RESEARCH AND DEVELOPMENT, SYNTHESIS-GAS LABORATORIES AND PILOT PLANTS, MORGANTOWN, W. VA., AND GORGAS, ALA.

Experimental Work on Synthesis-Gas Production

Fischer-Tropsch gasoline is expensive because of the high cost of synthesis gas made from coal. It is proving a major undertaking to develop a new coal-gasification process that will cut significantly the cost of synthesis gas for the Fischer-Tropsch process or the cost of hydrogen for the Bergius process. Extensive experimental programs are being carried out on all scales from laboratory to demonstration plant to evolve systematically but rapidly a new, successful, coal-gasification process. Operation of experimental gasification equipment furnishes data required for design of large plants and also discloses new problems requiring solution. All data are analyzed to point out methods of cutting costs.

The two gasification processes selected for major study and experiment are:

1. Gasification of finely pulverized raw coal, entrained in superheated steam containing oxygen.
2. Gasification of coal in place, underground.

Underground Gasification Project, Gorgas, Ala.

The underground gasification of coal is one of the processes that has been selected for both laboratory study and field-scale experiment. Successful application of this process would make available a source of energy for electric power generation and gaseous products suitable as the raw materials for synthetic-liquid-fuels manufacture. It offers a method of utilizing coal veins now difficult or uneconomic to mine, and it may be possible by the proper application of this process to recover the energy yet remaining underground in regions where the coal has been mined out. This would entail burning coal pillars left underground in old, worked-out mining operations.

During the calendar year 1949, construction of the second field-scale experiment in underground gasification was completed, and operation of the project was started (see fig. 52). Work during the first quarter of the year was confined to the completion of the project installation, and the final three quarters were devoted to operating. The construction and operation of the project were planned and supervised by Bureau of Mines engineers. Under a nonprofit contract with the Government, the Alabama Power Co. provided the personnel and equipment necessary for construction and operation. The Gorgas site, including the surface area and the underlying coal bed, was provided by the Alabama Power Co. without cost to the Government.

This experiment on underground gasification of coal is being conducted in a section of the Pratt coal bed isolated from the main body of the seam by natural terrain consisting of approximately 100 acres. The coal bed is 42 inches thick and relatively level. It lies under an average overburden of 150 feet. At the northern end of the project, the coal outcrop was squared up and an entry and air course were driven south for 1,240 feet. The entry and the air course are each 10 feet wide and are separated by a coal pillar 10 feet thick. Every 300 feet they are interconnected by means of crosscuts driven through the coal pillar. From the end of the double entry a single entry was continued for 350 feet, the last 50 feet being used as a sump for collecting water. At 300-foot intervals along the line of the underground development, a borehole was drilled from the surface to the underground passage.

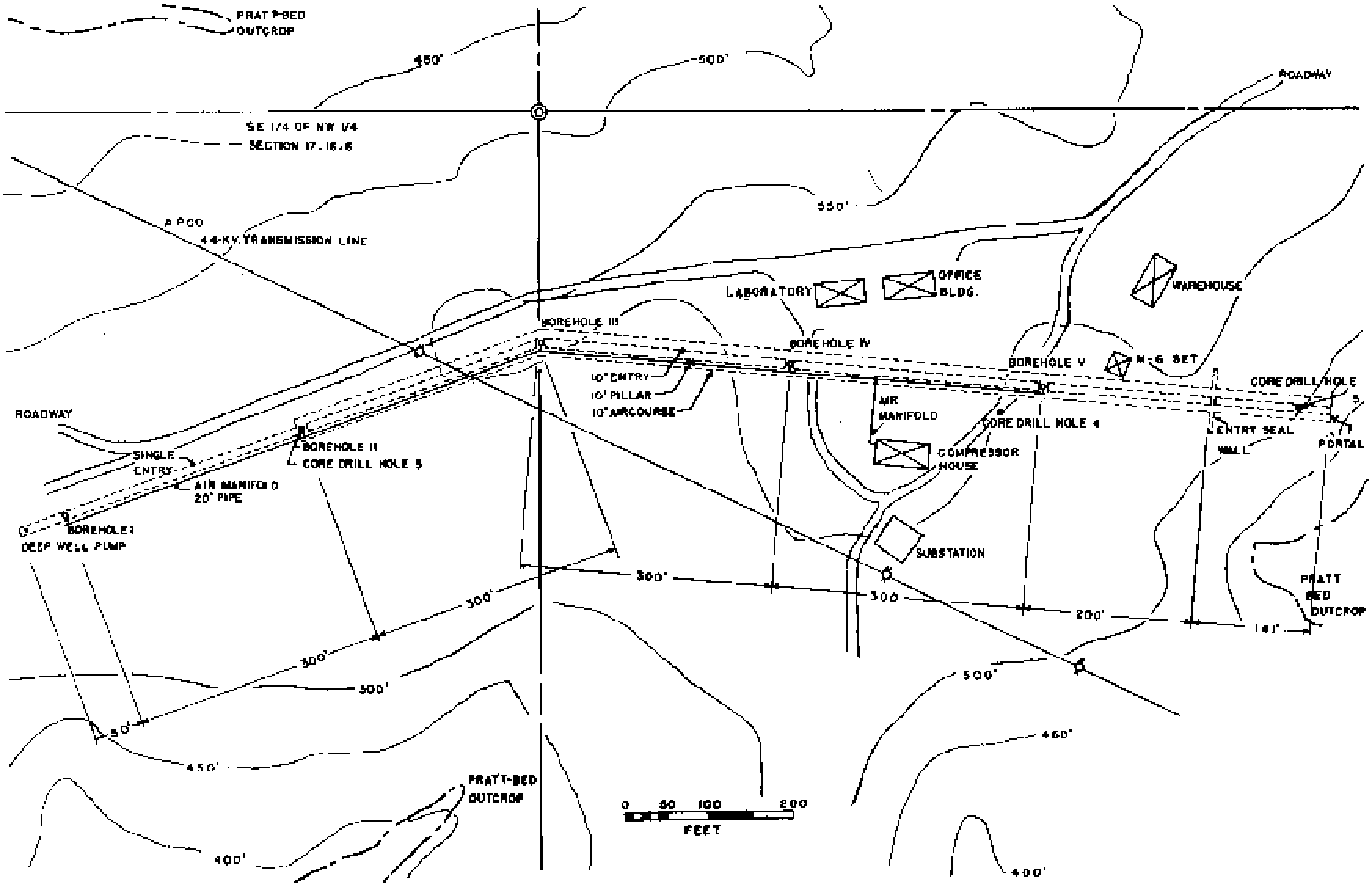


Figure 52. - Site of second experiment in underground gasification of coal.

Two of these boreholes are 18 inches in diameter and are unlined. Three of the boreholes were drilled 28 inches in diameter and fitted with a refractory lining 4 inches thick. Each of the boreholes is fitted with water-jacketed steel pipe as a surface connection either to a stack or the air manifold. One hundred forty feet in from the north outcrop a seal was constructed across the entry and the air course. A place was driven 4 feet wide and extending 25 feet beyond the outby ribs of the entry and the air course. Six feet of top rock and 2 feet of bottom rock were removed, and a 3-course fire-brick wall or seal 80 feet long and 12 feet high was constructed. This fire-brick wall was sealed by pressure grouting from the surface by means of 6-inch boreholes, was backed by steel buck stays and the residual opening in this 4-foot place then was filled with concrete. Twenty-four-inch-diameter outlet pipes were sealed in the wall in line with both the entry and the air course. These pipes can be utilized as gas outlets from the system or, as during the operation to date, they have been fitted with blow-out disks so that they will relieve pressure formed during any possible explosion underground.

On the surface a 20-inch steel pipe manifold (see fig. 53) has been constructed parallel to the line of the underground workings, and connecting the five boreholes with the air source located in the compressor house (fig. 54). The primary air supply for the project consists of a 7,900-c.f.m. reciprocating compressor (fig. 55) with a maximum discharge pressure of 30 pounds per square inch gage. Two standby compressors have been installed, the first a 2,000-c.f.m., 10-lb. discharge pressure unit, and the second a 7,000-c.f.m., 2-lb. discharge pressure unit. All compressors are driven by electric motors, and power is obtained from a 1,000-kilowatt substation connected with one of the distribution lines of the Alabama Power Co.

Off the line of the 300-foot single entry and near the southern end of the project, a series of 11 test holes was drilled at varying distances from the entry and extend from the surface to the coal bed. Each of these test holes is fitted with temperature-measuring equipment, so that the course of the combustion underground can be followed.

A second system has been installed for the purpose of following the course of combustion of coal underground. At points 100 feet north of the first and third boreholes on the west rib of the entry, 2-inch-diameter holes were drilled horizontally 30 feet into the coal seam. Mercury was sealed into small steel capsules and inserted in these drill holes. The capsules were spaced 5 feet apart and separated by refractory material. A mercury detector was installed on the surface and a sample of gas from the outlet stack pumped continuously through it. When combustion reaches one of these capsules it explodes, and the detector indicates the presence of mercury in the effluent gas. Thus the mercury capsules make it possible to measure the advance of the burning face in increments of 5 feet.

In March of this year, project construction was completed. Broken coal was piled in the single entry adjacent to the borehole at the southernmost end of the project. The ribs of the single entry were undercut to a depth of approximately 15 inches. Firewood was piled on top of the broken coal and the mass saturated with fuel oil and ignited (see fig. 56) by dropping a thermite grenade from the surface down the borehole. Air was supplied to the system at a rate of 2,000 c.f.m., and the product gases were removed by means of the second borehole, 300 feet north of the point of ignition. Since March the entire operation of the project has been confined to the single-entry passage between these two southernmost boreholes.

Following the ignition, air was blown from the first to the second borehole in a south to north direction for a period of 10 days, during which time the flow rate

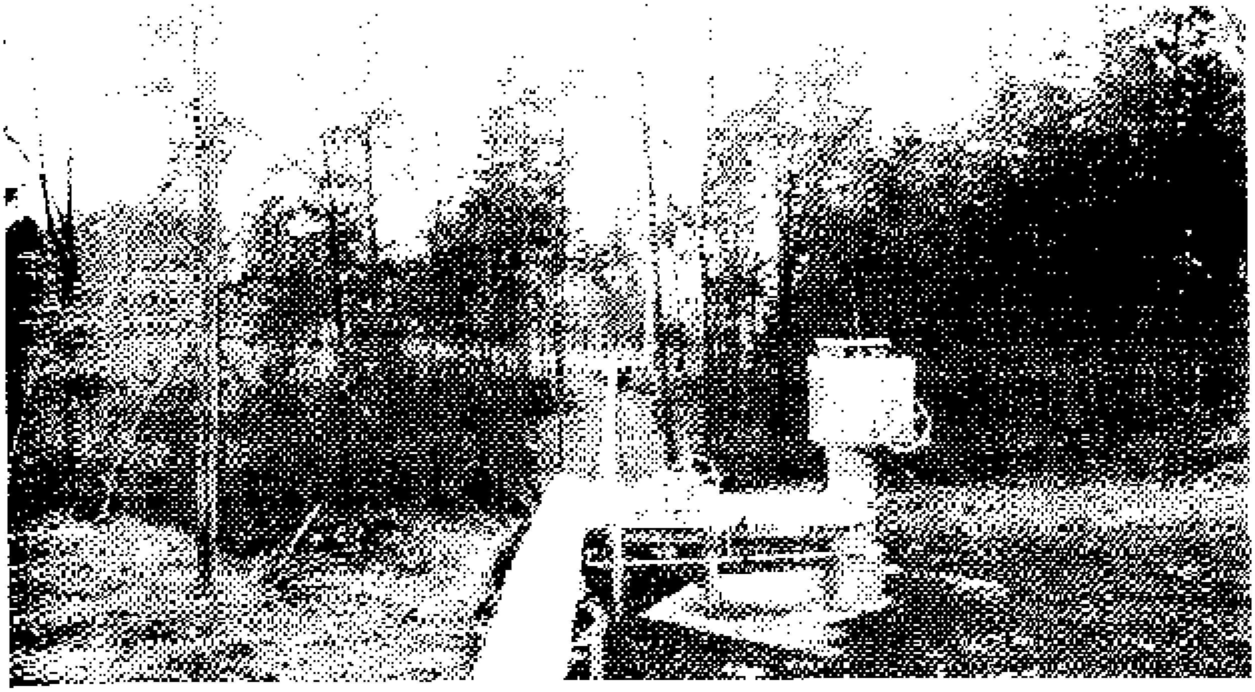


Figure 53. - Twenty-inch air manifold looking south from bore hole IV, in foreground.

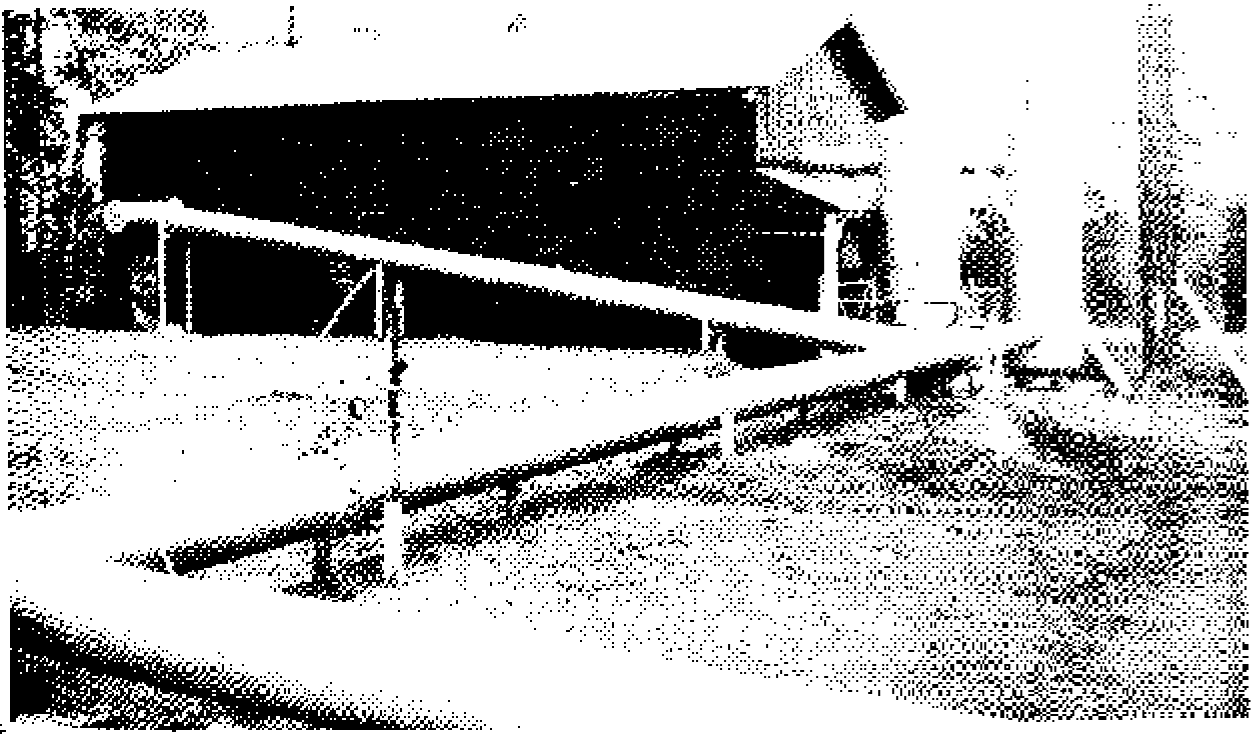


Figure 54. - Air manifold, flowrator, air receivers, and compressor house.

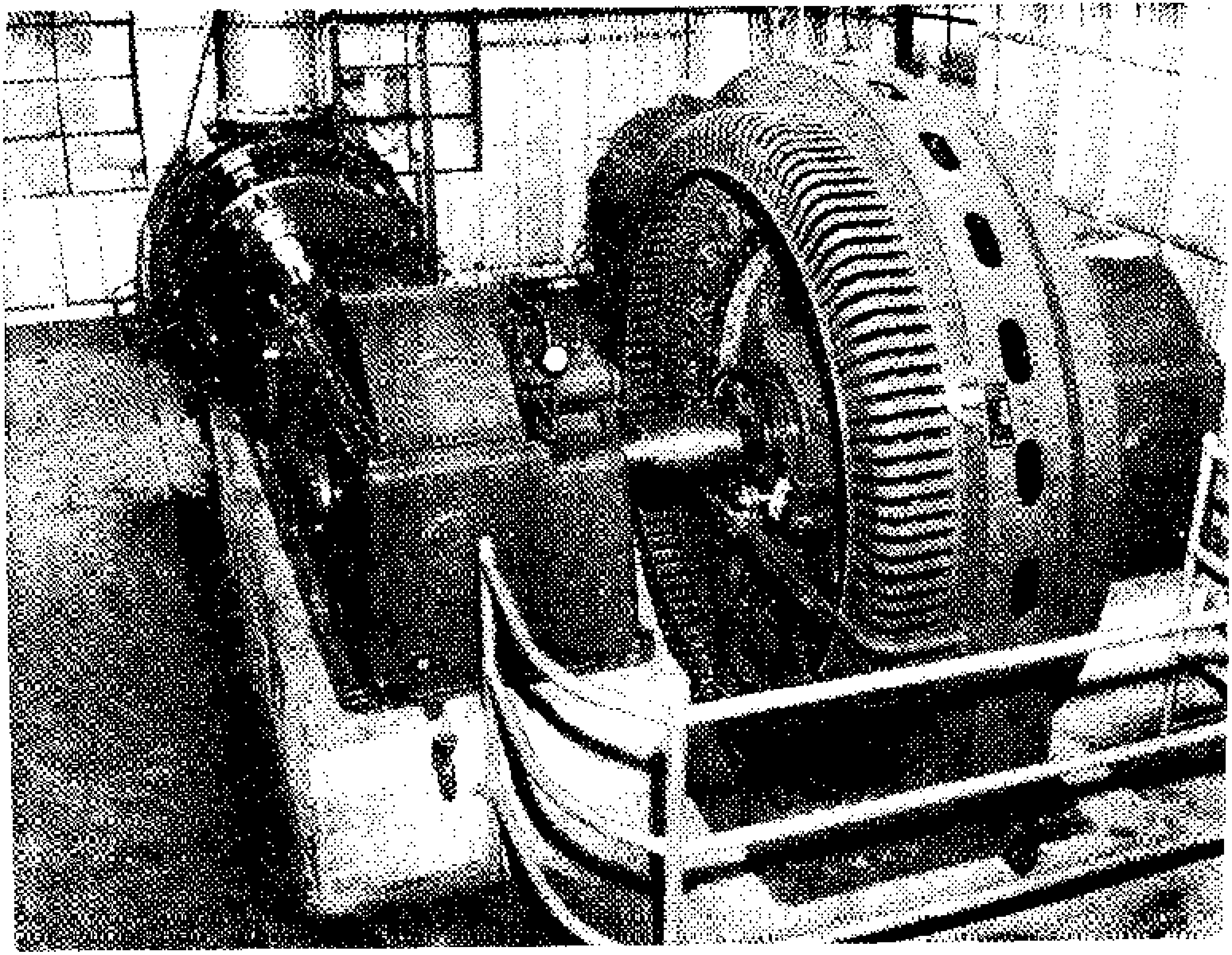


Figure 55. - 800-hp. reciprocating compressor (7,200 c.f.m. free air, 30 p.s.i.g. discharge).

Figure 56. - Smoke and steam issuing from stack at bore hole 11, 10 minutes after firing project on March 18, 1949.

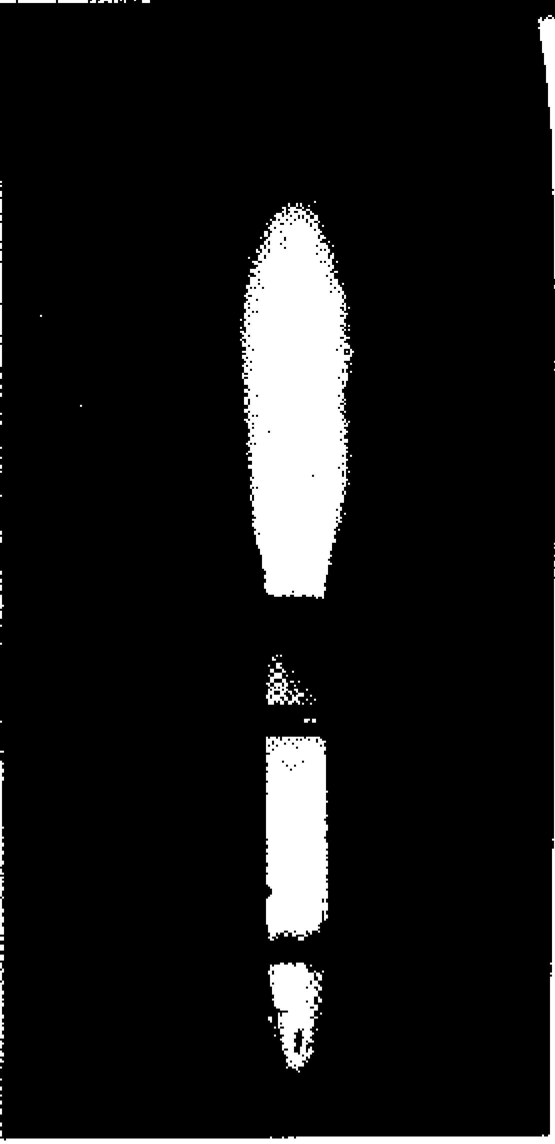


Figure 57. - Producer-gas-flame cone at stack 11 after product gas has ignited.

was varied from 2,000 to 5,000 c.f.m. At the end of this period, temperature measurements disclosed that the region adjacent to the first borehole was cooling while that adjacent to the second borehole was heating, indicating that the combustion zone was being driven downstream. For a few days after ignition, the gases evolved from the system showed decreasing percentages of oxygen and an increasing percentage of carbon dioxide. After 4 days of operation, the percentage of oxygen in the effluent gas began to increase and carbon dioxide to decrease. The direction of flow was reversed in an effort to distribute combustion over the entire 300-foot passage. From the first of April until the present time, direction of flow has been reversed periodically to maintain the temperature level of the 300-foot passage at as high a value as is possible. Another purpose of the periodic reversals in flow has been to store a maximum amount of heat underground to increase the rate of reaction and to reduce the percentage of oxygen in the effluent gas to a minimum value.

After 2 months of cyclic operation, the effluent gases still contained large volumes of excess oxygen, and it became apparent that poor contact was being obtained between the air and the hot coal faces. It was thought likely that a portion of the air was contacting hot carbonaceous material on the coal ribs but that a large percentage was passing through the broken rock along the center of the original entry without contacting coal faces. Two 6-inch churn-drill holes were drilled along the line of the original entry 100 and 200 feet, respectively, north of the first borehole. Void spaces were encountered at points 7 to 9 feet above the original top of the coal seam, and it was shown that a large volume of unreacting air was passing through these spaces. It was decided then to block off the void space along the line of the entry through the use of some finely divided solid medium. Sand was chosen for this purpose, and it was mixed with air, fluidized, and then blown down these boreholes into the void. Fluidized sand still is being added to the system as a means of controlling the contact between the air and the coal faces, and thus controlling the combustion. A short time after the use of fluidized sand was begun increased resistance to flow was noted, and the increase became greater as more and more sand was added. As the pressure drop through the system increased, the percentage of carbon dioxide in the effluent gases likewise increased. Meanwhile, the percentage of oxygen declined and the rate of coal combustion advanced.

TABLE 15. - Back-pressure development

	Ave. back pressure at 7,200 c.f.m. air flow, pounds per square inch gage
May........................	4.1
June.......................	1/5.0
July.......................	6.9
August.....................	8.2
September..................	9.4
October....................	13.1

1/ Admission of fluidized sand was started June 22.

During the first 3 months' operation, the air flow was increased to 7,200 c.f.m., the full capacity of the reciprocating compressor. Coal consumed in this period averaged approximately 10 tons per day on a moisture- and ash-free basis. Resistance to flow averaged approximately 4.5 pounds per square inch gage. In the next 2 months, the rate of coal consumption increased to 14.5 tons per day, and, the resistance to flow averaged 7.6 pounds per square inch. During the 2 months following, the rate of coal consumption again increased to from 15 to 20 tons per day, and the back pressure to approximately 11.3 pounds per square inch. At the present time (December 1949), coal consumption is between 20 and 25 tons per day, and the resistance to flow 16 pounds per square inch. Approximately 3,000 tons of coal have been burned in place so far. The ribs of the original 10-foot entry have been burned back so that the coal now has consumed from an area approximately 70 to 75 feet wide and 300 feet long.

TABLE 16. - Coal consumption and area of bed consumed

Period	Days of operation	Coal consumed, tons1/	Rate of coal consumption, tons per day1/	Average width of area from which coal was consumed,	Average daily advance of reacting face, foot
3/18 to 4/30	43	322	7.5	3.84	0.09
5/1 to 5/31	31	313	10.1	3.73	.12
6/1 to 6/30	30	346	11.5	4.12	.12
7/1 to 7/31	31	451	14.6	5.37	.17
8/1 to 8/31	31	444	14.3	5.29	.17
9/1 to 9/30	30	474	15.8	5.56	.19
10/1 to 10/20	20	404	20.2	4.81	.24
Total	216	2754			

1/ Basis of moisture- and ash-free coal.

As the resistance to flow and the coal consumption increased, small percentages of combustible constituents began to appear in the effluent gases. The oxygen content of the effluent gases decreases and the carbon dioxide content increases as an individual cycle progresses. The temperature of the effluent gases also increases with time during a given cycle. At present, when the effluent gas temperatures reach a value between 700° and 800° F., the temperatures rapidly rise from this point to approximately 2,000° F., indicating a combustion of make gas in the stack and/or adjacent to the base of the outlet borehole. At these times a flame cone appears over the stack (see fig. 57). Producer gases are being made along the coal ribs, mix with excess air before they leave the coal seam, and burn before they can be brought above ground. Calculations show that the gases being produced on the coal ribs should have a calorific value of approximately 115 B.t.u. per cubic foot, and samples taken as near the burning ribs as possible show by analysis that the calorific value varies from 80 to 110 B.t.u. per cubic foot.

TABLE 17. - Analysis of gas flowing near burning coal ribs

		Test hole 61/	Test hole 132/
Sample point			
Gas analysis:			
CO_2	Percent	10.4	8.5
Ill	do.	.3	.2
O_2	do.	.7	.0
H_2	do.	10.9	11.4
CO	do.	10.0	15.5
CH_4	do.	2.3	2.0
N_2	do.	65.4	62.4
Heating Value	B.t.u. per cu. ft.	97	111

1/ Sample point 75 feet north and 35 feet east of outlet stack, direction of blast north to south (Boreholes II to I).

2/ Sample point 30 feet west of outlet stack, direction of blast south to north (Boreholes I to II).

Cycle 431 is typical of recent operation of the project, and a summary of the data obtained during this cycle follows:

A product gas having the following average composition was obtained for a period of 42 hours:

	Average percent
CO_2	8.8
Ill	.3
O_2	10.0
H_2	2.6
CO	2.0
CH_4	.8
N_2	75.5
Heating value, B.t.u. per cu. ft.	29

The average temperature of the gases leaving the system was 490° F., and the blast rate was 6,500 c.f.m. Water was present in the effluent gases to the extent of 0.12 mol per mol of dry gas. During this part of the cycle coal (moisture and ash free basis) was being consumed at the rate of 22.4 tons per day. A heat balance on the operation showed that of the heat of combustion of the moisture- and ash-free coal being consumed, 12 percent was present in the dry product gases as sensible heat, 9.6 percent represented total heat content (including heat of vaporization) of the water vapor accompanying the dry gases, 41.7 percent was present as combustible constituents in the dry gas, and 36.7 percent was unaccounted for and presumed to be stored underground.

When the temperature of the gases in the outlet stack reached 805° F., the combustible constituents began to burn, and the composition of the effluent gases for the next 2 hours of the cycle averaged as follows:

	Average percent
CO_2	15.8
Ill	.0
O_2	2.6
H_2	.0
CO	.0
CH_4	.2
N_2	81.4
Heating value, B.t.u. per cu. ft.	2

The average temperature of the effluent gases was 1,621° F., and the rate of coal consumption was 27.6 tons per day. A heat balance on this part of the operation showed that, of the heat of combustion of the moisture- and ash-free coal, 37.7 percent was present as sensible heat of the dry gas, 11.6 percent was the total heat content of the water vapor accompanying the dry gases, 2.3 percent represented combustible constituents, and 48.4 percent was unaccounted for and presumed to be stored underground.

The blast rate was decreased to 4,000 c.f.m. for 15.6 hours and the average composition of the gases evolved became:

	Average, percent
CO_2	17.8
Ill	.0
O_2	1.1
H_2	.3
CO	.0
CH_4	.2
N_2	80.6
Heating value, B.t.u. per cu. ft.	3

The average temperature of the effluent gases was 2,065° F., the coal consumption was 19.1 tons per day, and the moisture content of the product gas was 0.30 mol per mol of dry gas. A heat balance on this part of the cycle showed that of the heat of combustion of the moisture- and ash-free coal, 41.9 percent was present as sensible heat in the dry gas, 28.1 percent was the total heat content of the water vapor accompanying the dry gases, 2.9 percent was present as combustible constituents, and 27.8 percent was unaccounted for and presumed to be stored underground.

A heat balance was made for the entire cycle and showed that, of the heat of combustion of the moisture- and ash-free coal, 20.6 percent was present as sensible heat in the dry gases, 14.5 percent was the total heat of the water vapor accompanying the dry gases, 30.3 percent was present as combustible constituents, and 34.6 percent was unaccounted for and presumed to be stored underground. At this stage in the investigation of the process of underground gasification, it is apparent that coal can be burned underground and the energy brought to the surface in the form of sensible heat which can be utilized for steam raising at the outlets from the system.

The operation of the project to date, as indicated by the foregoing test data, has shown that the major difficulty to be surmounted is the bypassing of air through nonreactive material and subsequent combustion of the product gases before they can be removed from the system. A measure of success in controlling or preventing this bypassing of air has been achieved through the introduction of fluidized sand into the void spaces along the line of the original entry. The indications are that roof action in this area is unfavorable to the process of underground gasification.

Two test holes have been drilled into areas where the coal has been consumed. In neither instance was any appreciable void space found. These test holes indicate that roof action away from the line of the original entry is favorable to the process. Combustion of the coal and liberation of heat have brought about such changes as fusion and swelling in the roof, so that no appreciable void spaces are left underground and the gas-making constituents are forced toward the coal faces by the roof action. Drill cuttings from each of these holes showed discoloration due to heat effects at a level 15 feet above the top of the coal bed.

During operation of the project, observations have been made with reference to the permeability of the overlying strata found in this area. Before the project was started, several core-drill holes were put down and the cores obtained. Tests of these cores show that the strata overlying the coal bed are themselves impermeable. This indicates that any leakage from the underground system would take place only through cracks or slips present in the strata and through the coal bed, the permeability of which is not known. After the project had been operating for several months, it was noted that on the west outcrop at a point approximately 500 feet west of the second borehole, air was seeping through the coal bed and the strata immediately below it. This flow was small and varied with the pressure applied to the underground system. The flow was through some discontinuity or fault in the strata adjacent to this coal bed, through the cleats of the coal bed, or along the line between the bottom of the bed and the adjacent strata.

Several experiments were made using the test holes drilled along the line of the 300-foot single entry as outlets and maintaining the entry under pressure. Gas flows were measured from these holes and analysis of the effluent material made. The analyses showed that the gases emerging were composed of products of combustion, coal-distillation products, and air. It was apparent that the air had passed through or near a high-temperature zone where combustion was taking place, then through or near a carbonizing zone where the coal was being coked, and thence to the test hole. In all cases the flows measured were low relative to the quantity of air being admitted to the system. The data obtained from such observations are of interest in connection with development of a percolation system of underground gasification.

No limit has as yet been found on the quantity of coal that can be gasified from an initial combustion zone. It has been possible to maintain combustion without difficulty.

The various types of equipment installed at the project have operated satisfactorily. Both the refractory-lined and the unlined boreholes have served well as hot-gas outlets. The construction of the entry seal has been moderately successful, although it has required several alterations. All compressors and other mechanical installations have operated satisfactorily.

The optimum length of passage in the coal bed required in underground gasification has not yet been established. All operations to date have been confined to a 300-foot passage, and it is planned to use a shorter path in the near future.

Some success has been achieved toward directing and controlling the combustion of coal in place by drilling holes and introducing fluidized sand into the system at points where the coal faces are being bypassed.

Pulverized Coal Gasification Pilot Plant, Morgantown, W. Va.

The purpose of the Morgantown pilot plant for gasification at atmospheric pressure and the general scheme for carrying on the experimental work have been outlined in the synthetic fuels reports of the Secretary of the Interior for 1947 and 1948.

Early in 1949 installation of the automatic control equipment for heating the pebble stoves was completed, and a purification train for studying the problem of dust removal was built.

The pebble stoves were operated with the original refractory linings and with the "sea-water periclase pebbles", 90 percent magnesium oxide, described in the 1948 report.

Starting in April 1949, gasification runs have been made with strongly-coking Sewickley-bed coal from the Bunker Hill mine near Cassville, W. Va. Up to the time of writing this report, 58,000 pounds of coal has been gasified at rates up to 490 pounds per hour. The gasifier has operated smoothly, and there has been no difficulty in starting runs or continuing them for the scheduled periods. As the pebble-stove linings could not be heated above 3,600° F., the top pebble bed and steam temperatures were limited to this temperature.

For the 14 runs using steam inlet temperatures of 2,700° to 3,500° F. and coal rates of 180 to 350 pounds per hour, the steam:coal ratios were varied over a wide range, 1.6:3.1. The percentage of gasification of the total carbon content of the coal was very satisfactory, ranging from 70 to 90 percent. The process allows considerable control of the hydrogen:carbon monoxide ratios in the gas. In the runs cited, these ratios were varied from 1.6 to 2.0. The oxygen required per thousand standard cubic feet of synthesis gas (CO + H_2) produced ranged from 121 to 265 standard cubic feet. This low oxygen requirement is due in part to the high steam temperature employed and is much lower than any reported for other plants. The following data illustrate this point.

Oxygen requirement for various steam:coal ratios and inlet steam temperature

	A	B	C	D	E	F	G
SCF O_2/1,000 SCF CO + H_2	133	181	183	193	319	338	363
Steam/coal, lb./lb.	2.07	2.45	2.36	2.28	0.19	0.38	0.58
Steam temperature, °F.	3,380	2,900	3,020	2,960	235	235	235

The lowest oxygen requirement using low-temperature steam is 318 (col. E) SCF per 1,000 SCF of CO + H_2, whereas that using high-temperature steam is 133 (col. A), a saving of 58 percent. The table also shows that as the steam:coal ratio increases for high-temperature steam, the oxygen requirement decreases; (cols. B, C, and D) whereas for low-temperature steam the oxygen requirement increases with increasing steam:coal ratios (cols. E, F, and G).

The materials cost of synthesis gas is the sum of the costs of coal, oxygen, and steam. As, on a weight basis, oxygen is the most expensive ingredient, a decrease in the oxygen requirement will provide a cost margin for superheating steam. The best German practice at atmospheric pressure in the oxygen gasification of coal indicated an oxygen requirement of 250 SCF per 1,000 SCF of CO + H_2 for large-scale operation. It may be seen from the data cited that this Bureau process has a considerably lower oxygen requirement, thus providing a cost margin for supplying reaction heat in the form of highly superheated steam.

Table 18 presents some of the results obtained with highly superheated steam. As the oxygen requirement of the process is low, the pounds of steam reacting with the coal must be high if the coal is to be substantially all gasified. That the steam reacting with the coal is high in this process may be seen from the column showing pounds of steam reacting per pound of coal in table 18.

The CO_2 produced by the process might be thought to be high. As a high hydrogen gas is desired for the manufacture of synthetic liquid fuels, however, a gas containing less CO_2 might require shifting to increase the hydrogen:carbon monoxide ratio. The end result could be the same after the shift. There is a tendency for high CO_2 content in the gas when the steam:coal ratio is high, for as the water gas shift reaction essentially reaches equilibrium at an equilibrium constant of about 0.4, and as the hydrogen:carbon monoxide ratio is about 2, the CO_2:H_2O ratio in the synthesis gas is about 0.2, or the CO_2 resulting from the high steam:coal ratio is about 20 percent of the dry synthesis gas.

During the course of the gasification runs, data were obtained on the problem of dust removal and the action of the various refractories under high temperature. Design of a new dust-removal train, new pebble stove construction, and a hot valve for use in the steam lines from the stoves to the generators have been completed. The new equipment will allow for heating steam to 4,000° F. and for continuous operation of the dust-removal trains so that longer operating periods can be maintained.

Construction work on the new dust-removal train and stoves started in November 1949. While this work is under way, a series of tests is being made with steam at temperatures of 230° to 2,500° F. to obtain further data on generator capacities.

Flow sheets and a photograph of the new equipment arrangement are presented in figures 58 to 60.

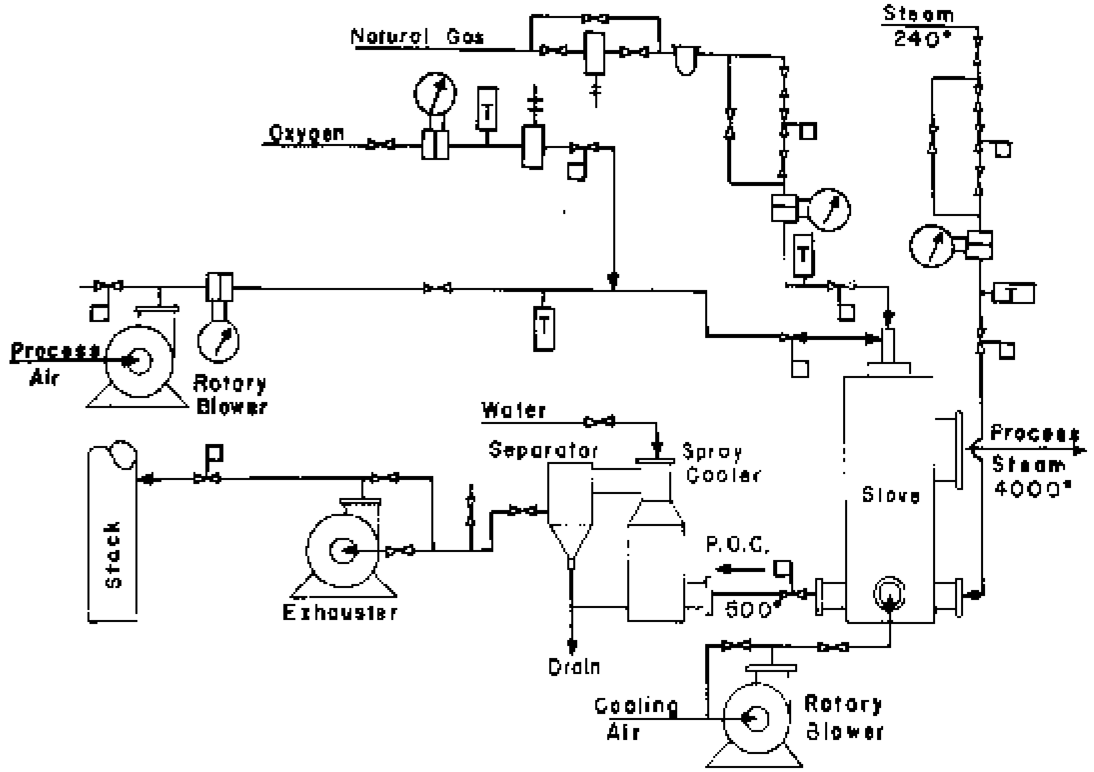


Figure 58. - Flow sheet of superheated-process steam generation.

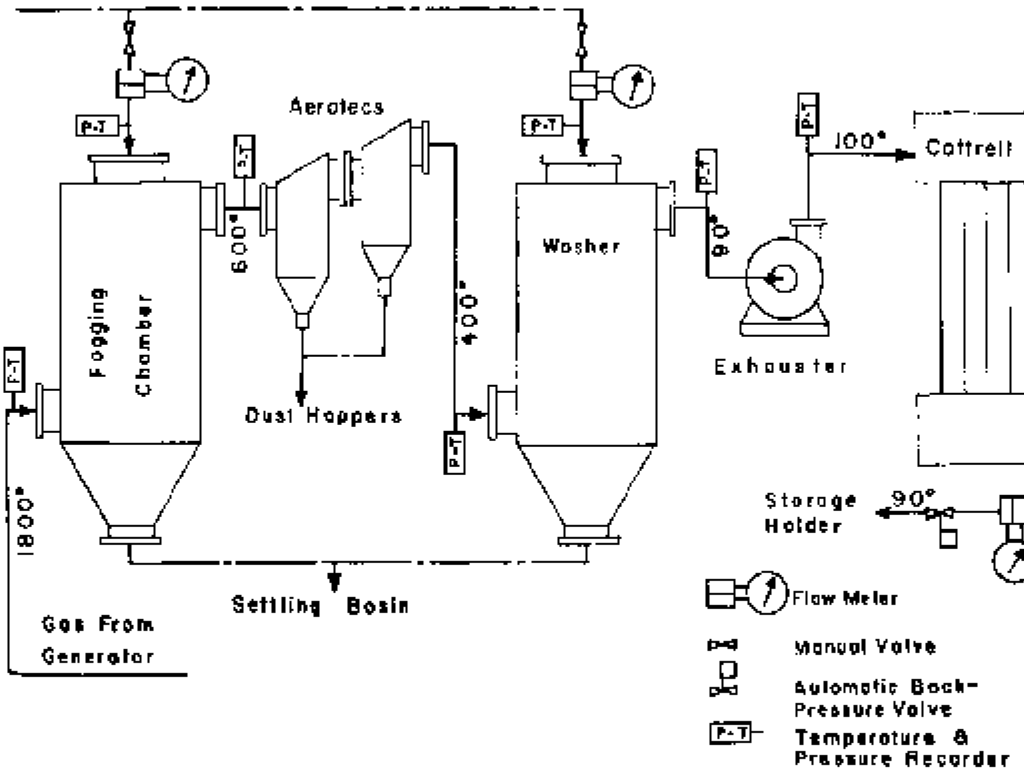


Figure 59. - Flow sheet of dust-removal and cooling system.

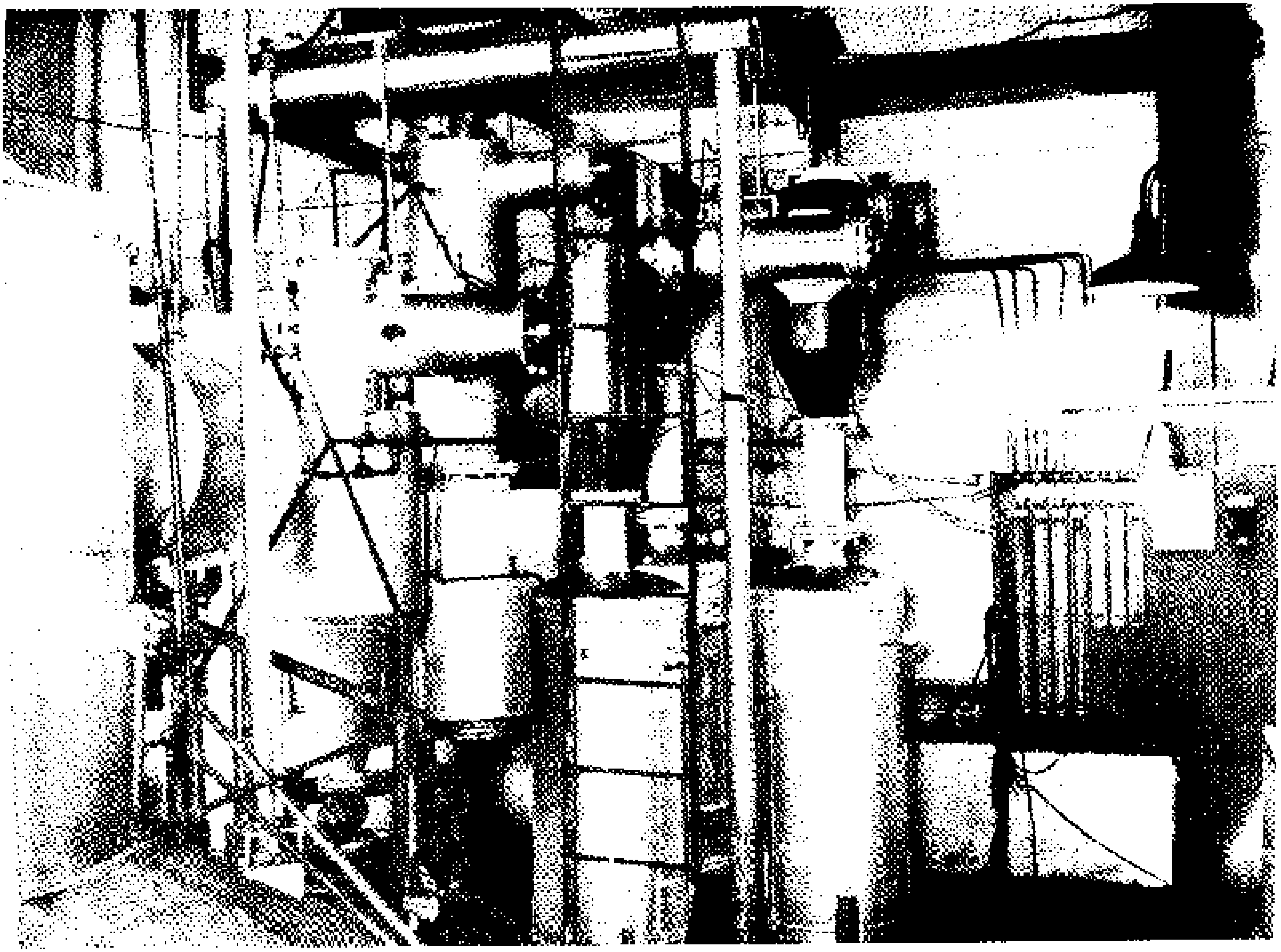


Figure 60. - Dust-removal and gas-metering equipment, pulverized-coal-gasification pilot plant, September 1949.

TABLE 18. - Summary of some high temperature steam runs of the Morgantown pulverized-coal gasifier

Run No.	1	2	3	4	5	7	8	10	11
Coal1/ rate, lb./hr.	212	200	294	354	299	238	200	199	245
Oxygen coal1/, lb./lb. ..	.47	.48	.47	.45	.504	.617	.514	.362	.294
Steam coal1/, lb./lb. ...	2.28	2.36	2.51	2.45	2.52	3.48	2.49	2.53	2.08
Steam temperature, °F. ..	2960	3020	2900	2900	3000	3045	3315	3350	3435
Exit synthesis gas temp.	1893	1934	2090	2140	2095	2035	1805	1790	1935
Synthesis gas analysis, percent:									
CO_2..................	21.1	19.3	17.7	16.7	20.6	22.2	18.1	17.8	17.4
H_2..................	51.4	49.2	45.8	43.5	46.3	55.9	50.3	51.2	52.7
CO..................	28.8	27.3	27.9	27.4	28.3	27.[illegible]	27.6	25.8	28.5
C_1^+..................	2.6	3.0	2.3	2.1	1.6	2.0	2.3	2.6	3.1
Carbon gasified, percent.	84	90	84	96	98	94	87	89	83
Lb. steam reacting/lb. coal1/..................	.59	.69	.56	.65	.63	.70	.69	.51	.57
SCF O_2/1,000 SCF CO + H_2.	193	183	199	182	206	218	187	235	136
Lb. coal1//1,000 SCF CO + H_2................	34.7	32.1	35.8	33.9	29.8	30.8	28.2	29.0	37.7
Net heating value of gas/ net heating value of coal1/.................	60.1	71.2	67.4	74.0	66.0	73.5	75.6	87.1	91.1

1/ Coal on as received basis with following analysis: Moisture, 0.9%; ash, 11.1%; carbon, 73.4%; oxygen, 5.5%; hydrogen, 5.0%; nitrogen, 1.5%; sulfur, 2.0%; and net heating value of 12,640 B.t.u. per lb.

Fluidized Coal Feeding Unit

The first test runs on the pilot-plant generator employed a coal-feeding system consisting of a single batch-type fluidized feeder.

A second coal-feeder system of Bureau design was constructed to maintain a more uniform coal level in the main feeder and to permit continuous rather than batch operation of the generator. This system consists of two fluidizers, the first having a capacity of 1,000 pounds of coal and the second 150 pounds of coal. Both fluidizers are equipped with Bristol pressure controllers to maintain constant pressures within the fluidizers. The first is operated as a batch feeder and supplies coal to the second, which is operated continuously. The second feeder has enough capacity so that it can operate continuously while the first is shut down for charging.

Investigations have shown that about 20 pounds of coal are conveyed through the feed lines by 1 cubic foot of air.

Further investigations indicate that the instantaneous coal-feed rate is directly proportional to the pressure drop across a given section of the feed line and independent of the discharge pressure if the oxygen flow and generator pressure are held constant. The instantaneous rate of feed to the generator is determined by reference to curves for coal flow vs. the differential pressure measured between the continuous feeder and a feed line sight glass.

Safety and Control Devices

As a result of experience with the unit, certain safety and control devices were added to improve the operation and decrease the danger of accidents.

The fluidized coal-feed unit with the safety-device panel indicated by the dotted lines is shown in figure 61 as well as a detailed diagram of the safety devices in figure 62. Safety device 1 gives a visual and audible warning of a pressure decrease at the sight glass due to a slight decrease of coal-feed or oxygen-flow rate. Safety device 2 stops the coal flow and oxygen flow and starts the carbon dioxide purge to the coal injector when the pressure differential between the sight glass and the generator falls off excessively owing to failure of coal feed or oxygen supply. Safety device 3 stops the coal feed and oxygen flow and starts the carbon dioxide purge when the sight glass pressure rises excessively owing to plugging or flashback within the coal injector. Safety device 4 gives a warning of faulty operation of the fluidizing air or controller causing a rise in pressure in the continuous feeder.

The injector consists of a sight-glass unit with an attached water-cooled tube ending at the inside wall of the generator. The sight-glass unit houses the end of the coal-feed line spaced a short distance from the entrance to the water-cooled tube or nozzle. The fluidized coal is fed through the coal-feed line to the sight glass, and process oxygen is admitted to the sight glass. As the oxygen enters the funnel-shaped nozzle entrance it carries the coal into the nozzle, and the mixture passes very rapidly through the tube into the generator.

Electronic Method for Measuring Ratio of Solid to Gas in Flow

In the course of studies on the flow of extremely dense coal-air mixtures at weight ratios of about 200 pound of coal per pound of conveying air, a method of measuring the instantaneous ratio of coal to air was desired. The purpose of the coal-flow studies was to assure a constant rate of coal supply to a reactor in which the coal is gasified with steam and oxygen. The purpose of the desired instrument was to measure the ratio of coal to conveying air over short time intervals so that the steadiness of the coal flow could be determined, the ultimate aim being to obtain a completely steady rate of coal supply to the gasifier.

The method of measurement selected was the change in the dielectric constant of the coal-air mixture as it flows between the plates of a condenser. The change in dielectric constant from all air to 20 percent coal and 80 percent air by volume is about 0.5 mmfd., a change large enough to make measurements possible in the condenser that was used.

Description of Circuit

The measurement of capacity required an oscillating circuit. The circuit used in the instrument described in this article is an adaptation from one described by Potter.1/ This circuit employs two synchronized oscillating circuits that are coupled inductively (see fig. 63). When the two oscillators have the same frequency and phase, no current flows in the inductively coupled circuit. The latter is shown in the diagram above the oscillating circuits, the coupling being obtained by winding L_1 and L_3 on one form and L_2 and L_4 on another form. If the capacity of C_1, which is in the circuit of oscillator I, is changed, the two oscillators are no longer in phase. A current is subsequently induced in the coupling circuit, the induced current being proportional to the phase difference, and therefore being a measure of the change in capacity of condenser C_1. The high-frequency current in the coupling circuit is rectified by diode V_1, and the voltage drop across a resistor, R_1, is used to measure this current.

1/ Potter, E. V., An Electrical Transducer Circuit for use with Capacity Pick-Up Devices: Rev. Sci. Instr., vol. 14, 1943, p. 130.

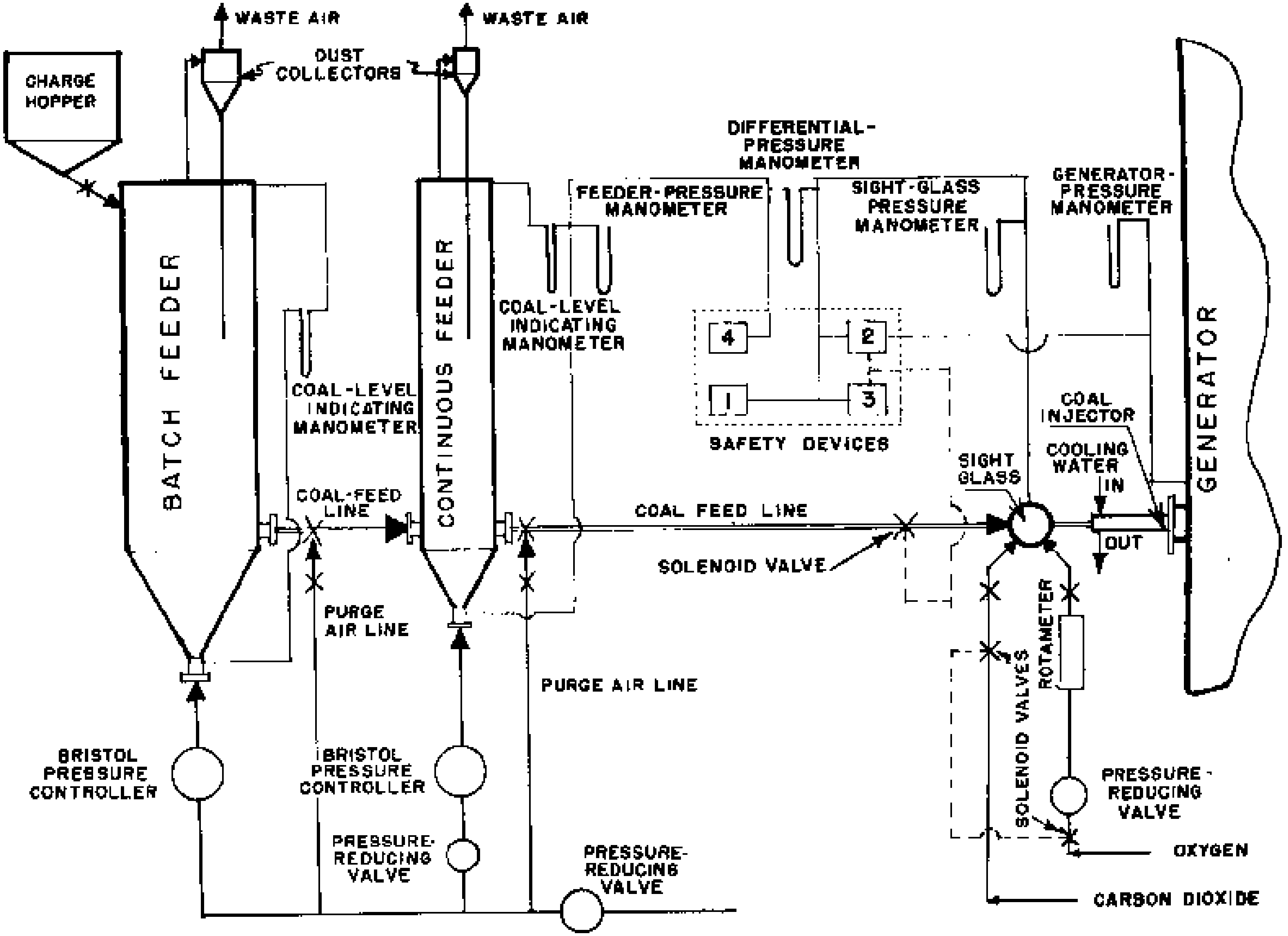


Figure 61. - Fluidized-coal feeder unit.

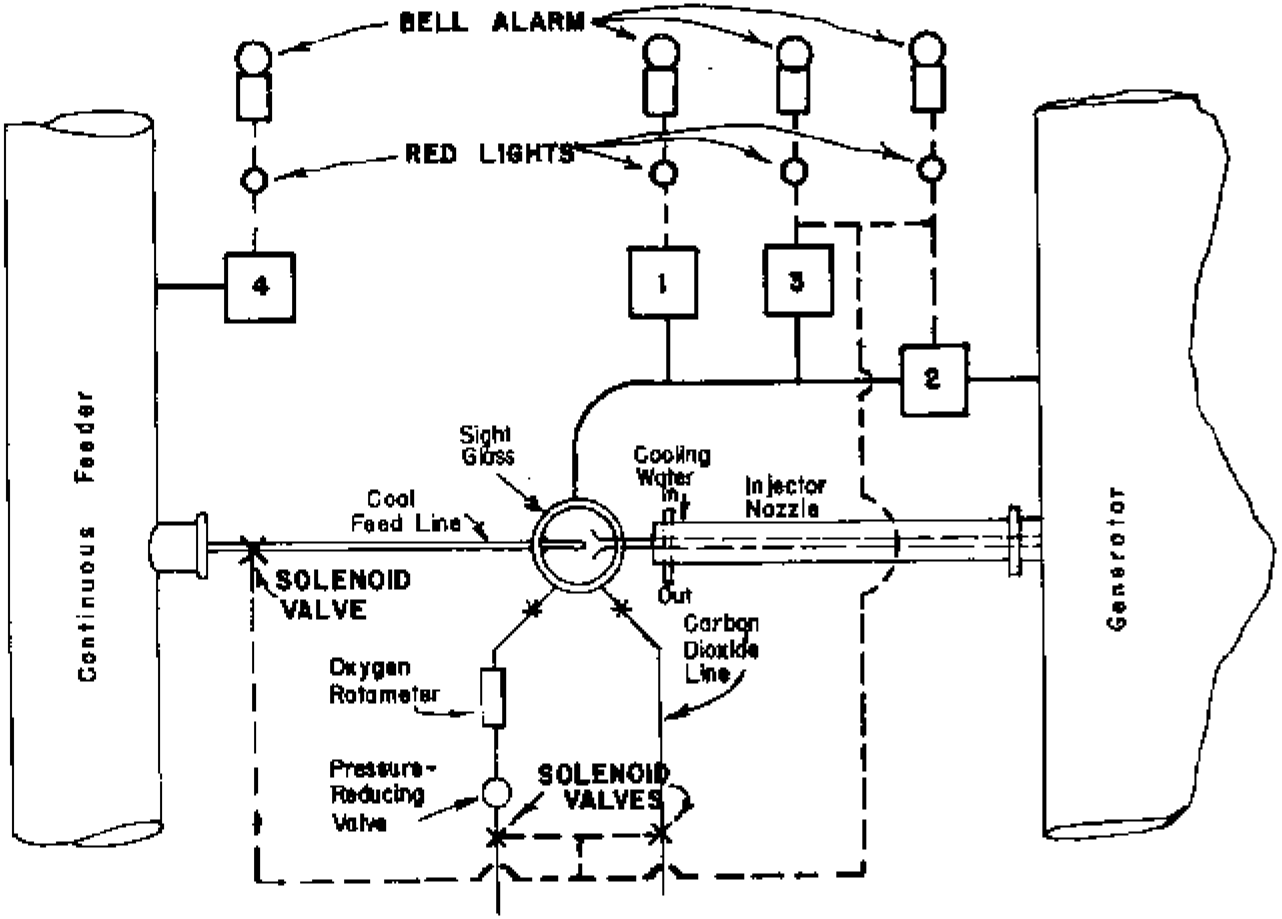


Figure 62. - Arrangement of safety devices.

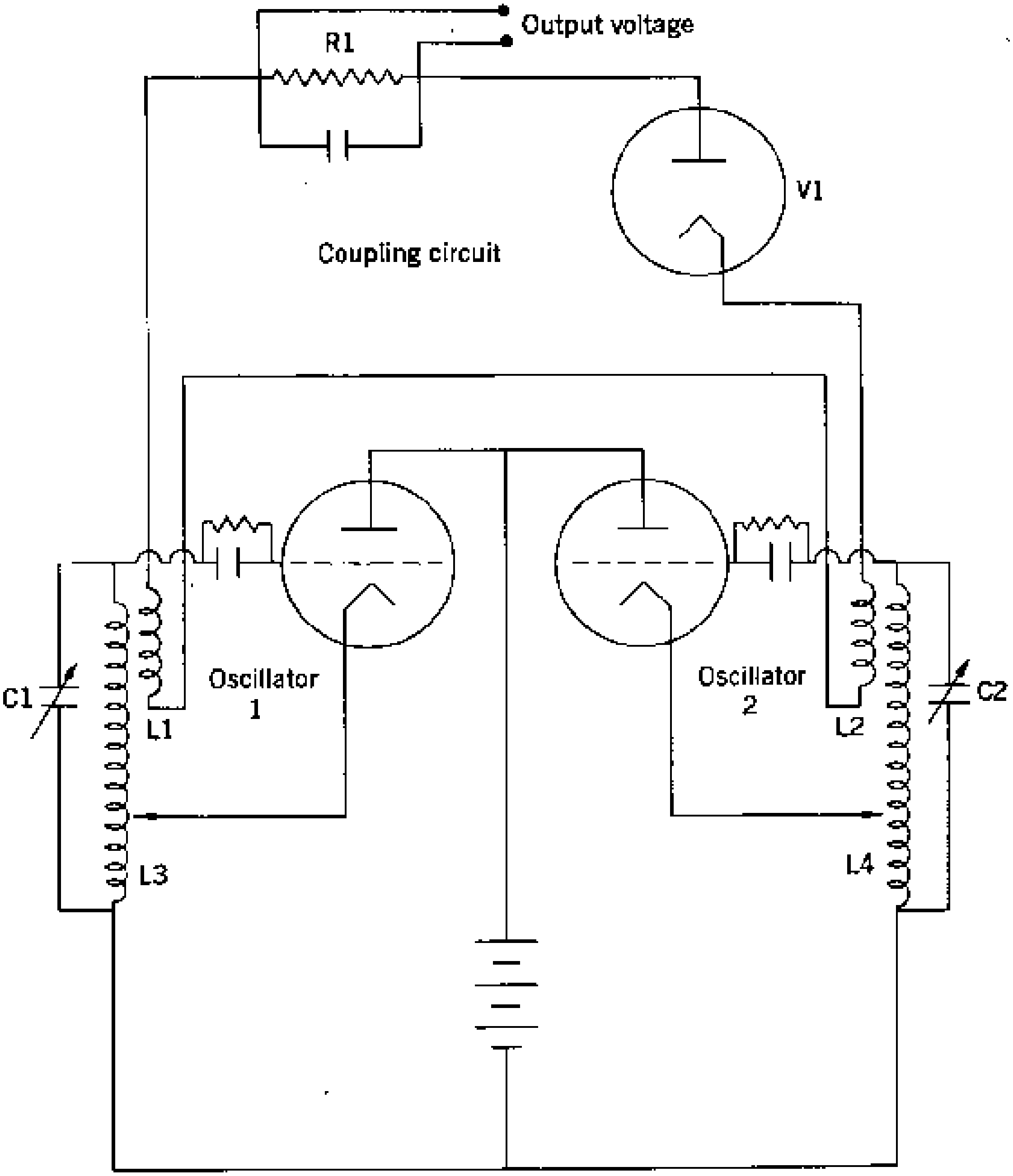
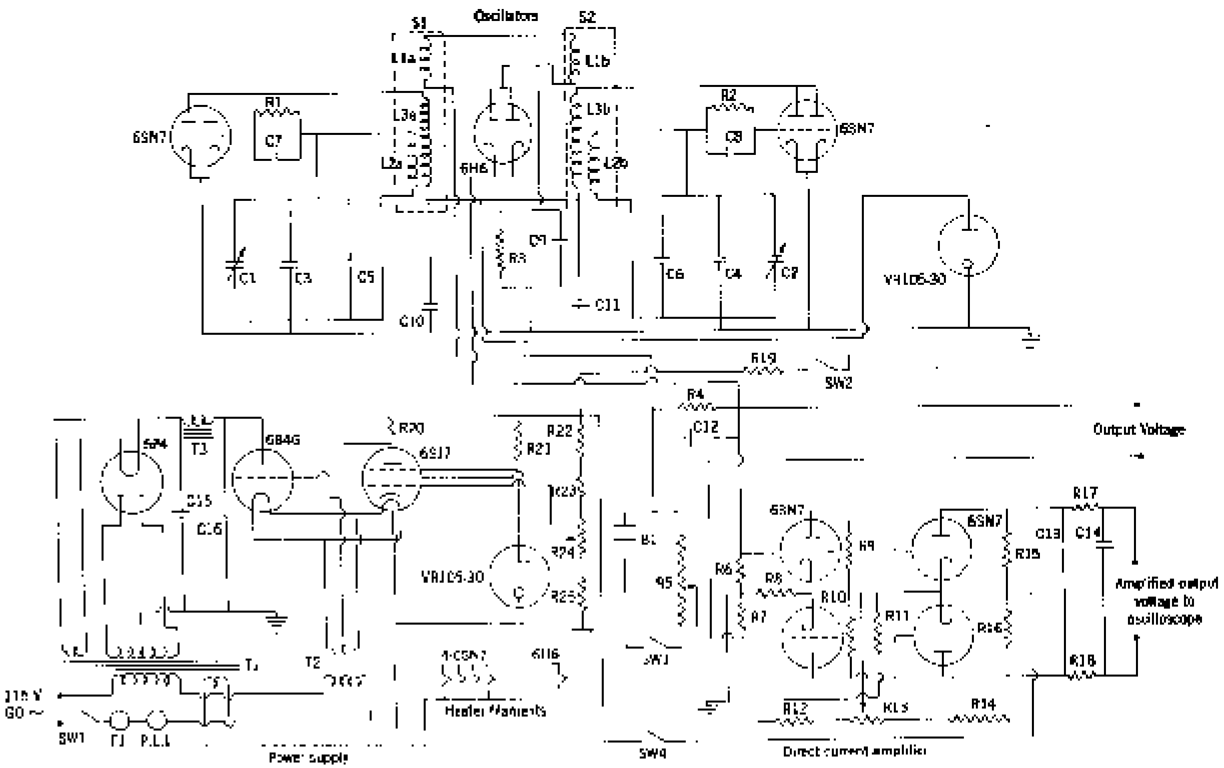


Figure 63. - Simplified circuit diagram.



LEGEND

B1 - 9-volt battery.
C1, C2 - 12-mmfd. variable calibration condensers.
C3, C4 - 1,176-mmfd. mica condensers.
C5, C6 - 200-mmfd. mica condenser.
C7, C8 - 75-mmfd. mica by-pass condensers.
C9 - 30-mmfd. mica condenser.
C10, C11 - .002-mfd. mica condenser.
C12 - 0.5-mfd. paper condenser.
C13, C14 - 0.1-mfd., 600 V. paper low-pass filter condensers.
C15 - 8-mfd., 600 V. electrolytic condenser.
C16 - 4-mfd., 600 V. electrolytic condenser.
F1 - 2-amp. cartridge fuse.
L1a, L1b - 20 turns, #25 D.C.C. copper wire, 1-3/4" diam. coil.
L2a, L2b - 42 turns, #25 D.C.C. copper wire, 1-1/2" diam. coil.
L3a, L3b - 34 turns, #25 D.C.C. copper wire, 1 3/4" diam coil
P.L.1 - 6-watt, 115V pilot light.
R1, R2 - 13,000 ohms, 1/2-w. grid leak.
R3 - 36,000 ohms, 1/2 w.
R4 - 15,000 ohms, 1/2 w.
R5 - 5,000-ohm bucking voltage rheostat.
R6, R7 - 39,000 ohms 1/2 w.
R8 - 2,000 ohms, 1/2 w.
R9, R10 - 75,000 ohms, 1/2 w.
R11 - 15,000 ohms, 1/2 w.
R12 - 1,500 ohms, 1 w.
R13 - 1,000-ohm amplifier adjustment rheostat.
R14 - 7,500 ohms - 10 w.
R15, R16 - 100,000 ohms, 1/2 w.
R17, R18 - 70,000 ohms, 1 w. low-pass filter resistors.
R19 - 7,500 ohms, 10 w.
R20 - 500,000 ohms, 1 w.
R21 - 75,000 ohms, 1 w.
R22 - 10,000 ohms, 1 w.
R23 - 25,000 ohms, 1 w.
R24 - 10,000-ohm D.C. voltage adjustment rheostat.
R25 - 10,000 ohm, 1 w.
S1, S2 - 2-1/4" diam. coil shields.
SW1 - D.P.S.T., A.C. power switch.
SW2 - S.P.S.T., D.C. oscillator plate voltage switch.
SW3 - S.P.S.T. battery switch.
SW4 S.P.S.T. D.C. amplifier plate voltage switch.
T1 - Power transformer, 400-0-400 V. at 200 m.a., 5V -3 amp.,
6.3 V. - 3-amp. Thordarson [illegible].
T2 - Heater transformer, 6.3 V. - 2.5 amp.
T3 - Choke coil, 10 h., 30 m.a.

Figure 64. - Circuit diagram of oscillator unit.

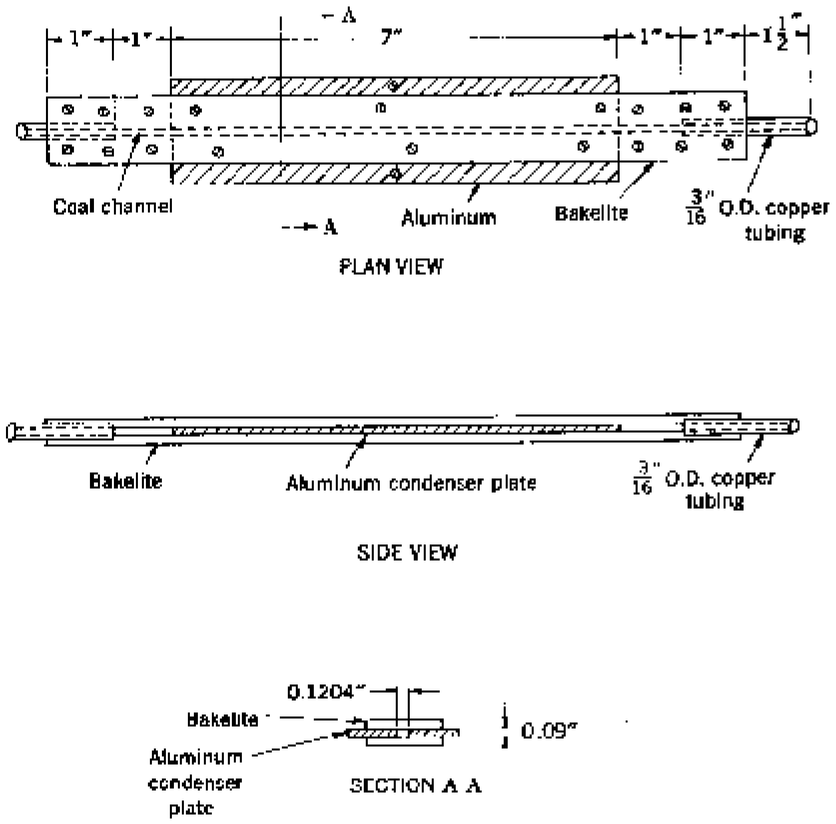


Figure 65. - Coal condenser.

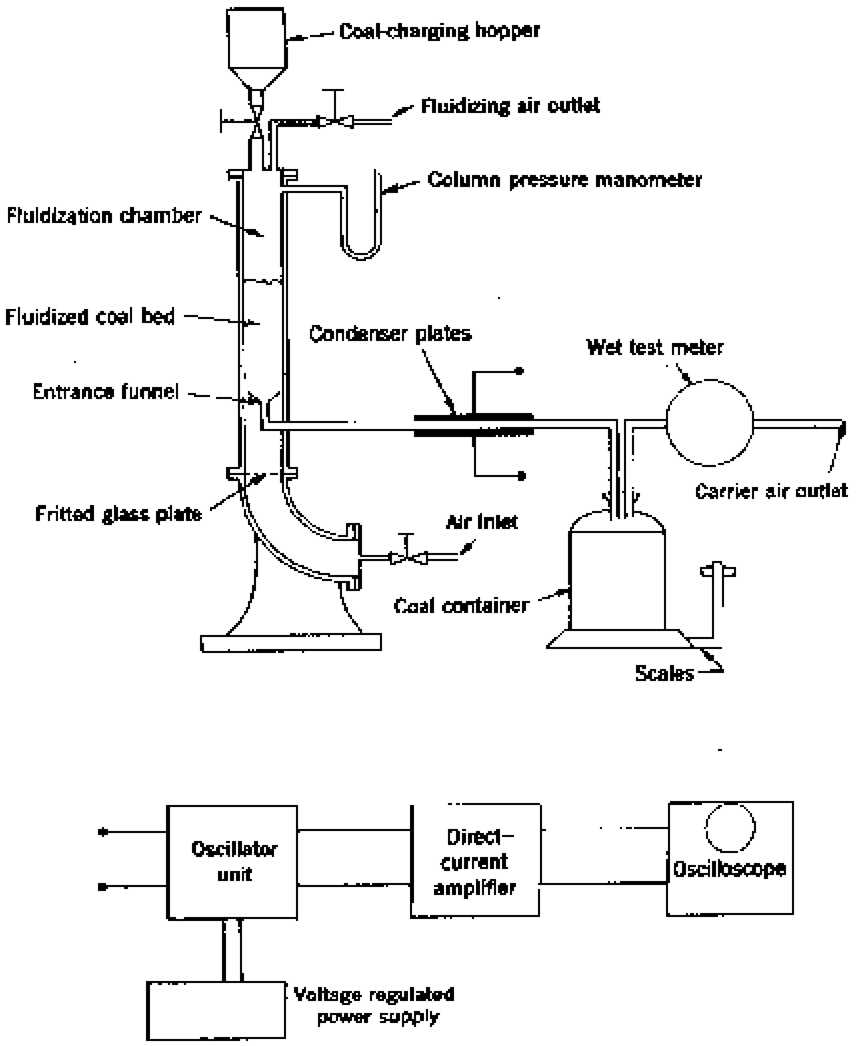


Figure 66. - Diagram of test equipment.

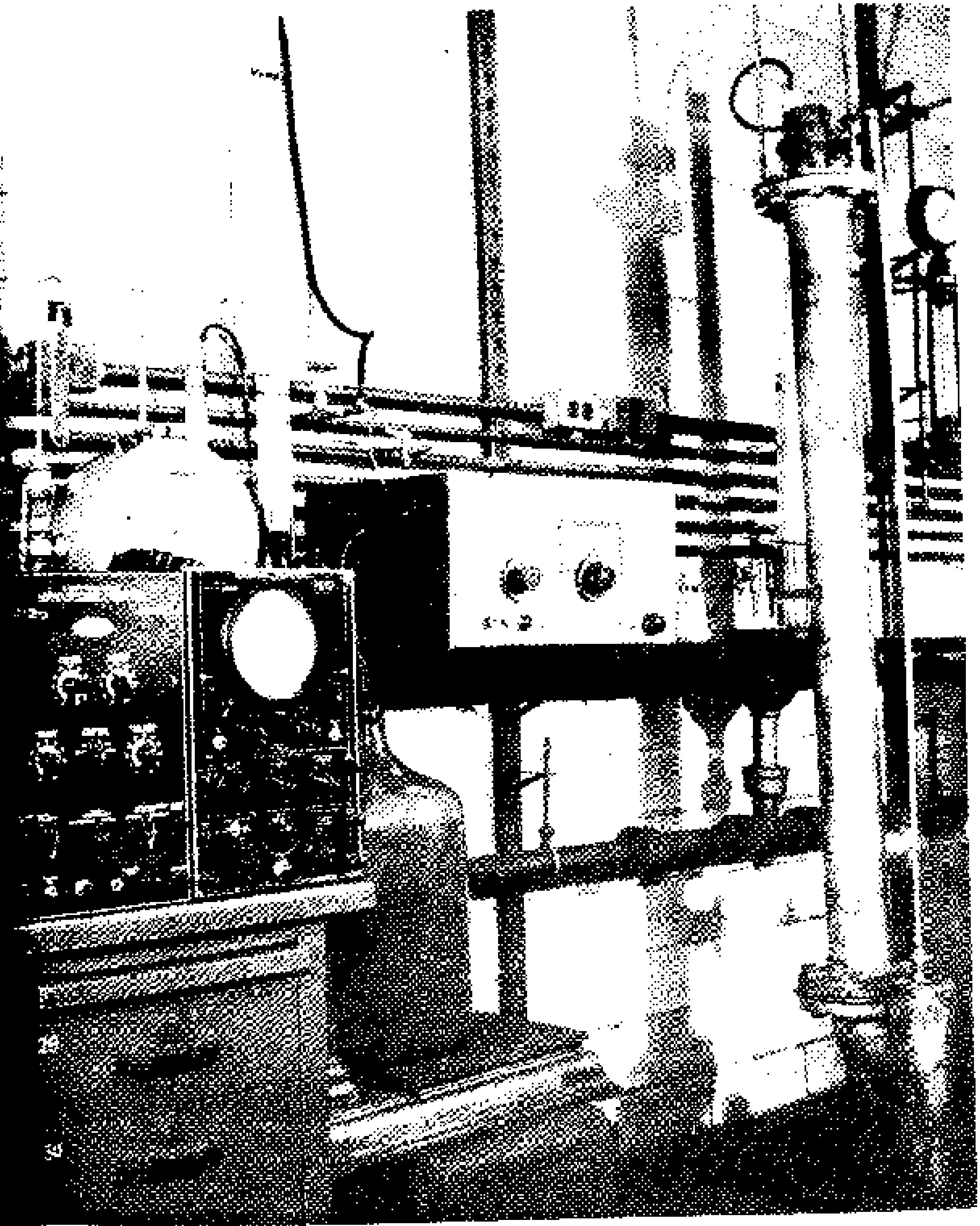


Figure 67. - Test equipment.

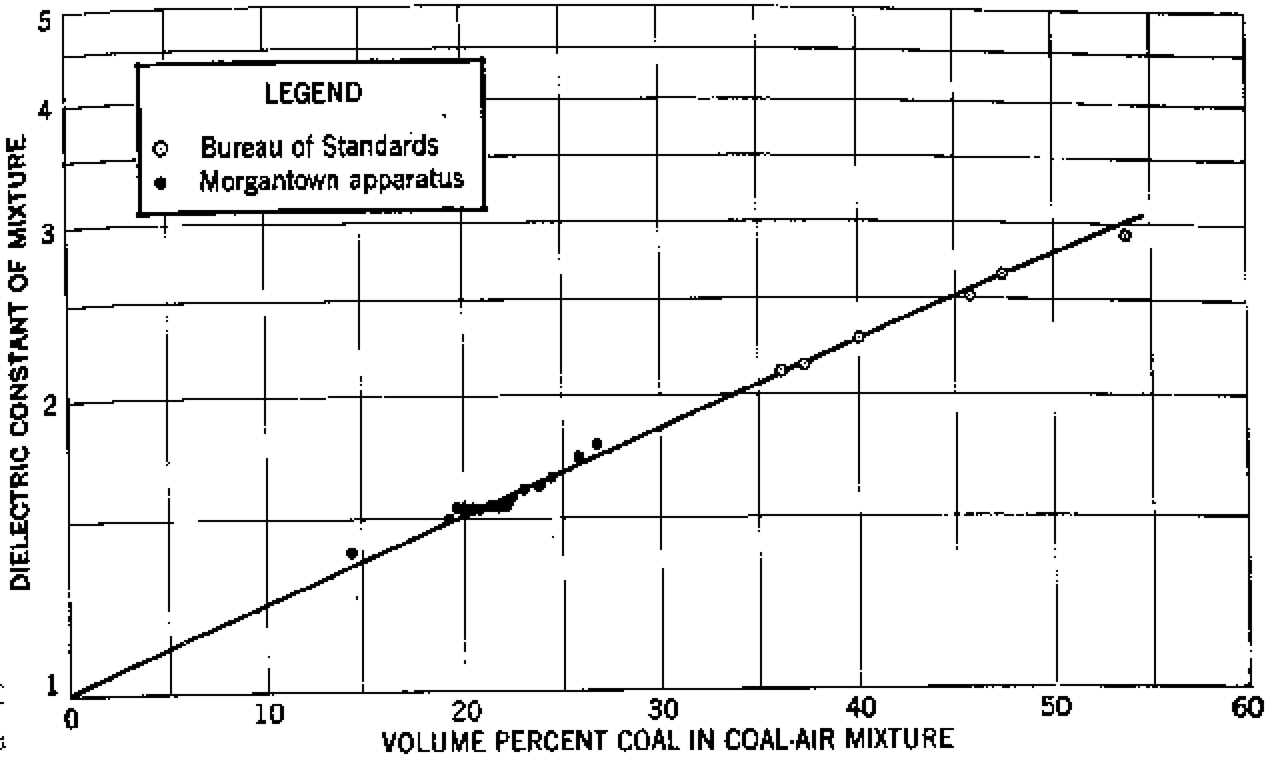


Figure 68. - Effect of volumetric percent of coal in coal-air mixture on dielectric constant of mixture.

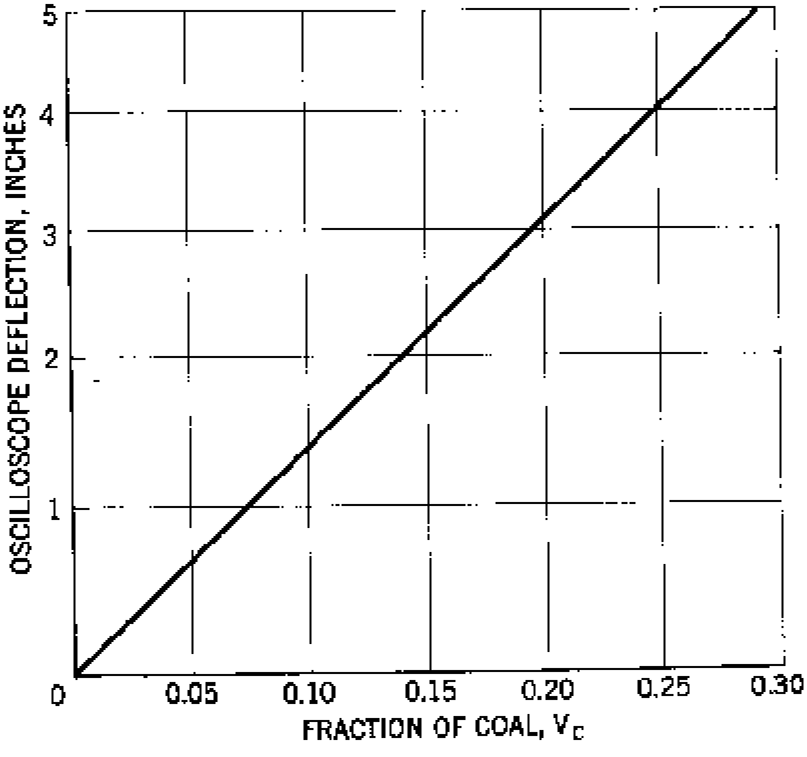


Figure 69. - Effect of volumetric fraction of coal in coal-air mixture on oscilloscope deflection.

The complete circuit consists of three units (see fig. 64): (1) A power-supply unit which provides a constant voltage input for the oscillators and the amplifier; (2) the oscillators and the coupling circuit, which measure the capacity change; and (3) a direct-current amplifier which amplifies the voltage input to the oscilloscope. The frequency of the oscillator circuits is 1.5 megacycles. The condenser through which the coal-air mixture flows is C_3. C_4 is identical with C_3 but is in the other oscillator circuit. Condensers C_1 and C_2, which are in parallel with C_3 and C_4, respectively, were used in calibrating the apparatus, since a change in C_1 is equivalent to a change in C_3. The voltage drop in the coupling circuit is measured across R_4. Since only a change in potential is necessary to measure the capacity change, battery B_1 was used to oppose the potential change in the coupling circuit and to adjust the input voltage of the amplifier to the range over which the output from the amplifier was linear.

The coal condensers, C_3 and C_4 (see fig. 65), were made of aluminum plates separated by bakelite strips. The passage through which coal and air mixture flows is about 0.1 inch square in cross section by 7 inches in length. From its dimensions, the capacity of the effective part of this condenser was calculated to be 1.176 mmfd. when it contained air.

Calibration of Instrument with Coal

A coal-air mixture was blown through the condenser from a pneumatic feeder developed in the Bureau laboratories at Morgantown for feeding coal to a reactor. The feeder operates by forming a fluidized bed of coal under pressure, bleeding off most of the fluidizing air from the top of the container, and causing the coal-air mixtures to flow from the bed through a coal-delivery tube to the point of utilization. Around the entrance to the coal-delivery tube is a shield to form a bed of uniform density by partial settling of the coal. The coal from the delivery tube flows through coal condenser C_3 in the oscillating circuit. The output voltage, which is recorded on the oscilloscope, measures the coal:air ratio in the tube. At the rates of flow used in the experiments, the time any particle of coal was in the condenser varied between 0.05 and 0.1 second.

The dielectric constant of a mixture of finely divided solid randomly spaced in a gas has been reported to follow the equation $\log D_m = V_c \log D$.[2]

where D_m - the dielectric constant of the mixture of solid and gas,

V_c = the volumetric fraction of solid in the mixture, and

D = the dielectric constant of the solid.

To test the applicability of this relation to coal-air mixtures (see figs. 66 and 67), simultaneous measurement of the coal:air ratio and deflection on the oscilloscope were made. The coal-air mixture from the feeder was passed through the condenser and the average deflection on the oscilloscope determined. The coal was subsequently caught and weighed in a container and the conveying air measured by a wet test meter.

The data are plotted as the logarithm of the dielectric constant of the mixture of coal and air against the volumetric percentage of coal in the mixture (see fig. 68). The experimental data are marked with dots. The points marked with circles are determinations made on a sample of the coal by the National Bureau of Standards

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[2] Argue, G. H. and Maass, O., Measurement of the Variation of Dielectric Constant of Water with Extent of Adsorption: Canadian Jour. Research, vol. 13B, 1935, pp. 156-166.

through the courtesy of Charles Moon, chief, Inductance and Capacitance Section, Division of Electricity and Optics. The logarithmic relation is shown to hold at least for the coal used in these experiments. A graph (fig. 69) shows the deflection on the oscilloscope in inches against the volumetric fraction of coal in the coal-air mixture passing through the condenser.

Use of Instrument

The instrument was used to determine the effect of the shield around the coal-air inlet on the coal:air ratio of the mixture flowing through the coal-delivery tube from the pneumatic feeder. A photograph of the deflection on the oscilloscope using various shields and using no shield is shown (fig. 70). The time required for the spot to move across the field of the oscilloscope was in all cases 1 second. The volumetric fraction of coal in the mixture is found from the distance of the spot above the datum line. The effect of the shield on the uniformity of the mixture flowing through the tube may be seen by comparing the lower right picture with the other three. No shield was used when the lower right picture was taken, whereas shields were used when the other three were taken.

The use of the instrument is restricted to solid:gas ratios high enough to cause a measurable change in the capacity of the condenser. Greater sensitivity can be obtained by increasing the amplification ratio, by increasing the length of the condenser, or by decreasing the inductive coupling in the coupling circuit. However, errors are also multiplied; and increasing the sensitivity of the instrument means that extreme care would be necessary in eliminating errors caused by line-voltage change, temperature change, etc. The effective range of solid concentrations is above about 5 percent solids by volume, when the solid has a dielectric constant similar to that of coal. This minimum effective range may be lowered, however, by using a solid such as titanium dioxide, which has a dielectric constant of 80, or about 10 times that of coal. The probable minimum variation in a high dielectric constant material that could be detected is about 0.1 percent solid by volume. At high solid concentrations, however, the instrument has proved to be very effective in measuring changes in the solid:gas ratio.

Engineering and Design Work

Pressure Gasification

Design work is about 40 percent complete on a pilot plant to gasify 500 pounds of coal per hour at pressures up to 450 p.s.i.g.

Preliminary designs were made up for the following pieces of apparatus:

1. A steam generator and superheater to deliver 1,000 pounds of steam per hour at 1,400° F.

2. An oxygen preheater to deliver 6,000 s.c.f.h. of oxygen at 1,000° F.

3. A fluidized feeder to hold 4,000 pounds of coal and to be capable of feeding at 600 p.s.i.g. and at rates up to 1,000 pounds per hour. Feeder is 32 feet high and 3 feet in diameter.

4. A gasification chamber consisting of a water-cooled reaction chamber with a water-cooled slag hopper for the generation of 18,000 s.c.f.h. of synthesis gas. Size of reaction chamber, 1 ft. in diameter by 4 ft. long. Over-all vessel dimensions, 30 inches in diameter by 12 feet long.

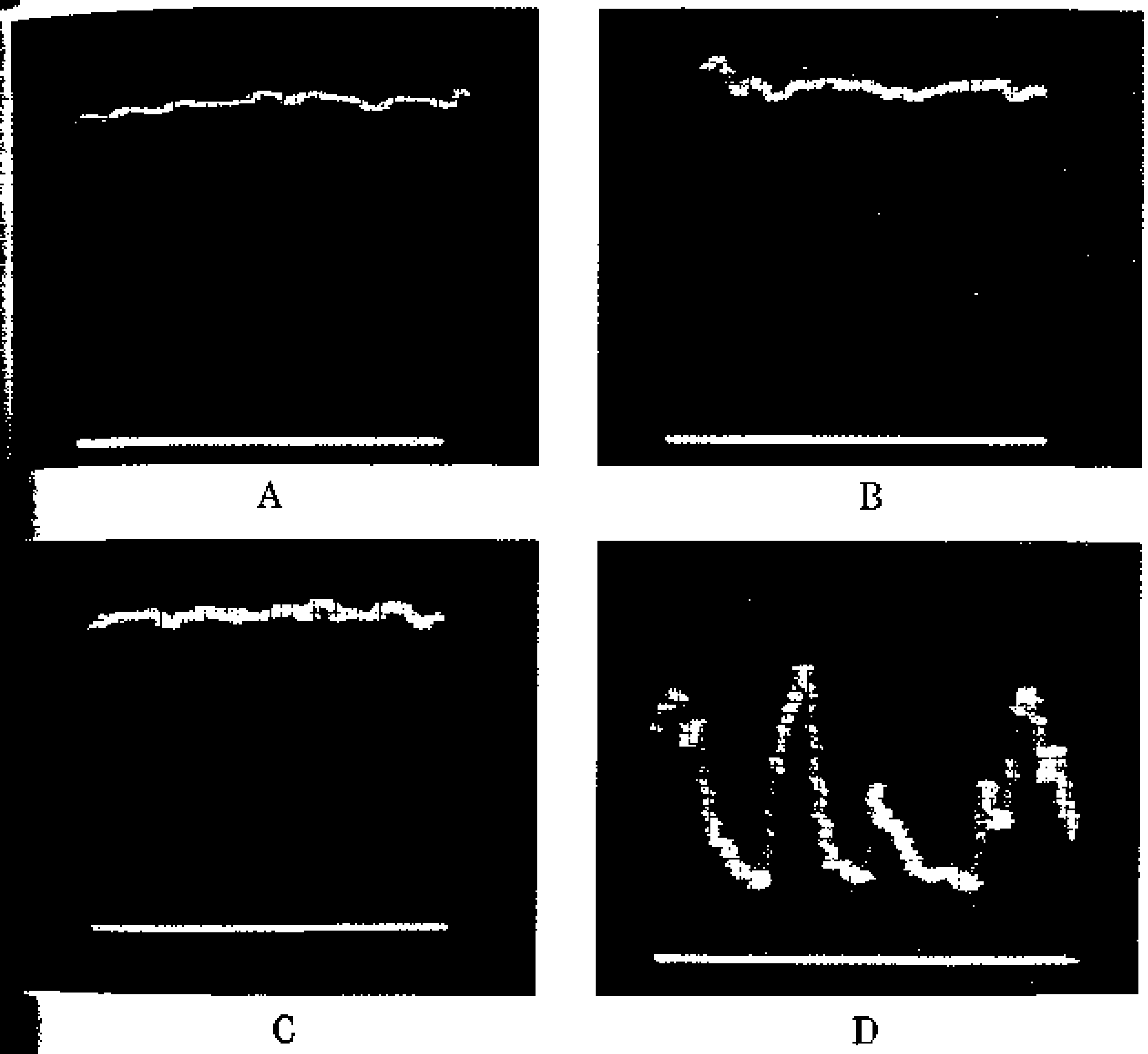

Figure 70. - Oscilloscope photographs showing effect of inlet shield on uniformity of flow.

5. A scrubber to cool and partly clean the generated synthesis gas. Vessel is 24 inches in diameter by 13 feet long.

Requests for bids were solicited, and the Babcock & Wilcox Co. was awarded the contract for the detailed design and fabrication of the vessels and superheaters.

In addition, the following pieces of equipment have been ordered:

1. A compressor to compress 100 c.f.m. of synthesis gas to a discharge pressure of 650 p.s.i.g.

2. A recycle compressor, which is a special development of a centrifugal compressor, to circulate 5,000 s.c.f.m. of fluidizing synthesis gas.

3. A boiler feed pump of 3 g.p.m. capacity at a discharge pressure of 750 p.s.i.g.

4. A high-pressure water pump of 30 g.p.m. capacity and discharge pressure of 600 p.s.i.g.

Pipe fittings and valve orders are 90 percent complete for the pilot plant.

Instrument orders are 60 percent complete.

Construction of the actual pressure gasification pilot plant is scheduled to start February 1, 1950.

Atmospheric Gasification

Complete vessel-design lay-outs and piping drawings were made for a dust-purification train to clean 20,000 s.c.f.h. of synthesis gas. This train consists of a fogging chamber where the gas is cooled by direct water admission to simulate the cooling done in a large plant by a waste heat boiler. After leaving this chamber, the gas goes through a battery of "Aerotec" cyclone separators and a washer-cooler packed with Raschig rings.

Final dust removal is accomplished by a Cottrell precipitator. The cleaned gas is measured in a lobe-type meter.

Miscellaneous

Made up lay-outs and piping drawings for a compressor room for the Morgantown station to house three air compressors and one high-pressure gas compressor.

Detailed a proposed atmospheric feeder to be used in conjunction with a coal pump to feed the combustion chamber in Locomotive Development Committee's gas-turbine locomotive.

Conferred with Ordnance Department of the United States Army and the Heyden Chemical Corp. on the possibilities of using pressure gasification from coal to reduce the cost of ammonia synthesis gas now made from coke.

Gas Treating and Testing

Analytical Work

This laboratory continued to perform the usual control tests and routine analytical determination needed for correlating data obtained from the pulverized-coal gasification experiments.

Many of the analytical methods that had been developed using a simulated synthesis gas required additional investigation to establish their validity when applied to raw synthesis gas as produced at this station. Unsaturated hydrocarbons, such as ethylene and butylene, are known to vitiate the isatin test for thiophene sulfur; but laboratory tests at Morgantown showed that these compounds, if present in the gas in amounts less than 3 percent by volume, do not affect the accuracy of the method. Similarly, the platinum spiral method for organic sulfur determinations had been developed using a 50-50 hydrogen-carbon monoxide mixture as the carrier gas. Further study showed that our synthesis gas, as produced, does not preclude the use of the spiral method, since 100-percent conversion of organic sulfur compounds to hydrogen sulfide is obtained if the gas under test contains as little as 15 percent hydrogen.

The determination of solid and liquid impurities in synthesis gas has been found especially difficult owing to water droplets mixed with the dust in crude and partly purified gases. Suitable methods have been developed and numerous tests made on the raw and purified synthesis gas.

Work is progressing on a photoelectric method for dust determination on highly purified gases.

Bench-Scale Purification Experiments

Various methods for desulfurizing synthesis gas have been investigated. These studies include catalytic conversion experiments, employing both fixed and fluidize beds, and activated-carbon adsorption tests at atmospheric and elevated pressures.

One type of desulfurization catalyst that has been studied is a material which, when reduced and sulfided, reacts catalytically, converting organic sulfur to hydrogen sulfide in the presence of high concentrations of hydrogen sulfide. The organic sulfur, although not completely removed, is so greatly reduced that activated carbon can be used economically for fine purification.

Another type of catalyst which is being investigated and which, from preliminar cost estimates, appears to be more promising than the former is one that removes the hydrogen sulfide and organic sulfur simultaneously by means of catalyst absorption. Whenever the catalyst becomes fouled with sulfur, it is revivified by means of air and steam.

Two catalysts of this latter type have been tested. At space velocities as high as 3,000 s.c.f. per cu. ft. catalyst per hr. and with a catalyst bed temperature of 450° F., both catalysts completely converted all the organic sulfur (with the exception of thiophene) to hydrogen sulfide, and until the catalyst became fouled had removed 99 percent of the hydrogen sulfide from the gas. At the same space velocities but with a lower catalyst bed temperature of 300° C., the outlet gas is completely free of hydrogen sulfide but the organic sulfur conversion is somewhat less, averaging 98.5 percent. Whenever the catalysts are revivified, approximately 50 percent of the sulfur absorbed is burned off as sulfur dioxide;

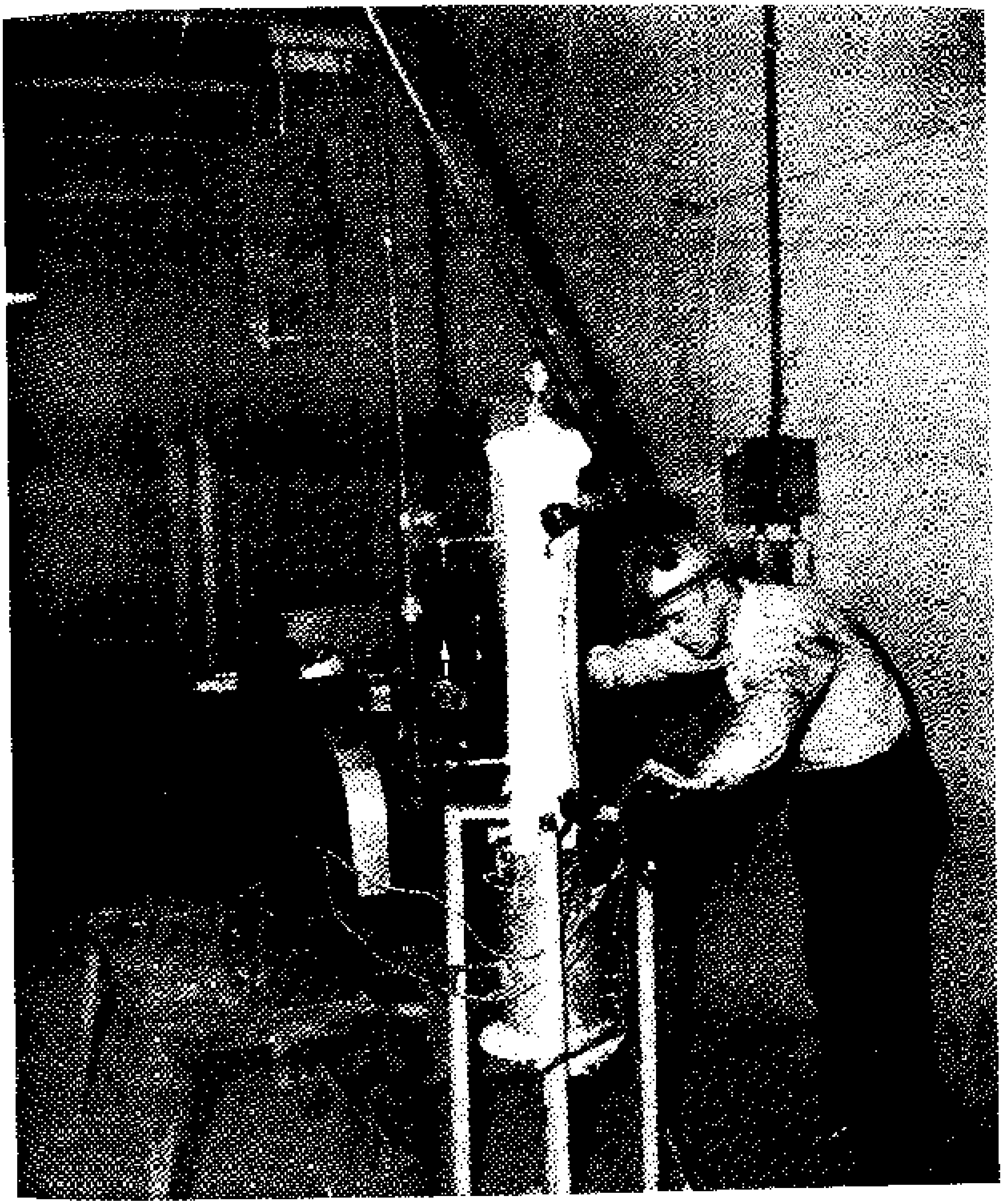

Figure 71. - Fluidizer used in simultaneous catalytic removal of hydrogen sulfide and organic sulfur.

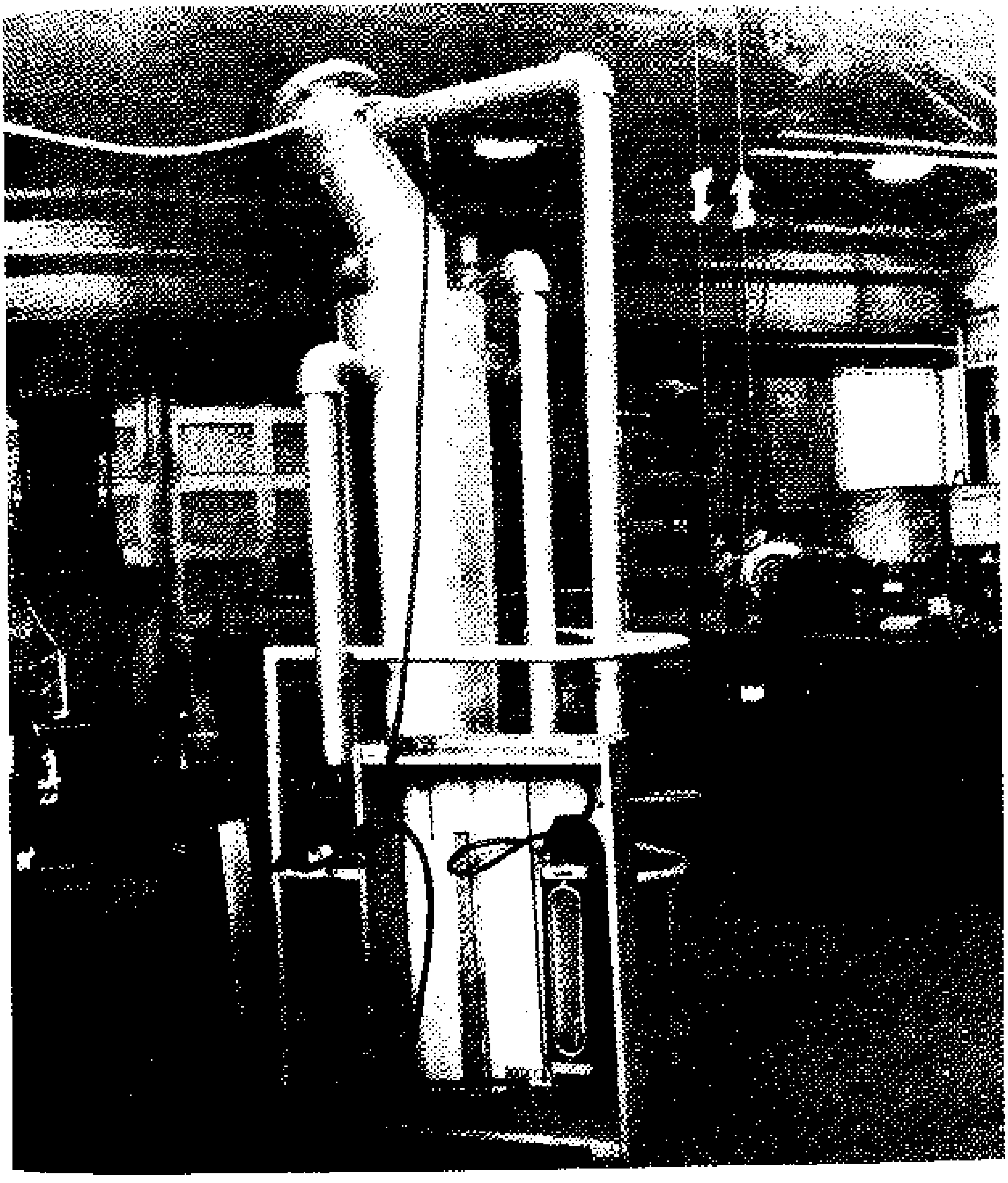

Figure 72. - View of top section of moving-bed filter used in removing dust from gas.

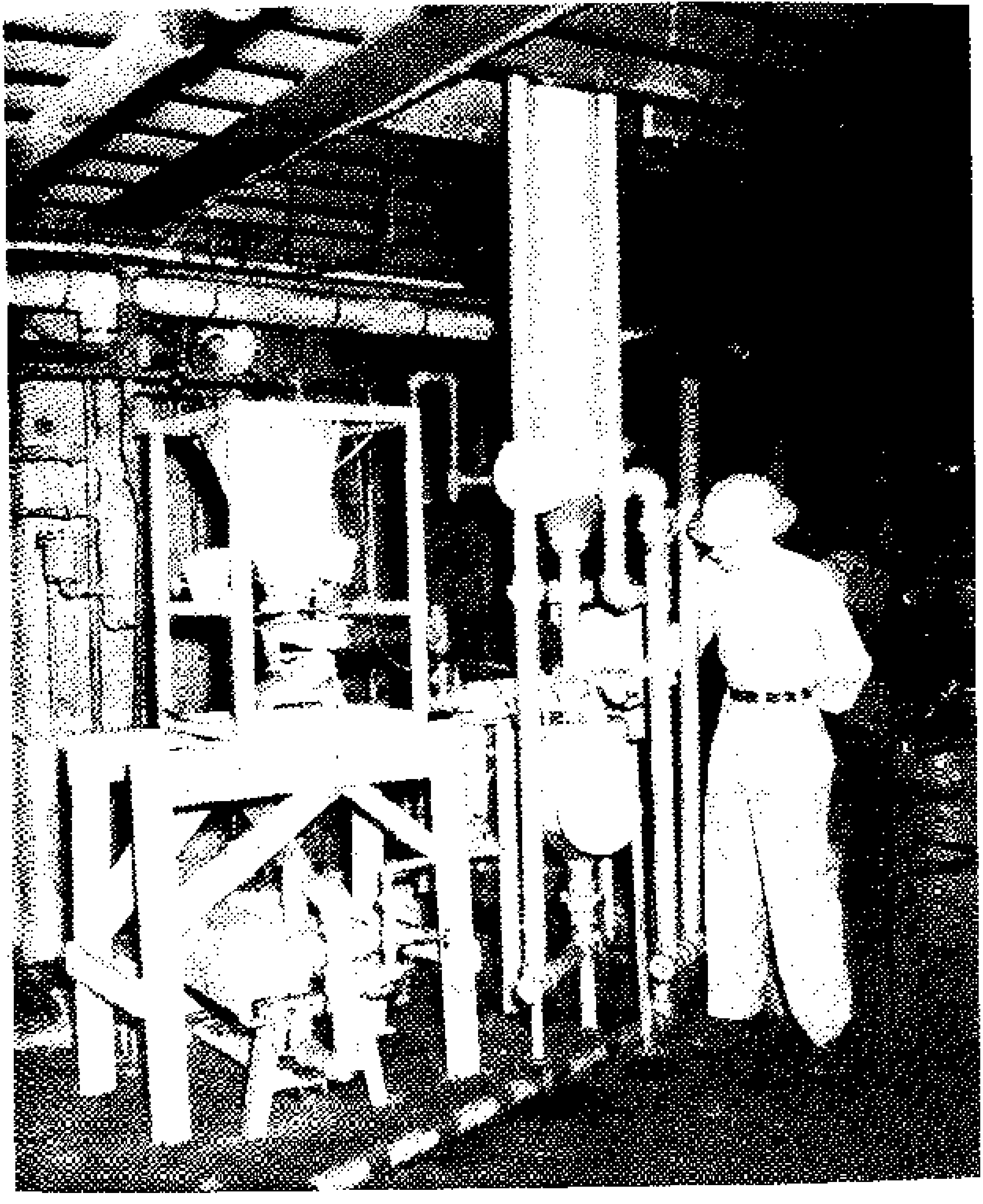

Figure 73. - Bottom section of moving-bed filter.

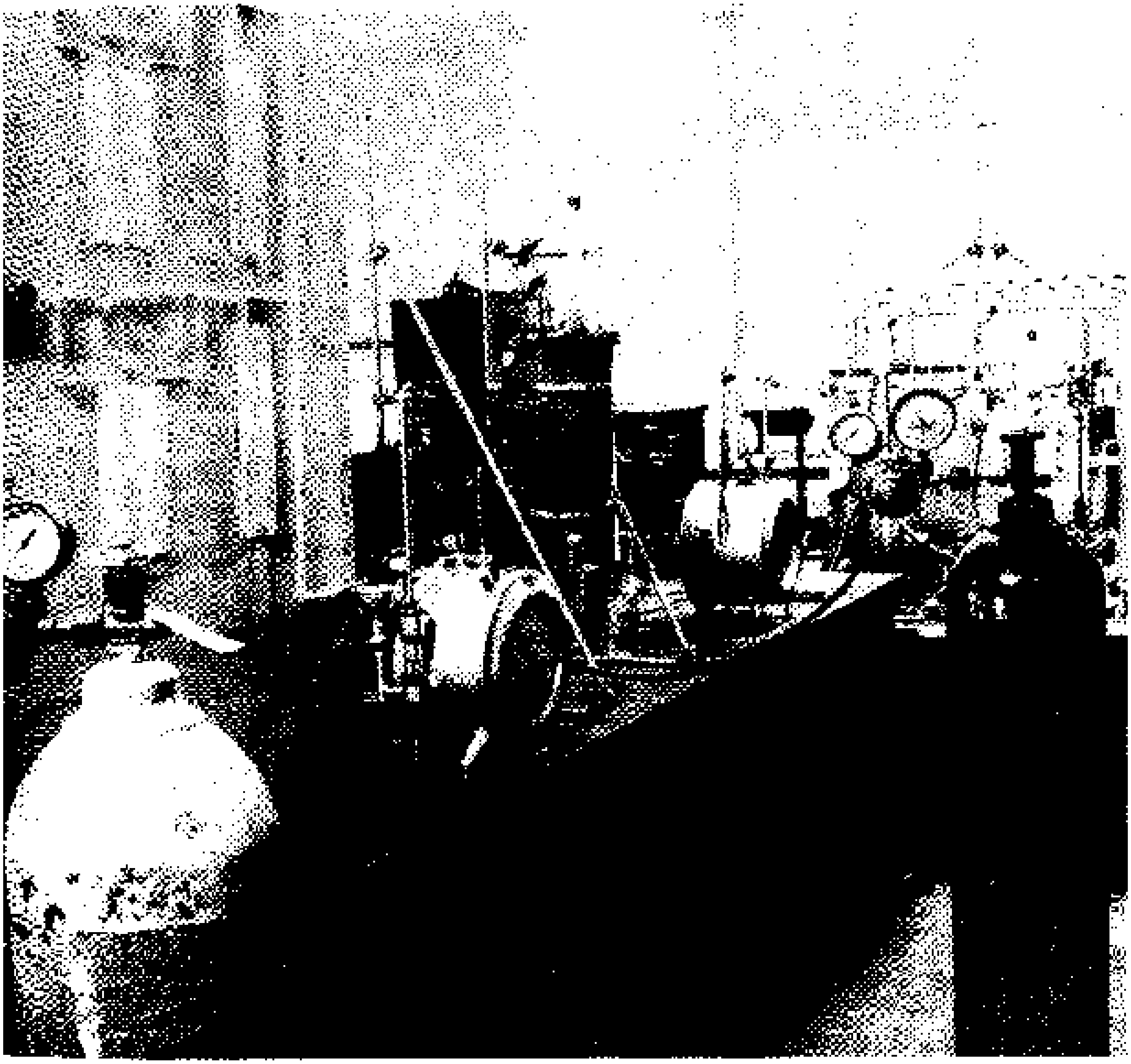

Figure 74. - Bench-scale apparatus for reverse-shift-reaction tests.

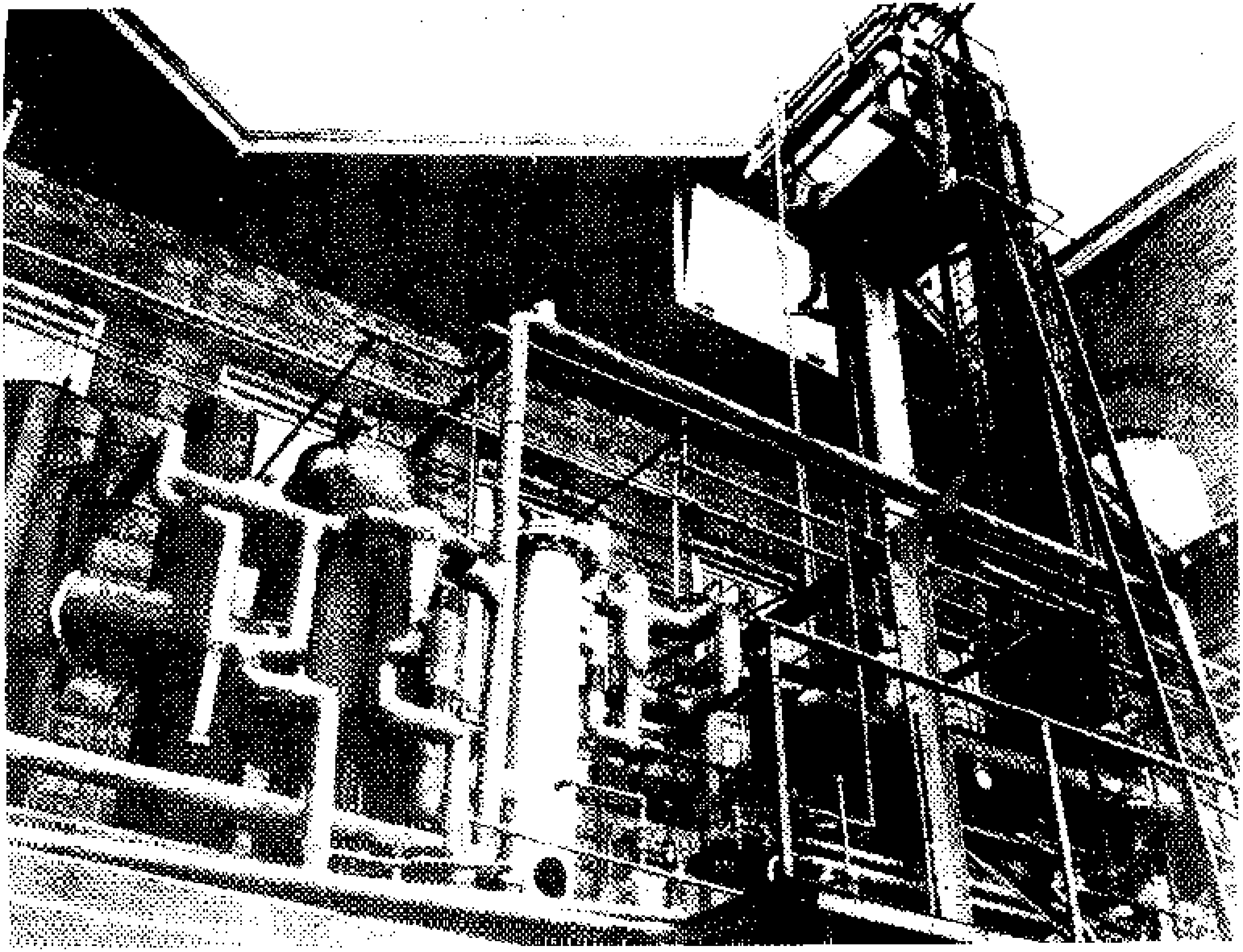

Figure 75. - Gas-purification pilot plant.

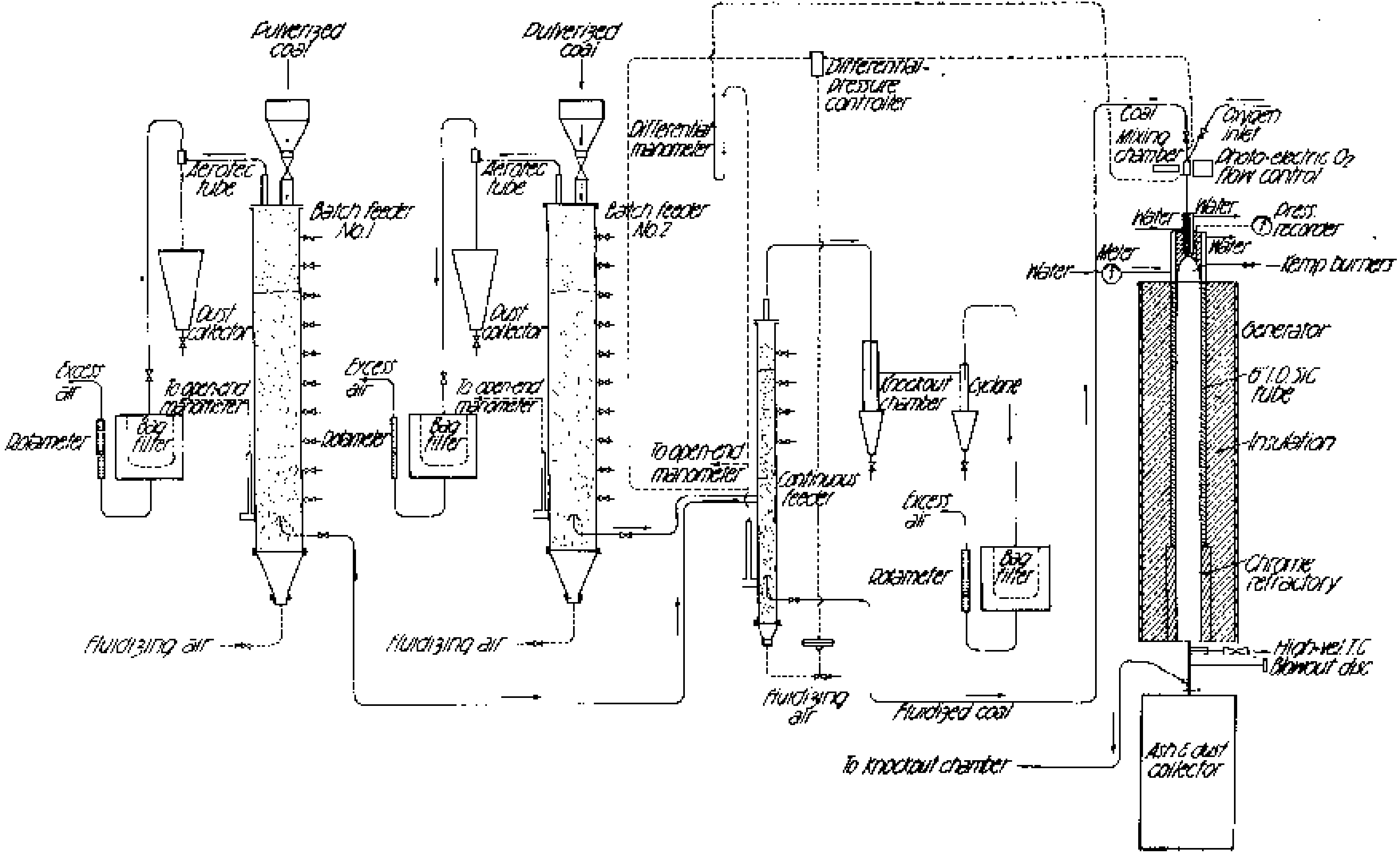

Figure 76. - Flow diagram of pneumatic feeding system and generator in latest stage of development for powdered-fuel gasification in laboratory-scale pilot unit.

the remaining goes to the sulfate of the metal. Upon subsequent reduction the sulfate is decomposed to the metal and sulfur dioxide. Laboratory experiments have shown that the sulfur dioxide given up by freshly revivified catalyst can be effectively removed from the gas by passing it over some fouled catalyst.

Fixed-bed operation of these catalysts has the disadvantage of being a cyclic process, thereby increasing catalyst cost. Preliminary studies have been made to determine the efficacy of this type of catalyst in a fluid bed (fig. 71). Initial results showed that more than 99 percent of the hydrogen sulfide and 97 percent of the organic sulfur are removed.

Numerous tests have been made on the removal of organic sulfur from gas with activated carbon at atmospheric as well as elevated pressures. The effect of carbon dioxide on the adsorption of carbon oxysulfide is being investigated.

Extensive tests were made on removing dust from gas using a moving bed filter designed after the German shaft filter. The filter (figs. 72 and 73), which consists essentially of a moving bed of coke or pumice as the filtering medium, has been found particularly successful, reducing dust concentrations from 1,000 to less than 0.1 grain per 100 cubic feet.

Experiments on the reverse shift reaction (fig. 74) are also underway. If such a process proves economical it may be advisable to produce gas with a high hydrogen:carbon monoxide ratio and then obtain the desired ratio by means of the reverse shift.

Purification Pilot Plant

A gas-purification pilot plant has been constructed (fig. 75) and is ready for operation. It has a capacity of 500 cu. ft. of gas an hour at atmospheric pressure and has provisions for studying catalytic conversion of organic sulfur, liquid purification, and dry box removal of hydrogen sulfide, and activated charcoal activities. The piping arrangement is such that any of the processes which appear promising on a laboratory-scale basis can be tried on the pilot-plant scale.

At present provisions are being made to operate the plant at elevated pressures.

Laboratory-Scale Powdered-Coal Gasification

Considerable improvements made in the laboratory-scale pilot plant for the continuous production of synthesis gas from powdered coal resulted in a simple, easily controlled process that is well-suited for testing various types of fuels for their utility in making synthesis gas on a commercial scale.

More than 60 gasification runs have been carried out to date. Up to 1,200 cubic feet of high-quality synthesis gas, containing 6 to 7 percent carbon dioxide, has been produced in an hour from the gasification of 25 to 55 pounds of finely powdered coal. Substitution of a pneumatic coal-feeding system (fig. 76) for the former Syntron feeder permitted charging the coal into the generator at a more constant rate and a considerably increased throughput. These, and very thorough mixing with oxygen before injection into the generator, resulted in substantial improvements in the quality of the synthesis gas produced, in the percentage of coal gasified per pass and in the thermal efficiency of the process.

A self-explanatory flow diagram (fig. 77) shows the silicon-carbide lined, 6-inch-diameter generator unit 7 feet in length, in which virtually any type of coal (regardless of its ash or sulfur content), pulverized so that 70, 80, or 90 percent passes a 200-mesh screen, may be gasified. The same flow sheet also shows the synthesis-gas purification train and the accessory units. Two Kemp low-pressure industrial burners installed in the water-cooled generator head, using premixed natural gas and air, are used to preheat the generator before each run to temperatures ranging from 2,400° F. on the top to 1,600° F. at the bottom.

Each run is started by shutting off the preheat burners and charging the powdered coal, carried by the oxygen into the generator head at a velocity of about 120 feet per second, with or without steam in addition to that formed from the moisture and combined water in the coal. The coal is gasified in entrainment (suspension) in a turbulent atmosphere, and the residual extremely fine carbonaceous residue plus fly-ash are carried along by the raw synthesis gas into the subsequent dust recovery units. Two pictures (figs. 78 and 79) show the external appearance of these units located on two floors below each other and the control board on the upper floor.

In spite of the comparatively small size generator, the heat losses were reduced to about 6 percent when coal was charged at a rate of 50 pound per hour. This has permitted thermodynamic calculation of the operating results, such as composition of the gas made, oxygen requirement per 1,000 cubic feet of synthesis gas, etc., under assumed zero heat loss conditions as obtaining in gasification on commercial scale. Calculations also have been made of the percentage of carbon in coal gasified and other operating results under thermal-balance conditions upon the assumption of charging superheated steam at various rates or introducing oxygen at various ratios to coal gasified.

Thus, it was found, for example, that, if the 5.7-percent heat loss obtained in a given run3/ were eliminated, the percent CO_2 in the gas would drop from 7.1 to 2.2, the volume ratio of H_2:CO would decrease from 0.63 to 0.46, the outlet temperature of the make-gas would increase from 1,820° F. to 3,200° F., the oxygen requirement would decrease slightly from 350 to 346 cubic feet per 1,000 cubic feet of CO + H_2, and the steam decomposition would decrease from 84 to 65 percent. However, upon increasing the steam:dry coal weight ratio from 0.06 to 2.23 4/ under thermal balance conditions, the percent CO_2 would increase to 21.1 percent, but the volume ratio of H_2:CO would increase to 2.20. The outlet temperature of the make-gas would drop back to 1,800° F., the oxygen requirement would decrease further to 204 cubic feet per 1,000 cubic feet of CO + H_2, only 36 percent of the steam would decompose, and 85 percent of the carbon in the coal would gasify.

The silicon carbide lining of the generator was found to have a limited life under the severe conditions to which it is exposed, such as repeated heating and cooling, abrasion, effects of slagging coal ash, and strongly oxidizing atmospheres at the top. The upper part of the lining (fig. 80) must, therefore, be replaced after a period equivalent to about 100 days of continuous use.

The carbonaceous residue, containing 25 to 30 percent of ash, can be recycled for a second pass through the generator, either alone or in admixture with fresh coal. However, owing to its extremely fine particle size (50 percent less than 7.5 microns and highly fluffy consistency (bulk density) 2.0 to 2.5 pounds per cu. ft.)

3/ Run 46. Coal feed-rates: 44.6 lb./hr.; oxygen:coal ratio, 0.55, and steam:coal ratio, 0.06 lb./lb. of dry coal. All these are fixed, and the percentage of carbon in coal gasified (59.5%) is assumed to remain constant.

4/ A temperature of 2,100° F. assumed for the steam introduced.

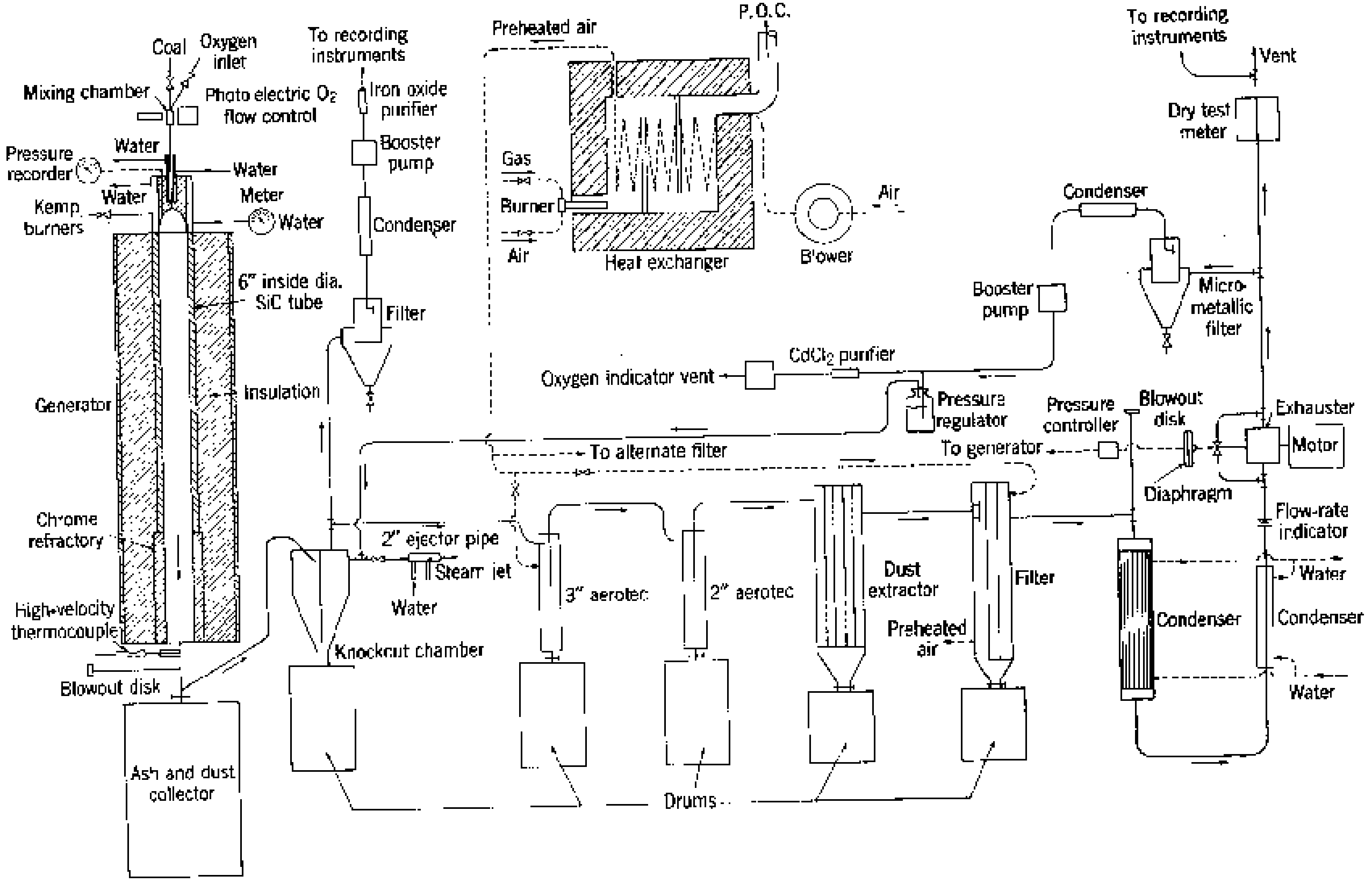

Figure 77. - Flow diagram of generator and synthesis-gas-purification train in latest stage of development for powdered-fuel gasification in laboratory-scale pilot unit.

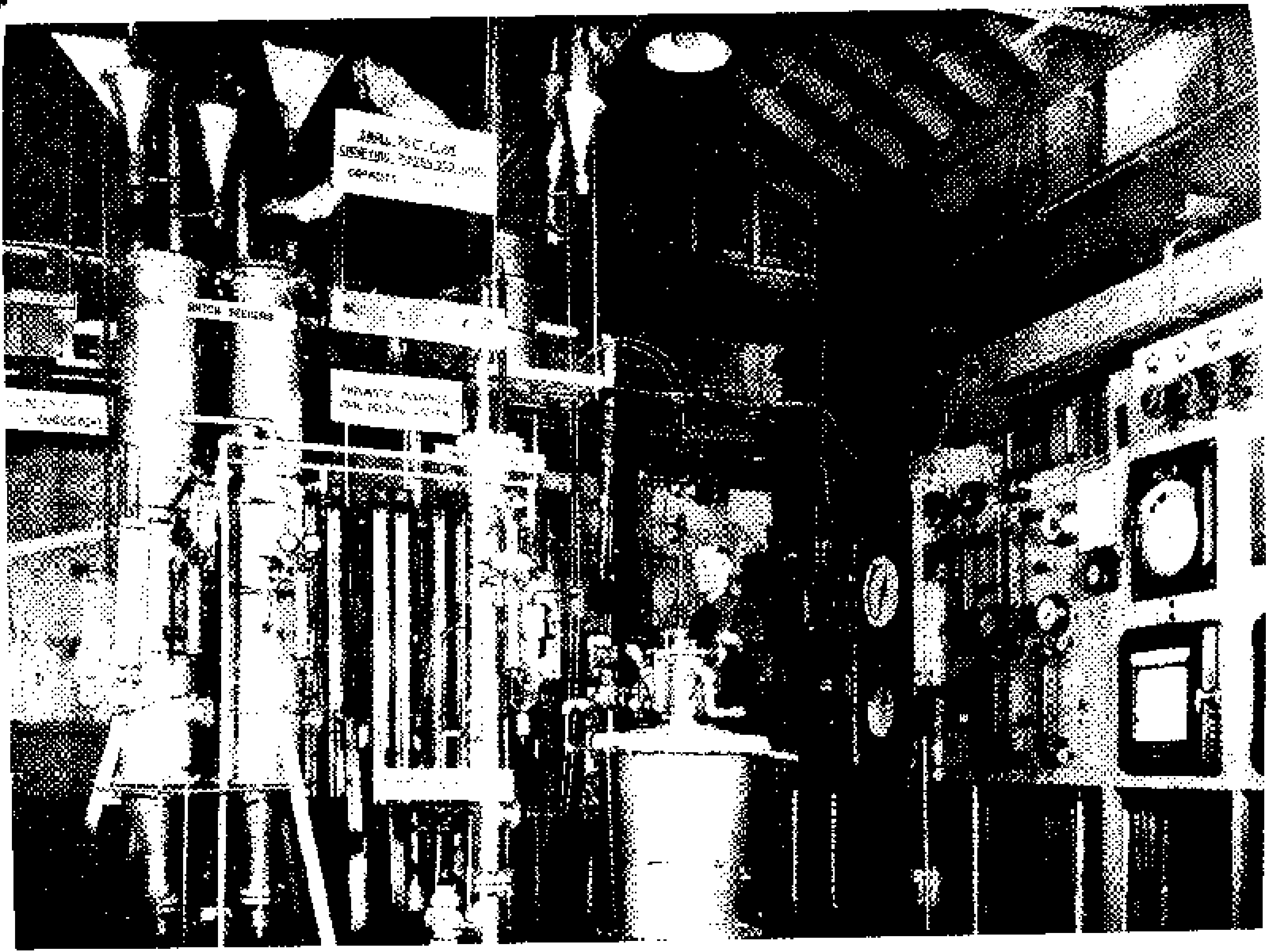

Figure 78. - Laboratory-scale pilot unit (upper floor) for powdered-fuel gasification in latest stage of development.

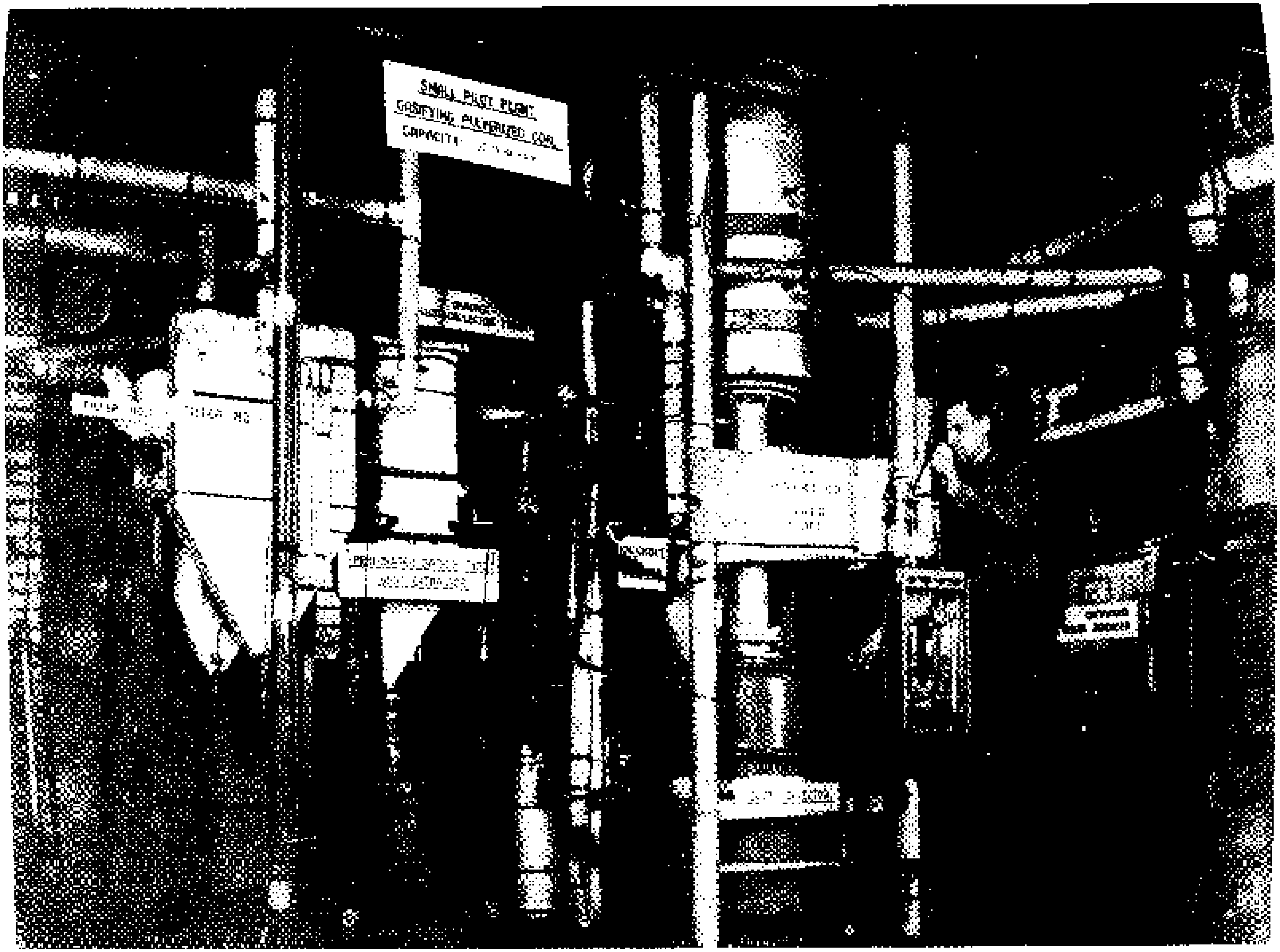

Figure 79, - Laboratory-scale pilot unit (lower floor) for powdered-fuel gasification in latest stage of development.

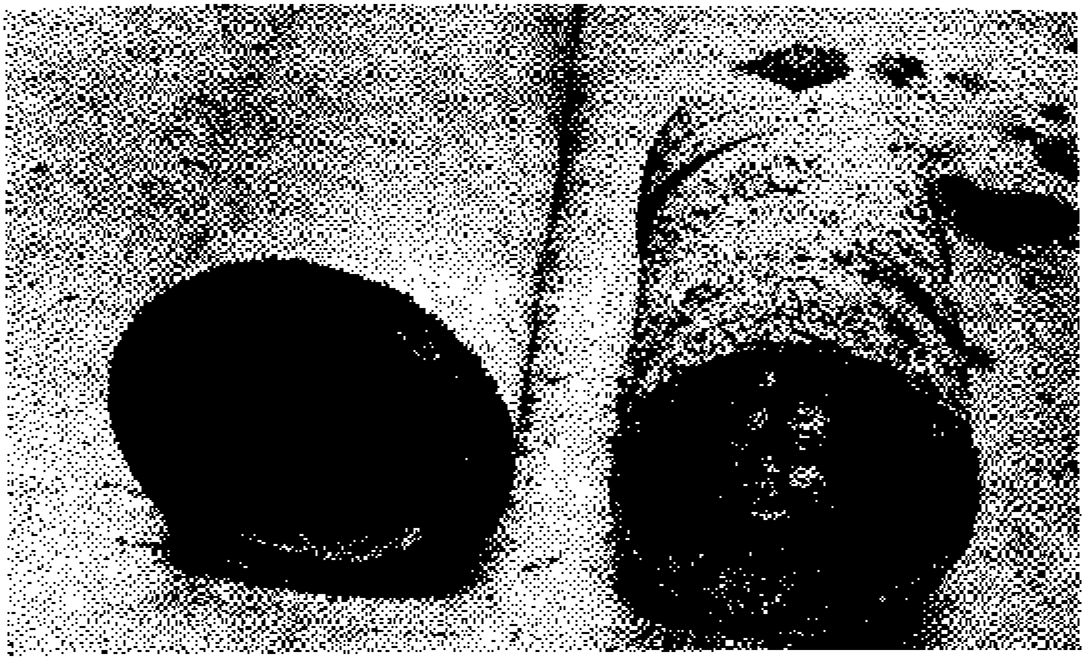

Figure 80. - Silicon carbide generator lining, originally 1 inch thick and 6 inches I. D., before and after 114 days of equivalent continuous use.

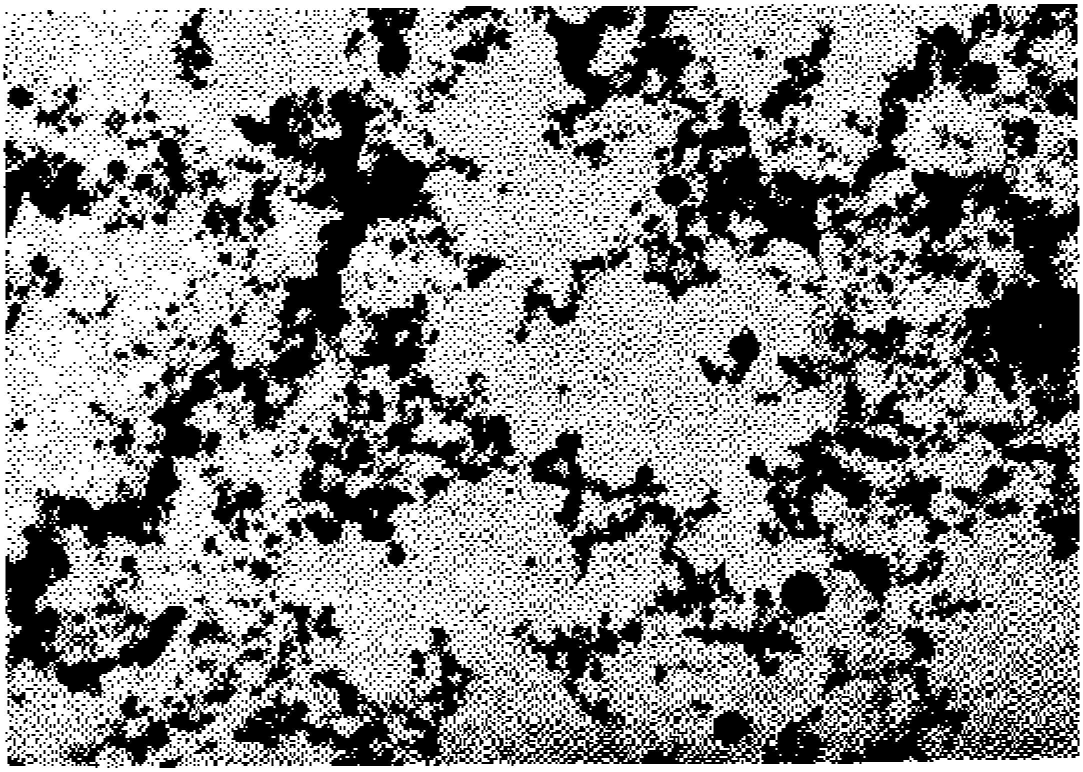

Figure 81. - Electron micrograph of extremely fine carbonaceous residue at high magnification (44,000 X) collected in an Aerotic tube of laboratory-scale pilot unit for powdered-coal gasification.

the residue might find industrial utilization for certain purposes at a lower cost than carbon black. Electron micrographs (see fig. 81) reveal a very close similarity to commercial carbon blacks. The carbonaceous residue also can be burned in standard equipment, using powdered coal for underfiring boilers.

APPENDIX. - BIBLIOGRAPHY OF PAPERS AND REPORTS PRESENTED AND PUBLISHED DURING 1949

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