Laboratory-Scale Powdered-Coal Gasification

A simple, easily controlled method was developed for the gasification of 10 to 40 pounds of powdered coal per hour in entrainment in oxygen and steam.[4] This unit was built to study the operating variables on which the efficiency and cost of gasification depend. The most essential of these variables are the type of coal and its degree of pulverization, coal throughput per unit time, oxygen:coal and steam:coal ratios, and temperature and pressure maintained in the gasification chamber. Optimum process efficiency and production cost should result from the most favorable combination of these operating conditions. The apparatus developed can be operated continuously, using various types of fuel, such as high-volatile or low-volatile, high- or low-ash, coking or noncoking coals, for the purpose of studying their synthesis-gas-making properties.

A flow diagram (fig. 58), which embodies a few essential modifications on the apparatus used before its present stage of development, shows the coal-feeding system, the generator chamber, and the subsequent dry-gas purification system before the synthesis gas is metered, tested, and either stored or vented. The gas-sampling arrangement and instrumentation are shown on a separate flow diagram (fig. 59).

The coal, pulverized so that 80 to 90 percent passes a 200-mesh-per-inch screen, is charged into the generator by means of a Syntron feeder. From a 1.25-cubic foot conical feed hopper, in which the coal is kept in a moderately turbulent state by means of fluidizing nitrogen or natural gas, the charge is fed into a 2-inch-diameter horizontal tubular trough. Both the hopper and the trough are vibrated by a pulsating D. C. current, which moves the charge and drops it at a uniform rate into the water-jacketed generator head.

The fluidizing nitrogen or natural gas is conducted through a 1/2-inch pipe into the top of the generator head, preventing thereby the upward surge of steam or oxygen toward the mouth of the feed tube. A scale on which the feeder machine rests indicates the weight of coal charged in each 3-minute period. Fluidization of the charge in the feed hopper was found to improve the variations in the feed rate from ± 25 percent to ± 5 to 10 percent over any 3-minute period.

Before each run, the 7-foot-long, 6-inch-interior diameter generator chamber, whose upper 5-foot length is lined with silicon carbide, is preheated by two Kemp industrial burners, using premixed natural gas and oxygen. When the upper half of the silicon carbide lining reaches a temperature of about 2,400° F., the run is begun by shutting the burners off and starting the feeding of the coal and the introduction of oxygen. Steam can be added by passing the oxygen used for gasification through water at constant temperature, which permits a close control of the ratio of steam to oxygen.

The fine-coal particles charged into the generator rapidly become entrained in turbulent eddy currents resulting from the impingement of the two oxygen-steam jets. The carbon in the coal reacts with oxygen to form carbon monoxide and with steam to form carbon monoxide and hydrogen, in addition to some carbon dioxide. Carbon in the coal being in excess, the carbonaceous residue of gasification is carried along in entrainment by the downward flow of "make" gas. Particles of slag and coarse

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4/ Sebastian, John J. S., Edeburn, P. W., Bonar, F., and Schmidt, L. D., Development of Synthesis-Gas Process in Experimental Unit Operating on Entrained Powdered Coal: Paper presented before the Gas and Fuel Chem. Div., Am. Chem. Soc. meeting, St. Louis, Mo., Sept. 6-9, 1948.

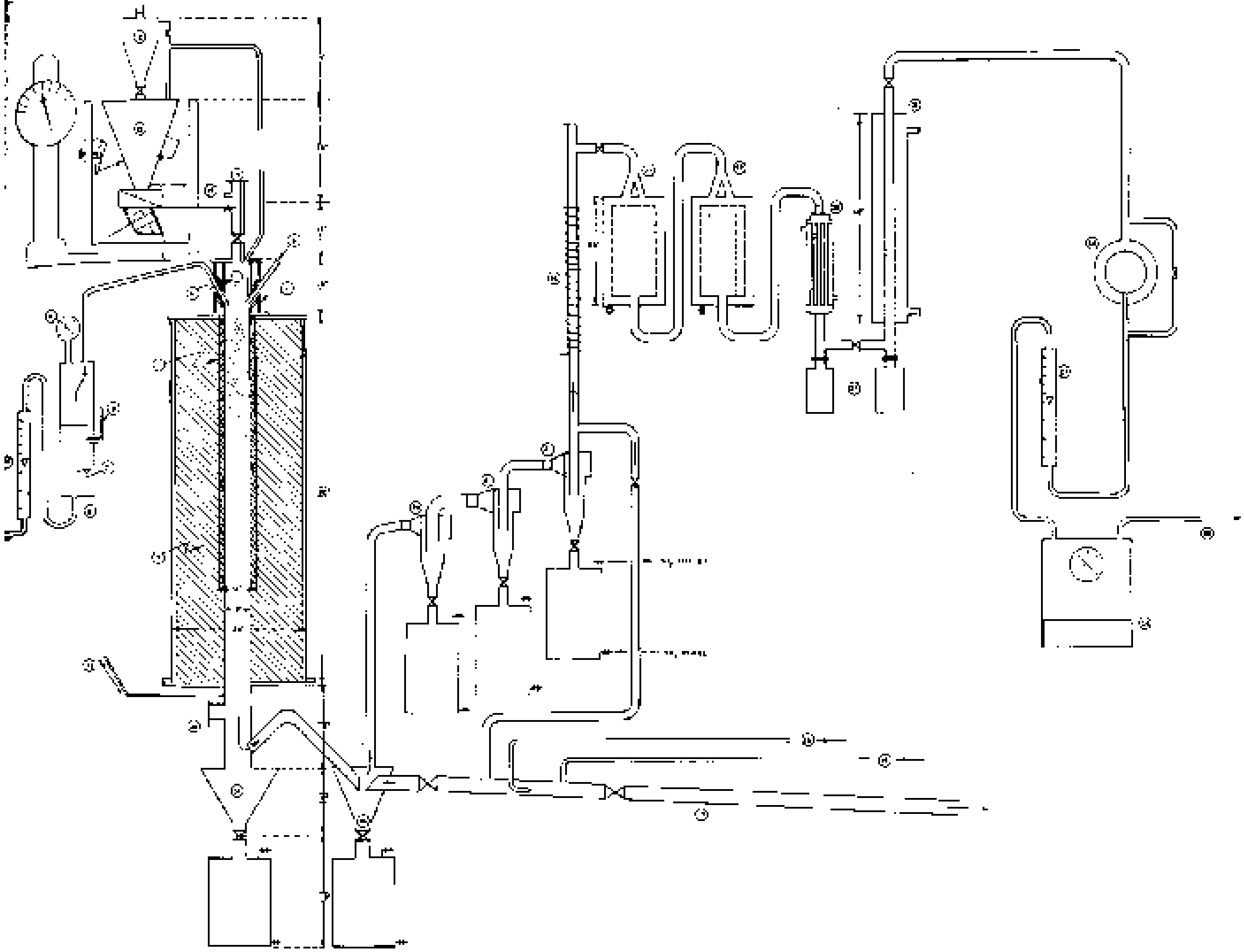

Figure 58. - Flow diagram of small pilot plant for powdered-coal gasification.

KEY:

- Silicon carbide generator tube.
- Water-cooled jacket.
- Oxygen jets.
- Burner ports.
- High-temperature insulating brick.
- Steam:oxygen ratio controller.
- Water.

8. Thermometer.
9. Oxygen.
10. Flow indicator.
11. Pressure gage.
12. Charge hopper.
13. Syntron hopper and vibratory feeder.
14. Feed tube.
15. Rupture disk.
16. Knock-out chamber.
17. 2-inch ejector pipe.
18. Steam to jet.
19. Water.
20. 3-inch Aerotec tube.
21. 2-inch Aerotec tube.
22. Fiberglass filters.
23. Tubular condenser.
24. Condenser water.
25. Secondary condenser.
25. Exhauster.
27. Rotameter.
28. Dry meter.
29. To gas holder.
30. Rupture disk.
31. Slag and residue collector.
32. Heating coil.
33. Gas sample to instruments.

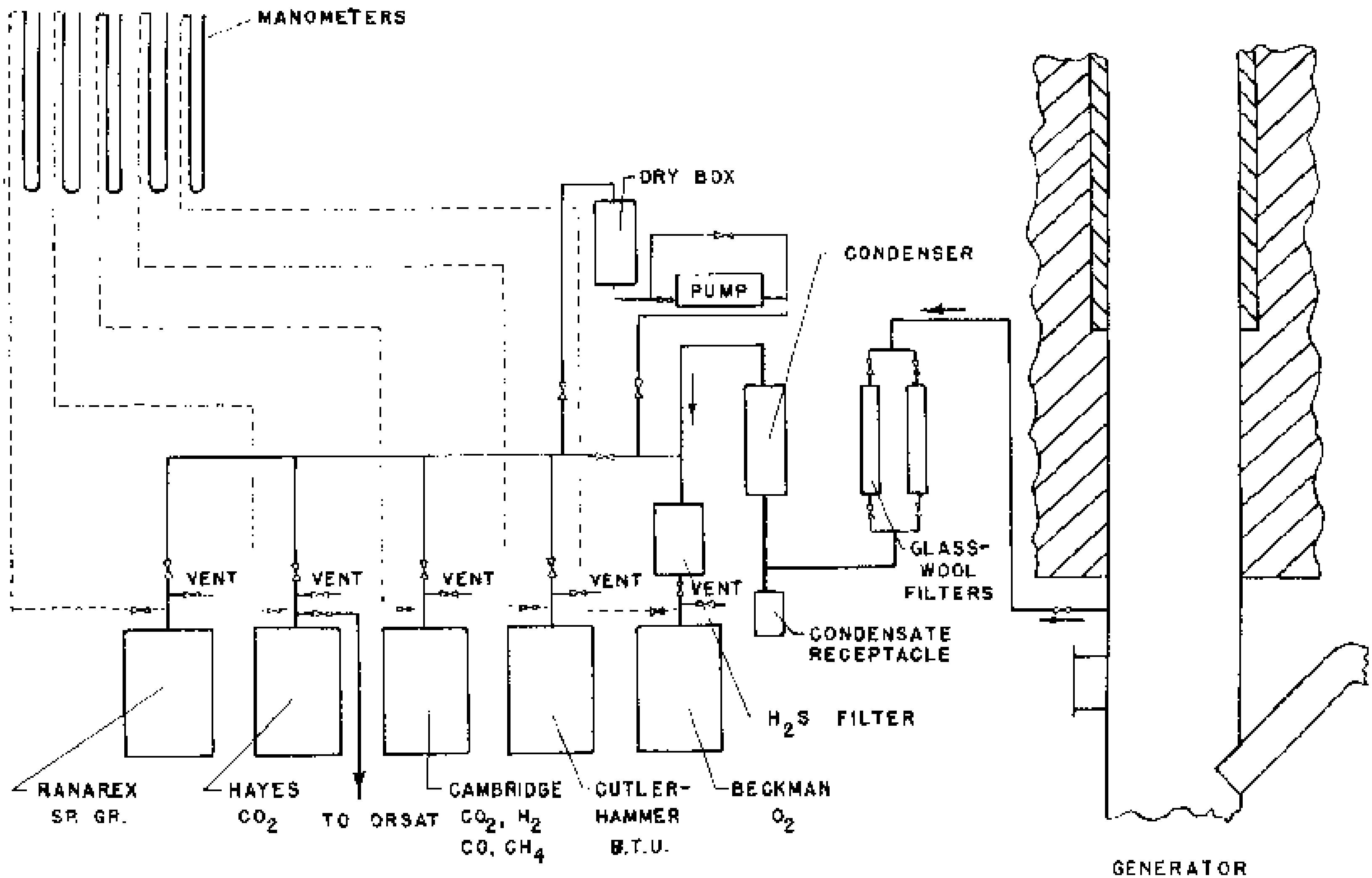

Figure 59. - Gas-sampling arrangement of small pilot plant for powdered-coal gasification.

Laboratory-Scale Powdered-Coal Gasification

A simple, easily controlled method was developed for the gasification of 10 to 40 pounds of powdered coal per hour in entrainment in oxygen and steam.[4] This unit was built to study the operating variables on which the efficiency and cost of gasification depend. The most essential of these variables are the type of coal and its degree of pulverization, coal throughput per unit time, oxygen:coal and steam:coal ratios, and temperature and pressure maintained in the gasification chamber. Optimum process efficiency and production cost should result from the most favorable combination of these operating conditions. The apparatus developed can be operated continuously, using various types of fuel, such as high-volatile or low-volatile, high- or low-ash, coking or noncoking coals, for the purpose of studying their synthesis-gas-making properties.

A flow diagram (fig. 58), which embodies a few essential modifications on the apparatus used before its present stage of development, shows the coal-feeding system, the generator chamber, and the subsequent dry-gas purification system before the synthesis gas is metered, tested, and either stored or vented. The gas-sampling arrangement and instrumentation are shown on a separate flow diagram (fig. 59).

The coal, pulverized so that 50 to 90 percent passes a 200-mesh-per-inch screen, is charged into the generator by means of a Syntron feeder. From a 1.25-cubic foot conical feed hopper, in which the coal is kept in a moderately turbulent state by means of fluidizing nitrogen or natural gas, the charge is fed into a 2-inch-diameter horizontal tubular trough. Both the hopper and the trough are vibrated by a pulsating D. C. current, which moves the charge and drops it at a uniform rate into the water-jacketed generator head.

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The fine-coal particles charged into the generator rapidly become entrained in turbulent eddy currents resulting from the impingement of the two oxygen-steam jets. The carbon in the coal reacts with oxygen to form carbon monoxide and with steam to form carbon monoxide and hydrogen, in addition to some carbon dioxide. Carbon in the coal being in excess, the carbonaceous residue of gasification is carried along in entrainment by the downward flow of "make" gas. Particles of slag and coarse

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residue drop into the "dust collector" below the generator, and residue of medium coarseness is removed by impact against a baffle in the subsequent "knock-out chamber," while the fine residue with some fly ash is removed in the following Aerotec tubes and fiberglass filters, placed in series.

Branching out from the knock-out chamber is a 2-inch ejector pipe for discharging the products of gasification to the outside atmosphere until conditions at the beginning of each run become stabilized.

The generator is run under a slight positive pressure (up to 3 inches of mercury) automatically maintained constant by means of an exhauster, at the end of the train, controlled by a pressure regulator (see figs. 60-61).

The dry-gas purification system has several advantages over the wet method of handling (scrubbers), such as complete recovery of the carbonaceous residue, which may be recycled back into the generator or otherwise utilized. Also, for experimental work on a laboratory scale requiring complete material and heat balances, it is essential not to scrub out any of the impurities or carbon dioxide from the "make" gas. To accomplish these objectives, it was necessary to change over to the dry-handling system.

For the development of the process, a noncoking, high-volatile bituminous coal from Rock Springs, Wyo., No. 9 seam was used. The coal as charged contained 4.5 percent moisture, 4.9 percent ash and 37 percent volatile matter, and its ultimate analysis showed 11.9 percent oxygen and 0.8 percent sulfur.

More than 40 runs have been made, each lasting 1 to 12 hours, under varied experimental conditions. Charging 10 to 40 pounds of coal per hour, a gas yield of 20 to 25 cubic feet per pound of dry coal was usually obtained. The gas made generally contained 25 to 30 percent of hydrogen, 45 to 50 percent of carbon monoxide, 1 to 2 percent of methane, 0.5 to 1.0 percent of oxygen, 0.2 to 0.9 percent of unsaturated hydrocarbons, 10 to 18 percent of carbon dioxide, and 1 to 2 percent of nitrogen. The heating value and specific gravity of the "make" gas ranged from 240 to 310 and from 0.72 to 0.81, respectively.

Owing to unavoidably high heat losses in internally heated gas generators of such comparatively small size, the oxygen consumption, 300 to 400 cubic feet per 1,000 cubic feet of "make"gas, was high as expected. In large-scale production by the same process, the consumption of oxygen would be considerably less, probably only half as much. The total steam consumption, including steam from the moisture originally in the coal and that resulting from the combination of oxygen and equivalent hydrogen in the coal, was 0.18 to 0.22 pound per pound of coal.

The coal consumption was generally 27 to 33 pound per 1,000 cubic feet of gas made, which means 61 to 67 percent of the coal charged actually gasified. The low percentage of conversion of coal into gas is due to the intentional use of excess carbon and a corresponding deficiency of oxygen, which allowed a considerable saving in the cost of oxygen and thus reduced production cost. The intention of the process is recycling of the carbonaceous residue for further gasification. However, the residue obtained from the gasification of Wyoming No. 9-seam coal was found to be so extremely fine and fluffy (its bulk density being 2.0 to 2.5 pounds per cubic foot) that its utilization for other industrial purposes is not excluded. An examination under electron microscope revealed that its particles approach the characteristic shape, structure and size of certain commercially used carbon blacks (see fig. 62). About 50 percent of the particles are less than 7.5 microns in size.

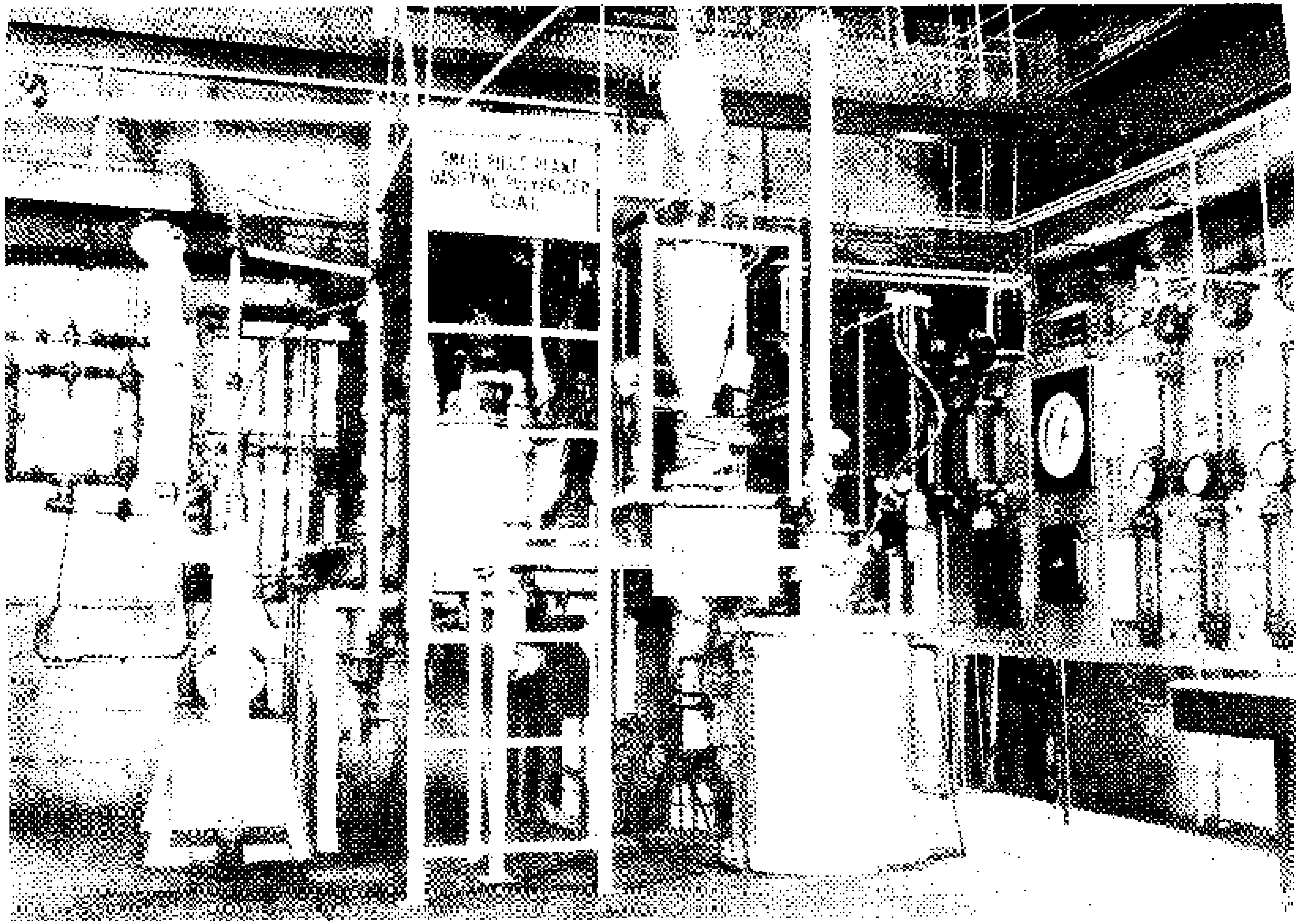
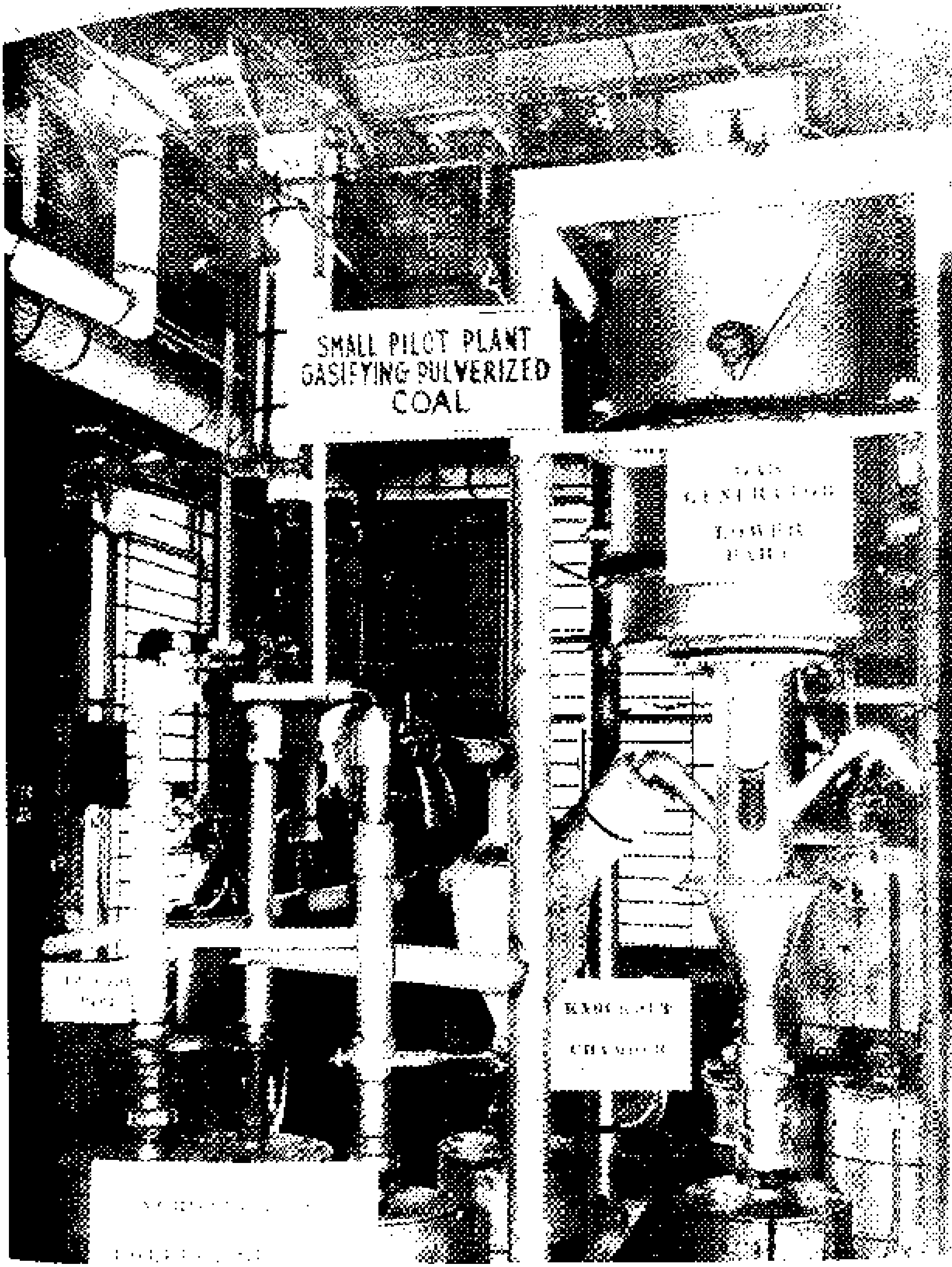
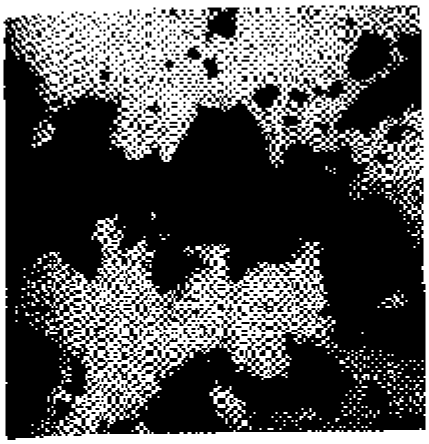


Figure 60. - Upoer section of small pilot plant for gasification of pulverized coal at Synthesis-Gas Production Laboratories, Morgantown, W. Va.

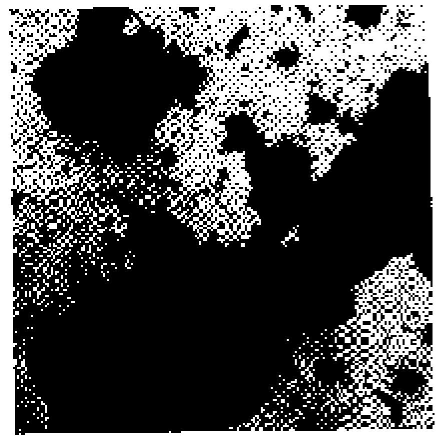


ure 61. - Lower section of small pilot plant for gasification of pulverized coal.

Photomicrographs

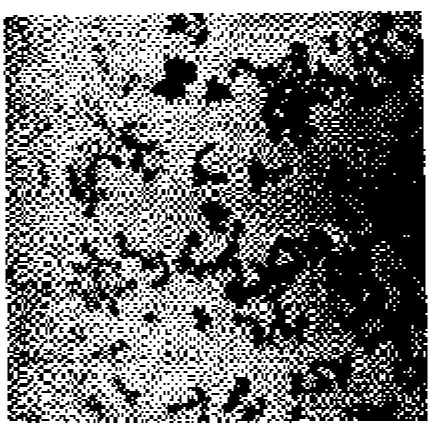


1000 X
Original Coal
91% through 200-mesh

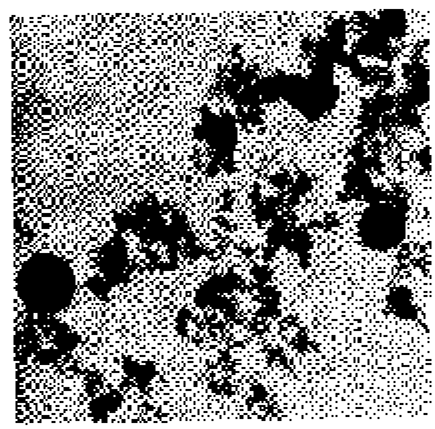


1000 X
Carbonaceous residue
from "Dust Collector"

Electron Photomicrographs



10,500 X
Carbon Black
Explosion of Acetylene
and Natural Gas



11,100 X
Carbonaceous residue
from
"Dust Collector"

Figure 62. - Photomicroscopic views of carbonaceous residue obtained in pulverized-coal gasification.

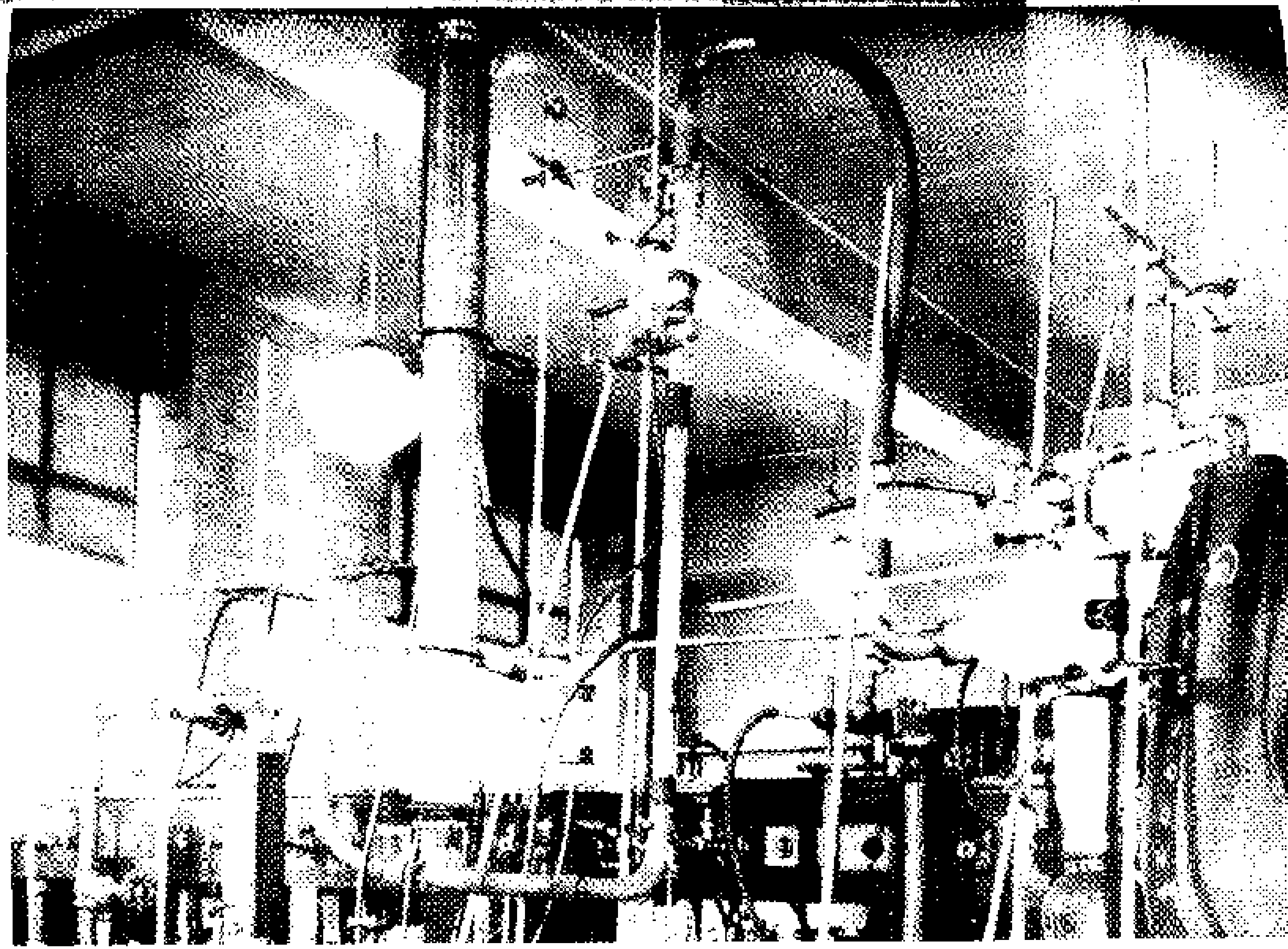


Figure 63. - Apparatus used in studying methods for sampling dust in gas.

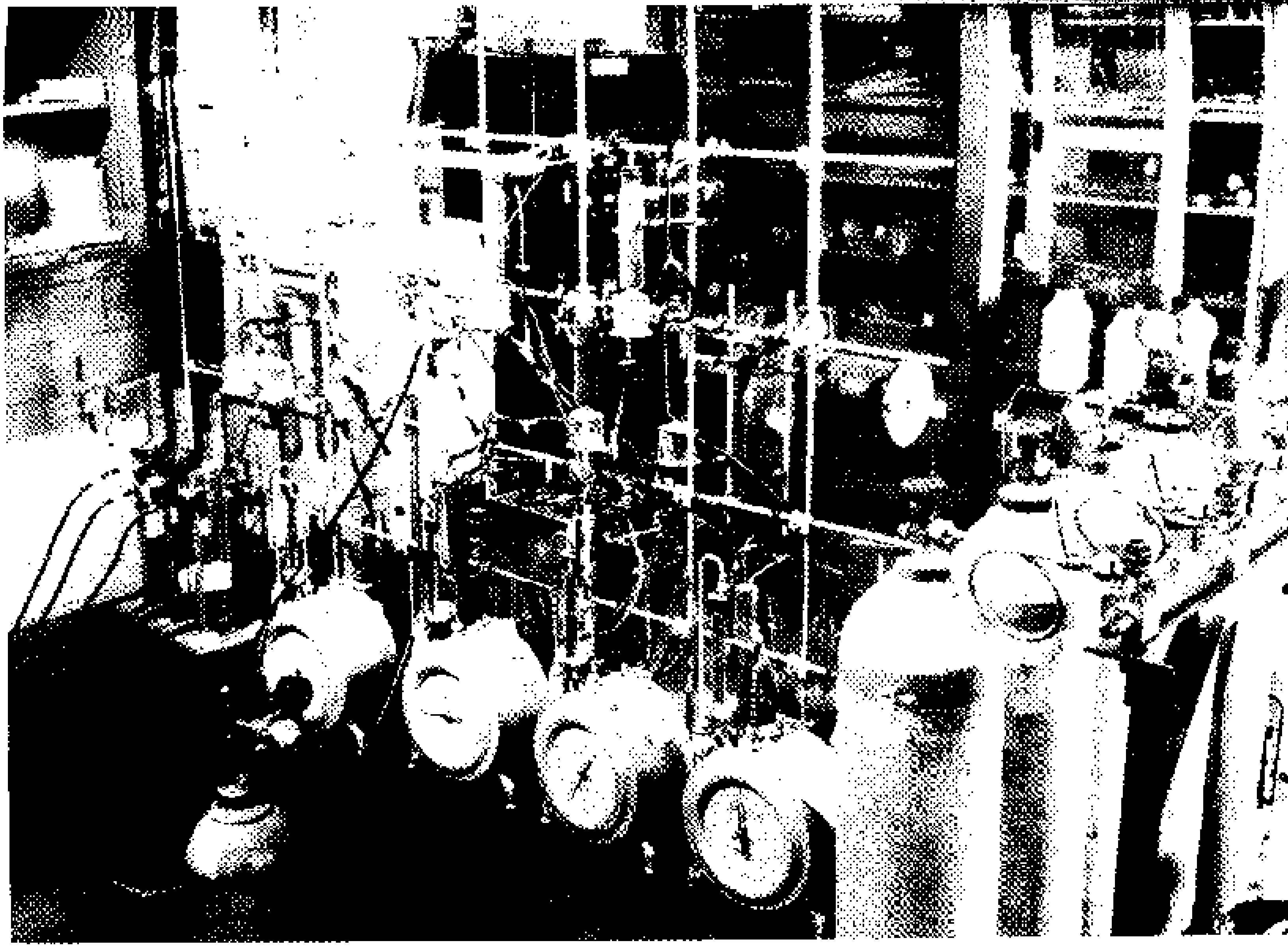


Figure 64. - Apparatus for removing organic sulfur from gas.

Heat-balance calculations showed that the thermal efficiency of the process (100 times ratio of B.t.u. in gas plus residue to B.t.u. in coal) was 74 to 82 percent, notwithstanding the high heat losses encountered due to the comparatively low throughput. The temperature of the generator during the runs was 2,200° to 2,450° F. on the top and 1,250° to 1,750° F. at the outlet on the bottom, depending on the combination of experimental variables. Under these conditions the total steam decomposed was always at least 50 percent.

Synthesis-Gas Treating and Testing

Analytical Work

The Gas Treating and Testing Laboratory carried out the necessary analytical work for the experimental work on pulverized-coal gasification as well as underground gasification. Service aid in the instrumentation for the station also was performed.

Major effort continued to be devoted to the improving or developing of analytical methods required in gas purification. Work continued on the method for determining thiophene sulfur. With this method, thiophene is scrubbed from the gas with sulfuric acid, and as little as 0.0001 grain of thiophene sulfur can be determined in approximately 50 milliliters of acid.

Studies of the determination of very low concentrations of organic sulfur in gas were continued. These studies included a method whereby organic sulfur is converted to hydrogen sulfide by means of a hot platinum spiral and the resulting hydrogen sulfide is determined by the ultra-sensitive methylene-blue test, as developed by this laboratory.

Further studies were made of methods for determining organic sulfur in gas by combustion followed by turbidimetric determination of barium sulfate. This work included application of the spectrophotometer for turbidimetric measurement.

Existing methods for sampling and determination of dust in gas were studied to learn the effect of various variables on their reliability (fig. 63).

Bench-Scale Purification Experiments

Small-scale experiments were made to determine the efficacy of various methods for gas purification. These included work with catalysts for the removal or conversion of organic sulfur (fig. 64), with active carbons for removal of thiophene and gum-forming constituents, and scrubbing solutions for hydrogen sulfide removal. A preliminary study of the pyrolysis of thiophene was undertaken to determine the extent of such decomposition at temperatures that may prevail in the pulverized coal gasification process.

One commercial catalyst was investigated which, while not giving sufficiently complete conversion of organic sulfur, is considered worthy of further study. This catalyst is capable of promoting the conversion of organic sulfur to hydrogen sulfide in the presence of high concentrations of hydrogen sulfide. In pure hydrogen, to which organic sulfur and hydrogen sulfide have been added, conversion is substantially complete, leaving less than 0.1 grain of organic sulfur unconverted per hundred cubic feet of gas. With synthesis gas containing carbon monoxide, however, approximately 2 grains of organic sulfur (carbonyl sulfide) per hundred cubic feet of gas remains unconverted. The catalyst manufacturer is making further studies of the catalyst to improve its performance.