SYNTHESIS GAS FROM COAL PILOT PLANTS, MORGANTOWN, W. VA., AND FIELD TESTS, GORGAS, ALA.

Experimental Development of Processes for Producing Synthesis Gas from Coal

Synthesis gas, consisting essentially of carbon monoxide and hydrogen, is a chemical intermediate that can be used for producing synthetic liquid fuels, ammonia, alcohol, and pipeline gas. The cost of synthesis gas is a major part of the total cost of gasoline produced from coal. To reduce it, intensive process development has been conducted on further improvements in gasification of pulverized coal in oxygen and steam at Morgantown, W. Va.

Field-scale experimentation in the production of synthesis gas by underground gasification of coal has been continued at Gorgas, Ala., in cooperation with the Alabama Power Co.

The new Morgantown Experiment Station is under construction and will afford improved facilities for process-development work in coal gasification.

Pulverized-Coal-Gasification Pilot Plants, Morgantown, W. Va.

Operation of the pulverized coal gasification pilot plants at Morgantown, W. Va., during the past year has brought nearer the realization of lower cost processes for producing synthesis gas commercially. Pioneer work with the high-pressure gasifier has shown that very large capacities may be obtained in the pressure range 300 to 450 p.s.i.g.

Coordinate work on the atmospheric-pressure gasifier, designed and built in cooperation with the Babcock & Wilcox Co., has shown that satisfactory units can be constructed which will give economical material requirements per unit of synthesis gas produced. This is the first gasifier known to operate on entrained pulverized coal with a practicable system for removing the ash as molten slag. This development of a practical system for removing molten slag particles from the gas in such a way as to permit economical waste heat recovery from the make gas has constituted a major step in developing low-cost coal gasification.

Atmospheric-Pressure Gasifier

Construction of the low-pressure gasifier (Morgantown-Babcock & Wilcox gasifier design 4) was completed early in 1951. This pilot plant, shown in figure 42, has been operated for over 30 test runs. Since the original installation, several important modifications have been made in the gasifier. To secure satisfactory life of equipment and refractories, cooling coils have been placed around the inner wall of the primary zone and between the primary and secondary zones to serve as supports for the upper brickwork. A number of reactant injector-nozzle designs have been tried, the one now in use (see fig. 43) being an adaptation of a design found very satisfactory in the high-pressure gasifier.

Coal from the pneumatic feeder is introduced into central space A, after being preheated to about 325° F. in a coil heater with steam. The steam-oxygen mixture at 600° F. is introduced into space B and directed into the coal stream through orifice ports as shown.

The nozzle orientation is such that cool streams enter the gasifier on a 32° angle from the vertical and tangential to a 20-inch-diameter circle.

The flow sheet for this pilot plant is shown in figure 44.

By removing a small amount (10 to 15 percent) of the make gas through the slag throat a continuous flow of molten slag into the slag pot is obtained. In this unit approximately 40 percent of the ash in the coal is taken out as a slag containing virtually no carbon. The remainder of the ash is carried out of the top of the gasifier in a finely divided state. This material contains about 60 percent carbon and does not show any tendency to build up on the cooling coils in the upper section of the unit.

The raw gas is scrubbed with water and then put through a wet-type Cottrell precipitator for final clean-up. The gas is then flared or piped to the holder for further experimental work on sulfur removal.

The experimental work on this unit has been limited to date to gasification experiments, using Sewickley-bed coal from Monongalia County, W. Va., ground to 70 percent through a 200-mesh screen, all through a 20-mesh screen. A typical analysis of this coal as used is given in table 22.

TABLE 22. - Chemical analysis, calorific value, and ash fusibility of Sewickley coal used in pilot-plant operations (Typical analyses, not from a specific sample).

Coal analysis, as-fired basis, percent					
Proximate		Ultimate		Calorific value	B.t.u./lb.
Moisture.........	1.5	H_2.............	5.0	Gross	12,610
V.M..............	34.5	C..............	70.0	Net	12,120
F.C..............	50.5	N_2.............	1.5	Ash fusibility	Temperature, °F.
Ash..............	13.5	O_2.............	7.5	Initial deformation	2,171
		S..............	2.5	Softening	2,248
		Ash............	13.5	Fluid	2,329

Screen analysis, mesh	Percent
+50..................	0.2
-50 + 100...........	4.0
-100 + 140...........	10.0
-140 + 200...........	14.0
-200.................	71.8

Table 23 presents some average results from operation of this gasifier.

During the early tests on this gasifier, the refractory used was B. & W. No. 80 firebrick, backed up by its K30 insulating brick. It was not expected that this relatively low cost brick would give very long service. However, except where directly impinged on by coal-oxygen streams, it has served very well. For the last two tests made, a lining of B. & W. Allmul backed by K30 insulating brick has been used. As other operating variables are stabilized, it is intended to try other refractories. The program will also be extended to test a wide range of fuels as regards rank, ash-fusion temperature, and sulfur content.

It has been found possible to test various items of equipment that can be adapted to high-pressure apparatus on this low-pressure unit. The low-pressure process itself will have application in those plants, now using $CO + H_2$ mixtures in various synthetic processes, where gas-compression equipment is available.

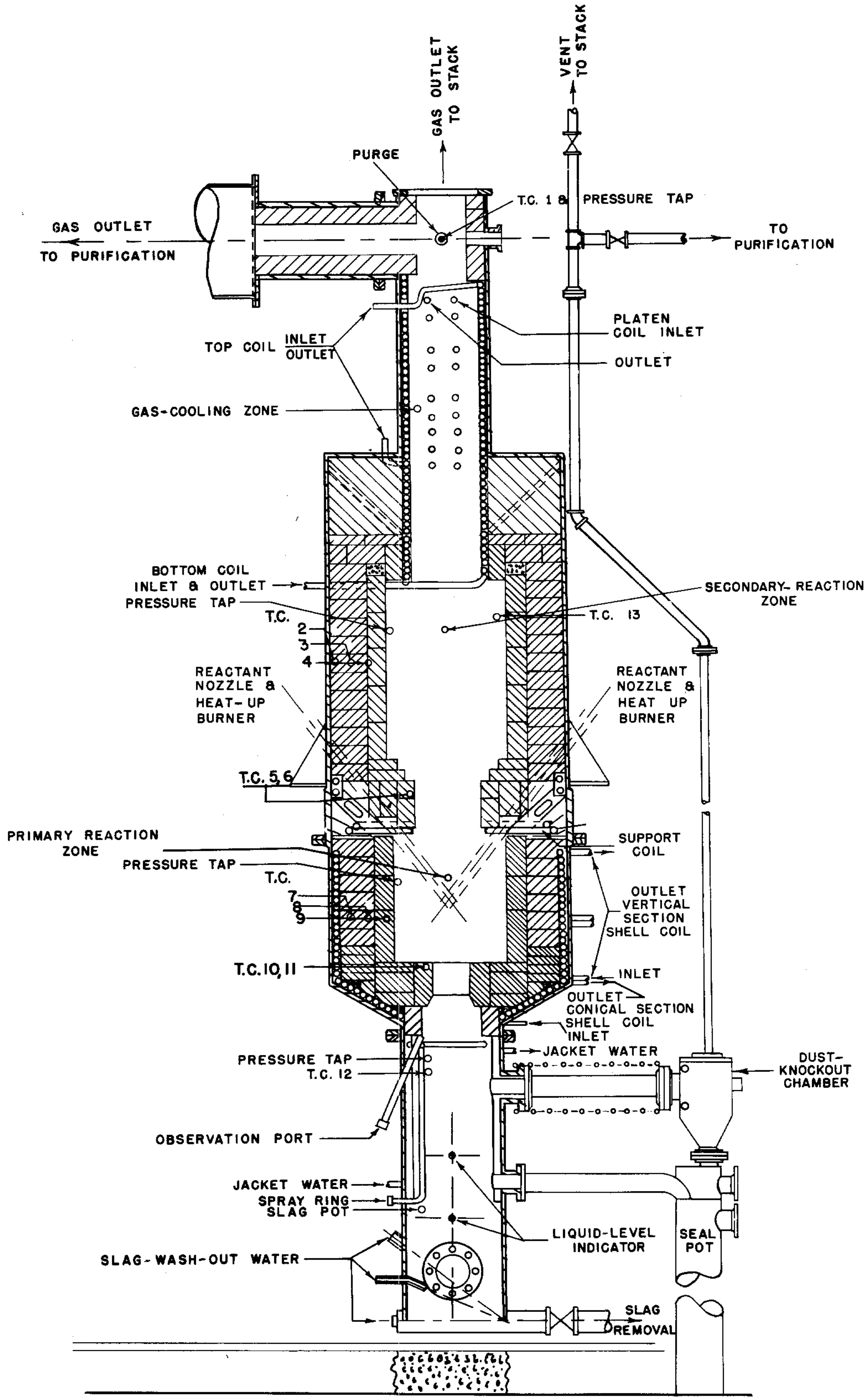
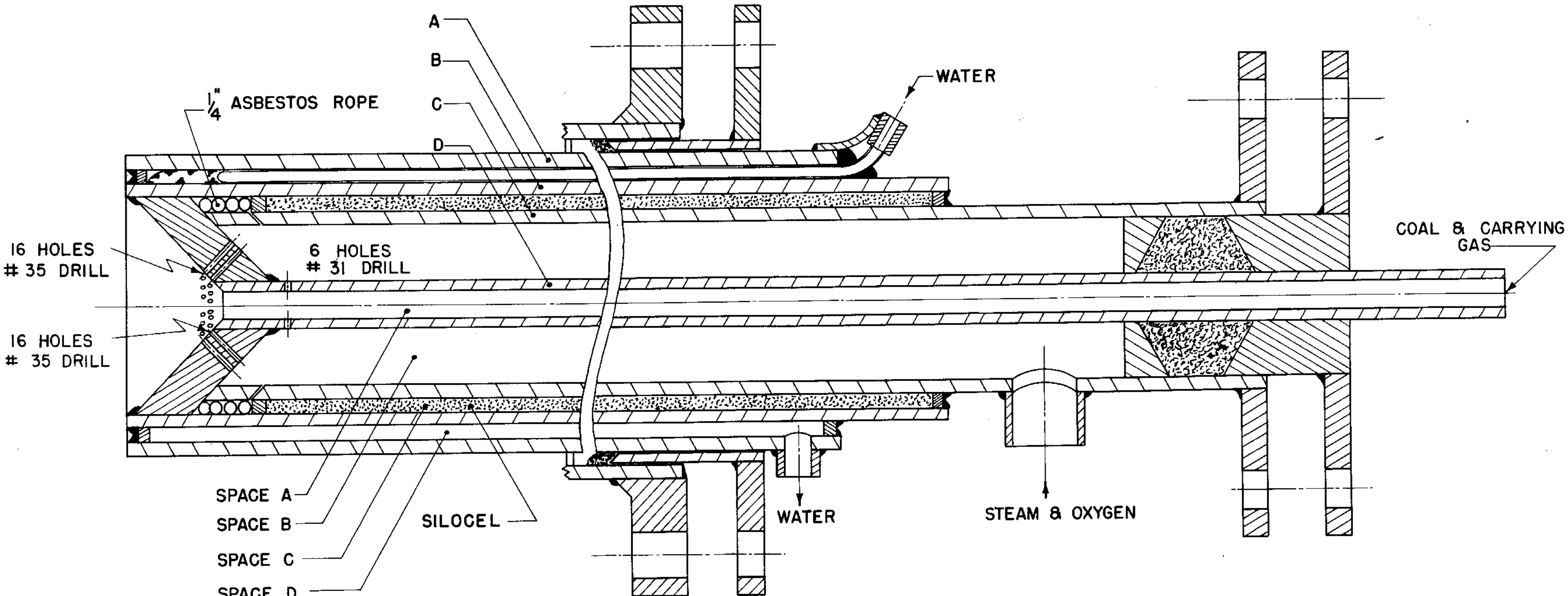


Figure 42. - Atmospheric-pressure gasifier design 4.



TUBE	I.D.	O.D.	MATERIAL	No.
A	5.047"	5.563"	5" S.S. PIPE	SCH 40
B	4.026"	4.500"	4" S.S. PIPE	SCH 40
C	3.390"	3.500"	3 1/2" BWG TBG.	18
D	.622"	.840"	1/2" S.S. PIPE	SCH 40

Figure 43. - Reactant injection nozzle for gasifier 4.

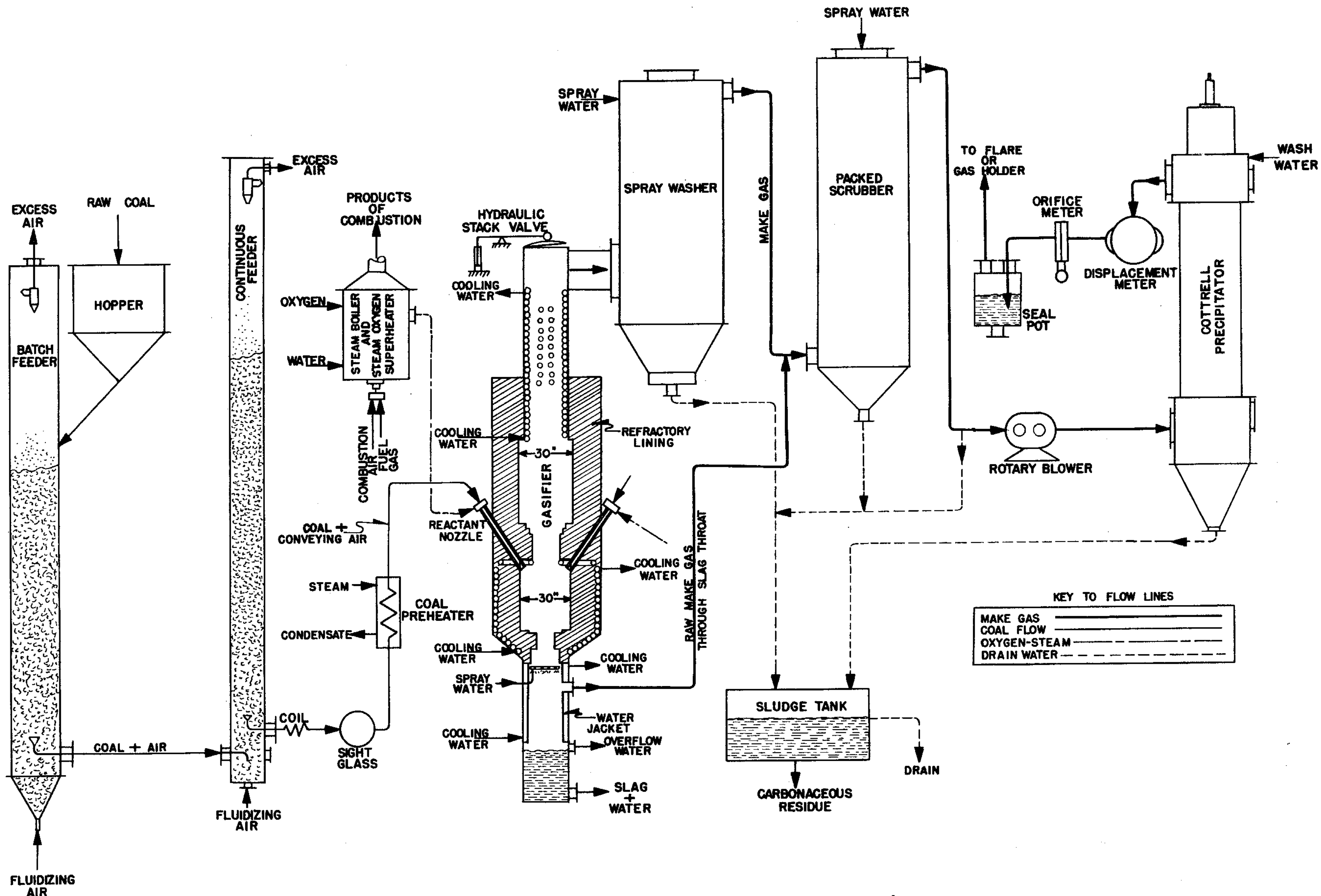


Figure 44. - Pilot-plant flow sheet for atmospheric-pressure gasification.

TABLE 23. - Typical performance of atmospheric-pressure gasifier operating at various coal-feed rates, using Sewickley-bed coal

Run No.	21	31	29	18
Duration of run....hours	7.00	6.50	10.75	2.50
Raw-coal rate....lb./hr.	355	407	514	598
Process steam-inlet temperature.... °F.	618	563	572	594
Process oxygen-inlet temperature.... Do.	618	563	572	594
Coal-inlet temperature.... Do.	300	304	285	287
Oxygen input per pound of coal....std. cu. ft.	9.05	8.33	8.28	7.83
Steam input per pound of coal....lb.	0.79	0.39	0.43	0.56
Product-gas analysis (corrected for inert gas introduced with coal), percent:				
CO_2	17.4	12.7	13.0	14.5
Illuminates	.4	.5	.7	.4
H_2	39.5	36.5	37.4	39.1
CO	40.5	49.1	47.7	42.6
CH_4	.4	.4	.4	.5
H_2 + CO....std. cu.ft./hr.	9,060	10,480	12,570	13,720
Total carbon gasified....percent	84.6	83.4	80.2	73.0
Coal required per M cu. ft. of (H_2 + CO)....lb.	39.2	38.8	41.0	43.6
Oxygen required per M cu. ft. of (H_2 + CO)....std. cu. ft.	355.	323.	340.	341.
Process steam input per M cu. ft. of (H_2 + CO)....lb.	30.9	15.3	17.6	24.3

The operating conditions that determine the cost of the raw materials (coal and oxygen) per 1,000 cu. ft. of product (carbon monoxide and hydrogen) are the ratios of oxygen to coal and of steam to coal. Over the range of operating conditions used in the tests (about 8 to 10 cu. ft. of oxygen per pound of coal and 0.4 to 1 lb. of steam per pound of coal), it has been found that there is essentially no variation of the materials cost with variation in the oxygen - coal ratio; that is, as the oxygen - coal ratio is increased, the coal requirement decreases, but the oxygen requirement increases to such an extent that the raw-materials cost is virtually unchanged. The raw-materials cost has been found to decrease, however, as the steam - coal ratio is decreased, the lowest materials costs being obtained at the lowest steam - coal ratios used in the tests. However, at low steam - coal ratios, refractory life is shorter, so that a balance is required between refractory life and raw materials cost to produce the lowest-cost synthesis gas.

High-Pressure Gasifier

In virtually all gas-synthesis processes (for example, ammonia, methanol, liquid fuels, and pipeline gas) the synthesis gas is used at pressures of 300 p.s.i.g. and higher. A very large savings in cost of product is possible if the synthesis gas can be generated under pressure, since compression costs are reduced about two-thirds. These savings can be realized if the capacity of gasifiers operating at pressures in the 500 p.s.i.g. range are large enough to offset the increased cost of apparatus. Theoretical considerations indicated that this was possible, and the gasifier now being operated at Morgantown was built to study design factors, including the effect of pressure generation on throughputs of reactants per unit of gasifier volume. The results obtained to date have shown that these capacities are very large. At 450 p.s.i.g., over 800 pounds of Sewickley-bed coal per hour per cubic foot of gasifier volume has been gasified at satisfactory raw-materials requirements. Recent tests have demonstrated that the reaction is substantially completed in the refractory-lined space. This volume is approximately 1.45 cu. ft. This is to be compared to throughputs of 10 to 20 pounds of coal per hour per cubic foot of gasifier volume at pressures under 2 p.s.i.g. Although there are a large number of subsidiary design and operating factors to be determined, it is evident that such capacities make the pressure process very attractive.

Figure 45 shows some data on throughput and pressure. While the throughputs shown may not be the optimum or the maximum possible at the given pressures, still the data show that at least these throughputs were practicable in this gasifier under the experimental conditions used. In general, it appears that the throughputs are so high at the higher pressures that any further increases would not result in significant savings.

The gasifier itself as now operated is shown in figure 45 A. Table 24 shows typical performances of the pressure gasifier. The low materials requirement per unit of synthesis gas made promises low-cost synthesis gas on a commercial scale. For example, if a coal cost of $4.00 per ton and an oxygen cost of 20 cents per 1,000 cu. ft. are assumed, the materials cost for the runs shown would be about 14 cents per 1,000 cu. ft. of carbon monoxide and hydrogen produced. If a waste heat boiler is used, a net steam credit would lower this 14-cent value somewhat. These low materials costs plus high throughputs, which will lower fixed charges per unit of synthesis gas made, indicate lower-cost synthesis gas in the near future.

TABLE 24. - Typical performances of pressure gasifier operating at pressures of 100, 250, 300, and 450 lb. per sq. in. on pulverized, Sewickley-bed coal

Run No.	14	17	23	30
Gasifier pressure ... p.s.i.g.	100	250	300	450
Duration of run ... hr.	10.0	7.2	5.2	4.0
Raw coal rate ... lb./hr.	463	588	869	1,120
Process-steam inlet temperature ... °F.	931	1,132	660	627
Process-oxygen inlet temperature ... Do.	60	58	660	627
Coal inlet temperature ... Do.	327	310	315	246
Oxygen input per pound coal ... std. cu. ft.	9.22	9.35	8.83	9.84
Steam input per pound coal ... lb.	0.30	0.28	0.28	0.33
Product-gas analysis (corrected for inert gas introduced with coal and at gasifier sight glass), percent:				
CO_2 ...	7.1	7.9	8.5	10.4
Illuminants ...	.5	.7	.6	.5
H_2 ...	34.4	33.9	34.4	32.9
CO ...	55.4	54.9	53.6	53.4
CH_4 ...	.4	.5	.6	.7
H_2 + CO ... std. cu.ft./hr.	12,870	16,120	23,160	31,180
Total carbon gasified ... percent	87.8	87.9	87.4	92.4
Coal required per M cu. ft. (H_2 + CO) ... lb.	36.0	36.5	37.5	35.9
Oxygen required per M cu. ft. (H_2 + CO) ... std. cu. ft.	333.	341.	331.	352.
Process steam input per M cu. ft. (H_2 + CO) ... lb.	10.9	10.2	10.5	11.8
Coal throughput/(hr.)(cu. ft. volume) ... do.	117	409	583	757

The pressure gasifier has been described fully in previous Annual Reports. Recent tests have indicated that the silicon carbide brick lining can be maintained for long periods of operation. Considerations of refractory life are important in experimental apparatus in the case of high-pressure gasification. For commercial-scale units, the throughputs will be so large that water-cooled walls, which will coat with slag, can be used without excessive loss of heat. The reactant injector nozzle is substantially the same as that shown in the 1951 Annual Report. The orifice ports for steam-oxygen injection are changed in size to maintain approximately constant injection velocities at the various operating pressures.

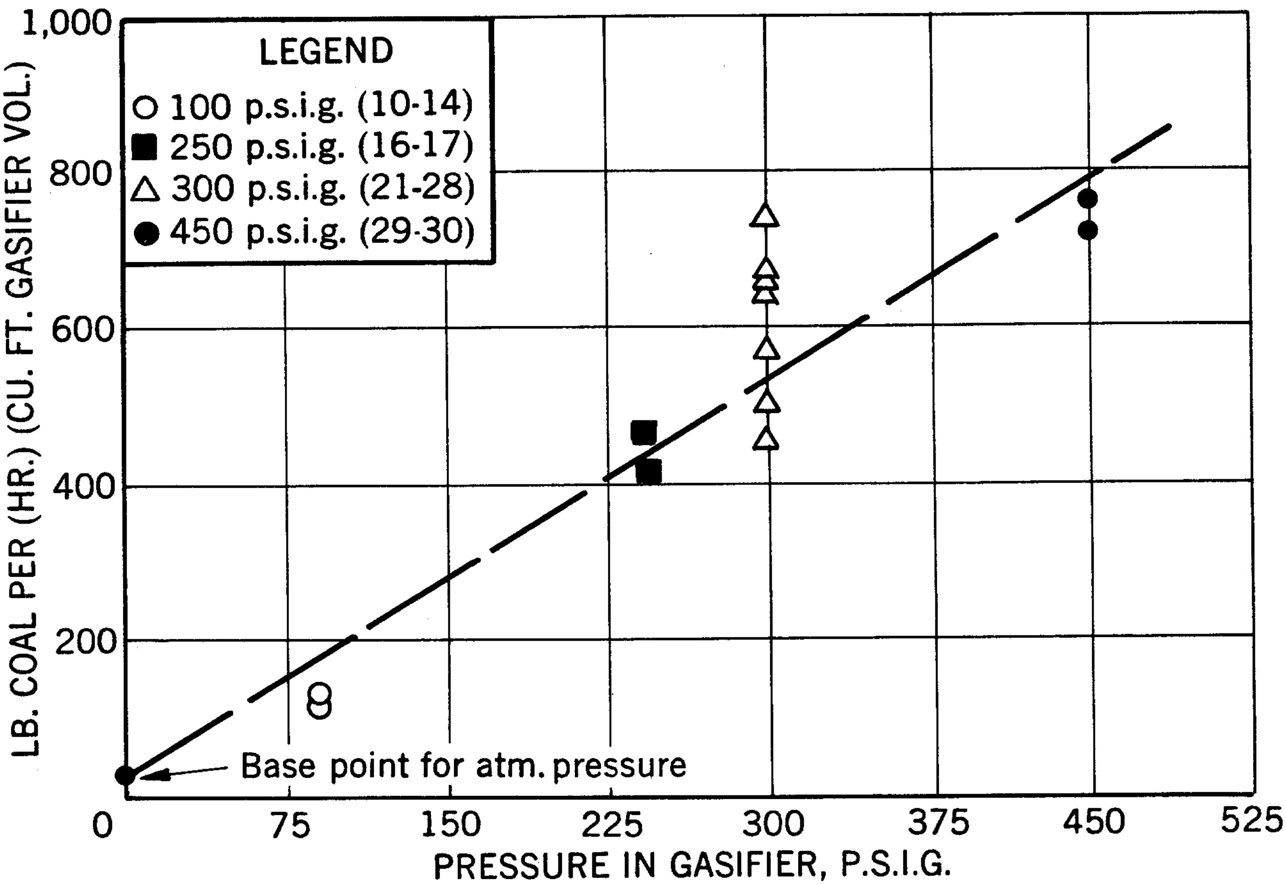


Figure 45. - Relation between gasifier pressure and coal throughputs.

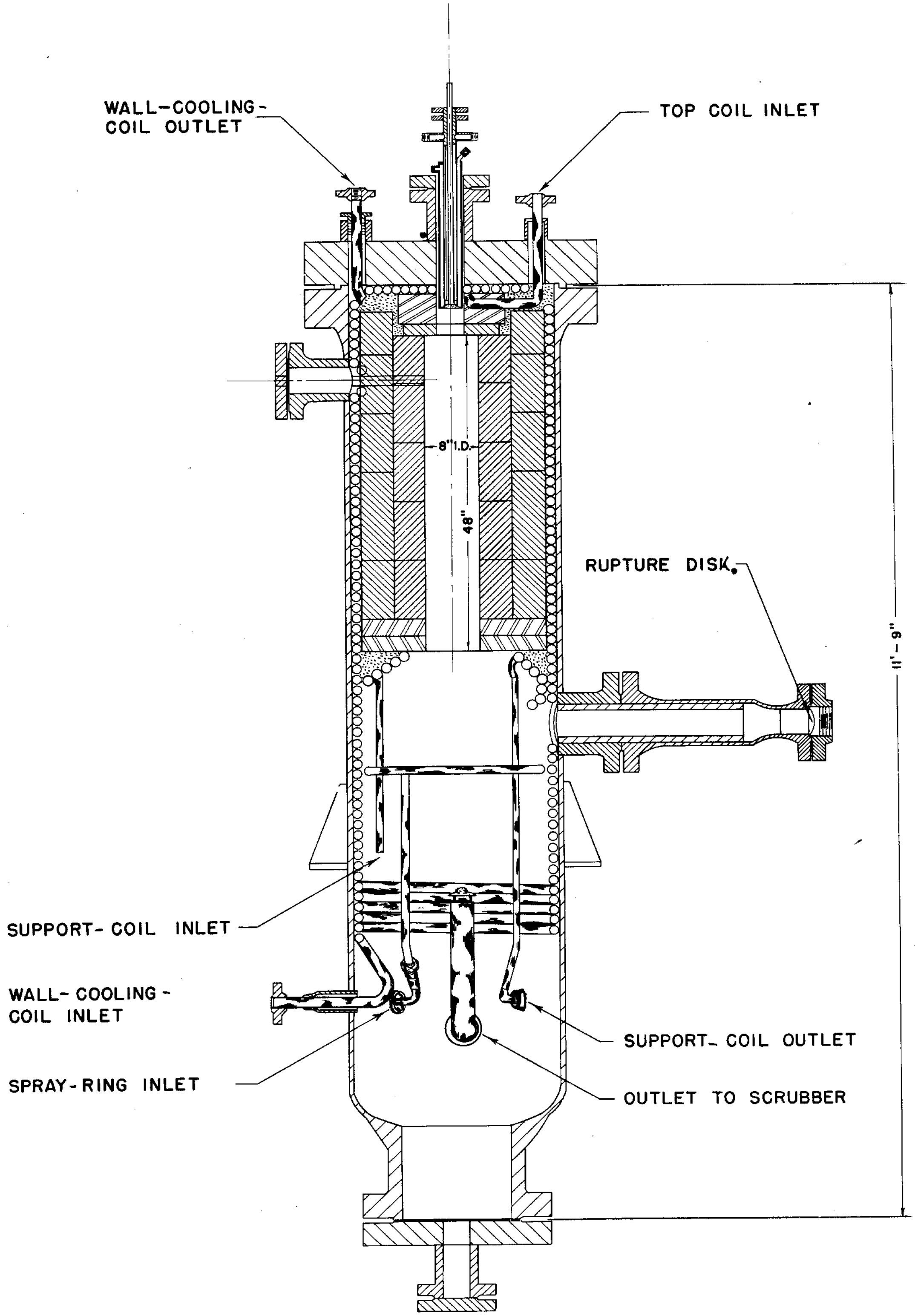


Figure 45A. - Reactor for pressure gasification.

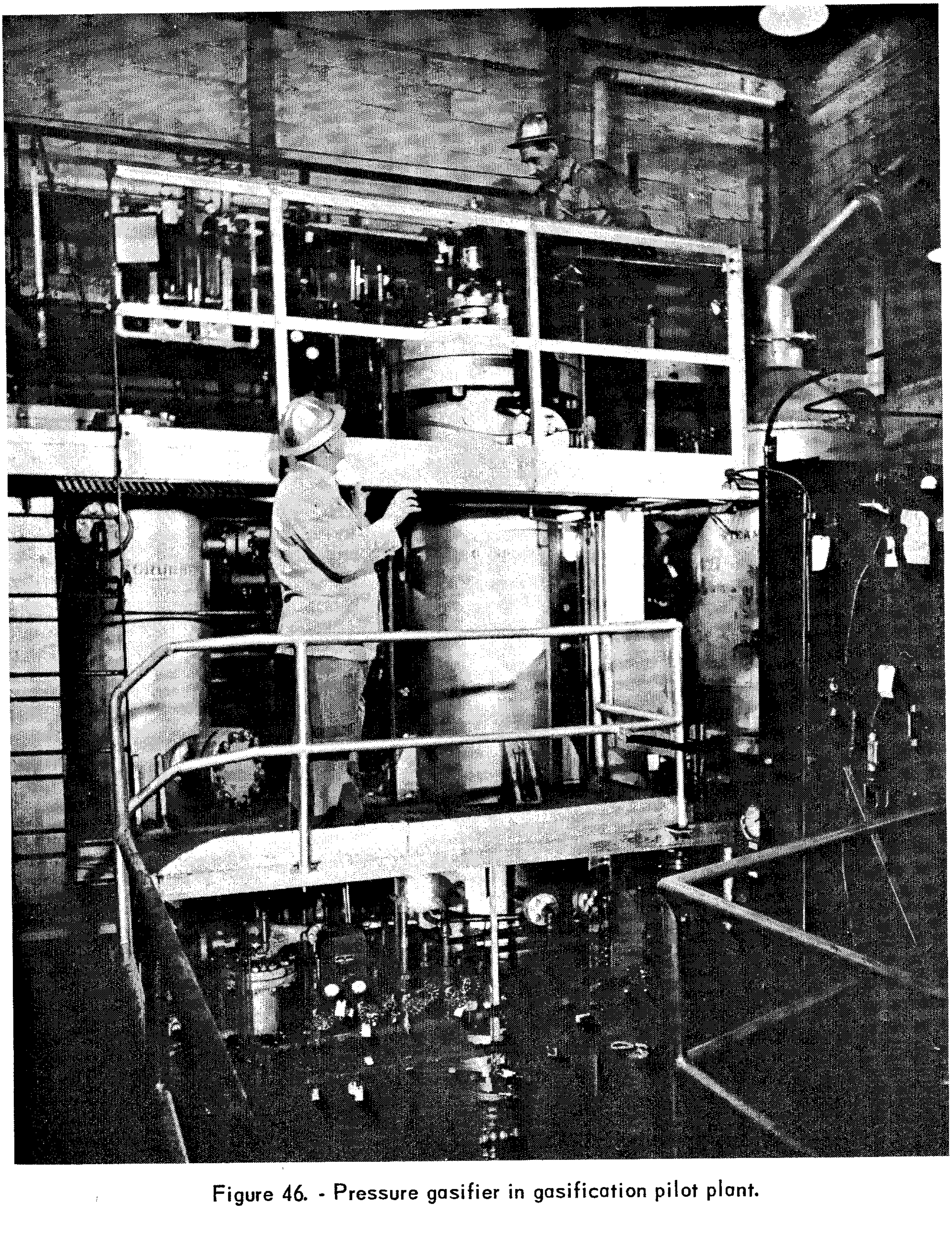


Figure 46. - Pressure gasifier in gasification pilot plant.

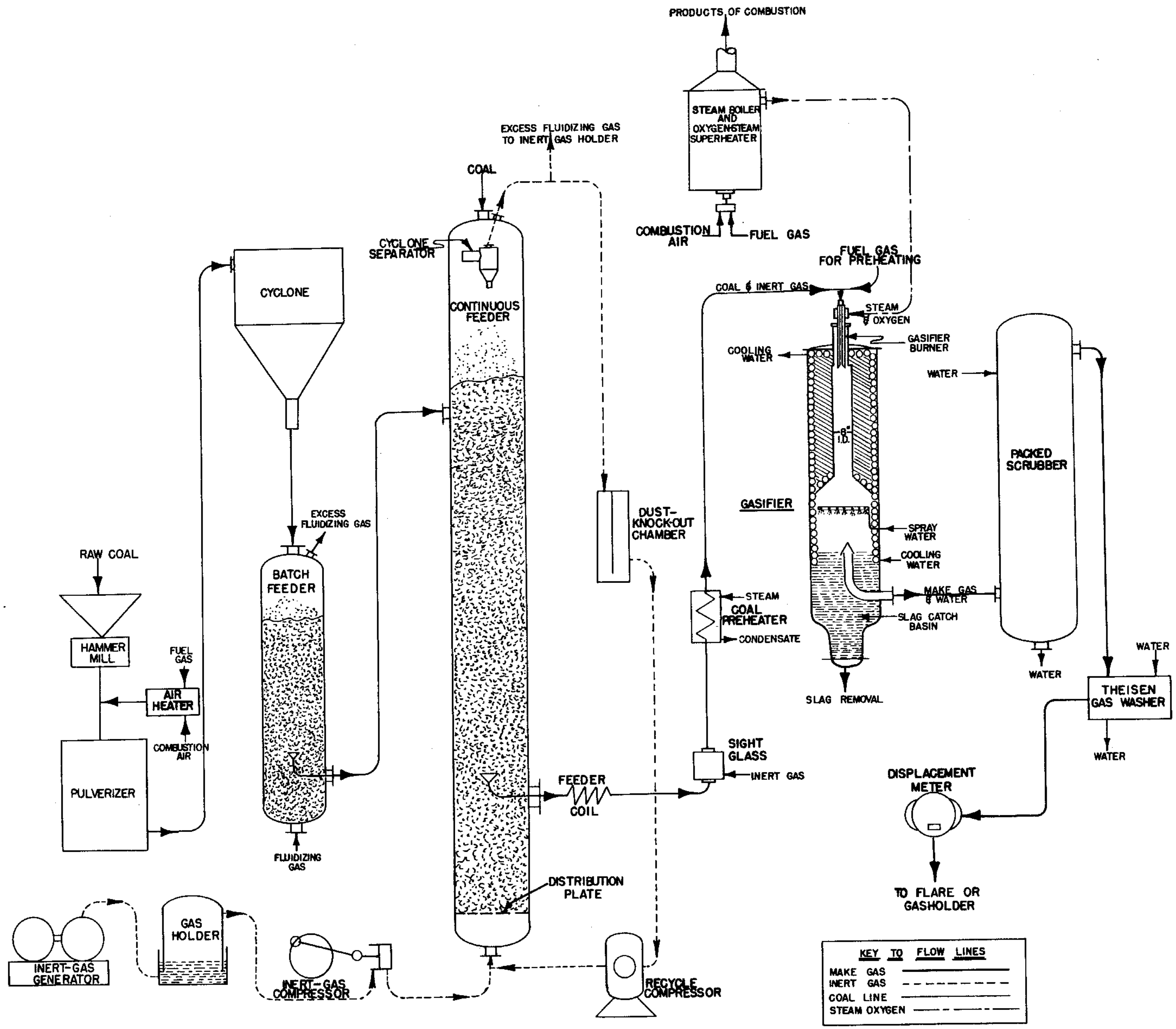


Figure 47. - Pilot-plant flow sheet for pressure gasification.

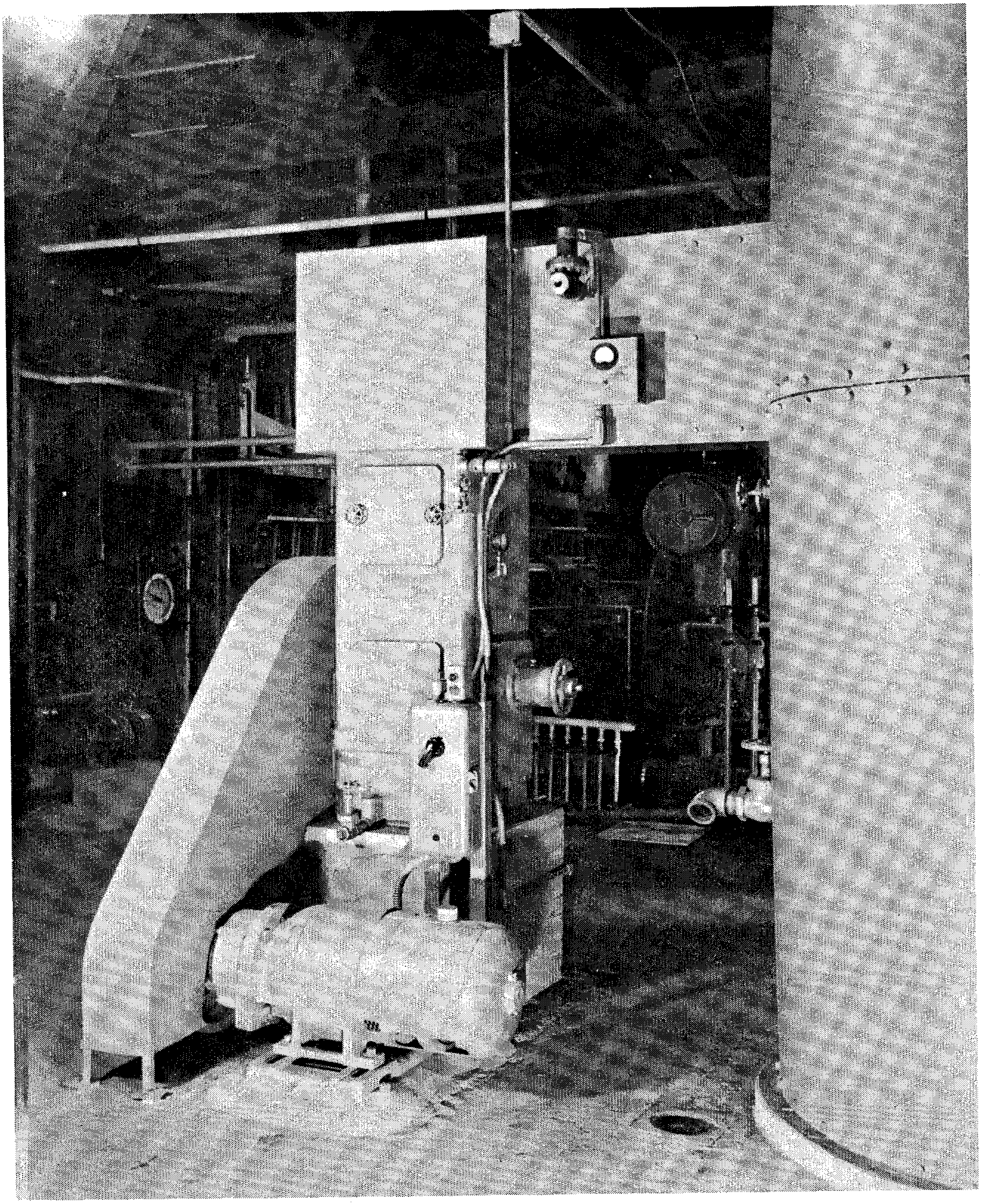


Figure 48. - Expansion engine in oxygen plant.

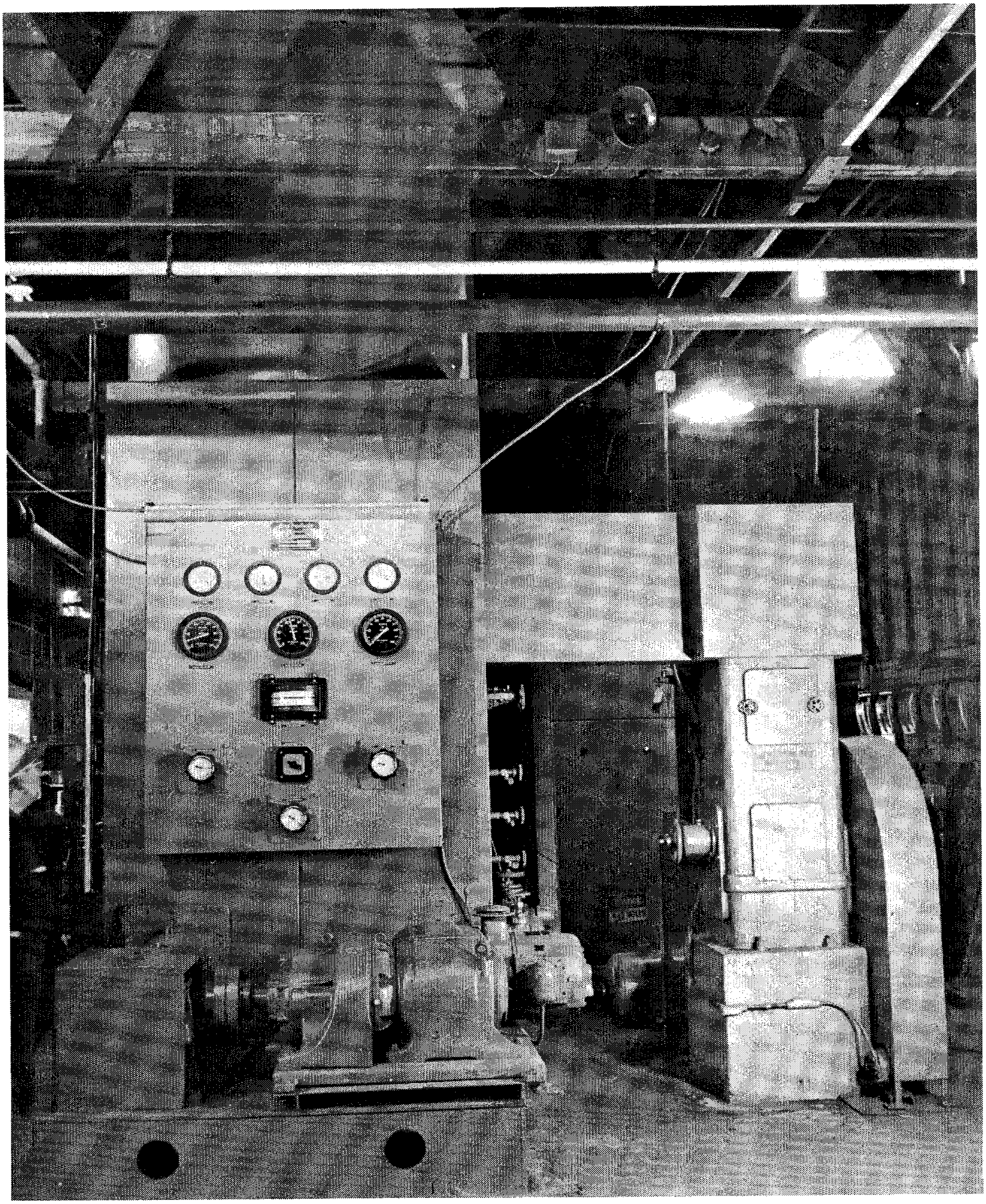


Figure 49. - Operating panel and oxygen pump in oxygen plant.

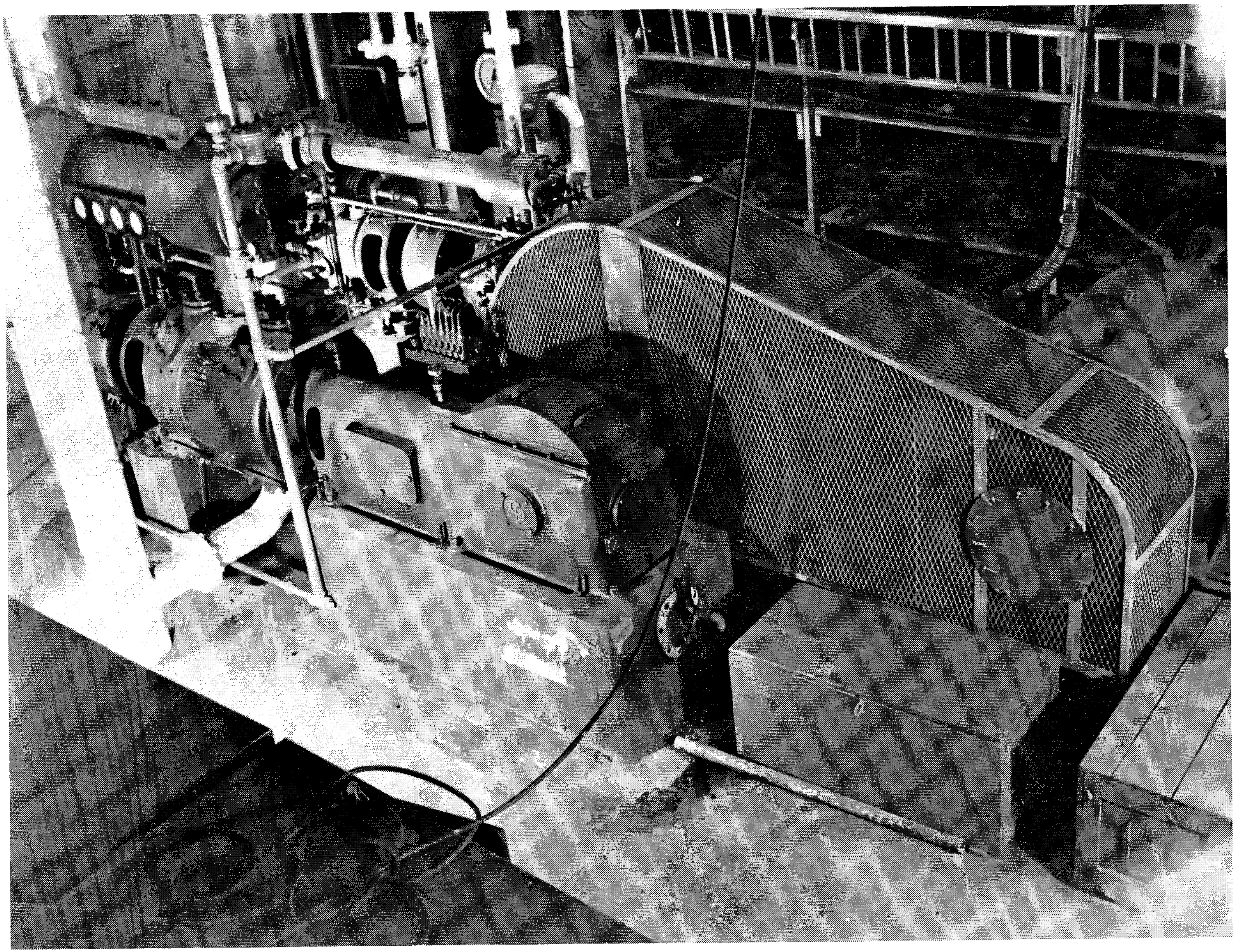


Figure 50. - 250-hp. air compressor in oxygen plant.

The general arrangement of the gasifier and auxiliary equipment is shown in figure 46, and a flow sheet for the pilot plant is given in figure 47.

Coal from a high-pressure pneumatic feeder is preheated to about 325° F. and introduced into the central tube of the reactant nozzle. Oxygen and steam preheated to 600° F. enter a tube, concentric with the coal tube and are directed into the coal stream substantially as in the case of the low-pressure gasifier nozzle. The raw gas containing slag and particles of partly reacted fuel leaves the refractory section and passes through a spray of water. The heavy slag particles drop out into the base of the gasifier and then into a slag pot, from which they can be removed periodically. The gas, fine carbonaceous particles, and cooling water go to the base of the scrubber. The fine dust is washed out here and leaves with the wash water through a let-down valve at the base. The scrubbed gas, after metering can be flared, or scrubbed further in the Theisen washer and taken to a gas holder for purification experimental work. In this unit about 20 percent of the ash is recovered as slag containing virtually no carbon. The remaining ash is found in the carbonaceous residue carried into the dust train. This material will vary in ash content from 40 to 50 percent. The slag and residues obtained by this method of operation do not appear to offer any particular problem as regards disposal. The scrubbing of the gas under pressure in the packed scrubber is very satisfactory - complete data on dust removal are not available, but some tests have shown the dust content of the gas leaving the scrubber to be under 0.30 grains per 100 cu. ft.

Oxygen Plant

An oxygen plant capable of producing 7,000 std. cu. ft. per hr. of 99.6 percent oxygen and 25,000 std. cu. ft. per hr. of 99 percent nitrogen has been installed. This plant was obtained from the Air Products Co., Inc. The heat exchange and rectifying equipment was loaned to the Bureau of Mines on a cooperative agreement. The air-compressing equipment was purchased outright (see figs. 48 and 49).

The plant is essentially a packaged unit with only four major pieces of equipment that had to be set up. These include:

1. The air compressor, a 630 cu. ft. per min. four-stage horizontal machine which will discharge up to 1,000 lb. per sq. in. gage (p.s.i.g.) (see fig. 50).

2. The air purifier, two caustic scrubbers in series with a mixing tank and circulating and transfer pumps.

3. The air drier, two tanks of activated alumina. One tank is on stream, while the other is regenerated with hot, dry nitrogen.

4. The air separator, an insulated cold box that houses the heat-exchange and rectifying equipment. The heat exchanger is a countercurrent recuperator design that is much simpler to operate than reversing exchangers. The rectifier is a modified Linde double column.

A novel feature of the plant is the liquid-oxygen pump. The liquid oxygen is withdrawn from the upper column, pumped up to the desired pressure (up to 2,000 p.s.i.g.), and then vaporized to gaseous oxygen in the heat exchanger.

Preliminary testing of the plant shows that the quantity and quality of both nitrogen and oxygen meet the guarantee.