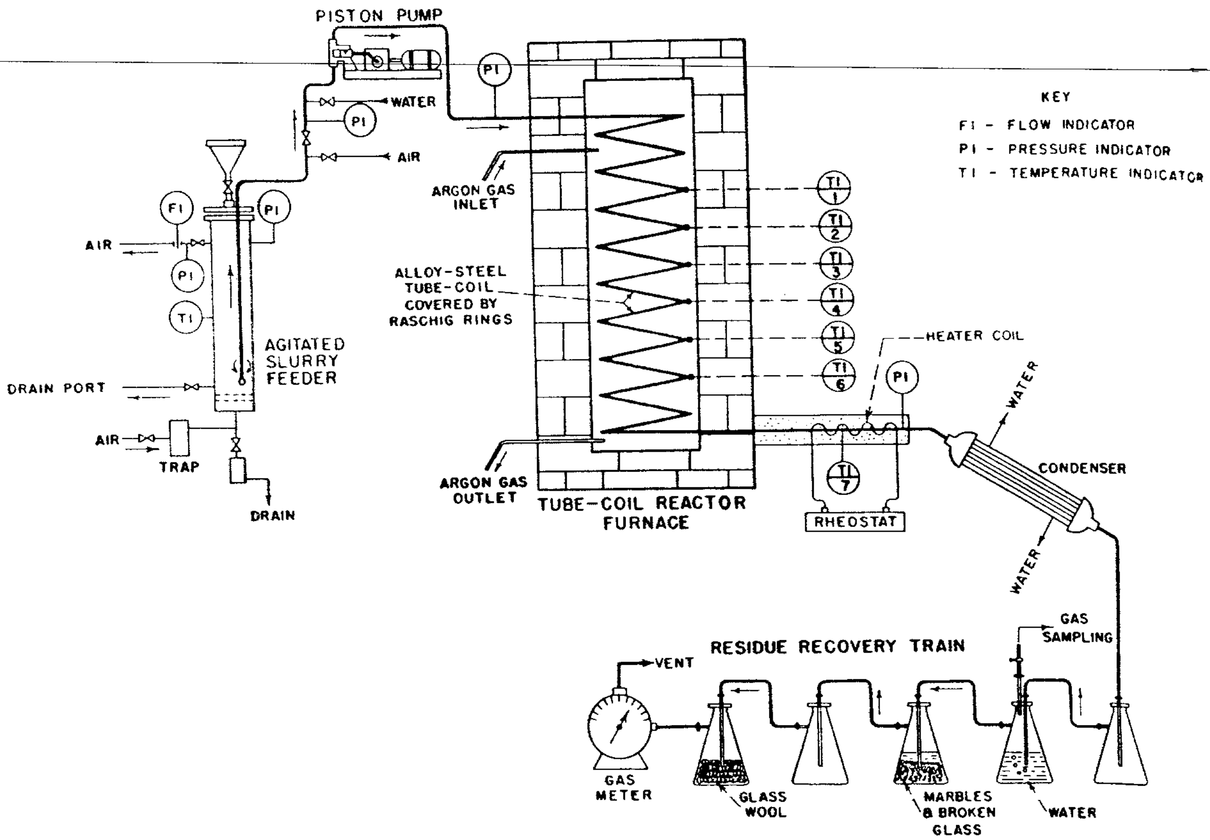

FIGURE 9. - Flow Diagram of Coil and Accessories for Gasifying Coal-Water Slurries.

3. Absorption at pressures below 75 p.s.i.a. and desorption not too far from atmospheric pressure.

4. Simple equipment so that the cost of a commercial plant may be economical.

5. The sorbent should not deteriorate in cycling.

For preliminary screening of potential oxygen carriers, a bench-scale glass apparatus was constructed to determine rapidly the properties of various sorbents on hand. Polarographic studies have also been made to determine the relative ease of sorption of oxygen by various metal chelates, confirming the results of sorption tests in the glass apparatus. It was found that none of the Versene-type chelates have oxygen-carrying properties comparable to salcomine (cobalt disalicylaldehyde ethylenediimine).

A metallic apparatus was constructed also to test promising sorbents under cyclic conditions. With the aid of this apparatus it was established that the salcomine-type chelate met all of the conditions listed above except the last one, that is, deterioration on cycling. Salcomine deteriorated very little, yet enough to make the process uneconomical.

Process Development

Pilot-Plant Gasifier

From studies of European processes and of proposed processes for gasifying American coals, a program for pilot-plant-scale work was developed. It was decided to erect a synthesis-gas generator at Morgantown capable of gasifying about 500 pounds of pulverized coal per hour.

Pneumatic Feeder. - One requirement for developing a coal gasifier was a means for charging pulverized coal at uniform rate. The Bureau developed a pneumatic feeder in which the coal was fluidized by flowing gas, usually an inert gas when the unit was used with gasifiers. The fluidized bed was held at high enough pressure so that the powdered coal would leave through a funnel near the bottom of the bed and flow (at an essentially constant rate) through a conveying line to the gasifier.

The feed rate was found to depend upon the differential pressure across the feedline. Per actual cubic foot of gas, however, the amount of coal conveyed was virtually the same at any operating pressure within the range studied (3). About 25.7 pounds of a high-volatile West Virginia bituminous coal was carried per cubic foot of gas for all operating pressures from atmospheric up to 150 p.s.i.g.

This pneumatic feeder has been described (1, 9), and its characteristics have been determined (2, 3, 10, 18). It was used for both atmospheric-pressure and high-pressure gasification; it has been developed to include a complete coal-handling system; the coal could be heated before it entered the gasifier (13, 30, 31).

Gasifier. - The problem of supplying heat for the steam-carbon reaction could be approached in several ways. If the reactants could be preheated cheaply to high temperatures (about 2,000° F. or higher) the steam-carbon reaction would proceed. The first approach by the Bureau was to study methods for preheating steam to about 3,500° F.; by using approximately 2 pounds of steam per pound of carbon fed to the reactor, the steam itself would carry much of the heat for the reaction.

A first pilot-plant-scale gasifier (32) of 500 pounds per hour coal feed-rate capacity and with pebble stoves for preheating the steam, was completed in 1948. A bituminous coal from the Upper Freeport bed was gasified in some first tests. In 1948 and 1949 this work was continued, using Sewickley-bed coal which is available in large quantities and used at present only for boiler firing.

Results. - Work with this gasifier demonstrated the feasibility of operating it at a temperature level high enough for continually tapping molten slag. The pneumatic or fluidized coal feeder was developed into a satisfactory device for large-scale test work. Suitable techniques were worked out for removing, either in dry form or as slurry from a water scrubber, the bulk of the dust (unconsumed carbon and ash) carried in the gas stream. For final cleanup of the gas an electrostatic precipitator was satisfactory. This gasifier had been designed for tangential introduction of the reactant materials (coal, steam, and oxygen) to insure better mixing. Experience showed that refractory erosion would be severe on large units of this design. Consequently, when the next low-pressure gasifier was built in 1950, the reactant burners were placed so as to minimize impingement of reactant streams on the refractory lining.

From operating experience with the gasifier, using pebble stoves to produce highly superheated steam at about 3,500° F., it was possible to make an adequate economic analysis of the feasibility of this approach to low-cost gas. It was concluded that this method was technically feasible, but that difficulties in securing the highly superheated steam made it uneconomic. With contamination from coal ash, pebble life was short. Only a clean gaseous fuel could be used for heating. Although preheating the coal to 300° F. or higher was possible, the relatively small amount of heat added to the reaction was not enough to offset the cost of the equipment required to obtain it.

Small-Scale Gasifier

Concurrently with the pilot-plant-scale work, experiments were carried on in a small-scale gasifier (28, 29). The operating temperature was high enough to slag part of the ash in the coal, indicating that it should be possible to tap the molten slag continuously. This work, carried on from 1947 to 1951, aided in the later developments of the larger scale pilot plants and the pneumatic coal feeder.

Preliminary tests were made of powdered coals for their relative value in synthesis-gas production. Coals of various ranks and grades, including lignite and anthracite, as well as carbonaceous residues obtained in gasifying coals (at feed rates of 45 to 55 pounds per hour) were gasified under precisely controlled conditions. In its final development, the apparatus (see figs. 10 and 11) included many improvements and allowed complete recovery of all gasification products, including extremely fine residual dust. As a result, precise material and heat balances could be made.

With this testing unit, continuous gasification of powdered coals with oxygen and steam was feasible for coking coals and for low-grade coals of high ash and sulfur content, as well as for high-grade coals free from impurities. Coals of all ranks could be gasified, but younger coals of high oxygen content allowed considerably higher carbon conversion and substantial reduction in oxygen requirement. The effects of variables and the optimum combination of experimental conditions for several types of coal were also studied (28, 29).

Vortex Gasifier

Experiments were carried out at Pittsburgh on a vortex gasifier with a throughput of about 100 pounds of coal per hour. The steam-oxygen mixture was admitted through tangential slots around the periphery of the gasifier. The

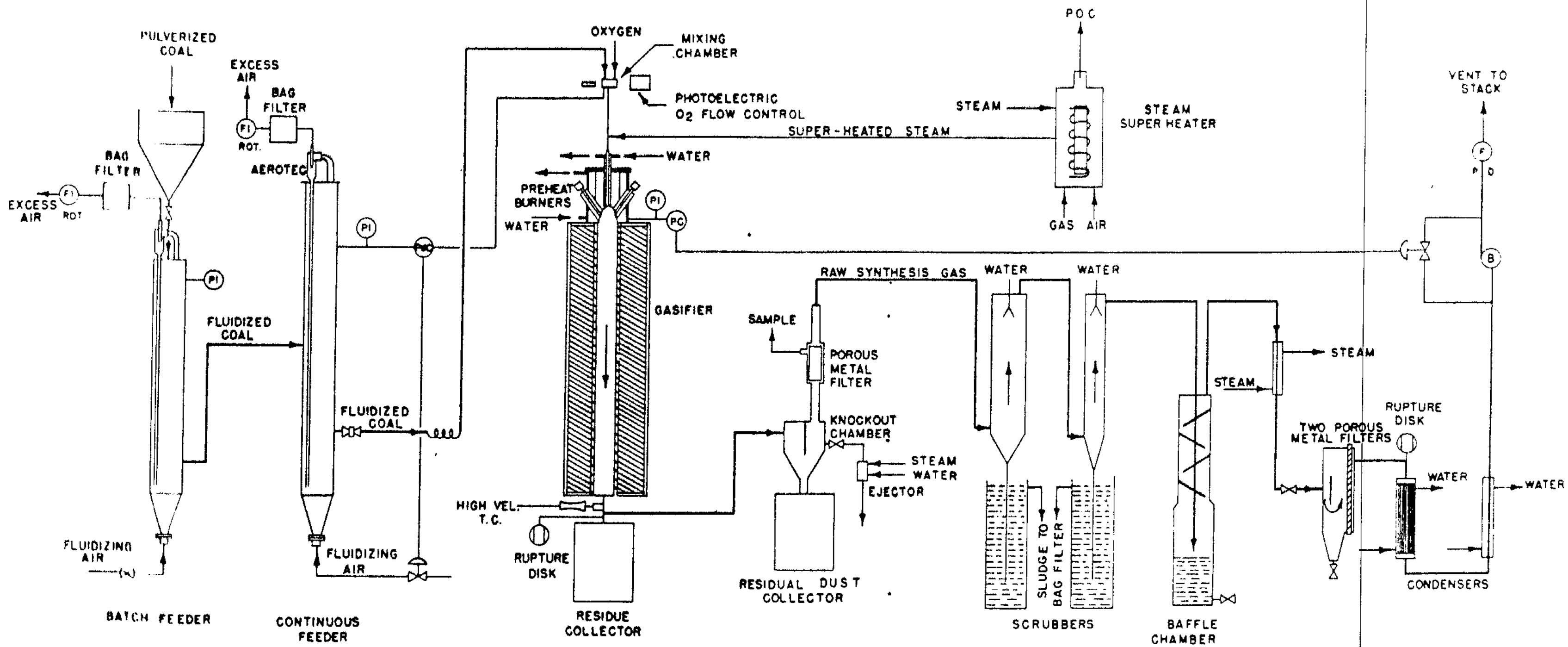

FIGURE 10. - Flow Diagram of 50-Pound-Per-Hour Gasifier. (B, blower; FI, flow indicator; F-PD, flowmeter; PC, pressure controller; PdC, differential pressure controller; PI, pressure indicator; P.O.C., products of combustion; TC., thermocouple.)

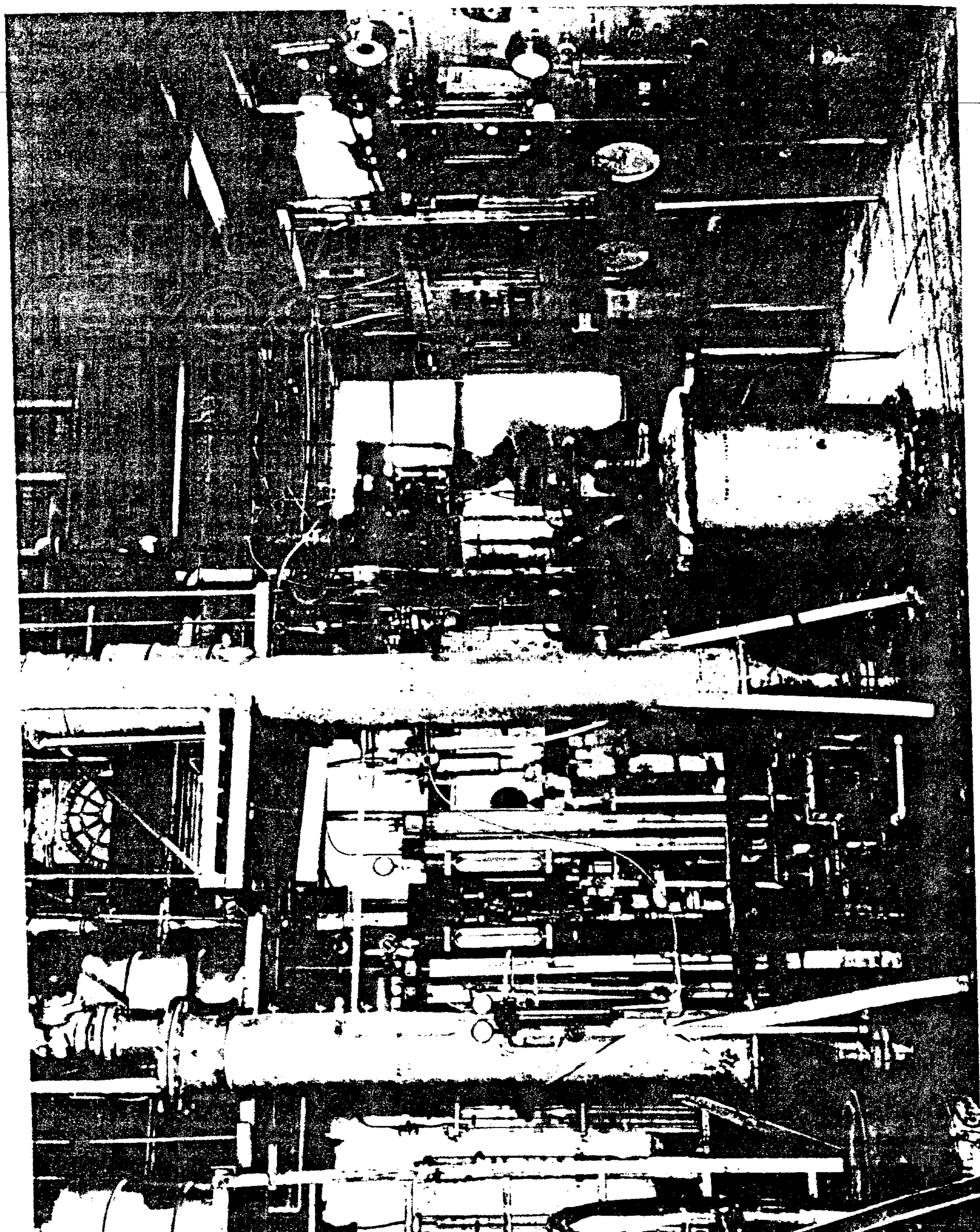

FIGURE 11. - 50-Pound-Per-Hour Gasifier for Producing Synthesis Gas From Coal.

results indicated (8, 9, 10, 11, 12, 21) that the rate of gasification was approximately first order with respect to the carbon available and that, above a temperature level of about 2,200° F., the controlling mechanism was diffusion of the gas to the carbon surface. It was found that the vortex principle did not increase the gasification efficiency enough to justify the increased complexity of the design, and this work was discontinued after 1951.

Lurgi Gasifier

Another contribution in coal gasification was also made at Pittsburgh. Beginning in 1945, in cooperation with the Southern Natural Gas Co., a study was made of the Lurgi process for gasifying American coals to produce a high-B.t.u. gas (17). Later, the work was extended to cover an investigation at Morgantown of the methanation of the Lurgi product gas.

Second Atmospheric-Pressure Gasifier

Design. - The work with the pilot-plant gasifier through 1949 had shown the feasibility of gasifying pulverized coal at temperatures that would slag a large portion of the coal ash. However, it appeared that radical changes would be needed to insure continued operation of a pilot-plant-scale gasifier. These changes could not be incorporated in the gasifier as then built. A new gasifier, to operate at near atmospheric pressure, was designed in cooperation with the Babcock & Wilcox Co., and construction was begun in 1950 (32). This plant was operated and developed into a satisfactory unit during 1951-54 (11, 12, 13, 14, 15, 30). One outstanding feature was development of a burner for introducing the reactants into the gasifier (30). This burner provided quick mixing of the coal, steam, and oxygen at the point of entry into the gasification chamber, minimized danger of flashbacks, and improved the life of the refractory lining by reducing to a practical minimum the impingement of reactants on it. By late 1953, the complete feasibility of this design for large-scale plants had been shown (30).

Tests. - In 1953 and 1954 tests were made with three types of coal: Lake deSmet, a subbituminous C coal from Wyoming; Sewickley-bed, a bituminous A coal from West Virginia; and a Pennsylvania anthracite. These tests were made at three different oxygen:carbon ratios, three different steam:carbon ratios, and three different coal rates.

Results are summarized in figure 12. Carbon gasification was highest for the Lake deSmet coal and lowest for the anthracite. Carbon conversion at constant oxygen:carbon ratio decreased with coal rank, the lowest rank coal having the highest carbon gasification. There was a large difference between the carbon conversion for these three coals. Lake deSmet coal had the lowest oxygen and coal requirements and anthracite the highest.

Heat loss from the gasifier was highest for the anthracite, and lowest for the Lake deSmet coal, in line with the high reaction temperature for anthracite and the lower reaction temperature for the more reactive subbituminous coal. For a large-scale commercial gasifier the same relative order of heat loss presumably would occur but would become of less significance in affecting the process as surface losses became smaller in proportion to the total energy involved.

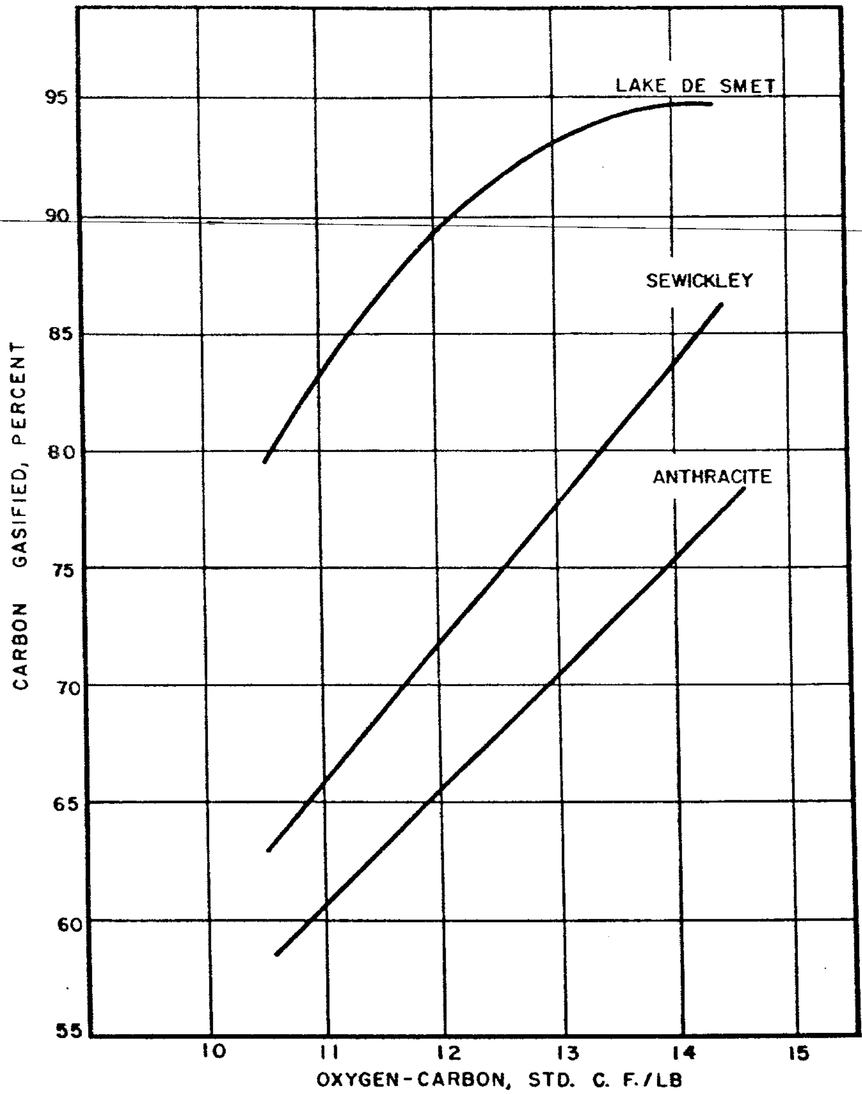

FIGURE 12. - Effect of Oxygen:Carbon Ratio on Extent of Gasification of Subbituminous C (Lake deSmet), Bituminous (Sewickley), and Anthracitic Coals at Atmospheric Pressure, a Steam: Carbon Weight Ratio of 0.70, and a Carbon Input of 430 Pounds Per Hour.

High-Pressure Gasifier

Coal gasification at Morgantown with steam and oxygen at atmospheric pressure had shown that a wide range of coals could be gasified, with a resulting product gas of good quality. However, in the search for cheaper means of producing carbon monoxide and hydrogen mixtures, it was decided to investigate gasification at elevated pressures (20-30 atmospheres, 294-441 p.s.i.). Preliminary consideration indicated the following advantages:

1. Reduction in size of gasification equipment for a specific output.

2. Simplification of dust removal when the product gas is handled at elevated pressures.

3. Saving in compression power and decrease in the amount of compression equipment needed when a subsequent process involves use of the synthesis gas at pressures of 20 atmospheres or above.

Gasifier Design. - Design of a high-pressure pilot plant was begun in 1949 ~~in cooperation with the Babcock & Wilcox Co. The gasifier was planned to handle~~ 500-600 pounds of coal per hour, at 450 p.s.i. working pressure. A design pressure of 900 p.s.i. was chosen, with a factor of safety of 4, as a safeguard against explosions. The pressure vessels were protected further by rupture disks, selected to yield at 600 p.s.i.

This high-pressure gasifier (fig. 13) was described in several publications (11, 12, 13, 14, 24, 31). Tests with it showed that tangential introduction of reactants was not feasible, and the design was changed to introduce the reactants vertically downward through the top of the gasifier. Several refractory linings were tried. At low steam:carbon ratios (0.3 pound of steam per pound of coal) the refractory lining slowly eroded. The gasifier was redesigned with a completely water-cooled reaction space (fig. 14); it was planned that slag accumulating on the cooled surface would prevent erosion and provide insulation to reduce heat loss. However, in tests with Sewickley-bed coal, only a thin layer of slag adhered to the wall and heat loss was still high; while with a high-ash anthracite culm results were unsatisfactory because of slag buildup in the reaction chamber. It was concluded that reaction-chamber coil design would require modification for the particular coal to be gasified.

Tests. - During 1953 and 1954 tests were made with the refractory-lined and later with the water-cooled reaction chamber. Pressure, coal rate, and oxygen:coal ratio were varied to determine the effect of residence time. It was necessary to eliminate the effect of varying heat loss, which otherwise obscured the effect of residence time. As a first approximation, oxygen requirement per unit of $CO + H_2$ could be represented as a linear function of the heat loss, with a slope of 3.0 std. c. f. for a 1,000-B.t.u. increase in heat loss. Using this relation, oxygen and coal requirements per unit volume of $CO + H_2$ were corrected to constant heat loss. Coal requirement then appeared a linear function of the reciprocal of residence time. The slope of this relation was 1.57 when coal requirement was measured in pounds per 1,000 std. c. f. of $CO + H_2$, and residence time in seconds. These results are preliminary estimates of the effects of heat loss and residence time and await confirmation by further tests.

Ignoring heat loss and other complications, in some runs with the feed rate per hour slightly above 1,000 pounds for coal and 10,000 cu. ft. for oxygen, 80-90 percent of the carbon was gasified in both the refractory-lined and the water-cooled reaction chambers; 1,000 cu. ft. of $CO+H_2$ was produced from about 40 pounds of coal, 350-400 cu. ft. of oxygen, and 12 pounds of steam.

Gasification Program at the New Morgantown Station

By 1954 a practical low-pressure gasification process had been demonstrated, and a large-scale plant embodying many of its design features was under erection by a chemical company. With the move to the new Appalachian Experiment Station,

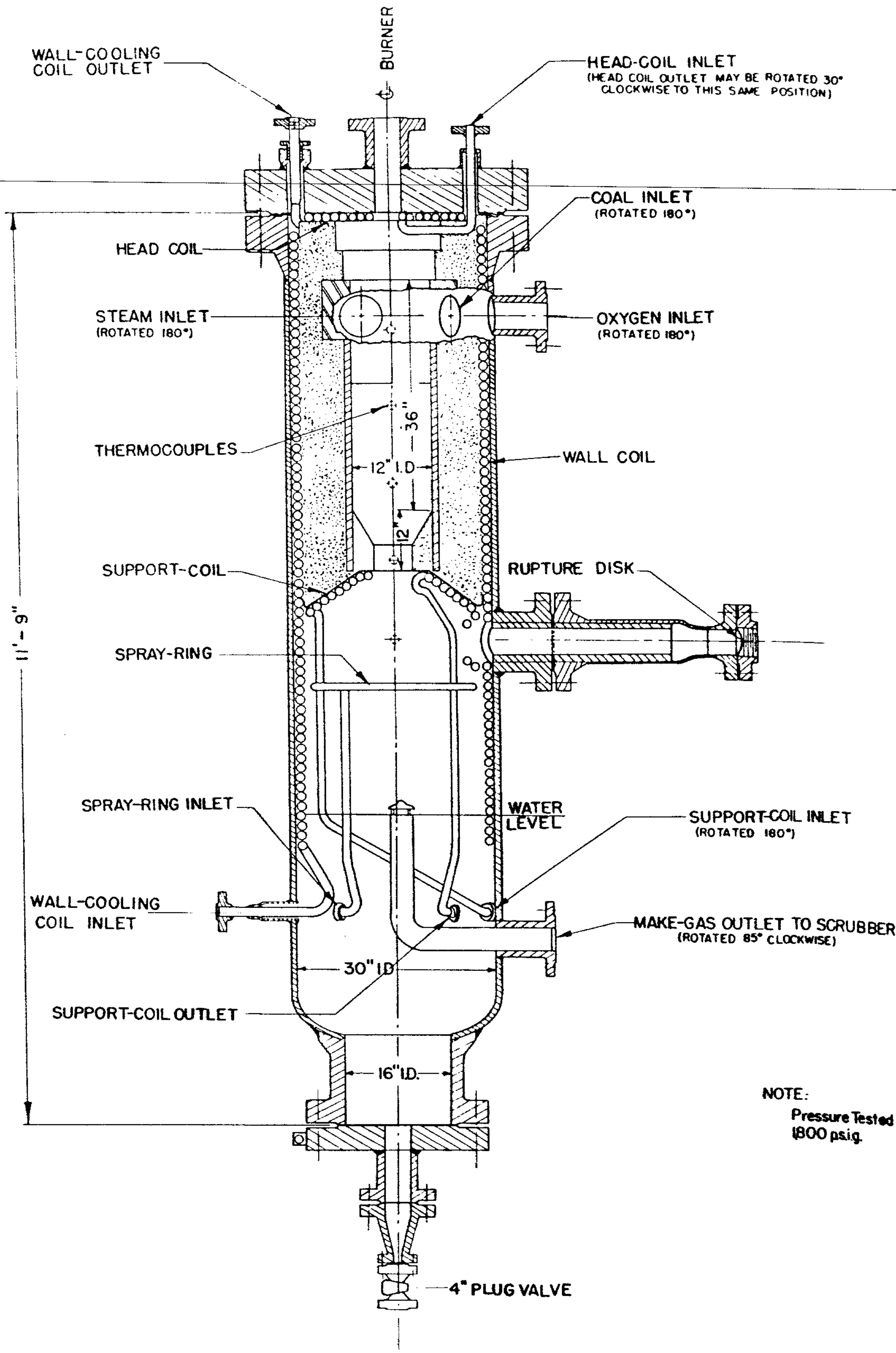

FIGURE 13. - Original High-Pressure Gasifier.

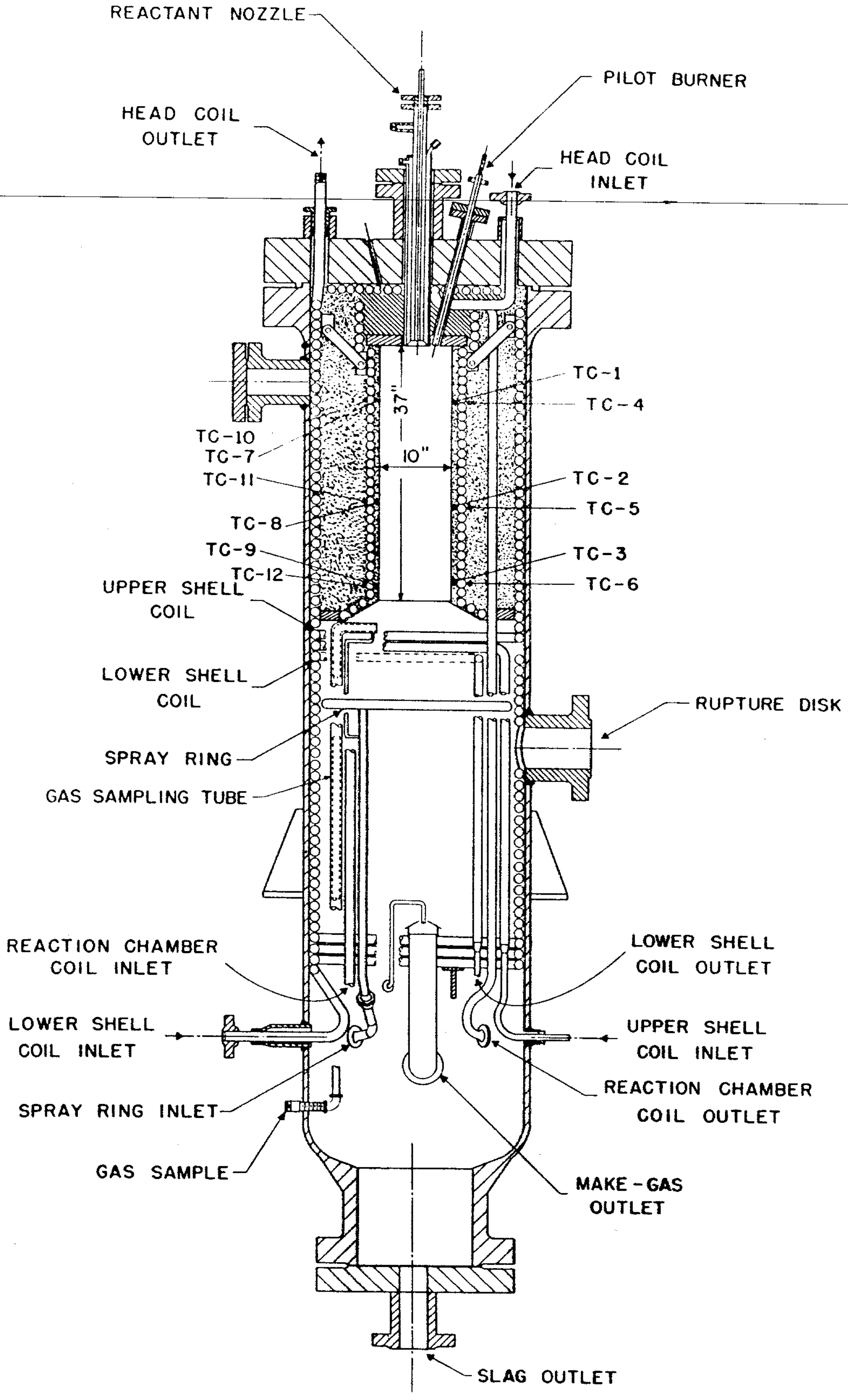

FIGURE 14. - Modified High-Pressure Gasifier.

pilot-plant work on gasifying coals at ordinary pressure was terminated, and increased emphasis was put on problems in high-pressure gasification, in gasification methods applicable to the synthesis of chemicals, and in development of a substitute for natural gas.

Pilot-plant facilities for high-pressure gasification at the new station are shown in figure 15 and a process flowsheet in figure 16.

Coal Feeding for Pressure Gasifiers. - The pneumatic feeder developed at Morgantown was a safe and economical method for feeding coal to gasifiers operating at low pressures, and was successful with the high-pressure gasifier. However, at 30 atmospheres (441 p.s.i.) compressing the fluidizing gas was costly.

Studies were therefore begun on other possible feeding methods. A slurry method, in which finely ground coal is mixed with water, the slurry compressed to the desired pressure, heated to flash the water into steam, and the steam-coal suspension then introduced into the gasifier, offers considerable promise of reducing feeding costs. Steam pickup of fine coal from a pressurized hopper might also be a cheaper method if the pressure hopper could be filled by some method other than lock hoppers. Filling the pressurized hopper by a screw feeder, if feasible, would cut costs materially. Pilot plants to study these methods were planned for the new station (14, 15).

Process and Cost Studies

Engineering studies and cost estimates have been made on various phases of gasification processes.

1. The economics of a waste-heat boiler for cooling the gas made in a 50-ton-per-hour pressure gasifier was compared with a direct-contact spray system. The estimate showed that generation of waste-heat steam was economical and that the payout time for the investment in a waste-heat boiler was less than 4 years.

2. For economic evaluation of the production of gas from coal and air, cost of a proposed air-blown powdered-coal producer was compared with that of a conventional fixed-bed gas producer. The results indicated that the use of pulverized coal in a producer, if technically feasible, would result in a substantial saving in gas cost.

3. Cost studies were made on three types of coal-steam-fed gas generators in which a fissionable nuclear fuel would supply the heat for the endothermic steam-carbon reaction. Potential savings in the cost of synthesis gas were indicated. However, the many problems inherent in the operation of such gasifiers at 2,500°-3,000° F. indicate need for considerable development work.

4. Cost of the oxygen is one of the large items in pressure gasification of coals. Economic study was initiated to obtain cost figures for oxygen produced in large quantities.