which stoves are operating and to indicate any failures of the mechanism (see fig. 11); this photograph shows the panel-board arrangement. All the valves on the gas, steam, air, and oxygen lines supplying the stoves are standard air-operated diaphragm motor type. Flow control is by hand valves and flowmeters.

The original refractory hot valves in the superheated steam lines between the stoves and the generator were fabricated from Harbison-Walker Co. HWRCO-brand magnesite bricks. Each brick was drilled for a shaft and pinned to it as shown in figure 12, design 1. In the preliminary steam runs the valves were reversed by hand. The bricks lasted for about 8 hours before shattering.

A second design was tried, using a water-cooled shaft extending through the brick with the brick held by washers welded to the shaft (fig. 12, design 2). This design also fractured after a few hour's use. Using the water-cooled shaft, several other types of refractories were tried, among them Kromo-cast cement manufactured by Babcock & Wilcox Co., but none were satisfactory. Failure of these valves seemed to be due to a combination of thermal and mechanical shock.

Coal Feeder and Flow Sheets

The coal feeding system, (fig. 13), consists of two fluidizers - the first or batch feeder having a capacity of 1,000 pounds of coal and the second or continuous feeder, 150 pounds (later increased to 400 pounds). Both fluidizers are equipped with Bristol pressure controllers to maintain constant pressure within the fluidizers. 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 at our working pressures and 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. In operation, the instantaneous rate of feed to the generator is determined by reference to previously prepared calibration curves for coal flow versus the differential pressure as measured between the continuous feeder and the feedline sight glass. The unit with control panel is shown in figure 14.

As a result of experience with the feeder, certain safety and control devices (see fig. 15) were added to improve the operation and decrease the danger of accidents. Safety device 1 gives a visual and audible warning of a pressure decrease at the sight glass caused by a slight decrease of coal feed or oxygen flow rate. Safety device 2 stops the oxygen flow and starts the carbon dioxide purge to the coal injector when the pressure differential between the sight glass and the generator falls excessively from failure of coal feed or oxygen supply. Safety device 3 stops the oxygen flow and starts the carbon dioxide purge when the sight-glass pressure rises excessively because of plugging or flash-back within the coal injector. Safety device 4 give a warning of faulty operation of the fluidizing air or controller causing a rise in pressure in the continuous feeder. In the development stage is a solenoid emergency coal-feed shut-off valve, which will be installed as indicated in figure 15, to operate in conjunction with the oxygen and carbon dioxide solenoid valves.

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 at 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.

Generator Construction

Considerations of a suitable design of the generator as regards the method of introducing the reactants led to the selection of tangential inlet lines for the coal and steam. These are tangential to a 24-inch-diameter circle, its center being at the center of the generator. By introducing the reactants in this way, the centrifugal forces involved cause the larger coal particles to be thrown to the generator wall, where they may be held by the slag and the reaction with the steam and oxygen completed.

The refractory-lined generator has a steel shell 8 feet 6-5/8 inches OD by 20 feet 7-inches high to the vent valve flange, and an effective internal volume of 86 cubic feet between the point of introduction of the reactants and the gas off-take. Lining details are shown in figure 16, and locations of the various test openings are given in figure 17. The tubes for steam admission are made of Harbison-Walker Co., HWRCO magnesite composition. Between them and the inside lining (The Carborundum Co. Carbofrax, silicon carbide brick), a ring of Harbison-Walker Co. HWRCO chrome brick was used. Both silicon carbide and chrome brick were laid using Thermolith cement.

Dust Train and Flow Sheet

The dust-removal train (see fig. 18) consisted of a wet-type cyclone dust collector followed by three Aerotec-type cyclone separators, operated dry and each equipped with a hopper. From the last Aerotec the gas enters a sprayed standpipe and a standard wash box, such as is used on water-gas sets. The gas, which still contains fine dust, is metered through a Roots-Connersville meter and then flared. Any material washed out in the wet cyclone and that entering the wash box from the sprayed standpipe is collected in a sludge tank. The overflow water from the sludge tank is metered over a weir and periodically sampled. Dust tests are run on the gas leaving the meter.

The Aerotec cyclone collectors are of two designs. The first two in line have 5 tubes 3 inches in diameter and the third 11 tubes 2 inches in diameter. The units have 8-inch inlet and outlet connections and are made of No. 309 stainless steel in anticipation of use at temperatures over

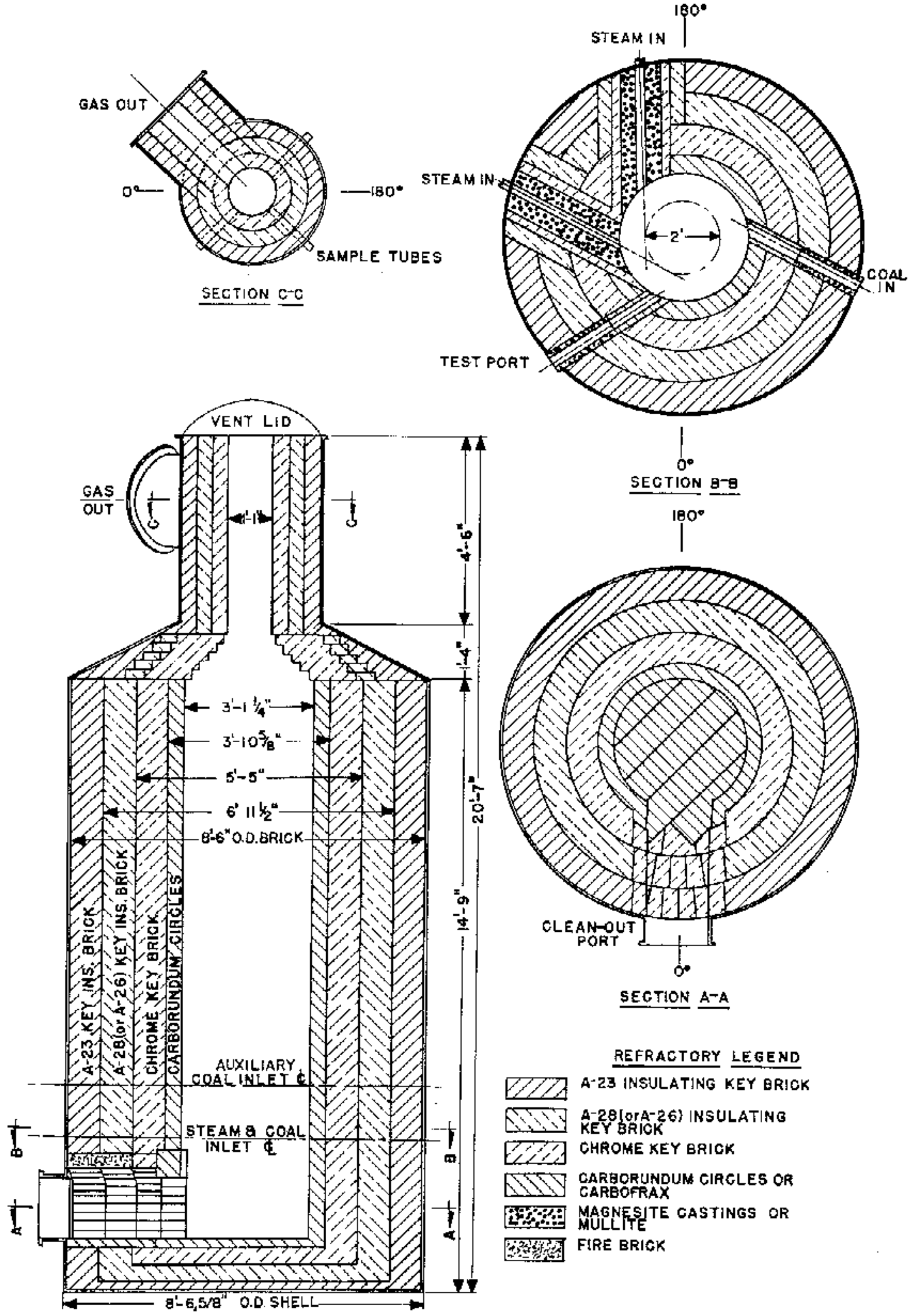

Figure 16. - Refractory detail of gas generator.

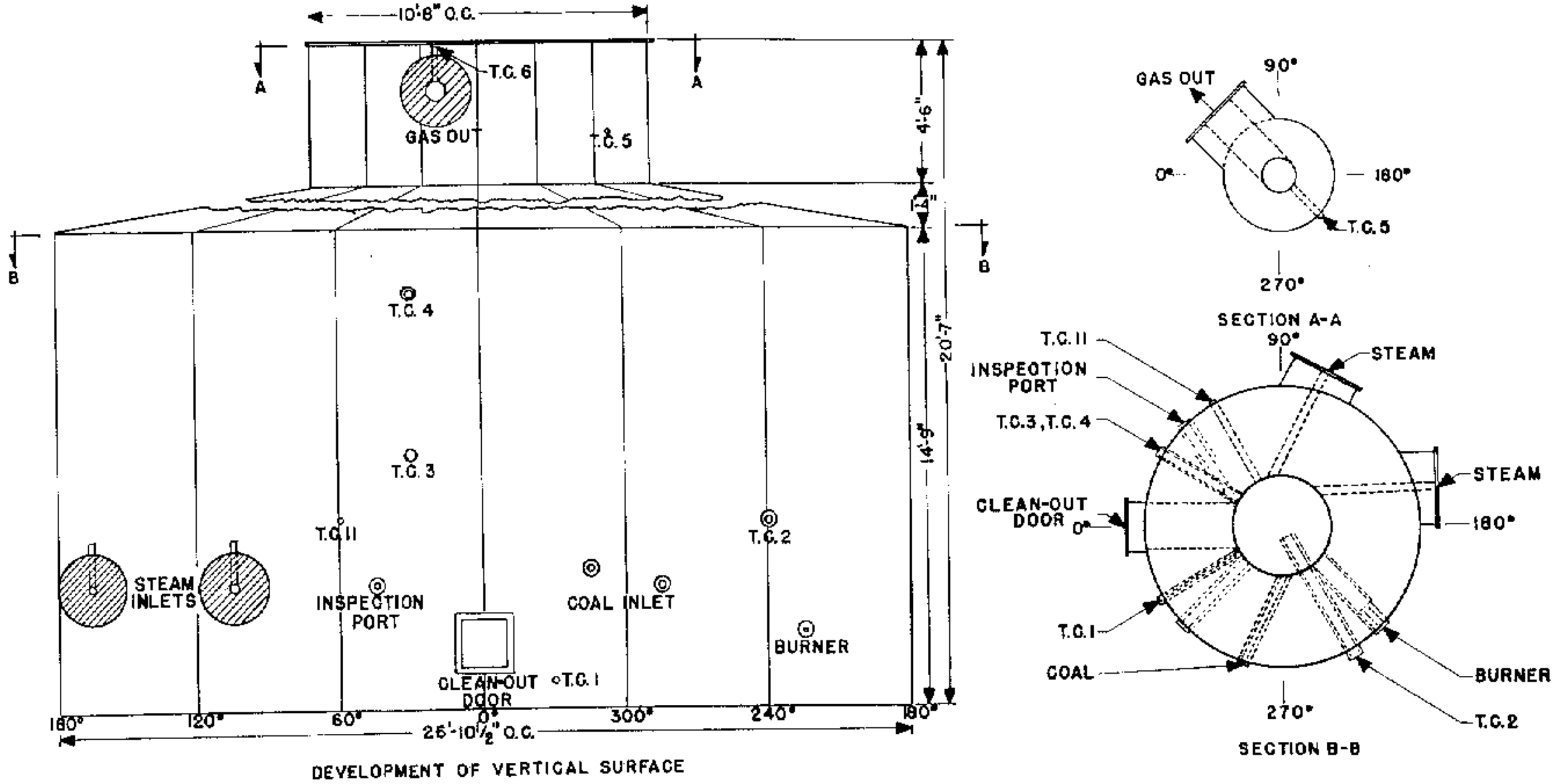

Figure 17. - Diagram showing location of generator openings.

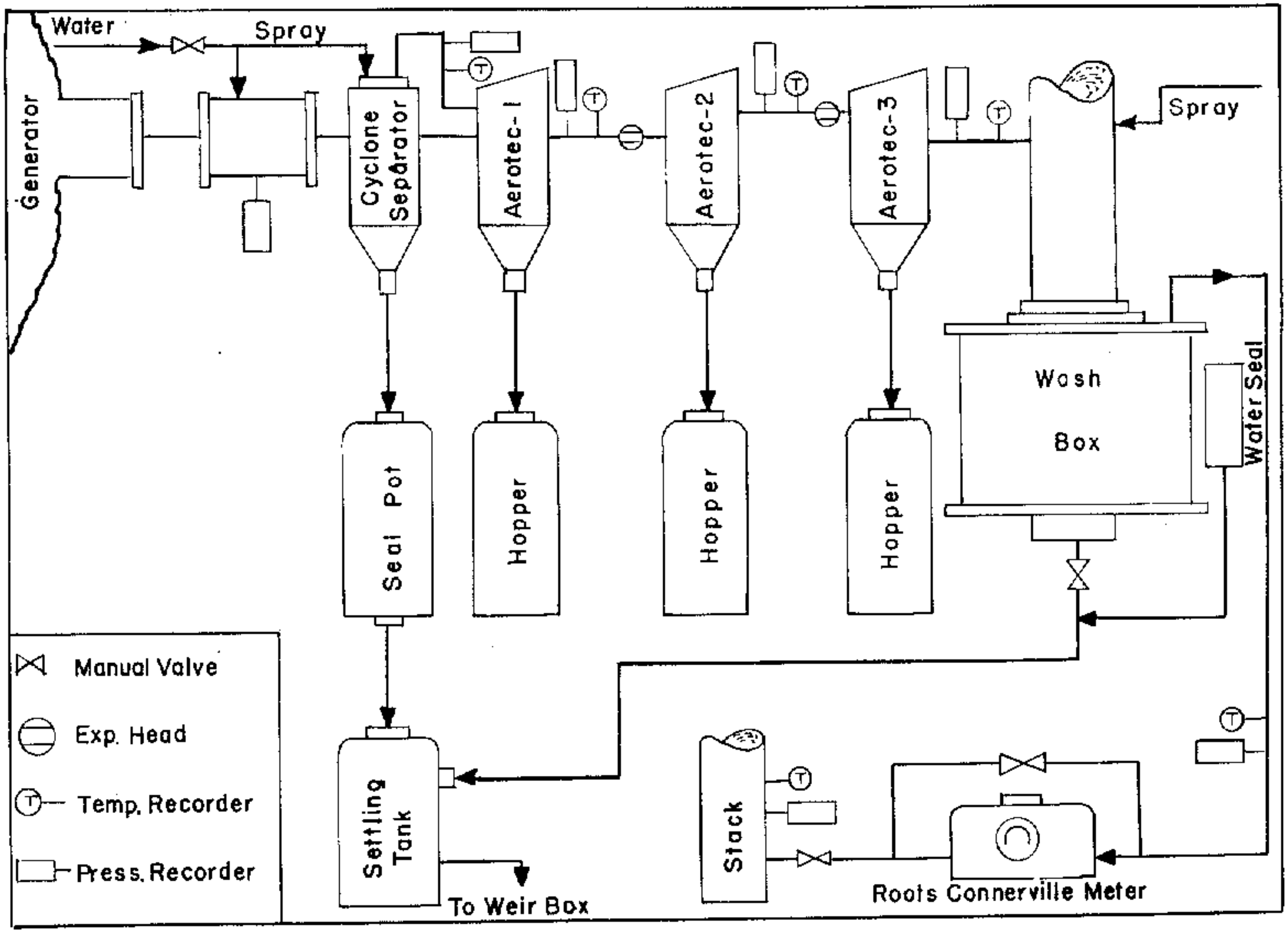

Figure 18. - Dust-removal train used in runs 1-31.

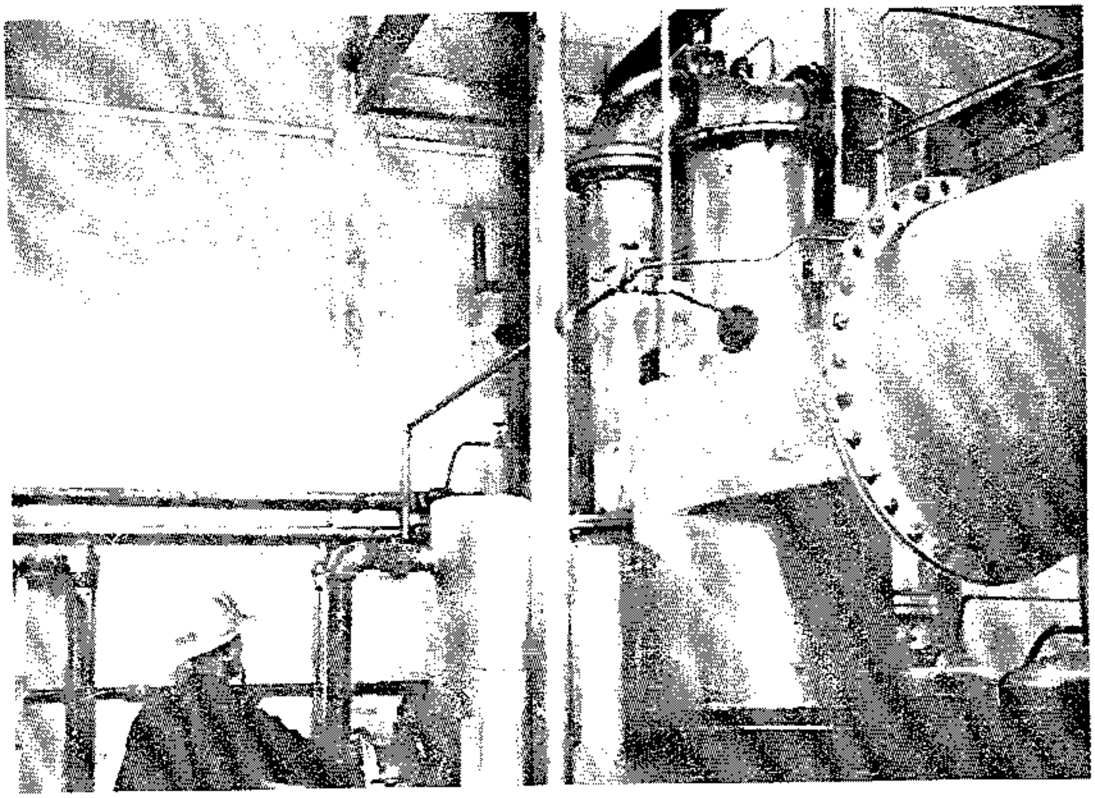

Figure 19. - View of dust-removal train; generator outlet at right.

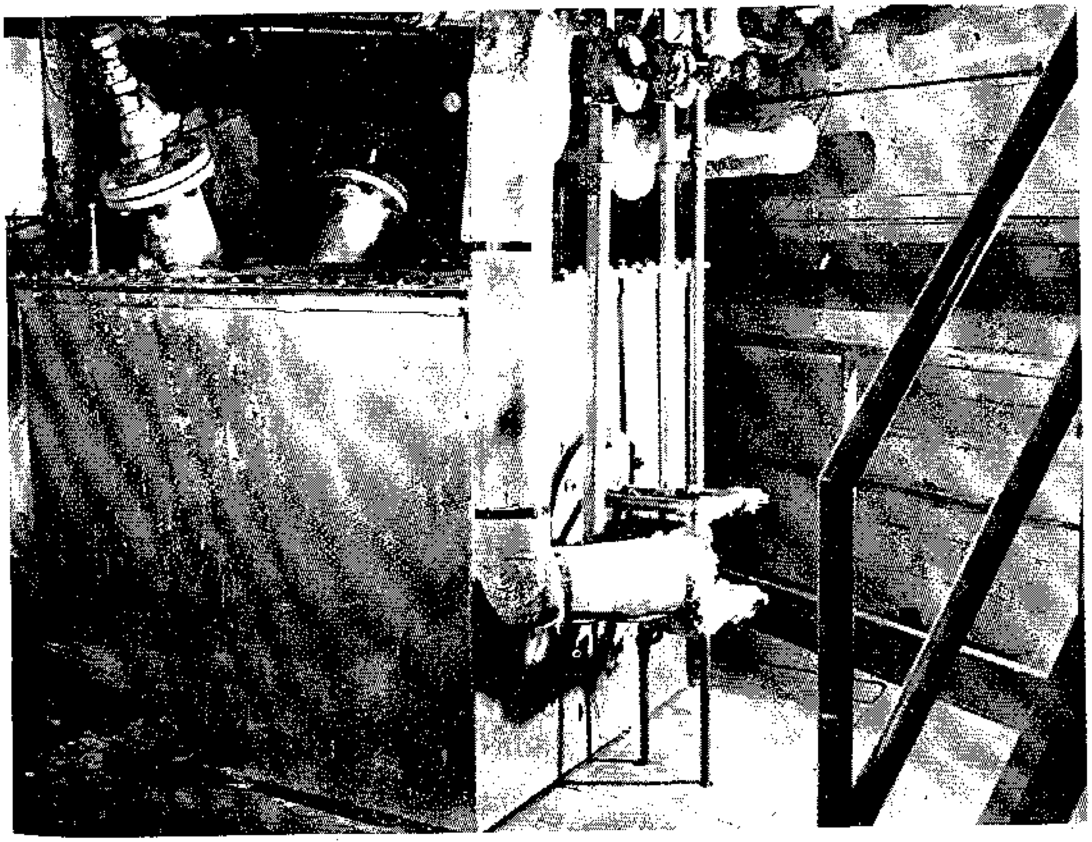

Figure 20. - View of steam superheater used in runs 26-31.

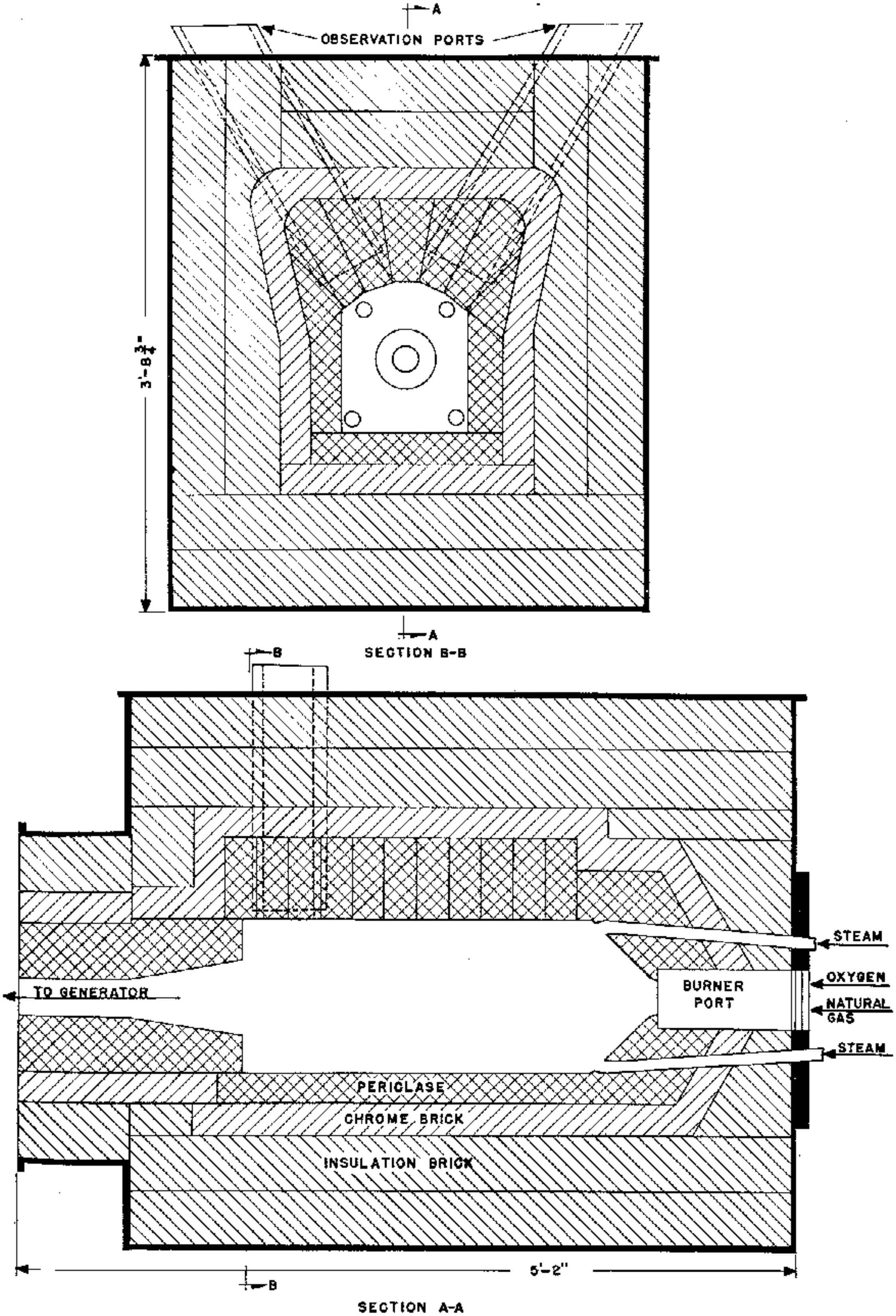

Figure 21. - Refractory detail of steam superheater used in runs 26-31.

1,000°F. Because of moisture condensation in the starting up of the unit, they corroded badly.

The use of water sprays of the fogging type in the wet cyclone was an expedient adopted to lower the gas temperature from approximately 1,800°F. leaving the generator, to 400°-500°F. entering the Aerotec collectors. In a large-scale plant a waste-heat boiler would probable be used for this purpose. In operation, a small amount of material is collected in this wet cyclone and washed to the sludge tank by a water stream in the base cone. Figure 19 shows part of the dust-removal train. The water-sprayed cyclone at the generator outlet may be seen and parts of the Aerotec hoppers.

Modifications of Unit for Runs 15-25

Inasmuch as these runs employed steam at line temperatures, 240°F., superheating by the Royster pebble stoves was unnecessary and the stoves were disconnected from the generator. One steam inlet to the generator was blanked off, and steam at 10 pounds gage pressure was passed through a moisture separater and admitted through the other steam inlet. Steam flows were regulated by hand and measured by flow meters. No changes were made in the generator or dust train.

Modifications of Unit for Runs 26-31

A temporary steam superheater, illustrated in figures 20 and 21, was connected to one of the steam inlets and used to supply superheated steam at 1,600°-2,000°F. for these runs. This superheater consisted of a refractory-lined chamber equipped with a natural gas-oxygen burner and steam inlet ports and provided with necessary openings for pressure and temperature readings. Gas, oxygen, and steam flows were regulated by hand valves and measured by standard flow meters. The burner was one that had been designed to supply high-temperature (4,000°F.) steam for another experiment. At the lower temperatures used here, it was found necessary to use considerable excess oxygen to reduce the amounts of unburned gases to under a few percent. Products of combustion, principally carbon dioxide and steam, entered the generator with the superheated steam and required certain adjustments in the material and heat balances. No other changes were made in the generator or dust train.

PROCEDURES USED

Preliminary Steam Runs on Royster Pebble Stoves

Before making any gasifying runs it was necessary to make extensive tests on the Royster pebble stoves to try out various materials for pebbles and to test the operation of reversing equipment. After each change in type of pebble material or modifications of the reversing-control equipment this work had to be repeated. Some of it was done just before making gasifying runs; and some of the test work as regards methods for determining steam temperatures, for example, was carried on during the gasifying runs. This work will be completely described in the subsequent report of investigations on the Royster pebble stove. Because of the way in which the experimental unit was constructed, it was necessary to carry on concurrently the development of operating procedures for the entire unit and the study of suitable refractories for the stoves, as well as the study of the actual gasification process. This has meant that to date it has not been possible, except in a few instances, to make check runs in which all operating variables could be exactly duplicated. During these tests, the top of the pebble bed in the stoves was held at about 3,600°F. for several months. Steam has been heated to about 3,400°F. The efficiency of the Royster stoves is generally greater than 80 percent.

First Gasifying Runs

During the preliminary stove tests, work was done on the development of a satisfactory coal feeder, and in October 1948 the pilot plant was ready for trial. During these and subsequent trials, the pilot plant gave an excellent performance. Twelve test runs were made, using Upper Freeport bed coal from Preston County, W. Va., ground to 70 percent through 200-mesh. This coal was used in spite of the fact that its characteristics, high ash, approximately 12 percent; high-ash melting point, approximately 2,900°F.; and strong coking properties, made it one of those probably most difficult to gasify. These runs were made to study: (1) Operation of the coal feeder, (2) method of introducing oxygen, and (3) integration of the pebble-stove operation with that of the generator. As a result, the runs were brief, and the data were not sufficient for extensive calculations. Also, the gas made was not of the quality to be expected under stable operating conditions.

These runs indicated that the coal-feeding arrangement was satisfactory and that, with the provision of an auxiliary feeder, coal flows could be maintained over long periods. Three methods were tried for introducing process oxygen, namely, all with the coal, all with the steam, and most with the steam and only that needed to secure safe injection velocities in the feed line with the coal. Since there was no apparent difference in results with these different injection methods, it was decided, as a matter of convenience, to introduce all the oxygen with the coal as is indicated in the flow sheet (fig. 13), and this procedure was used for all subsequent runs.

These tests also showed that the refractory linings in the stoves could not be operated at top temperatures of over 3,600°F., and this was the maximum temperature used in runs 1 - 14, inclusive.

Dust tests were made on the exit gas, and the sludges from the spray cooler were sampled. The results, while not quantitative, gave useful information for designing a more complete dust-removal train.

Superheated-Steam Runs (1-14)

The experimental unit, previously described in figures 6 to 17, was completed using the information obtained in the first gasifying runs on Upper Freeport bed coal. Steam runs were then made, and, after adjustment of the Royster-stove instrumentation, coal runs were begun using the procedure outlined below. (Refer to figs. 6, 7, and 18.)

(1) The generator, vented at the top to the stack, was heated to approximately 2,200°F., as measured by a thermocouple extending about 6 inches into the reaction chamber at the 5-foot 9-inch level, over a 48 - 72 hour period.

(2) Preceding the run, the pebble stoves were heated to approximately 3,000°F. top pebble-bed temperature.

(3) Shortly after starting to raise the stove temperatures, 5-minute cyclic operation was begun, and steam was used at approximately the rate to be used during the gasifying runs.

The purpose of these three steps was to have the stoves at nearly stable operating conditions as regards temperature gradients through the beds and to "soak" heat into the generator brickwork. Because of the limited generator heat-up burner capacity, it was not possible to preheat the generator higher than 2,200°F., although the temperature conditions near the end of the runs indicated that 2,400°F. would have been better. Consequently, during the early stages of the runs, heat was being added to the generator brickwork.

(4) The generator heat-up burner was shut off, spray-water flows were adjusted on the dust train, the generator vent was closed, and the flow of hot steam, plus CO_2 added at cyclone and Aerotec hoppers, was started through the dust train to purge it.

(5) When tests at the flaring stack indicated that the unit was purged, the coal feed was started at the desired rate with the process oxygen added at the coal-feeder sight glass (fig. 13).

(6) Steam, oxygen, and coal rates were then adjusted to those desired. Small pressure changes in the generator when gasification started caused minor changes in the necessary stove adjustments to secure the desired steam rates and top pebble-bed temperatures.

(7) Temperature readings were taken at 15-and 30-minute intervals, and, except for skin-temperature readings on the generator and stove shells, were also recorded on Brown 12-point electronic recorders.

(8) All steam, air, natural-gas, and oxygen flows were recorded on standard flow meters. The make gas was metered through a Roots-Connersville meter.

(9) The wash waters collected in the settling tank were sampled every 15 to 30 minutes to determine sludge content, and the waste was measured over a weir. The heavier residues settled out in the tank and were collected at the end of the run.

All water used in any of the dust-train equipment was metered, using "Rotameters" or standard rotary disc-type water meters.

(10) The products of combustion from the stoves were analyzed with an Orsat apparatus every 30 to 45 minutes. Samples of the make gas were collected every 20 minutes for complete analysis.

(11) The gas was also sampled for dust and moisture content at both the stack and generator outlet.

(12) At the conclusion of the runs, which were limited to a throughput of about 2,500 pounds of coal by the size of the Aerotec hoppers, all residues were collected for analysis.

(13) After the coal and oxygen feed was shut off, the entire unit was steam purged for 5 to 10 minutes, then vented. Before any hoppers containing fine dust were opened, they were purged with CO_2.

The usual temperature distribution throughout the unit for these runs (1 through 14) was as follows (See figures 22, 23, and 24 for generator temperatures):

	° F.
Steam-inlet temperature...	3,000-3,500
Coal and oxygen in at.....	Atmos. temp.
Outlet cyclone............	500
Outlet No. 3 Aerotec......	425
Outlet wash box...........	190
Outlet meter..............	170

The Aerotecs were run at the temperatures shown to keep the dust collected as dry as possible.

When gasification was started, the pressures in the generator and stoves were approximately 1.5 inches to 2.0 inches Hg, which was sufficient to force the products of combustion, during a stove heating cycle, directly to the stack, and the POC exhaustor was bypassed until the run was discontinued.

All manometer lines were equipped for blow-back with CO_2, as they plugged quite quickly due to the dirty gas.

It was necessary during these runs to bypass the Roots-Connersville meter periodically and flush it out with water.

Low-Temperature Steam Runs (15-25)

On completion of run 14, the condition of the stove linings was such that they needed complete rebuilding. This need for rebuilding resulted from abnormal use of the stoves during the early work on testing of refractory pebbles and development of suitable operating procedures. The magnesite brick lining performed very well, considering the severe temperature changes to which it was subjected, and under usual operating procedures for refractory-lined equipment it has been shown that a very economical life can be expected.

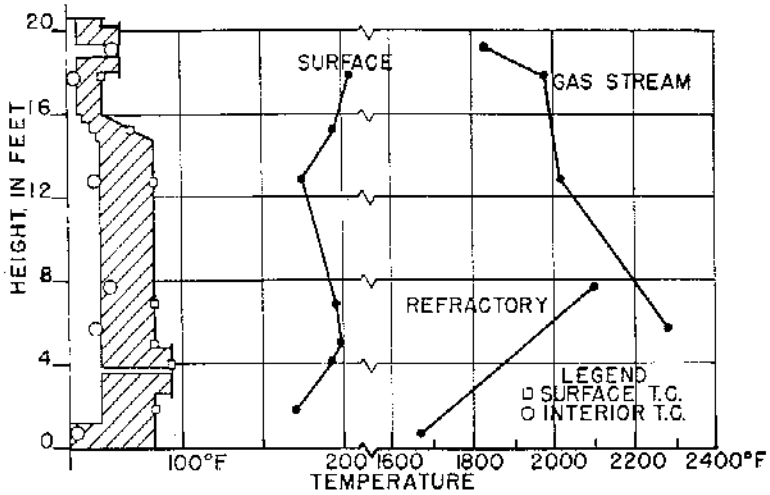

Figure 22. - Temperature distribution in generator for runs 1-14.

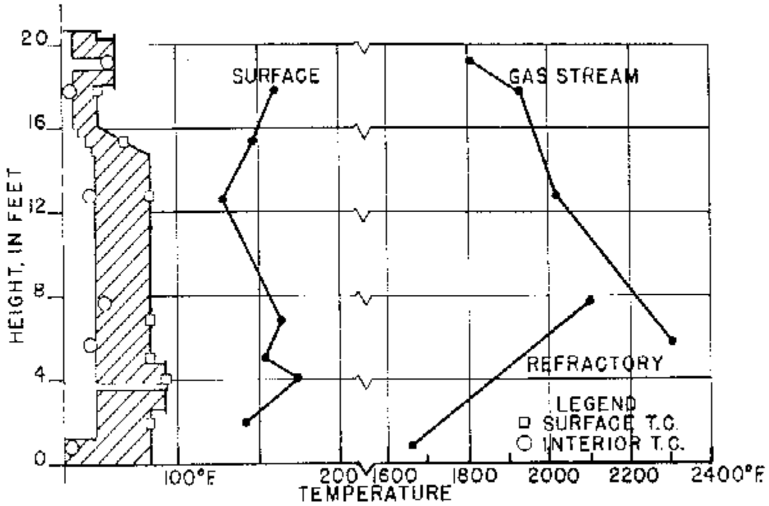

Figure 23. - Temperature distribution in generator for runs 15-25.

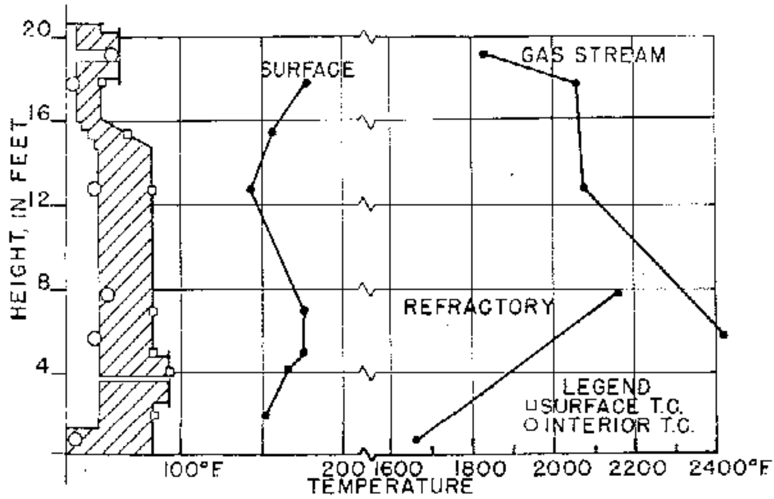

Figure 24. - Temperature distribution in generator for runs 26-31.