product less that in the the feed with the sum of the hydrogen contained in all of the light gases.

2.0.4 Yield and Octane Number

The variation of yield with the octane number resulting from the variations in processing severity provides an important item of data for refinery modeling. Yields of hydrogen and of the C_{5+} (debutanized product) are shown in Figures 2-12 and 2-13. The yield of hydrogen from the coal liquids was significantly higher than from the petroleum liquid. As noted above, the coal liquids reformed easily at low severity so most of their data was clustered near the high octane number end of the scale. The points at the low end represent the feed liquids. At the low octane end, the petroleum-based hydrogen yields were only slightly lower than an interpolated value for the coal-based liquids, but they dropped significantly below at higher octane numbers. There was no apparent difference between the hydrogen yields from the two coal liquids.

The coal liquid C5+ yields were 5 to 10% higher than the petroleum liquid yields at a given octane number level. Further, the DL2 liquids provided about 3 to 5 percent higher yields than the DL1 liquids in the region between octane number 85 and 95.

Figures 2-14 through 2-19 show the yield versus octane number for the light hydrocarbons, methane through the hexanes. In most cases the yields from the coal liquids remained low through about octane number 85 to 90, then increased sharply between 90 and 95. The yields from petroleum were generally higher in the low octane number range and increased less sharply above octane number 90 than yields from the coal liquids. The yields of hexane were the notable exception, with the yields from petroleum significantly higher than from the coal liquids in the low octane number range. Note that the highest octane number point for the hexane yield from petroleum, showing a drop with with increasing octane number, was probably due to an analytical error.

2.0.5 Summary

The reforming experiments with two coal-derived naphthas and a petroleum-derived naphtha have shown the coal naphthas to be excellent reformer feed stocks. Because of their high naphthene content, they reform readily at low- and moderate-severity reformer conditions to produce high octane products, out performing their petroleum counterpart in this respect. At low and moderate severity reforming they produced high hydrogen yields and low yields of light hydrocarbons. A slight catalyst deactivation occurred over the course of the reforming experiments, mostly during the highest temperature part of the experimental operations. The extent of catalyst deactivation was in line with expectations for the conditions used. The use of coal liquids provided high-value products and caused no negative effects.

Table 2-1 - Feedstock Properties - Reformer Run 13

Property	Method	DL1	DL2	Petroleum	Blend
SwRI ID		FL2476	FL2562	FL2536	FL2651
Specific Gravity	D 4052	0.7838	0.7825	0.7561	0.7647
Hydrogen, M%	D 4808	14.16	14.18	14.08	14.07
Hydrocarbon Type	D 2425				
Paraffins		9.5	10.8	45.6	34.0*
Monocycloparaffins		88.2	83.8	41.3	55.5*
Dicycloparaffins		0.7	0.4	0	0.1*
Total Naphthenes		88.9	84.2	41.3	55.6*
Alkyl Benzenes		1.3	5.0	13.1	10.4*
Indans/Tetralins		0.3	0	0	0*
Total Aromatics		1.6	5.0	13.1	10.4*
*Properties calculated based on component properties.					

Table 2-2 - Product Properties and Operating Conditions - Reformer Run 13

Sample ID	Feed Type	Specific gravity	H2 by NMR, M%	Aromatics, vol%	Temperature, F	LHSV, Hr^{-1}	Pressure, Psi
13A	Pet	0.7697	13.28	31.3	821	2.97	450.4
13B	DL2	0.8189	11.75	45.3	820	3.01	450.4
13C	DL2	0.8228	11.74	45.3	824	1.98	450.4
13D	DL2	0.8237	11.78	51.1	822	0.98	450.4
13E	Pet	0.7706	13.09	30.5	816	2.84	449.6
13F	DL1	0.8215	11.99	43.6	822	3.16	450.4
13G	DL2	0.8284	11.13	58.8	870	3.00	449.6
13H	DL2	0.8306	10.89	61.9	876	2.01	449.6
13I	Pet	0.7688	13.25	32.7	819	2.97	450.4
13J	Blend	0.7854	17.69	35.1	817	3.00	450.4
13K	Blend	0.8005	11.94	54.0	921	3.00	450.0
13L	DL2	0.8296	11.00	62.7	821	2.98	450.0
13M	DL1	0.8229	11.50	52.3	923	3.02	450.4
13N	Pet	0.8008	11.39	59.9	926	0.96	450.4
13O	Blend	0.7881	11.44	56.7	920	1.00	449.6
13P	DL2	0.8153	10.95	65.0	820	0.98	450.4
13Q	DL1	0.8194	11.07	62.5	920	1.01	450.4
13R	Pet	0.7667	12.11	50.0	920	1.01	450.4
13S	Pet	0.7555	13.84	18.3	822	2.75	450.4
13T	Pet	0.7803	12.55	42.5	873	2.01	449.6
13U	DL2	0.8187	10.79	68.2	950	1.00	450.4
13V	DL1	0.8209	11.07	65.3	953	1.02	449.6
13W	Pet	0.7580	14.11	18.4	823	3.00	300.2
13X	Pet	0.7578	13.93	17.7	825	3.04	200.0

Table 2-3 - Feed and Product Octane Values—Reformer Run 13

Sample ID	Type	RON on C5+ Fraction	MON on C5+ Fraction	(R+M)/2
FL2536	Pet	53.2	49.7	51.5
FL2562	DL2	52.7	51.3	52.0
FL2476	DL1	45.8	47.4	46.6
FL2651	Blend	53.0	50.5	51.7
13A	Pet	65.5	60.7	63.1
13B	DL2	84.2	76.3	80.2
13C	DL2	87.2	77.8	82.5
13D	DL2	89.6	82.3	85.9
13E	Pet	66.0	60.2	63.1
13F	DL1	86.0	77.5	81.7
13G	DL2	93.8	84.2	89.0
13H	DL2	96.0	85.1	90.5
13I	Pet	65.6	60.9	63.2
13J	Blend	72.8	67.1	69.9
13K	Blend	89.9	81.2	85.5
13L	DL2	97.4	85.6	91.5
13M	DL1	93.1	83.1	88.1
13N	Pet	91.4	82.5	86.9
13O	Blend	94.4	84.5	89.4
13P	DL2	99.0	86.9	93.0
13Q	DL1	98.2	86.4	92.3
13R	Pet	90.2	82.0	86.1
13S	Pet	58.9	54.6	56.7
13T	Pet	78.8	72.8	75.8
13U	DL2	100.0	87.9	93.9
13V	DL1	99.4	87.8	93.6
13W	Pet	58.7	54.2	56.4
13X	Pet	59.2	54.3	56.7

Table 2-4 - Mass Balance Summary - First Processing Session

			Reactor			Recycle	Gas Prod	Liq Feed	Duration	Btm Liq		Chem Liq	Chem Gas	Chem Bal Hgas/	C1-C3		C4-C6	
Sample ID	Feed	Feed SG	Temp	Psig	LHSV	SCF/Bbl	SCF/Bbl	Lbs	Hrs	Sp. Gr.	Gal.	H-Ga, lbs	H-Ga, lbs	Hliq, %	Ga, Lbs	Ga, %	Ga, Lbs	Ga, %
13A	Pet	0.7561	821	450	2.97	2561	463	35.71	7.11	0.7697	5.355	-0.4445	0.3882	87.34	0.1687	0.4725	2.5905	7.2538
13B	DL2	0.7824	820	450	3.01	2543	1356	21.58	4.10	0.8189	3.040	-0.6088	0.5775	94.86	0.0390	0.1806	-0.4832	-2.2386
13C	DL2	0.7824	824	450	1.98	2591	1431	10.28	2.97	0.8228	1.427	-0.3009	0.2980	99.04	0.0341	0.3319	-0.9811	-9.5470
13D	DL2	0.7824	822	450	0.98	2577	1216	9.66	5.62	0.8237	1.336	-0.2837	0.2448	86.31	0.0457	0.4724	-1.0017	-10.3652
13E	Pet	0.7561	816	450	2.84	2688	451	22.30	4.64	0.7706	3.458	-0.2192	0.2285	104.25	0.0545	0.2443	1.2066	5.4117
13F	DL1	0.7838	822	450	3.16	2431	1300	23.22	4.20	0.8215	3.060	-0.7769	0.6013	77.40	0.0672	0.2893	0.1333	0.5742

Sample	Feed, lbs	Feed by Component										Product by Location					Total	Gain
ID		'i-C4 %	n-C4 %	C5 %	C6 %	C7+ %	'i-C4 lbs	n-C4 lbs	C5 lbs	C6 lbs	C7+ lbs	Btms lbs	Ovhd lbs	HPV lbs	LPV lbs	SV lbs	Prod. lbs	Wt%
13A	35.713	0.0000	0.0000	0.0000	0.6890	99.3110	0.000	0.000	0.000	0.246	35.467	34.328	0.0275	0.3872	0.0019	0.2252	34.970	-2.08
13B	21.584	0.0000	0.0000	0.0775	1.3474	98.5751	0.000	0.000	0.017	0.291	21.277	20.729	0.0091	0.5997	0.0024	0.0470	21.387	-0.91
13C	10.277	0.0000	0.0000	0.0775	1.3474	98.5751	0.000	0.000	0.008	0.138	10.130	9.780	0.0087	0.3333	0.0010	0.0299	10.153	-1.21
13D	9.664	0.0000	0.0000	0.0775	1.3474	98.5751	0.000	0.000	0.007	0.130	9.527	9.163	0.0047	0.2599	0.0024	0.0653	9.495	-1.75
13E	22.295	0.0000	0.0000	0.0000	0.6890	99.3110	0.000	0.000	0.000	0.154	22.142	22.190	0.0148	0.2296	0.0017	0.1204	22.557	1.17
13F	23.222	0.0000	0.0000	0.0000	0.1205	99.8795	0.000	0.000	0.000	0.028	23.194	20.938	0.0075	0.6515	0.0071	0.0321	21.636	-6.83

Sample	Product by Component									Gain by Component ([Prod - Feed] / Feed)								
ID	H2, lbs	C1, lbs	C2, lbs	C3, lbs	'i-C4 lbs	n-C4 lbs	C5 lbs	C6 lbs	C7+ lbs	H2, Wt%	C1, Wt%	C2, Wt%	C3, Wt%	'i-C4 Wt%	n-C4 Wt%	C5 Wt%	C6 Wt%	C7+ Wt%
13A	0.2759	0.0211	0.0455	0.1022	0.0555	0.0983	0.2661	2.8597	31.2459	0.7726	0.0590	0.1273	0.2861	0.1553	0.2751	0.7452	7.3184	-11.8184
13B	0.5661	0.0050	0.0116	0.0224	0.0208	0.0104	0.0197	0.8908	19.8402	2.6228	0.0232	0.0535	0.1039	0.0964	0.0482	0.0138	2.7797	-6.6543
13C	0.2810	0.0073	0.0104	0.0164	0.0315	0.0085	0.0135	0.3903	9.3938	2.7342	0.0712	0.1015	0.1592	0.3066	0.0827	0.0537	2.4504	-7.1661
13D	0.2225	0.0075	0.0153	0.0228	0.0123	0.0123	0.0150	0.3836	8.8040	2.3019	0.0777	0.1587	0.2361	0.1274	0.1270	0.0778	2.6217	-7.4758
13E	0.1938	0.0058	0.0125	0.0361	0.0276	0.0429	0.1323	1.6928	20.4129	0.8691	0.0260	0.0563	0.1620	0.1238	0.1923	0.5934	6.9036	-7.7549
13F	0.5786	0.0095	0.0229	0.0348	0.0246	0.0183	0.0292	0.1817	20.7364	2.4918	0.0411	0.0985	0.1497	0.1060	0.0788	0.1256	0.6621	-10.5825

Table 2-5 - Mass Balance Summary - Second Processing Session

Sample ID	Feed	Feed SG	Reactor Temp	Reactor Psig	Reactor LHSV	Recycle SCF/Bbl	Gas Prod SCF/Bbl	Liq Feed Lbs	Duration Hrs	Btm Liq Sp. Gr.	Btm Liq Gal.	Chem Liq H-Ga, lbs	Chem Gas H-Ga, lbs	Chem Bal Hgas/ Hliq, %	C1-C3 Ga, Lbs	C1-C3 Ga, %	C4-C6 Ga, Lbs	C4-C6 Ga, %
13T	Pet	0.7561	873	450	2.01	2545	668	7.48	2.20	0.7803	1.029	-0.2090	0.1282	61.35	0.0825	1.1020	0.1489	1.9901
13G	DL2	0.7824	870	450	3.00	2543	1903	22.48	4.28	0.8284	3.053	-0.8255	0.8771	106.25	0.2430	1.0807	0.1527	0.6793
13H	DL2	0.7824	876	450	2.01	2535	1794	19.95	5.68	0.8306	2.691	-0.7859	0.7712	98.14	0.3457	1.7330	0.1775	0.8897
13I	Pet	0.7563	819	450	2.97	2582	418	8.70	1.73	0.7688	1.294	-0.1203	0.0857	71.26	0.0384	0.4414	0.0646	0.7431
13J	Blend	0.7647	817	450	3.00	2533	694	20.61	4.01	0.7854	2.984	-0.4162	0.3052	73.33	0.0754	0.3657	0.7009	3.4010
13K	Blend	0.7647	921	450	3.00	2542	1373	22.14	4.31	0.8005	2.900	-0.7952	0.7874	99.01	0.7632	3.4476	1.8438	8.3295
13L	DL2	0.7824	921	450	2.98	2554	2211	26.66	5.11	0.8296	3.534	-1.0743	1.3609	126.68	0.8999	3.3751	1.4787	5.5458
13M	DL1	0.7838	923	450	3.02	2524	1826	25.68	4.85	0.8229	3.313	-1.0235	1.1208	109.50	1.0432	4.0622	1.3544	5.2741
13N	Pet	0.7561	926	450	0.96	2651	929	11.06	6.84	0.8008	1.289	-0.5683	0.4332	76.23	0.6904	6.2419	0.7666	6.9308

Sample ID	Feed, lbs	Feed by Component 'i-C4 %	n-C4 %	C5 %	C6 %	C7+ %	'i-C4 lbs	n-C4 lbs	C5 lbs	C6 lbs	C7+ lbs	Product by Location Btms lbs	Ovhd lbs	HPV lbs	LPV lbs	SV lbs	Total Prod. lbs	Gain W t%
13T	7.483	0.0000	0.0000	0.0000	0.6890	99.3110	0.000	0.000	0.000	0.052	7.432	6.688	0.0062	0.1407	0.0110	0.1518	6.998	-6.49
13G	22.483	0.0000	0.0000	0.0775	1.3474	98.5751	0.000	0.000	0.017	0.303	22.163	21.065	0.0205	1.0190	0.0040	0.1337	22.242	-1.07
13H	19.947	0.0000	0.0000	0.0775	1.3474	98.5751	0.000	0.000	0.015	0.269	19.663	18.613	0.0160	0.9990	0.0051	0.2243	19.857	-0.45
13I	8.699	0.0000	0.0000	0.0000	0.6890	99.3110	0.000	0.000	0.000	0.060	8.639	8.286	0.0106	0.0882	0.0015	0.0712	8.457	-2.77
13J	20.610	0.0000	0.0000	0.0258	0.9085	99.0657	0.000	0.000	0.005	0.187	20.417	19.516	0.0057	0.3156	0.0036	0.1133	19.954	-3.18
13K	22.136	0.0000	0.0000	0.0258	0.9085	99.0657	0.000	0.000	0.006	0.201	21.929	19.331	0.0388	1.1849	0.0227	0.6791	21.256	-3.98
13L	26.664	0.0000	0.0000	0.0775	1.3474	98.5751	0.000	0.000	0.021	0.359	26.284	24.413	0.0224	2.2095	0.0045	0.4382	27.088	1.59
13M	25.680	0.0000	0.0000	0.0000	0.1205	99.8795	0.000	0.000	0.000	0.031	25.650	22.704	0.0160	1.8984	0.0038	0.4834	25.106	-2.24
13N	11.061	0.0000	0.0000	0.0000	0.6890	99.3110	0.000	0.000	0.000	0.076	10.985	8.597	0.0286	0.6057	0.0059	1.1728	10.410	-5.89

Sample ID	Product by Component H2, lbs	C1, lbs	C2, lbs	C3, lbs	'i-C4 lbs	n-C4 lbs	C5 lbs	C6 lbs	C7+ lbs	Gain by Component ([Prod - Feed] / Feed) H2, Wt%	C1, Wt%	C2, Wt%	C3, Wt%	'i-C4 Wt%	n-C4 Wt%	C5 Wt%	C6 Wt%	C7+ Wt%
13T	0.0914	0.0140	0.0210	0.0474	0.0241	0.0620	0.1031	0.6486	5.9859	1.2210	0.1876	0.2807	0.6338	0.3226	0.8287	1.3784	7.9789	-19.3186
13G	0.8116	0.0380	0.0727	0.1323	0.0412	0.0799	0.1005	1.3561	19.6101	3.6099	0.1690	0.3232	0.5885	0.1831	0.3552	0.3693	4.6844	-11.3533
13H	0.6647	0.0557	0.1089	0.1811	0.0652	0.1316	0.1360	1.2696	17.2444	3.3321	0.2790	0.5459	0.9081	0.3267	0.6599	0.6043	5.0173	-12.1246
13I	0.0691	0.0041	0.0077	0.0265	0.0221	0.0252	0.0641	0.6422	7.5963	0.7949	0.0476	0.0889	0.3049	0.2540	0.2902	0.7367	6.6939	-11.9838
13J	0.2774	0.0073	0.0181	0.0499	0.0271	0.0499	0.1183	1.4399	17.9664	1.3458	0.0354	0.0880	0.2422	0.1316	0.2422	0.5482	6.0781	-11.8905
13K	0.5364	0.1159	0.2263	0.4210	0.1000	0.3262	0.4947	1.8572	17.1786	2.4232	0.5235	1.0222	1.9019	0.4518	1.4738	2.2090	7.4813	-21.4618
13L	1.0608	0.1682	0.2637	0.4680	0.0870	0.5967	0.3164	1.9035	22.2237	3.9783	0.6308	0.9891	1.7552	0.3263	2.2378	1.1091	5.7917	-15.2271
13M	0.8189	0.2170	0.3316	0.4947	0.0879	0.3995	0.2980	0.6894	21.7690	3.1887	0.8448	1.2911	1.9263	0.3424	1.5558	1.1604	2.5641	-15.1110
13N	0.1333	0.0937	0.2041	0.3927	0.1685	0.3696	0.4660	0.4517	8.1310	1.2053	0.8469	1.8450	3.5499	1.5229	3.3411	4.2125	3.3941	-25.8032

Table 2-6 - Mass Balance Summary - Third Processing Session

			Reactor			Recycle	Gas Prod	Liq Feed	Duration	Btm Liq		Chem Liq	Chem Gas	Chem Bal Hgas/	C1-C3		C4-C6	
Sample ID	Feed	Feed SG	Temp	Psig	LHSV	SCF/Bbl	SCF/Bbl	Lbs	Hrs	Sp. Gr.	Gal.	H-Ga, lbs	H-Ga, lbs	Hliq, %	Ga, Lbs	Ga, %	Ga, Lbs	Ga, %
13O	Blend	0.7647	920	450	1.00	2553	1195	4.98	2.91	0.7881	0.620	-0.2306	0.2077	90.07	0.5164	10.3775	0.0921	1.8508
13P	DL2	0.7824	820	450	0.98	2595	1830	10.37	6.04	0.8153	1.362	-0.4494	0.5312	118.19	1.0451	10.0803	0.2918	2.8141
13Q	DL1	0.7838	920	450	1.01	2507	1881	8.33	4.70	0.8194	1.013	-0.4134	0.4879	118.04	1.0933	13.1179	0.7477	8.9710
13R	Pet	0.7561	920	450	1.01	2531	783	7.85	4.61	0.7667	0.970	-0.3480	0.2652	76.21	0.7786	9.9240	0.6998	8.9197
13U	DL2	0.7824	950	450	1.00	2546	1951	7.62	4.37	0.8187	0.957	-0.3674	0.4336	118.03	0.9293	12.1940	-0.1489	-1.9533
13V	DL1	0.7838	953	450	1.02	2483	1842	8.48	4.73	0.8209	0.946	-0.4827	0.4923	101.98	1.1694	13.7910	0.8760	10.3311
13S	Pet	0.7561	822	450	2.75	2768	481	10.51	2.26	0.7555	1.740	-0.2610	0.2275	87.16	0.6286	5.9820	0.5661	5.3870
13W	Pet	0.7561	823	300	3.00	2545	139	26.08	5.14	0.758	3.961	-0.1235	0.1081	87.54	0.1919	0.7358	1.2336	4.7293
13X	Pet	0.7561	825	200	3.04	2510	178	16.05	3.12	0.7578	2.428	-0.1132	0.0991	87.55	0.2245	1.3992	0.5674	3.5358

Sample	Feed, lbs	Feed by Component									Product by Location					Total	Gain
ID		'i-C4 %	n-C4 %	C5 %	C6 %	C7+ %	'i-C4 lbs	n-C4 lbs	C5 lbs	C6 lbs	C7+ lbs	Btms lbs	Ovhd lbs	HPV lbs	LPV lbs	SV lbs	Prod. lbs	Wt%
13O	4.977	0.0000	0.0000	0.0258	0.9085	99.0657	0.000	0.000	0.001	0.045	4.930	4.068	0.0150	0.2477	0.0092	0.4847	4.825	-3.05
13P	10.368	0.0000	0.0000	0.0775	1.3474	98.5751	0.000	0.000	0.008	0.140	10.220	9.246	0.0091	0.6946	0.0032	0.8039	10.757	3.76
13Q	8.334	0.0000	0.0000	0.0000	0.1205	99.8795	0.000	0.000	0.000	0.010	8.324	6.915	0.0110	0.6540	0.0020	0.9295	8.512	2.13
13R	7.846	0.0000	0.0000	0.0000	0.6890	99.3110	0.000	0.000	0.000	0.054	7.792	6.196	0.0129	0.2952	0.0017	0.8138	7.320	-6.70
13U	7.621	0.0000	0.0000	0.0775	1.3474	98.5751	0.000	0.000	0.006	0.103	7.512	6.523	0.0379	0.7516	0.0017	0.5446	7.859	3.13
13V	8.480	0.0000	0.0000	0.0000	0.1205	99.8795	0.000	0.000	0.000	0.010	8.470	6.464	0.0221	0.8569	0.0020	0.7632	8.108	-4.38
13S	10.509	0.0000	0.0000	0.0000	0.6890	99.3110	0.000	0.000	0.000	0.072	10.436	10.950	0.0018	0.0261	0.0007	0.9508	11.929	13.51
13W	26.084	0.0000	0.0000	0.0000	0.6890	99.3110	0.000	0.000	0.000	0.180	25.905	25.002	0.0405	0.0704	0.0020	0.2467	25.362	-2.77
13X	16.046	0.0000	0.0000	0.0000	0.6890	99.3110	0.000	0.000	0.000	0.111	15.936	15.323	0.0146	0.0435	0.0012	0.3033	15.686	-2.25

Sample	Product by Component									Gain by Component ([Prod - Feed] / Feed)								
ID	H2, lbs	C1, lbs	C2, lbs	C3, lbs	'i-C4 lbs	n-C4 lbs	C5 lbs	C6 lbs	C7+ lbs	H2, Wt%	C1, Wt%	C2, Wt%	C3, Wt%	'i-C4 Wt%	n-C4 Wt%	C5 Wt%	C6 Wt%	C7+ Wt%
13O	0.0840	0.0426	0.1342	0.3397	0.0962	0.1642	0.2318	0.5342	3.1979	1.6888	0.8551	2.6966	6.8258	1.9338	3.2988	4.6323	9.8255	-34.8065
13P	0.3004	0.1235	0.2793	0.6423	0.1276	0.2801	0.3099	0.9990	7.6950	2.8973	1.1908	2.6943	6.1953	1.2306	2.7021	2.9121	8.2882	-24.3535
13Q	0.2284	0.1266	0.3010	0.6656	0.0947	0.2317	0.1816	0.3600	6.3220	2.7404	1.5191	3.6119	7.9869	1.1368	2.7802	2.1794	4.1994	-24.0225
13R	0.0697	0.0673	0.2029	0.5084	0.1490	0.2441	0.3955	0.6002	5.0830	0.8888	0.8584	2.5855	6.4801	1.8991	3.1110	5.0412	6.9613	-34.5249
13U	0.2233	0.1556	0.2749	0.4988	0.0936	0.2271	0.2549	0.7004	5.4306	2.9300	2.0418	3.6075	6.5447	1.2286	2.9796	3.2673	7.8432	-27.3166
13V	0.2194	0.1851	0.3361	0.6483	0.0890	0.2337	0.2329	0.4409	5.7229	2.5875	2.1828	3.9633	7.6449	1.0499	2.7555	2.7464	5.0793	-32.3904
13S	0.0601	0.0151	0.1118	0.5017	0.1159	0.1927	0.1559	0.7907	9.9852	0.5723	0.1438	1.0638	4.7744	1.1025	1.8335	1.4831	6.8353	-4.2949
13W	0.0603	0.0116	0.0332	0.1472	0.0678	0.0984	0.2079	1.5485	23.1872	0.2312	0.0444	0.1271	0.5643	0.2600	0.3772	0.7971	5.2474	-10.4179
13X	0.0433	0.0077	0.0396	0.1772	0.0591	0.0958	0.1510	0.9504	14.1614	0.2696	0.0483	0.2468	1.1041	0.3685	0.5973	0.9408	5.2340	-11.0579

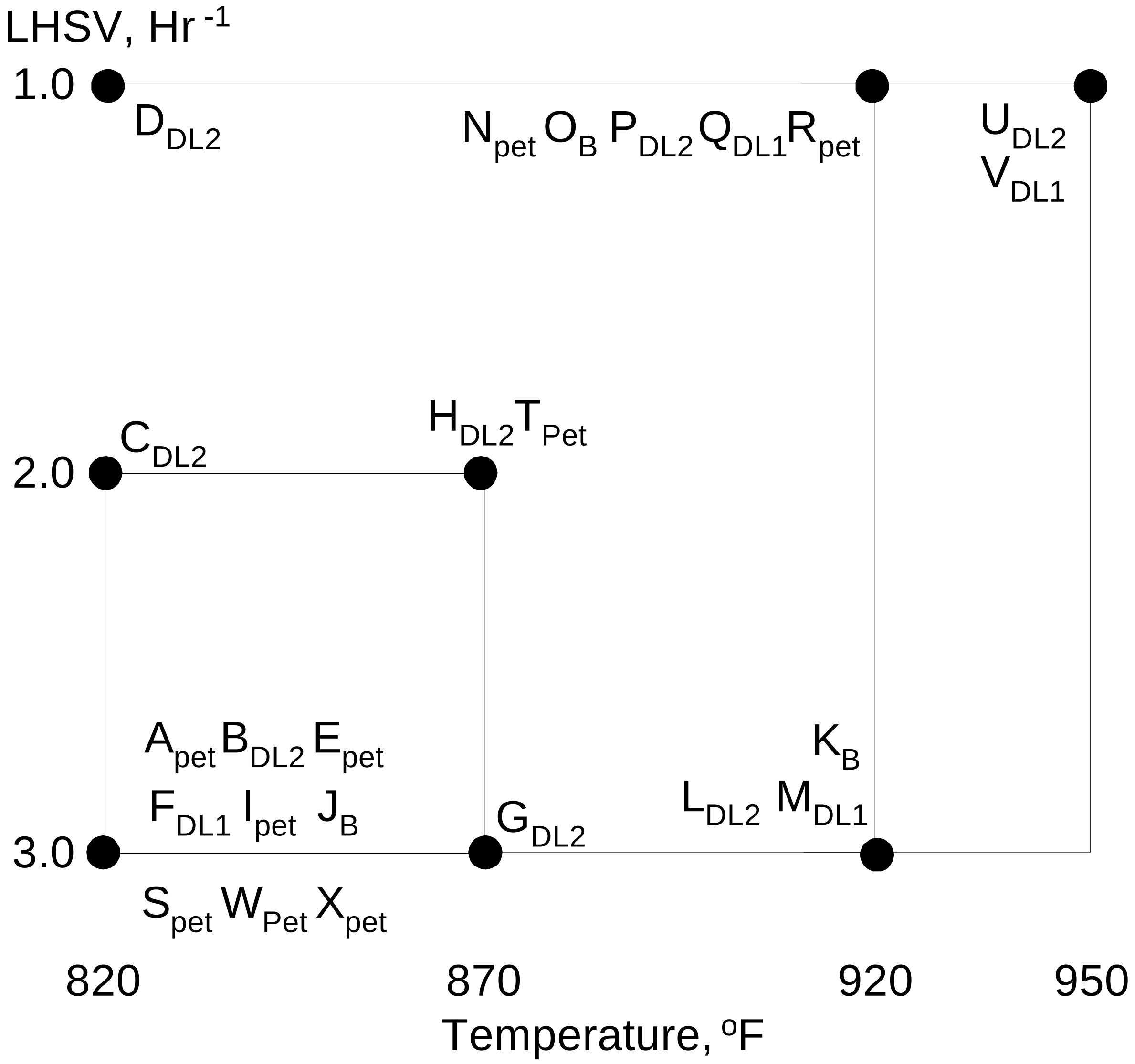

Figure 2-1 - Experimental Matrix for Reforming Run 13

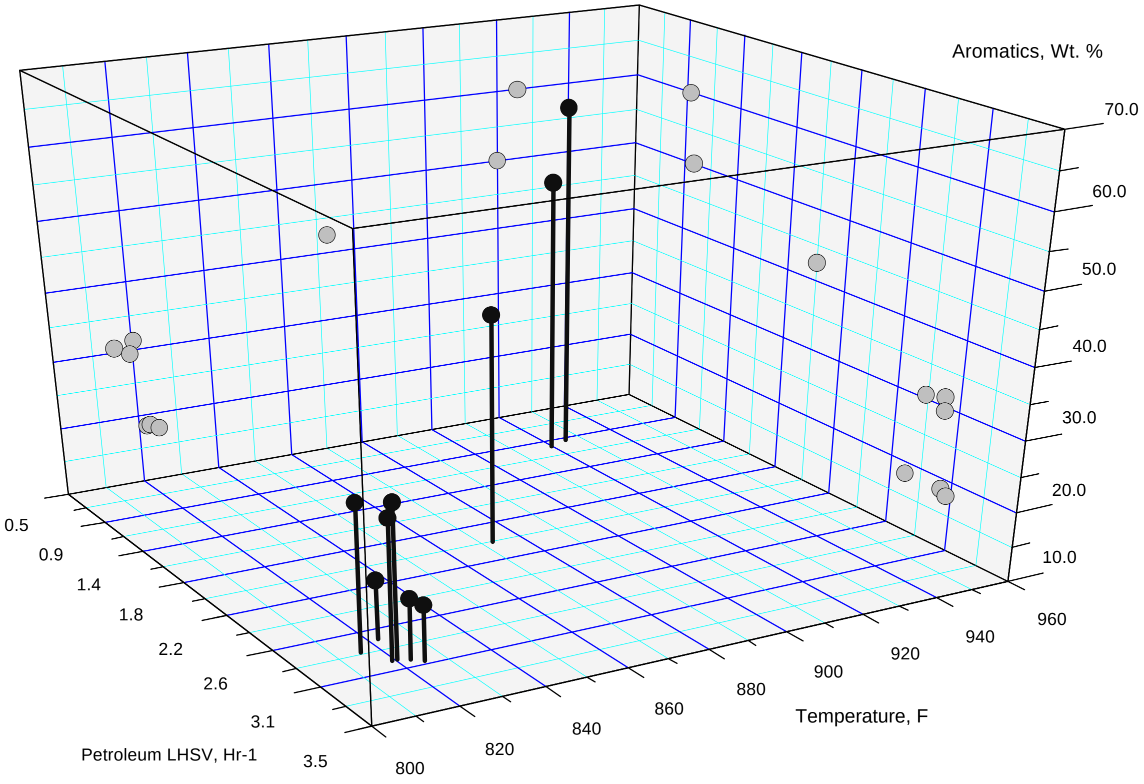

Figure 2-2 - Aromatics vs. Operating Parameters for Petroleum Feed

The points without drop lines are projections of the data points onto the vertical planes.

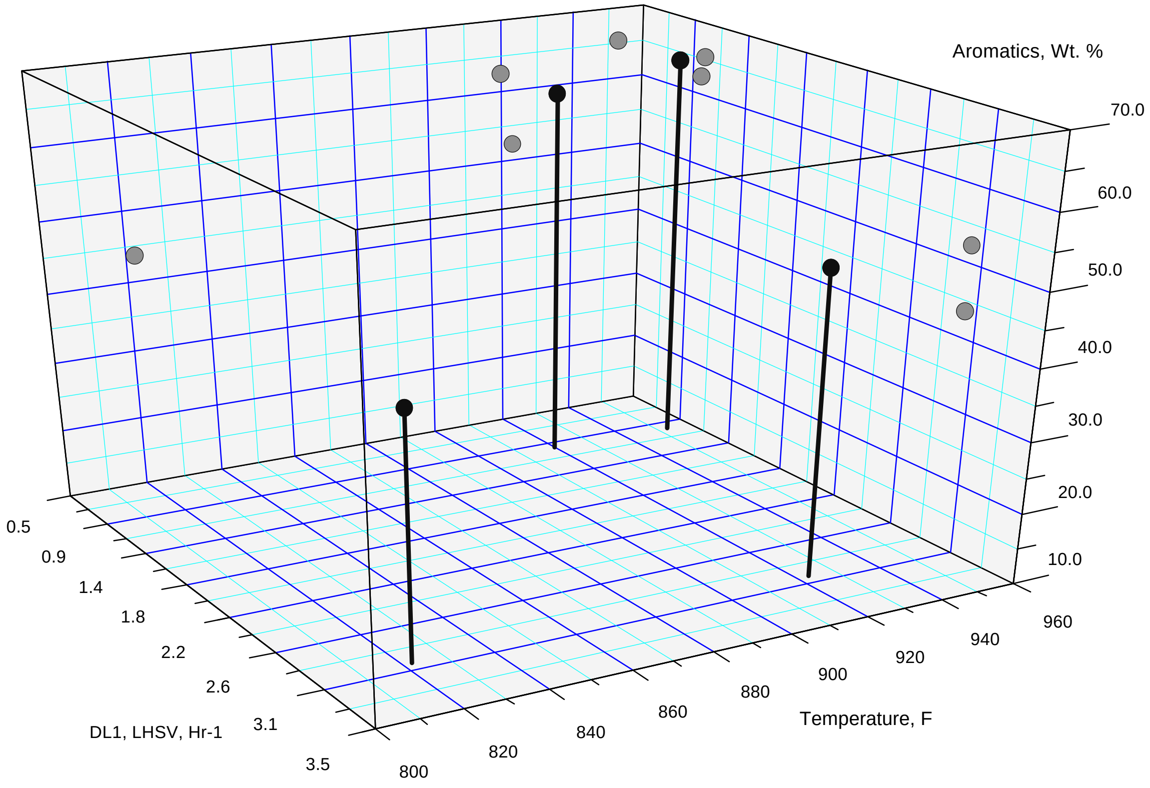

Figure 2-3 - Aromatics vs. Operating Parameters for DL1 Feed

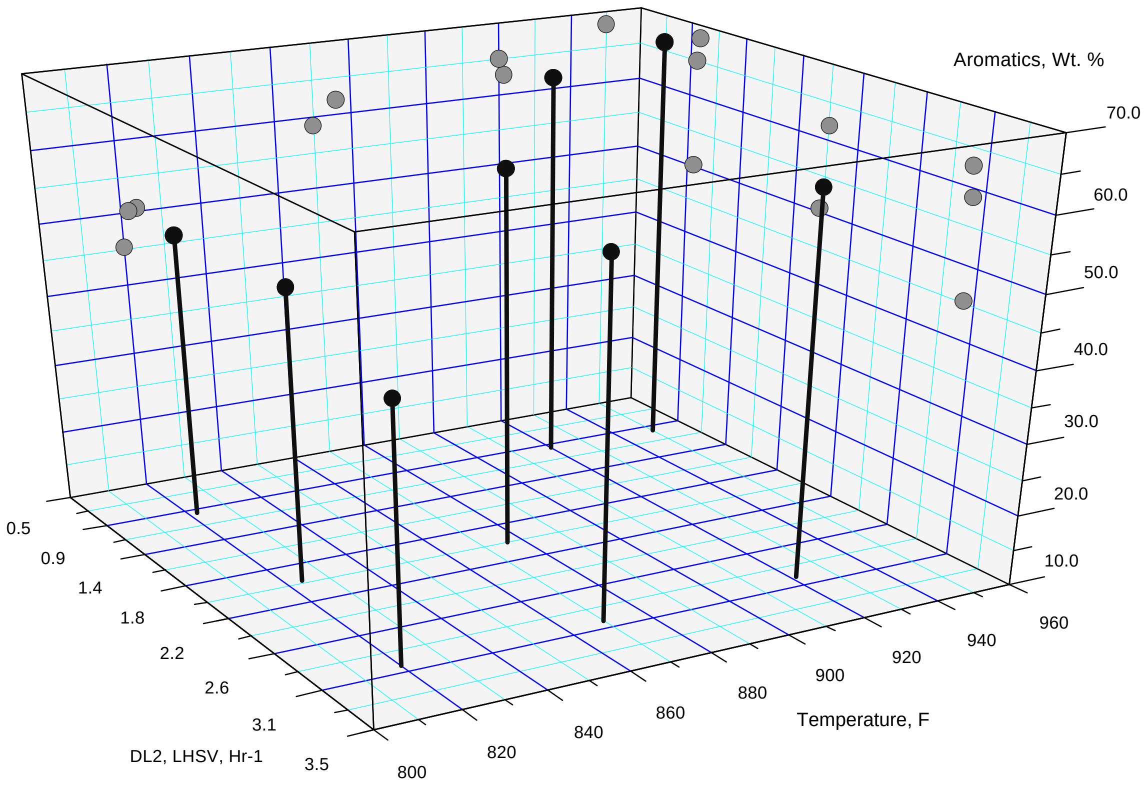

Figure 2-4 - Aromatics vs. Operating Parameters for DL2 Feed

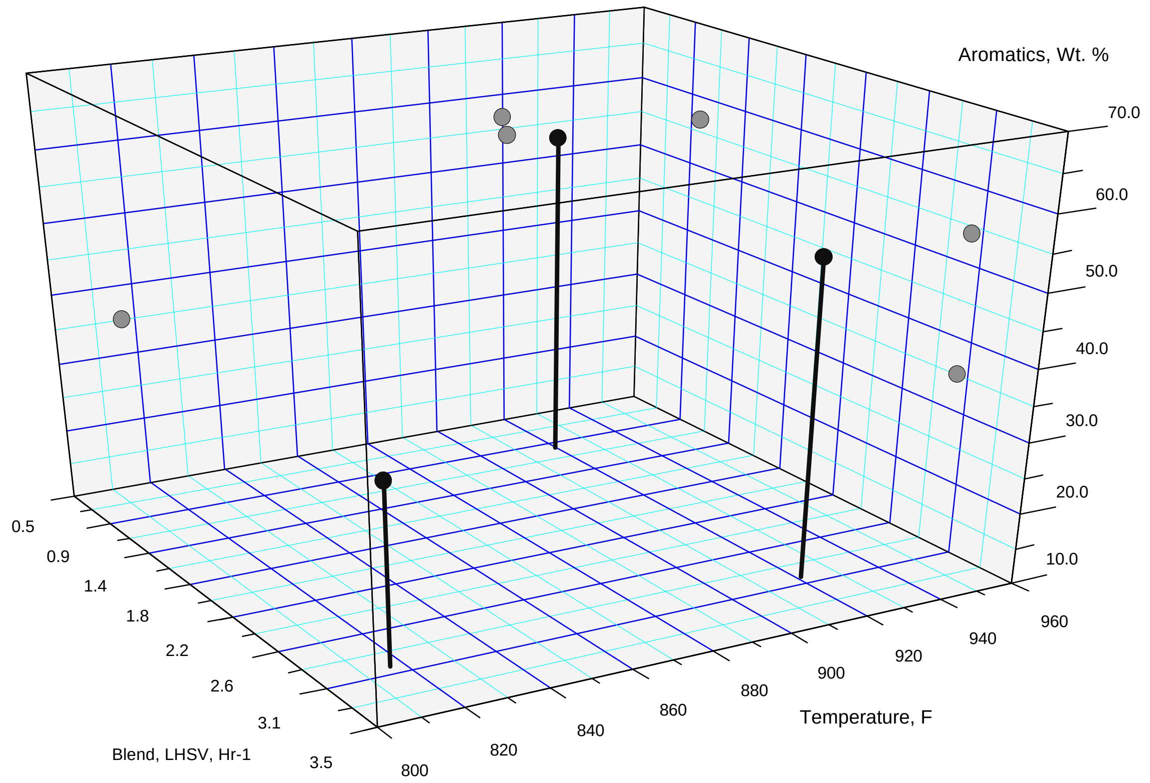

Figure 2-5 - Aromatics vs. Operating Parameters for the Blend Feed

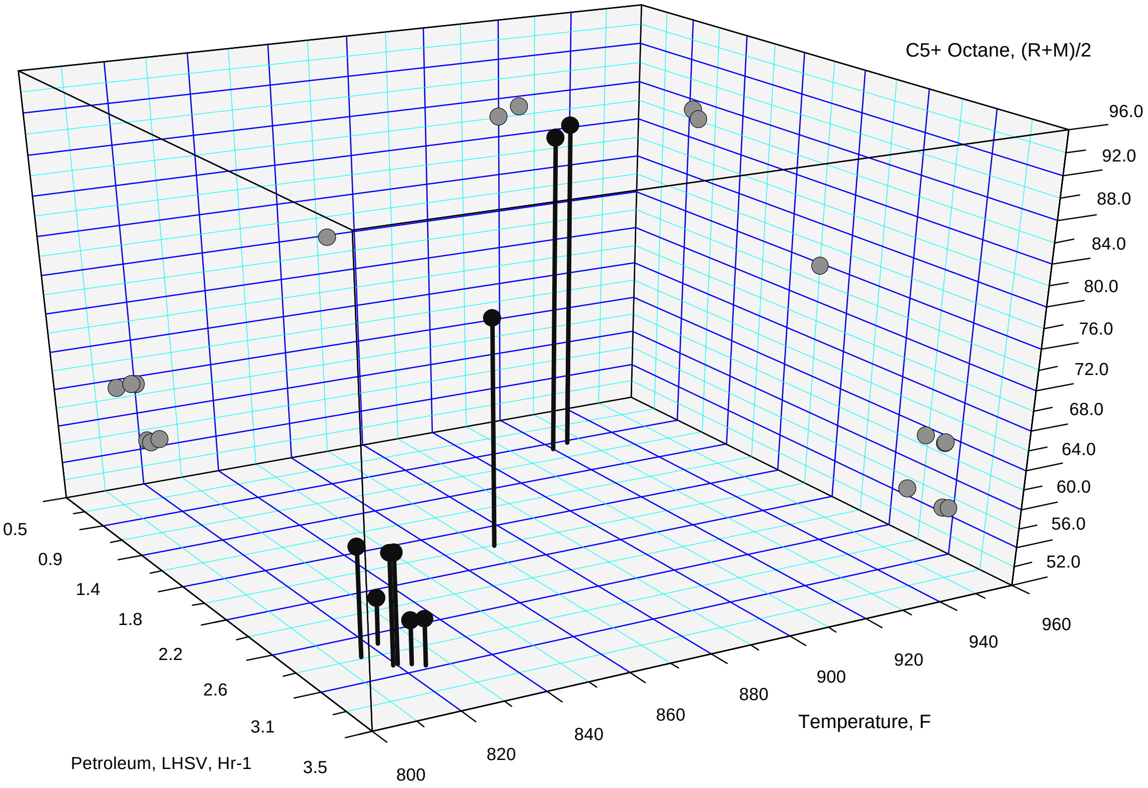

Figure 2-6 - C5+ Octane Number vs. Operating Parameters for Petroleum Feed

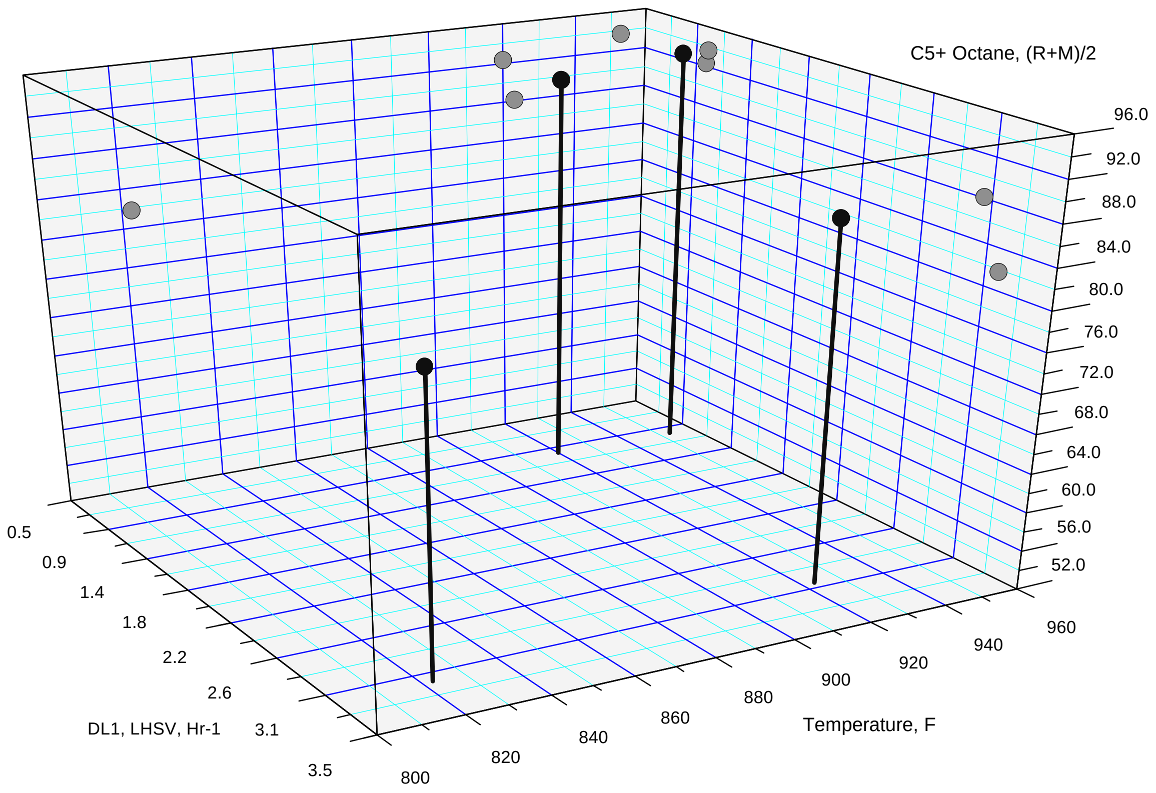

Figure 2-7 - C5+ Octane Number vs. Operating Parameters for DL1 Feed

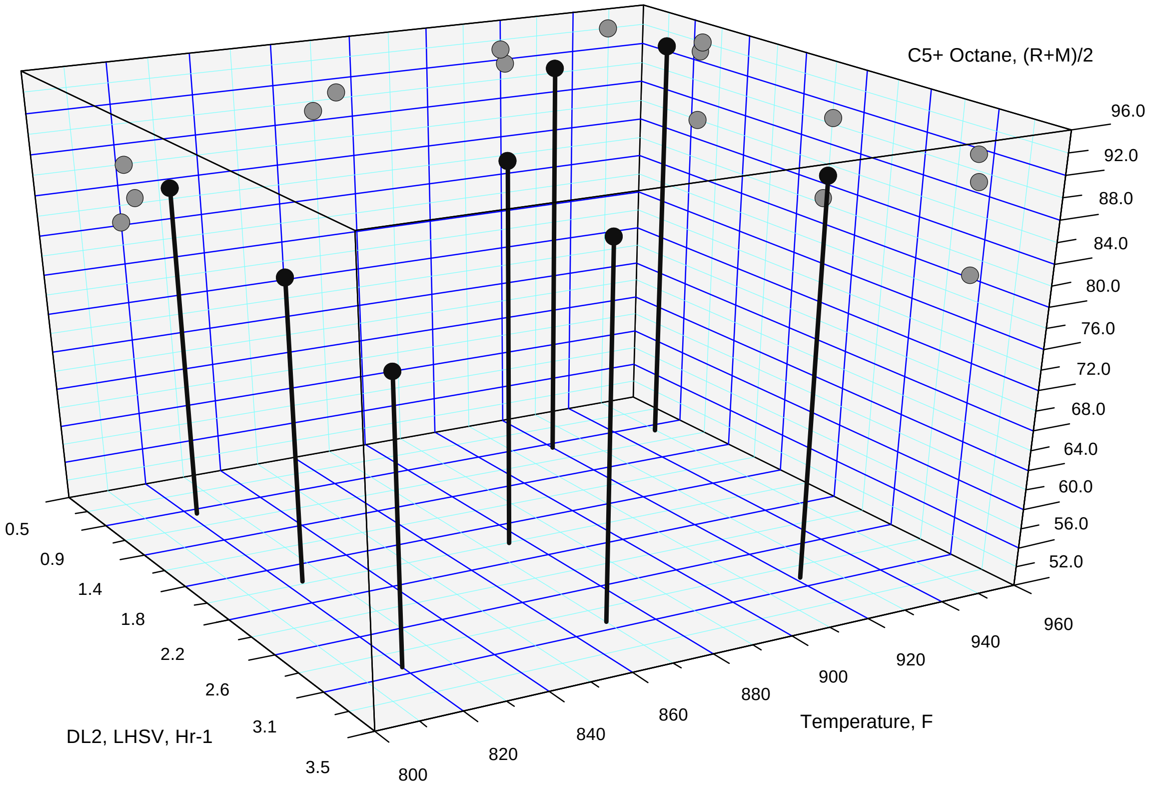

Figure 2-8 - C5+ Octane Number vs. Operating Parameters for DL2 Feed

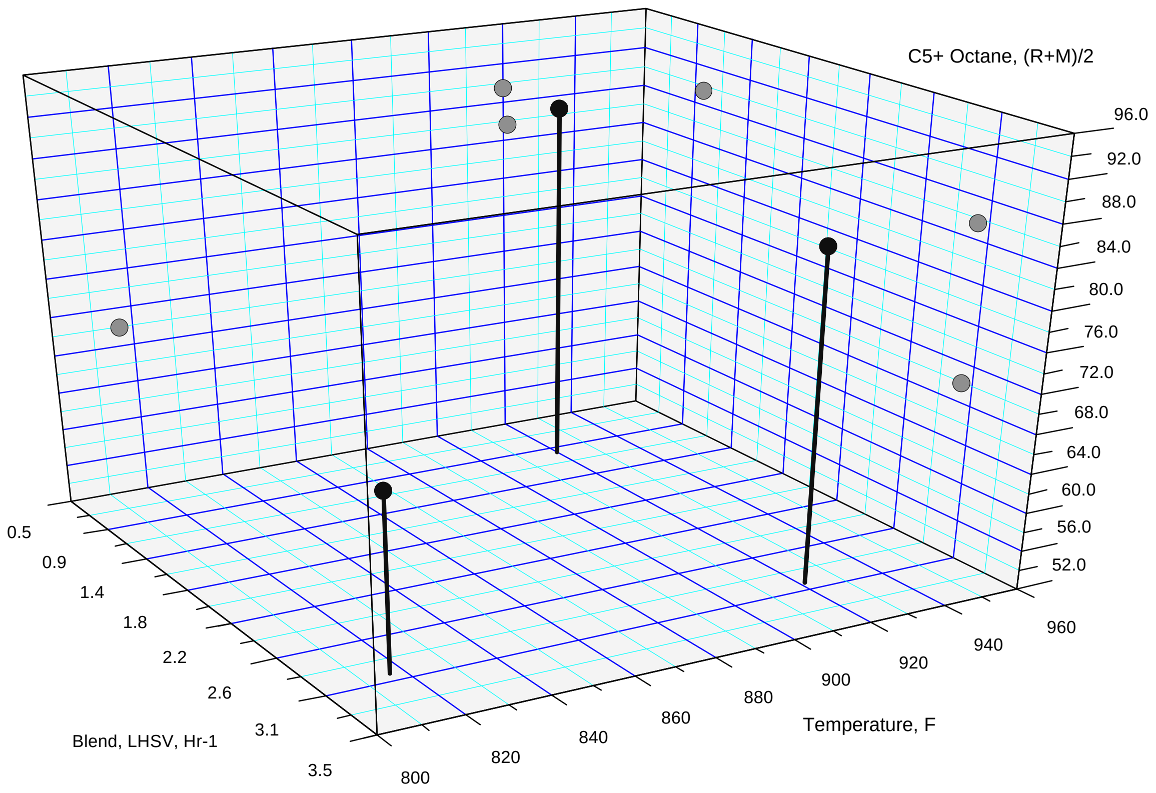

Figure 2-9 - C5+ Octane Number vs. Operating Parameters for the Blend Feed

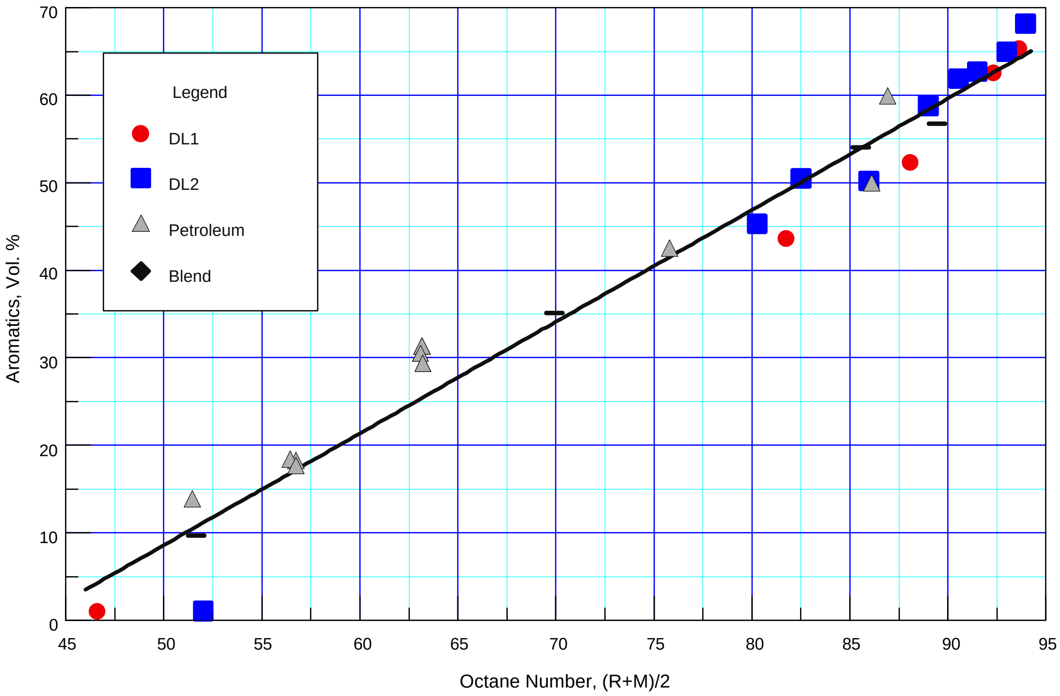

Figure 2-10 - Aromatics vs. Octane Number for all feeds

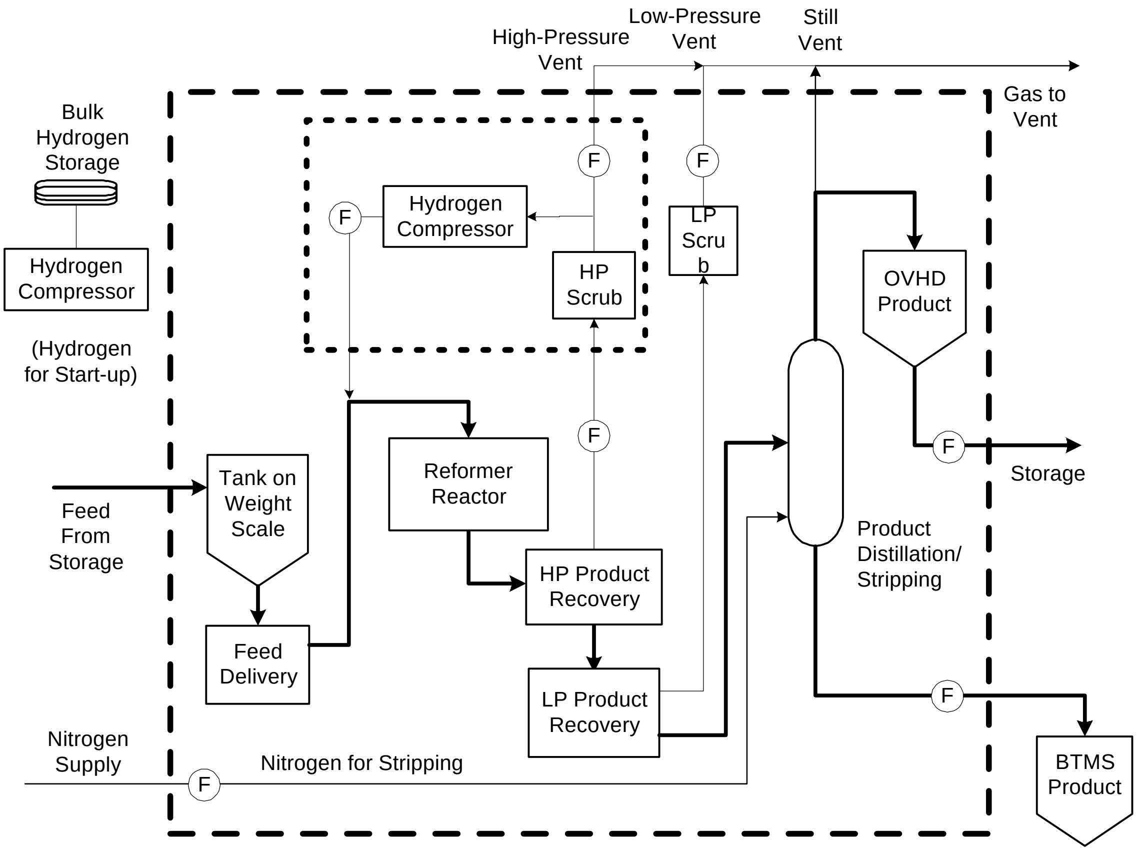

Figure 2-11 - Flow Diagram of Reformer Pilot Plant

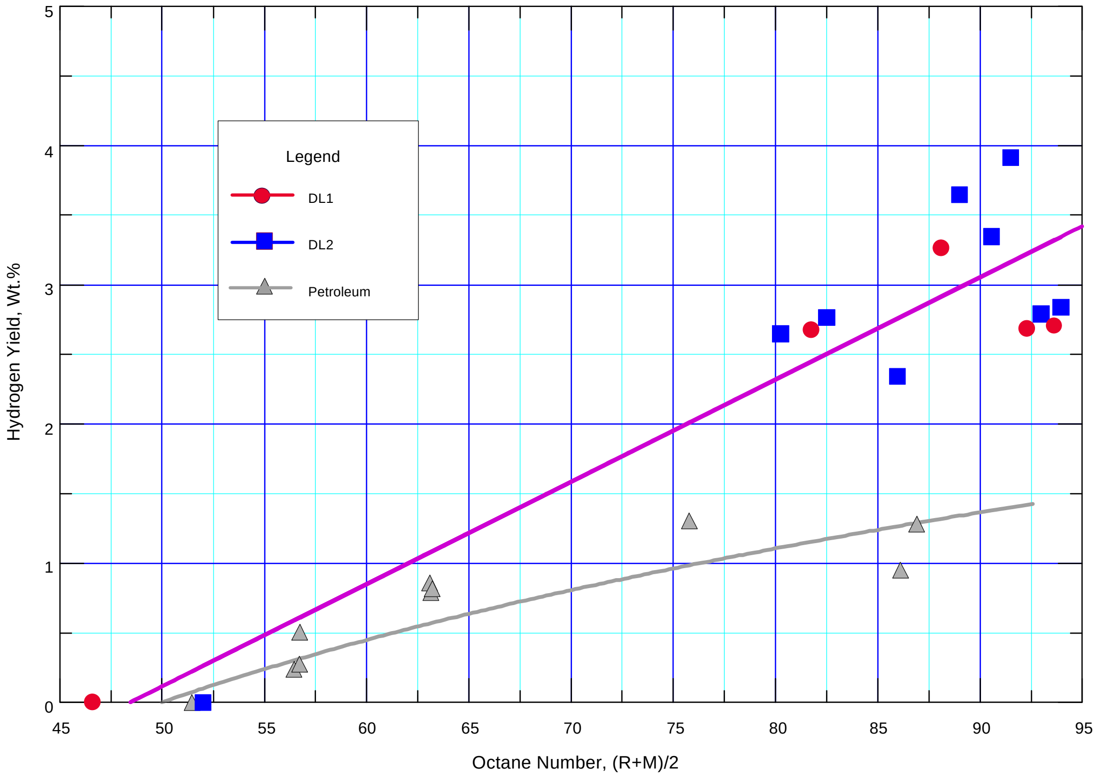

Figure 2-12 - Hydrogen Yield vs. Octane Number

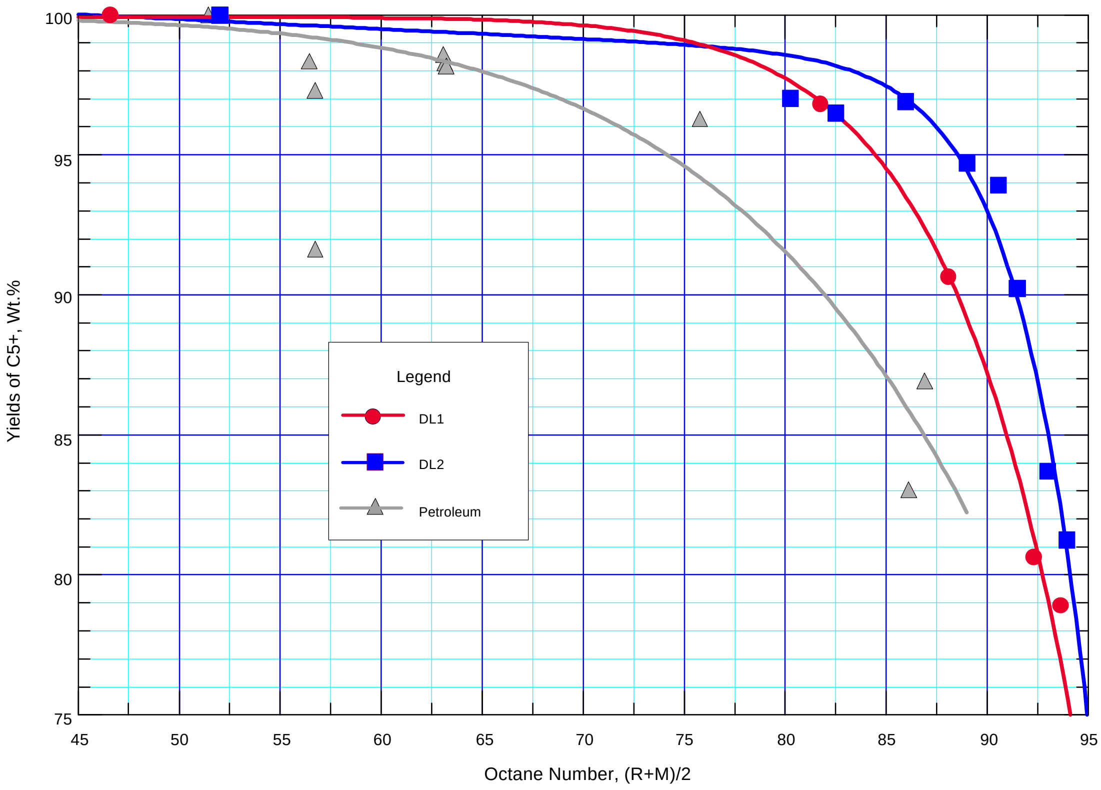

Figure 2-13 - C5+ Reformate Yield vs. Octane Number

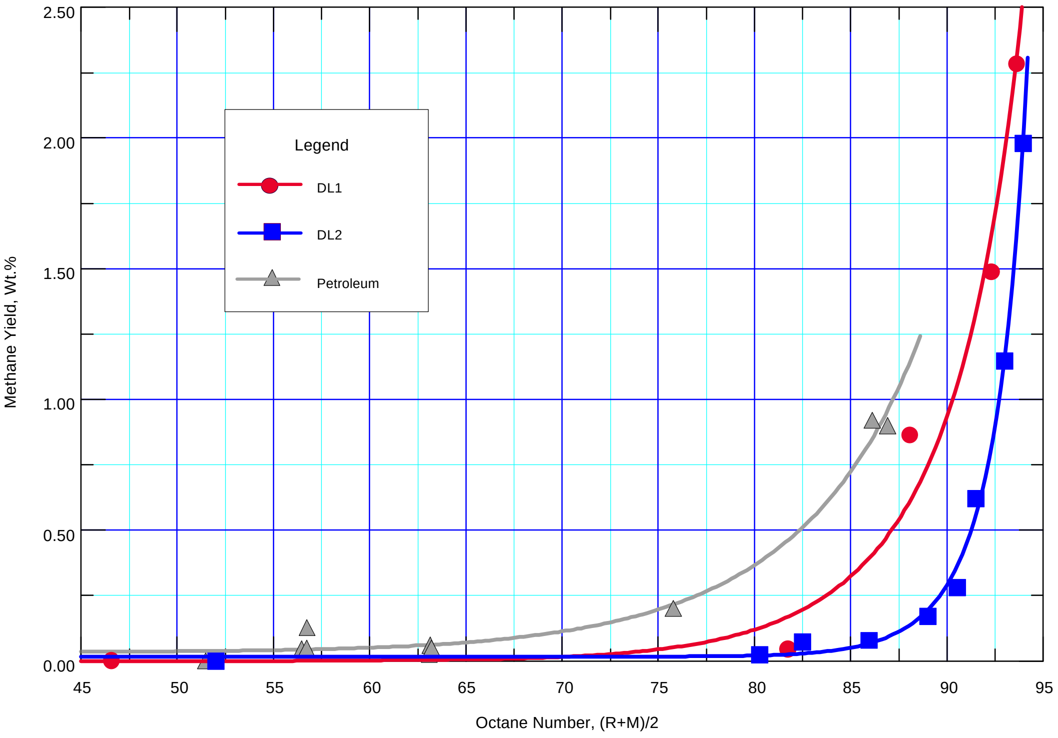

Figure 2-14 - Methane Yield vs. Octane Number

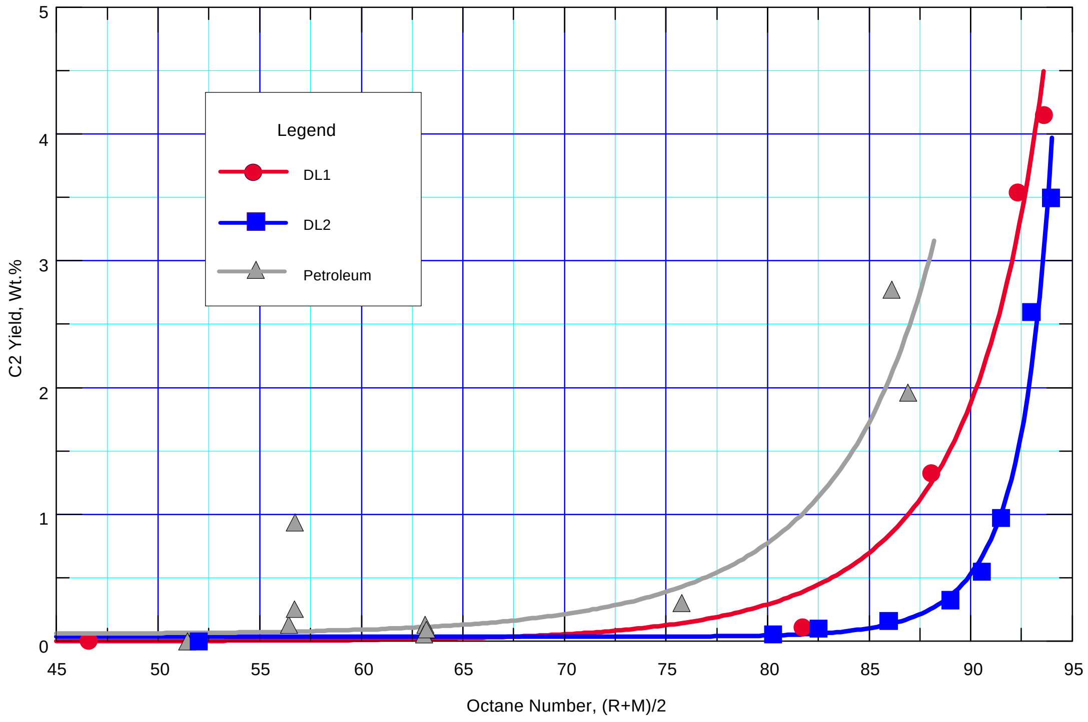

Figure 2-15 - C2 Yield vs. Octane Number

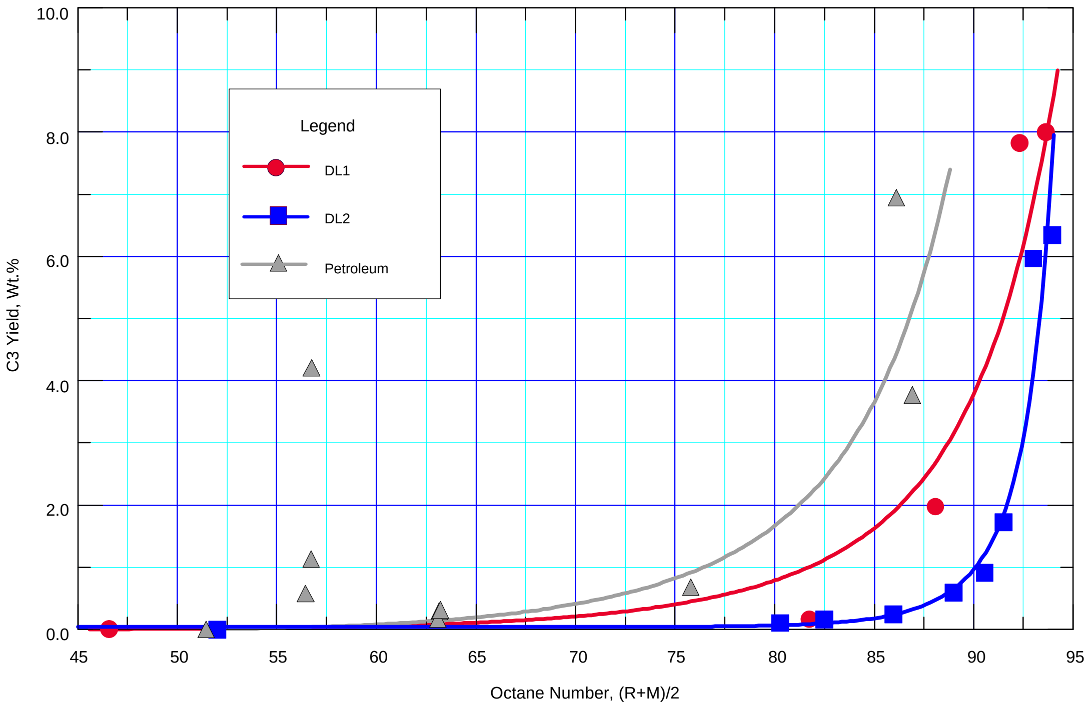

Figure 2-16 - C3 Yield vs. Octane Number

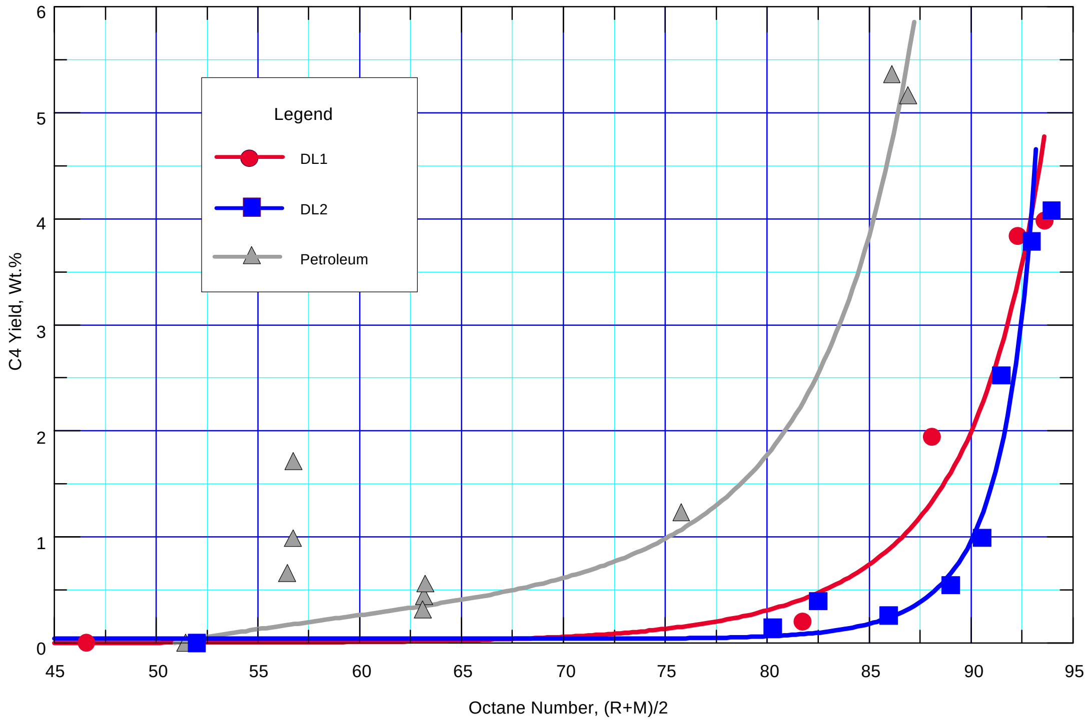

Figure 2-17 - C4 Yield vs. Octane Number

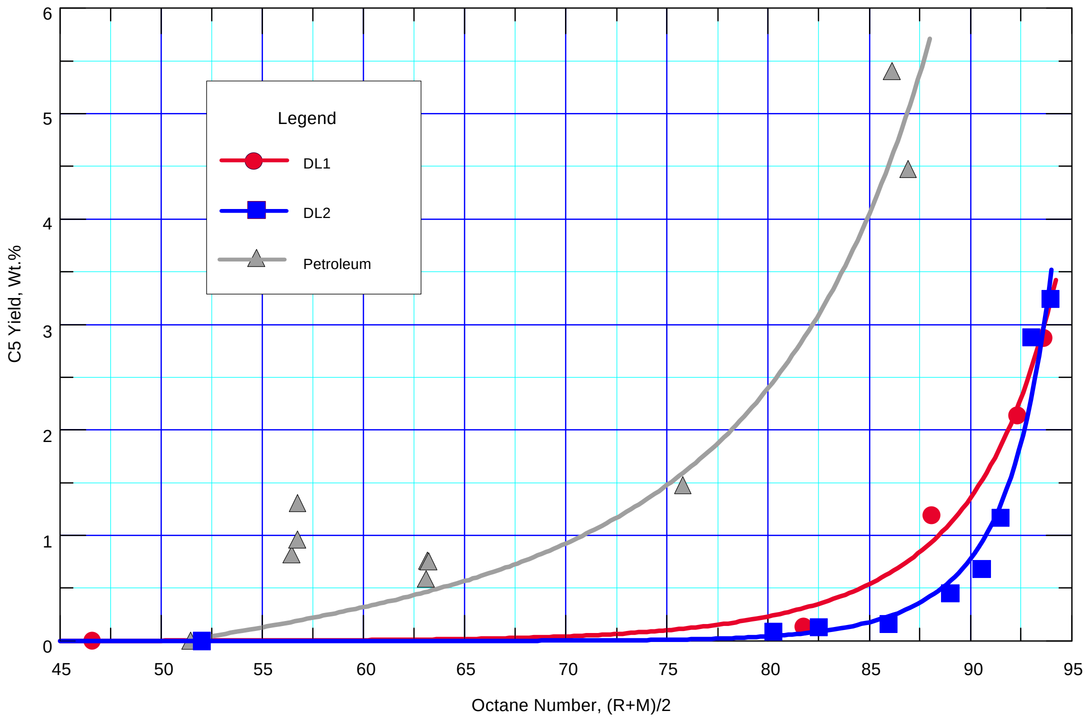

Figure 2-18 - C5 Yield vs. Octane Number

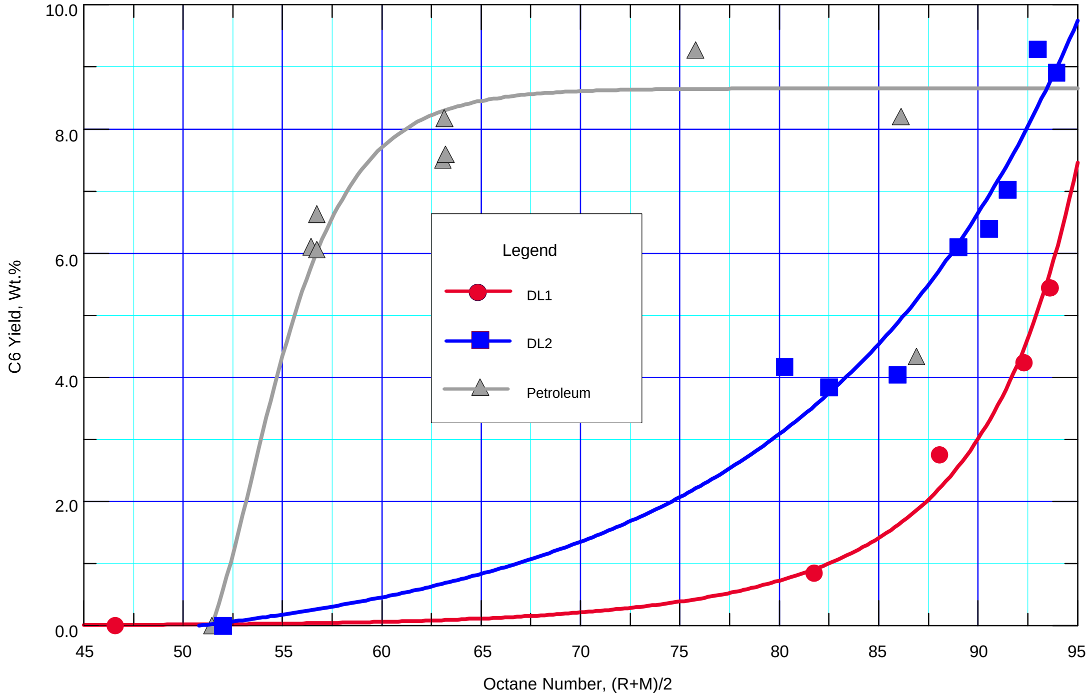

Figure 2-19 - C6 Yield vs. Octane Number

Section 3

Bechtel Activities

3.0 Analysis of Low Pressure (Run 9) and High Pressure (Run 13) Reforming Tests

3.0.1 Introduction

While the effect of operating conditions on product octane number is useful information, the key issue from an economic standpoint is selectivity , i.e. the yield of C_{5+} reformate at a given level of product octane. Selectivity has been correlated by SWRI for Run 13, at 450 psi operating pressure but Run 9, at 250 psi, was judged to have too large an activity loss to permit a correlation to be made. Bechtel has now performed a more detailed correlation effort on Runs 9 and 13 in order to ascertain the effect of pressure. In doing this, it has been found necessary to make certain adjustments to the data to (1) normalize for total product recovery and (2) correct for an aging effect on catalyst selectivity at the lower pressure.

SWRI has reported a severe loss in catalyst activity for 250 psi operation. There was a much less noticeable effect of aging on catalyst activity at 450 psi, and then only at the higher temperatures. An analysis of the 250 psi yield-octane data shows an effect of aging on selectivity. This effect is less severe than on activity and can be corrected for by applying an expression of the form:

Additive Yield Correction = Aging Constant x Catalyst Age in Hours x (100 - observed yield).

The logic in multiplying by (100 - observed yield) is that the effect is one of increased gas yield and the correction ought to be related to the size of the gas yield.

3.0.2 Conclusions

Figure 3-1 summarizes the overall results of this effort in a single correlation of C_{5+} Yield Vs C_{5+} Research Octane Number (RON). Correlation lines are shown for the different feeds at both 250 psi and 450 psi operating pressure. The feeds rank in selectivity in the order: DL2 >DL1 > Blend > Petroleum. At the higher pressure level, where selectivity is lower, this difference is most apparent. The improvement in reforming selectivity with the direct liquids from coal represents an important economic advantage which will be quantified by a linear programming analysis using PIMS.

The improvement in selectivity and the higher aging rate with reduced reforming pressure was expected. Modern reformers use lower pressures, with periodic or continuous catalyst regeneration, to permit both improved selectivity and higher octane levels. It will be noted in Figure 3-1 that, at 450 psi, the various feeds show an ultimate octane level of 100 RON, or less, where the yield of product nose-dives. At 250 psi pressure, the ultimate octane level is above 100 RON.

The differences in selectivity between feedstocks also are not unexpected. PIMS currently has a yield adjustment for N2A (N +2*A, where N is the Vol. % naphthenes and A is the Vol. % aromatics in the feed). Feeds having a higher naphthene content are better aromatics producers and the direct liquid naphthas have high naphthene contents. The larger difference between feeds at the higher pressure is, however, subject to some qualification since it is not known how the aging correction for Run 9 may have affected the analysis. A more sophisticated aging correction, involving temperature as well as pressure, is probable from a theoretical standpoint but could not be substantiated with the data available.

3.0.3 Adjustments to the Data - Run 13

The only adjustments made to the Run 13 data, as produced, were (1) normalization to 100 % Recovery and (2) the elimination of runs 13S, 13W and 13X. Normalization simply involves dividing by the overall recovery on the assumption that product is lost (or gained) in direct ratio to the observed product distribution (a feed loss would give the same result.) Run 13S, however, had an overall recovery of 113.5% which was considered too large to warrant such a correction. Runs 13W and 13X were at 300 and 200 psi, respectfully, and would have been of great interest in this study, except that there had been a deactivation of the catalyst during the previous 950 degree F operations so that the octane of the product was much lower than expected. These points, when plotted, also indicate that some selectivity may have been lost but it was impossible to determine how much loss had occurred and the points (at 97 & 98 % yield at 59 RON) were eliminated to simply clear up the plot.

3.0.4 Adjustments to the Data - Run 9

As stated before, there was clearly an activity loss in Run 9 and the following is a description of the correlation effort. Figures 3-2 and 3-3 are yield - octane plots which show Run 9 data before and after normalization, with time on stream indicated as a parameter. It is clear that normalization improved the data fit and that aging is a significant correlating parameter.

Figures 3-4 and 3-5 show the data corrected for aging with two aging loss correction factors, 0.0010 and 0.0015 %/hr. The higher aging correction (Figure 3-5) was judged to give the best result and was used for Figure 3-1. Data for all the different feeds are brought close to parallel correlation lines, with DL2 showing the best selectivity.

3.1 Linear Programming Analysis

3.1.1 Background

The PIMS library reformer submodel for petroleum naphtha feed is based on provided volumetric yields at four different severity levels (RON 90, 94, 98, and 102). The yields are based on a low pressure reforming operation and, therefore, the selectivity levels are higher than the 450 psig results reported by SwRI for petroleum naphtha feed.

The task for utilizing the SwRI reformer data was not only to create submodels for both coal liquids (DL1 and DL2), but to revise the petroleum model to reflect the data obtained from SwRI on petroleum naphtha feed. In this way, the yields will be consistent in respect to operating pressure and the source of the data (i.e. the petroleum and coal liquid submodels will be based on SwRI data, not a combination of PIMS library data and SwRI data).

3.1.2 Reformer Submodels Development

The normalized SwRI data was used to plot the wt% yields vs C_{5+} RON curves for each of the light gases (hydrogen, methane, etc.) and the C_{5+} reformate. Attempts were made (without success) to regress equations for the curves through the data for each of the three feeds (petroleum, DL1 and DL2). Instead, curves were hand drawn through the data for each feed. In addition, since there was no data above RON 100, the severity points were then changed to RON 88, 92, 96, and 100.

At each severity point and for each feed, estimates of the wt% yields for each of the product components were made. Because of the scatter in the data for hydrogen, it was decided to use the hydrogen yield to achieve a 100% mass balance. It also should be noted that there was a significant amount of extrapolation used to estimate the yields for the petroleum feed at the higher octane severties.

The wt% yield estimates were then converted to volume percent yields for input into the PIMS model. The results are shown in Tables 3-1 through 3-3. Note that the volume percent yields for hydrogen, methane, and ethane are based on a fuel oil equivalent.

DL1 Yield Adjustment

The PIMS model was developed based on assuming that the petroleum and the coal liquids would be co-processed throughout the refinery in the same upgrading units. In other words, there would not be separate facilities for the coal liquids. Specifically, to prepare the reformer feed, the operating conditions for hydrotreating the petroleum naphtha are the same as they would be for either of the two direct coal liquids.

The DL1 reformer feed, however, was hydrotreated at much more severe conditions than was used for the DL2 naphtha (1500°F, 1.1 LHSV vs 800°F, 1.85 LHSV). This resulted in the hydrogenation level of the DL1 reformer feed being very similar to the hydrogenation level of the DL2 reformer feed, despite the fact that the neat (before hydrotreating) DL1 naphtha has a much lower hydrogen content than the neat DL2 naphtha (13.62 wt% vs. 13.86 wt%). To place the DL1 material on a level playing field along with the DL2 material, a three-step process was used.

1. The properties (hydrogen, naphthene, aromatic contents, etc.) were estimated for a DL1 naphtha hydrotreated at the same conditions as the DL2 naphtha hydrotreating.

2. The delta yield factor, N2A (see section 3.1), was calculated for the actual DL1 reformer feed and the "revised" DL1 reformer feed (from item 1).

3. The difference in the N2A between these two feeds was used to adjust the actual reformer yields for DL1. The resultant yields represent the reformer operation for a DL1 naphtha feed hydrotreated at the same conditions as used for the DL2 naphtha. These adjusted yields are shown in Table 3-2.

3.1.3 Effect of reformer pilot plant data on coal liquid value

Prior to inputing the reformer pilot plant data into the LP model, the reformer submodels for petroleum and both coal liquids were identical. In other words, the yields, properties, etc. for a petroleum feed were exactly the same as for a coal liquid feed. The model was run for both the no-expansion and expansion cases[1].

The yield and property data for both the petroleum and coal liquid feeds was then inputed into the model. The model was rerun for both cases.

The preliminary results showed that due to results from the reformer pilot plant testing, the value of coal liquid increased significantly. Specifically, the DL2 value increased 22 cents/barrel for the no-expansion case and 32 cents/barrel for the expansion case. These increases are solely due to the higher selectivities of the coal liquid versus the petroleum feed. The DL1 material value increased less because of its lower selectivity relative to DL2.

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[1] Ist Quarter 1995 Technical Progress Report, Refining and End Use Study of Coal Liquids, May, 1995

Table 3-1 - Low pressure reforming - petroleum feed

Severity level	1	2	3	4
Product research octane	88	92	96	100
Product yields, vol% of feed				
Hydrogen (FOE)	5.08	5.84	8.88	15.19
Methane (FOE)	0.63	1.02	1.56	2.44
Ethane (FOE)	1.32	2.05	3.02	4.38
Propane	3.35	6.32	9.71	13.41
Iso-butane	1.21	1.74	2.78	3.61
N-butane	2.59	3.35	4.28	5.62
Reformate	85.75	81.55	75.37	66.52

FOE = fuel oil equivalent

Table 3-2 - Low pressure reforming - DL1 medium naphtha feed

Severity level	1	2	3	4
Product research octane	88	92	96	100
Product yields, vol% of feed				
Hydrogen (FOE)	6.11	8.90	11.12	14.04
Methane (FOE)	0.08	0.22	0.47	2.03
Ethane (FOE)	0.36	0.94	2.01	3.96
Propane	1.17	2.09	5.02	11.49
Iso-butane	0.25	0.39	0.87	1.78
N-butane	0.50	0.98	1.97	3.98
Reformate	93.94	90.54	85.31	73.95

Table 3-3 - Low pressure reforming - DL2 medium naphtha feed

Severity level	1	2	3	4
Product research octane	88	92	96	100
Product yields, vol% of feed				
Hydrogen (FOE)	3.73	6.52	8.76	11.45
Methane (FOE)	0.00	0.01	0.29	1.27
Ethane (FOE)	0.15	0.29	0.68	2.24
Propane	0.31	0.62	2.23	6.93
Iso-butane	0.14	0.28	0.56	1.67
N-butane	0.20	0.40	1.07	3.08
Reformate	92.86	90.93	87.50	78.71

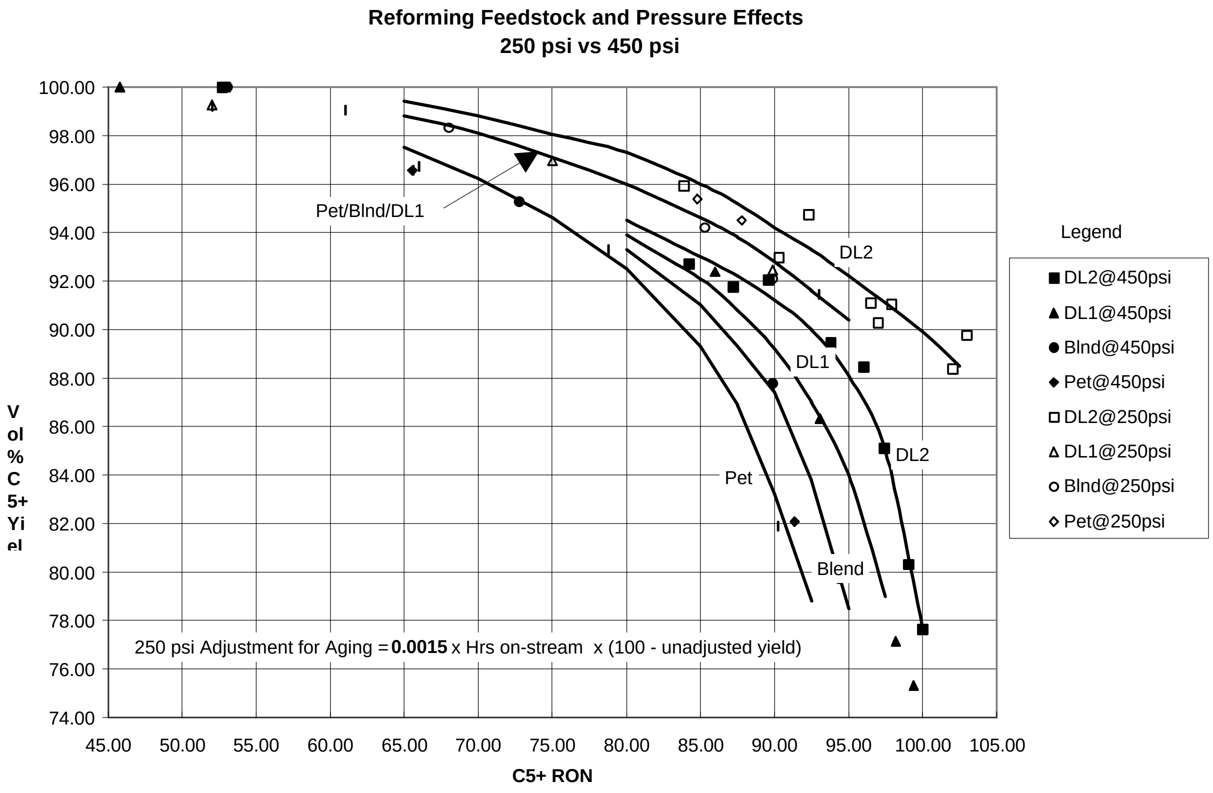

Figure 3-1 Combined Run 9 and Run 13 Correlation Showing Effects of Pressure and Feedstock

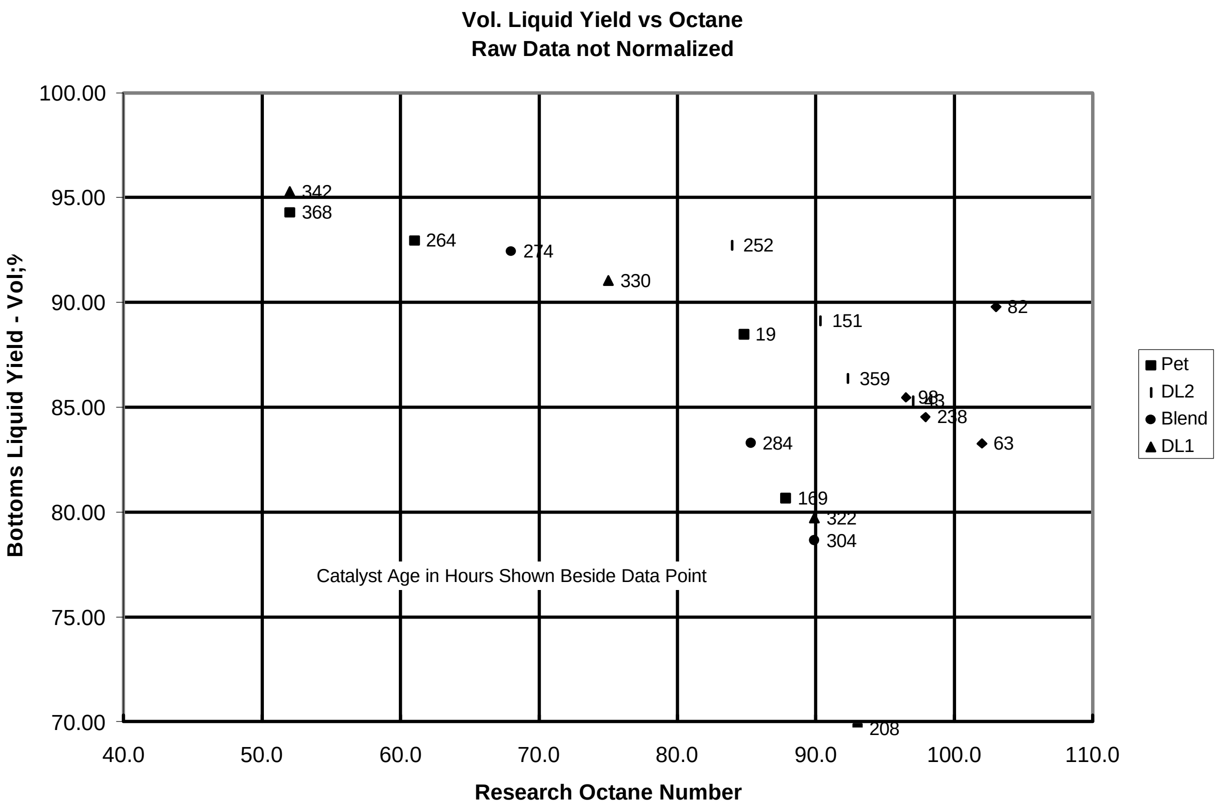

Figure 3-2 250 psi Reforming (Run 9) Raw Data with Time on Stream Noted

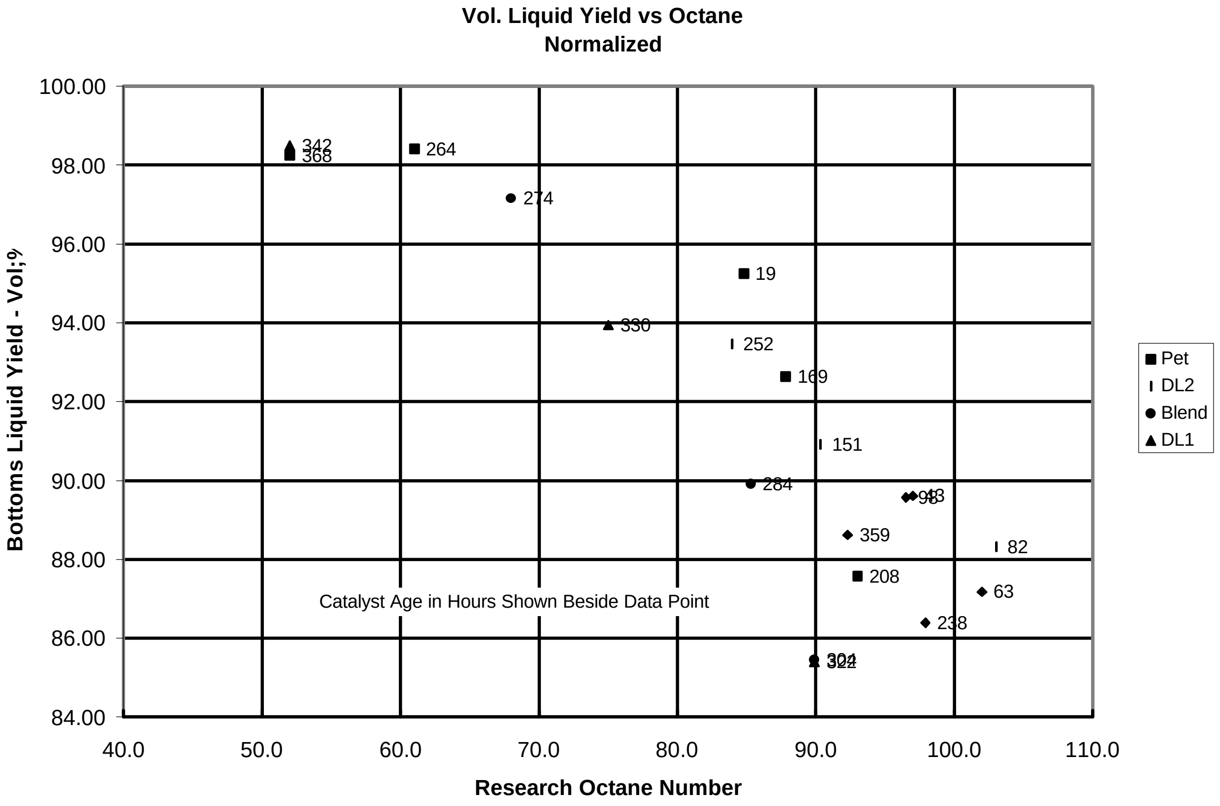

Figure 3-3 250 psi Reforming (Run 9) Data Normalized to 100% Recovery with Time on Stream Noted

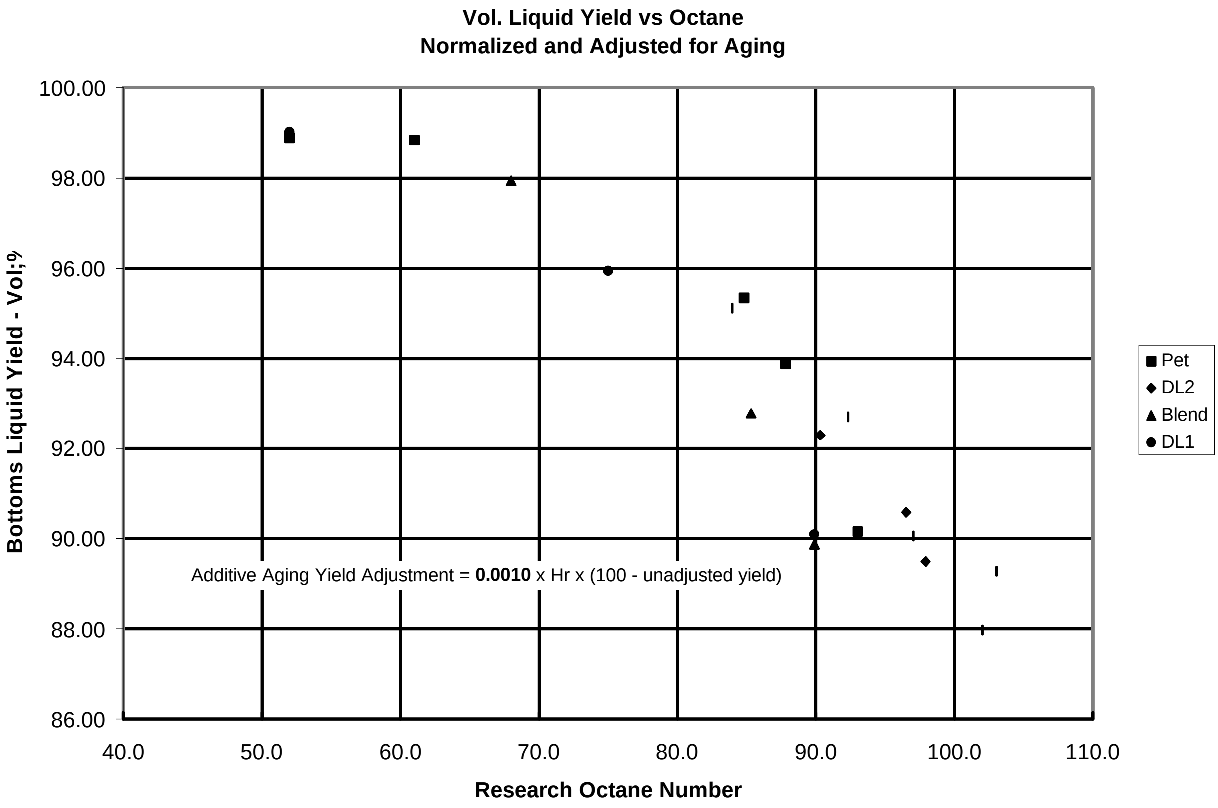

Figure 3-4 - 250 psi Reforming (Run 9) Normalized with 0.0010 %/hr Aging Rate Adjustment

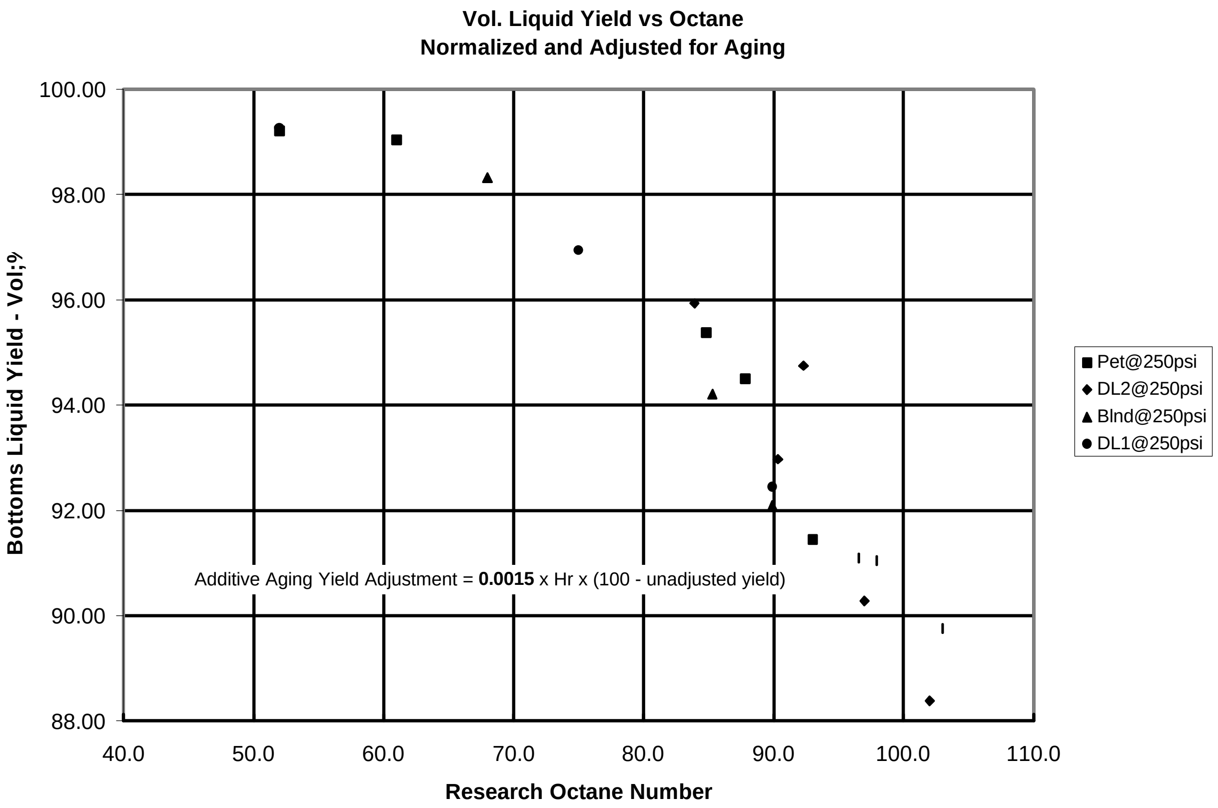

Figure 3-5 250 psi Reforming (Run 9) Normalized with 0.0015 %/hr Aging Rate Adjustment

Section 4

Amoco Activities

There was no project activity for this reporting period.

Section 5

M.W. Kellogg Activities

There was no project activity for this reporting period.

Section 6

Project Management

6.1 Reports and Schedules

The milestone schedule and status for the Basic Program and Option 1 is shown in Figure 6-1.

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(11.84)

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OMB NO 1901.1400

Figure 6-1
Milestone Schedule for Basic Program & Option 1

☐ PLAN ■ STATUS REPORT

1. TITLI Refining and End Use Study of Coal Liquids

2. REPORTING PERIOD 7/1/97 to 9/30/97

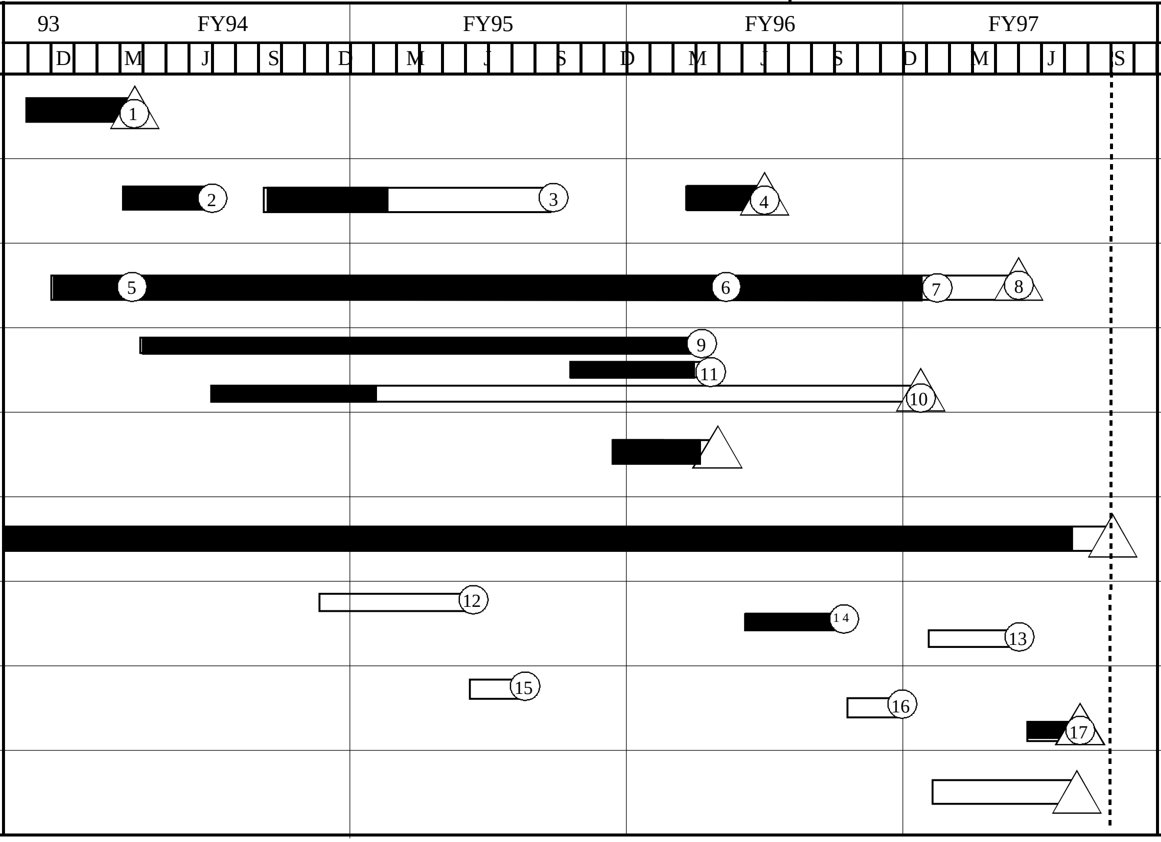
3. IDENTIFICATION NUMBER DE-AC22-93PC91029

4. PARTICIPANT NAME AND ADDRESS

Bechtel Corporation
50 Beale Street
San Francisco, CA 94105

5. START DATE 11/1/93

6. ESTIMATED COMPLETION DATE 8/30/98



7. ELEMENT CODE	8. REPORTING ELEMENT	10. PERCENT COMPLETE a. Plan	b. Actual
Task 1	Project Work Plan	100	100
Task 2	Feed Characterization	100	70
Task 3	Linear Programming (LP) Analysis	100	84
Task 4	Pilot Plant Analysis	100	77
Task 5	Option 1 Work Plan	100	80
Task 6	Administration Task	88	88
Option 1 Task 1	Pilot Plant Analysis (Produce Fuels)	100	33
Option 1 Task 2	Characterization, Blending, and Testing	10	100
Option 1 Task 3	Economic Study	30	20

1 Submit Final Work Plan
2 Characterize DL1 liquid
3 Characterize IL liquid
4 Characterize DL2 liquid
5 Develop LP model
6 Input DL pilot plant data
7 Input IL pilot plant data
8 Conduct evaluation runs
9 Conduct DL1 pilot plant tests
10 Conduct IL pilot plant tests
11 Conduct DL2 pilot plant tests
12 Production runs for DL1 (deleted from program)
13 Production runs for IL(deleted from program)
14 Production runs for DL2
15 ASTM tests for DL1 (deleted from program)
16 ASTM tests for IL(deleted from program)
17 ASTM tests for DL2

11. SIGNATURE OF PARTICIPANT'S PROJECT MANAGER AND DATE