the design of the pebble heaters or Royster pebble stoves, allows for investigation of the relative advantages of supplying the heat needed for the steam:carbon reaction from either highly superheated steam or from partial combustion of the coal with oxygen.

Discussion of Subsidiary Problems Involved

To carry out the process as described, several problems had to be solved. The production of steam at temperatures above 3,000° F. has required a study of refractories suitable for use as pebbles and for lining the stoves. Also, to be certain that the best materials for lining the generator would be chosen, studies have been made of the action of various coal slags on refractories at high temperatures. This work will be described more fully in a later report on the Royster pebble stoves.

In any process for gasifying pulverized coal, the method used for introducing the coal into the reaction zone assumes major importance. The method must allow for continuous, steady, controllable flow of the coal in such a way that flash-backs are reduced to a minimum. As a result of the study of this problem, a pneumatic coal feeder was developed and used successfully in the gasification runs. This feeder has been described in the literature.15/16/17/18/

When a gas has been heated above 3,000° F., the problem of securing an accurate measurement of its temperature is very difficult. Pyrometer protecting tubes suitable for insertion into the steam stream in the temperature range 3,500°-4,000°F. are not commercially available because of refractory problems. Our work here has followed two lines - (1) attempts to develop protecting tubes that could be inserted in the steam stream and (2) attempts to determine such relationships as may exist between the steam temperature and the top pebble-bed temperature that can be measured with an optical pyrometer.

Since operation of the steam superheaters or pebble stoves is cyclic (that is, they are heated for 5 minutes and then steamed for 5 minutes), it is necessary to prevent the flow of the products of combustion from the stove being heated into the generator. Also, since the materials used in the refractory linings of the stoves and in the pebbles are particularly subject to slag attack, it is necesary to prevent any fine dust from the generator blowing back into the stoves during the reversal periods.

15/ Albright, C. W., Holden, J. H., Simons, H. P., and Schmidt, L. D., Pneumatic Feeder for Finely Divided Solids: Chem. Eng., vol. 56, June 1949, pp. 108-111.

16/ Dotson, J. M., Holden, J. H., Seibert, C. B., Simonds, H. P., and Schmidt, L. D., New Method Measures the Solid:Gas Ratio in High-Solid Flow: Chem. Eng., vol. 56, October 1949, pp. 128-130.

17/ Secretary of the Interior, Synthetic Liquid Fuels 1948 Annual Report: Bureau of Mines Rept. of Investigations 4456, 1949, pp. 41-59.

18/ Secretary of the Interior, Synthetic Liquid Fuels 1949 Annual Report: Bureau of Mines Rept. of Investigations 4651, 1950, pp. 43-59.

The original design of the unit called for use of refractory valves in the steam lines from the stoves to the generator. The difficulties encountered with these will be described later in this report. The hot valves proved unsatisfactory and were eliminated before any gasifying runs were made. No immediate solution to the problem was available, so it was decided to equip the unit with a differential-pressure-control device so arranged that the pressure on the top of the pebble stove, while heating, would be kept slightly above (approximately + 0.05 inch H_2O) that in the generator. This, of course, caused some slight contamination of the "make gas" with P.O.C., but, what was more serious, apparently permitted occasional blow-backs of dust from the generator into the pebble stove. Consequently, a water-cooled valve that will be described later has been designed for this service.

From the nature of the process chosen, it would be expected that the ash from any coal would be heated above the ash-fusion temperature. Consequently, the generator design allowed for removal of part or all of the ash as slag. However, no method of determining, in advance, the amount of slag to be removed exists, and in the early work such slag as formed was allowed to accumulate in the base of the generator and was removed periodically after the generator had cooled.

It was apparent early in the investigation of the various processes used or advocated for the gasification of pulverized coal that the problem of dust removal from the gas was very difficult. It was also evident that the physical nature of the dusts would depend upon the particular method of gasification used as well as upon operating variables - for example, steam:coal and oxygen:coal ratios - and the kind of coal used. Consequently, the equipment found satisfactory in one instance might not be suitable in another. It was, therefore, considered advisable to make some preliminary runs with very simple equipment for cooling and washing the gas in order to obtain some indications of the nature and quantities of dust that would be obtained. Another part of the dust-removal problem is disposal of the material recovered. The economic answer to this problem depends upon the value of the residue obtained, and this in turn determines the method chosen for its recovery. If the carbon content of the residue is high enough and if the amount is such that to send it to waste would constitute a serious cost charge against the process, the dust should be removed from the gas in the dry state. Dry recovery of the residue facilitates recycling the residue in the process or its transport and use as boiler fuel. The cost of disposal of waste must also be considered, and dry recovery is again indicated so that the residue may be used as boiler fuel if for nothing else. Tests have shown that this dust in the dry state can be easily fluidized and transported in the pneumatic feeder, so that utilization in a large plant is simplified by dry recovery. The problem of removing dust from the gas steam is being concurrently studied on a laboratory and bench scale, as well as on a pilot-plant scale.

The problem of purification of the make gases after dust removal is also being studied. Some of the analytical methods used to determine the sulfur content and types of compounds in the gases from the pilot-plant generator have been described.19/20/

DESCRIPTION OF PILOT PLANT

Royster Pebble Stoves and Superheated-Steam Flow Sheet

The arrangement of the pilot plant is given schematically in figure 6. In order to conserve space, the air heater originally planned was eliminated. Natural gas is admitted through a flowmeter to the stove burner, and hand regulation of the flow to secure the desired pebble-bed temperature is done at the burner. The combustion air is sent to the burner from the rotary blower, its flow rate being controlled to secure the desired air:gas ratio by an Askania differential flow controller actuated by the gas flow. To obtain pebble-bed temperatures over 3,000° F. the combustion-air supply is enriched with oxygen admitted after the flow controller. The proportions of oxygen and air used are determined by the temperature needed and adjusted to maintain a slightly oxidizing atmosphere. In a large-scale plant the combustion air would, of course, be preheated and not enriched with oxygen.

The products of combustion leaving the pebble stoves go through a spray cooler and then to an exhauster. This arrangement was used merely because the exhauster available for the work was not designed for operation in the 500°F. range. During the gasifying runs the pressures in the stoves and generator were such that the exhauster was bypassed and the gases sent directly to the stack. The exhaust gases are not metered but are periodically analyzed and temperature and other data secured so that heat balances may be obtained. The cooling-air blower was used during preliminary heating up of the stoves to prevent the bottoms from becoming too hot.

Figure 7 shows the Royster pebble stoves and generator in the early stages of construction of the plant. Figure 8 shows a close-up view of the stoves with the valves used for hand reversal before installation of the automatic reversing equipment. Figures 9 and 10 show the stove lining and the burner used in the work reported here.

To control timing of the stove reversing cycle and the air-actuated valves, Taylor Flex-O-Timer equipment is used. This is composed of three standard Flex-O-Timer units, one for each stove and one spare unit. Each unit is arranged so that reversals may be effected by hand operation if necessary and the cycle times can be varied from approximately 2 minutes to 40 minutes. The units are equipped with the usual signal devices to show

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19/ Sands, A. E., Wainwright, H. W., and Schmidt, L. D., Purification of Synthesis Gas Produced from Pulverized Coal: Ind. Eng. Chem., vol. 40, April 1948, p. 607.

20/ Sands, A. E., Grafius, M. A., Wainwright, H. W., and Wilson, M. W., The Determination of Low Concentration of Hydrogen Sulfide in Gas by the Methylene Blue Method: Bureau of Mines Rept. of Investigations 4547, 1949, 19 pp.

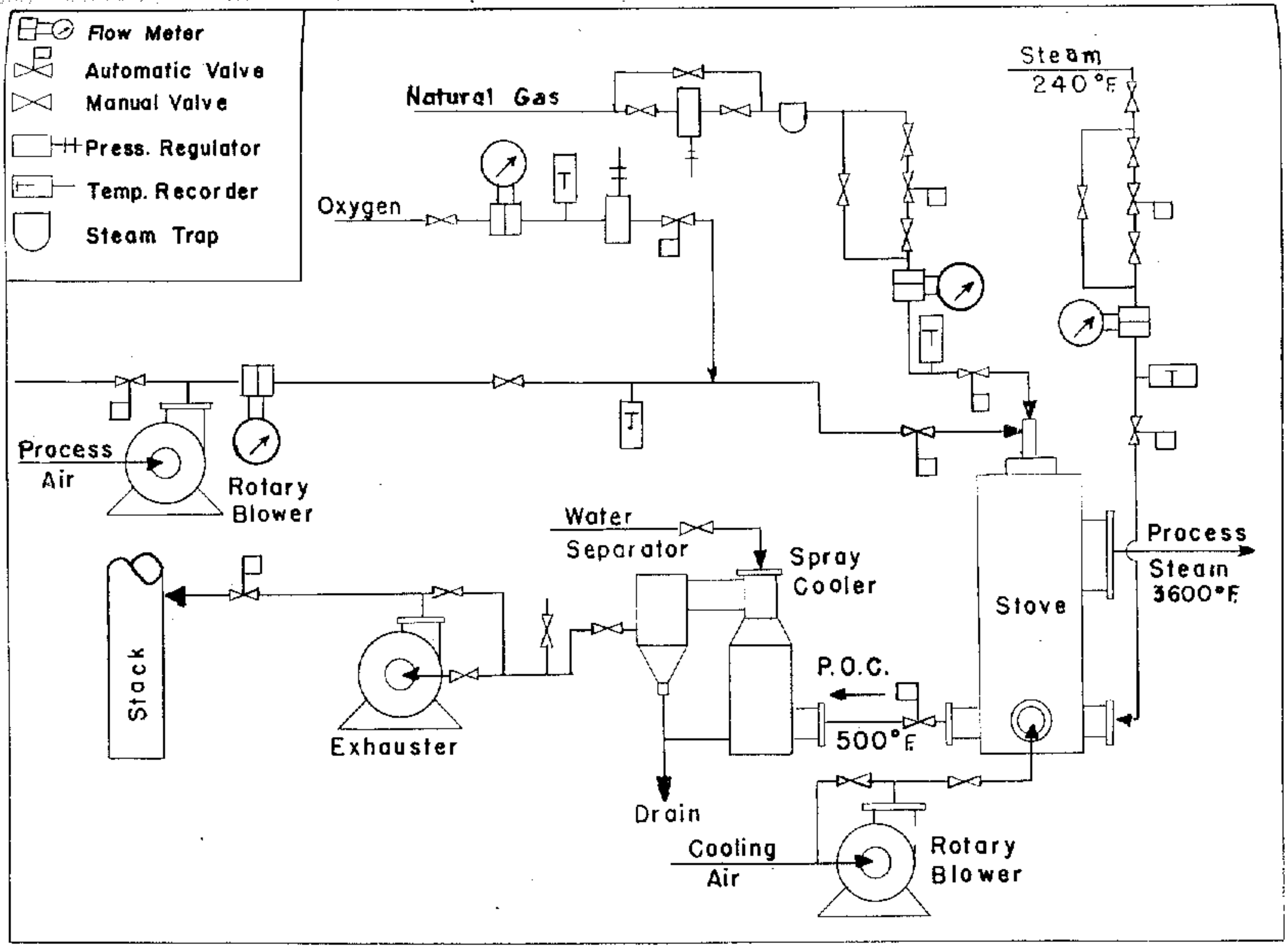

Figure 6. - Flow sheet for superheated-steam process.

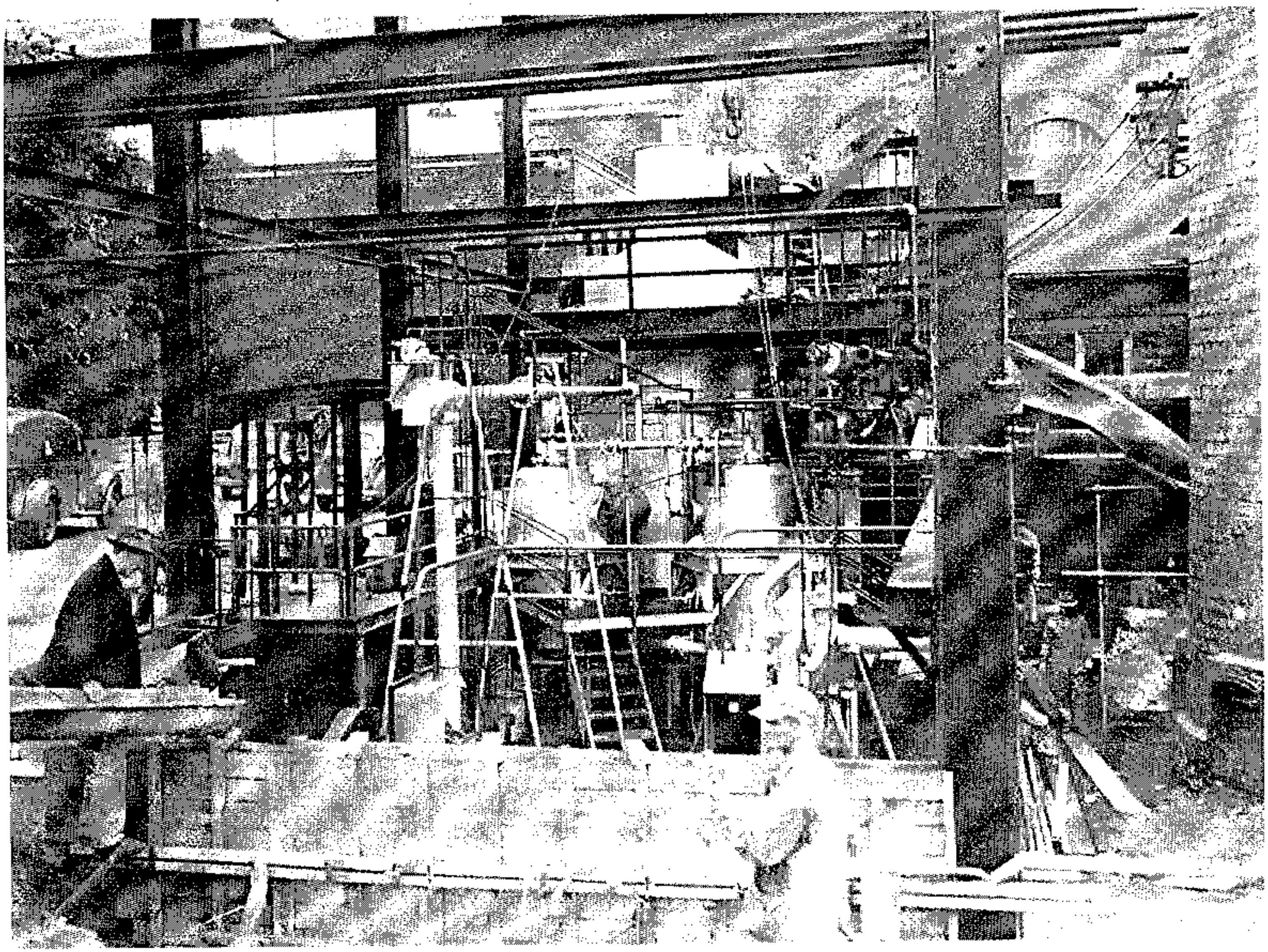

Figure 7. - Arrangement of Royster pebble stoves in relation to generator.

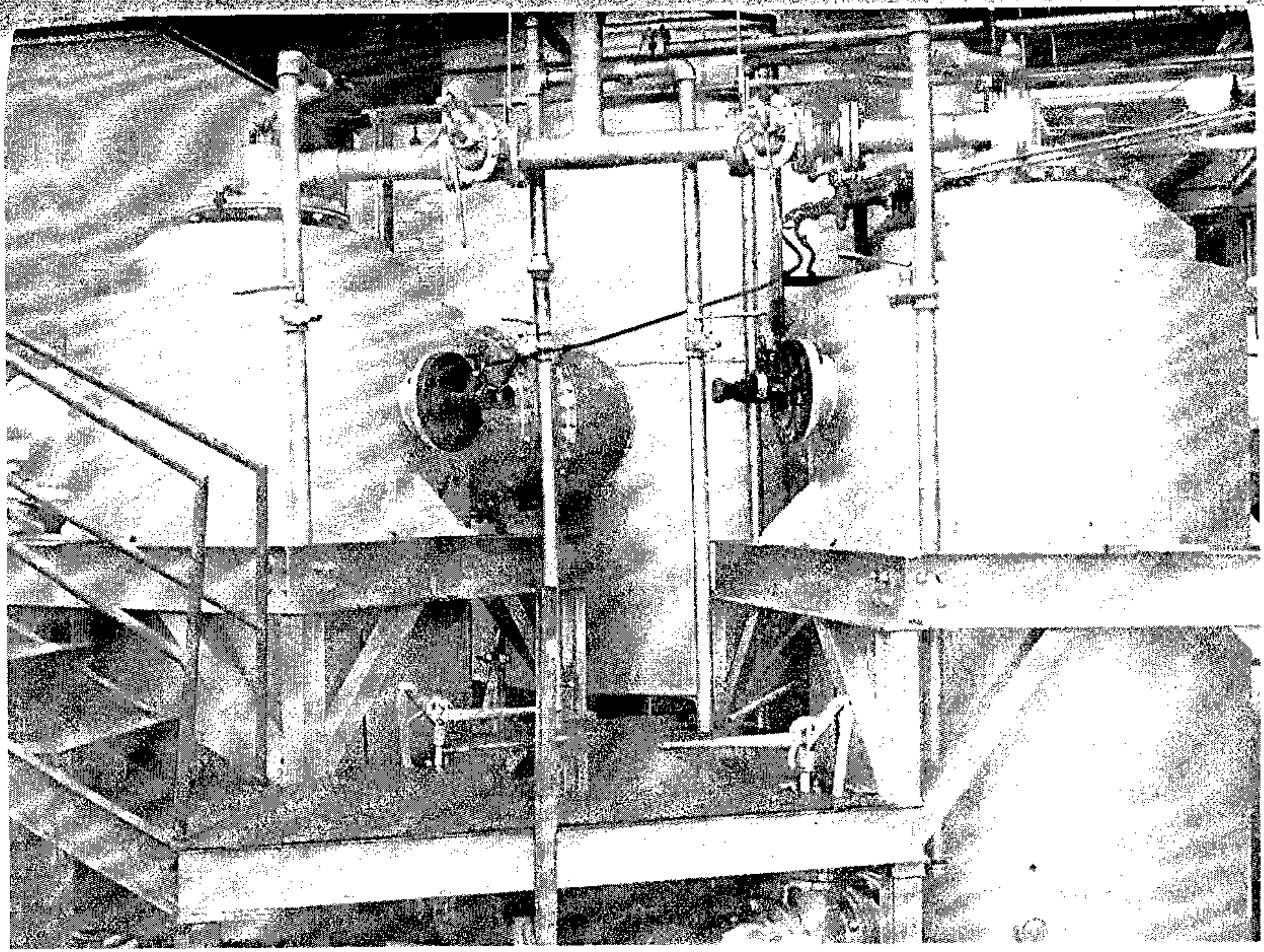

Figure 8. - Close-up view of Royster pebble stove, showing valve arrangement for hand reversal.

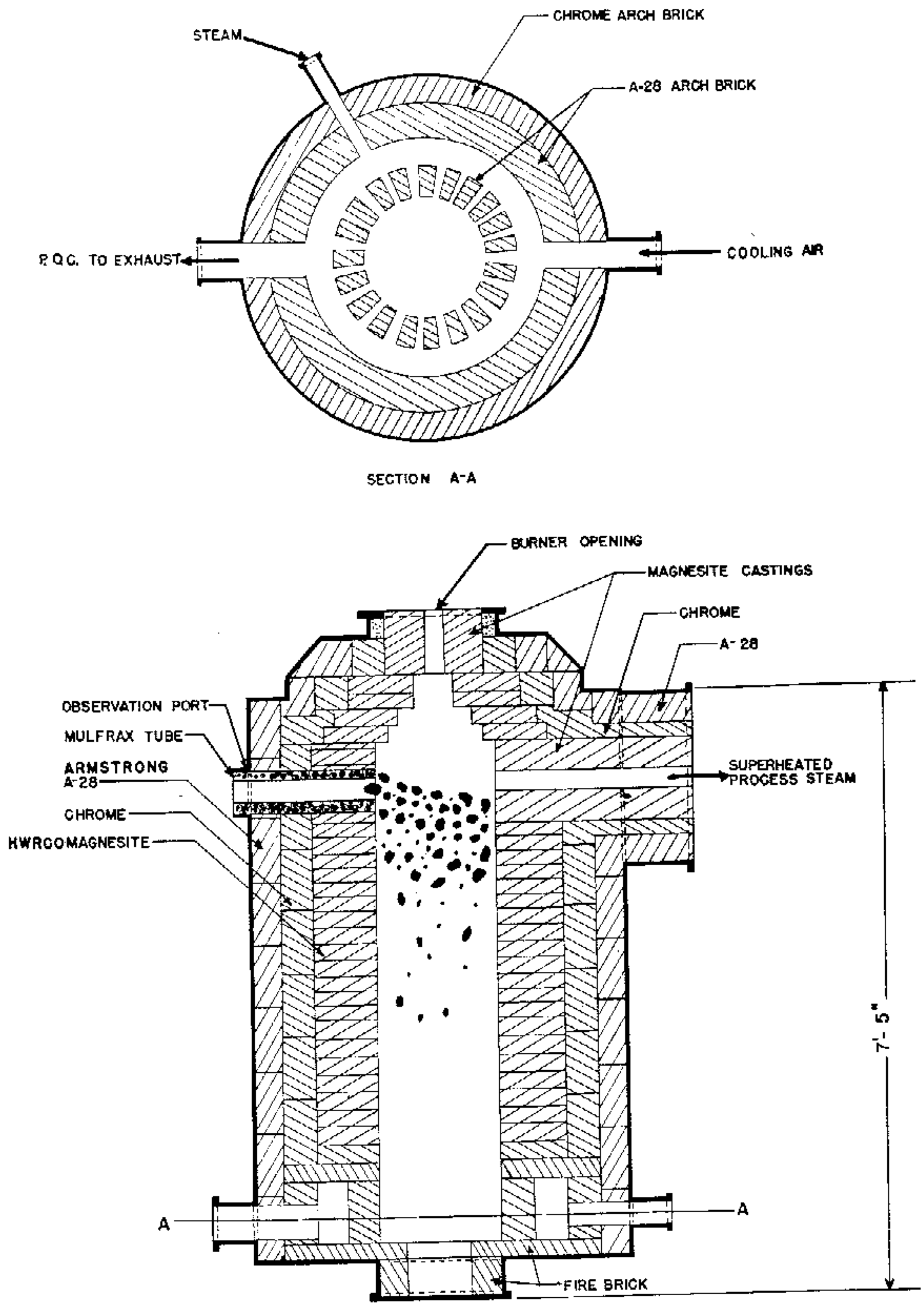

Figure 9. - Royster pebble-stove design used in runs 1-14.

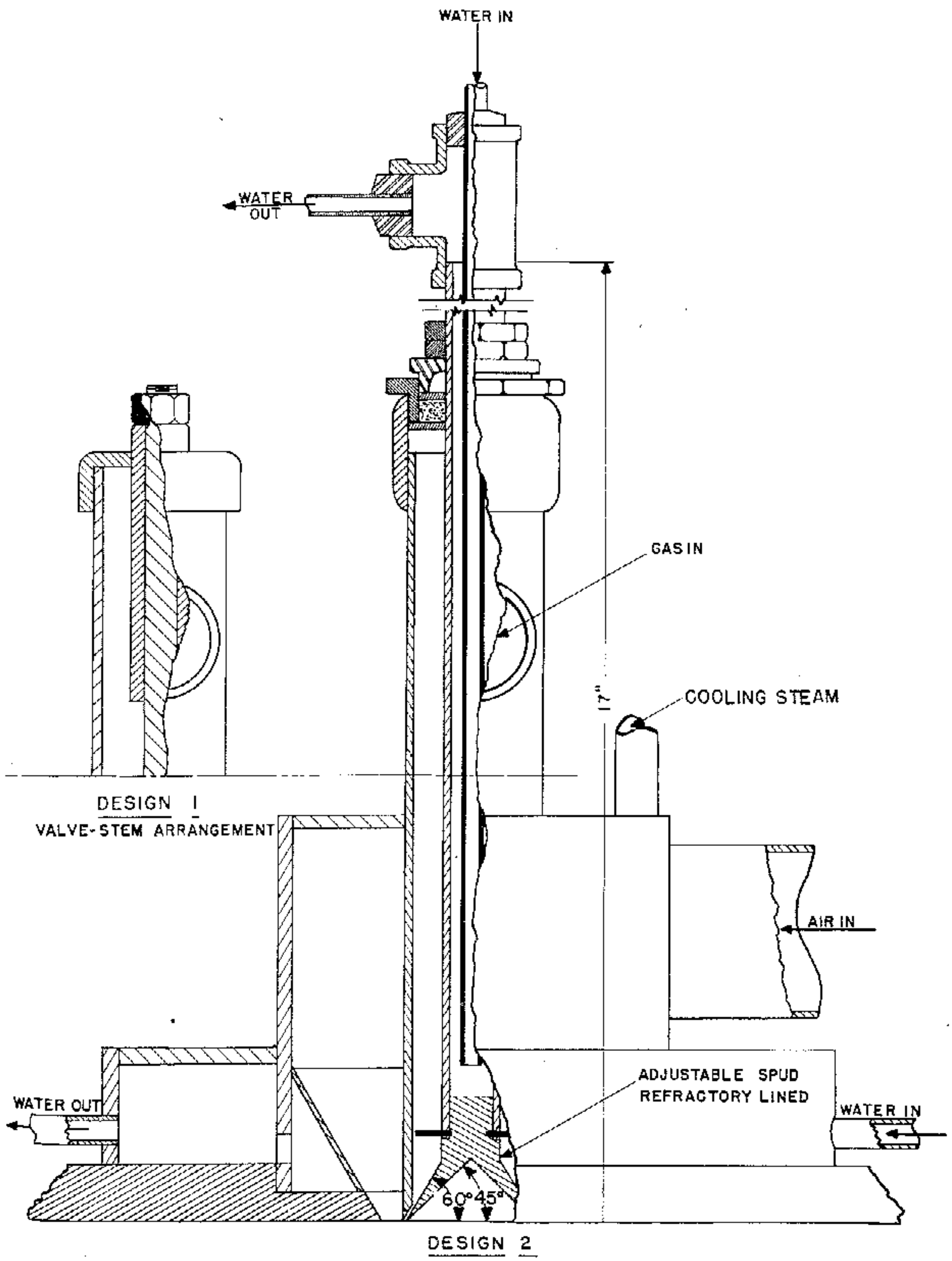

Figure 10. - Burner design used in Royster pebble stoves.

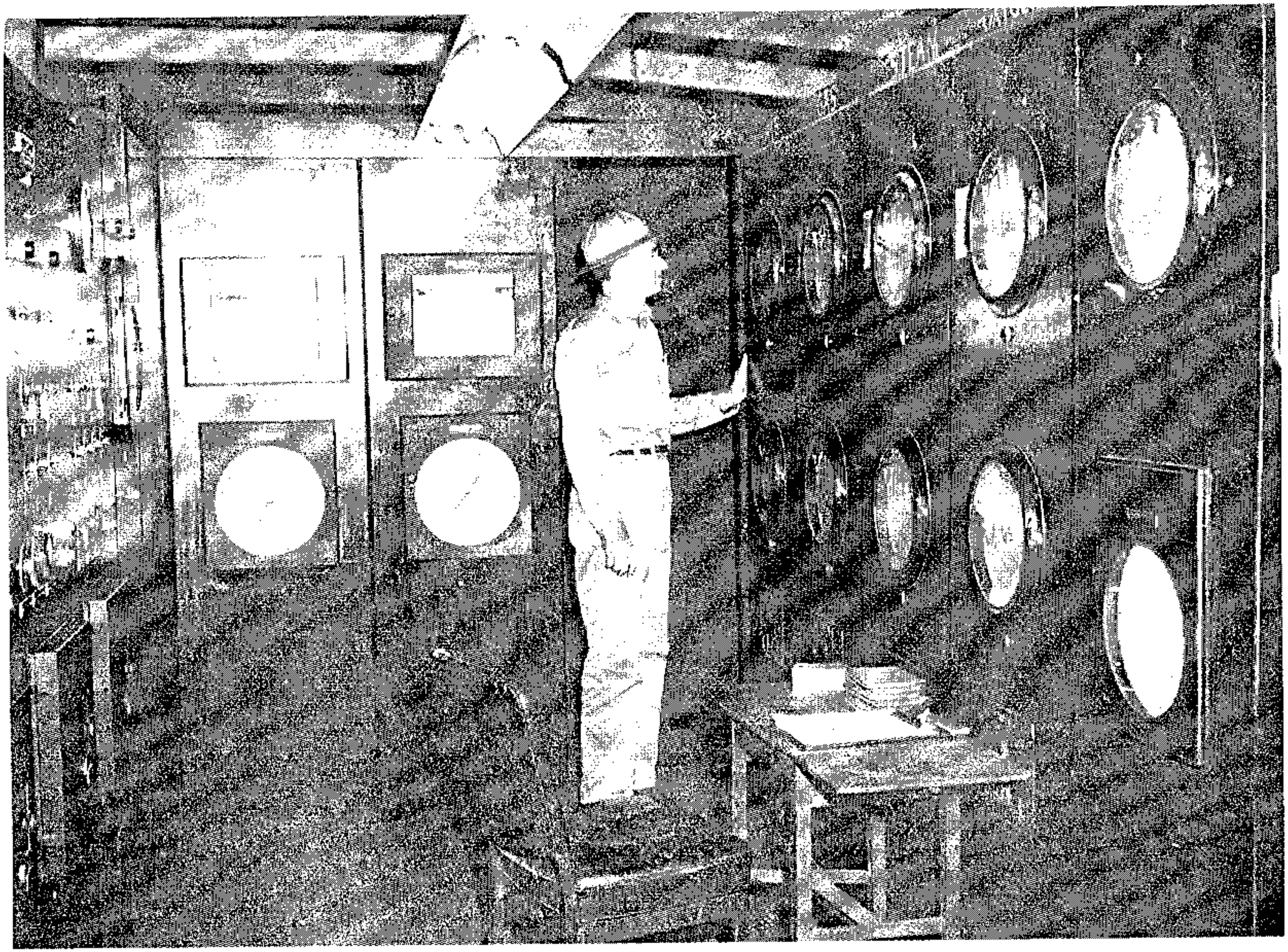

Figure 11. - Control instruments used in runs 1-31.

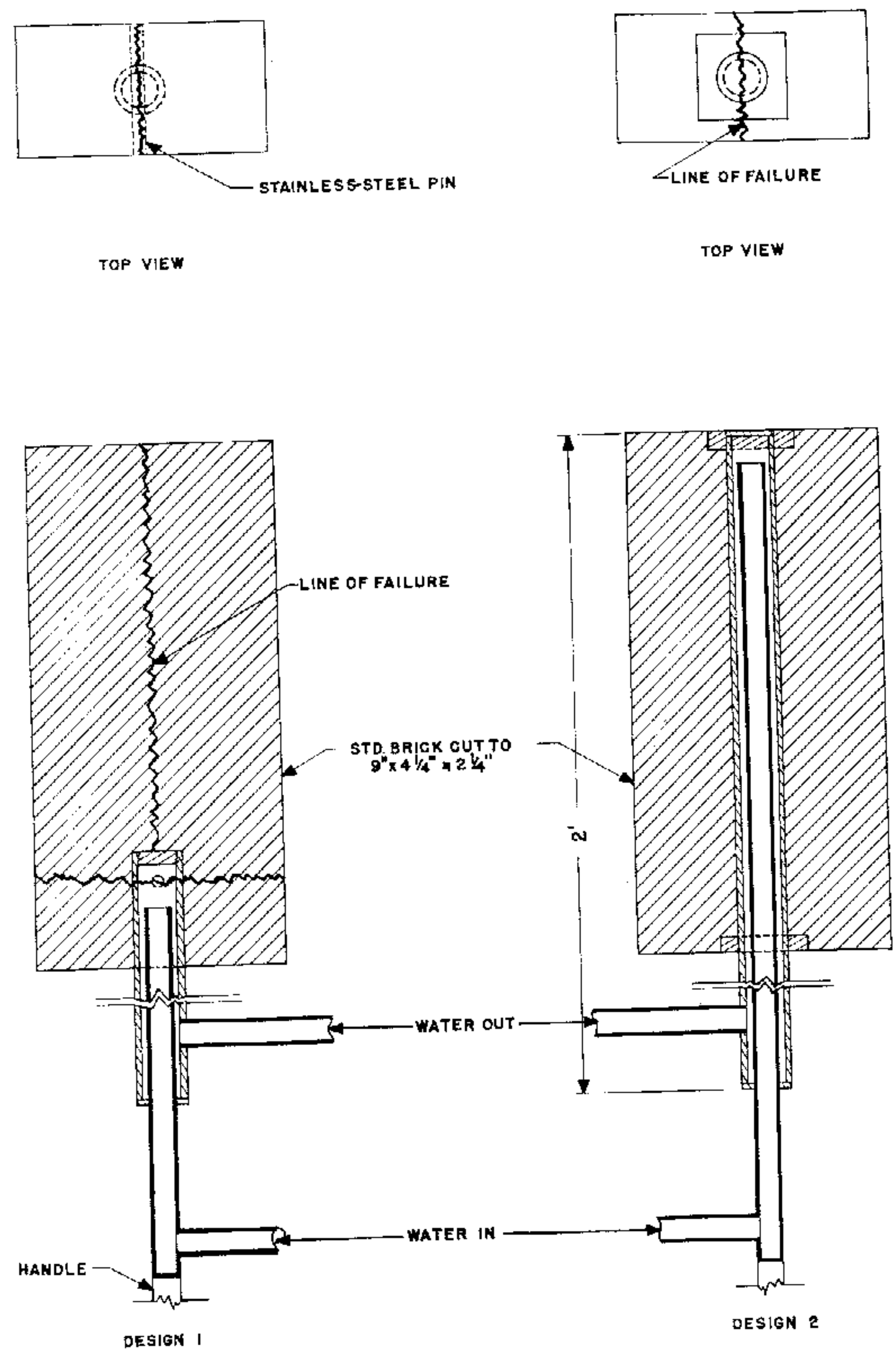

Figure 12. - Construction of refractory valves used in Royster pebble-stove steam-exit lines.

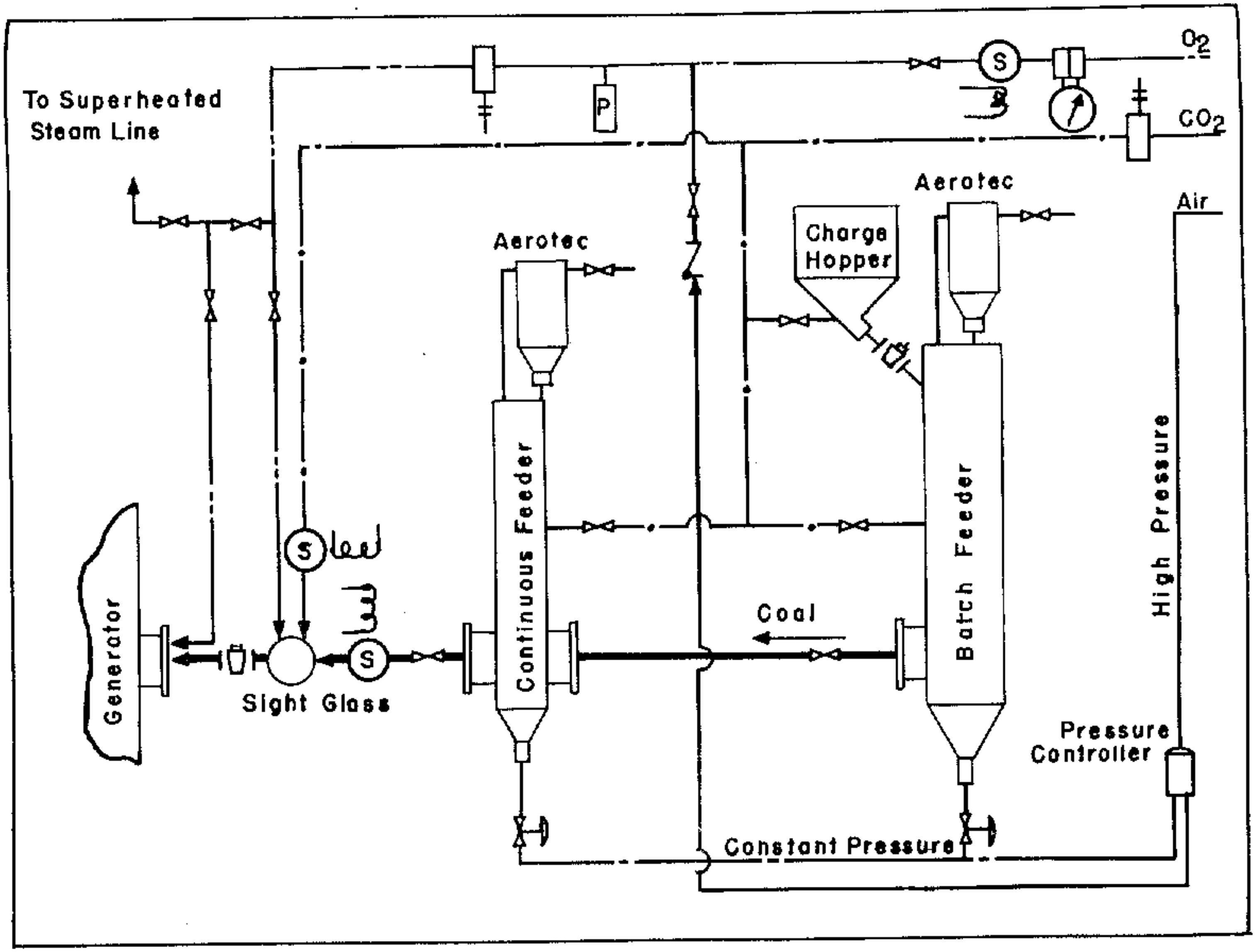

Figure 13. - Flow sheet for pneumatic coal feeder.

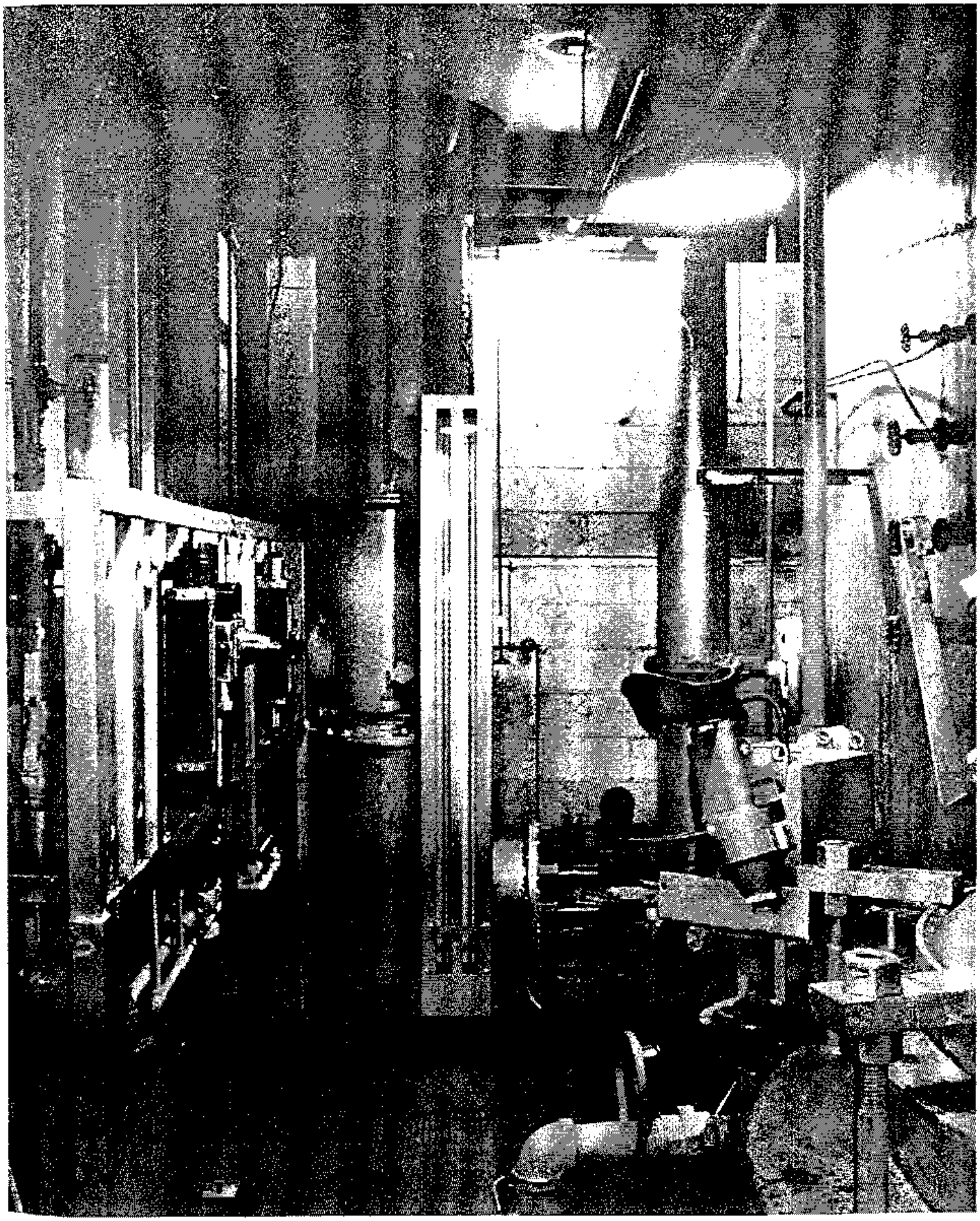

Figure 14. - Pneumatic coal feeder; small vertical cylinder in right rear is continuous feeder.

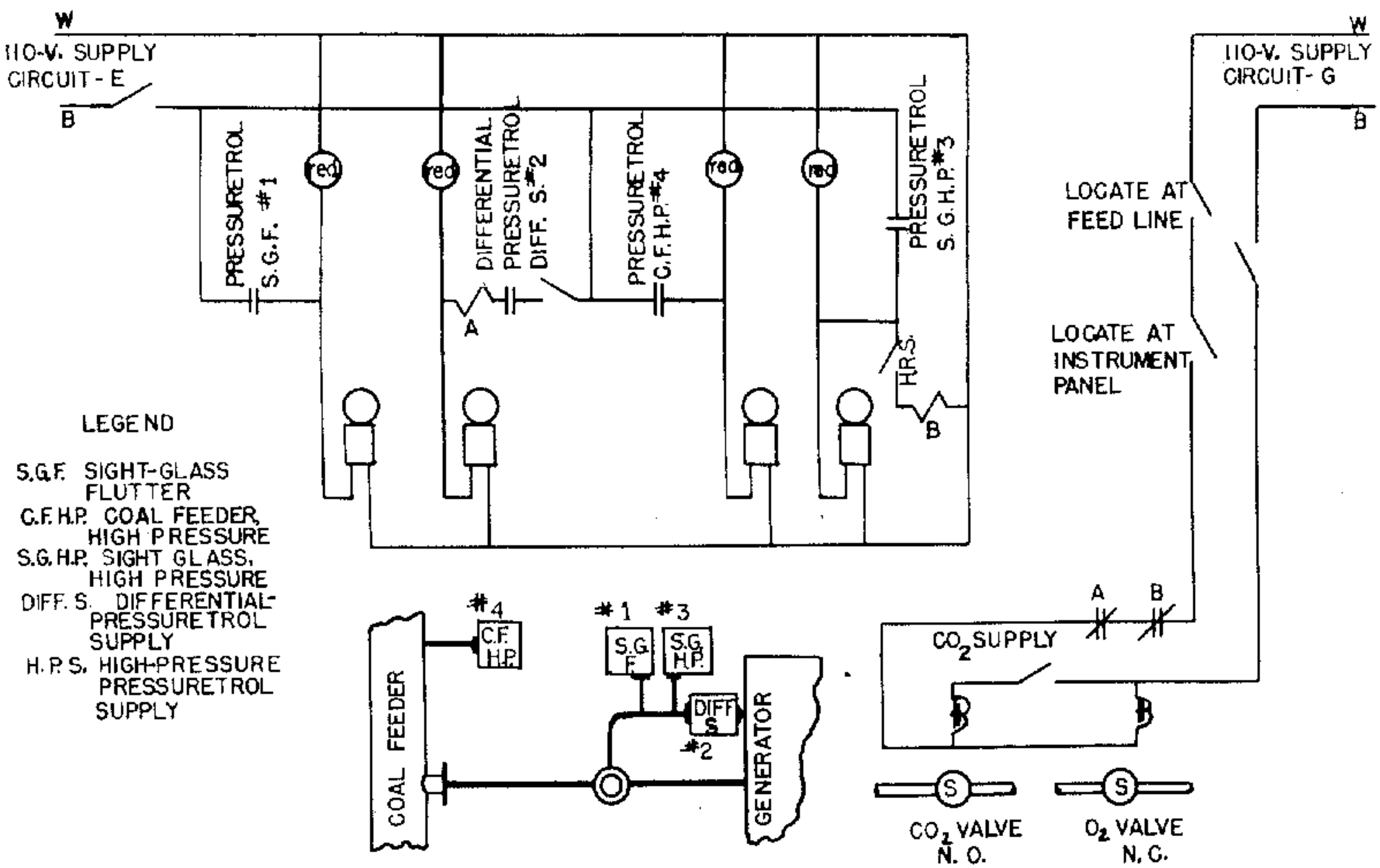

Figure 15. - Schematic diagram of pneumatic coal-feeder control system.