ECONOMICS OF UPGRADING FISCHER-TROPSCH PRODUCTS

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The upgrading of Fischer-Tropsch (F-T) light ends was studied at UOP in a program sponsored by the Pittsburgh Energy Technology Center of the U.S. Department of Energy. The goal of the program was to increase the overall yield of marketable transportation fuels from the F-T upgrading complex by focusing on liquefied petroleum gas (LPG) and naphtha. An overview of the entire light-ends program is presented in this paper. Although this contract is specifically concerned with light products (C_3-C_{11}), a separate DOE-sponsored program [1] at UOP investigated the characterization and upgrading of the heavy end of the F-T product spectrum: F-T wax (Figure 1). An economic analysis of the light and heavy ends upgrading was performed to evaluate the conversion of F-T products to marketable transportation fuels.

PRODUCT DISTRIBUTION FROM F-T REACTORS

The F-T reaction is a fundamental component of indirect coal liquefaction. As the first step, coal or other carbon-containing materials are converted to a synthesis gas composed primarily of hydrogen and carbon monoxide. In the F-T reaction, these synthesis gas components are recombined into a wide range of hydrocarbons, from methane to paraffinic wax. [2]

The distribution of F-T products can be described by the Anderson-Schulz-Flory polymerization law, which states that the probability of the stepwise chain growth of hydrocarbons is independent of carbon number. The chain-growth probability has been shown to be a function of the F-T catalyst and operating conditions and determines the overall product distribution. [3]

In F-T processing, the selectivity to specific product distributions can be adjusted through the careful choice of catalysts and process operating conditions. [4] Maximizing the production of transportation fuels is generally desired. However, one consequence of the Anderson-Schulz-Flory law is that a wide range of products are produced. Accordingly, the theoretical maximum yield of transportation fuel is relatively low.

For example, if maximum gasoline yield is desired, a penalty must be paid through the associated production of light ends (C_1-C_4). This type of operation is typical of F-T synthesis in fluidized-bed reactors. Fixed-bed reactors operate under conditions that favor the production of diesel-range products. Fewer light ends are made because operations favor high chain growth. In the fixed-bed mode, a large fraction of waxy material is produced (C_{19}+). In either case, the production of transportation fuels generates a relatively large amount of less desirable by-products (Table 1). [5]

Recent indirect coal liquefaction work has focused on the development of highly active F-T catalysts and advanced reactor designs that minimize the production of light hydrocarbons and waxes and maximize the production of transportation fuels. Significant advances continue to be made in these areas. Nevertheless, given the fundamental constraints in controlling F-T product distributions, the upgrading of F-T light hydrocarbons and wax by-products is likely to remain an important consideration for indirect coal liquefaction.

NEW TECHNOLOGIES APPLIED TO LIGHT-ENDS UPGRADING

In this contract, F-T light hydrocarbons were treated as two separate species: LPG (C_3-C_5 liquefied gasses) and naphtha (C_5-C_{11} liquid product). New processes developed for the petroleum refining industry were evaluated as upgrading routes for F-T LPG and naphtha.

LPG to Aromatics via the Cyclar Process

The UOP* and BP Cyclar* process, a one-step conversion of LPG to aromatics simultaneously increases the liquid-product yield of the F-T upgrading complex and produces a valuable coproduct: hydrogen. [6] The yield of the liquid product increases because LPG is converted to aromatics. The hydrogen coproduct may be used in hydroprocessing units within the upgrading complex or in the upstream synthesis of hydrocarbons from coal.

Aromatics also contribute to the quality of the liquid product. The aromatic Cyclar product can be used to shift the gasoline pool octane upward to a more valuable grade of gasoline or to blend with low-octane materials to further increase the size of the gasoline pool.

Naphtha Upgrading via New Reforming Technologies

Two new reforming technologies were used to upgrade the F-T naphtha into high-octane gasoline. The low-pressure CCR Platforming* process is an extension of existing commercial technology. [7] This second-generation CCR Platforming process operates at half the pressure of a typical first-generation unit to achieve higher liquid-product yield for a given product octane. A new light-naphtha Platforming* process was also used for improved liquid product yield from the C_6-C_8 portion of a full-boiling-range (FBR) naphtha.

TASK DESCRIPTIONS

The program was split into seven tasks:

Task 1. Project work plan
Task 2. Feedstock procurement and analysis
Task 3. Feedstock preparation
Task 4. Cyclar processing study
Task 5. Light-paraffin conversion study
Task 6. Low-pressure platforming process study
Task 7. Economic evaluation

Task 1. Project Work Plan

The project work plan described the overall research program in detail. It provided the basis for monitoring and controlling the program.

Task 2. Feedstock Procurement and Analysis

The objective of this task was to procure and analyze the feedstocks to be used in the pilot plant studies. Coal-derived naphtha was obtained from a commercial F-T facility. Petroleum-derived LPG blends were used in place of LPG from a commercial F-T facility because of sample procurement and transportation difficulties.

Task 3. Feedstock Preparation

The F-T naphtha has high levels of olefins and oxygenates that must be converted prior to reforming. A two-step pilot plant hydrotreating operation was used to saturate olefins at low severity and then convert oxygenates at high severity. The initial low-severity operation avoided gum formation by the olefins. High-severity second-stage treatment reduced oxygenates to a low level to prevent water formation during reforming. The hydrotreated product was then batch fractionated into a FBR naphtha (C_5-C_{11}), a light naphtha (C_6-C_8), and a heavy naphtha (C_9-C_{11}). A minor amount of reagent-grade paraffin was blended into the FBR naphtha to achieve the desired carbon number distribution.

Task 4. Cyclar Processing Study

The use of the Cyclar process for upgrading F-T LPG was studied at UOP. [8] The Cyclar process converts LPG into aromatics.

The LPG derived from the F-T reactor is highly olefinic. Two routes for upgrading F-T LPG were investigated (Figure 2). In one route, olefinic LPG was fed directly to a Cyclar unit (Direct Cyclar). The alternative flow scheme used the Huels CSP complete saturation process to saturate LPG olefins upstream of the Cyclar unit (Indirect Cyclar). An 18-run pilot plant study verified that each route is technically feasible.

The LPG olefins were easily converted in the Cyclar process. Compared to paraffins, olefins result in higher liquid-product yields. This situation permits more flexibility in choosing process conditions, particularly with respect to process pressure. A significant disadvantage with olefinic feedstocks is that they can lead to excessive catalyst coking under certain conditions.

An economic evaluation procedure was designed to choose between the Direct and Indirect Cyclar options for upgrading LPG. Four cases involving three different F-T reactor technologies were defined. The main distinction among the four cases was the degree of olefinicity, which ranged between 32 and 84 wt-% of the fresh feed. In the two lower olefin cases, Direct Cyclar was preferable, but for the two higher olefin cases, Indirect Cyclar was preferable. On the basis of what has been learned in this contract, a Cyclar unit that would best fit into an F-T upgrading complex would not use complete saturation. Instead, partial saturation of the feed would be employed to take advantage of the LPG olefins without the excessive costs associated with high catalyst coking rates at olefin levels above 65 wt-%.

The Cyclar process is a promising technology for use within an F-T upgrading complex. The Cyclar process directly addresses the problem of what to do with F-T LPG. The Cyclar process uses not only C_3 and C_4 olefins, which can be polymerized as an alternative, but also C_3 and C_4 paraffins. With the exception of alkylation, which uses isobutane, few process alternatives are available for the direct conversion of LPG paraffins into liquid products.

For a 5,675 MT/d Arge upgrading complex with a wax hydrocracker operating at high severity (large LPG production rate), a Cyclar unit would contribute more than 4,500 BPSD of a high-octane (106 R+M/2), low Reid vapor pressure (RVP; 1.6 psia) aromatic product. The liquid product would be 89.1 wt-% benzene, toluene, and xylenes (BTX) aromatics and 10.9 wt-% heavier aromatics. Aside from the liquid product, the Cyclar process makes a valuable 95 vol-% purity hydrogen coproduct. The hydrogen production rate would exceed 1,200 SCFB of LPG feed, or about 14 MM SCFD. This volume of hydrogen is sufficient to change the upgrading complex from a hydrogen consumer to a net exporter of hydrogen.

Task 5. Light-Paraffin Conversion Study

The light-naphtha Platforming process is capable of converting light naphtha into a high-octane product at high liquid-volume yields. This process can make a significant contribution to light-ends upgrading. Hydrotreated F-T naphtha is extremely paraffinic, and light paraffins are the most difficult component of a FBR naphtha to reform into aromatics with traditional technology. A light naphtha (C_6-C_8) derived from an F-T reactor was used as the feedstock for this pilot plant program.

Task 6. Low-Pressure Platforming Process Study

Low-pressure (second-generation) CCR Platforming is an extension of current technology. The process pressure for the second generation is typically half that of the first generation. Significant advancements in the catalyst regenerator design have allowed this pressure reduction. Lower pressure results in higher liquid-volume yields for any given product octane.

Details of Tasks 5 and 6 have been published in a topical report. [9] The conclusion of this work was that reforming naphtha at low pressure (50 psig) rather than at high pressure (125 psig) has a significant economic advantage. This advantage is particularly true for an extremely lean naphtha produced by F-T synthesis. For the case of a 40,000 BPSD unit processing an FBR Arge naphtha, an additional 5.4 vol-% yield is obtained at low pressure. This high yield translates into 767,000 bbl of additional reformate over the course of a year. Process economics are tightly related to liquid-product yield, and the additional reformate yield of the 50 psig operation adds more than $29,000/d to the gross margin. Although the low-pressure unit has a larger catalyst regenerator (more capital) and has a higher utility consumption, the internal rate of return (IRR) increases by a factor of 1.3 as pressure is reduced from 125 to 50 psig because of the yield advantage.

Two naphtha-upgrading flow schemes were evaluated (Figures 3 and 4). Low-pressure reforming of the FBR naphtha was compared to a split-naphtha scheme in which light and heavy naphtha was processed separately to maximize yield. For gasoline production, the study showed that the additional complexity and capital required for the split-naphtha case were not economically justified.

Finally, two sources of F-T naphtha were evaluated. Arge synthesis produces a straight-chain naphtha without aromatics. Synthol F-T synthesis produces a naphtha that is highly branched and has some aromatic content (15 wt-%). Although branched paraffins are more difficult to reform than are normal paraffins, Synthol naphtha produces more attractive reforming economics than does Arge naphtha. The economic advantage results from a lower capital-cost design (higher LHSV), which is made possible by the presence of aromatics.

Task 7. Economic Evaluation

The economic evaluation examined the overall impact of new technologies on upgrading F-T products into transportation fuels. The results of this task are described in the next section.

ECONOMICS OF UPGRADING F-T PRODUCTS

The F-T upgrading flow schemes are based on the work performed under the two UOP F-T contracts: F-T Arge wax hydrocracking and F-T light-ends upgrading. Two upgrading complexes were configured: one for Arge reactor products (Figure 5) and one for Synthol reactor products (Figure 6). The price and cost basis used in the economic evaluation is shown in Table 2.

Arge Products Upgrading

The flow scheme of the Arge upgrading complex is shown in Figure 5. The overall complex material balance is based on 5,675.5 MT/d of Arge reactor products (Table 3). The gasoline and diesel pool properties are listed in Table 4. For the Arge case, the following process units were included in the flow scheme:

- **Cyclar Process.** The UOP Cyclar process converts the F-T LPG and LPG product from the CCR Platforming unit and the hydrocracker to aromatics. The C_6 aromatic product from the Cyclar process is sent to the UOP Alkymax* process, and the C_7+ aromatics are blended into the gasoline pool. The past work on the use of the Cyclar process to upgrade LPG was covered in the Topical Report issued under Task 3. [8]
- **Alkymax Process.** The UOP Alkymax process offers a new method of producing high-octane gasoline with reduced benzene levels. The process converts the benzene in gasoline streams into alkyl aromatics by reaction with light olefins in F-T LPG over a fixed bed of catalyst. The Alkymax process offers the opportunity to upgrade F-T LPG, increase pool octane, and simultaneously reduce

benzene content. The product from the Alkymax process is added to the gasoline pool. Typically, the Alkymax process may not be used to alkylate an almost pure benzene stream. This benzene would be sold for its chemical value. Because the objective of the current program is to maximize the production of transportation fuels, the Alkymax unit was included to lower the benzene content of the gasoline pool. The reformulated gasoline specified in the future Clean Air Bill may limit benzene content in gasoline to a maximum of 0.8 vol-%.

- **Naphtha Hydrotreater Process.** The naphtha hydrotreater (NHT) processes the F-T C_5-C_{11} stream as well as the C_5-C_{11} naphtha stream from the hydrocracker. The primary purpose of the NHT unit is to saturate olefins and to convert small quantities of oxygenates and organic acids that may otherwise affect performance of the downstream Platforming unit. The C_5-C_6 product is charged to the Penex* isomerization unit, and the C_7-C_{11} product from the NHT is fed to a CCR Platforming unit.
- **Penex-Molex* Units.** The highly paraffinic C_5-C_6 product from the NHT is charged to the Penex isomerization unit. The octane of the fraction is improved as low-octane normal paraffins are isomerized to higher octane isoparaffins. The conversion of normal paraffins to isoparaffins is limited by thermodynamic equilibrium. The Molex unit separates and directs higher octane isoparaffins to the gasoline pool and lower octane normal paraffins back to the Penex unit for isomerization.
- **CCR Platforming Unit.** The C_7-C_{11} naphtha from the NHT product is fed to the UOP CCR Platforming or reforming unit. The unit is used to convert F-T naphtha to high-octane gasoline. The details of the process are given in Tasks 5 and 6 of the Topical Report. [9] The resulting product is blended into the gasoline pool.
- **Hydrocracker.** The hydrocracker (HC) provides a means of upgrading heavy material, primarily F-T wax, into transportation fuel. The yields and product properties were derived from past work done under the PETC-sponsored contract on F-T wax hydrocracking.

The gasoline and diesel pool properties for the Arge case are shown in Table 4. The gasoline blend from the complex has a research octane (RONC) of 98, RVP of 6.9 psia, aromatics level of 48.2 vol-%, and benzene content of 0.4 vol-%. The diesel pool has an extremely high cetane of 73.1 and meets all diesel specifications. The capital cost and operations summary is shown in Table 5. The complex before-tax IRR is 36.7% based on market feed and product prices (Table 6).

Synthol Products Upgrading

A similar complex flow scheme was developed for the Synthol case (Figure 6). The differences in the Synthol product upgrading complex are:

- The highly olefinic F-T LPG feed to the Cyclar unit is saturated using the Huels CSP process to prevent excessive catalyst coking in the Cyclar unit. The Huels CSP process hydrogenates olefins contained in the C_3-C_5 LPG stream to their respective paraffins.
- The F-T C_{12}-C_{18} stream is processed in a distillate hydrotreater before sending it to the diesel pool. The purpose of this distillate-finishing step is to saturate the olefins and remove any oxygenates or organic acids. The cetane number of the distillate stream improves with hydrotreating.
- No hydrocracker is specified for the F-T C_{19}+ wax stream. The quantity of wax from a Synthol reactor is extremely small, and the wax is used as fuel in the complex.

The overall material balance for the Synthol case is shown in Table 7. The gasoline and diesel pool properties are shown in Table 8. The gasoline blend from the complex has a research octane (RONC) of 99.7, RVP of 7.1 psia, aromatics level of 48.8 vol-%, and benzene content of 0.5 vol-%. The capital cost and operations summary is shown in Table 9. The complex before-tax IRR of 19.7% is based on market feed and product prices (Table 10).

Sensitivity Analysis

The sensitivity of the F-T complex economics was studied over a range of product prices, feedstock costs, and plant capital investment. The results are summarized in Figure 7.

First, the prices of the gasoline and diesel products were increased by a factor of 1.5 over the base case. The high-end case more closely represents the market prices prevalent since the onset of the Middle East crisis. Next, the feedstock costs were increased by a factor of 1.2. The feedstock costs make up more than 70% of the net cost of production. The rate of return is extremely sensitive to both the product price and the cost of feed to the upgrading complex. In reality, the feedstock costs should represent the costs of indirect liquefaction of coal. For the base case, market values were assigned to feedstock costs because the economics of synthesis gas production and the F-T reactor section was beyond the scope of the current work. Finally, the plant capital investment was increased by a factor of 1.5 over the base case. The plant capital investment does not have as much of an impact on the F-T upgrading complex economics as the product prices and the feedstock costs.

Summary

When the economics of the Arge and the Synthol complexes are compared, middle distillate production via Arge is seen as less complex and cheaper than gasoline production via Synthol. This conclusion assumes that the costs of products derived from the Arge and the Synthol reactors are the same. Apart from the economics, if F-T products are considered as liquid fuels, Arge should be used to produce middle distillate (jet fuel plus diesel) for two good reasons:

- The chain-growth mechanism inherent in F-T technology is not selective to a particular boiling range, and the probability of high chain growth maximizes the formation of reactor wax, which can be hydrocracked easily to distillates.
- The F-T diesel and jet fuel have unique property attributes, such as no sulfur, no nitrogen, and no aromatics.

Acknowledgments

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* UOP, Cyclar, CCR Platforming, Platforming, Alkymax, Penex, and Molex are tradenames and/or service marks of UOP.

Table 1

F-T Reactor Selectivities

Products	Arge, wt-%	Synthol, wt-%
Methane	2.0	10.0
Ethylene	0.1	4.0
Ethane	1.8	4.0
Propylene	2.7	12.0
Propane	1.7	2.0
Butylene	3.1	9.0
Butane	1.9	2.0
C_5-C_{11} Gasoline	17.9	40.0
C_{12}-C_{18} Diesel	13.9	7.0
C_{19}-C_{23}	7.0	--
C_{24}-C_{35} Medium Wax	19.9	4.0
C_{35}+ Hard Wax	24.8	--
Water-Soluble Chemicals	3.2	6.0
	100.0	100.0

Table 2

Price and Cost Basis for the Economic Analysis of an F-T Complex

	Costs and Product Values	
Feedstock:		
Gasoline	$242 $/MT	28.4 $/bbl
Diesel	193 $/MT	26.0 $/bbl
Fuel Gas	3.00 $/MM Btu	2.84 $/GJ
LPG	140 $/MT	1132 S/bbl
Hydrogen (95 vol-%)	694 $/MT	2.25 $/M SCF
Naphtha, FBR	160 $/MT	16.9 $/bbl
Diesel	193 $/MT	26.0 $/bbl
Wax	125 $/MT	
Utilities:		
Power	0.06 $/kWh	
Steam, 600 psig (HP)	4.50 $/M lb	
Steam, 350 psig (MP	4.00 $/M lb	
Steam, 50 psig (LP)	3.00 $/M lb	
Boiler Feed Water	0.40 $/M lb	
-Condensate	0.40 $/M lb	
Cooling Water	0.10 $/M gal	
Fuel Fired	3.00 $/MM Btu	
Labor:		
Operators	36,000 $/year	
Supervision	25%	
Labor Overhead	35%	

Table 3

Overall Material Balance of the F-T Complex Arge Case

Feed from Arge	MT/d
C_1-C_2 Fuel Gas	221.3
C_3-C_4 LPG to Cyclar	423.5
C_3-C_4 LPG to Alkymax	110.0
C_5-C_{11} Naphtha to NHT	1015.9
C_{12}-C_{18} to Diesel	788.9
C_{19}+ to Wax to Hydrocracking	2934.2
	5493.8
Misc. Chemicals	181.6
	5675.4

Product	MT/d
Hydrogen	39.1
C_1-C_4 Fuel Gas	532.4
Gasoline:	
Alkylate	166.0
C_7+ from Cyclar	280.0
Isomerate	648.0
Reformate	1025.9
Diesel:	
C_{12}-C_{18} from Arge	788.9
C_{12}-C_{18} from Hydrocracking	2013.6
	5493.9
Misc. Chemicals	181.6
	5675.5

Table 4

Product Properties for the F-T Complex-Arge Case

GASOLINE POOL:

	Alkymax	Cyclar	Penex-Molex	CCR Reforming	Blend	U.S. Unleaded Pool Comp.	Possible Reform. Gasoline Specs.
Flow Rate, MT/d	166.0	280.0	648.0	1025.9	2119.9	--	--
Specific Gravity	0.8666	0.893	0.641	0.8022	0.7585	--	--
API	31.8	26.95	89.2	44.9	55.1	--	--
RVP, psia	0.1	0.7	14.4	3.3	6.92	8-12	8 max.
Molecular Weight	130	101.4	78.4	103.5	95.4	--	--
RONC	118	113.2	89	100	98.7	87-88	(R+M)/2
MONC	108	102.5	87.3	88.6	91.0	--	--
ASTM D-86, °F							
IBP	198	223	75	107	--	--	--
50% over	268	268	105	282	--	--	--
90% over	354	354	132	340	279	300-350	300 max.
EP	441	441	150	411	--	--	--
Aromatics, vol-%	100.0	100.0	0.0	65.9	48.2	30-35	20-25 max.
Benzene, vol-%	0.0	0.0	0.0	0.9	0.4	1-2	0.8 max.
Olefins, vol-%	0.0	0.0	0.0	1.0	0.5	10-12	5 max.

DIESEL POOL:

	Arge	Hydrocracking	Blend	Specs.
Flow, MT/d	788.9	2013.6	2802.4	--
Specific Gravity	0.7752	0.7891	0.7851	--
API 51.0	47.8	48.7	--	--
ASTM 50% Pt., °F	501	583	560	--
Cetane Index	73.3	73.0	73.1	40 min.
Flash Point, °F	191.7	210.5	203.8	125 min.
Pour Point, °F	40.9	-13.3	17.1	20 max.
Freeze Point, °F	N/A	N/A	N/A	--
Viscosity, cSt @ 100°F	2.91	4.61	3.99	1.9-4.1

Table 5

Capital Cost and Utilities Summary for the F-T Complex Arge Case

	Cyclar	Splitter+ Alkymax	NHT+ Splitter	CCR Reforming	Penex-Molex	HC Unibon
Feed Rate, MT/d	614.6	211.5	1881.3	1231.6	651.3	2934.2
EEC, $MM	28.55	6.89	8.80	13.02	10.20	29.15
Utility Consumptions:						
Power, kW	3533	100	705	2183	353	2148
HPS, M lb/h	-6.6	9.0	0.0	-6.9	0.0	16.8
MPS, M lb/h	0.0	0.0	0.0	0.0	9.2	7.5
LPS, M lb/h	2.2	0.0	0.0	0.1	20.3	0.0
BFW, M lb/h	9.7	0.0	0.0	11.6	0.0	0.0
Cool Water, M gal/h	241.6	14.6	9.9	159.4	0.2	67.2
Fuel, MM Btu/h	53.5	5.0	65.6	88.8	0.0	121.4
Labor: Operators/Shift	3	2	1	2	2	3

Table 6

Economic Evaluation (Base Case) for the F-T Complex Arge Case

Capital Items	$ MM
Plant Investment (ISBL)	96.61
OSBL (50% ISBL)	48.31
Interest	29.16
Total Fixed Investment	174.08
Royalties & Fees	12.24
Inventory	8.91
Working Capital	44.75
Total Capital Investment	239.98

Economic Analysis	$ MM
Gasoline Sales	171.01
Diesel Sales	180.29
By-Products Credits	30.3
Feedstock Costs	260.5
Gross Margin	121.1
Variable Costs	14.91
Fixed Costs	17.99
Cash Flow	88.2
Internal Rate of Return (before tax), %	36.68

Table 7

Overall Material Balanceof F-T Complex Synthol Case

Feed from Synthol	MT/d
C_1-C_2 Fuel Gas	1021.6
C_3-C_4 LPG to Cyclar Unit	1218.9
C_3-C_4 LPG to Alkymax Unit	200.0
C_5-C_{11} Naphtha to NHT	2270.2
C_{12}-C_{18} Diesel	397.3
C_{19}+ Wax to Fuel	227.0
	5335.0
Misc. Chemicals	340.5
	5675.5

Product	MT/d
Hydrogen	32.9
C_1-C_4 Fuel Gas	1573.5
C_{19}+ Wax to Fuel	227.0
Gasoline	
Alkylate	413.5
C_7+ from Cyclar	607.8
Isomerate	1025.5
Reformate	980.7
Diesel	
C_{12}-C_{18} from Distillate Finishing	397.3
	5258.2
Misc. Chemicals	417.3
	5675.5

Table 8

Products Propertiesof the F-T Complex Synthol Case

GASOLINE POOL:

	Alkymax	Cyclar	Penex-Molex	CCR Reforming	Blend	U.S. Unleaded Pool Comp.	Possible Reform. Gasoline Specs.
Flow Rate, MT/d	413.5	607.8	1025.5	980.7	3027.5	--	--
Specific Gravity	0.8665	0.893	0.6424	0.8054	0.7622	--	--
API	31.8	26.95	88.76	44.2	54.1	--	--
RVP, psia	0.1	0.7	14.4	3.39	7.09	8-12	8 max.
Molecular Weight	127	99.9	78.4	106.6	95.7	--	--
RONC	118	113.2	88.3	100	99.7	87-88	(R+M)/2
MONC	108	102.5	87.3	88.6	92.8	--	--
ASTM D-86, °F							
IBP	198	223	89	114	--	--	--
50% over	268	268	109	271	--	--	--
90% over	354	354	130	341	274	300-350	300 max.
EP	441	441	150	401	--	--	--
Aromatics, vol-%	100.0	100.0	0.0	64.1	48.8	30-35	20-25 max.
Benzene, vol-%	0.0	0.0	0.0	1.7	0.5	1-2	0.8 max.
Olefins, vol-%	0.0	0.0	0.0	1.0	0.3	10-12	5 max.

DIESEL POOL:

	Distillate Finishing	Blend	Specs.
Flow, MT/d	397.3	397.3	--
Specific Gravity	0.79	0.79	--
API	47.6	47.6	--
ASTM 50% Pt., °F	475	475	--
Cetane Index	66	66	40 min.
Flash Point, °F	160	160	125 min.
Pour Point, °F	15.0	15.0	20 max.
Freeze Point, °F	N/A	N/A	--
Viscosity, cSt @ 100°F	3.00	3.00	1.9-4.1

Table 9

Capital Cost and Utilities Summary of the F-T Complex Synthol Case

	Huels CSP +Cyclar	Splitter Alkymax	NHT+ Splitter	CCR Reforming	Penex-Molex	Distillate Finishing
Feed Rate, MT/d	1371.4	461.7	2270.2	1177.3	1043.8	397.3
EEC, $MM	52.48	11.01	9.85	12.67	13.53	6.94
Utility Consumptions:						
Power, kw	7678	218	851	2087	566	310
HPS, M lb/h	-47.6	19.6	0.0	-6.6	0.0	0.0
MPS, M lb/h	0.0	0.0	0.0	0.0	14.8	0.0
LPS, M lb/h	8.3	0.0	0.0	0.1	32.6	0.0
BFW, M lb/h	55.6	0.0	0.0	11.1	0.0	0.0
Cool. Water, M gal/h	879.7	31.9	11.9	152.4	0.4	5.2
Fuel, MM Btu/h	306.0	10.0	79.1	84.9	0.0	11.1
Labor: Operators/Shift	3	2	1	2	2	2

Table 10

Economic Evaluation (Base Case) of the F-T Complex Arge Case

Capital Items	$ MM
Plant Investment (ISBL)	106.48
OSBL (50% ISBL)	53.24
Interest	32.14
Total Fixed Investment	191.86
Royalties & Fees	13.9
Inventory	17.27
Working Capital	38.14
Total Capital Investment	261.17

Economic Analysis:	$ MM/y
Gasoline Sales	244.22
Diesel Sales	25.56
By-Products Credits	63.38
Feedstock Costs	242.83
Gross Margin	90.33
Variable Costs	19.84
Fixed Costs	17.7
Cash Flow	52.79
Internal Rate of Return (before tax), %	19.66

FIGURE 1

TWO CONTRACTS CONCERNING UPGRADE OF F-T PRODUCTS

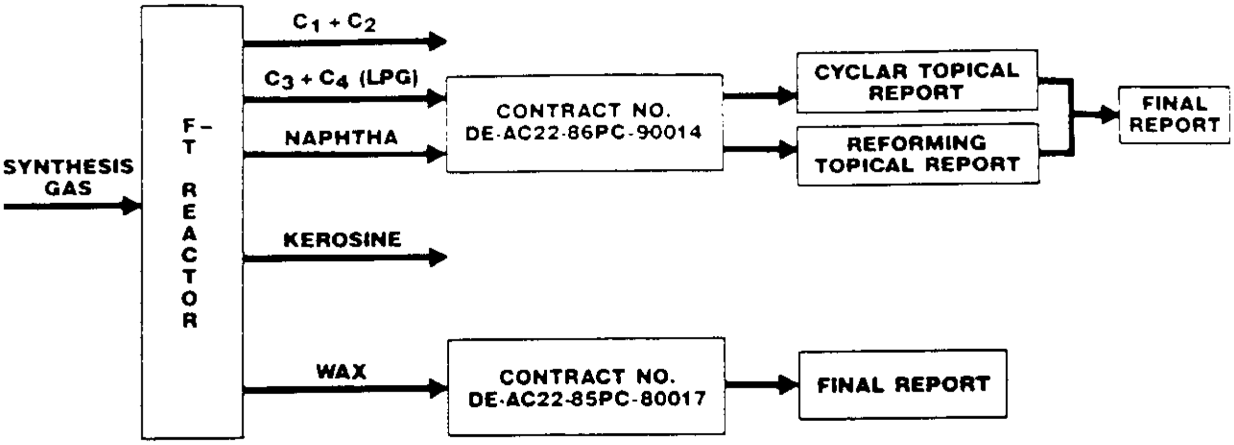

FIGURE 2

DIRECT AND INDIRECT CYCLAR FLOW SCHEMES

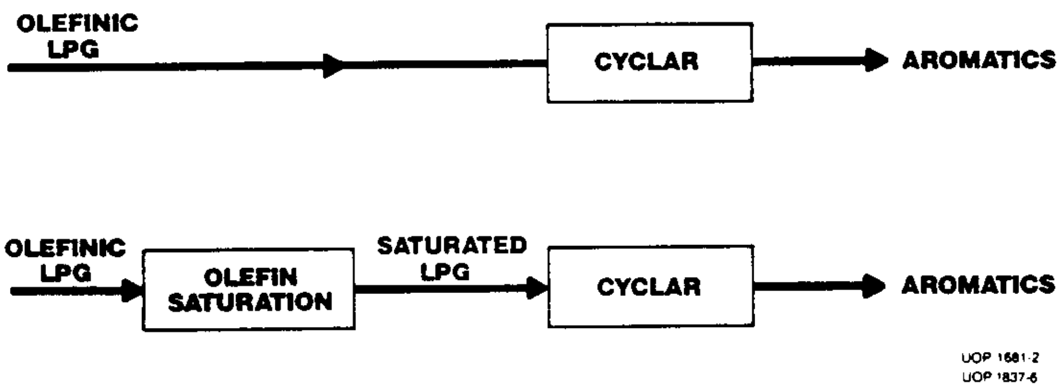

FIGURE 3

FULL-BOILING-RANGE NAPHTHA PROCESSING

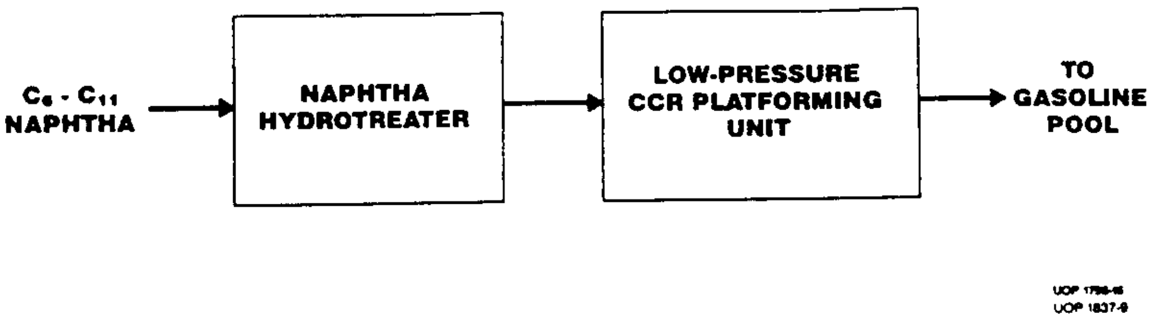

FIGURE 4

SPLIT-NAPHTHA PROCESSING

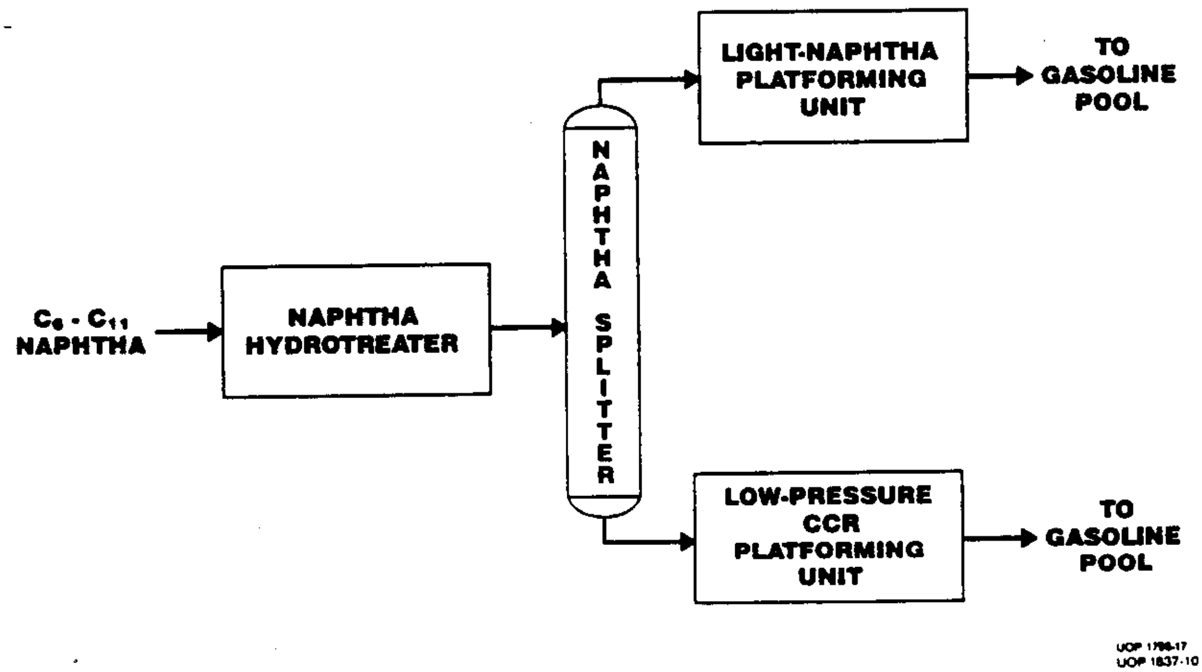

FIGURE 5
F-T UPGRADING COMPLEX (ARGE CASE)

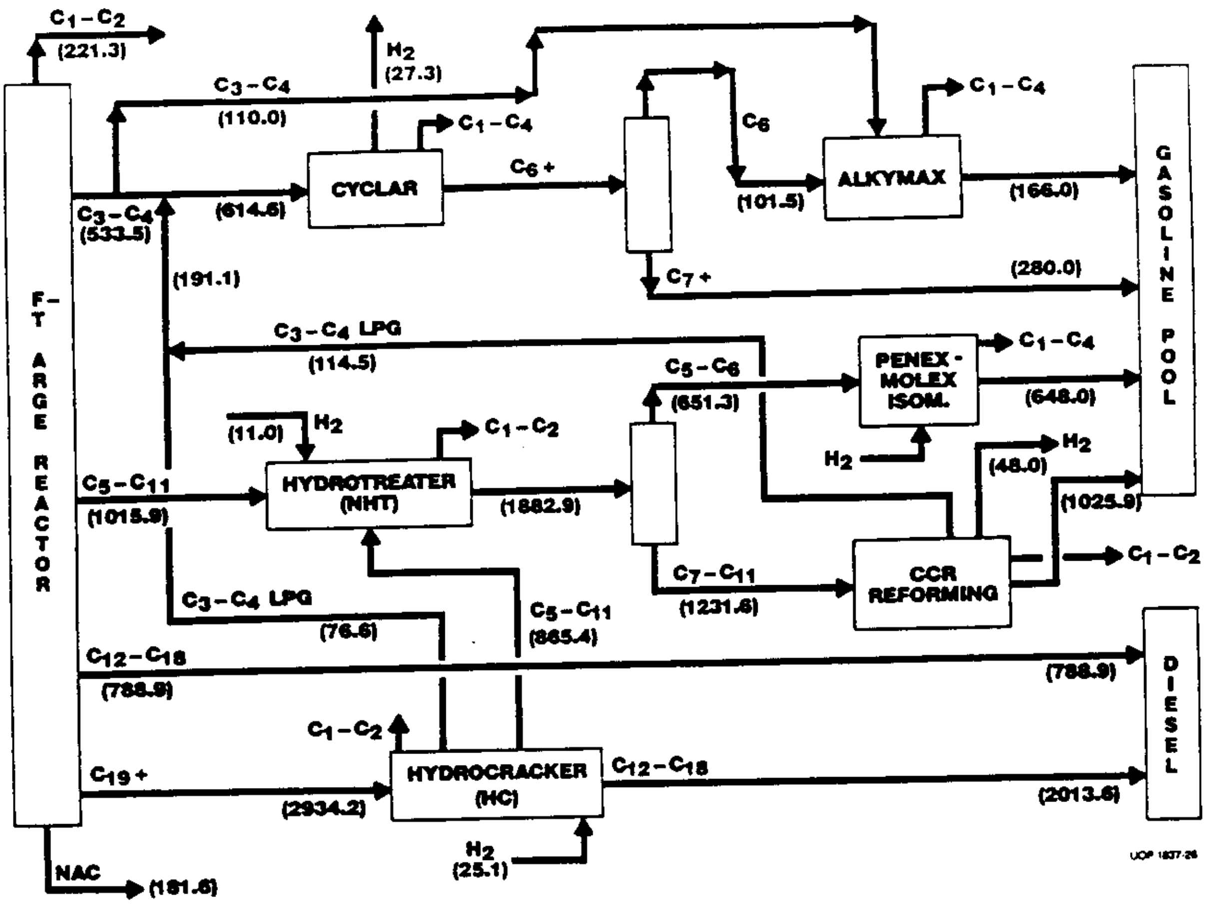

FIGURE 6

F-T UPGRADING COMPLEX (SYNTHOL CASE)

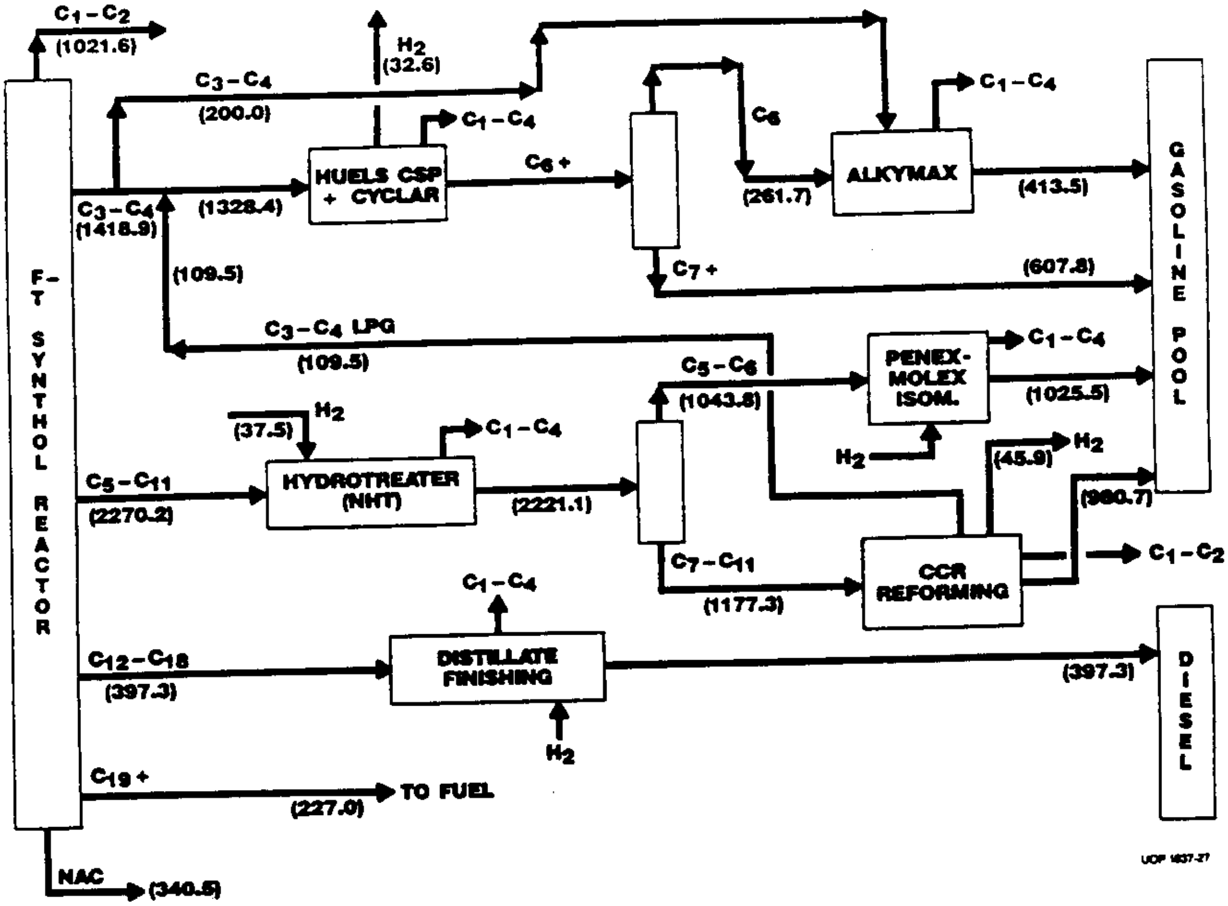

FIGURE 7

FISCHER-TROPSH COMPLEX SENSITIVITY ANALYSIS