Engineering and Economic Studies for Commercial-Size Operations

Rock Springs, Wyo., and Western Kentucky (30,000-Barrel-per-Day Coal Hydrogenation Plant)

Three studies were completed during the year dealing with the economics of commercial-size coal-hydrogenation plants. One consisted mainly of a review of Bureau of Mines Report of Investigations 4564, Estimated Plant and Operating Cost for Producing Gasoline by Coal Hydrogenation, which was prepared in 1948 and issued in August 1949. The purpose of the review was to present an up-to-date cost estimate and to determine the average return on equity capital after allowing for all normal operating and capital charges and taxes, assuming that 50 percent of all capital requirements is funded debt and 50 percent equity capital. Whereas the previous report was concerned only with the cost of making synthetic fuels, this new report considers the current selling price of the products and uses a realistic capital structure comparable with recent industry trends. The process used was the so-called "conventional plant" as described in Report of Investigations 4564, with certain minor improvements that are well enough developed at present to assure successful operation.

The improvements are as follows:

(1) The liquid-phase hydrogenation was adjusted to reflect the use of wrapped-vessel construction instead of the forged vessels originally used.

(2) The liquid-phase and vapor-phase hydrogenation was adjusted to reflect an increase in throughput of 10 percent because instrumentation was more complete than in the German plants.

(3) Drum coking was substituted for the flash-distillation unit.

(4) The product distribution shown in the new report differs from that shown in Report of Investigations 4564. Since the latter report was issued, the coals reported on in the new report have been processed at the demonstration plant, and the new product distribution is based on the results obtained.

(5) An aromatic separation unit was added to recover the benzene, toluene, and xylene present in the vapor-phase gasoline. The decision to include this unit was based on the fact that the chemicals that could be produced in a coal-hydrogenation plant are in high demand. Today's increased demand for benzene and avgas plus a growing market for tar acids has justified the inclusion of chemical production in the synthetic fuel picture.

As a result of this first study, two cost estimates were prepared - one for a single 30,000-barrel-per-calendar-day plant in Wyoming, and the second for a similar plant in Western Kentucky. Table 11 shows the plant-cost summaries for the two operations. Several sections of these estimates have been reviewed by Ebasco Services, Inc.; the estimates shown herein represent the Bureau of Mines data adjusted to conform to the results of this review wherever applicable. The points covered by Ebasco were the power plant, hydrogen purification and compression, company-financed housing and community facilities, operating costs, financing program, and a market survey of the aromatic and tar acid products.

TABLE 11. - Cost summary for coal-hydrogenation plant of conventional design

	Rock Springs 30,000 bbl. per calendar day	Western Kentucky 30,000 bbl. per calendar day
Coal-preparation plant	$ 6,680,000	$ 6,680,000
Paste-preparation plant	3,180,000	3,160,000
Liquid-phase hydro plant	54,000,000	58,700,000
Delayed-coking plant	7,550,000	8,710,000
Vapor-phase hydro plant	30,250,000	30,250,000
Product-distillation unit	11,700,000	11,250,000
Tar-acid-recovery unit	2,510,000	2,510,000
Low-temperature separation unit	7,510,000	8,000,000
Hydrocarbon-steam-cracking unit	9,150,000	9,810,000
Coal-gasification unit	5,970,000	4,860,000
Oxygen plant	8,800,000	7,320,000
H_2-purification and compression	56,184,000	53,664,000
Tankage	7,060,000	7,060,000
Power plant	51,400,000	51,400,000
Plant utilities	37,000,000	37,000,000
General plant facilities	27,975,000	28,000,000
Aromatic-extraction unit	5,000,000	4,700,000
Water supply	18,000,000	2,000,000
Total plant cost	349,919,000	335,074,000
(tax and insurance base)		
Interest during construction	15,657,000	15,112,000
Subtotal	365,576,000	350,186,000
(for depreciation)		
Paid-up royalties	2,000,000	2,000,000
Housing assistance fund	250,000	250,000
Cost of mine development	13,000,000	19,430,000
Total fixed investment	380,826,000	371,866,000
Working capital	20,000,000	20,000,000
Total investment	$400,826,000	$391,866,000

The over-all capital investment for a 30,000-barrel-per-calendar-day coal-hydrogenation plant, processing Wyoming bituminous coal, is $400,826,000, including the coal mine, power plant, working capital, and employee housing assistance. Calculations show that the average return, based on present market prices of product (see table 12), on $200,413,000 equity capital would be 2.81 percent after taxes and may be increased to 3.59 percent on $201,913,000 equity capital by the addition of sulfur- and ammonia-recovery equipment which adds $3,000,000 to the total capital requirements. On the same basis the capital investment for a plant processing Western Kentucky coal is $391,866,000, and the average return on $195,933,000 equity capital is 5.21 percent after taxes. Sulfur- and ammonia sulfate-recovery facilities would increase the total capital requirements to $395,986,000 and the average return after taxes would be 6.22 percent on $197,933,000.

Tables 11A and 11B show detailed operating cost summaries for the two plants.

The coal price used includes all mining costs, as well as depreciation, welfare payments, royalties, etc., but excludes profit on the mine investment and sales expense.

Operating and maintenance labor requirements are based on a detailed organization chart and amount to 260 operating men per shift, and 1,170 maintenance workers.

Payroll overhead amounts to about 18 percent of the labor payroll and includes vacations, social security, sick leave, workmen's compensation, and other benefit programs.

The administrative and indirect operating costs are based on a detailed analysis of the entire plant.

Fixed costs include 1 percent of plant investment to cover local, county, and State taxes, and plant insurance. Depreciation is included at 4 percent, which corresponds to an average plant life of 25 years.

Figure 22 is the flow diagram and material balance for the Western Kentucky base plant. The motor fuel produced exceeds present specifications for regular-grade gasoline and has a research octane number of 83 clear before separation of aromatics It is estimated that 1 cc. of tetraethyllead will be required to give premium-grade gasoline after aromatics separation. In addition to gasoline and LP-gas, basic chemicals, which are in heavy demand and command a high selling price, as compared to fuels, are produced by coal hydrogenation. The two groups of chemicals that coal hydrogenation produces most readily are (1) aromatic hydrocarbons, such as benzene, toluene, and xylene, and (2) tar acids, such as phenol, cresols, and xylenols. The product stream is rich in these chemicals, and they can be extracted and recovered without difficulty.

TABLE 11A. - Rock Springs, Wyo. - 30,000-barrel-per-calendar-day plant of conventional design

Operating costs and financial analysis

a. Raw materials:	
Coal, 14,800 tons per stream day x 330 x $2.50	$12,200,000
Catalyst, chemicals, $5,429 per day	1,790,000
Tetraethyllead	828,000
b. Direct labor:	
Operating labor, 260 per shift	4,713,000
Operating supervision	645,000
c. Plant maintenance, 1,170 men	4,974,000
Material	5,873,000
d. Payroll overhead	1,890,000
e. Operating supplies	712,000
Total direct cost	33,625,000

Indirect cost

General administrative	1,978,000
Indirect operating cost	2,048,000
Total indirect cost	4,026,000

Fixed costs

Local, county, and State taxes, insurance at 1 percent	3,499,000
Depreciation at 4 percent	14,623,000
	18,122,000
Cost of operation without profit and interest	55,773,000
Cost per gallon of total product (460,000,000 gal.)	12.1¢

Financial analysis[1]	With ammonia and sulfur recovery	Without ammonia and sulfur recovery
Total value of products	$76,181,000	$69,927,000
Cost of operation without profit and interest	58,753,000	55,773,000
Gross profit	17,428,000	14,154,000
Interest on funded debt(3-1/2 percent)[2]	3,675,000	3,650,000
	13,753,000	10,504,000
Coal depletion allowance at $0.15 per ton	732,000	732,000
Taxable net income	13,021,000	9,772,000
Income taxes at 50 percent	6,511,000	4,886,000
Net income after taxes	6,510,000	4,886,000
Coal depletion allowance	732,000	732,000
Net funds available	7,242,000	5,618,000
Net funds as percent of (unchanged) equity capital[3]	3.59	2.81

1/ Average year of operation.
2/ 50 percent of total investment.
3/ 50 percent of total investment.

TABLE 11B. - Western Kentucky, Union County - 30,000-barrel-per-calendar-day plant of conventional design

Operating costs and financial analysis

a. Raw materials:	
Coal, 14,720 tons per stream day x 330 x $2.50	$12,120,000
Catalyst and chemicals, $5,400 per day	1,780,000
Tetraethyllead	775,000
b. Direct labor:	
Operating labor, 260 per shift	4,713,000
Operating supervision	639,000
c. Plant maintenance, 1,170 men	4,968,000
Material	5,873,000
d. Payroll overhead	1,878,000
e. Operating supplies	697,000
Total direct cost	33,433,000

Indirect cost

General administrative	1,895,000
Indirect operating costs	2,027,000
Total indirect cost	3,922,000

Fixed costs

Local, county, and State taxes, insurance at 1 percent	3,351,000
Depreciation at 4 percent	14,007,000
	17,358,000
Cost of operation without profit and interest	54,723,000
Cost per gallon of total product (460,000,000 gal.)	11.9¢

Financial analysis[1]	With ammonia and sulfur recovery	Without ammonia and sulfur recovery
Total value of products	$86,658,000	$79,173,000
Cost of operation without profit and interest	57,715,000	54,723,000
Gross profit	28,943,000	24,450,000
Interest on funded debt(3-1/2 percent)[2]	3,604,000	3,565,000
	25,339,000	20,885,000
Coal depletion allowance at $0.15 per ton	730,000	730,000
Taxable net income	24,609,000	20,155,000
Income taxes at 53 percent	13,030,000	10,680,000
Net income after taxes	11,579,000	9,475,000
Coal depletion allowance	730,000	730,000
Net funds available	12,309,000	10,205,000
Net funds as percent of (unchanged) equity capital[3]	6.22	5.21

1/ Average year of operation.
2/ 50 percent of total investment.
3/ 50 percent of total investment.

A market survey was made to determine the quantity of products that could be absorbed without reduction in price. The amount of chemicals credited to the operation in each case was determined on the basis of this survey. For each of the plants all potential chemical byproducts, except o-cresol, m-p-cresol and the xylenols, are believed to be marketable at current prices. The maximum production of these materials was limited as follows: 6,800,000 pounds of o-cresol, 50,000,000 pounds of m-p-cresol and 25,000,000 of xylenol.

Table 12 shows the quantity and products produced in both Rock Springs, Wyo., and the Western Kentucky 30,000-barrel-per-calendar-day cases.

Southern Colorado (15,000-Barrel-per-Day Coal-Hydrogenation Plant)

In the two remaining economic studies completed during the year, specific sites were chosen that could be considered for synthetic fuel production. It should be noted that the plants considered in these economic studies include numerous improvements over the so-called conventional plants discussed previously. Also, platforming units are included for maximum chemicals production. These estimates, therefore, are not directly comparable to the Rock Springs, Wyo., and the Western Kentucky studies presented above.

For the first of these studies a location in southern Colorado was selected. The site had the following factors that appeared to be very attractive: (1) Ample coal supply, (2) available labor market, (3) railroad adjacent to plant site, (4) natural gas available at 15 cents per 1,000 cubic feet and (5) purchased power available in amounts up to 50,000 kilowatts at 5-1/2 mills.

Table 13 is a preliminary plant-cost summary of a 15,000-barrel-per-calendar-day coal-hydrogenation plant at the Colorado site using natural gas for hydrogen production and purchasing 50,000 kw.-hr. of electrical energy.

Figure 23 is a flow diagram and material balance showing throughput quantities and products.

Northern Wyoming (15,000-Barrel-per-Day Coal-Hydrogenation Plant)

The other economic study was for a 15,000-barrel-per-day coal-hydrogenation plant in northern Wyoming. The site chosen had the following advantages: (1) Ample supply of very cheap coal, (2) water supply ample for once-through cooling, (3) United States highway passing by plant site, and (4) natural gas possibly available.

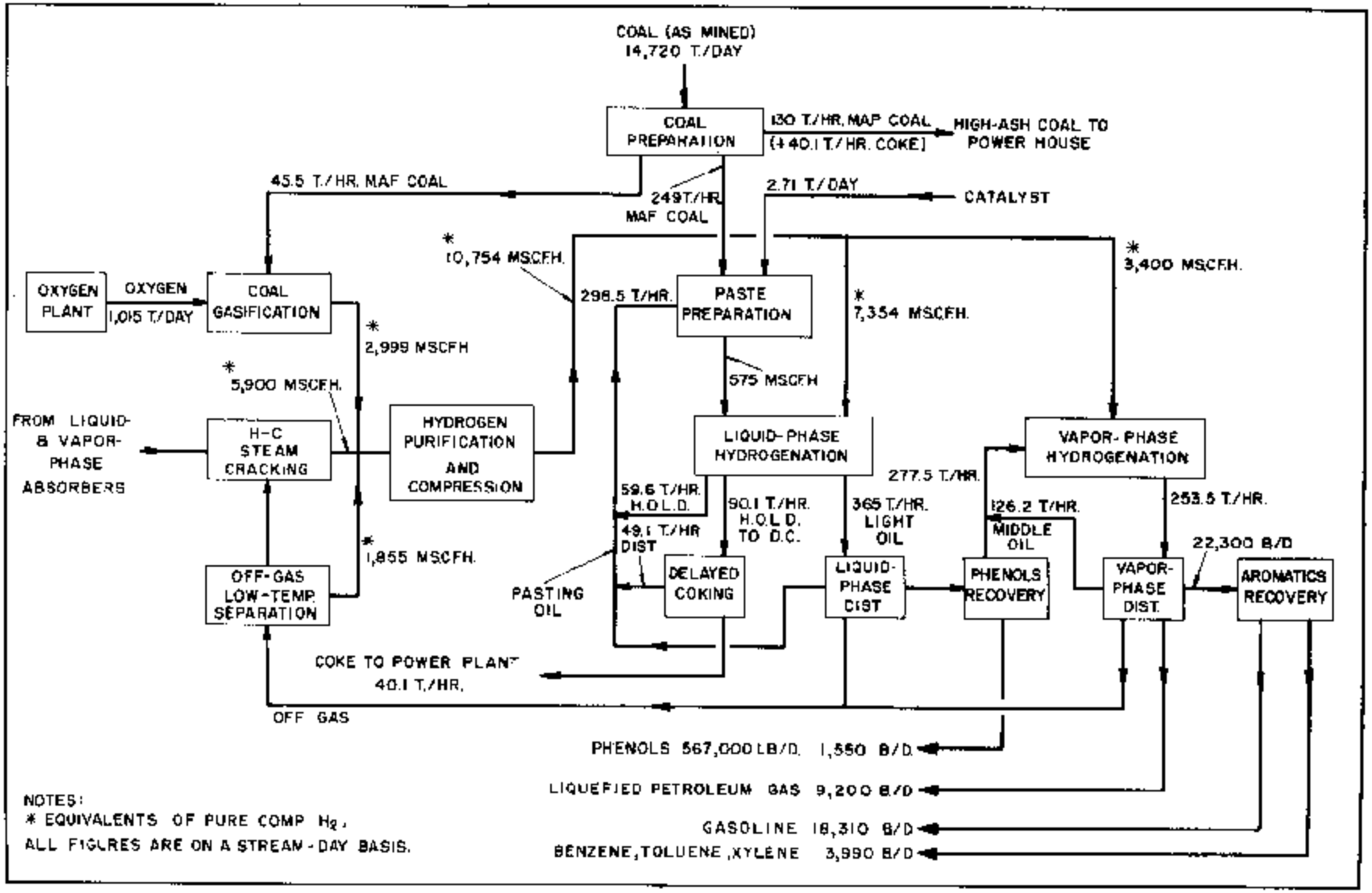


Figure 22. - Flow diagram of coal-hydrogenation plant to produce 30,000 barrels per calendar day (37,038 barrels per stream day) from Western Kentucky Union County coal.

TABLE 12. - Product quantity and value ... Rock Springs, Wyo. - 30,000-barrel-per-calendar-day plant of conventional design

	Products				Annual value
Benzene ..... gal. per yr.	11,750,000	at	$0.335	gal.	$ 3,936,250
Toluene-xylene ..... do.	39,350,000	at	.285	gal.	11,214,750
Phenol ..... lb. per yr.	43,800,000	at	.155	lb.	6,789,000
m-p-Cresol ..... do.	50,000,000	at	.155	lb.	7,750,000
o-Cresol ..... do.	6,600,000	at	.155	lb.	1,023,000
Xylenol ..... do.	25,000,000	at	.135	lb.	3,375,000
Ammonium sulfate ..... tons per yr.	131,000	at	45.00	ton	5,895,000
Sulfur ..... do.	17,100	at	21.00	ton	359,100
Motor fuel ..... gal. per yr.	286,260,000	at	.11	gal.	31,488,600
LP-gas ..... do.	108,800,000	at	.04	gal.	4,350,000
					76,180,700

Aromatic hydrocarbons reduced by 3.5 cents per gallon for freight differential.
Tar acids reduced by 1.5 cents per pound for freight differential.

Product quantity and value ... Western Kentucky, Union County - 30,000-barrel-per-calendar-day plant of conventional design

	Products				Annual value
Benzene ..... gal. per yr.	12,700,000	at	$0.37	gal.	$ 4,700,000
Toluene-xylene ..... do.	42,390,000	at	.32	gal.	13,565,000
Phenol ..... lb. per yr.	77,000,000	at	.17	lb.	13,090,000
m-p-Cresol ..... do.	50,000,000	at	.17	lb.	8,500,000
o-Cresol ..... do.	6,800,000	at	.17	lb.	1,155,000
Xylenol ..... do.	25,000,000	at	.15	lb.	3,750,000
Ammonium sulfate ..... tons per yr.	129,000	at	45.00	ton	5,805,000
Sulfur ..... do.	80,000	at	21.00	ton	1,680,000
Motor fuel ..... gal. per yr.	255,210,000	at	.11	gal.	28,073,000
LP-gas ..... do.	126,800,000	at	.05	gal.	6,340,000
					86,658,000

TABLE 13. - Cost summary for 15,000-bbl.-per-calendar-day coal hydrogenation plant in southern Colorado

Coal-cleaning plant	$ 1,680,000
Paste-preparation unit	2,170,000
Liquid-phase hydrogenation unit	37,000,000
Liquid-phase distillation unit	1,490,000
Phenol-recovery unit	1,500,000
Vapor-phase hydrogenation unit	16,500,000
Refining section	9,355,000
Continuous-coking unit	2,240,000
Water gas sets	1,000,000
H-C-combustor unit	1,960,000
Oxygen plant	7,900,000
Oxygen-compression unit	1,080,000
H_2-purification and compression unit	13,000,000
Tankage	3,450,000
Utilities	12,500,000
Power plant (50,000 kw. purchased)	15,000,000
General plant facilities	12,500,000
Total construction	140,325,000
Contingency (additional 10 percent)	14,000,000
Total plant cost (tax and insurance base)	154,325,000
Interest during construction	7,140,000
Paid-up royalties	2,500,000
Subtotal (for depreciation)	163,965,000
Cost of mine development	6,060,000
Total fixed investment	170,025,000
Working capital	12,000,000
Total investment	$ 182,025,000

As the natural-gas supply required for the production of hydrogen was questionable, two plans were undertaken. One depended on a supply of natural gas and the other on operating with a minimum of extraneous gas. This latter arrangement involved the direct-pressure gasification of H.O.L.D. as a source of hydrogen. This required a slightly greater throughput in the liquid-phase hydrogenation and a 26-percent increase in total hydrogen requirements but would eliminate the need for coking operations on the H.O.L.D., and the overall economics are not penalized. A larger initial investment is required, however, as shown in table 14, which outlines the comparative costs for the alternate designs. Both designs are based on liquid-phase hydrogenation at only 6,000 p.s.i.g. pressure, owing to the greater reactivity of the low-rank coal available.

Figures 24 and 25 show the respective flow quantities and products for the two designs.

TABLE 14. - Cost summary for 15,000-bbl.-per-calendar-day coal-hydrogenation plant in northern Wyoming

Unit	H_2 from natural gas	H_2 from H.O.L.D. gasification
Coal-cleaning plant	$ 3,740,000	$ 4,420,000
Coal-preparation plant	2,000,000	2,860,000
Paste preparation	2,100,000	2,620,000
Liquid-phase hydrogenation	19,050,000	22,760,000
Liquid-phase distillation	1,640,000	2,030,000
Phenol recovery	1,500,000	1,500,000
Vapor-phase hydrogenation	9,640,000	9,640,000
Refining	9,320,000	9,400,000
Continuous coking unit	2,720,000	-
Water gas sets	1,450,000	-
H.O.L.D. combustor	-	2,090,000
H-C combustor	1,985,000	635,000
Oxygen compressor	855,000	1,485,000
H_2 purification and compression	14,520,000	17,100,000
Tankage	3,450,000	3,450,000
Oxygen plant	7,900,000	12,600,000
Utilities	9,800,000	11,000,000
Power plant	26,000,000	29,250,000
General plant facilities	10,000,000	10,000,000
Total construction	127,670,000	142,840,000
Contingency (additional 5 percent)	6,380,000	7,140,000
Total plant cost (tax and insurance base)	134,050,000	149,980,000
Interest during construction	6,220,000	6,970,000
Paid-up royalties	2,500,000	2,500,000
Subtotal (for depreciation)	142,770,000	159,450,000
Land, water, and coal	5,000,000	5,000,000
Total fixed investment	147,770,000	164,450,000
Working capital	11,500,000	12,000,000
Total capital requirements	159,270,000	176,450,000

The two economic studies of proposed 15,000-barrel-per-calendar-day coal-hydrogenation plants included process improvements and equipment arrangements representing the latest thoughts on commercial coal-hydrogenation designs. The improvements, though differing from the so-called "conventional plant," are not particularly revolutionary. Many of the improvements have gone beyond the pilot-plant stage and could be developed to commercial status readily within 12 months.

Work on the cost estimate for a 10,000-barrel-per-day coal-gasification and gas-synthesis plant continued. Recommended process alterations are being studied and considerable work remains to be done.

Aromatic Hydrocarbons and Chemicals from Synthetic Liquid-Fuel Plants

The continuing shortages in the supply of aromatic hydrocarbons, particularly benzene, and the tar acids became more acute during 1951. The conventional sources are completely inadequate to meet the enormously increased demand, and the shortages must be supplied by imports from foreign countries, from petroleum refining, and, eventually, from commercial coal-hydrogenation plants.

As more information on the composition of the coal-hydrogenation products made in the demonstration plant was obtained, it has been possible to revise earlier estimates and determine the position of coal-hydrogenation plants in supplying part of the shortage of the aromatic hydrocarbons and chemicals. The most recent analytical data support and extend all claims and estimates previously made.

To estimate the demand for aromatic hydrocarbons and chemicals in 1951-60, a series of production and market studies was made. In these studies, all pertinent statistical information relating to the production and distribution of benzene, toluene, xylene, phenol, the cresols, and cresylic acid (xylenols) was carefully analyzed, and trend lines were established for each commodity covering a span of years before 1951. By extending these trend lines to 1960, an estimate of the possible production required to meet the normal peacetime and mobilization demands was obtained. An example of this work is figure 26, showing the actual production and projected demand for chemical-grade benzene over the period 1936-60.

Except for m-p-cresol and the xylenols, the studies indicate that all the chemicals from a 30,000-barrel-per-day coal hydrogenation plant could be readily marketed. While most of the cresols could be marketed and a substantial amount of the xylenols could be absorbed, the excess production of these materials would have to be recycled to the plant and converted into fuels, pending the development of expanded markets for these chemicals.

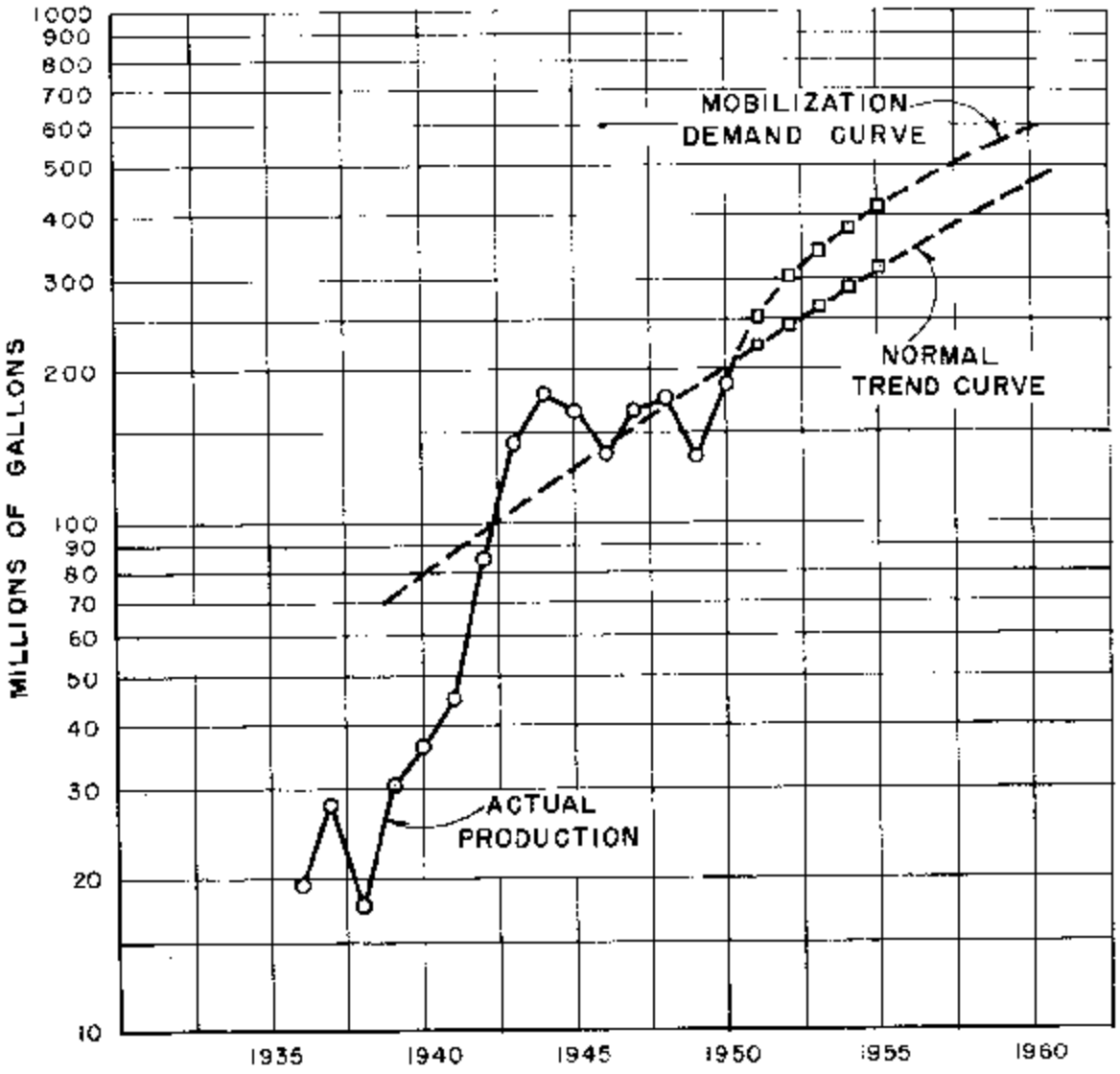


Figure 26. - Actual production and projected demand of chemical-grade benzene, 1936-60.

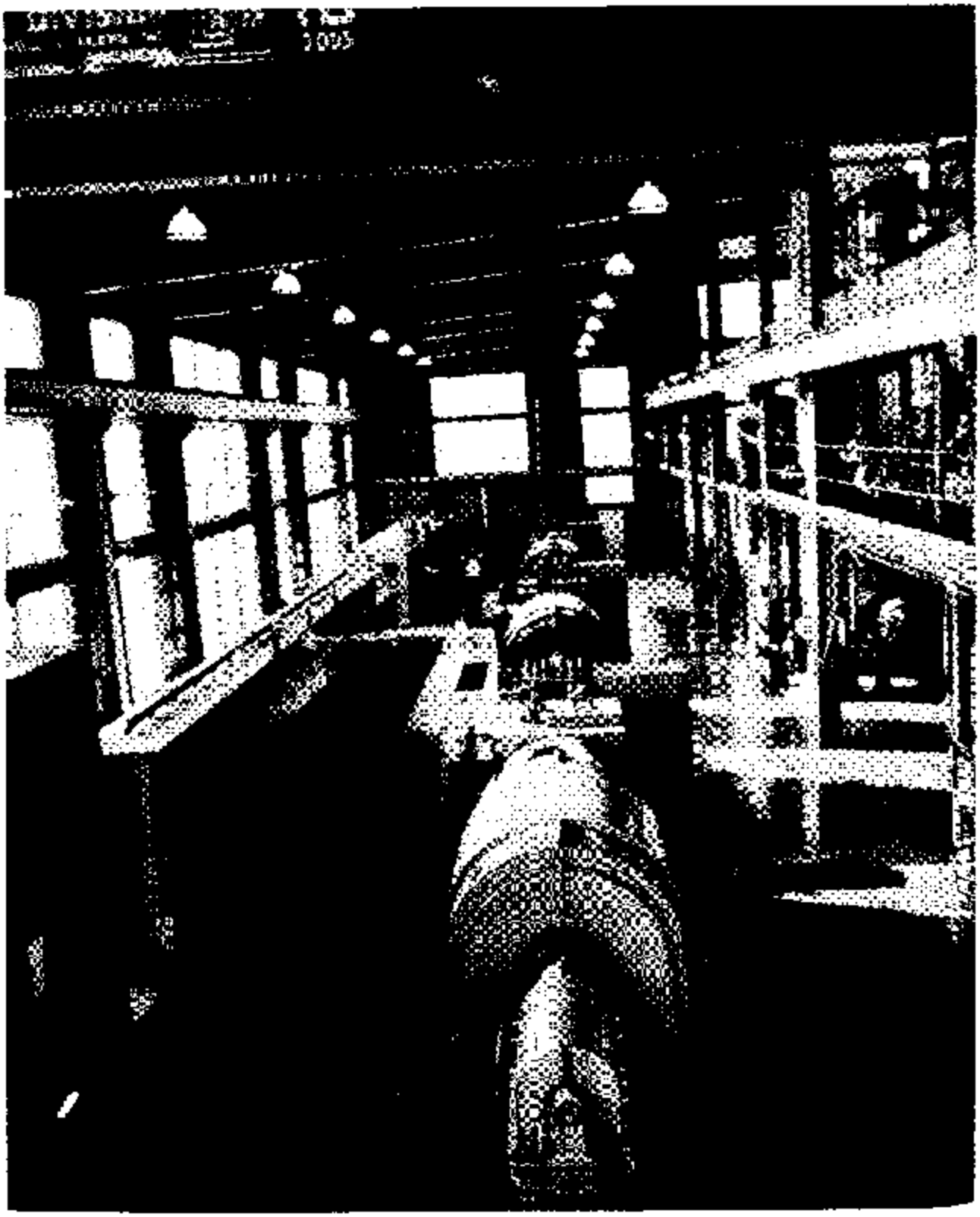
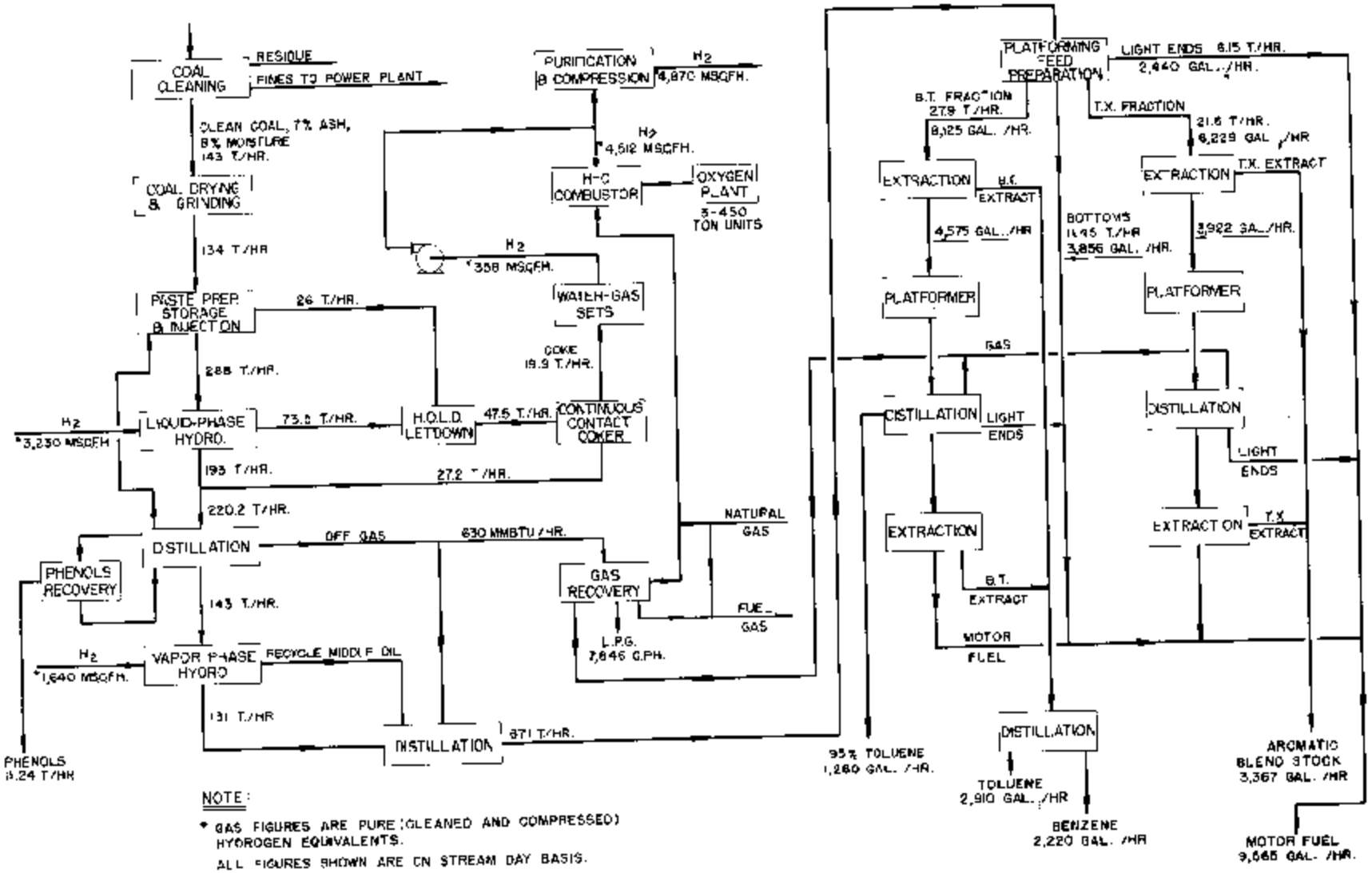


Figure 27. - Main operating floor in powerhouse, showing control boards and turbine generators.



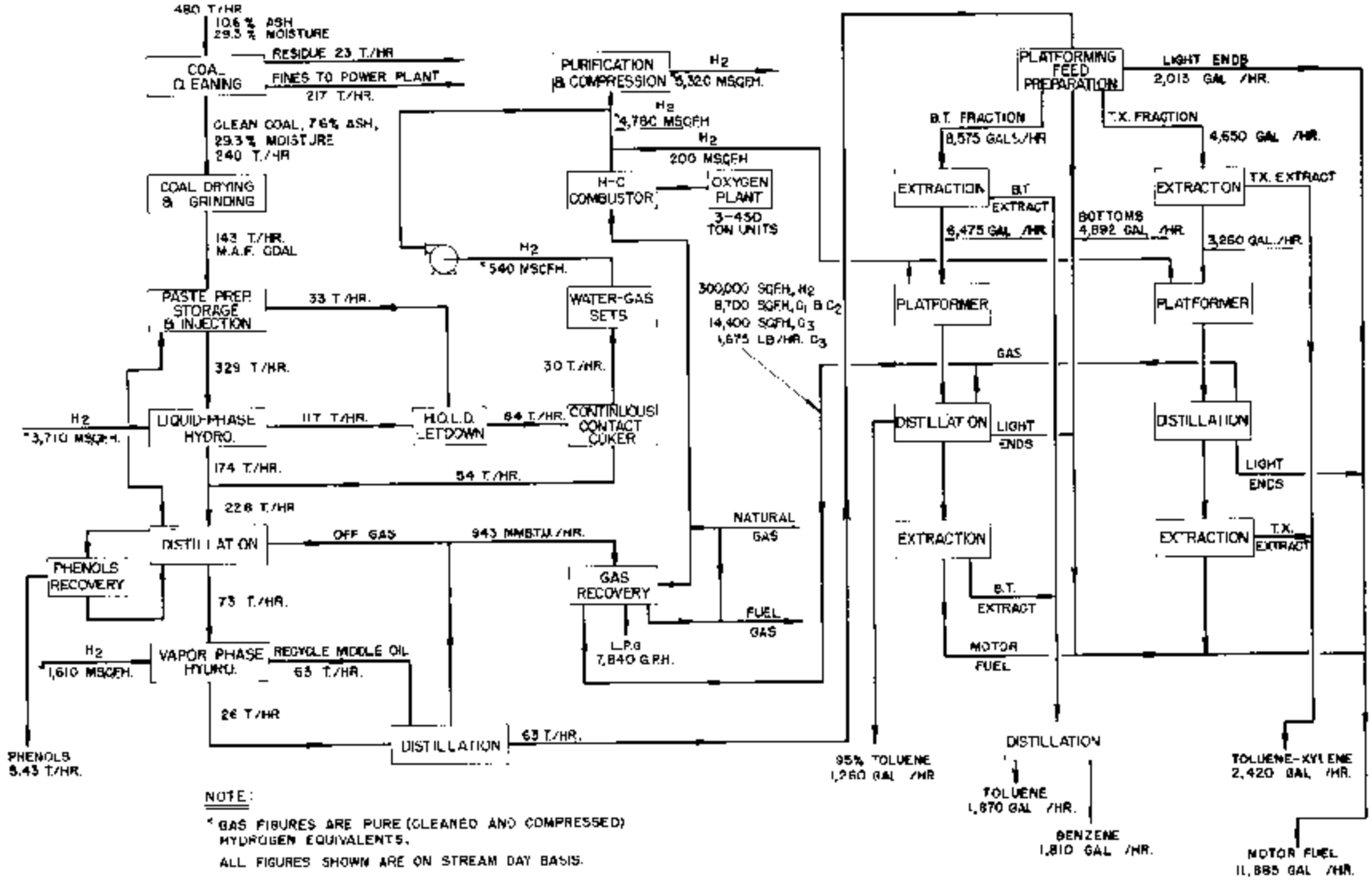
NOTE:

* GAS FIGURES ARE PURE (CLEANED AND COMPRESSED) HYDROGEN EQUIVALENTS.

ALL FIGURES SHOWN ARE ON STREAM DAY BASIS.

Figure 23. - Flow diagram of 75,000-barrel-per-calendar-day coal-hydrogenation plant.

213668 O - 52 - 7

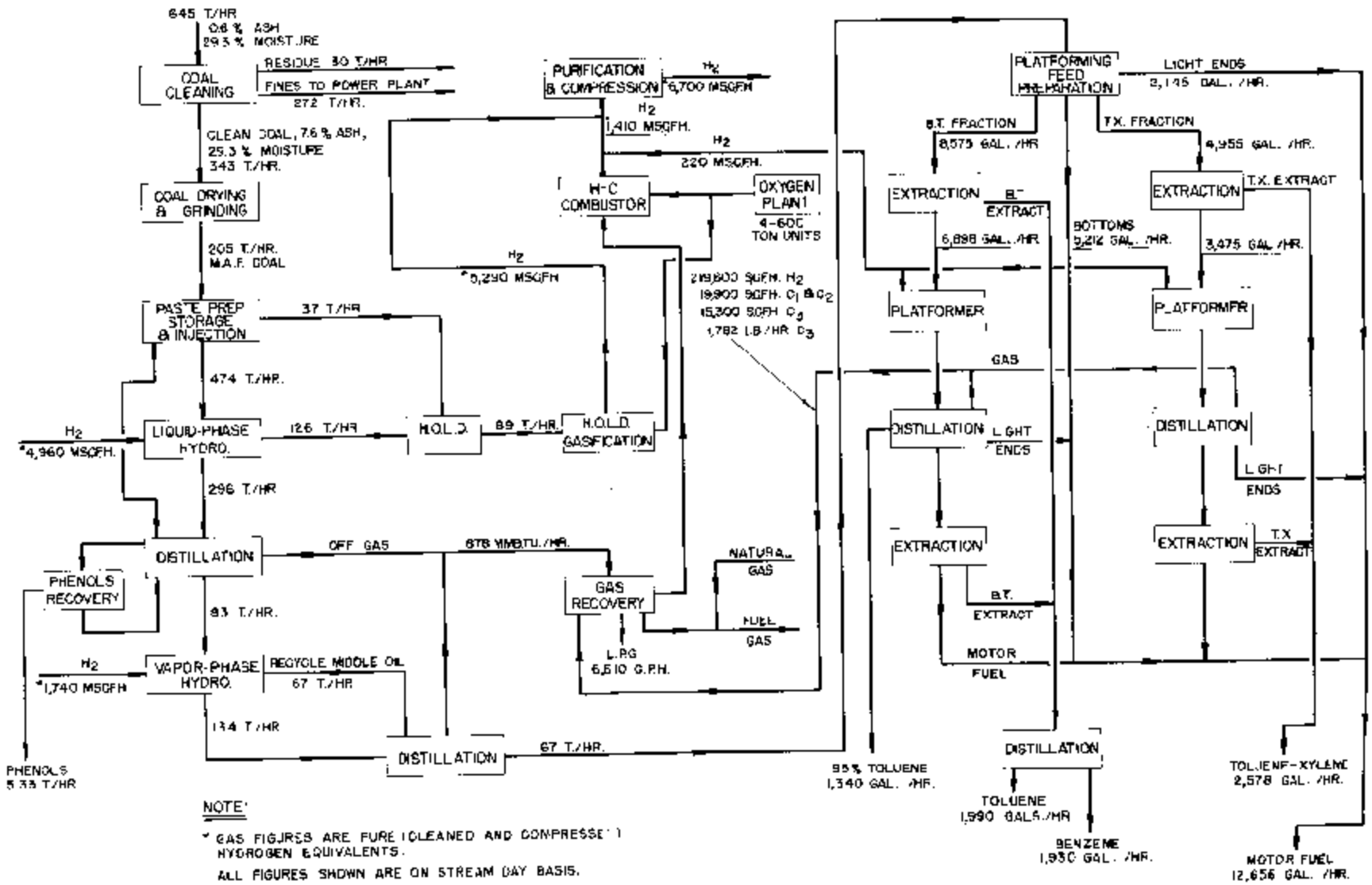


NOTE:

* GAS FIGURES ARE PURE (CLEANED AND COMPRESSED) HYDROGEN EQUIVALENTS.

ALL FIGURES SHOWN ARE ON STREAM DAY BASIS.

Figure 24. - Flow diagram of Northern Wyoming 15,000-barrels-per-calendar-day coal-hydrogenation plant: hydrogen produced from nuclear gas.



NOTE:

* GAS FIGURES ARE PURE (CLEANED AND COMPRESSED) HYDROGEN EQUIVALENTS.

ALL FIGURES SHOWN ARE ON STREAM DAY BASIS.

Figure 25. - Flow diagram of Northern Wyoming 15,220-barrel-per-stream-day coal-to-gasoline plant producing hydrogen produced by gasification of H.O.L.D.

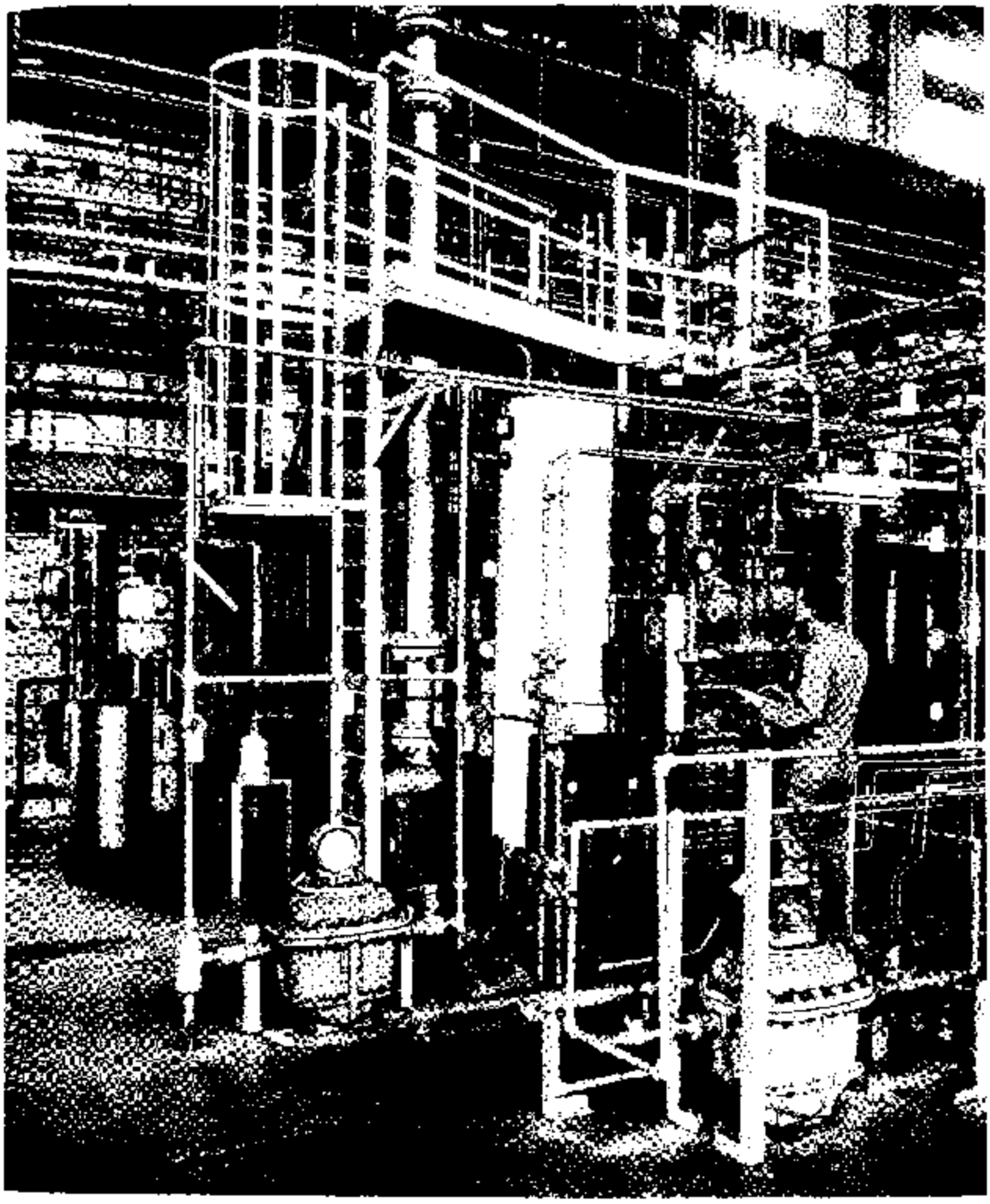


Figure 28. • Barrel-per-day Fischer-Tropsch plant.

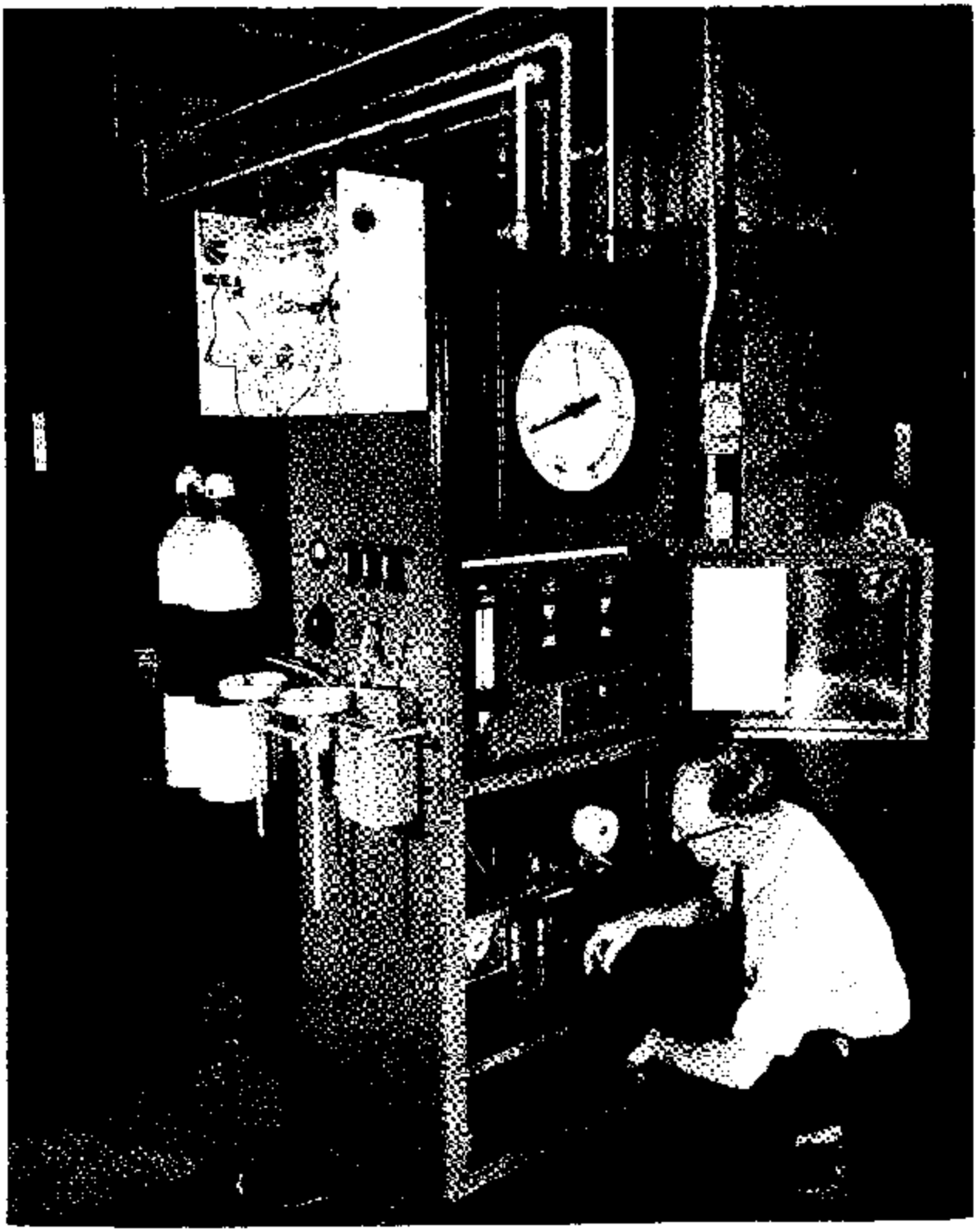


Figure 29. - Hydrogen sulfide analyzer.

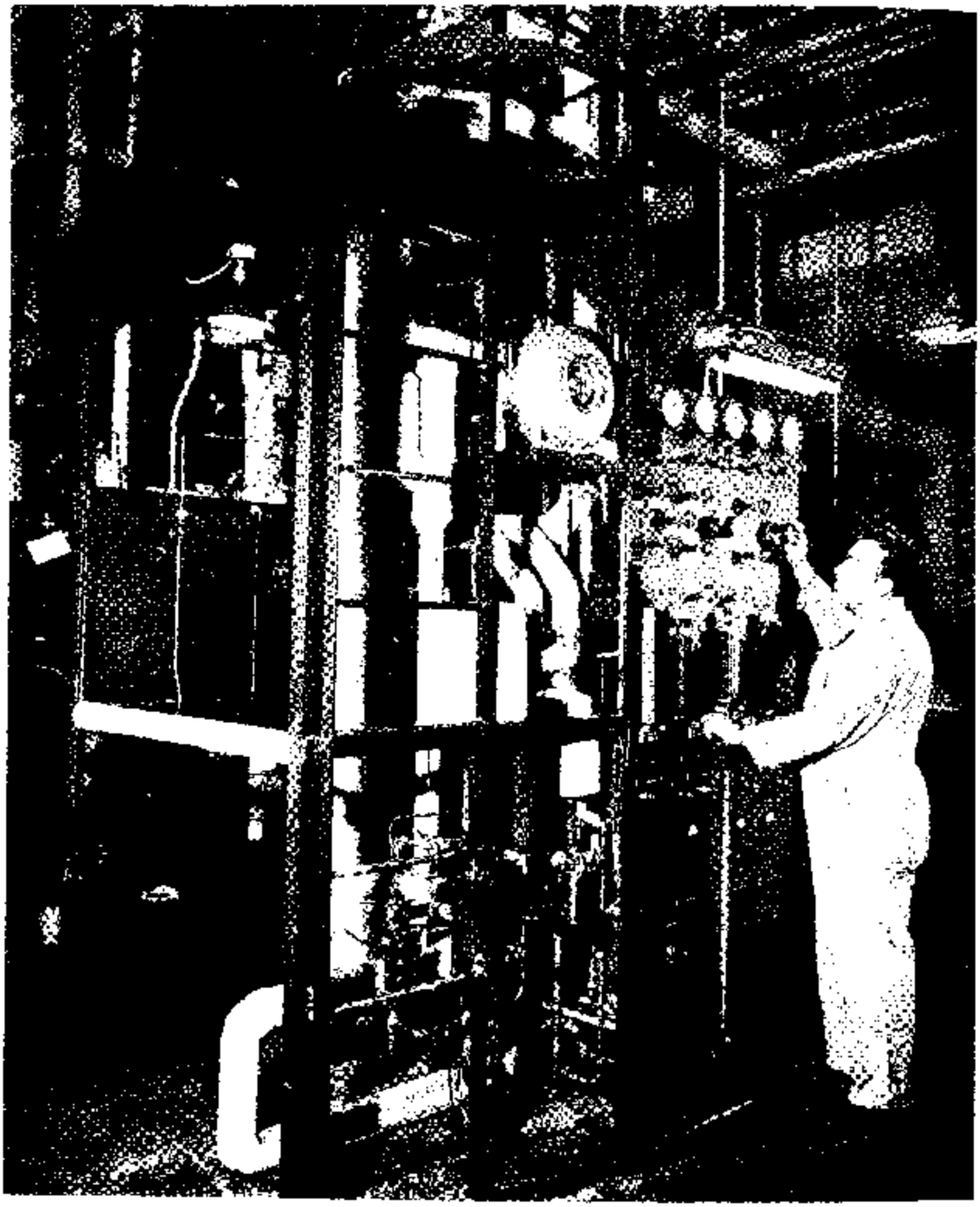


Figure 30. - Unit for fluidized Fischer-Tropsch process.

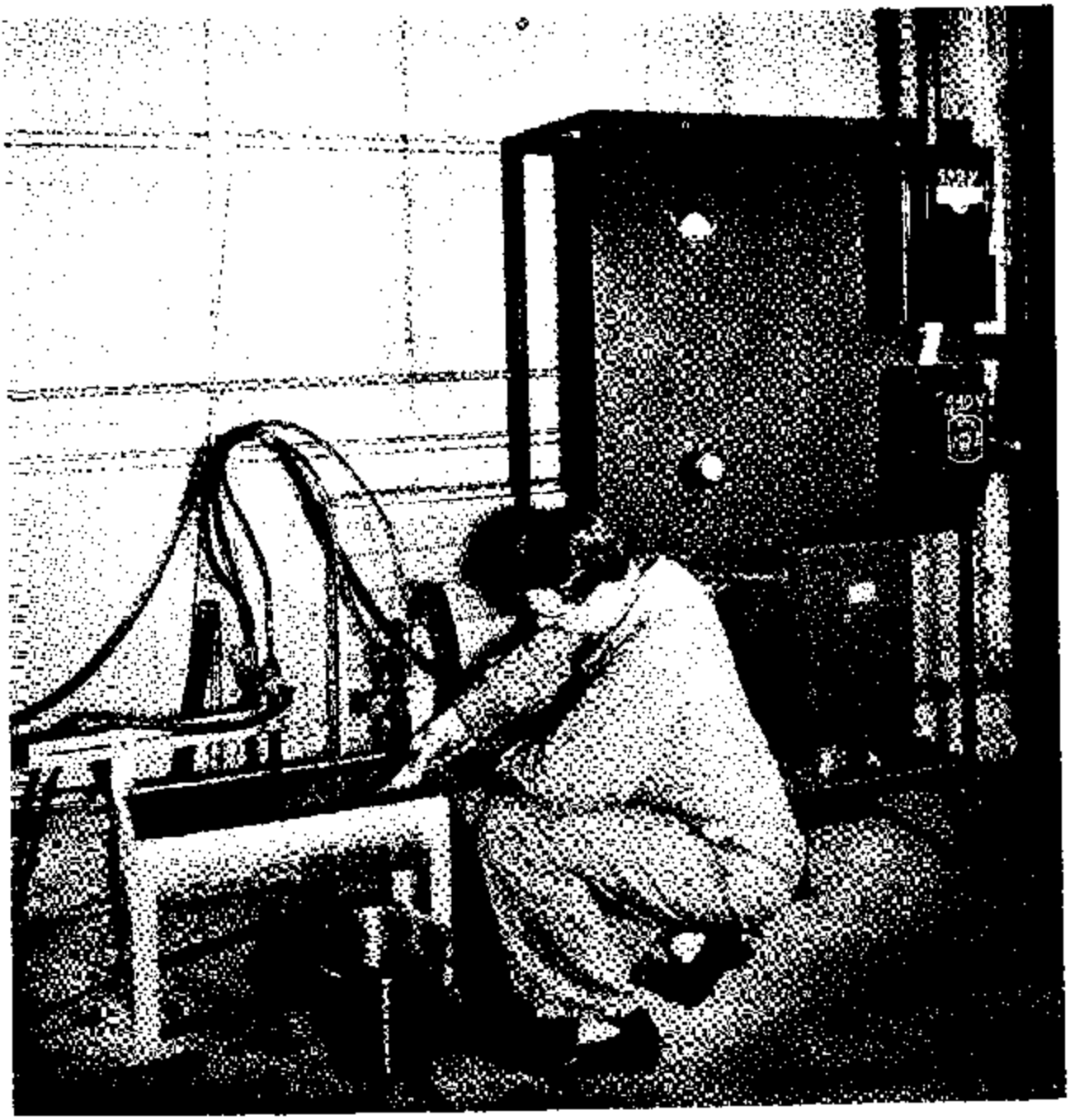


Figure 31. - Small fusion unit.