necessary, in general, to employ a multistage recycle system to obtain gases of high purity. A simplified flow diagram for a three-stage permeation process is shown in figure 24.

For appropriate gas mixtures, the power requirements of a permeation process are in the same order of magnitude as for low-temperature separation. Relatively large plants will be required because of low film permeabilities. The total film area (that is, plant size) needed is approximately inversely proportional to the pressure used on the high-pressure side. An increase in pressure therefore will decrease the film area that is needed. According to available data, production of pure oxygen by a permeation process is not competitive with the Linde process because of high power requirements and large-plant size. The production of slightly enriched air, helium from natural gas, and the enrichment of hydrogen-containing gases seem more promising.

SYNTHETIC LIQUID FUELS DEMONSTRATION PLANTS

Coal-Hydrogenation Plant

Considerable information regarding early operating experience and plant improvements in the coal-hydrogenation demonstration plant has been published.31/ The following discussion covers additional tests and improvements to the plant, some of which have been described in more detail 32/ Part of the plant, including products storage and refinery equipment, is shown in figure 25. From June 27 through August 20, 1950, the unit was down for cleaning, mechanical repairs, and installation of six improved injection pump blocks.

Following the usual inert gas tests, hydrogen circulation was established for instrument testing and reactivation, and normal hydrogenation was started on August 21 on liquid-phase run No. 5, using Rock Springs, Wyo., coal. This was a combination 8,000 and 10,000 p.s.i. test that continued satisfactorily until September 10. At that time a leaky flange near the inlet to the first converter and a subsequent fire necessitated an emergency shut-down, 2 days before the normal shut-down planned for September 12, due to depletion of the supply of coal. During the 20-day test, approximately 1,130 tons of coal were converted to 143,000 gallons of oil, a yield of approximately 3 barrels per ton. The operation was carried out at 8,000 p.s.i. and 880° to 890° F. converter temperature except for the 4 days from August 27 through September 2, when the plant was operated at 10,000 p.s.i. with fair success. However, it was considered advisable to reduce pressure to improve injection-pump operation and to conserve the rapidly depleting stock of let-down valves. Another reason for the lower pressure was the desire to distribute the reaction between the two converters more equitably, because at the higher pressure most of the reaction took place in the first converter, and the second converter had a decided tendency to lose reaction, thus upsetting the smooth operation of the entire unit. As a result of this experience, plans were initiated to reduce the reaction volume by installing a liner in each converter.

In addition to the production of oils required for the vapor-phase manufacture of gasoline, the most important findings during the run were:

31/ Cheffee, C. C., and Clarke, E. A., Operating Experience with the Coal-Hydrogenation Demonstration Plant: Am. Soc. Mech. Eng. paper 50-PET-10, 1950; abs. in Mech. Eng., vol. 72, No. 12, December 1950, p. 1007.

32/ Synthetic Liquid Fuels. Annual Report of the Secretary of the Interior for 1950. Part I. Oil from Coal: Bureau of Mines Rept. of Investigations 4770, 1951, 74 pp.

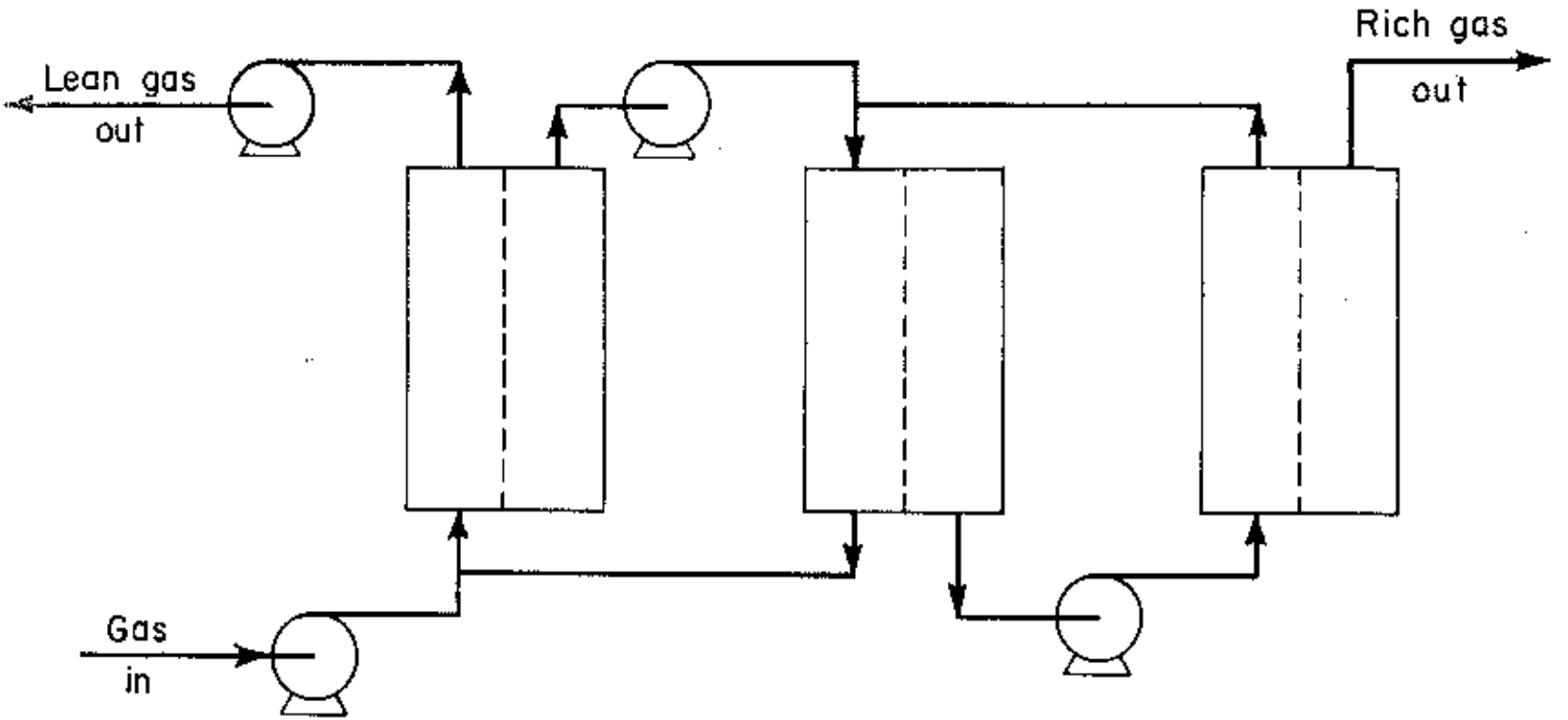

Figure 24. - Simplified flow diagram of a three-stage permeation process for the separation of gases.

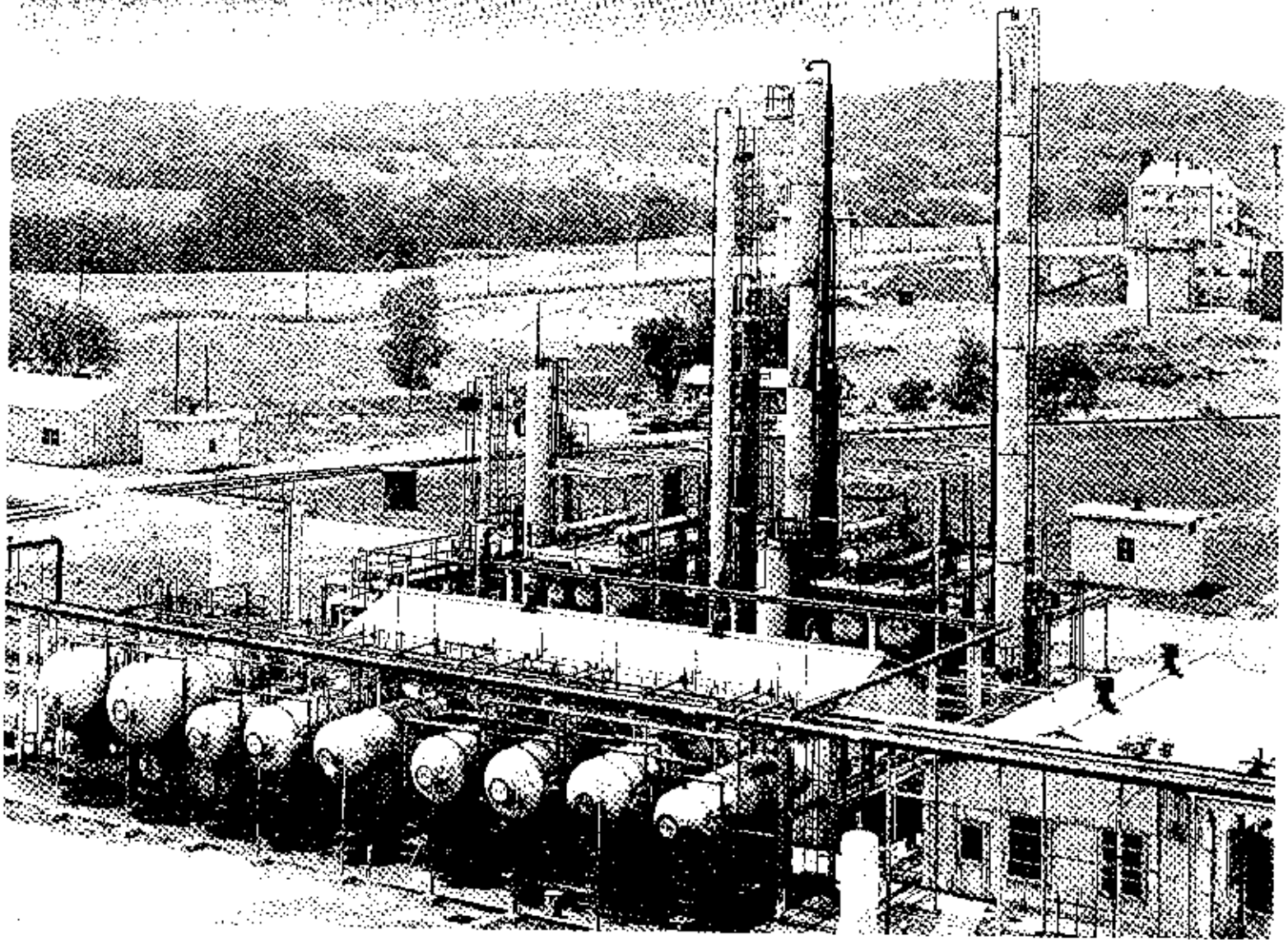

Figure 25. - Small modern refinery and storage vessels, Synthetic Fuels Demonstration Plant, Louisiana, Mo.

1. The improved pump blocks, with exterior ball valves, satisfactorily pumped any of the hydrogenation injection oils or water at speeds up to 12 r.p.m.

2. The life of the chevron packing used in injection pumps was markedly improved by the addition of adequate, forced lubrication to the lantern ring and by the use of exterior drip lubrication to the plungers.

3. Owing to excessive breakage of stellite seats and disks, control-valve seats and disks in the high-pressure gas and clean-oil let-down service were changed to Cro-mo-van or chrome-molybdenum-vanadium alloy. Effectiveness of restricting orifices downstream from the control valves to absorb much of the wear and pressure drop was proved.

4. The duplex general service pump, equipped with hardened Madsen valves and Darcova cup plungers, continued to give excellent service in paste circulation at 250° C., but gave poor service at higher temperatures.

5. The horizontal, continuous centrifuge used to remove solids from the hot catchpot let-down continued to operate satisfactorily throughout the run at rates of 5 to 20 g.p.m. This apparatus was effective in removing a substantial part of the unconverted coal and ash in the oil without preferential removal of asphalt.

6. Readjustment of the tangential flow unit separator in the cold catchpot reduced the liquid carryover into the wash-oil scrubber.

7. Wash-oil scrubber operation was improved by increasing the vapor space below the packed section of the tower.

8. Wherever possible, flanged piping joints should be replaced by welded connections to eliminate potential sources of leakage.

A vapor-phase run (No. 2) was started October 5, using vapor-phase feed stock from Rock Springs, Wyo., coal, but the tar-acid content of the product indicated leakage, and the unit was shut down October 13. Upon completion of necessary repairs, production of 77 to 78 octane number (motor method), 8 to 10-pound vapor-pressure gasoline was resumed October 24. The product-feed heat exchanger continued to give considerable trouble, and there was a tendency for the preheater tubes to overheat, owing to the erratic operation of the exchanger and to the parallel flow arrangement of the preheater. Therefore, a new tubular exchanger was designed, and the preheater was changed to series flow.

The injection pumps equipped with improved blocks and better lubrication gave good service, and packing life increased to 15 days. Approximately 300,000 gallons of vapor-phase feed stock was converted to finished gasoline during the successful 30-day run.

After an extended winter shut-down, during which the liquid-phase system was completely cleaned and inspected and most of the indicated improvements were incorporated into the plant, liquid-phase run No. 6, using West Kentucky coal, was started March 30 and was completed May 17, after the entire coal supply was exhausted. During the run 2,160 tons of moisture- and ash-free coal was processed. All operating equipment continued to function satisfactorily throughout the run, and markedly improved results were obtained. This coal hydrogenated readily at a conversion pressure of 7,700 p.s.i. and a temperature of 875° F., using a 0.5 percent iron catalyst, at rates

of 50 to 75 tons per day. All equipment in the stall and high-pressure area remained tight throughout the run. Despite high paste rates and considerable injection pump valve trouble that developed as the run progressed, flow, pressure, and temperature conditions remained smooth and controllable throughout the run. The rather frequent difficulties with ball valves in the paste pumps have been traced to solid deposits in the suction lines. To eliminate these deposits, the lines have been redesigned. While the service life of most high-pressure control valves was excellent, the performance of heavy-oil let-down valves continued erratic, despite the installation of 3/32-inch restricting orifices immediately downstream from these valves. Hot catch-pot level control difficulties were accentuated by a tendency for reaction to start in the vessel, causing coke deposits. To alleviate these conditions, more agitation gas will be used.

Arrangements have been completed for a desander line to facilitate the removal of fine, sandy solids during operation. The flash-distillation system was operated about half of the time, usually with the Bird centrifuge, to reduce further the solids in the pasting oil, but mainly to control the asphalt level of the oil. To improve fume conditions and reduce manpower, a water-cooled metal conveyor for removal of solids will be obtained.

The vapor-phase charge from West Kentucky coal was fed to the unit for vapor-phase run No. 3 at an average rate of 12,740 gallons per day and was converted to an average rate of 12,713 gallons of gasoline per day. This above operation was performed smoothly at 10,000 p.s.i., with the inlet to the converter at 845° F. and with average bed temperature of 900° F. The over-all mechanical performance of the high-pressure plant equipment was adequate throughout the run. Likewise, all equipment in the distillation and gas-manufacturing areas remained satisfactory at all times.

At the end of this run, the following finished products were available for plant consumption and testing: 225,000 gallons of regular gasoline, 7,000 gallons of aviation base stock, 400 gallons of jet fuel, all from west Kentucky coal, and 60,000 gallons of regular gasoline produced from creosote-slop distillate. Samples of the first three items and gasoline from Rock Springs coal were sent to a commercial laboratory for complete tests.

A number of interesting process and mechanical improvements have contributed materially to make the present run more successful than previous operations. In the hydrogenation plant proper, the dependable operation of injection pumps and recycle compressors has allowed smooth flows to the unit at all times. The successful operation of the new, narrow range (800° - 900° F.) recording-temperature controller, regulating the flow of cooling gas to the preheater outlet line, held the converter entrance temperature within plus or minus 1°, which is essential for smooth control of bed temperatures. Improved operations in the distillation area resulted in supplying a well-blended feed stock.

Typical analytical and operational data of the liquid-phase operations are shown in tables 16 and 17.

TABLE 16. - Typical analytical data, liquid-phase hydrogenation of west Kentucky coal

	Coal paste	Pasting oil	H.C.L.D.	Gasoline	Naphtha	Middle oil	Light oil bottoms	Cold autoclave product
Distillation, °F.:								
I.B.P.	-	475	360	116	210	242	592	190
5 percent	-	560	550	138	312	434	622	240
10 percent	-	604	606	194	360	464	638	297
20 percent	-	636	616	224	378	491	654	390
50 percent	-	-	-	270	402	534	686	593
70 percent	-	-	-	296	418	552	712	668
90 percent	-	-	-	334	446	578	-	731
E.P.	-	680	560	364	516	610	760	750
Recovery, percent	-	49.	32.	96.2	99.	99.	87.	93.5
Gravity	1.204	1.117	1.25	47.0	17.1	12.0	1.06	11.2
C_6H_6 - P. E. insolubles	41.3	8.4	25.2	-	-	-	-	-
C_6H_6 insolubles	43.7	5.5	19.0	-	-	-	-	-
Tar acids	-	-	-	4.1	38.0	22.0	-	-
Tar bases	-	-	-	2.5	.9	.1	-	-

Coal analysis

Proximate (moisture-free basis)

	Weight, percent
Moisture	-
Volatile matter	38.9
Fixed carbon	53.9
Ash	7.2

Ultimate

	Weight, percent
Ash	7.2
Sulfur	1.4
Hydrogen	5.2
Carbon	74.5
Nitrogen	1.4
Oxygen	10.3

Screen

	Weight, percent
On 35	0.2
Through 35, on 60	1.4
Through 60, on 100	5.7
Through 100, on 200	22.0
Through 200, on 230	10.1
Through 230	60.6

TABLE 17. - Operational data, liquid-phase runs for fiscal year 1950-51; selected periods representative of lined-out operations

	Run 5		Run 6	
	Rock Springs (Wyo.) coal		West Kentucky coal	
	Period 1	Period 2	Period 2	Period 5
Pressure, p.s.i.g.	10,000	8,100	8,300	8,300
Recycle hydrogen, percent H_2	80	81	81.4	81.0
Paste injection, gal./day	30,000	29,200	25,000	31,000
Paste oil, gal./day	22,400	21,600	15,582	18,736
Coal, moisture-free, tons/day	56	56	54.5	67.5
Coal, moisture-free, weight percent	33.5	34.2	42.8	42.8
Catalyst, type	Tin oxalate	Tin oxalate	SnC_2O_4 - $FeSO_4$	Ferrous sulfate
Weight percent on moisture-free coal	0.7	0.1	0.34 0.8	2.5
Naphtha injection, gal./day	7,300	5,700	3,958	4,761
Wash oil injection, gal./day	14,500	12,500	40,500	45,100
Gas flows, cu.ft./day:				
Make-up hydrogen gas	3,960,000	4,150,000	2,215,000	2,287,000
Total hydrogen to stalls	10,900,000	10,200,000	9,420,000	9,031,000
Compressor recycle	2,500,000	13,100,000	11,900,000	12,400,000
Total paste gas	7,200,000	7,030,000	6,112,000	5,650,000
Cold paste gas	1,200,000	1,630,000	1,260,000	1,306,000
Hot paste gas	6,000,000	5,800,000	4,532,000	4,298,000
Total cooling gas	2,030,000	2,470,000	2,665,000	2,393,000
Hot catchpot agitator	890,000	720,000	628,000	792,000
Purge gas	1,580,000	1,720,000	600,000	389,000
Temperatures, °F.:				
Paste, preheater, inlet	154	159	157	157
1st section outlet	464	462	456	443
Preheater outlet	852	853	832	822
First converter, °F.:				
Reaction, top zone	874	878	858	856
Reaction, middle zone	865	854	871	872
Reaction, bottom zone	-	839	867	870
Second converter, °F.:				
Reaction, top zone	874	865	862	859
Reaction, middle zone	874	862	870	869
Reaction, bottom zone	866	877	866	866
Temperatures, °F.:				
Hot catchpot, vapors	852	798	822	838
Hot catchpot, liquid (average)	698	690	637	634
Cold catchpot, liquid	187	196	193	195
Products from hydro, gal./day (based on run-down quantities):				
Heavy oil let-down	12,000	11,100	9,638	10,864
Cold catchpot, product-net	16,800	16,900	15,210	18,050
Gasoline	2,400	2,200	2,050	2,408
Naphtha	-	-	1,525	2,585
Middle oil	5,530	5,000	3,765	2,840
Flushing oil	510	-	-	-
Light oil bottoms	6,470	9,200	7,920	10,217
Total vapor-phase charging stock (recovery), bbl./ton of coal	3.2	3.3	3.11	3.07
Gasification (C4 and lighter):				
Cu.ft./day	402,200	390,000	220,200	299,400
Weight percent on moisture- and ash-free coal consumed	26.7	26.4	13.6	13.3

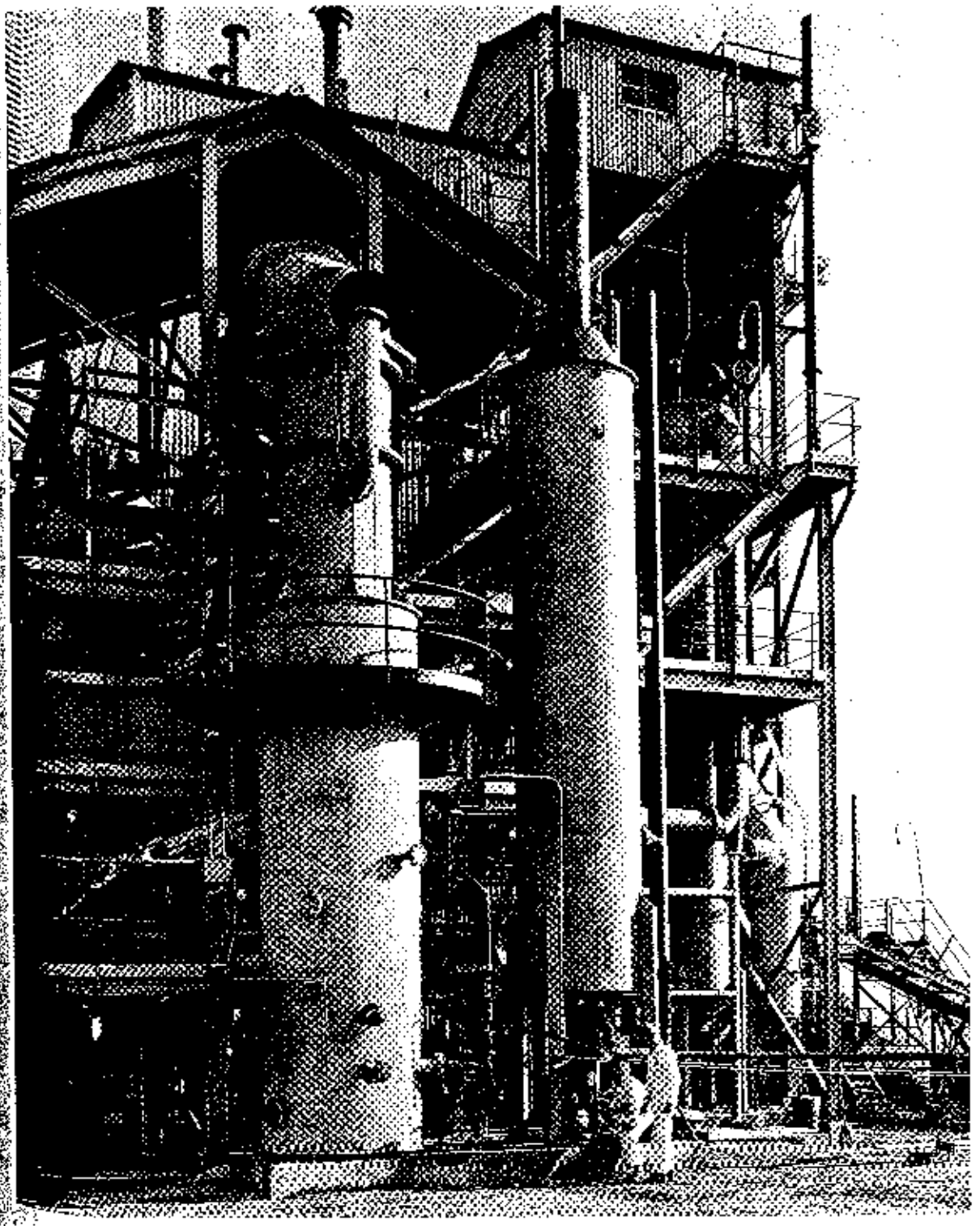

Figure 26. - Morgantown-type vertical coal gasifier and steam-coal preheater, Gas-Synthesis Demonstration Plant, Louisiana, Mo.

Gas-Synthesis Plant

The contractors' work on the Synthesis and Distillation Units of the Gas-Synthesis Demonstration Plant was completed during the fiscal year. The demonstration plant has been described previously.33/34/ The plant operations have covered trials on a new, vertical, coal-gasification unit, the use of the Kerpely producer to manufacture synthesis gas for testing, the initial operation of the compression and purification units, the production and reduction of catalysts for the synthesis unit, and the testing and preliminary operation of the synthesis and distillation units.

Vertical Gasifier

The trial runs on the Koppers gasification unit made last year indicated that economy of operation would be improved if higher conversion of steam was obtained by reaction with the carbon of the coal. There was reason to believe that changes in the shape of the unit and the method of feeding coal, oxygen, and steam would result in increased conversion. In order to explore this, a new gasifier was built, which consisted of a vertical, refractory-lined cylinder, 4-feet 4-inches inside diameter, and approximately 20 feet high. Figure 26 shows the new unit.

The refractory chosen for the gasifier lining was a high purity aluminum oxide, ram-packed against inside forms, and fired in place to produce a monolithic lining. This material has the advantage of a higher melting point and a higher slag resistance than the silica brick used in the Koppers unit. If tests here show that monolithic linings are satisfactory, important savings in construction cost may result. Under a cooperative agreement, the Aluminum Co. of America supplied technical assistance and much of the material.

Feed materials are introduced tangentially near the bottom, and the products flow out the top to the same gas-handling system that was used for the Koppers unit. Provision has been made for either feeding the coal suspended in oxygen, as with the Koppers unit, with steam entering separately at about 1,000° F., or for feeding the oxygen separately, with the coal and steam preheated together to 1,000° F.

A unit was built to test this second, new method of feeding coal. A slurry of pulverized coal and water is pumped through a fired-coil preheater. The steam formed in the first part of the coil carries the coal in suspension through the rest of the coil in which both steam and coal are heated to 900° to 1,000° F. The trials made to date on this unit have given trouble with fluctuating flow rate and variations in the steam-coal proportions. Further tests are necessary to determine if a steady flow of a uniform mixture can be achieved.

There have been eight periods of test operation of the new gasifier, one of 30 hours' duration. Results have been promising, and in one test practically complete gasification of the carbon was achieved. In this case the requirements of 30.5 pounds of coal and 354 std. cu. ft. of oxygen per 1,000 cu. ft. of synthesis gas were lower than in any work previously done here. However, to date the tests have also shown that many difficult problems remain to be solved. Among these are very high local temperatures, removal of slag, and others of a similar nature.

33/ Dressler, R. G., and Dirober, J. R., The Bureau of Mines Gas-Synthesis Demonstration Plant at Louisiana, Mo. Am. Soc. Mech. Eng. paper 50-PET-9, 1950; abs. in Mech. Eng., vol. 72, No. 12, December 1950, p. 1007.

34/ Synthetic Liquid Fuels. Annual Report of the Secretary of the Interior for 1950. Part I. Oil from Coal: Bureau of Mines Rept. of Investigations 4770, 1951, 74 pp.

Pebble-Type Steam Superheater

In the course of the previous operation of the Koppers gasification unit, a study was made of the performance of a circulating pebble-type steam superheater, with flow rates of 1,400 to 2,300 pounds per hour of steam superheated to 1,600° to 2,300° F.35/ Thermal efficiencies were calculated for different conditions, and data were presented on the rate of wear of the two types of pebbles used. Loss due to pebble wear amounts to about one-half pound per million B.t.u. transferred to the steam.

Kerpely Gas Producer

At the conclusion of tests of the Kerpely producer using oxygen and oxygen-enriched air blast, the results were analyzed and compared with similar operations previously reported.36/37/ The performance of the unit was quite satisfactory. It appears that the ultimate capacity of the producer is well above the capacity of the gas-handling system and of the oxygen plant. The raw-material requirements per M cu. ft. of CO + H_2 appear to be slightly lower for this unit than those achieved elsewhere.

Gas-Purification Unit

The adequate purification of the synthesis gas has been considered to be one of the major potential problems of the Fischer-Tropsch process. In addition to the substantially complete removal of sulfur compounds, it recently developed that the removal of the bulk of the carbon dioxide was highly desirable. Plans at Louisiana were modified accordingly by the substitution of diethanolamine for the triethanolamine previously chosen as a scrubbing medium, and the whole purification unit was put in preliminary operation. The first results have indicated that the removal of the necessary CO_2 in existing equipment is feasible and that a purified gas can be obtained containing appreciably less than 0.1 grain of total sulfur per 100 cu. ft. of gas, the figure set as a safe maximum for the Fischer-Tropsch catalyst. The purification unit is shown in figure 27.

The amine scrubbing system will reduce the CO_2 from 16 percent inlet to about 2 percent outlet and the H_2S from 130 grains per 100 cu. ft. to 10 to 15 grains. The balance of the H_2S is removed by passage through iron oxide on wood shavings and the organic sulfur by adsorption on active carbon. As a final insurance, the gas is then passed through beds of hot iron-oxide soda ash mixture, in case any organic sulfur passes the carbon beds.

Synthesis Reactor and Distillation Unit

In the course of testing operations of the synthesis and distillation units some modifications were found desirable. The most important change in the synthesis

35/ Batchelder, H. R., and Ingels, E. A., Performance of a Pebble-Heater-Type Steam Superheater: Bureau of Mines Rept. of Investigations 4781, 1951, 8 pp.

36/ Batchelder, H. R., Dressler, R. G., Tenney, R. F., Kruger, R. E., and Segur, R. D., Operation of Kerpely Producer with Oxygen-Enriched Blast: Proc. Am. Gas Assoc., 1950, pp. 348-354.

37/ Batchelder, H. R., Dressler, R. G., Tenney, R. F., Skinner, L. C., and Hirst, L. L., The Role of Oxygen in the Production of Synthetic Liquid Fuels from Coal: Bureau of Mines Rept. of Investigations 4775, 1951, 15 pp.

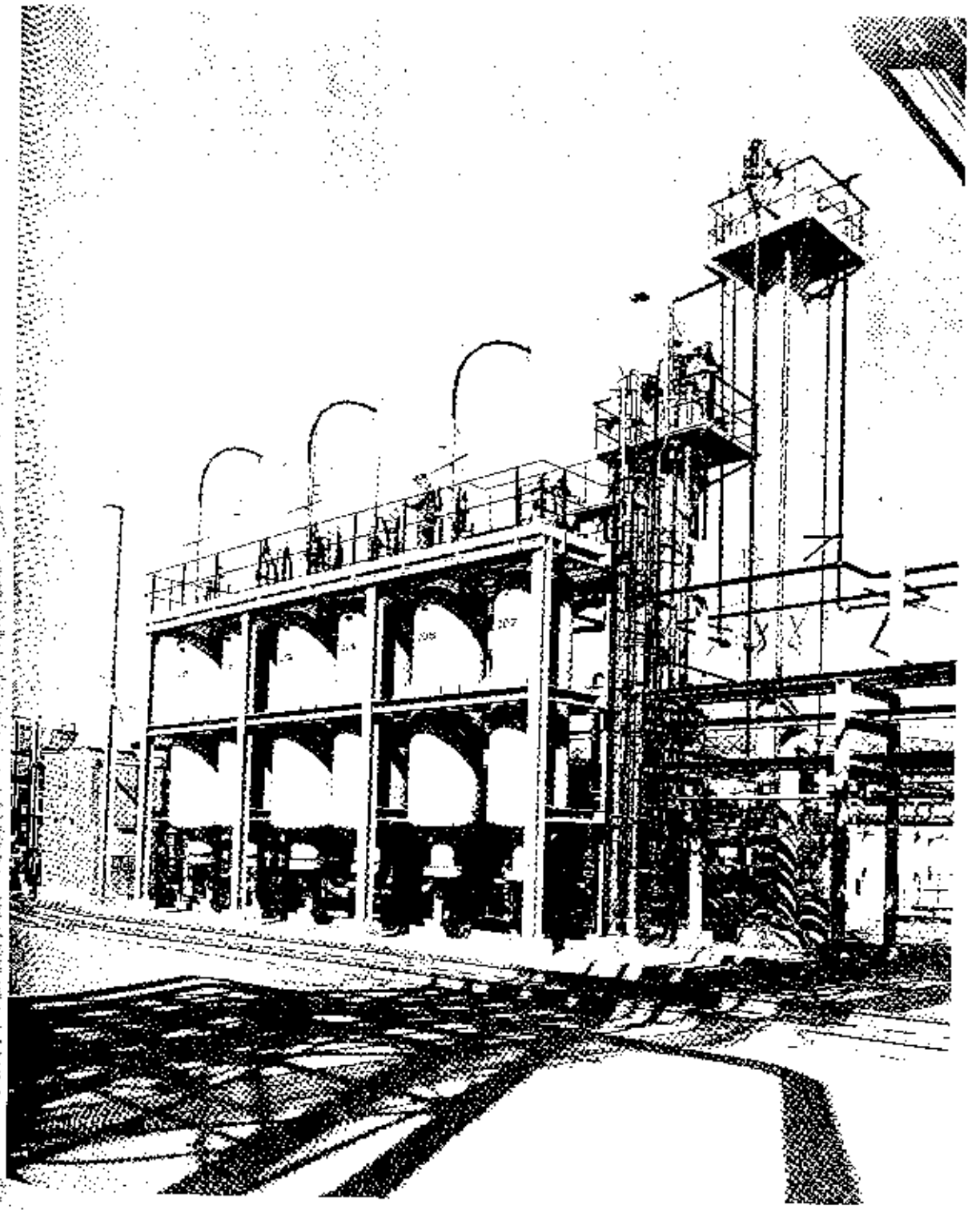

Figure 27. - Gas-purification unit, Synthetic Fuels Demonstration Plant, Louisiana, Mo.

reactor was to adapt it for "jiggling" or fluid-suspension bed operation. Originally the reactor, 6 feet in diameter by approximately 30 feet overall, was designed for fixed-bed operation, as an internally cooled converter. With the development of the fluid-suspension bed process at the Bruceton laboratories, requiring coolant oil and gas velocities within specific limits, it became necessary to modify the synthesis reactor. This was done by installing a steel liner, backed up by a ceramic mass in the lower part of the vessel so that this section of the reactor was reduced to a diameter of 3 feet for a height of 19 feet 5 inches. At this point the reactor diameter was enlarged to the original 6 feet by means of a conical transition section. A sand-lime mixture, cured with steam, then impregnated with oil, was used for this lining. With this modified reactor, it will be possible to operate at the optimum oil and gas velocities.

The entire synthesis unit was thoroughly tested in a series of dummy runs, using gravel and water in place of catalyst and coolant oil. Much was learned from these operations about the functioning and limitations of equipment and the conditions for obtaining the fluid-suspension bed in a larger than a laboratory-size reactor.

In the distillation unit, the equipment comprising the primary fractionating system, absorbers, debutanizer, stabilizer, rerun column, and vacuum still have been completely tested using various petroleum fractions. One phase of the distillation unit testing program included distilling 18,500 gallons of low-sulfur crude oil to produce a suitable coolant oil for use in the synthesis reactor. The material chosen was a crude oil from the East White Lake Field in Louisiana, which contained only 0.06 percent sulfur. The distillation of this crude oil yielded 8,000 gallons of coolant oil and additional quantities of gasoline and naphtha.

Catalyst Preparation and Reduction

One of the most satisfactory catalysts for the fluid-suspension bed process is a fused-iron oxide synthetic ammonia catalyst, which is available commercially at 57 to 63 cents a pound. However, the number of producers is small, and the time of delivery is normally quite long. The high price and long delivery are due in part, to the high purity of raw materials used by commercial catalyst manufacturers. A manufacturing unit, with a capacity well over 2 tons of sized catalyst per day, was built to make this catalyst for use in the Bureau's operations. In this unit, ordinary rolling mill scale is blended with the desired promoters and fused between water-cooled electrodes in a trough furnace by means of alternating current. On completion of the fusion, the pig is permitted to cool and is then crushed to 8- to 16-mesh in jaw and roll crushers, followed by sizing in conventional screening equipment. In this manner an excellent catalyst was produced at approximately one-fourth the cost of a similar catalyst from commercial producers.

A catalyst reduction unit was designed to reduce 1 ton of fused catalyst per day. Some difficulties in operation, due to high carbon monoxide concentrations in the hydrogen gas available for reduction, were completely eliminated by using a nickel methanation catalyst before the reduction vessel. Tests on the reduced catalyst indicated a high degree of reduction, and it is believed that this material will perform well in the synthesis unit.

Engineering Studies and Cost Estimates

Process and equipment improvements in the demonstration plants have so progressed that space time yields assumed for commercial-scale plant estimates can be

supported by operational data. Related industries and equipment manufacturers have continued to furnish reliable cost figures on the various plant components required in large-scale operations. The approach and methods used in synthetic fuel cost estimated were described in detail, with several examples.38/ The Bureau of Mines synthetic fuel cost estimates are being reviewed by a Subcommittee of the National Petroleum Council. Under the detailed scrutiny of this procedure, valuable technical and economical information is being exchanged between Bureau and industrial representatives.

A cost estimate of high-pressure residual oil hydrogenation was presented in condensed form.39/ Based on residual feed stock ranging from 1/2 to 2 dollars per barrel, figure 28 shows the predicted pay-out time for a 10,000 p.s.i. residual oil-hydrogenation plant based on prevailing product prices in effect at the time of publication.

A survey was made to determine the investment cost, steel requirements, manpower requirements, time to construct, and cost of construction of two, 15,000-barrel-per-day coal-hydrogenation plants. Each of these plants would produce:

	Barrels per calendar day
Phenols	620
Benzene	1,110
Aromatic blending stock	1/ 4,100
Motor gasoline	3,210
Butane and propane (LP-gas)	4,080

1/ Consists of 85 to 90 percent toluene and xylene.

Each plant was estimated to cost 163 million dollars, including 6-million-dollar interest during construction; approximately 100,000 tons of steel would be required, and approximately 14 million man-hours of construction labor would be required for each plant.

A design and cost estimate was made of a hydrocarbon combustor unit for hydrogen production in a 30,000-barrel-per-day hydrogenation plant. Oxygen requirement for the combustor was calculated to be 827.5 M std. c.f.h. of 95 percent purity, steam requirement in the shift reactors to be 214,000 pounds per hour. This unit could be used to replace a 6-unit pressurized pebble heater plant described previously.40/

A rough cost estimate was made for a Fischer-Tropsch plant using air instead of oxygen to gasify the coal. It was found that the capital cost of a 10,000-barrel-per-day plant using air is 23 million dollars greater and that the plant would consume 1,388 tons per day more coal because the heating and power requirements would be greater.

38/ Skinner, L. C., Preparation of Synthetic-Fuel Cost Estimates by the Coal-to-Oil Demonstration Branch: Am. Soc. Mech. Eng. paper 50-PET-11, 1950; Abs. in Mech. Eng., vol. 72, No. 12, December 1950, pp. 1007-1008.

39/ Skinner, L. C., Donath, E. E., Scheppert, E., and Frase, E., Residual Oil-Hydrogenation: Petrol. Refiner, vol. 29, July 1950, pp. 83-87.

40/ First, L. L., Merkovits, J. A., Skinner, L. C., Dougherty, R. W., and Donath, E. E. Estimated Plant and Operating Costs for Producing Gasoline by Coal Hydrogenation: Bureau of Mines Rept. of Investigations 4564, 1949, 83 pp.

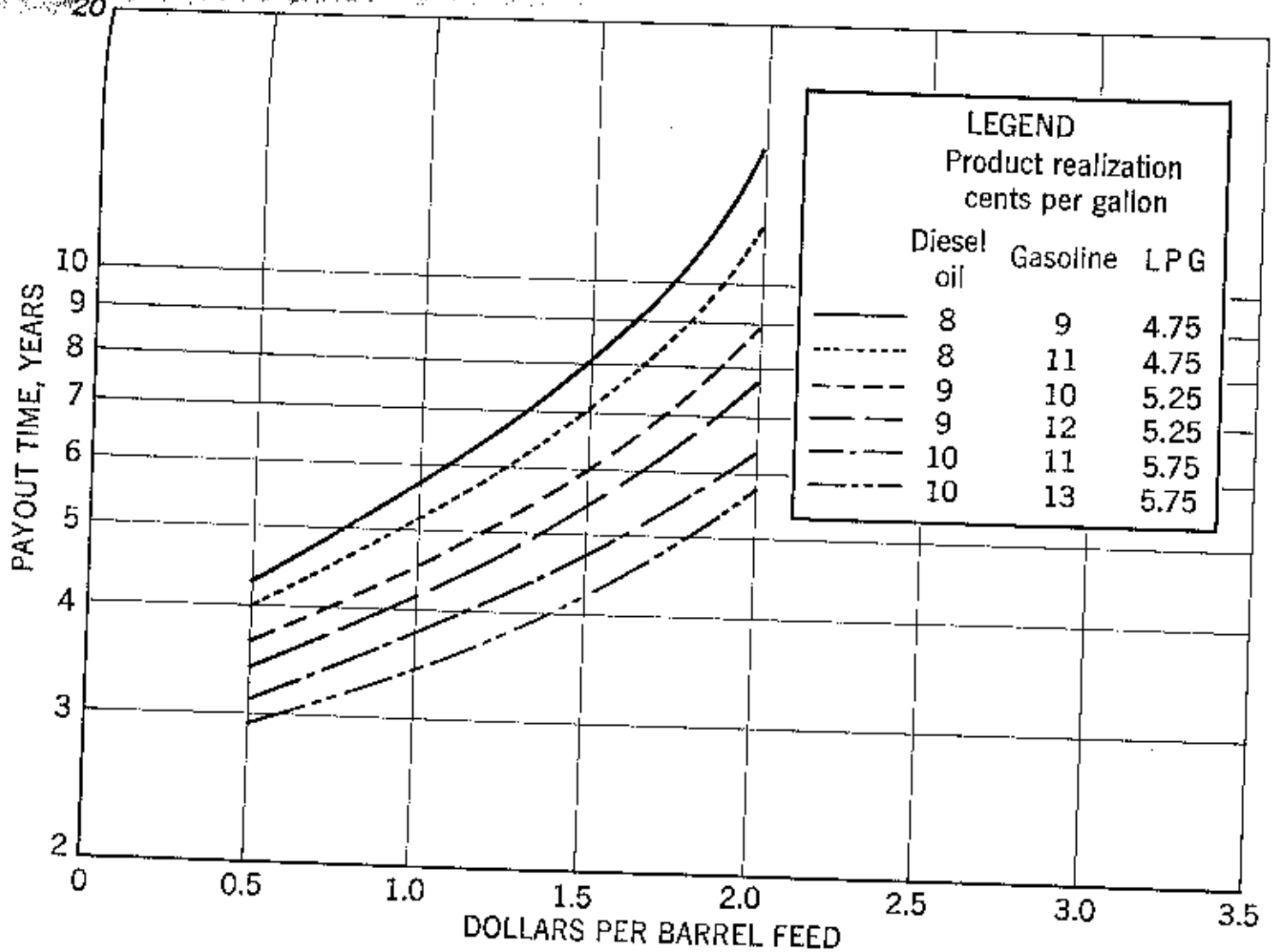

Figure 28. - Predicted payout time for a 10,000 p.s.i. residual oil-hydrogenation plant for various cost and realization values.

The possibilities of ammonia as a byproduct from a gas-synthesis plant was investigated. It was found that the potential ammonia production from the tail gas of a 10,000-barrel-per-day plant would be about 1,283,000,000 pounds per year, and, therefore, it would not find a ready market. Natural gas is a much cheaper raw material for ammonia production, because the tail gas from a gas-synthesis plant contains appreciable carbon dioxide, which must be removed for ammonia synthesis.

A preliminary cost estimate was prepared for producing 3,600,000 std. c.f.h. of gas by atmospheric gasification of Pittsburgh seam coal for use in an existing ammonia plant as raw ammonia synthesis gas, raw methanol synthesis gas, or as a combination of the two. Production of 650 tons per day of ammonia on four lines would require 540 tons per day of oxygen and 668.8 tons per day of coal. Production of ammonia on one line (162 tons per day) and methanol on three lines (150,000 gallons per day) would require 850 tons per day of oxygen and 1,032 tons per day of coal. The investment required, using some existing equipment, would be $12,900,000, which gives a cost of raw synthesis gas of 13.2 cents per 1,000 cu. ft. This includes amortization of 6-2/3 percent per year, but no profit or taxes.

A study was made to determine the quantity of sulfur that can be recovered from one 15,000-barrel-per-day, coal-hydrogenation plant requiring 225 tons per hour of "as mined" western Kentucky coal. The study indicated that 58.2 tons per day of free sulfur could be recovered. In addition to the free sulfur, 203 tons per day of ammonium sulfate and refuse material containing 175 tons per day of pyrites could be recovered. To produce the ammonium sulfate, 180 tons per day of sulfuric acid would be required, containing 58.7 tons per day of sulfur, which is almost equal to the total free sulfur produced. Thus, the net sulfur produced would be in the form of ammonium sulfate.

Other engineering and cost estimate studies included: Estimation of high-pressure tubing requirements for a coal-hydrogenation plant; estimation of utility (power, water, and steam) requirements for commercial-scale production of hydrogen by the hydrocarbon steam cracking process for use in shale oil hydrogenation; and comparison of operating costs for atmospheric and pressure gasification, for which data are shown in table 18.

SYNTHETIC LIQUID FUELS PUBLICATIONS

Books

A book on the Fischer-Tropsch and related syntheses has been published[41] as the result of an extensive and critical review of the large number of reports and documents pertaining to these processes. In addition, much information on thermodynamics and on heterogeneous catalysis is included.

A resumé of synthetic liquid fuels processes, previously published in the technical press, was incorporated in a book on chemical processes.[42]

41/ Storch, H. H., Golumbic, N., and Anderson, R. B., The Fischer-Tropsch and Related Synthesis, Including a Summary of Theoretical and Applied Contact Catalysis: John Wiley & Sons, Inc., New York; Chapman & Hall, Ltd., London, April 1951, 610 pp.

42/ Rastens, Merritt L., in collaboration with First, M. L., and Shaffee, C. C., Liquid Fuel from Coal: Ind. Eng. Chem., vol. 41, No. 5, May 1949, pp. 870-885; vol. 42, No. 8, August 1950, p. 1607; Modern Chemical Processes (by Editors of Ind. Eng. Chem.), Reinhold Pub. Corp., 1950, pp. 56-71.

TABLE 18. - Operating cost of atmospheric vs. pressure gasification for a 10,000-bbl./day gas-synthesis plant

	Gasification, atmospheric			Gasification, 450 p.s.i.g.		
	Capital cost	Operating hp.	Daily operating cost	Capital cost	Operating hp.	Daily operating cost
Unit:						
Coal preparation	1/$4,734,000	7,500	$4,357	1/$4,734,000	7,500	$4,357
Gasifier	2/15,300,000	6/(66,800)	1,067	3/10,700,000	6/(58,500)	6/(1,913)
Oxygen	4/17,600,000	70,800	18,921	4/17,600,000	70,800	18,921
Oxygen compression	300,000	2,600	450	3,700,000	22,600	5,570
Synthesis-gas compression	5/14,035,000	101,155	21,108	-	-	-
Coal.....246 ton/hr. @ $2.75 ton	-	-	16,236	-	-	16,236
Total	7/$51,969,000	115,255	$62,139	7/$36,734,000	42,400	$43,171
Cost of synthesis gas to purification....¢/1,000 cu. ft.	-	-	15.00	-	-	10.40
Cost of synthesis gas to purification....., ..¢/gal. of hydrocarbon product	-	-	13.50	-	-	9.40

1/ Obtained from a proposal from Kennedy-Van Saun Manufacturing & Engineering Corp., Apr. 5, 1951.
2/ Obtained from N.P.C. atmospheric-pressure gasification design, letter Gaucher to Hirst, Dec. 18, 1950. A preliminary capital cost figure from N.P.C. of $3,550,000 total direct cost, for 3 units. 9 are required.
3/ Bureau of Mines pressure gasification unit with some adjustments in design to make comparable with N.P.C. design. Bureau's cost figures. Letter, Hirst to Carlsmith, May 2, 1951.
4/ Capital cost and power from N.P.C. letter Carlsmith to Hirst, April 5, 1951.
5/ Capital cost and operating costs from Clark bid of Aug. 25, 1950, as per letter, Skinner to Schmidt, April 9, 1951.
6/ Parentheses indicate credit.
7/ Total does not include 3 percent interest and 5 percent working capital.

Reviews and Abstracts

The current (1949-50) literature on fluid dynamics was summarized in a review,[43] which also included references to earlier material in foreign journals. A review on the oxo synthesis and its modifications[44] discussed postwar developments of this reaction. Research on synthetic fuels by the Bureau of Mines has been outlined for an Office of Technical Services publication.[45]

Compilation of Synthetic Liquid Fuels Abstracts has been continued bimonthly to give a comprehensive coverage of current literature and patents.

Bibliographies

Part I of a bibliography of pressure hydrogenation has been published.[46] This publication is a review and compilation of technical literature dealing with the history, development, and commercial application of the Bergius and related processes for the hydrogenation, under pressures greater than atmospheric, of liquid and solid carbonaceous materials, including coal, lignite, their distillation and extraction products, pitches and tars, and petroleum and its distillation residues. A bibliography of the Fischer-Tropsch reaction and related processes has been compiled and is being prepared for publication.

Foreign Documents

Several foreign documents in the field of synthetic fuels have been translated and published. These include a German publication[47] on basic calculations for designing converters; a discussion of German research on the isosynthesis,[48] describing the synthesis of branched-chain hydrocarbons; and Japanese reports on the synthesis of hydrocarbons from carbon monoxide and hydrogen,[49/50] including a description of process development.[51] About 500 more foreign documents have been indexed and are now being processed. An eight-volume German text on high-pressure hydrogenation was translated as a restricted document.

43/ Leva, M., and Weintraub, M., Fluid Dynamics: Ind. Eng. Chem., vol. 43, January 1951, pp. 90-99.

44/ Wender, I., Orchin, M., and Storch, E. H., New Modifications of the Oxo Process: Armed Forces Chem. Jour., vol. 4, October 1950, pp. 4-9.

45/ Cohn, E. M., Bureau of Mines Research on Synthetic-Liquid-Fuels Processes: Bibliography of Tech. Reports, U. S. Dept. of Commerce, Office of Tech. Services, vol. 15, January-June 1951, pp. 65-66.

46/ Wiley, J. L., and Anderson, H. C., Bibliography of Pressure Hydrogenation. I. Review and Compilation of the Literature on Pressure Hydrogenation of Liquid and Solid Carbonaceous Materials: Bureau of Mines Bull. 485, 1950, 306 pp.

47/ Wirth, Gustav. (translated by Grass, R. C. and Kandiner, E. J.), The Evaluation of Converters for Exothermic and Endothermic Catalytic Reactions Occurring Within Narrow Temperature Limits: Bureau of Mines Inf. Circ. 7587, 1950, 13 pp.

48/ Pichler, Helmut, and Ziesecke, Karl-Heinz, (translated by Brinkley, H., technical revision by Columbic, N.), The Isosynthesis: Bureau of Mines Bull. 488, 1950, 39 pp.

49/ Tsutsumi, Shigeru. (revised and edited by Grass, R. C., translated by Technical Japanese Translation Service), The Synthesis of Hydrocarbons. (Report of the Imperial Fuel Research Institute of Japan, July 25, 1935): Bureau of Mines Inf. Circ. 7594, 1951, 60 pp.

50/ Watanabe, Shiro. (revised and edited by Grass, R. C., translated by Technical Japanese Translation Service), Bench-Scale Studies of the Fischer-Tropsch Synthesis over Iron, Nickel, and Nickel-Cobalt Catalysts (Japan): Bureau of Mines Inf. Circ. 7611, 1951, 26 pp.

51/ Kodama, S., Kunsbashi, W., Hashimoto, G., Hirao, T., Tahara, H., Matsumura, A., Kato, J., and Tarama, Y. (revised and edited by Grass, R. C., translated by Technical Japanese Translation Service), Process Development in the Hydrocarbon Synthesis to 1941: Bureau of Mines Inf. Circ. 7593, 1951, 41 pp.

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