FISCHER-TROPSCH WAX CHARACTERIZATION AND UPGRADING PROGRAM SUMMARY

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INTRODUCTION

The Fischer-Tropsch process is a commercially proven method of obtaining distillate product via indirect coal liquefaction. In this process, synthesis gas from a coal gasifier is converted into transportation fuel, with light gases and wax being formed as by-products. Actual yield and product characteristics are dependent on the specific Fischer-Tropsch reactor configuration and operating conditions.

The focus of the subject program was to maximize the yield of marketable distillate fuels from the Fischer-Tropsch process in a technically feasible and economic manner. With this in mind, UOP investigated the molecular nature of several Fischer-Tropsch by-product waxes. Processing methods were developed for upgrading and blending the light gas and wax by-products of the Fischer-Tropsch (F-T) reaction. Related program elements included an overall economic evaluation of the proposed processing schemes.

TASK DESCRIPTIONS

The program was split into six tasks. A brief description of each task follows.

<u>Task 1.0 --Procurement of Fischer-Tropsch Material</u>

UOP procured several materials from the product pool of a fixed-bed commercial Arge reactor. Commercially produced Arge wax was used in the characterization (Task 2) and hydrocracking (Task 3) portions of the program. Several liquid products were also obtained from the Arge complex. These materials were used in the blending study (Task 4).

Samples of three F-T waxes produced in pilot plants were also obtained for characterization. One of the pilot plant samples (Mobil wax) was used in the hydrocracking study.

Task 2.0 --Characterization of Fischer-Tropsch Waxes

Techniques were developed to characterize Fischer-Tropsch waxes using gel permeation chromatography (GPC), high resolution mass spectrometry (HRMS), nuclear magnetic resonance (NMR), infrared spectroscopy (IR), gas chromatography and various other physical analyses.

Task 3.0 --Hydrocracking of a Commercial Fischer-Tropsch Arge Wax

UOP's HC Unibon* process was used to upgrade the commercial Arge Fischer-Tropsch wax. Pilot plant work completed under this program demonstrated that catalytic hydrocracking is an excellent process for producing high quality transportation fuel from Fischer-Tropsch wax in a relatively low severity operation. Optimum conditions for conversion of wax to diesel fuel by hydrocracking were determined in this task.

Task 4.0 --Blending Study of Fischer-Tropsch Material

UOP used a proprietary Catalytic Condensation process (oligomerization) to upgrade C_3/C_6 by-products of the Fischer-Tropsch reaction to obtain a more valuable distillate product. The blending characteristics of this material, as well as those of the hydrocracked wax, with other straight-run Fischer-Tropsch synthesis products were evaluated.

Laboratory analyses were obtained for these blends and used to adjust computer-based blending correlations. Also, laboratory analyses were obtained for blends of Fischer-Tropsch products with aromatics rich, low value light cycle oil (LCO) from fluid catalytic cracking of petroleum derived vacuum gas oils. Corrections were made to traditional blending correlations to account for the blending characteristics of LCO.

Blends of hydrocracked F-T wax and LCO were studied because of the exceptional quality of the distillate made from F-T wax. The distillate has virtually no aromatic content. The absense of aromatics gives this product the desirable features of high cetane number and high smoke point. The diesel fuel produced by the hydrocracker shatters the 2-D diesel specification of 40 (minimum) by over 30 cetane numbers. A good way to capitalize on the high cetane product is to blend a low value, highly aromatic material such as LCO into the diesel pool. Results of the blending study show that the final diesel pool could contain up to 60 wt-% of a typical LCO and still have the required product cetane. The API gravity of the diesel pool would actually improve as a result of the blending because the hydrocracked wax distillate was at the high end of a typical range (almost too light). Blending the hydrocracked distillate with the heavier LCO brings the diesel pool back in line with a typical diesel API gravity.

Key diesel properties such as cetane number, pour point, flash point, viscosity, API gravity and distillation were determined for components and blends to evaluate the accuracy of normal blending correlations.

<u>Task 6.0 --Economic Evaluation of the Upgrading Process Scheme</u>

The results of the studies outlined above were used to evaluate the overall economics of maximizing transportation fuel yield of the Fischer-Tropsch process via by-product upgrading and blending.

Wax hydrocracking was incorporated into an overall Fischer-Tropsch product upgrading complex along with other processes such as catalytic condensation and the catalytic reforming. The associated product streams were blended to yield maximum distillate. In this task, the capital and operating costs were determined and economic calculations were made to verify the feasibility of the proposed conceptual complex.

Task 6.0 --Characterization and Hydrocracking of a Pilot Plant Derived Mobil Fischer-Tropsch Wax

The Mobil wax was produced in a two-stage Fischer-Tropsch synthesis process in a slurry reactor using a precipitated iron catalyst. This system used a low ratio H_2/CO feed gas.

The Mobil wax was characterized and upgraded using catalytic hydrocracking. The objective of this task was to demonstrate the processibility of the Mobil wax in pilot plant hydrocracking and to compare the properties and processibility to that of the commercial Arge Fischer-Tropsch wax. The operating conditions were the same as the "optimum" cases in Task 3.0: Commercial Arge Wax Hydrocracking. Also, Mobil wax is very high in iron content and techniques to remove this iron were investigated.

The development program for Fischer-Tropsch Wax Characterization and Upgrading was completed by UOP at the end of July, 1988. The final report covering all the described tasks is available from the National Technical Information Center. The following section describes the approach and key findings in Task 5: Economic Evaluation of the Upgrading Process Scheme.

ECONOMIC EVALUATION (TASK 5)

An economic evaluation of wax hydrocracking is achieved by comparing two upgrading complex flow schemes (Figures 1 and 2). In the base case, Arge wax is hydrocracked to distillate. In the alternative case, the hydrocracker is removed and the Arge wax is sent to the fuel oil pool.

One financial technique used to evaluate the economics of wax hydrocracking determines the increased value of the feedstock (or the product from the Fischer-Tropsch reactor) due to wax hydrocracking instead of burning it as fuel oil. In the two cases, the products from the upgrading complex, namely, LPG, gasoline, diesel and fuel oil, were assigned market values. Feedstock (condensate, wax, etc.) value was determined once an expected return on investment was assigned.

The next economic approach assigned market values to feedstock (condensate, wax, etc.) as well as to products (LPG, gasoline, diesel and fuel oil) in the upgrading complex. The change in rate of return was determined due to the addition of the wax hydrocracker.

The economic evaluation calculations were done using a standard discounted cash flow calculation to find an internal rate of return (IRR). The object of each calculation was to either calculate an IRR directly, or determine the feedstock value so that the IRR for the complex was 20%. If an actual economic analysis for a complex showed a 20% IRR, then the complex was assumed to be economically attractive in this study. This analysis assumes that one cannot obtain a 20% return by investing that money elsewhere.

Erected cost estimates were made for each process unit in the complex. Variable and fixed costs were also estimated. Table 1 presents a cost summary for the base case flow scheme. Table 2 provides the same information for the alternative case.

The feedstock and product prices used for this study are shown in Tables 3. These prices are market values when the price for oil was $18-19 per barrel. The utility and labor costs used in the study are shown in Table 4.

The price per gallon for gasoline and diesel were kept constant, but the $/MT values vary slightly because the density depends on the material balance for the particular case.

F-T Wax Value

The feed stream of the greatest interest in the complex is the F-T wax. The wax has previously been regarded as a F-T product whose value can be increased by upgrading. The first point of the economic analysis was to test the validity of that hypothesis. The test was done by determining the change in the IRR for the base (with hydrocracker) and alternative (without hydrocracker) cases. If the base case has a higher IRR, the conclusion is that upgrading the wax into distillate products with a hydrocracking unit is attractive.

The calculations were started with the alternative case. The values for the three F-T product streams (LPG, condensate and wax) were assumed to be equal. These values were varied until the IRR for the complex was 20%. From this point on, these F-T product stream values were used in all the economic calculations. This is a rational approach as it is difficult to assign market value to F-T product streams. The second step in the evaluation was to add the HC Unibon unit to the complex and recalculate the IRR for the complex. A F-T product value of $121/MT gives a 20% IRR for the complex that does not include an HC Unibon unit. If the hydrocracking unit is added to the complex, the IRR increases to 31%.

These calculations show that including a hydrocracking unit in the complex is economically attractive. The erected cost for the complex will increase significantly, but the added cost is justified by the value added to the F-T wax stream. The erected cost for the alternative case was estimated at $50 MM, including an allowance for offsites. Adding an HC Unibon unit to the complex increases the complex Estimated Erected Costs (EEC) to $109 MM. The added cost includes the costs for the HC Unibon unit, larger process units in the complex, and larger offsite facilities. To understand the sensativity of EEC on F-T wax upgrading economics, the costs were increased by more than 50%. For the base case, increasing the Estimated Erected Costs to $168 MM from

$109 MM, drops the IRR from 31% to 20%. This shows that the base case EEC determination is not critical for a favorable comparison. Even if the EEC increases 50%, the base case IRR is equal to the return without a hydrocracker.

The next step in the evaluation was to determine the value added to the F-T wax by including the hydrocracking unit in the complex. This calculation was done by adjusting the F-T wax value for the base case until the complex IRR was 20%.

Assuming a constant 20% IRR, adding an HC Unibon unit to the complex increases the F-T wax value from $121/MT to $146/MT -- an increase of $23/MT. This is a very large change. It is equivalent to an increase in value for the wax of over $21,000,000 per year.

Effect of F-T Product Cost on Complex Economics

The final step in the economic evaluation was to determine the effect of the overall F-T product value on the complex economics. This was done by simply calculating the complex IRR for different F-T product values. This analysis was only done for the base case (Figure 3).

The steep slope of Figure 3 indicates that the complex economics are highly dependent on the cost of the F-T products. The costs for raw materials will determine if an upgrading complex is economically attractive.

Diesel Pool Blending

A hydrocracker is justified in a Fischer-Tropsch upgrading complex based on the value added to F-T wax as it is upgraded from fuel oil to distillate fuel. Additional economic gains are possible simply by blending a low value material into the diesel pool without deviating from pool specifications. The size of the pool will increase while the unit value ($/gal.) remains constant. A refinery LCO was used to represent a low value, high aromatic blend stock. LCO was blended into the diesel pool until the cetane index of the blended product fell to within 5 numbers of the minimum. At this point, the diesel pool was comprised of 60 wt-% LCO. This shows how tolerant the hydrocracked distillate is to blending. It will accept more than its weight of highly aromatic blend stock. As the LCO content of the diesel pool is increased from 0 to 60 wt-%, the IRR for the upgrading complex increases from 32 to 40%. In this case, the magnitude of the IRR increase obtained by blending is almost as large as the IRR increase obtained by adding a hydrocracker to the complex (increase of 20 to 32% IRR).

The actual amount of LCO added to the diesel pool would depend on other factors as well. Fuel stability may limit blending. Also, the diesel pool aromatics content or sulfur level may be limited for environmental reasons. In either of these events, hydrocracked F-T wax distillate would still maintain excellant blending capacity because it is inherently low in sulfur and aromatics content.

F-T technology would most likely be implemented on a wide scale at a time when petroleum stocks were dwindling. Under these conditions, a large portion of the crude oil being refined would be very heavy and sour, and blend stocks such as LCO would be prevalent. Given this scenerio, it is especially important to consider what to do with materials such as LCO.

CONCLUSIONS

Fischer-Tropsch wax is a valuable feedstock. Hydrocracking the wax is economically attractive. The value added to the wax during conversion is high enough to justify the expenditure for a hydrocracking process unit.

On a relative basis, adding a hydrocracker to a Fischer-Tropsch upgrading complex is justified, assuming the untreated wax is valued as fuel oil. On an absolute basis, the economic success of the complex is a strong function of the costs for raw materials, that is, the cost of converting coal into liquid hydrocarbons.

Distillate produced by hydrocracking F-T wax has a tremondous potential for blending with low value stocks. F-T diesel has virtually no aromatics and no sulfur. A low value blend stock such as LCO could be added to the diesel pool until a specification such as cetane number or sulfur level were reached. Blending not only improves the IRR for the complex, but also addresses the strategic issue of what to do with a material such as LCO. At a time when F-T technology is widely practiced, materials like LCO will be even more prevalent than today.

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* HC Unibon is a trademark and/or service mark of UOP.

Table 1

Capital and Operating Cost Summary
Fischer-Tropsch Upgrading Complex

Base Case
4th Quarter 1987 $

Process Unit	Cat. Con.	DHT	NHT + Splitter	Reforming	Isom./Sep.	HC Unibon
Feed Rate, MT/D	1008.6	243.4	1601.4	1042.2	551.2	3142.3
EEC, $MM	11.7	4.6	7.1	14.1	8.2	27.0
Utility Consumptions						
Power, kW	1175	190	600	778	299	2300
HPS, M lb/hr*	38.8	0.0	0.0	(12.5)	0.0	18.0
MPS, M lb/hr	0.0	0.0	0.0	0.0	7.8	8.0
LPS, M lb/hr	0.0	0.0	0.0	0.0	17.2	0.0
BFW, M lb/hr	0.0	0.0	0.0	21.5	0.0	0.0
Cooling Water, M gal/hr	46.2	3.2	8.4	34.6	0.2	72.0
Fuel, MM Btu/hr	58.0	6.8	55.8	82.8	0.0	130.0
Utility Costs, $MM/yr	2.57	0.18	1.14	1.42	0.76	3.74
Catalyst Loading, lb	309,000	24,442	17,951	67,439	38,285/47,623	72,008
Catalyst Loading, $MM	0.510	0.066	0.048	0.604	0.507/ 0.405	0.720
Expected Life, yr	0.24	5	4	3.5	3/5	5
Catalyst Costs, $MM/yr	2.124	0.013	0.012	0.172	0.169/ 0.081	0.144
Catalyst Work. Cap., $MM	0.51	0.07	0.05	2.72	1.28/ 0.40	0.72
Royalty, $MM	1.30	0.40	0.70	1.00	1.10/ 1.10	3.00
Labor-Operators/Shift	2	2	1	2	2	3
Labor Costs, $MM/yr	1.24	1.24	0.62	1.24	1.24	1.86

(*) HPS = High Pressure Steam, 600 psig, Superheated to 725-750°F
MPS = Medium Pressure Steam, 150 psig, Saturated
LPS = Low Pressure Steam, 50 psig, Saturated
BFW = Boiler Feed Water

Table 1
(Continued)

Capital and Operating Cost Summary
Fischer-Tropsch Upgrading Complex

Base Case
4th Quarter 1987 $

Process Unit	Cat. Con., $MM/yr	DHT, $MM/yr	NHT + Splitter, $MM/yr	Reforming, $MM/yr	Isom./Sep., $MM/yr	HC Unibon, $MM/yr
Operating Cost Summary						
Variable Costs						
Utility Costs	2.57	0.18	1.14	1.42	0.76	3.74
Catalyst Costs	2.12	0.01	0.01	0.17	0.17/0.08	0.14
Total Variable Costs	4.69	0.19	1.15	1.60	1.01	3.89
Fixed Expenses						
Labor Costs	1.24	1.24	0.62	1.24	1.24	1.86
Maintenance	0.23	0.09	0.14	0.28	0.16	0.54
Taxes and Insurance	0.18	0.07	0.11	0.21	0.12	0.41
Total Fixed Expenses	1.65	1.40	0.87	1.74	1.53	2.81
Fixed Charges						
EEC Depreciation	1.17	0.46	0.71	1.41	0.82	2.70
Offsite Depreciation	0.59	0.23	0.35	0.71	0.41	1.35
Total Fixed Charges	1.76	0.69	1.06	2.12	1.23	4.05

Table 2

Capital and Operating Cost Summary
Fischer-Tropsch Upgrading Complex

Alternative Case
(No HC Unibon Unit)
4th Quarter 1987 $

Process Unit	Cat. Con.	DHT	NHT + Splitter	Reforming	Isom./Sep.
Feed Rate, MT/D	1008.6	243.4	670.0	284.6	382.1
EEC, $MM	11.7	4.6	4.2	6.5	6.6
Utility Consumptions					
Power, kW	1175	190	251	212	207
HPS, M lb/hr	38.8	0.0	0.0	(3.4)	0.0
MPS, M lb/hr	0.0	0.0	0.0	0.0	5.4
LPS, M lb/hr	0.0	0.0	0.0	0.0	11.9
BFW, M lb/hr	0.0	0.0	0.0	5.9	0.0
Cooling Water, M gal/hr	46.2	3.2	3.5	9.4	0.1
Fuel, MM Btu/hr	58.0	6.8	23.4	22.6	0.0
Utility Costs, $MM/yr	2.57	0.18	0.48	0.39	0.53
Catalyst Loading, lb	309,000	24,442	7,511	18,415	26,542/33,016
Catalyst Loading, $MM	0.510	0.066	0.020	0.165	0.352/ 0.281
Expected Life, yr	0.24	5	4	3.5	3/5
Catalyst Costs, $MM/yr	2.124	0.013	0.005	0.047	0.117/ 0.056
Catalyst Work. Cap., $MM	0.51	0.07	0.02	0.74	0.89/ 0.28
Royalty, $MM	1.30	0.40	0.29	0.27	0.76/ 0.76
Labor-Operators/Shift	2	2	1	2	2
Labor Costs, $MM/yr	1.24	1.24	0.62	1.24	1.24

Table 2
(Continued)

Capital and Operating Cost Summary
Fischer-Tropsch Upgrading Complex

Alternative Case
(No HC Unibon Unit)
4th Quarter 1987 $

Process Unit	Cat. Con., $MM/yr	DHT, $MM/yr	NHT + Splitter, $MM/yr	Reforming, $MM/yr	Isom./Sep., $MM/yr
Operating Cost Summary					
Variable Costs					
Utility Costs	2.57	0.18	0.48	0.39	0.53
Catalyst Costs	2.12	0.01	0.01	0.05	0.12/0.06
Total Variable Costs	4.69	0.19	0.48	0.44	0.71
Fixed Expenses					
Labor Costs	1.24	1.24	0.62	1.24	1.24
Maintenance	0.23	0.09	0.08	0.13	0.13
Taxes and Insurance	0.18	0.07	0.06	0.10	0.10
Total Fixed Expenses	1.65	1.40	0.77	1.47	1.47
Fixed Charges					
EEC Depreciation	1.17	0.46	0.42	0.65	0.66
Offsite Depreciation	0.59	0.23	0.21	0.32	0.33
Total Fixed Charges	1.76	0.69	0.63	0.97	0.99

Table 3

Price and Cost Basis for Economic Analysis

	$/Gal	$/MT
LPG	0.30	140
Gasoline	0.52	193-199
Diesel	0.50	158-170
LCO	0.46	128
Fuel Oil	0.40	115
Hydrogen	2.20/M SCF	900
Fuel Gas	2.10/MM Btu	100

Table 4

Utility and Labor Costs

Power, $/kWh	0.04
High Pressure Steam, $/M lb	3.80
Medium Pressure Steam, $/M lb	3.40
Low Pressure Steam, $/M lb	3.30
Boiler Feed Water, $/M gal	0.80
Cooling Water, $/M gal	0.10
Fuel, $/MM Btu	2.10
Wage Rate, $/hr	20
Fringe Benefits, %	35
Supervision, %	25
Overhead, %	50

FIGURE 1

FISCHER-TROPSCH PRODUCT UPGRADING COMPLEX BASE CASE FLOW SCHEME (FLOW RATES IN METRIC TONS PER DAY)

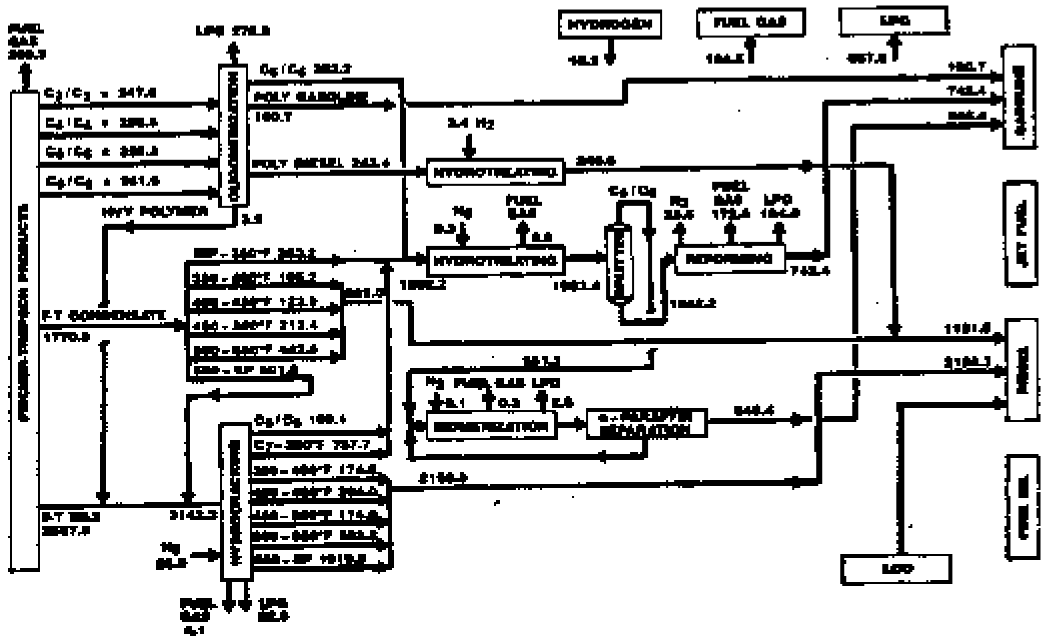

FIGURE 2

FISCHER-TROPSCH PRODUCT UPGRADING COMPLEX ALTERNATIVE CASE FLOW SCHEME

(FLOW RATES IN METRIC TONS PER DAY)

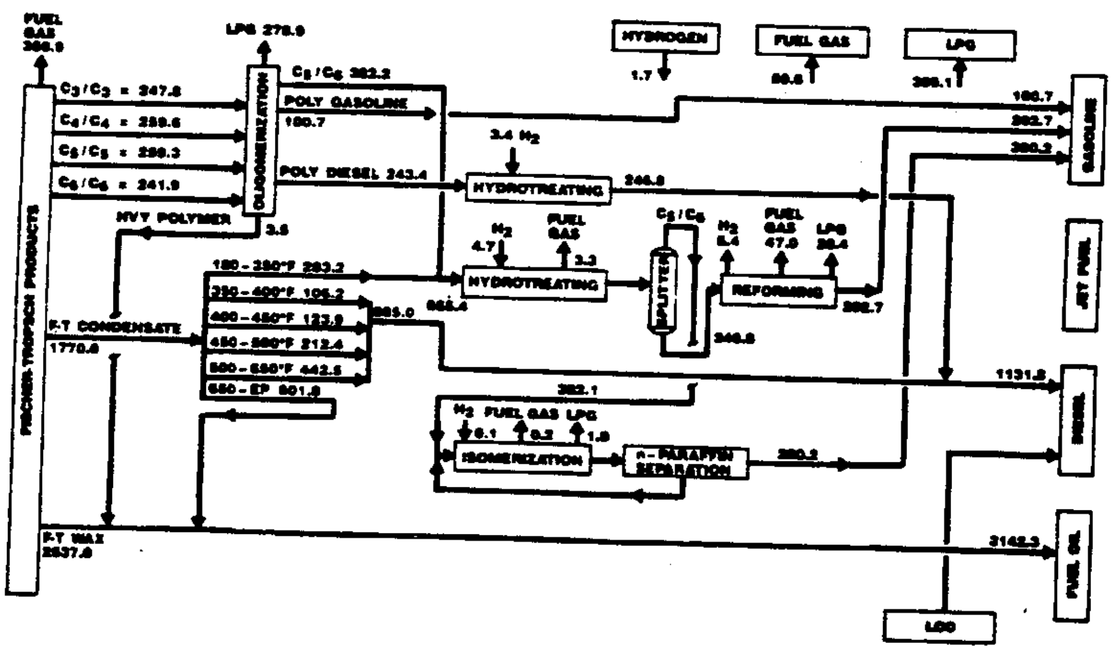

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FIGURE 3

ECONOMIC EFFECT OF F-T PRODUCT COST

(INTERNAL RATE OF RETURN, %
vs.
F-T PRODUCT COST, $/MT)