1. Evaluation and correlation of experimental data of the I. G. C. pilot-plant runs at the Bruceton laboratories.

2. Function and preliminary design of the vacuum column for coolant oil in the distillation unit. As a result, a vacuum column was built in the demonstration plant.

3. Comprehensive evaluation and correlation of Bruceton data for the reduction of synthetic ammonia catalysts. The resulting flow sheet and design were used to build the demonstration-plant catalyst reduction unit, and serve as a basis for this section of the 10,000-barrel-per-day Fischer-Tropsch plant estimate.

4. Analytical methods for the control and evaluation of synthetic fuel products.

5. Pressure drop through the internally cooled converter when both gas and liquid are flowing. This study indicated the necessity for increasing the diameter of the vessel from 5 to 6 feet in the demonstration plant.

6. Product distribution and specifications of synthetic liquid fuels from the demonstration plant.

7. Frequent checks were made of equipment, instrument, and piping costs for the synthesis, distillation, and storage sections of the Gas Synthesis Demonstration Plant, and the information gained has been valuable as a guide.

Effort is now being centered on the preparation of operating directives. This study involves a thorough review of all drawings relative to synthesis and distillation operations, calculations of flows and yields under varying conditions, labor requirements, and possible variations in procedure. Although this study is an essential preliminary to the actual writing of the operating procedures, the final drafts will incorporate not only the findings of the study but the advice and recommendations of the operating section of this plant as well.

Engineering Studies and Cost Estimates for Commercial-Size Plants

Hydrogenation of Petroleum Residuum

In 1948 the consumers of heavy fuel, particularly in the heavy-industry areas of eastern United States, were concerned over a tight supply situation, and at their request a study was made of the possible methods of converting coal to heavy fuel oil. Two basic processes and their economics were presented in the 1948 annual report on synthetic liquid fuels. In 1949 the supply situation completely reversed, so that, particularly in certain midcontinent areas, the supply was so great as to build up burdensome inventories for some refiners. The problem now became, not one of producing more heavy fuel oil from coal but rather the upgrading of petroleum residuum into marketable products. Accordingly, a process and economic study was made for the hydrogenation of 16,500 barrels per calendar day of heavy petroleum residuum to produce 50-cetane-number Diesel fuel and motor gasoline. The design was made with a combined liquid- and vapor-phase stall, and the liquid and vapor-phase convertors were to operate in series without pressure let-down to permit efficient utilization of the heat of reaction by heat exchange and improved heat economy.

A cost estimate was prepared for the hydrogenation and hydrogen-production sections by preparing an itemized list of all major equipment. Costs for each individual item then were determined and totaled. From this total equipment cost the final installed cost, including all indirect costs as well as a 10-percent contingency and 5-percent fee, was determined by the use of factors established in Bureau of Mines Report of Investigations 4564, Estimated Plant and Operating Cost for Producing Gasoline by Coal Hydrogenation. Spare equipment, especially pumps and compressors, was included to maintain production on the basis of a 90-percent service factor. A flow sheet with material balance (fig. 23) and the summary of the cost estimate (table 13) are shown. Calculated pay-out time varies with plant location as follows:

Pay out time for a 16,500-barrel-per-calendar-day plant for hydrogenation of petroleum residuum

Total plant cost, million $	34.1					
Plant location	California area		Atlantic coast		Midwestern area	
Feed, $ per barrel	1.92	1.45	1.60	1.13	1.10	0.63
Income, ¢ per gal. feed[1/]	2.37	3.01	1.71	2.40	2.26	2.96
Pay-out time, years	5.7	4.1	7.9	5.6	6.0	4.6

1/ After 38% income tax on taxable income. Taxable income calculation based on total amortization in 15 years.

Cost of Liquid-Fuel Products from Coal Hydrogenation

A comparative cost estimate was made for producing motor- and aviation-grade gasoline and jet fuel in a 30,000-barrel-per-day coal-hydrogenation plant using Illinois No. 6 bituminous coal as raw material at $3.12 per ton. The results of this estimate are summarized and shown in table 14. It should be noted that these figures are costs and do not include return investment. Therefore, they cannot be compared directly with the refinery prices of petroleum products.

One hundred-octane-grade aviation gasoline produced by coal hydrogenation at a cost of 15 cents per gallon may be competitive with that produced from crude oil. The production of this material is only 11,920 barrels per day in a 30,000-barrel-per-day plant. In addition, 12,208 barrels per day of 91-octane-number gasoline is made. If alkylate could be purchased an additional 17,450 barrels per day of 100-octane aviation gasoline could be produced by blending with this 91-octane-number product.

City Gas As a Byproduct from Synthetic Fuels Plants

Hydrocarbons recovered from the off-gas of synthetic fuels plants have been suggested as a source of city gas. The value of this gas to the synthetic fuels process is obtained by determining the cost of additional coal-gasification facilities required to replace the hydrogen or synthesis gas normally made from the off-gas. Its value has been calculated as 44 cents per million B.t.u., using a bituminous coal costing $3.56 per ton.

The use of this gas as a source of city gas will have an important and far reaching effect upon the gas industry. Assuming 1 million barrels per day of synthetic liquid fuel (about 18% of present petroleum production) and only 75% utilization of byproduct hydrocarbons from synthetic liquid fuels plants, about 710 million cubic feet per day, or roughly, 7-1/2 million therms per day will be available. This volume of gas is about 1-1/2 times the 1946 combined consumption of the cities of New York, Chicago, Philadelphia, and Detroit and about 90 percent of the total manufactured-gas production of the entire United States in 1944. Cost chart and flow diagram for this study are shown in figures 24 and 25.

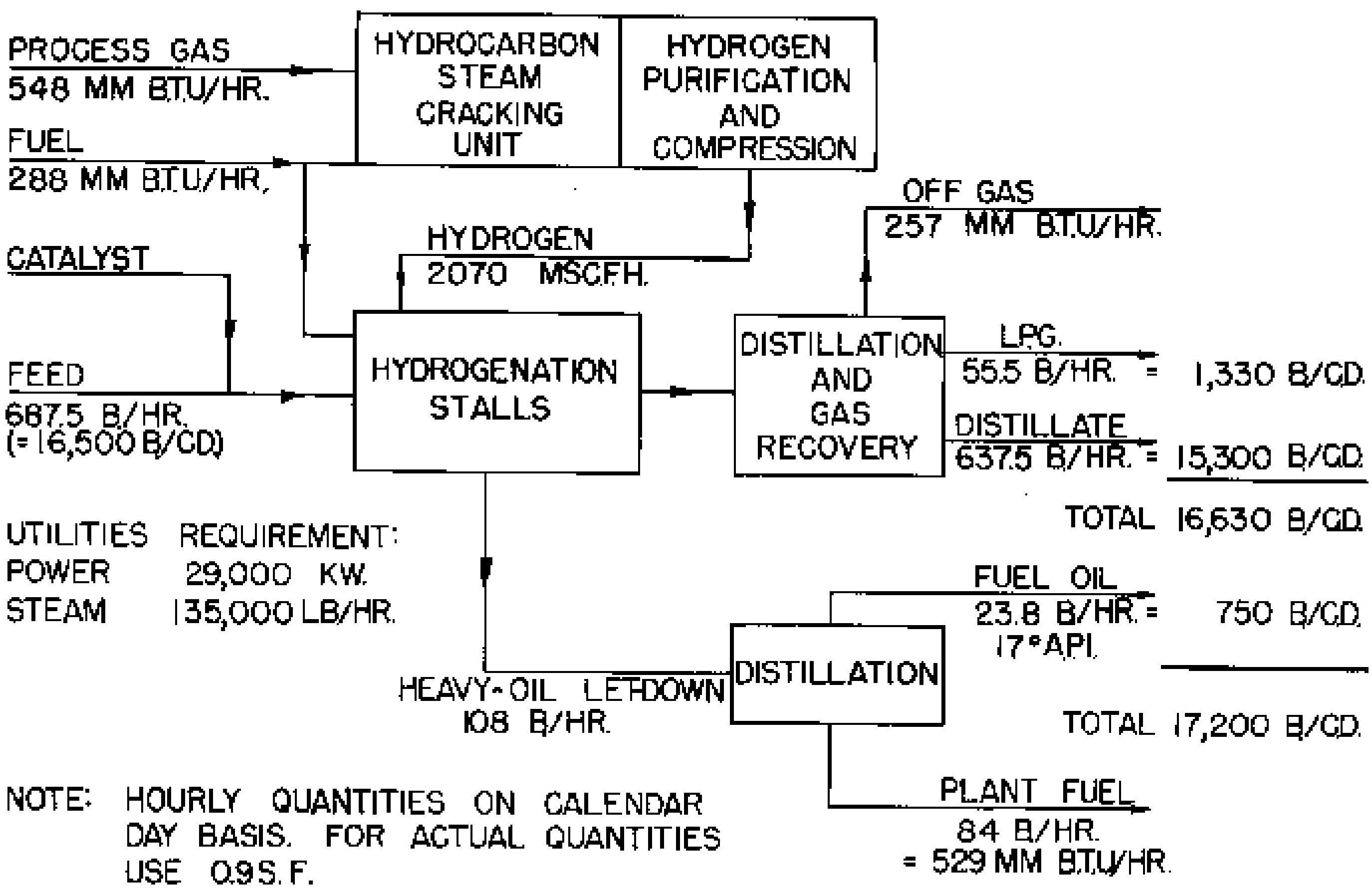


Figure 23. - Flow sheet and material balance of residual-oil hydrogenation plant.

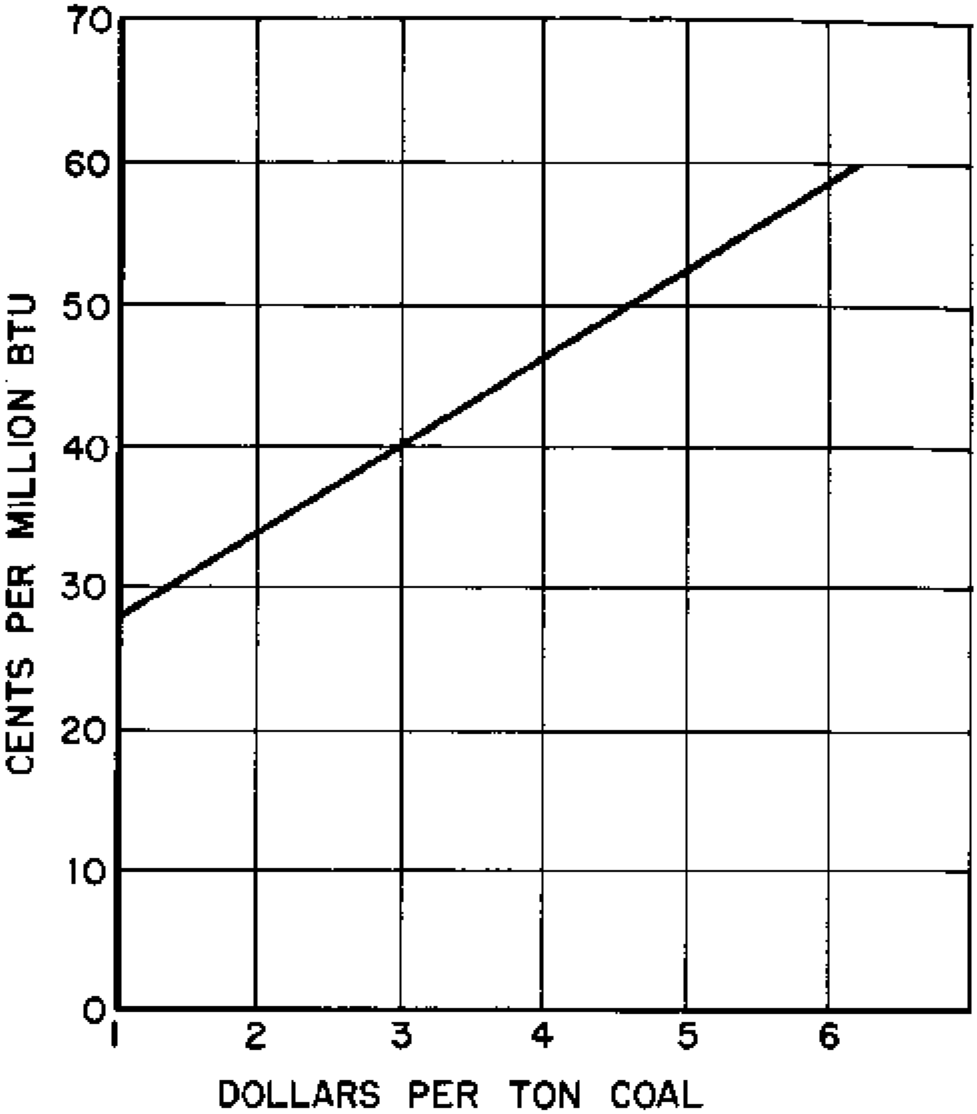


Figure 24. - Cost of byproduct city gas from synthetic liquid fuels plants vs. cost of coal at the plant site.

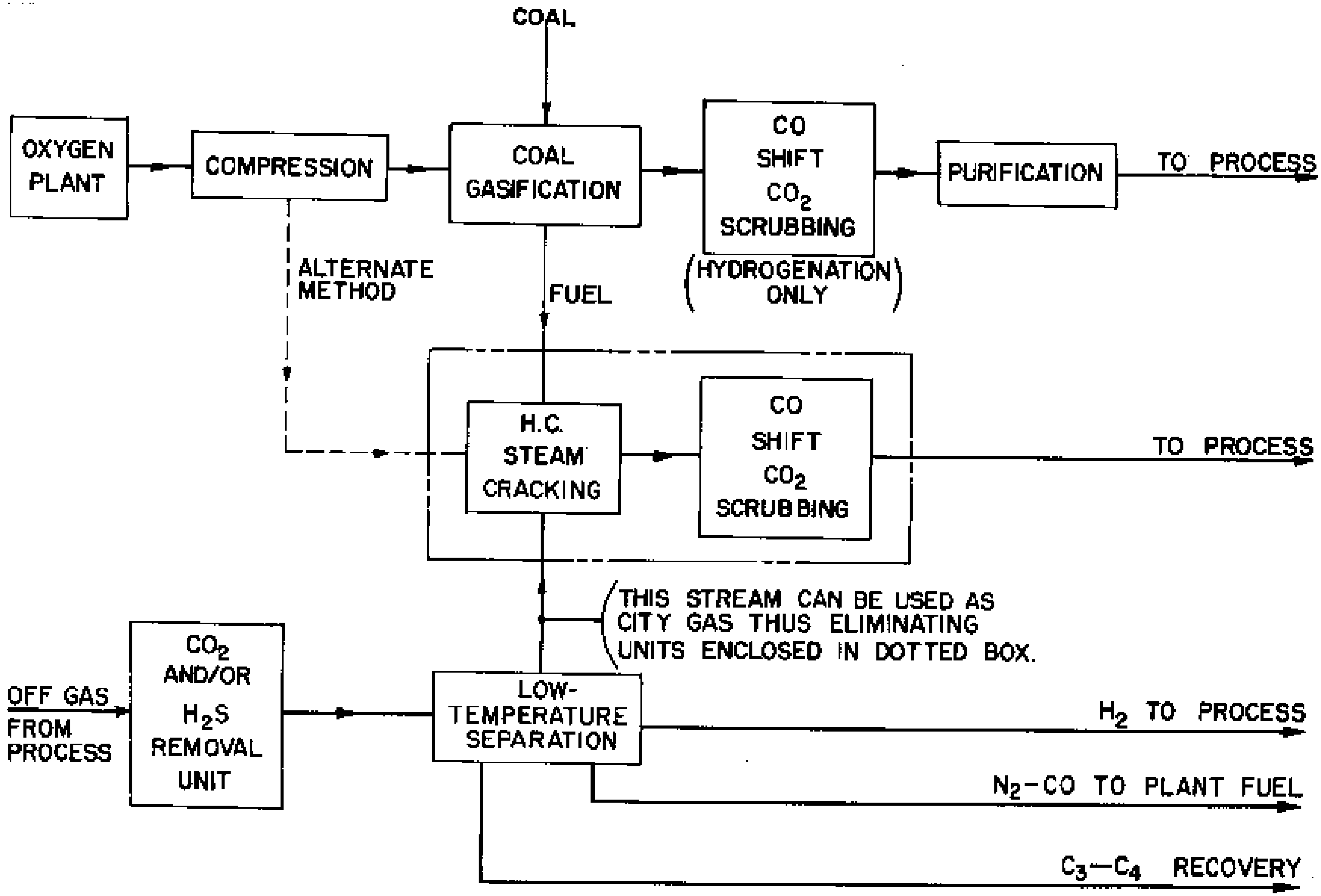


Figure 25. - Process units in synthetic liquid fuels plants making byproducts city gas.

TABLE 13. - Summarized estimated plant costs of a 16,500-barrel-per-calendar-day petroleum residual hydrogenation plant

	Equipment	Other mat'l.	Labor	Indirects[1/]	Contingent	Fee	Total
Hydrogenation	$6,466,000	$2,770,000	$1,950,000	$1,625,000	$1,285,000	$704,000	$14,800,000
Hydrogen production	4,862,000	2,010,000	1,970,000	2,084,000	1,010,000	554,000	12,490,000
Distillation and gas recovery	640,000	521,000	432,500	396,600	198,500	111,400	2,300,000
C_3 - C_4 storage		(@ $36.70/bbl., total erected cost)					367,000
Feed and product storage		Available in existing plant					
Utilities distribution (elec., steam, air, gas, and water, incl. cooling towers)	1,310,000	520,000	742,000	670,000	324,000	177,000	3,743,000
Start-up cost							400,000
Total							$34,100,000

1/ Includes indirect field costs, engineering, overhead, and purchasing costs.

TABLE 14. - Cost of producing various grades of products by coal hydrogenation

(30,000 barrels per day total liquid products)

Product	Motor gasoline		Aviation gasoline		Jet fuel	
					Motor-gasoline plant	Jet-fuel plant
Major product	78 octane No.	82 octane No.	91 octane No.	100 octane No.	JP-3	
Products, bbl./day						
Motor gasoline	21,630	21,630				
Aviation gasoline, 91 O.N.			20,121	12,204		
Aviation gasoline, 100 O.N.				11,920		
Jet fuel, JP-3					24,260	24,260
L.P.G.	7,130	7,130	8,639	2,582	4,165	4,465
Phenols	1,240	1,240	1,240	1,240	1,275	1,275
Total	30,000	30,000	30,000	27,950	30,000	30,000
Plant cost (thousands of dollars)	246,803	246,803	248,119	276,940	253,639	242,589
Cost of major product, cents per gallon[1/]						
With credit for phenols	10.2	10.3	11.4	15.0	10.3	9.8
Without credit for phenols	14.2	14.3	15.7	17.9	14.0	13.5

1/ Includes cost of raw materials, operating costs, linear depreciation at 6-2/3% per year, a credit of other products at market value, and no return on investment.

Alaska Coal-to-Oil Plant

Process flow sheet, material and heat balances, and cost studies were prepared for a 10,000-barrel-per-day synthetic fuels plant using Alaskan coal. It was proposed to use coal of the following analysis as the raw material:

	As mined	Moisture- and ash-free basis
H_2O	23.9	
Ash	5.1	
Volatile matter ..... percent		51.8
Fixed carbon ..... do.		48.2
H ..... do.		5.4
C ..... do.		71.5
N ..... do.		.9
O ..... do.		21.9
S ..... do.		.3
B.t.u. per pound		12,217

The proposed plant would yield the following products needed in Alaska:

	General specs.
Aviation gasoline	100/130 grade
Motor gasoline	75 ASTM O.N.
Diesel oil	Grade "C"
Distillate fuel oil & L.P.G.	No. 2
Jet fuel	JP-3

The diversification of the liquid fuels produced shows the versatility of the coal-hydrogenation process when combined with a catalytic cracking unit, such as was contemplated for this plant. The flow diagram of the proposed plant is shown in figure 26.

Summary of cost study on the coal-to-oil plant in Alaska compared to a similar plant in the United States is as follows:

	Costs, plant located in U. S.	Costs, plant located in Alaska
Coal at plant site ..... dollars/ton	1.85	6.50
Labor ..... dollars/hour	1.75	2.75
Power ..... cent per kw.-hr.	0.5	0.5
Period of amortization	15 years	15 years
Total product cost ..... cents per gallon	15.0	35.0
Total capital cost ..... dollars	93,700,000.00	243,800,000.00

Cost of Purified, 700-Atm. Hydrogen

The cost of producing purified and compressed hydrogen for a 700-atmosphere 30,000-barrel-per-day coal-hydrogenation plant using Wyoming coal has been calculated. The capital cost attributed to hydrogen manufacture is $88,609,000, representing 36.5 percent of the total capital cost of the plant. Operating cost for hydrogen manufacture depends on the value assigned to coal-hydrogenation off-gas. The cost of producing hydrogen with various values of off-gas is summarized as follows:

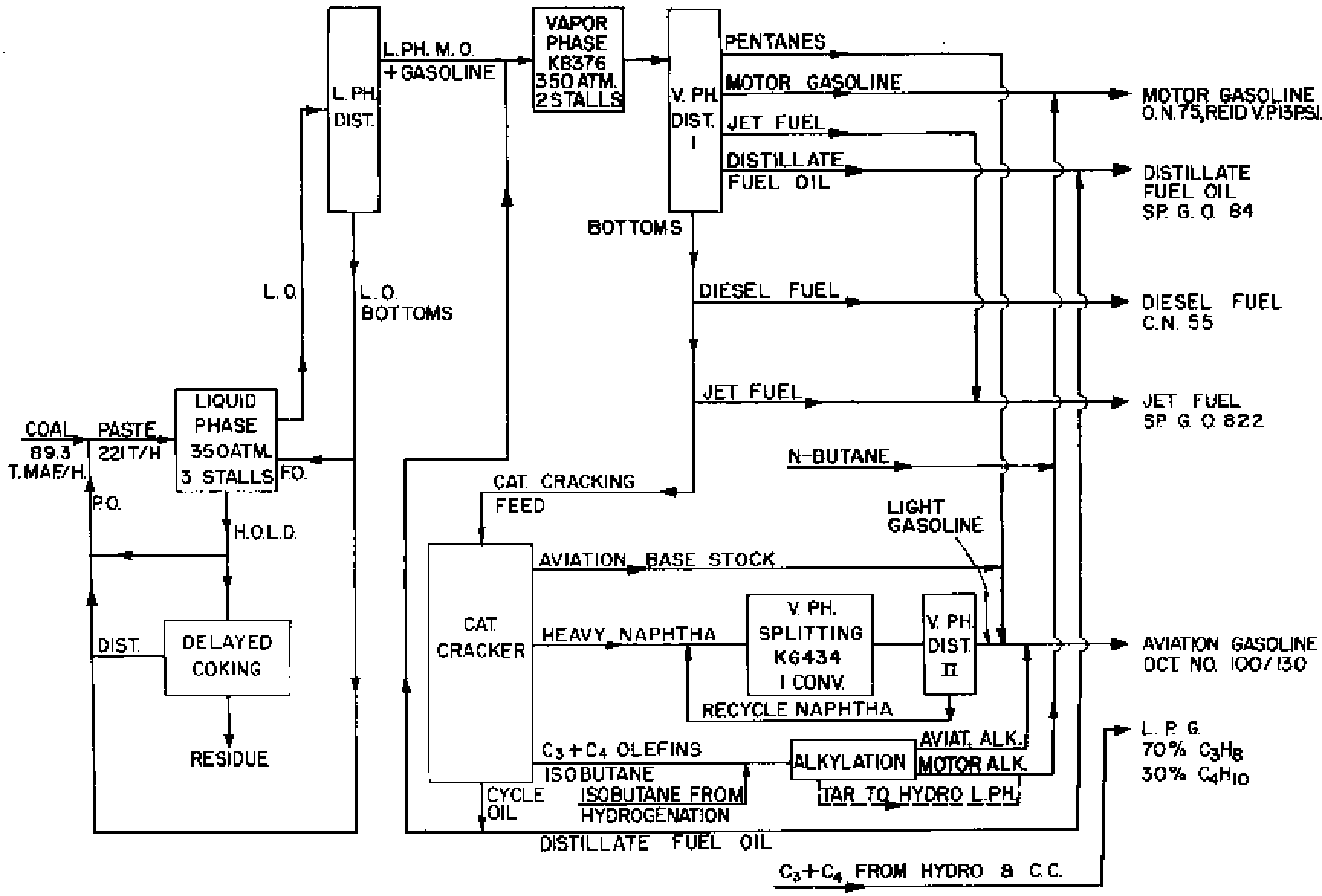


Figure 26. - Flow sheet for 10,000-barrel-per-day coal-to-oil plant using Alaska subbituminous coal.

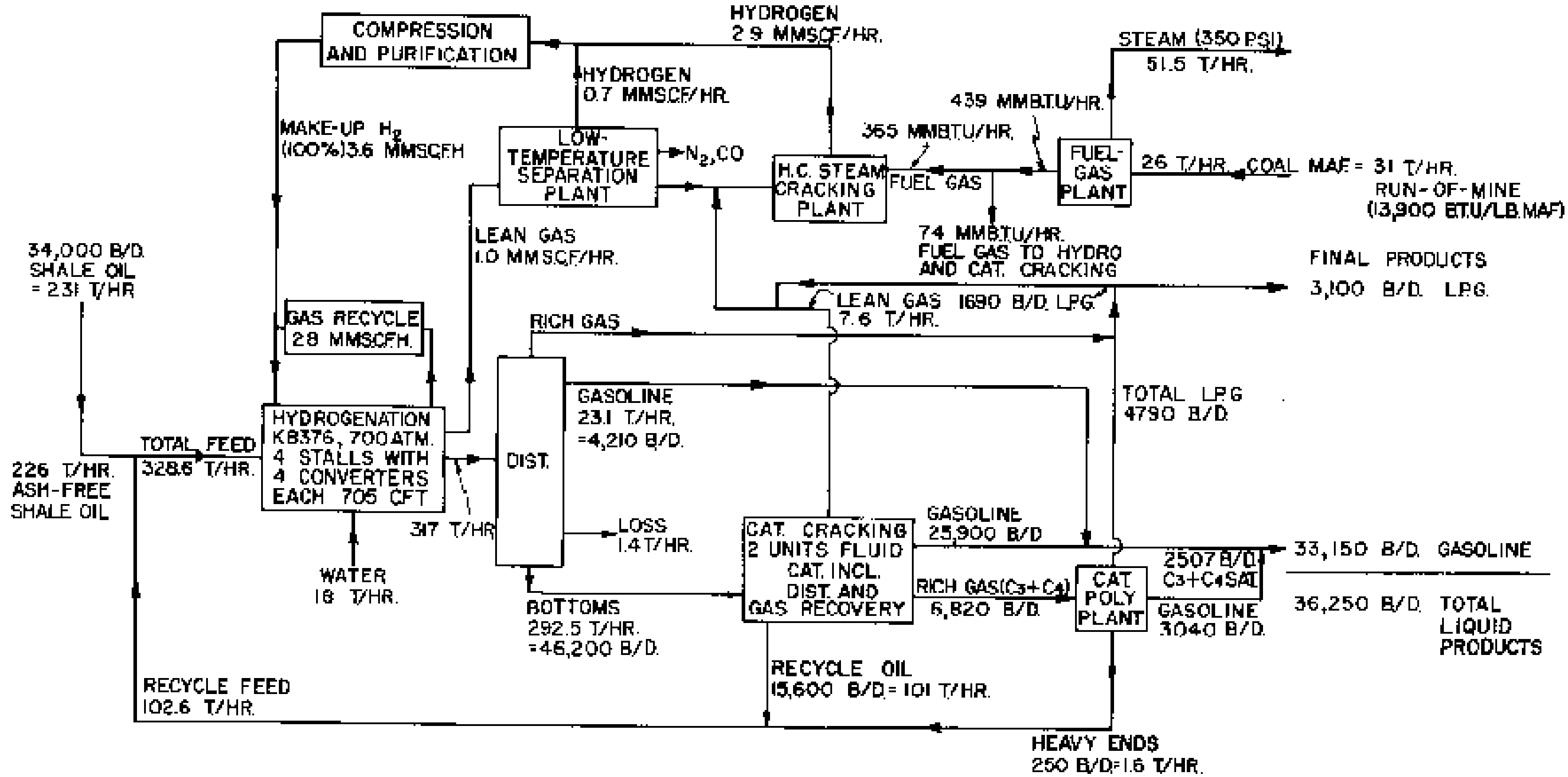


Figure 27. - Flow sheet and material balance for 34,000-barrel-per-day shale-oil hydrogenation plant.

Cost of hydrogen production (purified and compressed)

Value of off-gas cents per MM B.t.u.	Daily operating cost of hydrogen production	Percent total plant operating cost	H_2 cost, cents per M.S.C.F.
15.5 (coal equiv.)................	$58,433	36.4	23.7
30.0 (approx. byproduct)..........	63,173	39.4	25.7
44.0 (city gas value).............	67,773	42.0	27.5

Submerged Coastal Land Drilling vs. Synthetic Fuels

Calculations were made for comparing the investment cost of submerged coastal land oil drilling plus additional refining capacity with synthetic liquid fuels plants. Depending on the submerged coastal land available and the life of the wells, the investment cost ranges from $6,400 to $10,700 per daily barrel. This figure compares with a $6,830-per-daily-barrel average investment for the synthetic liquid fuels industry, making two-thirds gasoline and Diesel oil from coal and one-third fuel oil from oil shale.

Shale-Oil Hydrogenation

Plant construction and operating cost figures were estimated for the production of 33,150 barrels per day of gasoline and 3,100 barrels per day of liquefied petroleum gases from 34,000 barrels per day of Colorado shale oil by high-pressure hydrogenation and catalytic cracking (see fig. 27). Gasoline-manufacturing costs of 9.1 and 10.3 cents per gallon were obtained if shale oil costs $2 and $2.50 per barrel, respectively. A construction cost of $106,200,000 was indicated. Basic hydrogenation-process data for shale oil from Esthonia and Spain and for bituminous coal were used. Hydrogenation experiments with Colorado shale oil are required to substantiate these data.

Chemicals as Byproducts from Hydrogenation

A study was made showing possible production of chemicals from coal hydrogenation. A 30,000-barrel-per-day plant with solvent extraction of the light liquid phase middle oil would produce the following amounts of phenols:

	Million pounds per year
Phenol....................	34.5
Cresols...................	57.0
Xylenols..................	75.0
	166.5

If the heavy middle oil from this plant were solvent-extracted, an additional 166.5 million pounds of phenols boiling higher than xylenols could be recovered, with a decrease of 1,240 barrels per day of gasoline. As an alternative case, if these higher-boiling phenols were recycled through the liquid-phase hydrogenation, an additional 80,000,000 pounds per year of phenols, cresols, and xylenols could be produced, decreasing the gasoline production by 680 barrels per day.

By solvent extraction of the vapor-phase gasoline fractions, the following aromatics can be recovered from a 30,000-barrel-per-day bituminous-coal hydrogenation plant:

	Barrels per day (42's)
Benzene........................	1,640
Toluene........................	2,350
Xylene.........................	2,190
Higher aromatics...............	2,000
	8,180

Gasoline production would decrease by about the same amount, and its octane number would decrease. By hydroforming the gasoline or gasoline fractions, an increase in the cited amount of aromatics could be obtained.

Coal-hydrogenation products contain no recoverable naphthalene. However, about 100 million pounds per year of naphthalene could be produced by hydroforming heavy naphtha fractions. Gasoline production would be reduced by about 1,200 barrels per day.

Data for Corps of Engineers

A chart of synthetic-fuel-plant requirements was completed and submitted to Washington for the Corps of Engineers. Typical of the information shown on the chart for a 10,000-barrel-per-day plant is the following:

	Hydrogenation	Synthine, using coal	Synthine, using natural gas
Over-all thermal efficiency......percent	50.5	46.0	52.0
B.t.u./calendar day required...........	98×10^9	114×10^9	100×10^9
Plant personnel required...............	1,175	1,045	795
Area required..................(acres)	70	77	56
Products..................... bbl./day:			
L.P.G.	2,367		
Gasoline...........................	7,220	8,290	8,290
Gas oil............................		1,325	1,325
Fuel oil...........................		385	385
Phenols............................	413		
Total bbl./day..................	10,000	10,000	10,000
Oxygenated compounds................		1,104	1,104
Total bbl./day..................	10,000	11,104	11,104

The water requirements for the three types of synthetic fuel plants, in barrels of water per barrel of products are:

	Hydrogenation	Synthine, using coal	Synthine, using natural gas
Ample water available (once-through operation).............	300	390	190
Limited water available (using cooling towers)...............	12.7	16.3	10.4
Combination cooling (air and water).......................	8.75	11.2	7.94

The foregoing figures are for an average coal of approximately subbituminous rank.

Equipment for Commercial-Scale Hydrogenation-Plant Use

Detailed engineering studies were continued on equipment for commercial-scale hydrogenation plant use and may be summarized as follows:

Demonstration plant standards based on design stress=22,900 P.S.I.				Proposed new standards based on upset tube ends and design stress = 30,000 P.S.I.		
Nom. size, inches	Spec. wall, inches	O.D./I.D. ratio	Wt., lb./ft.	Spec. wall, inches	O.D./I.D. ratio	Wt., lb./ft.
3/8	0.337	2.89	2.51	0.153	1.78	0.884
5/8	.447	2.4	5.19	.217	1.68	.956
1	.621	2.2	11.05	.317	1.63	4.48
1 1/2	.785	2.09	18.90	.442	1.588	9.2
2	1.005	1.99	32.60	.567	1.565	15.6
2 1/2	1.169	1.95	45.29	.692	1.55	23.7

Figure 28. - Comparison of standards for high-pressure tubing.

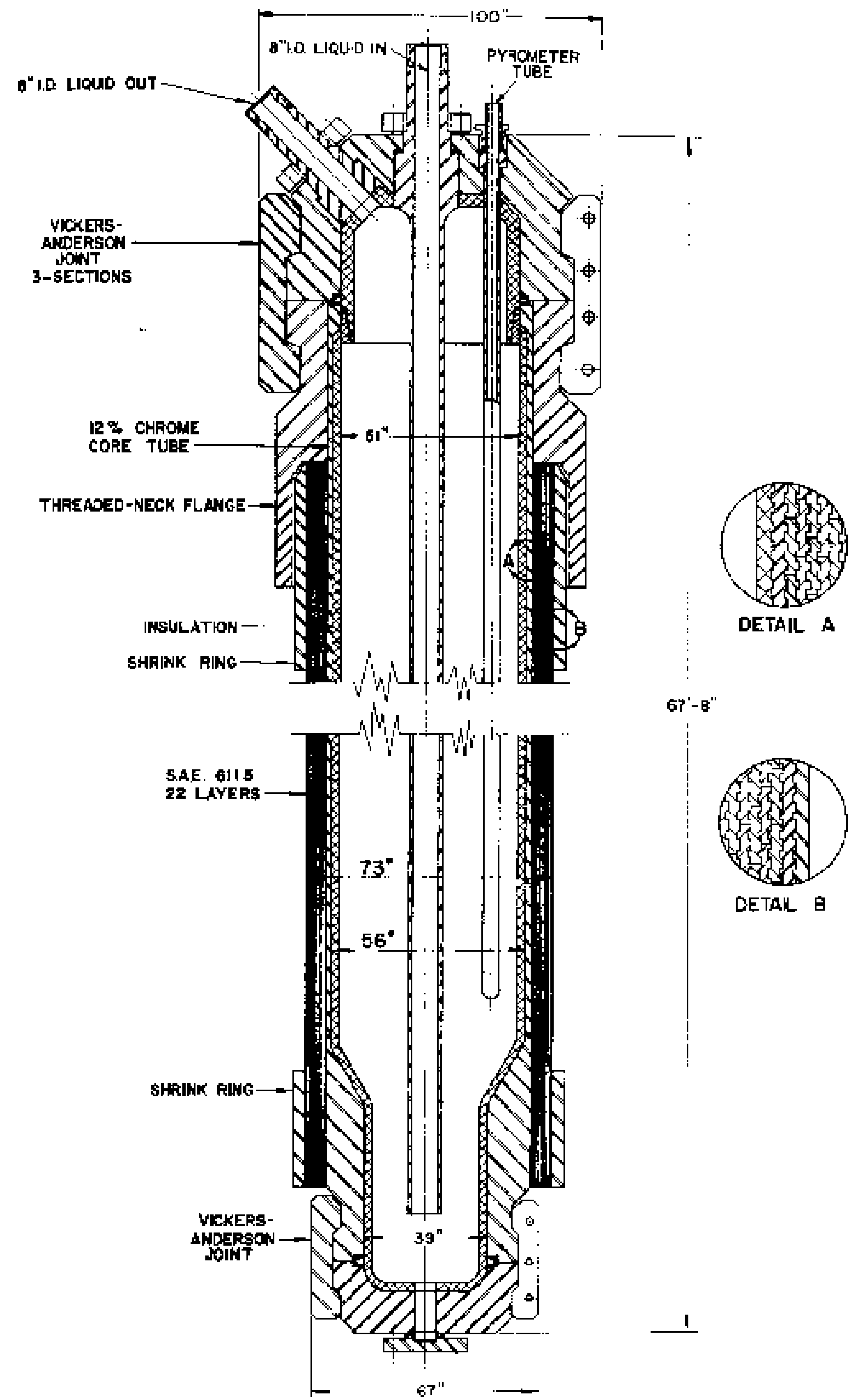
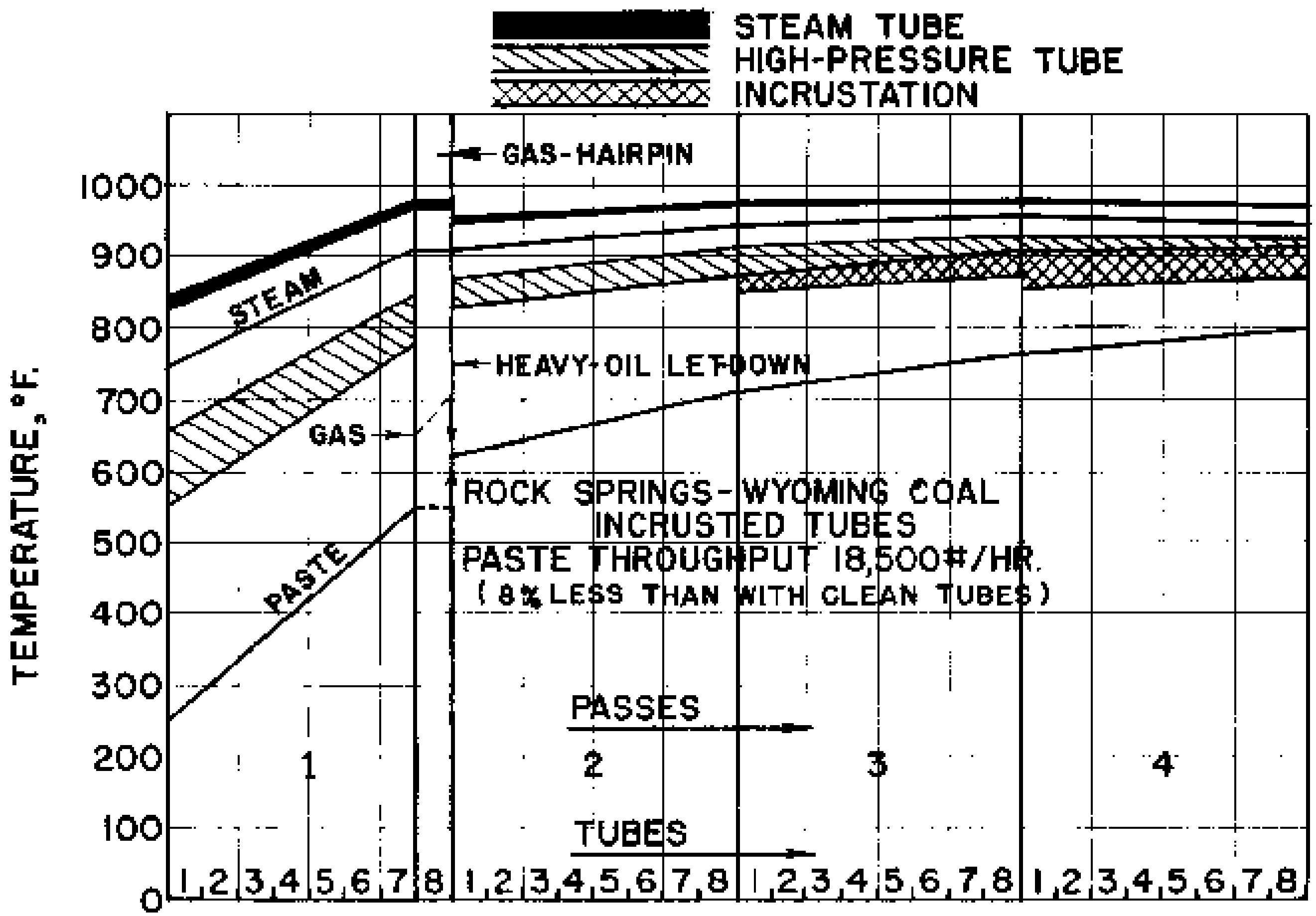
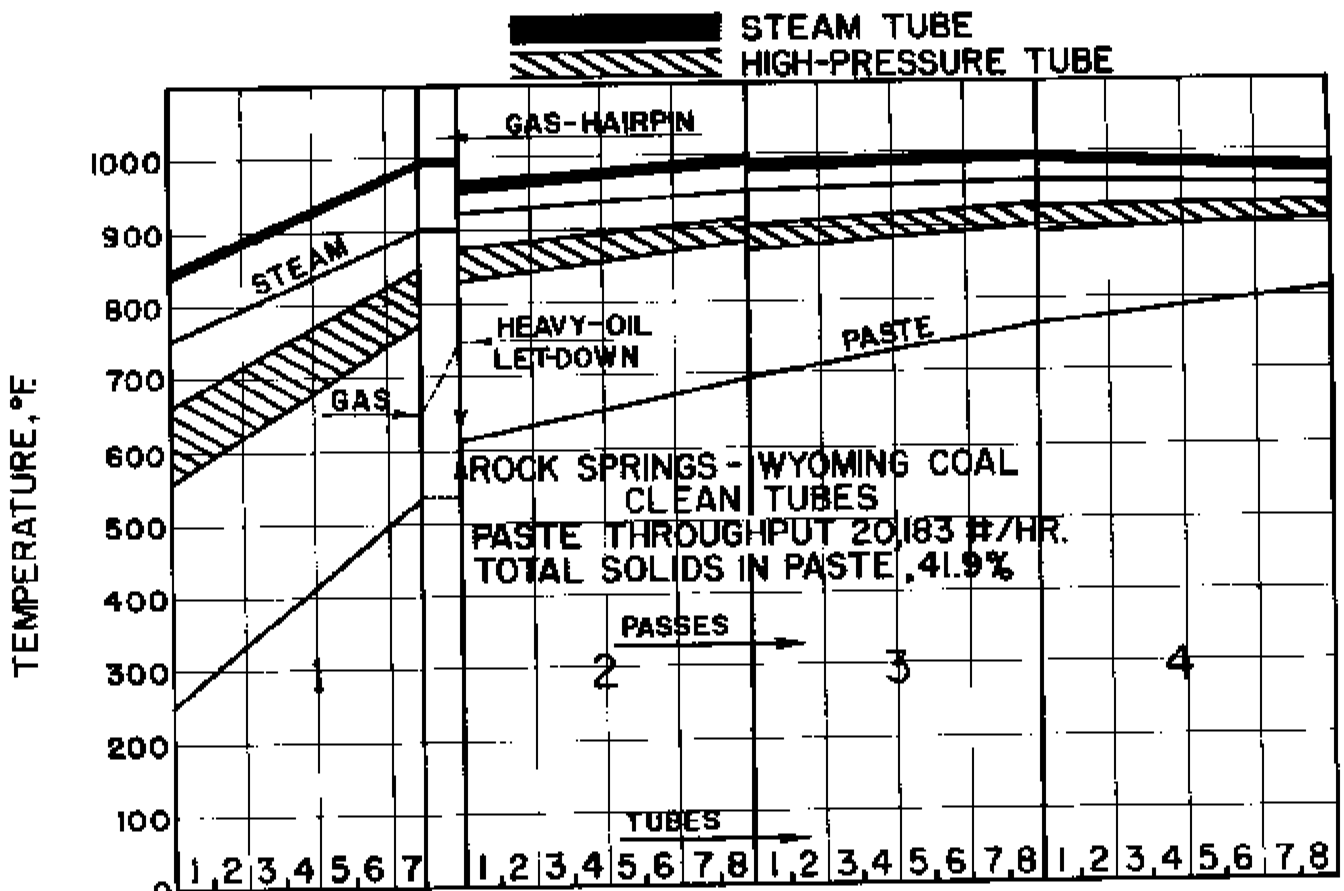


Figure 29. - Full-scale plant converter.



U (STEAM TO PASTE)	35.6	118	26.7	25.3	23.3	B.T.U./HR.-SQ. FT.-°F.
HEAT DUTY	2,600,000	630,000	1,350,000	1,035,000	760,000	B.T.U./HR.
PASTE TUBE	170	24	194	194	194	AREA SQ. FT.
HEAT DENSITY	15,300	26,300	6,950	5,350	3,900	B.T.U./SQ. FT.-HR.

Figure 30. - Calculated temperature conditions in a four-pass paste preheater with incrusted tubes when heating 18,500 lb. per hr. of gas and paste to 800° F. with maximum allowable skin temperature of 1,000° F.



U (STEAM TO PASTE)	35.6	118	26.7	29.6	32.2	B.T.U./HR.-SQ. FT.-°F.
HEAT DUTY	2,680,000	630,000	1,455,000	1,293,000	1,060,000	B.T.U./HR.
PASTE TUBE	170	24	194	194	194	AREA SQ. FT.
HEAT DENSITY	15,750	26,300	7,500	6,670	5,470	B.T.U./SQ. FT.-HR.

Figure 31. - Calculated temperature conditions in a four-pass paste preheater with clean tubes when heating 20,183 lb. per hr. of gas and paste to 615° F. with maximum allowable skin temperature of 1,000° F.

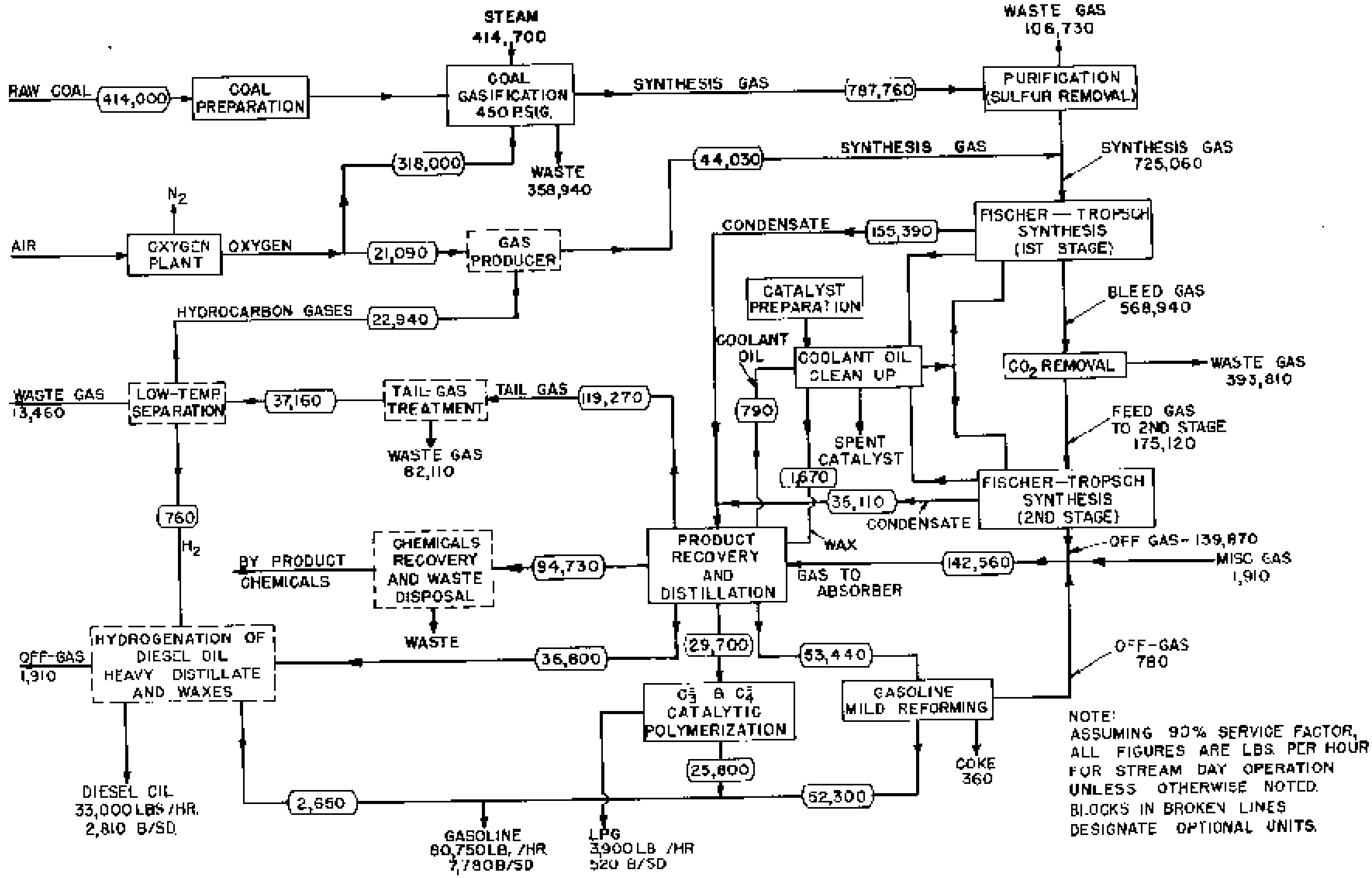


Figure 32. - Process-flow block diagram of gasification and synthesis plant based on a stream day.

(a) By utilizing upset ends for threading and maximum stress figures of 30,000 p.s.i., the wall thickness, pounds per foot, and flange dimensions of the high-pressure tubing have been reduced considerably under the demonstration-plant standards. Figure 28 shows a comparison of the two standards.

(b) The substitution of welded tees and ells for the flanged, forged-type also indicates a considerable saving for large-diameter pipe. For example, a saving of at least $100 could be realized on a 2-1/2-inch welded tee owing to elimination of the six flanges, three gaskets and necessary machining.

(c) A full-scale plant-converter design, using the wrapped-vessel type of wall construction, was developed. It is estimated that a weight saving of nearly 20 percent would be achieved when compared to the solid-wall forged type. Figure 29 is a lay-out of the proposed full-scale plant vessel.

(d) A new design for a high-pressure valve bonnet was made to eliminate the holding bolts, thereby decreasing the valve-body dimensions. This design also permits easy disassembly.

(e) Another study was made on the operation of the paste preheater, and figures 30 and 31 show the calculated temperature gradients through the tube-wall and steam-jacketed section for clean and incrusted tubes when using Rock Springs coal.

Design and Cost Estimates for a Commercial-Scale (10,000-Barrel-Per-Day) Gasification and Synthesis Plant

Work on this problem was started late in 1948 and is now considered to be about 40 percent complete.

In order to make a complete and reliable estimate it was necessary to select a tentative plant site and type of coal. A sampling survey made in Western Kentucky by the Army Engineers for the Bureau of Mines disclosed suitable general areas with adequate water supply, transportation facilities, and sufficient quantities of suitable coal. One of these areas near Caseyville in Union County was chosen to determine typical site conditions.

With the limited washability data available on the selected No. 9 and 11 seams in this area, an average analysis on a moisture-free basis was calculated to be: O_2 - 8.9, H_2 - 5.2, sulfur - 3.2, C - 74.1, N_2 - 1.6, and ash - 7.0. With this analysis as a basis, the material balance was started and has been completed to the extent shown in figure 32, the process flow block diagram of this plant based on a stream day. This material balance makes allowance for a 90-percent operating factor and represents the actual daily production necessary to obtain an average 10,000 barrels per calendar day.

For convenience and close study of details, the problem was subdivided into the following 19 sections, corresponding to the logical operating departments of the plant:

1. Coal preparation and storage.
2. Gasification and dust removal.
3. Gas purification.
4. Oxygen production and compressions.
5. Synthesis-gas production from tail gases.
6. Low-temperature off-gas separation.

7. Synthesis - 1st and 2d stages.
8. CO_2 removal.
9. Catalyst preparation.
10. Coolant-oil clean-up.
11. Product recovery and distillation.
12. Gasoline treating.
13. Hydrogenation of Diesel oil, heavy distillate, and wax.
14. Polymerization.
15. Waste recovery and disposal.
16. Tankage.
17. Power plant.
18. Other plant utilities.
19. General plant facilities.

Each of these sections is being studied in detail. Such studies include a thorough investigation of the process or processes involved, the preparation of a flow diagram, equipment lay-out, an equipment summary, heat and material balances, and estimates of the cost of construction and operation. A compilation and summary of these separate studies will constitute the final report.

While this work is well under way it is deemed advisable to withhold cost figures until the entire estimate of the plant cost has been completed.

Indexing Technical Oil Mission Microfilm Reels

The indexing and cross indexing of the 258 Technical Oil Mission microfilm reels collected in Germany after World War II were completed. This work comprises about 800 typewritten pages and is being assembled into 4 volumes.

Current articles of German literature are reviewed, evaluated, and, if advisable, translated.

General

When the Coal-Hydrogenation Demonstration Plant construction contract was terminated, the new laboratory building was completed, but the laboratory furniture and equipment were not yet delivered. Upon arrival of the furniture, Bureau of Mines forces completed the plans and the installations. The work was finished in July, and the laboratory personnel moved in. Physical and chemical control testing is well-organized and is in step with the operations of the demonstration plants.

Accident-prevention activities included operation of the former Missouri Ordnance Works area. The two synthetic fuel plants and the new construction work accident rates of Bureau employees for 1949 is at this writing:

Frequency rate.................... 5.8
Severity rate.................... .28

483,033 man-hours were worked, with 4 disabling injuries and 196 days lost.

Koppers Co. record on the construction of the Gas-Synthesis Demonstration Plant is:

Frequency rate....................14.2
Severity rate.................... .03

421,529 man-hours worked resulted in 6 disabling injuries and 12 days lost.

Frequency rate is defined as number of disabling injuries per 1,000,000 man-hours worked. Severity rate is defined as number of days lost per 1,000 hours worked.

Maintenance of the former Missouri Ordnance Works, the 2 new demonstration plants, and 51-unit housing area has functioned smoothly. The power plant provided all electric power and steam for process work, prime movers, and all heating purposes, together with plant water and compressed air for the entire installation. With advancement of new construction during the year, average electrical load increased from 800 kw.-hr. to 3,500 kw.-hr., steam generation from 70,000 pounds per hour to 125,000 pounds per hour, and process-water make from 350,000 gallons per day to 900,000 gallons per day.

The demonstration plants were dedicated on May 8, 1949. Considerable work was done in the preparation for the dedication, but the efforts were amply compensated by the general interest manifested in the number of visitors. During "open house" on May 6 about 1,200 people visited the plants. More than 600 persons participated in the briefing session and the banquet on May 7. Two thousand visited the plants on dedication day. Six hundred of them came and left on the special Diesel train fueled with products from the hydrogenation plant. On May 13, 30 students of the Rolla School of Mines visited the plants, and on the 17th, 350 coal men participated in an independently organized "Pilgrimage of Progress."

Public interest in the facilities and processes of the demonstration plants has continued at a high level. The normal number of visitors is approximately 100 per month, consisting mainly of technical representatives of the chemical and petroleum industries, mine operators, railroad men, business executives, research men, foreign observers, students, engineering organizations, and representatives of equipment manufacturers.