From May to October 1944 small construction proceeded, and contracts for furnishing the equipment and major parts of the plant were awarded to several companies. After the land was accepted by the Government, construction proceeded rapidly. Figures 4, 5, and 6 show the plant during various stages of construction. Figures 5 and 6 show the progress attained by December 1, 1944, and figure 3 shows the plant as it looked when completed on February 15, 1945, prior to the preliminary test. The cost of the project up to February 1, 1945, was $138,100.

Retort Building and Shop

The retort building was the only new structure erected on the plant site. It is of steel with asbestos insulating-board sidewalls, and the interior stairs and landings are of steel. The cost of the 25- by 30- by 60-foot structure was $31,641. The building was erected by a contractor who also installed all services, including the 5-ton traveling crane. The main retort building is adequate for the water-gas generator, the steam-drying unit, and part of the condensing equipment.

An existing structure adjacent to the main retort building was converted into a shop and a pump and blower room. Part of the cooling and condensing equipment was placed next to the pump, as indicated in figure 1.

Chemical Laboratory and Services

The chemical laboratory, offices for plant engineers, instrument shop, and storage rooms were housed in existing structures, which were remodeled to accommodate the services. The chemical laboratory was equipped with gas-analysis apparatus, calorimeters, coal-analysis equipment, and other services necessary for the analysis of fuels. Special sampling devices were set in the chemical laboratory, and space was available for adjustment and calibration of pyrometric equipment. The facilities are adequate for testing a gas plant but not for research, which requires special equipment and services.

Flow Diagram and Description of Operations

Figure 8 shows the original drawing of the Grand Forks pilot plant based upon the design previously tested on a small scale.[10] This drawing was used in planning the arrangement of the large plant, as it shows the major features of the process. Figure 9 gives a more detailed view of the plant as it was prepared for making the first test after the preliminary run. This figure, drawn to scale, gives the function and relative location of auxiliary equipment. It should be noted in figure 9 that the coal-handling and weighing equipment is not shown because by June 1945 these pieces of equipment had not been delivered, and the emergency coal-handling charging bucket was employed to feed lignite to the retort. Also, the char-discharging arrangement is of different design than that shown in figure 8, which was not used.

Lignite enters the hopper at the top, which is closed by a tight-fitting butterfly valve. The hand-operated cone valves at the base of the hopper are then opened, and the lignite moves into the charging dome, which connects with

[10] Work cited in footnote 6.

the heated annular section. Steam is introduced in the charging dome through a jacket surrounding the gas off-take pipe, and it moves with the coal into the annular reaction zone. Steam and coal and the products of distillation from the coal react in the heated annular zone to make water gas, which contains some CH_4 and illuminants derived from the volatile matter from the coal. The products of gasification pass out of the system through the center offtake and into the cooling and scrubbing system. After char passes the gas offtake port it encounters preheated steam, which is introduced at the bottom of the annular section and moves upward countercurrently to the char. The steam to the char zone is introduced at the top of the retort near the gas offtake pipe and is preheated before it enters the lower heated annular reaction zone.

Char is removed from the system by a revolving scraper, which moves the residue to a central outlet above the char receivers. The rate of char removal is controlled by regulating the speed of the scraper to give the desired percentage of gasification. In later improvements the char is handled pneumatically and is blown from the char receiver to an outside container.

The vertical retort is heated by gas introduced at several ports. The air for combustion is mixed with about 2-1/2 times its volume of products of combustion and passes through the recuperator to a bustle pipe, then to each port through separate flues. The amount of air introduced is regulated to be about 5 percent more than that theoretically required to burn the gas.

The products of combustion leave the system through a steam preheater, as indicated in figure 9. A portion of the products of combustion is cooled and then used in the purge-gas system, which can handle about 5,000 cubic feet per hour if necessary. Purge gas is used to seal the charging system and to flush out equipment that may need repairs.

The products of gasification leave the retort through the central offtake pipe and pass directly to a water scrubber. This scrubber combines a wash-box and water scrubber, which employs Raschig rings in the upper section, as the contact media. A conventional water spray cools the gas to within 5°F. of the inlet water temperature. The cooled gas passes through a water separator to remove entrained moisture, and it then passes into a packed oil scrubber, which is of the same design as the water scrubber but it does not have the interior wash-box seal. After the oil scrubber, the gas passes through a shavings scrubber and thence through the exhauster, which forces it into the gas holder. As the experimental objective was to study production of gas, no provisions are made to remove sulfur in this plant. The sulfur content, however, when low-sulfur lignites are gasified, is very low and is less than the limits prescribed for city distribution.

The make gases leaving the generator travel at high velocity and carry over fine char and ash particles, which are removed in the water scrubber. If the system is operated at low temperatures, some tar vapors are not decomposed, and these also are partly condensed in the water scrubber. The dust-laden water passes into a sump tank, through a separator, and thence to the sewer, as shown in figure 9.

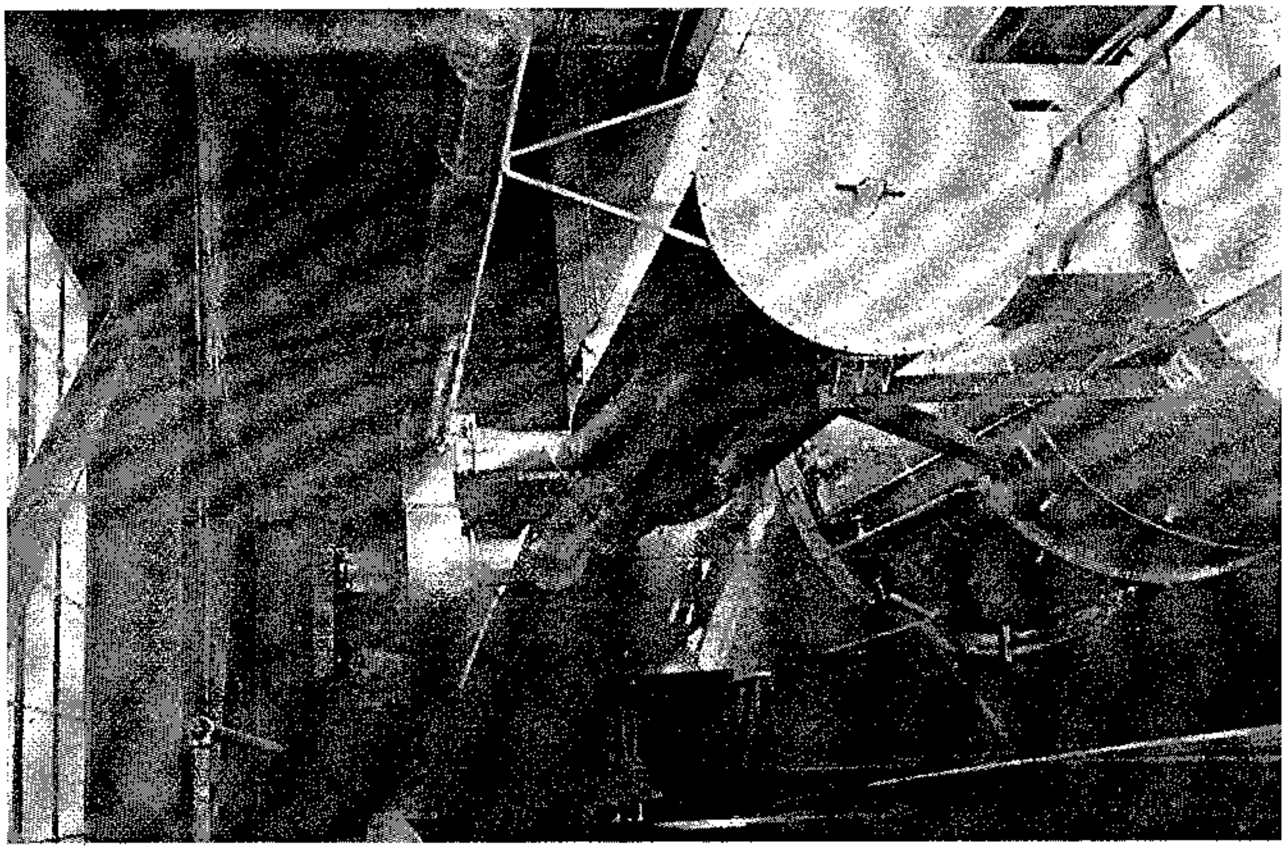

Figure 10. - Top view of retort and recuperator unit, Grand Forks.

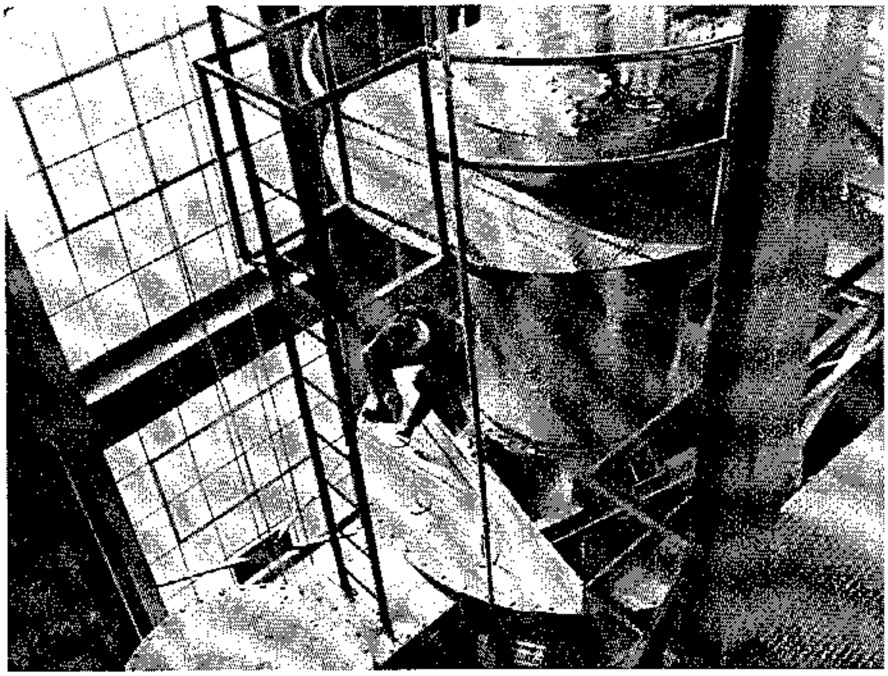

Figure 11. - Retort unit charging dome, Grand Forks.

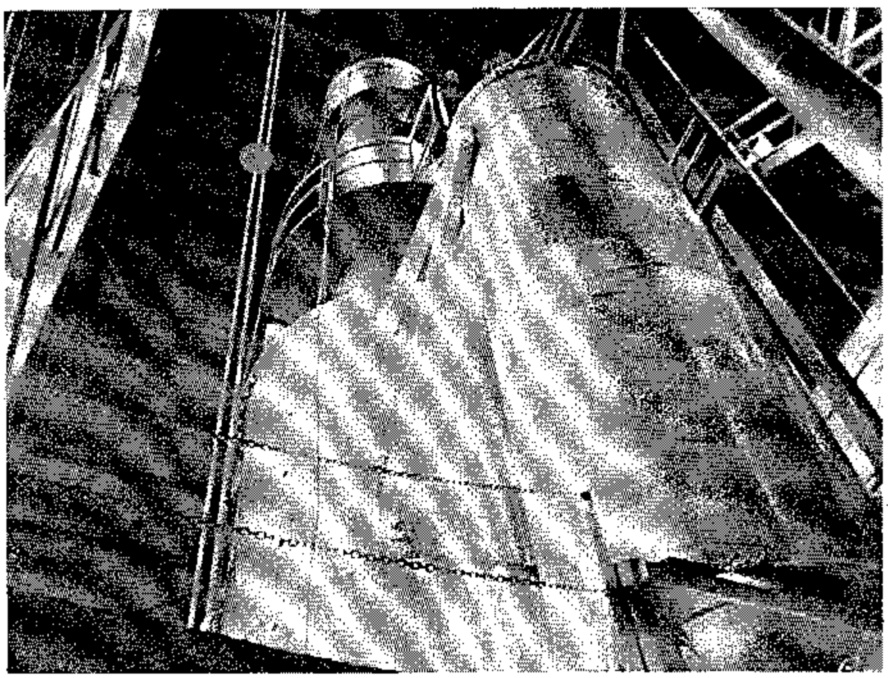

Figure 12. - Lower view of retort and recuperator unit, Grand Forks.

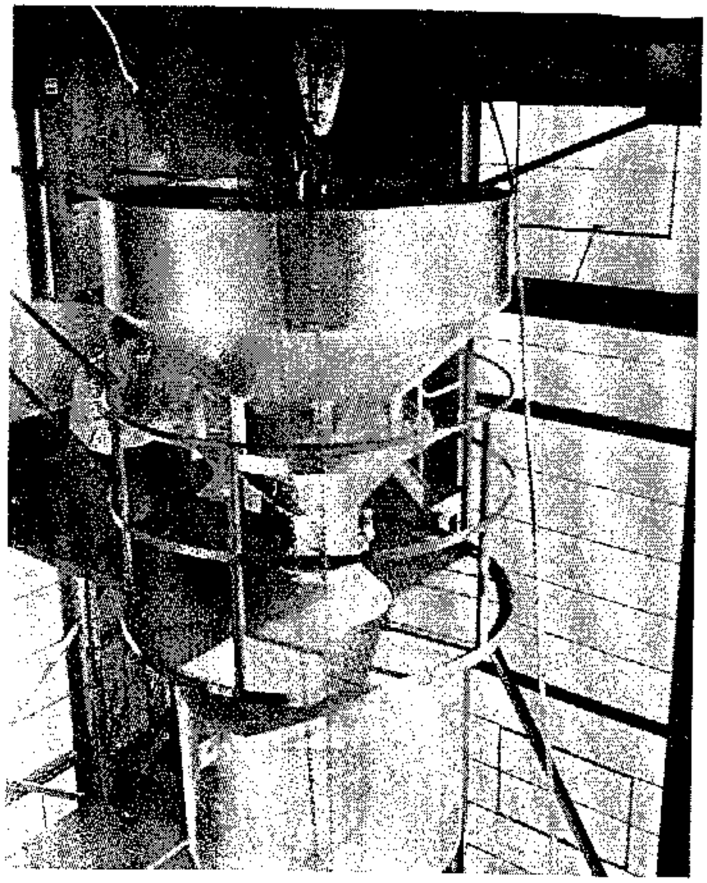

Figure 13. - Charging hopper on retort, Grand Forks.

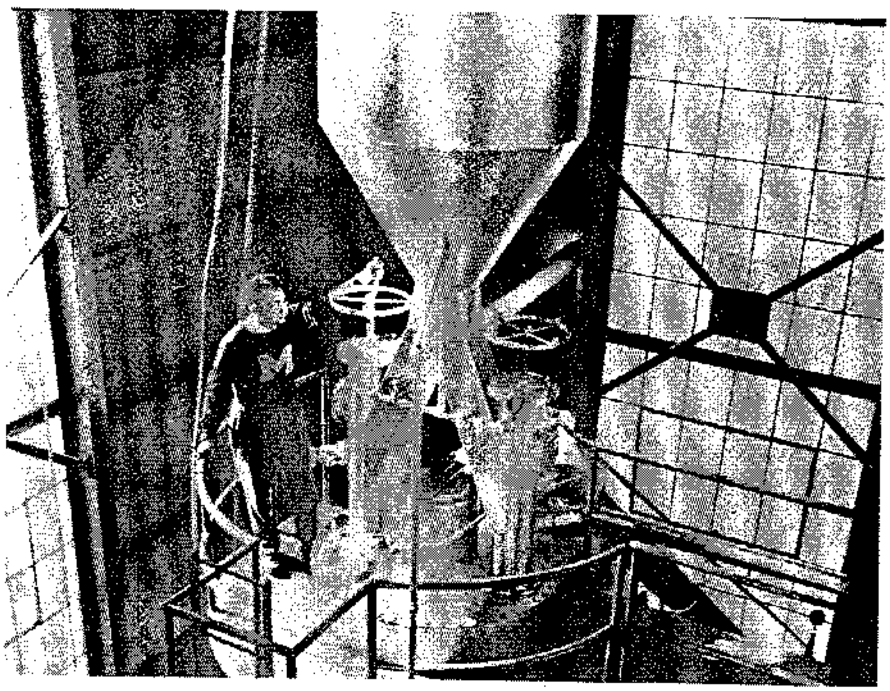

Figure 14. - Charging valves on retort dome, Grand Forks.

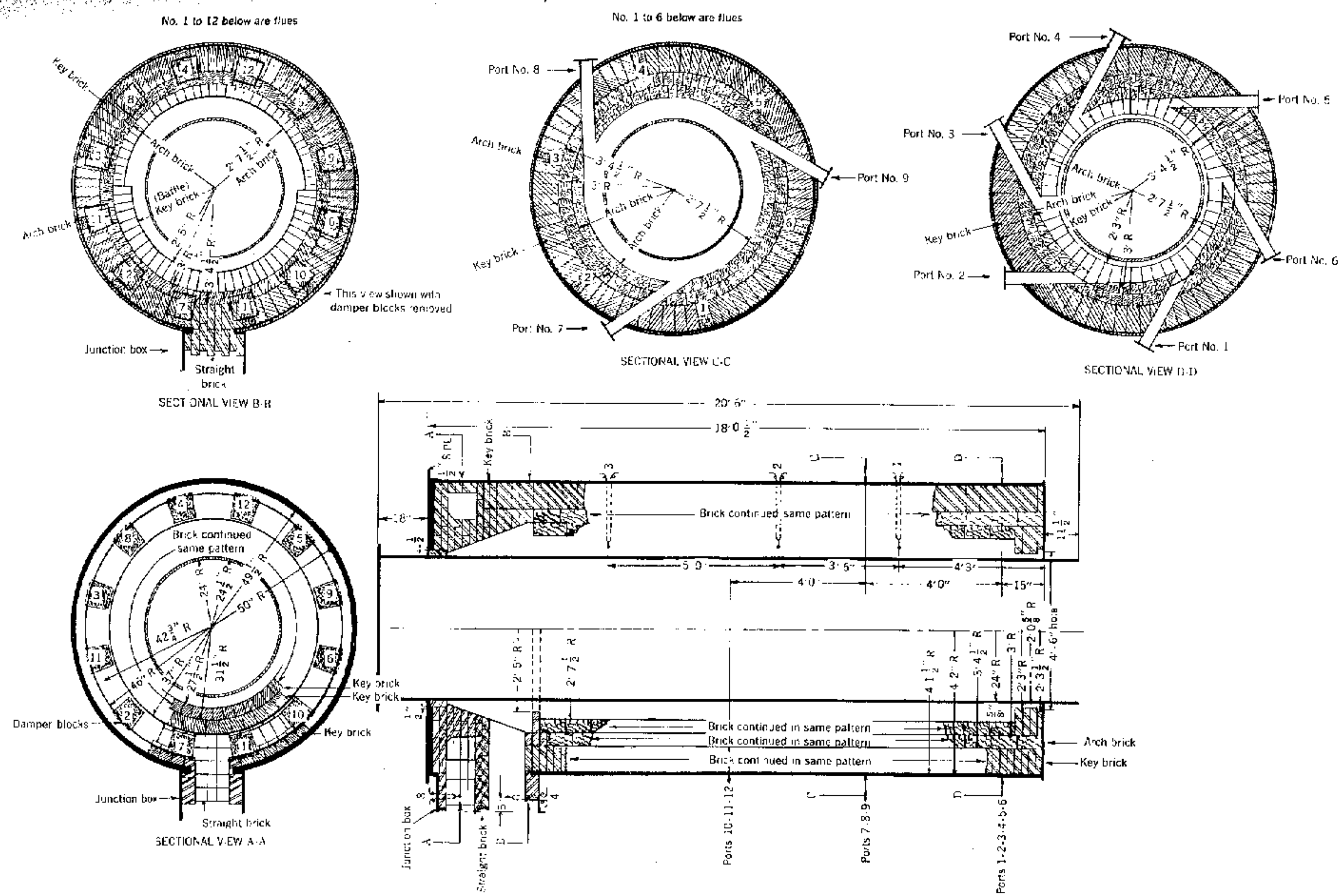

Figure 15. - Annular retort, sectional views of brickwork and combustion chamber.

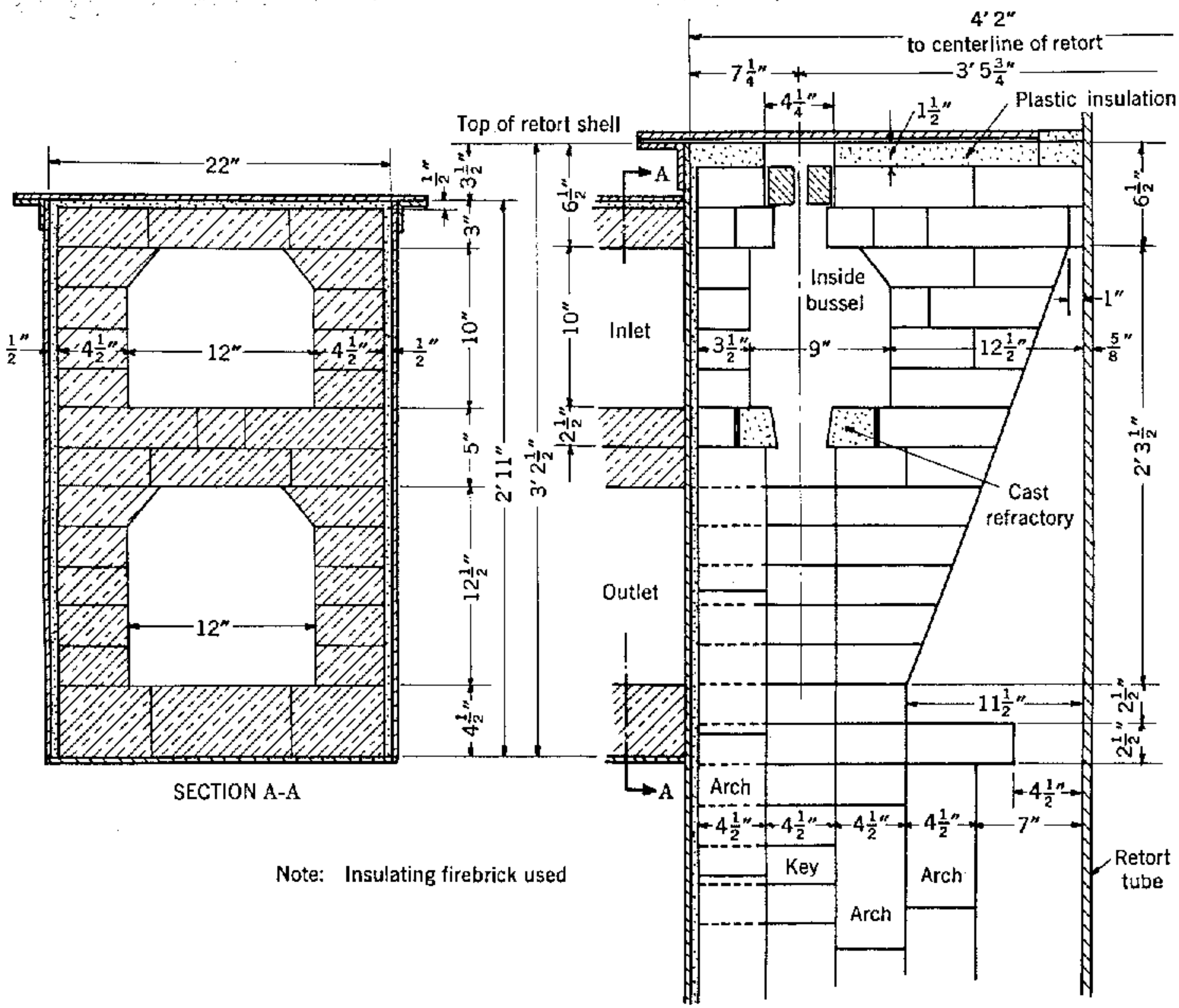

Figure 16. - Detail of brickwork in retort, Grand Forks plant.

The process operates continuously and makes different grades of gas by adjustment of the temperature in the combustion chamber and of the amount of steam entering the top and bottom retort annuli. The quality of the gas and the rate of heat transfer are influenced by the width of the annular reaction zone, as will be explained in the description of experimental work. Generally speaking, the rate of gasification is inversely proportional to the width of the reaction zone.

An important control or variable when gasifying coal in this externally heated retort is the percentage of gasification. By controlling the rate of char removal, the amount of carbon gasified can be varied from 60 to 90 percent.

Although the mechanism of gasification and a theoretical interpretation of the process were deduced before the pilot plants were built, it was necessary to experiment a great deal to find the relationship of the several variables. The major variables that affect the yield and quality of gases and the efficiency and rate of gasification by this process are:

1. Temperature of the retort. This depends on the rate of heat release and the distribution of the heating gases and products of combustion.

2. The width of the annular reaction zones.

3. The relative length of top and bottom reaction zones.

4. The amount of steam introduced in each reaction zone.

5. The rate of char removal or percentage of gasification.

6. The physical and chemical properties of the coal particularly its moisture and ash content. The size of the fuel is a minor variable if it contains no excessive fine dust and is small enough to move into and through the narrow reaction annulus.

The Retort Unit

Several views of the retort unit are shown in figures 10, 11, 12, 13, and 14. Most of the fabricated parts of this unit are circular. The main shell is 100 inches in diameter and 18 feet in length. It is lined with insulating firebrick, but about one-half inch of plastic insulating cement separates the firebrick from the steel shell, as shown in figures 15 and 16. The lightweight insulating firebrick is laid in conventional patterns, as illustrated in figure 15, which shows the position of ports and burners. As noted in figure 15, six tangential ports supply gas to the burners in the lower part of the retort, and three additional ports are situated at the 4- and 8-foot levels above the lower burners.

The recuperator is suspended from the side of the generator, as indicated in figures 8, 9, and 10. The recuperator shell is 4 feet in diameter and 15 feet in length and is lined with 6 inches of pre-formed insulating brick.

The recuperator tube nest is 12 feet 7 inches long and has eight equally spaced baffles to direct the gases across the tubes. The tube nest is made up of 258 tubes of 1-1/4-inch outside diameter, with 12-gage walls, and these are spaced on 2-inch centers on an equilaterial triangle pattern. The tubes, headers, and baffle sheets were made of Sicromo 5-S, heat-resisting, alloy steel of the following composition: Chromium, 4.0 to 6.0 percent; molybdenum, 0.45 to 0.65 percent; carbon, 0.15 percent maximum; manganese, 0.50 percent maximum; silicon, 1.0 to 2.0 percent; sulfur and phosphorus, each 0.03 percent maximum. An alloy of greater heat resistance should have been selected for the recuperator.

The metal retort, which is 48 inches in diameter, is suspended in the center of the main shell and supported on springs, as indicated in figures 8 and 18. The compression on the springs is adjusted to place the hottest part of the retort under neutral strain. The first retort tested was made of mild carbon steel coated with a thin sprayed-on coating of heat-resisting alloy. The steel retort was selected because of early delivery, and, also, the possibilities of sprayed-on heat-resisting coatings were encouraging. An alloy-clad steel retort having a 1/8-inch-thick 25.6 percent chromium alloy surfaces over a 3/8-inch steel center was installed during the fall of 1945 and was operated for 1,300 hours.

The inner retort, which forms the annulus with the main outer retort tube, is of mild steel with no protective coating. Because the final dimensions of the inner retort or arrangement of the annulus could not be decided upon without preliminary experimental testing, the inner retorts of mild steel were selected to permit changes and adjustments in the field. Also, it was indicated from experience on the small pilot plant at Golden that mild steel should have adequate life because of the lower temperature and reducing gas environment. Experience proved the wisdom of using mild steel for the center retorts because several changes in width and length of the two annuli were made to improve the capacity and efficiency of the retort. The changes of the inner retort arrangement are discussed in a later section of this report with the explanation and record of each test.

Considerable experimenting was done to find the best method for removing char from the lower annulus. The first method employed used a curved scraper, which moved the char into the central offtake. Improvements were made as further experience was obtained. The scraper shown in figure 17 performed satisfactorily for about 1,300 hours of operation.

The top part of the main retort has a 3-inch flange for attachment to the charging dome, as shown in figure 15. The lower part of the retort is plain and fits into a cup, which makes a bell and spigot-type joint. The spacing in the joint is 1/4 to 1/2 inch wide and is packed with asbestos rope. The joint has given no trouble and withstands 30 inches of water pressure without leaking. The joint is checked at intervals and is tightened to insure against gas leakage.

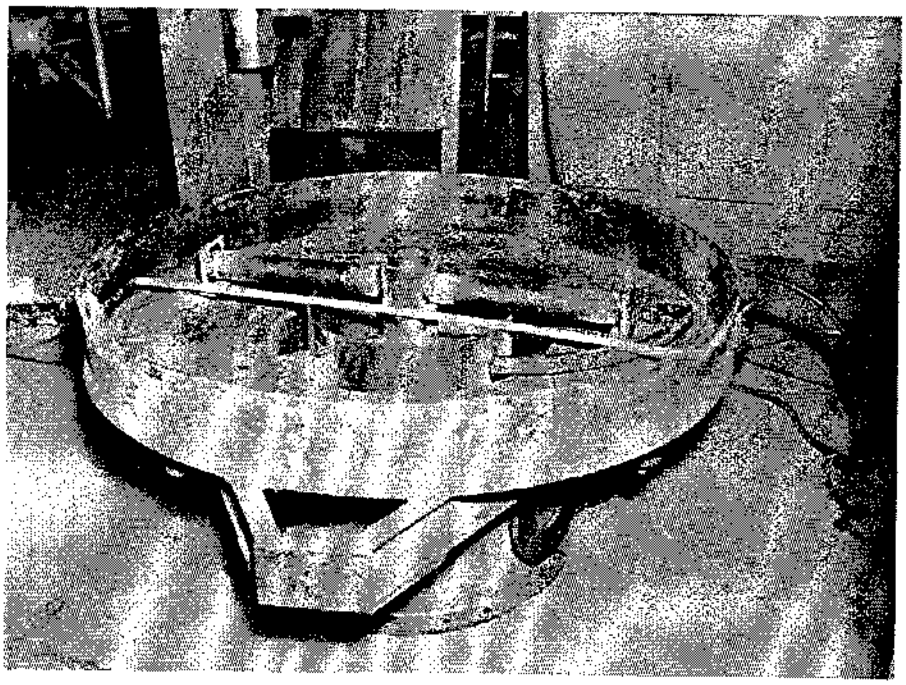

Figure 17. - Char discharge scraper, Grand Forks pilot plant.

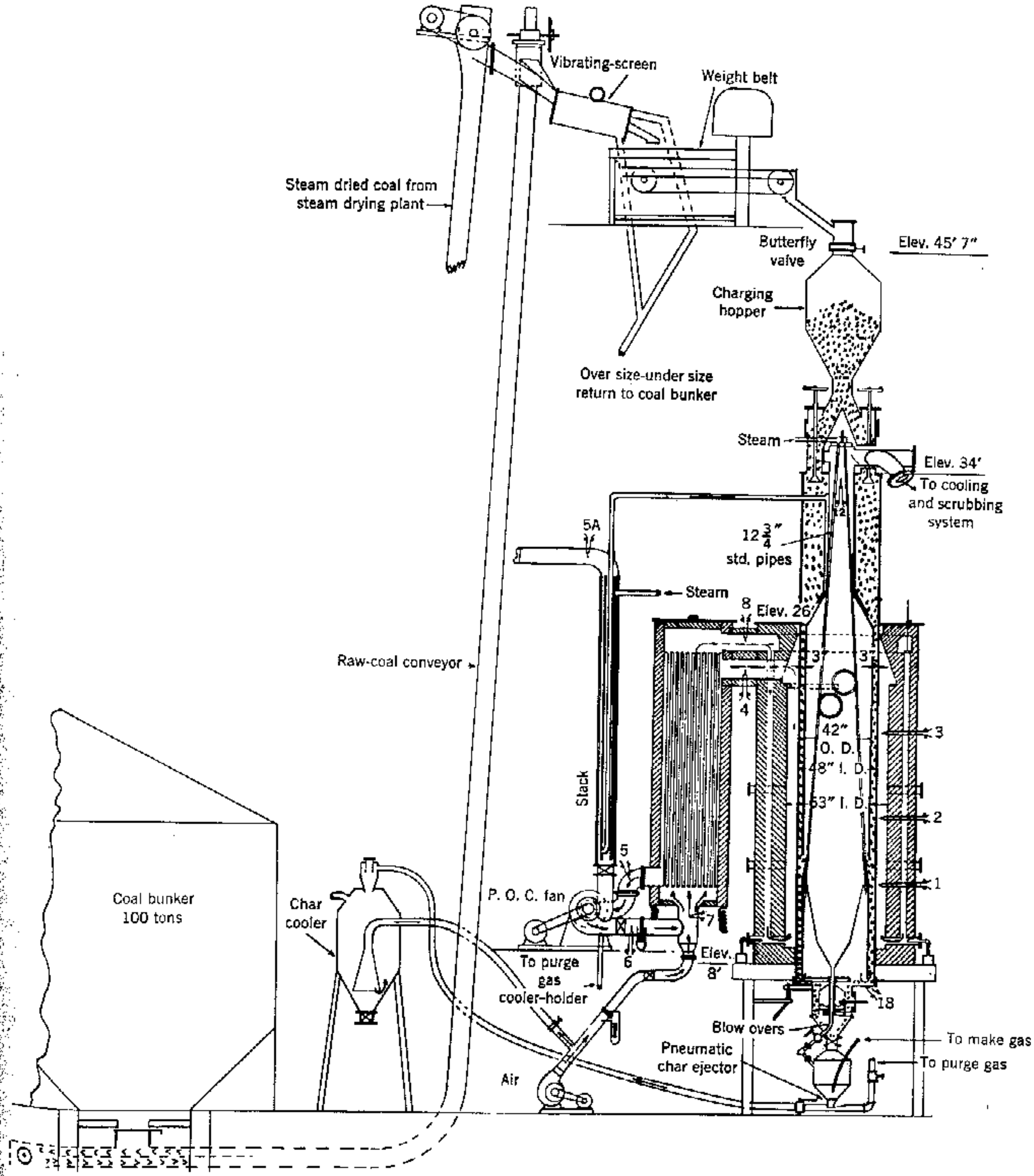

Figure 18. - Bureau of Mines pilot plant for gasification of lignite, Grand Forks, N. Dak., December 1945.

The original basic design of the retort unit was not altered, but the coal-charging and char-discharging devices were improved as experience was gained. By December 1945, the Bulk-flo conveyors, the vibrating screen, and weigh-belt were installed, as shown in figure 18. Also, the improved char-discharge equipment was placed in operation. The pneumatic char ejector reduced much of the nuisance in disposing of the carbon residues. Figure 18 shows the main features of the retort unit, including later arrangements of the annular retorts. Because of the physical structure of lignite, it was not handled satisfactorily in the original conveyors, and changes in the design of the flights were necessary before it would operate satisfactorily. Because of the temporary failure of the conveyors, the coal-handling system described in figure 18 was not operated up to the time of writing this report, and coal has been handled through the emergency system for all runs.

The emergency coal-handling system receives coal directly from freight cars, and a portable conveyor lifts it to a shaking screen, which discharges into a chute leading to the charging bucket. The charging bucket is weighed directly on a beam-scale and is then hoisted by the traveling electric crane into position above the charging hopper. This system is satisfactory and gives little trouble, but it is relatively expensive to operate because the coal has to be removed from the cars by hand shoveling.

Instrumentation and Methods of Obtaining Data

Instruments were installed in both pilot plants to measure and control operations for complete heat and material balances. As the process is continuous, emphasis was placed on measuring rates per hour, and the time of making observations was extended to give an accuracy of 1 percent or less.

Coal was measured by direct weighing on beam scales, and the dry char extracted was accounted for in the same way. Dust carried by the gas was obtained by extracting the dust from a given quantity of gas. In the later extended runs on the large plant, the char residues and dusts were collected over 24-hour periods, and all of the material was weighed.

Make gas was measured by an orifice meter in the large plant, whereas in the small plant a displacement-type meter was employed. The orifice meter was connected to a recording differential gage, which was integrated for the testing period in question. Steam supplied to the upper and lower annuli was measured by orifice meters, which were previously calibrated by weighing condensed steam. Air and gas for the combustion system also were measured by orifice meters, and the differential pressures indicating rate of flow were read periodically from draft gages. Since the fluctuations in these meters were very small, the average of hourly readings over a 24-hour period was accurate to 1 percent or less. Water supplied to the cooling system also was measured by orifice meters.

Considerable attention was given to temperature measurement and control. Thermocouples were located in many parts of the plant, as indicated by the numbered stations on figures 8, 9, 15, 18, and 21. The construction of thermocouples for the Golden plant is shown in figure 24. This same type construction was employed on the large plant, but the dimensions were changed to fit the space requirements of the Grand Forks plant.