PROCESS ECONOMICS EVALUATION STAFF

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Subject: 10,000 BPOD FISCHER-TROPSCH SYNTHESIS PLANT

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Summary and Conclusions

A synthetic liquid fuels plant, designed to produce 10,000 barrels per operating day of liquid hydrocarbon product from the synthesis unit, will require an investment of approximately $114,356,500. Operating costs, with the cost of coal as a variable, are estimated to amount to the following:

Coal cost/ton	Operating cost/gallon
$3.00	$0.215
4.00	.230
5.00	.244

Federal corporate income tax and a capital return are not included in the above costs. Incorporating these two items as a gross return on investment results in the following production costs:

Gross return on investment, %	Production cost/gallon Coal at $3/ton	Coal at $4/ton	Coal at $5/ton
6	$0.274	$0.289	$0.303
12	.333	.348	.362
20	.412	.426	.441
30	.510	.525	.540

Process Description

Three major processing steps are required to convert coal to liquid fuels:

1. The manufacture of purified synthesis gas with a desired 1:1 H_2:CO ratio for use in the subsequent step,

2. Synthesis of liquid hydrocarbons, and

3. The refining of the hydrocarbons to produce gasoline, gas oil, LPG, and refinery off-gas.

Synthesis gas with an H_2:CO ratio of 1:1 is produced by gasifying coal with 95 percent oxygen and superheated steam. The synthesis gas is cooled in a waste heat recovery system after which the dust is removed by cyclones and electrostatic precipitators. The CO_2 content of the gas is then reduced to 0.1 percent by hot carbonate scrubbing. The hot carbonate system will also remove the greater portion of the sulfur content of the gas; however, iron oxide boxes are required for final sulfur clean up.

The conversion of synthesis gas to hydrocarbons is accomplished in fixed bed reactors which are filled with steel lathe-turnings catalyst. The synthesis gas is mixed with recycled oil which absorbs most of the heat of reaction. The oil is separated from the non-condensable gases, cooled in a waste heat recovery system, and then recycled to the synthesis reactors. The gases are cooled and further processed in the refining section. The process flowsheet is shown in figure 1, and detailed equipment lists are given in tables 18 through 22.

The following sections give a general description of the various processing operations.

Coal Preparation

The coal preparation facilities are designed to handle approximately 5,300 tons per day of run-of-mine coal. The coal as received has the following analysis:

H_2	4.9%
C	70.1
S	1.4
N_2	1.4
O_2	6.6
Ash	14.3
Moisture	1.3

The coal is conveyed from the track hopper to the hammer mills where the size is reduced to minus 3/4 inch. After leaving the hammer mills the coal passes over magnetic separators and then to storage hoppers or to the outdoor storage pile. The coal feeds from the storage hoppers to the ball mills where the size is further reduced to 70 percent through 200 mesh. The pulverized coal is conveyed by air to the storage bins and from there it is fed through a lock hopper and a Bailey feeder to the gasifier.

Gasification

The gasification process is designed to produce synthesis gas, a mixture of carbon monoxide and hydrogen, with an H_2:CO ratio of 1:1. The gasification reaction is carried out at approximately 435 p.s.i.g. so that no recompression is necessary prior to the synthesis reaction.

The feed to the three operating gasifiers consists of 190 tons of coal per hour, 332,000 pounds of superheated steam per hour, 135 tons of 95 percent purity oxygen per hour, and 10,000 pounds of oxygenates and water per hour. The exit gases leave the gasifier at 2,200° F. Approximately 50 percent of the ash and unreacted carbon is removed as slag through the slag accumulating system to a settling basin while the remainder is entrained in the raw synthesis gas and subsequently removed in a dust removal system.

A waste heat recovery system consisting of economizers, vaporizer, superheaters, and boiler feed water pumps is designed to cool the exit gases to 300° F. The heat recovery unit will produce 740,000 pounds per hour of steam at 460 p.s.i.g. and 1,000° F. A portion of this steam is recycled to the gasifier and the surplus is used in other sections of the plant.

The oxygen supply for gasification is provided by three 1100 ton-per-day oxygen plants. Steam driven compressors are used to compress the oxygen to 460 p.s.i.g.

The composition of the gas leaving the gasification system is as follows:

H_2O	29.6%
H_2	29.7
CO	29.7
CO_2	9.4
N_2	1.3
S^2	0.3

Dust Removal

The entrained ash and carbon must be removed from the gas stream prior to the synthesis stage. This is accomplished by cyclone separators and electrostatic precipitators operating in series.

The cyclones are designed on the basis of an allowable entrance velocity of 50 feet per second. The electrostatic precipitators are sized for a 5 second retention time with a linear velocity of 4 feet per second.

Purification

After the entrained ash has been removed from the gas stream it is necessary to remove the CO_2 and sulfur. Specifications for the synthesis reaction necessitate the reduction of the CO_2 content of the gas feed to 0.1 percent. Further, since the synthesis catalyst is rapidly poisoned by sulfur, it is essential that the sulfur be reduced to 0.1 grain per 100 cubic feet.

The CO_2 content of the gas stream is reduced to the required concentration by use of hot K_2CO_3 solution. The hot solution, approximately 194° F., is circulated countercurrently to the gas stream in packed towers. The fouled hot carbonate solution is regenerated with low pressure steam in packed towers and the sour gas is sent to the sulfur recovery unit.

Sulfur removal is accomplished primarily in the hot carbonate towers but the residual must be removed by passing the gas through iron oxide boxes. Facilities have been provided to revivify the iron oxide without removing it from the catch boxes.

The composition of the exit gas from purification is:

H_2O	0.2%
H_2	48.8
CO	48.8
CO_2	0.1
N_2	2.1

Primary Synthesis

The purified synthesis gas is fed to the fixed bed catalytic reactors where it is reacted over an oxidized iron catalyst. Catalyst preparation is outlined in a later section. By varying the temperature and pressure of operation it is possible to control, within limits, the type of product which will be formed. By operating the reactors at about 400 p.s.i.g. and an average temperature of about 525° F., the formation of gasoline range hydrocarbons is favored at the expense of oxygenated chemical synthesis.

The synthesis gas is fed at a space velocity of 500 V/V/H to the 9 foot diameter by 30 feet high reactors where 90 percent of the feed gas is reacted. The pressure drop across the catalyst bed is 30 p.s.i. and an oil recirculating pump is required for each reactor.

The overhead stream from the reactors is separated into three streams, water and water soluble oxygenates, the light hydrocarbons and CO_2, and the heavy oil which is recirculated to the reactors. The water and oxygenates are recycled to the gasifier and replace part of the steam required for gasification. The hydrocarbon stream is scrubbed to remove CO_2 and then the liquid products are recovered as outlined in a later section on refining.

Recycle CO_2 Scrubbing

The hydrocarbon stream which contains approximately 11 percent CO_2 is scrubbed in hot carbonate scrubbers to reduce the CO_2 content to approximately 0.5 percent. The design and operation of this section is similar to the initial purification except that no sulfur removal equipment is required.

Secondary Synthesis

In order to obtain the maximum gasoline yield from coal a secondary synthesis unit has been designed. The reactors and auxiliary equipment of this unit are the same as the primary synthesis unit and may be used as primary synthesis reactors if required.

In the second-stage synthesis 50 percent conversion of the feed gas is achieved at a space velocity of 300 V/V/H. No recycle, and therefore, no intermediate CO_2 scrubbing is required. The product streams from this unit are added to the product streams from the first-stage synthesis unit.

Catalyst Preparation

The conversion of synthesis gas to hydrocarbons is greatly accelerated by the use of oxidized iron catalysts. An oxidized iron lathe-turnings catalyst has been developed by the Bruceton laboratory of the Bureau of Mines. This catalyst presents high active surface with fairly low pressure drop. Careful control of cutting speed and depth of cut in the lathe operation results in a catalyst with about 83 percent to 85 percent void space. The turnings will be cut from S.A.E. 1018 steel on 40 standard lathes. The operation of these lathes would be programmed so that an operator would not be required for each lathe.

A batch oxidation process is then carried out in a stainless steel lined reactor where 20 percent of the iron is oxidized by superheated steam. The steam is fed to the reactor at 1,110° F. and a space velocity of 400 V/V/H. After an oxidation period of approximately 40 hours the batch is cooled and impregnated with a solution of potassium carbonate. After drying to remove the water the oxidized catalyst is transferred to the synthesis reactors.

The final reduction step, with hydrogen, is done in the spare synthesis reactors. The hydrogen is fed to the reactors at 840° F. and a space velocity of 2,000 V/V/H. The iron oxide is reduced to iron and water is produced. Since it is necessary to remove this water, the hydrogen recycle stream is cooled, dehydrated with silica gel, and reheated before re-entering the reactor. The reduction cycle is approximately 48 hours.

Refining

The refining section includes four units:

1. Light ends recovery,

2. Catalytic cracking,

3. Catalytic polymerization, and

4. Catalytic reforming

The refinery is designed to refine a high gravity crude for maximum gasoline yield.

Sulfur removal is accomplished primarily in the hot carbonate towers but the residual must be removed by passing the gas through iron oxide boxes. Facilities have been provided to revivify the iron oxide without removing it from the catch boxes.

The composition of the exit gas from purification is:

H_2O	0.2%
H_2	48.8
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Refining

The refining section includes four units:

1. Light ends recovery,
2. Catalytic cracking,
3. Catalytic polymerization, and
4. Catalytic reforming

The refinery is designed to refine a high gravity crude for maximum gasoline yield.

The light ends recovery unit is designed to accumulate and compress the light overhead streams and to separate and recycle them to the polymerization or reforming units. The off-gas, principally methane, is distributed to the plant for process heating.

The catalytic cracking unit is designed to process 3,835 barrels per operating day of heavy oil and wax product from the synthesis unit and heavy polymers from the polymerization and reforming units. With reactor operating conditions of 900° F. and 12 p.s.i.g. the following yield structure has been estimated:

C_1	1.0%	C_4	3.1%
C_2	1.1	C_5^+	37.1
$C_3^=$	3.2	Gas oil	40.1
C_3	1.6	Coke	6.0
$C_4^=$	4.8	Water	2.0

The catalytic polymerization plant will use the U. O. P. solid phosphoric acid catalyst type process. Olefins in the C_3 - C_4 range are converted to gasoline range material by contacting them with the catalyst at 425° F. and 1,100 p.s.i.g. At these operating conditions 90 percent olefin conversion can be accomplished if the olefin concentration in the feed stream is maintained at 40 percent (by volume). This is done by recycling a portion of the propane from the top of the depropanizer back to the polymerization unit.

The straight-run gasoline boiling range material will be reformed over a platinum catalyst using the "Ultra-forming" process. Use of this process is well suited to a low sulfur feed and will give a maximum yield of high octane reformate. The following yield pattern has been estimated:

H_2	2.0%	C_4	5.4
C_1	1.5	C_5^+	79.1
C_2	3.5	Heavy	
C_3	5.3	Polymer	3.2

The refinery product has high lead susceptibility and the addition of 3 cc. of TEL will give a product with an octane rating comparable to premium gasoline. Sufficient butane will be recovered for blending to 10 pounds Reid vapor pressure.

Tankage facilities have been designed to insure adequate storage for the finished product and all intermediate streams.

Capital Investment

As shown in table 1 the total capital investment, including working capital, is $114,356,500. The capital investment costs include allowances for spare parts. The capital requirements for each operating unit are given in tables 5 through 13. The cost of the oxygen plant and the sulfur recovery plant were estimated from available quotations.

The power plant cost was estimated on the basis of the steam and power balance, figure 9. A spare boiler and turbogenerator were provided. The cost of individual items for plant facilities and plant utilities are given in tables 2 and 3.

Table 1 shows a total construction cost of $101,006,500. The capital investment for initial catalyst and chemical requirements is $1,604,900. Interest during construction, calculated on the basis of a two year construction period, is $2,052,200.

Total working capital, $9,692,900, is estimated as shown in table 4.

Operating Costs

Table 15 shows the estimated annual operating cost summary. It has been assumed that this plant will have a 90 percent operating factor. This 35 day down time allowance assumes two 10 day shutdowns for equipment overhaul and 15 days for unscheduled interruptions.

Personnel requirements have been estimated using as a base the synthetic fuel plant operation at Brownsville, Texas. They are summarized in the two manning tables, table 16 and 17.

The operating cost with coal at $4 per ton is shown in table 15 as $26,656,700. The unit operating cost is calculated by considering the gas oil to have 70 percent of the value of gasoline. Credit is taken for propane at the current market price. The resulting operating cost is $0.230 per gallon of premium gasoline. Gross return on the investment is an important variable which exerts a large effect on the cost of the finished product. The effect of this variable is shown in figure 11.

The principal item of operating cost is the cost of coal. Coal at $3 per ton represents 20 percent of the annual operating cost; at $4 per ton coal is 26 percent of the operating cost, and at $5 per ton coal is 30 percent of the operating cost. Figure 10 shows the effect of coal price on the operating cost.

APPENDIX

TABLE 1

10,000 BPOD Fischer-Tropsch Synthesis Plant

Total Estimated Capital Requirements

Unit	Cost	Percent
Coal Preparation	$ 2,985,200	2.6
Oxygen Plant	20,700,000	18.1
Gasification	3,304,700	2.9
Primary Waste Heat Recovery	1,804,100	1.6
Dust Removal	243,800	0.2
Primary Purification	4,886,700	4.3
Primary Synthesis	9,132,100	8.0
Recycle CO_2 Scrubbing	4,531,300	4.0
Secondary Synthesis	982,800	0.9
Catalyst Preparation	2,907,800	2.5
Refining	12,209,000	10.7
Tank Farm	4,691,600	4.1
Sulfur Recovery	590,000	0.5
Power Plant	6,000,000	5.2
Plant Facilities	12,321,000	10.7
Plant Utilities	13,716,400	12.0
Total Construction Cost	$101,006,500	88.3
Initial Catalyst Requirements	1,604,900	1.4
Total Plant Cost (Tax & Insurance Bases)	$102,611,400	89.7
Interest During Construction	2,052,200	1.8
Sub-Total for Depreciation	$104,663,600	91.5
Working Capital	9,692,900	8.5
Total Investment	$114,356,500	100.0

TABLE 2

10,000 BPOD Fischer-Tropsch Synthesis Plant

General Plant Facilities Cost Summary

Administration	$ 644,000
Cafeteria	266,000
Medical Building	42,000
Employee Building	637,000
Field Laboratory	238,000
Warehouse and Equipment	812,000
Shops and Equipment	1,064,000
Gate and Guardhouse	25,000
Area Toilets	18,000
Garage	56,000
Site Preparation	1,155,000
Railroad	171,500
Roads, Park Area	294,000
Fence	24,500
Trucks, Cars	161,000
Refinery Equipment	84,000
Waste Disposal	987,000
Miscellaneous	1,162,000
	$ 7,841,000
Others*	4,480,000
Total	$12,321,000

* Includes a contingency factor, engineering, overhead, administration, and indirect field construction costs.