SUMMARY AND CONCLUSIONS

A small, annular-retort gasifier having a nominal capacity of 40 pounds of lignite per hour was designed and constructed at the Lignite Experiment Station, Grand Forks, N. Dak. The purpose of the investigation was to increase the capacity of an annular-retort gasifier by better temperature distribution in the heating chamber (adjacent to the annulus) and by supplemental internal heating with controlled amounts of air. Correct control of air admission should yield crude ammonia-synthesis gas having a $(H_2+CO)-N_2$ ratio of 3. Dakota Star stoker-size lignite was used during the exploratory experimental program. The effects of temperature level and distribution in the heating chamber and of addition of air to the reactor were investigated.

Hydrogen - carbon monoxide ratios ranged from 1.9 to 2.5, and $(H_2+CO)-N_2$ ratios were as low as 2.9. Hourly gas production ranged from 970 to 2,580 cu. ft., or 62.0 to 164 cu. ft. per sq. ft. of heated surface, or 350 to 940 cu. ft. per cu. ft. of reactor volume. Data from the small gasifier could be readily correlated with those previously obtained in the commercial-scale unit under comparable experimental conditions.

The conclusions may be summarized as follows:

1. The rate of gas production in the small gasifier, operated with the heating chamber at 1,900° F., was approximately 20 percent greater per square foot of reactor surface than that in the commercial-scale gasifier, operated with a temperature of 1,925° F. at the bottom and 1,600° F. at the outlet of the heating chamber. An increased gas-production rate from about 14,000 cu. ft. to 17,000 cu. ft. per hr. can be expected in the commercial-scale gasifier with a heating system capable of maintaining a uniform temperature over the length of the heating chamber.

2. The increased unit rate of gas production with the small gasifier was caused entirely by increased rates of heat transfer due to a uniformly high heating-chamber temperature.

3. The rate of gas production of the small gasifier was increased 34 percent by increasing the (uniform) temperature of the heating chamber from 1,800° to 1,900° F.

4. Heat requirements, for gasification by external heating only, were 107 and 103 B.t.u. per cu. ft. of synthesis gas at nominal temperatures of 1,800° and 1,900° F.

5. With addition of 3.7 cu. ft. of air per lb. of lignite and 68.5 percent carbon conversion, synthesis gas having a $(H_2+CO)-N_2$ ratio of 3.7 was produced at the rate of 164 cu. ft. per hr. per sq. ft. of reactor surface, at a nominal retort temperature of 1,800° F.

6. Crude gas with a $(H_2+CO)-N_2$ ratio of 2.9 was obtained at a rate of 123 cu. ft. per hr. per sq. ft. of reactor surface by adding 7.4 cu. ft. of air per lb. of lignite and operating at 82.6 percent carbon conversion, at a nominal retort temperature of 1,800° F.

7. External heat requirements decreased with increasing air-lignite ratios fr from 107 B.t.u. (no air) to 60 B.t.u. per cu. ft. of gas at an air-lignite ratio of 7.4 cu. ft. per lb. of lignite, at a nominal retort temperature of 1,800° F.

8. The rate of gas production of the small gasifier was limited by the rate of gas passing through the bed. At excessive gas velocities the lignite bed became unstable, resulting in appreciable entrainment of fine residue in the gas.

INTRODUCTION

In 1943 the Bureau of Mines became interested in gasifying lignite to produce gases rich in hydrogen for reducing iron ore by the Brassert process (9).[6/] Based on preliminary work at Golden, Colo. (10), a commercial-scale pilot plant was constructed at Grand Forks, N. Dak., in 1945, designed for gasifying lump lignite with steam at atmospheric pressure in an externally heated metal retort.

Interest in gasification continued because of the possibility of using the gas for the production of synthetic liquid fuels or chemicals. The commercial-scale unit at Grand Forks was operated for over 8,700 hours during a 6-year period to obtain information on process variables, performance, and improvements in design. Details of these investigations, including a theoretical evaluation, have been published (1, 2, 3, 4, 8, 11).

The operability and flexibility of the gasifier were satisfactory; however, the rate of gas production was relatively low and limited by heat transfer through the externally heated metal wall and lignite bed and by temperatures considered safe for the alloy-steel retort.

Two possibilities were considered to increase retort capacity. One of these was modification of the temperature distribution in the heating chamber which surrounds the reaction zone, by increasing the temperature at the entrance to the retort. The other was to supply some heat internally by burning part of the lignite with oxygen bled into the upper section of the reactor. Admission of air would not only supply oxygen for burning but would also add enough nitrogen to produce a crude ammonia-synthesis gas with a $(H_2+CO)-N_2$ ratio of 3.0 in one operation.

Such gas might be of commercial interest in future because of the continuous increase in demand and large potential market for fertilizer in the North Dakota-Minnesota-South Dakota area (5), coupled with large proven reserves of lignite. Construction of an integrated ammonia-fertilizer plant in this area has been recently proposed, although admittedly the venture would be a marginal proposition (6, 7).

To investigate this possibility for producing crude ammonia-synthesis gas, the Bureau of Mines in September 1952 authorized the design, construction, and operation of a small-scale, partly internally heated, annular retort for gasifying lump lignite. Experimental investigation was necessary because of the difficulty in predicting the performance of a partly internally heated gasifier on the basis of

6/ Underlined numbers in parentheses refer to citations in the bibliography at the end of this report.

available data. Construction of a small unit was advisable because costs for remodeling the commercial-scale retort were prohibitive, being larger than that for building a small-scale unit. Additional savings would result from reduced operating costs because fewer operators and less raw materials would be required, and closer control would be possible in a small unit.

The work was concerned primarily with the effect of the temperature distribution in the heating chamber and of internal heating by partial combustion on the production of $(H_2+CO)-N_2$ mixtures suitable for conversion to ammonia-synthesis gas. The results of this exploratory investigation are presented here.

ACKNOWLEDGMENTS

Lignite was donated by the Truax-Traer Coal Co., Minot, N. Dak.

DESIGN AND OPERATION OF PILOT PLANT

Description of Small Gasifier and Gas-Handling System

Basically, the small gasifier is similar to the commercial-scale gasifier previously described (1, 2, 8, 10), in that lignite flows through a vertical, annular space between two concentric metal tubes where carbon is reacted with steam at elevated temperatures to form water gas. In the large unit, heat for the endothermic water-gas reaction, as well as for drying, preheating, and carbonizing the charge, is supplied by burning gas in a heating chamber surrounding the reactor. In the small unit, external heating is supplied by electric heating elements with closely controlled power input. Supplemental internal heating is possible by admission of air to the reaction space.

Table 1 shows the dimensions and materials of construction of the two gasification units. The ratio of reaction volumes is 18.7:1; that of heating surfaces is 13.1:1. Design capacities are 750 and 40 pounds of lignite per hour.

TABLE 1. - Comparison of reaction tube and reaction zones between small and large gasifier

Item	Small unit	Large unit
Outer tube		
Inside diameter .... in.	10	48.5
Wall thickness .... do.	0.188	0.500
Material	310 alloy steel	310 alloy steel 0.7 % Cb.
Inner tube		
Outside diameter .... in.	4	42.5
Wall thickness .... do.	0.125	0.375
Material	310 alloy steel	Mild steel
Annular width .... in.	3	3
Reaction zone length .... ft.	6	17.2
Total annulus volume .... cu. ft.	2.8	51.5
Annulus volume per linear ft. ...... cu. ft.	0.5	3.0
Total heating surface .... sq. ft.	15.7	210
Heating surface per linear ft. ..... do.	2.6	12.7

A schematic diagram of the small plant is shown in figure 1; figure 2 gives an overall view of it. As shown in figure 1, lignite is charged through an independently sealed hopper and descends through the annulus cocurrently with steam and air introduced in the hopper or just below it. Refuse, or char, is removed at a controlled rate by a screw conveyor at the bottom of the retort. Gas and unreacted steam pass from the reaction space into the bottom of the inner tube and from there to the gas outlet at the top. Some sensible heat is recovered and transferred to the lignite through the wall of the inner tube. Gas is cooled; and dust, unreacted steam, and traces of tar removed in a water scrubber. Cooling water is introduced through a spray nozzle at the top of the upper coke-packed chamber of the scrubber, countercurrent to the gas flow. A 1-inch water seal is provided at the gas inlet. Water carrying the dust is discharged from the bottom of the scrubber into a settling tank. Slurry from the settling tank is filtered to collect the dust. The washed and cooled gas passes through a gas meter to a disposal system.

Design and Construction of Retort

Reaction Tube

A 10-inch I. D. stainless steel tube, type 310, 7 feet in length and with a wall thickness of 3/16 inch, served as the externally heated reactor. To provide a 3-inch annular reaction space, a smaller, 310-alloy tube, 4-inch O. D., was centered in the larger tube. The 310-alloy reaction tube in the commercial-scale pilot plant contained 0.7 percent columbium to prevent excessive grain growth. Because of the short program planned with the small unit, the presence of columbium was considered unnecessary.

Electrical Heating System

Electrical heating was chosen because of its amenability to automatic control and the ease with which energy input could be determined.

Heating requirements for the gasifier were estimated at 145,600 B.t.u. per hr. or 42.7 kw. The basis for this estimate was an energy consumption of 2,800 B.t.u. to preheat, dry, carbonize, and gasify 1 pound of natural lignite, and the nominal hourly feed rate of 40 pounds of as-received lignite. A 30-percent safety factor was provided to allow for increased resistance of the heating elements with use.

The heating chamber was designed with 3 compartments (not shown in fig. 1), each 2 feet high, to permit independent variation of power input to each compartment. The temperature in each compartment was regulated by an electronic controller-recorder.

Resistance wire of 0.229-inch diameter, fabricated from Jellif Alloy K, A. W. G. No. 3, was selected for continuous operation at heating compartment temperatures to 2,000° F. Final specifications for the heating elements were as follows:

Voltage	120 v. a.c.
Maximum power output per element	7 kw.
Electrical connection	3-phase wye
Wire length per element	125 ft.
Pitch of coiled element	0.5 in.
Inside diameter of coiled element	1 in.
Length of coiled element	15.7 ft.
Weight of coiled element	16.2 lb.
Resistance per element, cold	1.94 ohms
Number of elements per compartment	3

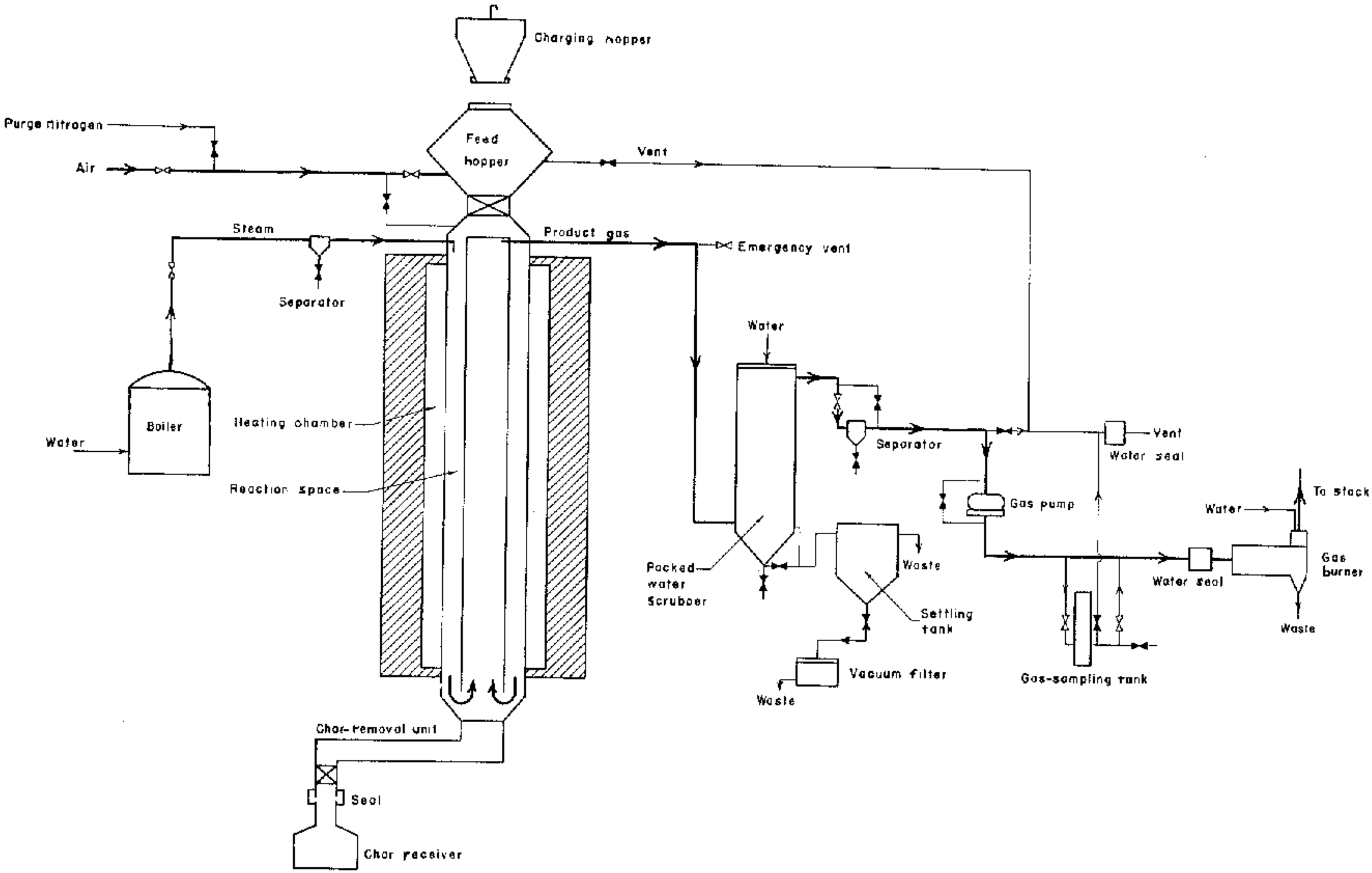

Figure 1. - Schematic diagram of small-scale annular-retort gasifier, Bureau of Mines, Grand Forks, N. Dak.

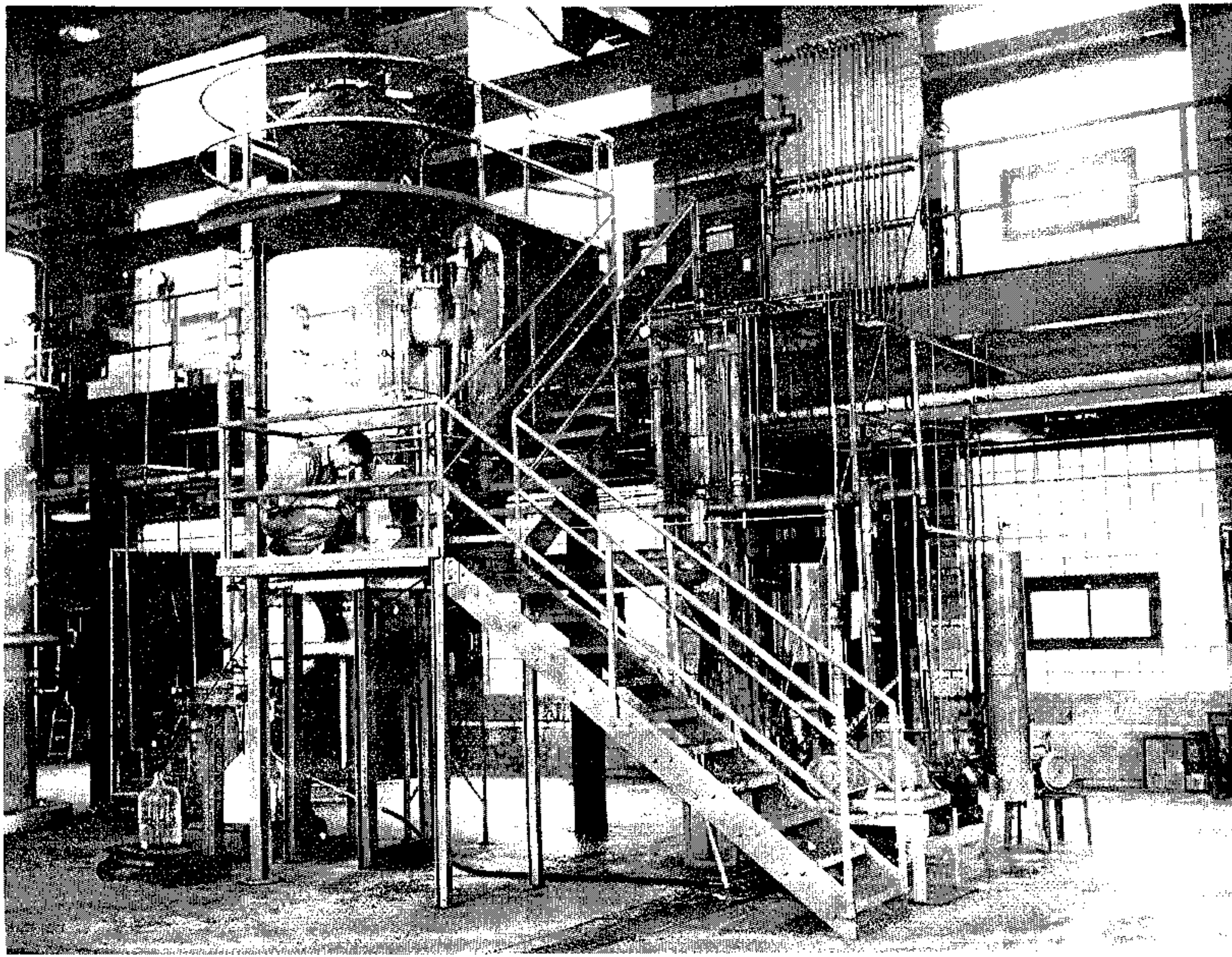

Figure 2. - Overall view of completed small gasifier, Bureau of Mines, Grand Forks, N. Dak.

The coils were arranged to form a helix encircling the reaction tube 9 times in each compartment on a 20-inch-diameter circle.

A coiling machine was designed and constructed, similar in principle to a pipe-cutting machine. The center roll was relatively wide, with a central groove around the periphery to guide and bend the incoming wire. The rollers were attached to the frame in such a manner that they were adjustable with respect to the coiling mandrel, thus allowing various coil pitches. During coiling the mandrel rotated, while the machine, propelled by a hand-operated crank, moved laterally along an I-beam. To prevent breakage, the relatively brittle wire was preheated with an acetylene torch to approximately 600° F. at the entrance to the coiling roll. Preheating made the wire ductile enough to allow the entire heating element to be wound without breakage. The surface temperature of the wire was checked with a surface pyrometer near the front of the rolls and was maintained by occasional adjustment of the flame. The rollers of the coiling device were oil-cooled to prevent overheating. During operation occasional minor adjustments of the roller angle were required to maintain the correct pitch. The coiling operation is shown in figure 3.

To obtain balanced heating loads the resistance of each coil was measured at room temperature with a Wheatstone bridge, and coils having equal resistances were assembled into groups of three. Maximum deviation in resistance within groups was less than 5 percent.

The complete wiring diagram for the heating system is given in figure 4. Each compartment contained three wye-connected elements energized through a controller-operated contactor. Totalizing watt-hour meters recorded power consumption in each compartment, while indicating ammeters showed instantaneous current demand in each main phase line.

After some experimentation, power leads were fabricated from 1/2-inch, 316-alloy-steel rods welded to the resistance wire. The alloy rod rested on doughnut-shaped refractory sections inside a 310-alloy-steel conduit, thus allowing rapid heat dissipation.. Details of the power terminal are illustrated in figure 5.

Heating Compartments and Retort Insulation

The retort was insulated in two steps: First, three cast-refractory liners were used to support the heating coils and to form the outer wall of the heating compartment; second, a 10-inch layer of granular insulation was placed between the refractory casting and a steel shell surrounding the gasifier. To obtain satisfactory strength at temperatures above 2,000° F., the refractory liners of 4-inch wall thickness were cast from Super-Fracto-Crete No. 70, having a service temperature of 2,800° F. The calculated outside temperature of the casting was approximately 1,700° F. at an operating temperature of 1,900° F. With the casting technique a continuous helical groove to support the heating elements could be produced without difficulty.

The groove on the inner surface of the casting was obtained by use of a 1-1/2-inch rubber hose secured helically by fasteners on the face of the inner mild-steel mold. The gap between hose and mold wall was closed with a 1/4-inch rope surfaced with wood putty. Spaces in the liner for thermocouples, optical ports, and leads for heating elements were formed by tapered steel dowels. The fluid refractory-water mixture was poured slowly with hand tamping to insure complete enclosure of inserts. Design details of a cast refractory section are given in figure 6.

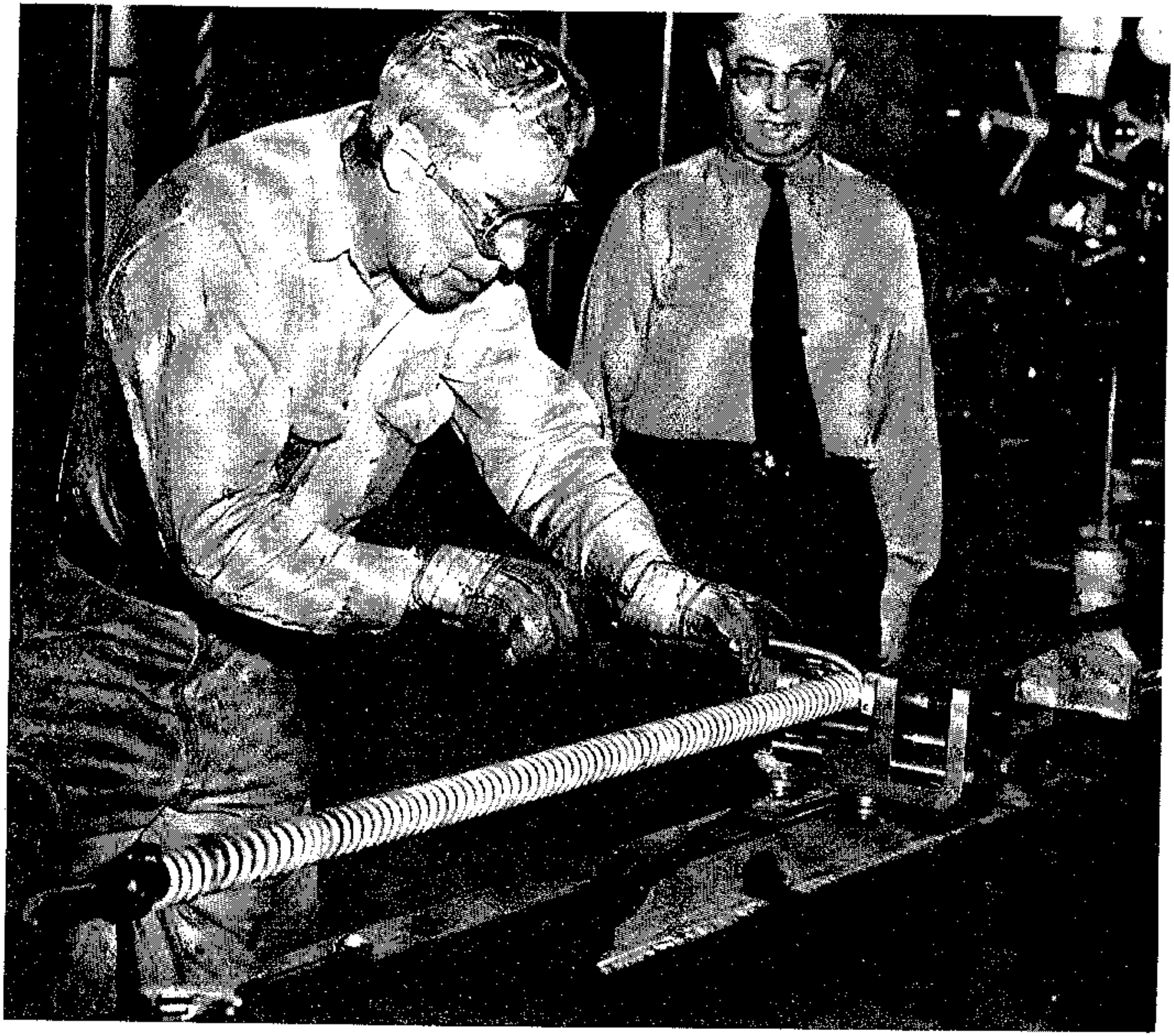

Figure 3. - Forming heating element for small gasifier with coiling machine, Bureau of Mines, Grand Forks, N. Dak.

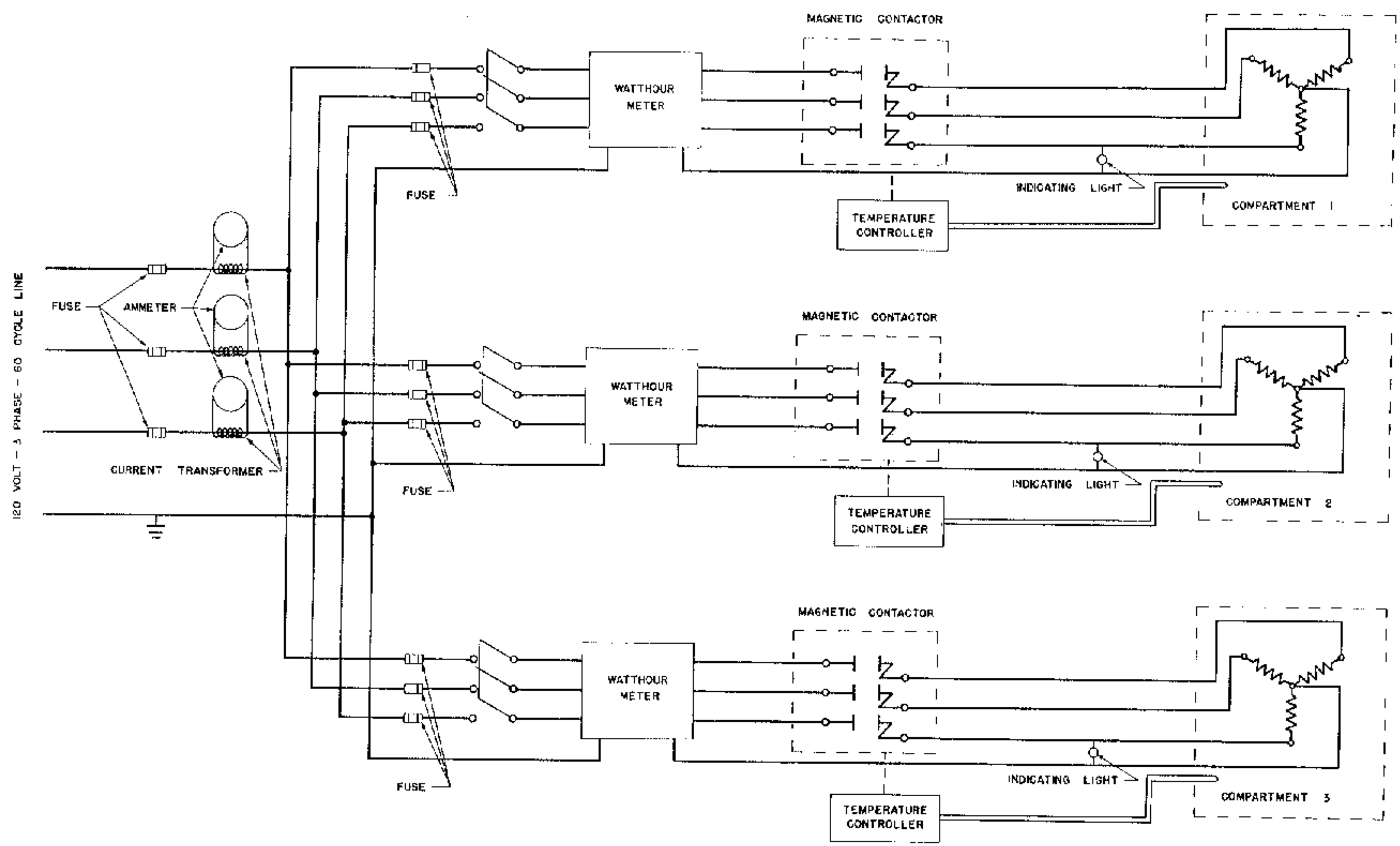

Figure 4. - Wiring diagram for heating circuit of small gasifier, Bureau of Mines, Grand Forks, N. Dak.

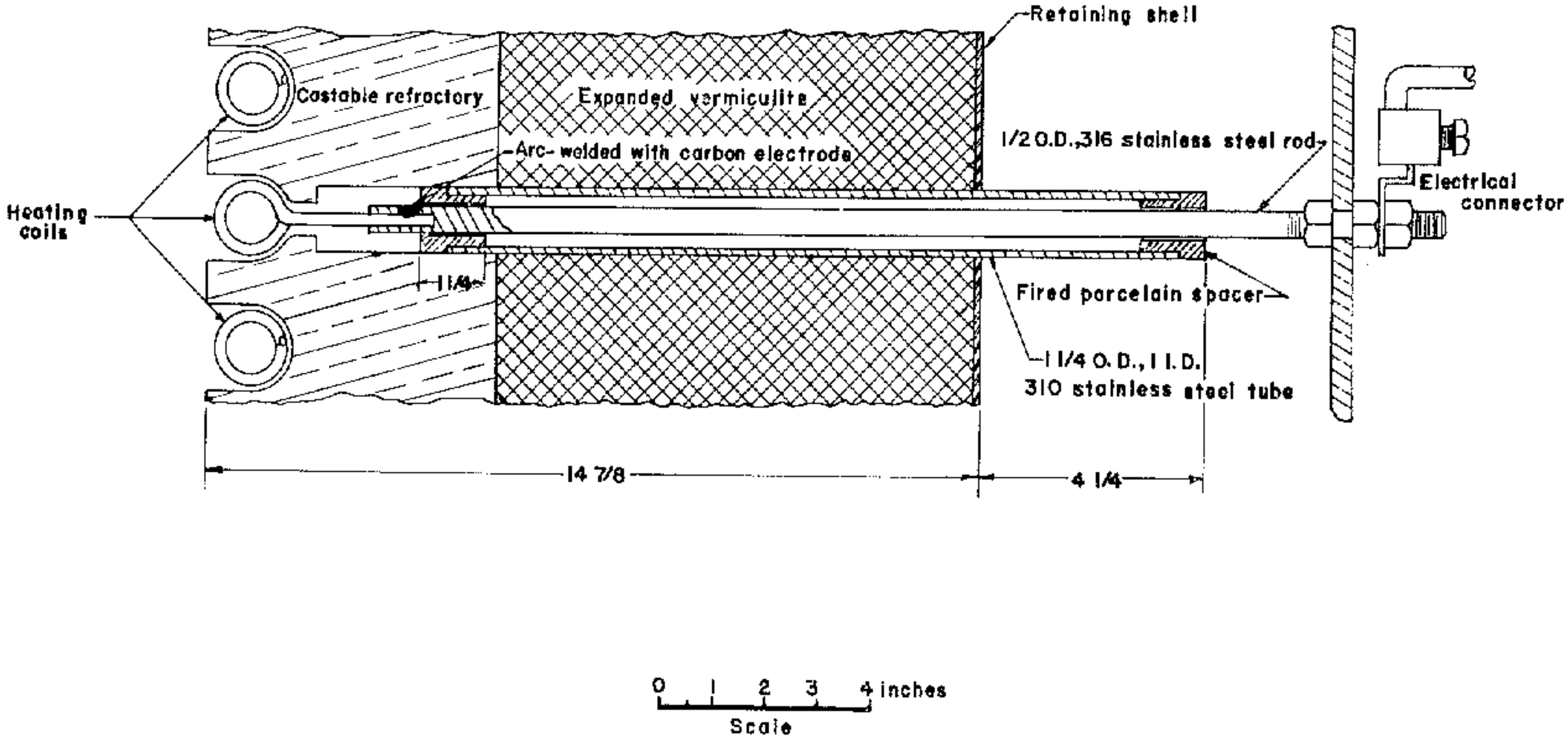

Figure 5. - Details of power terminal connector to resistance heating wires, small gasifier, Bureau of Mines, Grand Forks, N. Dak.

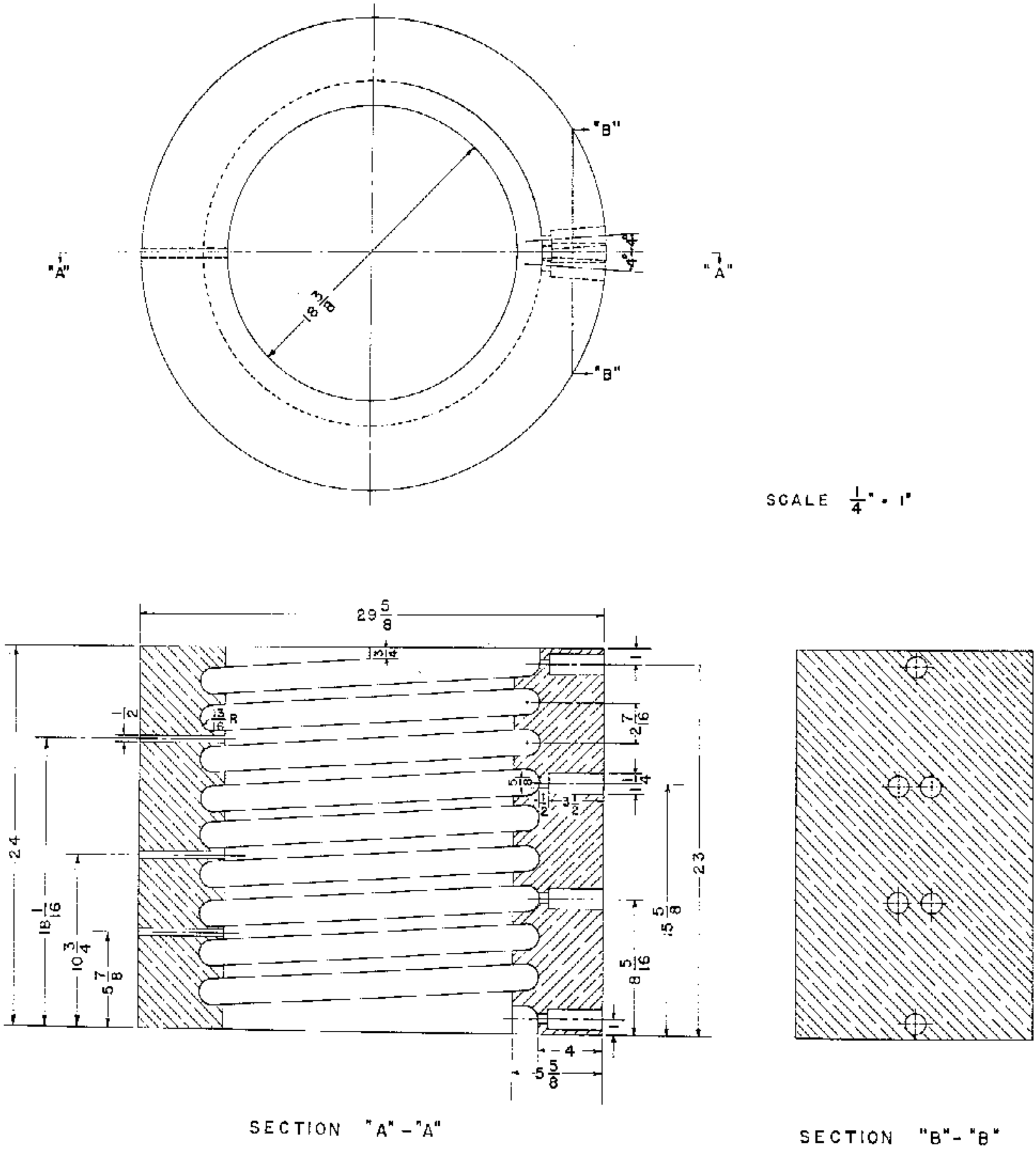

Figure 6. - Refractory casting for small gasifier, Bureau of Mines, Grand Forks, N. Dak.

The 10-inch layer of granular vermiculite was placed outside the cast refractory after the retort was assembled. Details of assembled refractory-liner sections and granular insulation may be seen in figure 7.

Charging Unit

To keep the annular reaction space full during operation, a 500-pound-capacity feed hopper was charged intermittently as required by the rate of lignite consumption.

Due to limitation in head room the hopper was built with only a 45° bottom cone, approximately 15° less than the angle of repose for lignite. To insure flow from the hopper, a vibrator and prodding rods were installed. The rods were also used to probe the lignite level in the hopper. Charge was added from a traveling bucket positioned by means of a hoist. Closure at the bottom of the feed hopper during charging was provided with a 6-inch slide valve. Lines were installed for purging the hopper with nitrogen or flushing with recycle gas. Details of the hopper assembly are shown in figure 7.

Residue-Removal Unit

The throughput was controlled by regulating the rate at which refuse or "char" was removed. From a small hopper with slide gate, attached to the bottom of the outer alloy tube, the char was discharged through a sealed screw conveyor into a receiver of 3-cu. ft. capacity. The discharge rate of the screw conveyor could be varied between 3 and 37 pounds of char per hour by means of a variable drive and gear reducers. A flexible-joint seal between the screw discharge and char receiver allowed the char to be weighed directly on a platform scale. The rate of char removal could thus be determined during operation without the necessity of exchanging char receivers. The seal also allowed free expansion of the reaction tube during temperature changes. Design details of the char removal unit are given in figure 7.

Process Steam and Air

Saturated steam was generated at about 65 p.s.i.g. in a small, vertical, gas-fired boiler. The pressure was reduced, and the steam was metered and fed through insulated lines to the top of the reactor. The outlet of the steamline was arranged to allow steam to enter cocurrently with lignite and to minimize condensation of steam in the feed hopper. The process steam generator may be seen in figure 8.

Compressed air was reduced in pressure, metered, and passed into the retort below the feed hopper.

Instrumentation

Extensive use was made of instrumentation both for control and data purposes. Controllers were used to regulate the temperature individually in the three heating compartments. Chromel-alumel thermocouples to operate the electronic temperature controllers were installed at the point of highest temperature level in each compartment, while a second thermocouple in each compartment was connected to a recording potentiometer. To prevent contact of the stainless-steel protection tubes with the heating coils, a sillimanite sleeve was slipped over the well, leaving the well tip uncovered to insure rapid response to temperature changes. Design details of the protection tubes are shown in figure 9. Gas temperatures were measured by thermocouples and recorded by a potentiometer. An inspection port was provided in each heating compartment through which the temperature of the retort wall could be determined with an optical pyrometer.

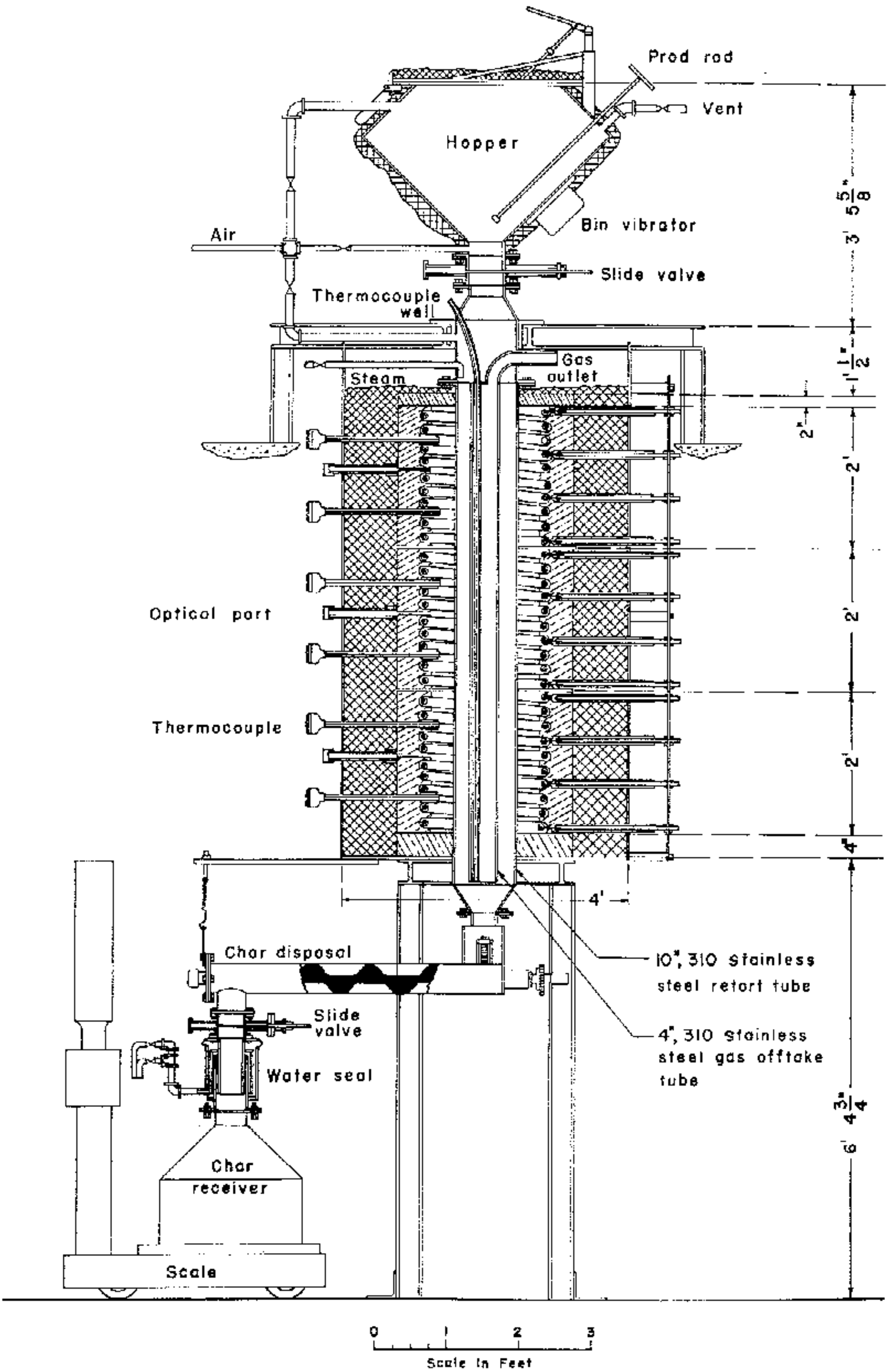

Figure 7. - Details of retort, small gasifier, Bureau of Mines, Grand Forks, N. Dak.

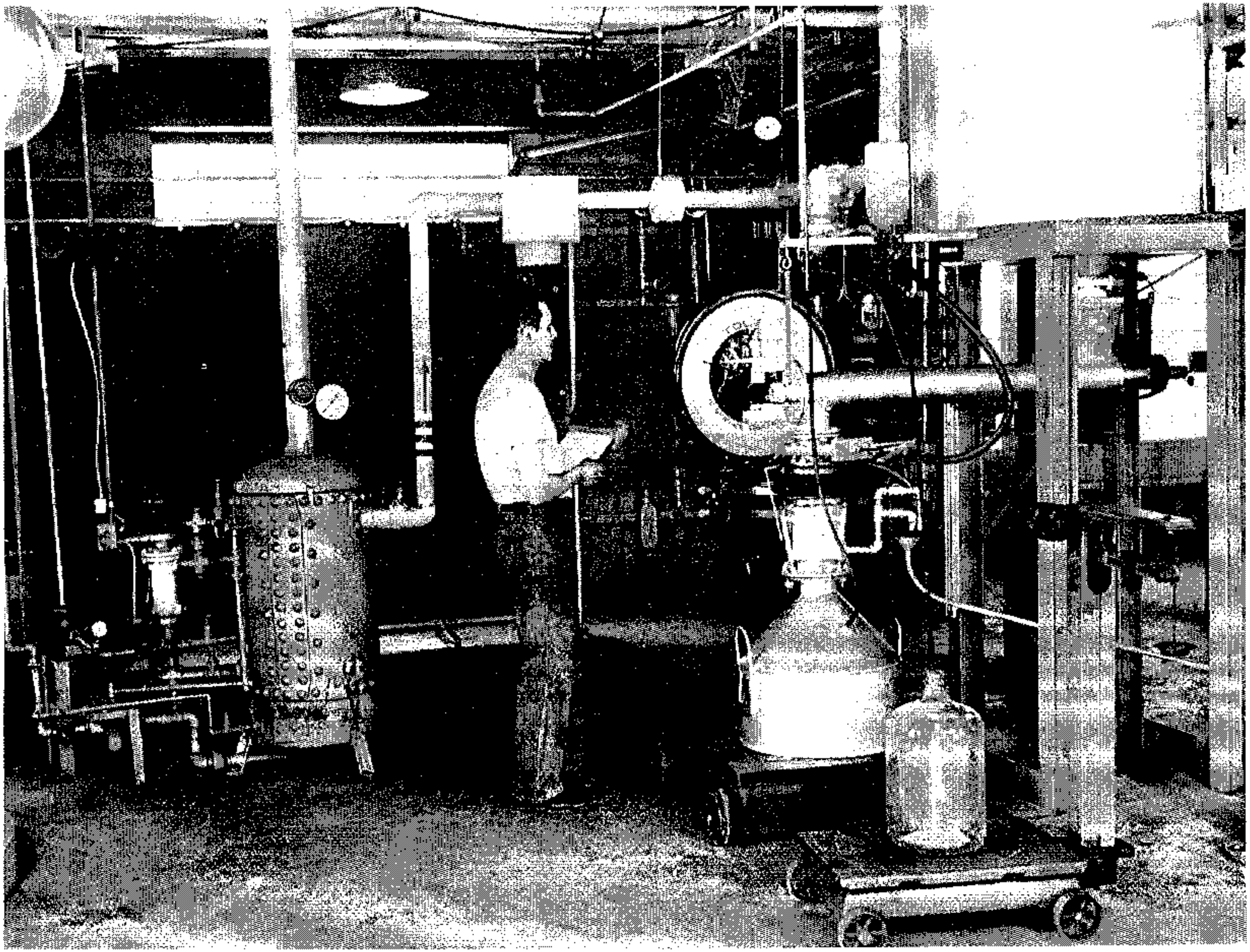

Figure 8. - Residue-removal unit and process-steam boiler, small gasifier, Bureau of Mines, Grand Forks, N. Dak.

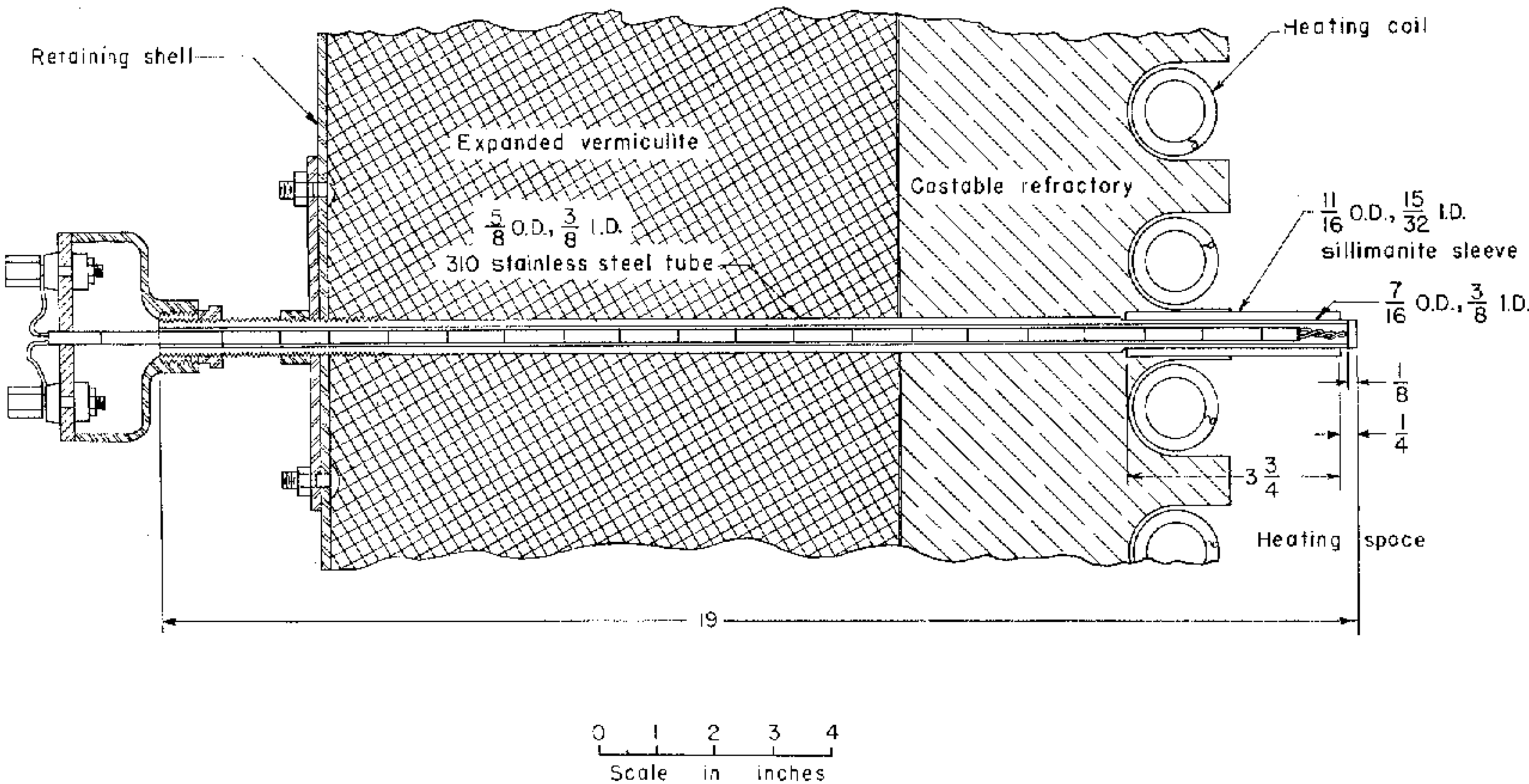

Figure 9. - Modified protection tube for control thermocouples, small gasifier, Bureau of Mines, Grand Forks, N. Dak.