RESEARCH AND DEVELOPMENT, SYNTHESIS-GAS LABORATORIES AND PILOT PLANTS, MORGANTOWN, W. VA., AND GORGAS, ALA.

Experimental Work on Synthesis-Gas Production

Fischer-Tropsch gasoline is expensive because of the high cost of synthesis gas made from coal. It is proving a major undertaking to develop a new coal-gasification process that will reduce significantly the cost of synthesis gas for the Fischer-Tropsch process or the cost of hydrogen for the Bergius process. Extensive experimental programs of laboratory to demonstration-plant scale are being carried out to evolve systematically but rapidly a new, successful, coal-gasification process. Operation of experimental gasification equipment provides data required for the design of large plants and also discloses new problems requiring solution. All data are analyzed to determine methods of cutting costs.

The two gasification processes selected for major study and experiment are:

1. Gasification of finely pulverized raw coal, entrained in superheated steam containing oxygen.

2. Gasification of coal in place underground.

Underground Gasification of Coal

The underground gasification of coal, for successful application, will depend upon many interrelated factors. Certain of these factors cannot be evaluated with present knowledge, and technical and economic control of the process can be achieved only by means of large-scale field-test operations under natural conditions, together with laboratory tests designed to evaluate some of the variables encountered.

Gorgas, Ala., Project

The second experiment at Gorgas, Ala., is planned to obtain fundamental engineering data upon which to base further development of the method. This work was planned by and will be conducted under the supervision of Bureau of Mines engineers. Construction and operation of the project will be handled by the Alabama Power Co., under a nonprofit contract with the Government. The Gorgas site, including surface area and the underlying coal bed, was provided by the Alabama Power Co. without cost to the Government.

Objectives of the proposed underground gasification experiment are:

1. To determine the quantity of coal that can be gasified from a given initial combustion zone and the shape and extent of the burned-out area formed by this gasification.

2. To determine the practicability of a fixed-product gas outlet, both at the outcrop of the coal bed and through the use of vertical boreholes. It is the intention to test various designs of inlets and outlets, including the seals required.

3. To determine the operational characteristics of the experimental installation under such variations of conditions as may be desirable, such as: the length of passage required, the optimum rate of flow, and the pressure drop encountered.

4. To determine the quality and quantity of the air-blow product gas generated under the experimental conditions. A secondary phase will be the determination of the quantity of tar and related products obtained.

5. To obtain all possible information regarding the action of heat on the overlying strata.

6. To ascertain such fundamental technical and economic facts having bearing on a choice of plant sites, plant installation, and operating processes as can be obtained without interfering with the foregoing major objectives.

At the outset, factors pertinent to the design of an underground gasification installation were studied carefully. These included gas-making reactions, geology of the coal-bearing strata, and methods of driving underground passageways, drilling boreholes, and handling, purifying, and utilizing product gas. These studies, together with the experience gained in the first field-scale experiment, determined the design of the experimental unit now being constructed.

A "unit" of an underground gasification system consists of: (1) A gasification chamber, which is a passageway in the coal bed; (2) entry and exhaust ports for blast and product gas, respectively; and (3) machinery and piping necessary to propagate and control the gasification.

As it is the purpose of the experiment to study the characteristics of the unit, the simplest design possible was desired. Thus, the experimental plant consists of a straight-line passage in the coal, with surface connections at one end through an outcrop seal, and at various points along its length through vertical boreholes. The passage is divided into five sections, each 300 feet in length. Each section may be used separately as a gasification unit, or several sections may be combined to form a larger unit. The passage in the coal bed consists of two parallel entries 10 feet wide, separated by a solid pillar of coal 10 feet thick. The boreholes are drilled into crosscuts connecting the entries. The last 300-foot section consists of a single 10-foot-wide entry. It is anticipated that the single-entry section will provide fundamental data upon which to plan further operations. A wide choice of operating methods may be used during the experiment. Initially, it is planned to use a simple, continuous, unidirectional air blast. If conditions necessitate, a reversing air blast may be used. The use of steam also is possible, either intermittently, as in a cyclic water-gas operation, or continuously with air. Oxygen has been considered for use in underground gasification, but its cost is prohibitive in large quantities, and most of the experimental work will be done with air.

The construction of an underground gasification unit, designed to operate 1 year or longer, requires equipment and construction work on a magnitude comparable to that of a small industrial plant. The first requisite was an air compressor capable of delivering approximately 10,000 cubic feet per minute at 30 pounds per square inch gage pressure. After exhaustive inquiry, two war-surplus units were found. One was a gas turbine, designed for a Houdry cracking unit. Combined with an axial air compressor having a capacity of 23,000 cubic feet per minute at 45 pounds per square inch gage, this turbine could be adapted to the installation. The other unit was a two-stage reciprocating compressor, designed to deliver 3,600 cubic feet per minute at 120 pounds per square inch gage. By replacing the high-pressure cylinder with a second low-pressure cylinder, the machine is made capable of delivering 7,200 cubic feet per minute at 30 pounds per square inch gage. This is being done, and the

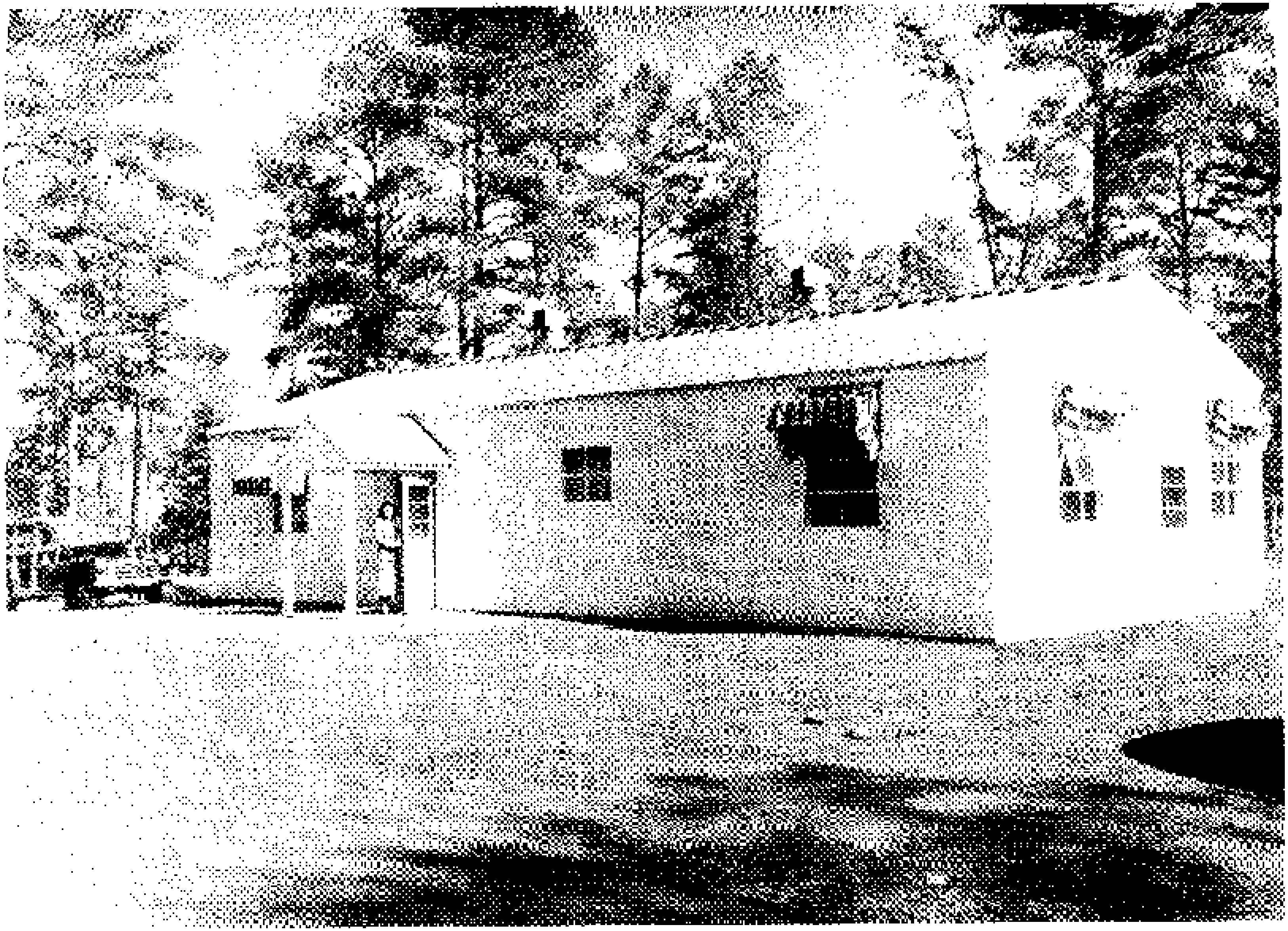

Figure 45. - Office building, underground-gasification project, Gorgas, Ala.

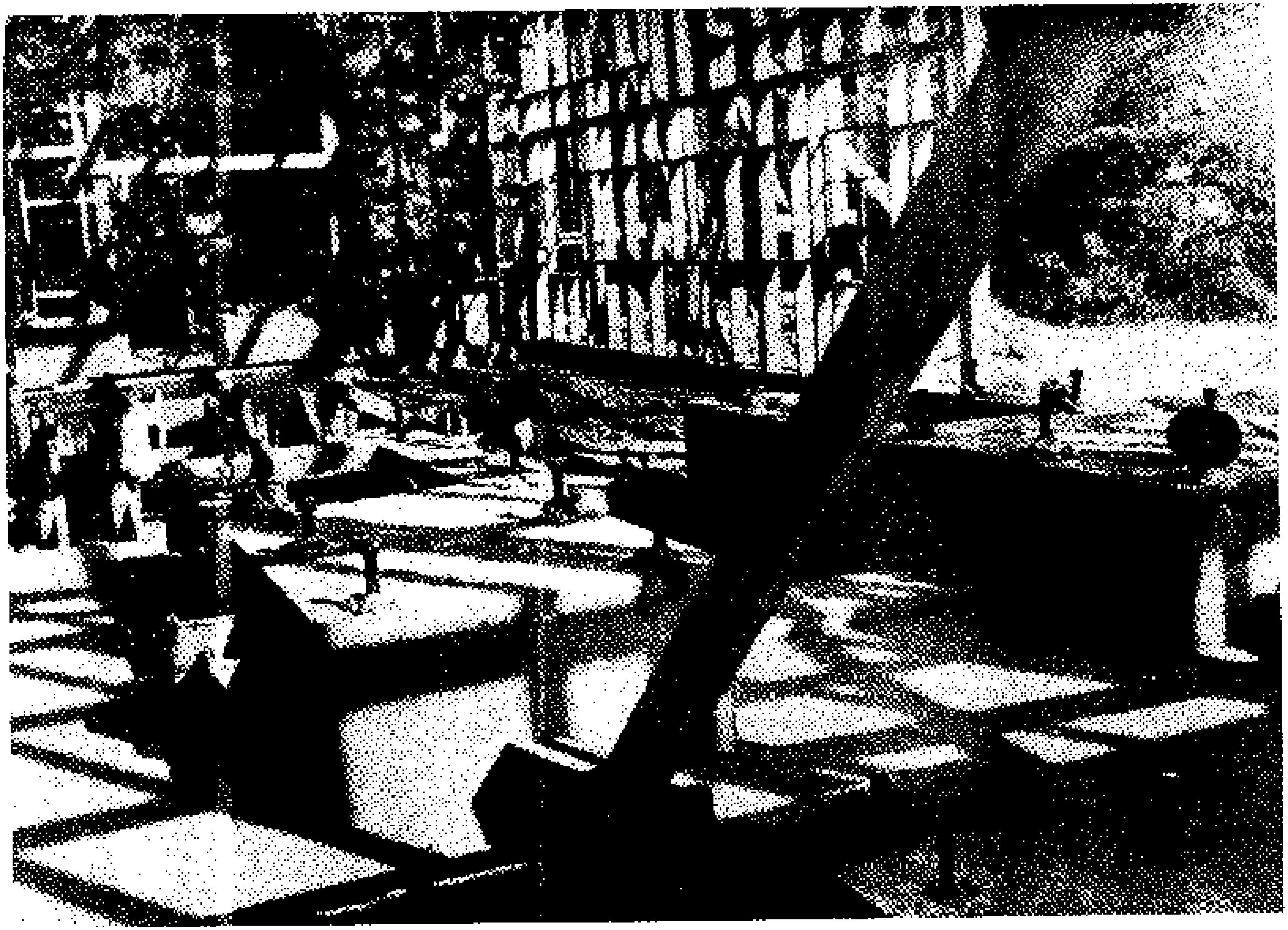

Figure 46. - Interior of compressor house, showing 78-cubic-yard foundation for reciprocating compressor in foreground.

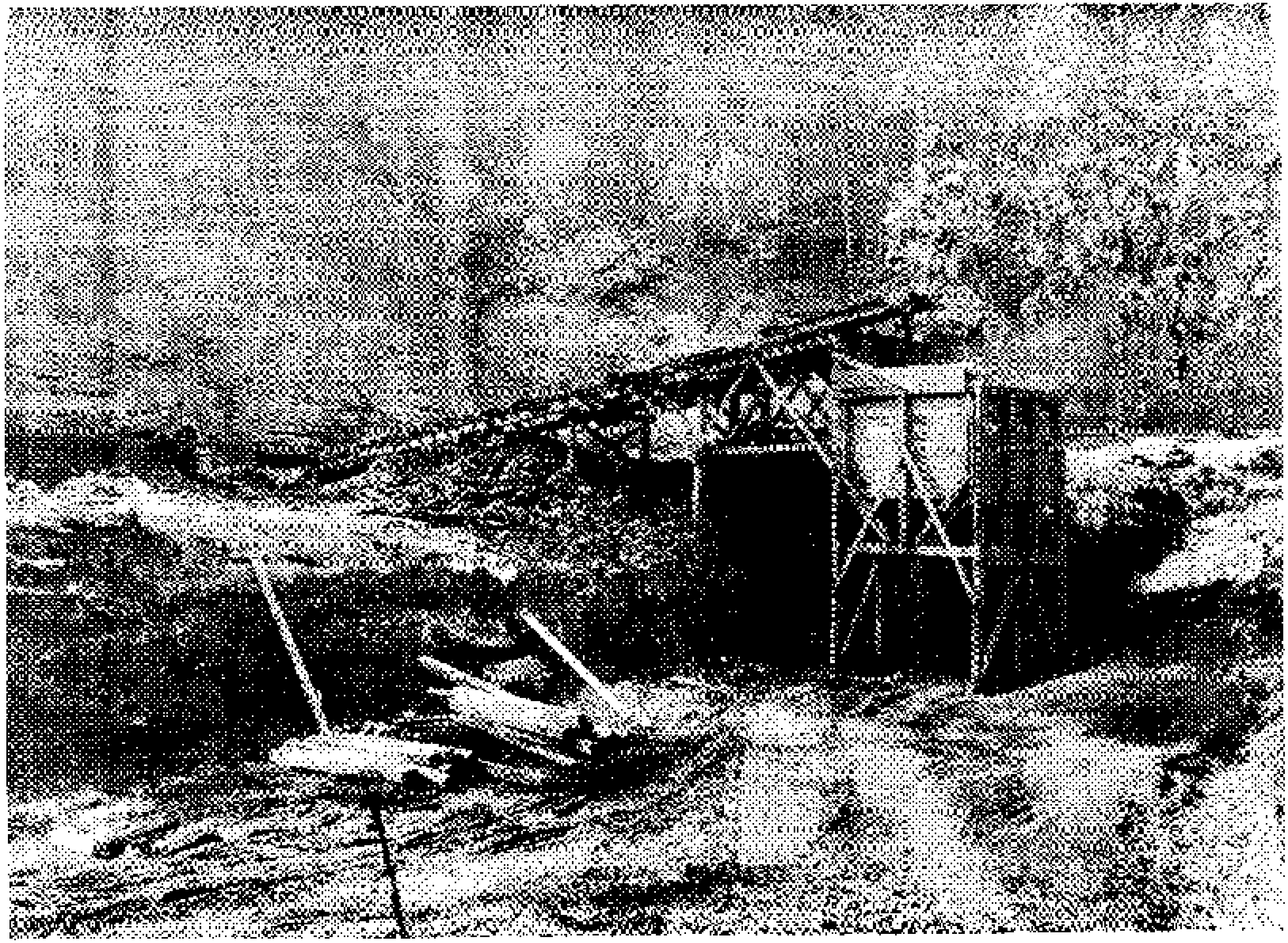

Figure 47. - Mine portal with conveyor and loading bin. Fan house at left.

Figure 48. - Rig used to drill No. 1 churn-drill hole. Note 16-inch bit in foreground and bailer standing upright at left of rig.

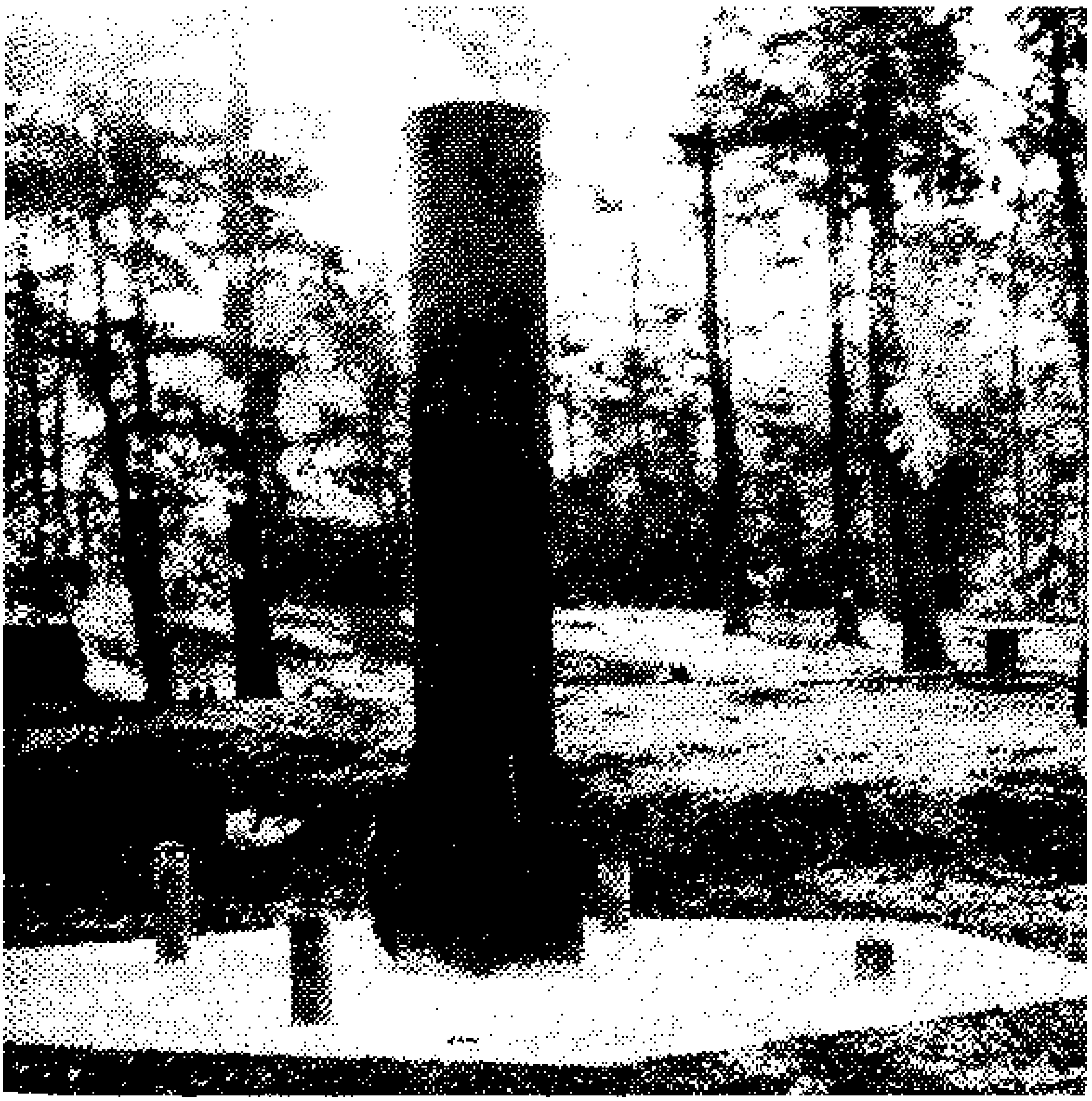

Figure 49. - Water-cooled seal installation at borehole No. 5.

machine will be installed at the site. The gas turbine will be installed if gas production is successful enough to justify its use. Two lobe-type, rotary, low-pressure blowers are being installed as standby equipment.

An office building (fig. 45), a laboratory, and a warehouse have been erected at the site. These buildings are of prefabricated-steel construction. Also, a wooden-frame, galvanized sheet building has been erected to house the compressor, blowers, and their electrical controls (fig. 46).

A 20-inch manifold pipe line connects the air compressor to the boreholes. A valved tee connection at each borehole will allow its use as either an inlet or exhaust port.

To provide the water needed, a 150-gallon-per-minute, 400-foot-head, centrifugal pump has been installed on the Warrior River, approximately 3/4 mile from the site of the experiment. Water is required for cooling the product gas, the water-jacketed borehole seals, and the compressor, and for miscellaneous purposes. Five-inch armored fuel hose was obtained from war surplus and is used to deliver water from the pump to the site.

Entries are being driven in the coal bed, using conveyors to load out the coal (fig. 47). This equipment includes one 30-inch belt conveyor, extended in 250-foot sections; two 300-foot pan conveyors, extended in 6-foot lengths; and one short cross conveyor. Coal is drilled, blasted, and hand-loaded into the conveyors. An average advance of 18 feet per shift has been achieved in each entry. Using such equipment as was readily available, rapid progress is being made at reasonable cost, and the entries are expected to be completed about December 15, 1948.

Two 18-inch and three 28-inch churn-drill holes are being bored from the surface to the entry (see fig. 48). Strata through which each borehole passes have been pressure-grouted by means of four 6-inch churn-drill holes spaced 4 feet from the center point of the large hole. It is significant that, in each location, the last two 6-inch holes refused to take grout under 800 pounds per square inch pressure. At several locations, the first two holes consumed appreciable quantities of the grout - one of them requiring 300 bags of cement. Refusal of grout by the last two holes, therefore, indicates that the underground crevices are securely stopped.

The two 18-inch and three 28-inch boreholes are being drilled by a truck-mounted cable-type rig. The two 18-inch holes, which have been completed, are satisfactory for air and possibly hot-gas transmission purposes. Rate of advance in the boreholes has been slightly more than 1 foot per hour, on an average shift basis.

The five large boreholes will be sealed at the surface by a length of water-jacketed pipe set in concrete (see fig. 49). The seal will extend approximately 25 feet below the surface to reach hard strata. Concrete will prevent gas from seeping around the seal to the atmosphere.

The two 18-inch-diameter boreholes will be unlined below the seal. The three 28-inch boreholes, however, will be lined with cast refractory concrete. It is expected that the natural strata will crumble and possibly slag at high temperature, blocking the borehole. To prevent this, a refractory lining will be cast. A 20-inch-diameter pipe casing will be set in the hole. The refractory concrete mix will be poured in the 4-inch annulus between the pipe and the wall of the hole. The pipe casing will remain in the hole.

In addition to the large-access boreholes, a number of 6-inch-diameter holes are being drilled to measure temperature rise in the coal bed. Holes are being placed in a pattern arranged so that the progress of the combustion zone may be traced. It is desired, also, to obtain heat-transfer data with respect to the overlying strata.

The entry seal will consist of a wall, extending across both entries and 25 feet into the strata on either side. This wall also will extend approximately 12 feet into the roof rock and 3 feet into the bottom. It will be constructed of a double thickness of firebrick, backed, and sealed with concrete and grout. An outlet pipe will be set in the wall. The design of an adequate seal is a requisite in underground gasification experimentation.

Firing of the coal bed in the underground passageway is scheduled for early 1949. Combustion will be begun at the bottom of No. 1 borehole in the entry and at the end farthest from the outcrop. Air will be supplied at borehole No. 1 and products of combustion taken off at borehole No. 2, 300 feet away. A low rate of air blast will be used initially, gradually increasing as combustion is established. At first, the outlet gas will consist of carbon dioxide, nitrogen, and water vapor and will have no value. As the temperature in the gasification chamber rises, carbon monoxide will be formed, roughly in accordance with the carbon monoxide-carbon dioxide temperature-equilibrium data. The gas also will be enriched by carbonization products, methane, hydrogen, light oils, and tar. It is planned to air-blast continuously in one direction throughout the gasification phase. The required blast pressure is expected to rise, owing to falls of roof rock, probable swelling of this rock, ash accumulation, and slagging. The pressure rise may limit the length of passage that can be utilized. As gasification proceeds, effective contact may lessen between the blast air and the coked coal face. Loss of contact will cause the zone of active combustion to move slowly in the direction of the air-gas flow. When the gasification phase is well-established, several zones will be set up in the underground gasification chamber. The air blast first will enter the blast preheating zone, where combustion has lessened owing to loss of contact with the coal face. Heat previously absorbed by the strata will be picked up by the air in this zone. Second will be the active combustion zone where good contact with the coal face will result in the production of carbon dioxide. Third comes the reduction zone where the hot gas, which now contains no oxygen, will react with the incandescent coke face to form carbon monoxide. In the fourth zone, the coal is carbonized and the roof and floor rock preheated by sensible heat in the gas. The products of carbonization will enrich the gas. These four zones comprise the gasification chamber in the underground passageway.

Laboratory Experiments

A horizontal, rectangular, laboratory-scale retort has been built to investigate some of the problems and proposed methods of underground gasification of coal at a fraction of the time, labor, and cost required for field-scale operations. The retort (fig. 50) was constructed of standard refractory materials, well-insulated with diatomaceous earth, and the whole contained in a steel jacket, open at the top. Inlet and exhaust openings to the retort were provided with regenerators or heat exchangers and suitable equipment for handling air and product gas. The retort was altered repeatedly in size and construction as experimentation progressed, remaining, however, essentially horizontal and rectangular. These alterations are grouped in table 11 for comparison.

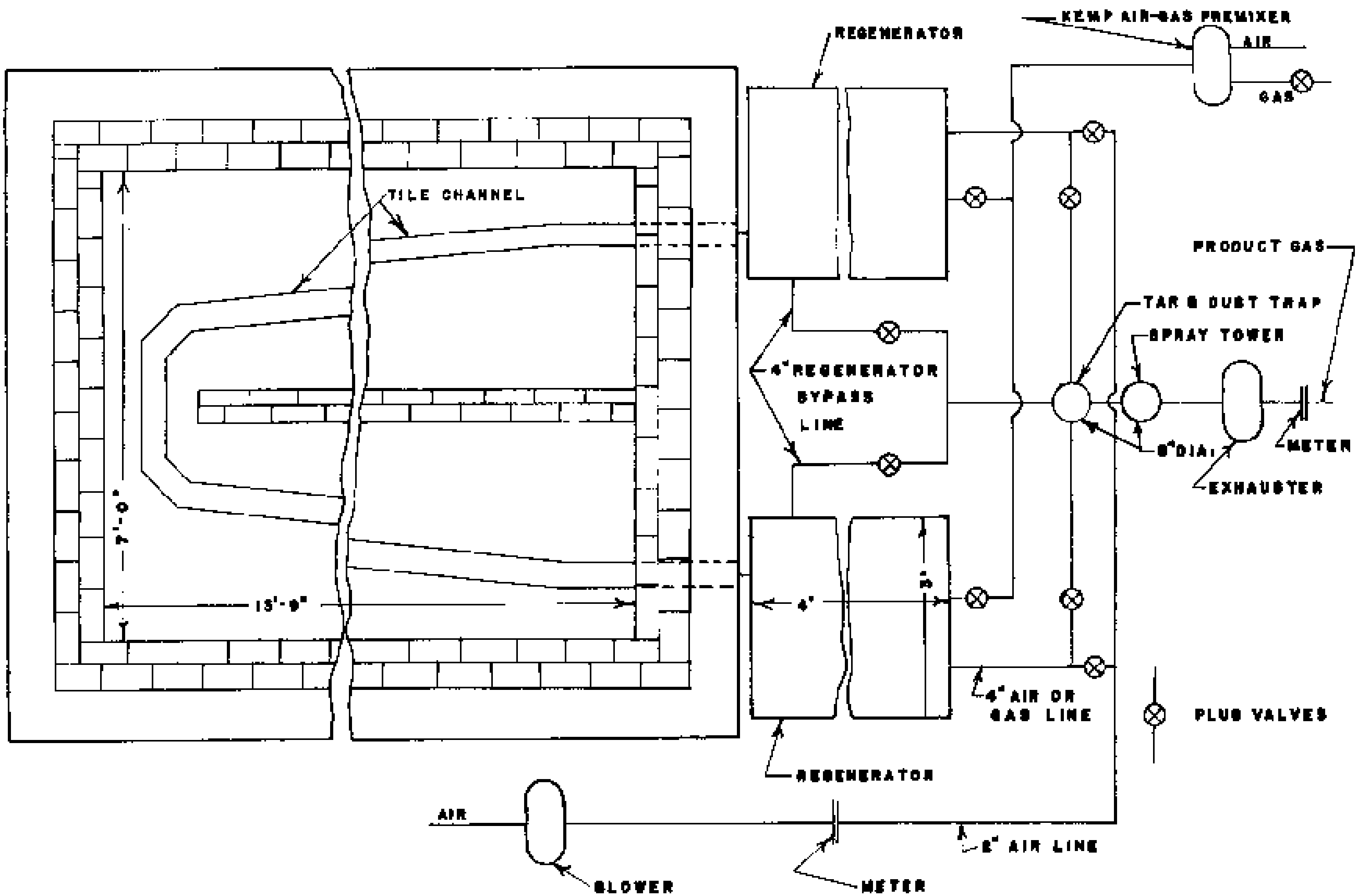

Figure 50. - Plan of laboratory model underground-gasification unit.

TABLE 11. - Alterations of retort

Retort	A[1]	B	C	D	E	F
Type of channel	W	W	W	W	U	U
Length of retort .... feet	9	9	13.75	13.75	13.75	13.75
Width of retort .... do.	5	5	7	7	7	7
Coal depth .... inches	14	14	14	16-1/2	16-1/2	24
Coal capacity .... pounds	2,400	2,400	4,300	5,300	5,200	8,200

1/ A did not have regenerators.

Two types of channels or air passages with similar construction (except for retort A) were utilized by the unit. The first type of channel traveled the length of the fuel bed four times in the shape of the letter W. The second-type channel traversed the length of the fuel bed twice in the shape of the letter U. Twenty-four refractory tubes were installed at different positions on the floor of the retort for gas sampling and measurement of pressure and temperature.

The regenerators consisted of steel shells 4-1/2- by 3-1/2- by 3-3/4-feet, lined with a layer of insulating brick and a layer of firebrick and filled with broken pieces of refractory. An automatic-mixing-type gas burner was used to preheat these regenerators to operating temperature.

The following operating procedure was standard practice for all experiments:

1. The retort was charged, and all equipment and instruments were checked.

2. Preheating of regenerators with the gas burners was begun.

3. An air blast of about 1,000 cubic feet per hour was passed through the retort after the regenerators had reached 1,500° F. Combustion of the coal took place automatically from contact with the hot air. (In the first experiments, combustion was started by inserting an oxygen-gas lance into the channel.)

4. The air flow was reversed periodically to elevate temperatures evenly throughout the fuel bed. (The time of these reversals varied with temperatures attained).

5. The air flow was increased in steps, for specified periods, to a predetermined maximum, which varied with different tests.

6. When the scheduled maximum air flow was reached, reversals were made every 1-1/2 hours.

7. A steam purge was used between reversals when the percentage of carbon monoxide and hydrogen together was 10 or more.

8. Pressures and temperatures were recorded 15 minutes after and 15 minutes before a reversal.

9. Composite samples of the product gases and grab samples at various points along the channel were taken periodically.

10. Humidity determinations of the atmosphere and product gases were made periodically to obtain material balances.

Thus far, a series of 11 experiments has been carried out on the underground gasification retort. Mention can be made of experiments 5, 7, 9, 10, and 11, which, in general, were the best of the series. However, a great deal was learned about procedure in operating the retort from those considered unsuccessful from the standpoint of gasification.

Experiments 1 and 2 were trial runs - the first, 3 hours long and the second, 48 hours long. Experiment 1 produced a small amount of coke around the air passage for about two-thirds of its length. Experiment 2 coked about three-fourths of the charge and produced temperatures at several points exceeding 2,400° F. These tests were terminated when the inlet and outlet passages became plugged. To realize higher temperatures within the fuel bed, fire-brick regenerators were installed at the inlets of the retort. Improvement in operation was evidenced by the fact that experiments 3 and 4 lasted 85 and 104 hours, respectively, and produced gas having an average heating value of 69 and 75 B.t.u. per cubic foot, respectively.

The first four experiments indicated the need for a larger retort capacity if steady operation was to be achieved. Subsequently, the retort was enlarged, and experiment 5 was carried out with nearly twice as much fuel as used in previous runs. Experiment 5 lasted 186 hours, consuming 72 percent of the charge at an air-blast rate of 1,200 cubic feet per hour. Although carbon monoxide in the product gas reached a maximum concentration of 17.3 percent, it did not level off at this point, indicating that a steady operation had not yet been attained. Retort capacity, therefore, was enlarged another 25 percent.

One of the outstanding features of this test was the relationship between oxygen, carbon dioxide, and carbon monoxide, as shown by analysis of gas samples taken after the air gas had traveled 5, 20, 50, 70, and 95 percent of the length of the channel. These analyses clearly show a decrease in oxygen and an increase in carbon dioxide, then a decrease in carbon dioxide and an increase in carbon monoxide as the percentage of travel through the channel increased. The 5-percent point was characterized by high oxygen, the 20-percent point by high carbon dioxide, and the 50-, 70-, and 95-percent points by increasing percentages of carbon monoxide with a maximum percentage at the 95-percent point and in the product gas.

Experiment 6 was to be made at 2,400 cubic feet per hour but had to be terminated after 75 hours because a short circuit developed from one leg of the channel to the other. Thirty-one percent of the charge was consumed. Short-circuiting, or bypassing from one leg of the air passage to the other ultimately was found in all experiments using the W-shaped channel. The shape of the channel was changed from that of a W to a U, with a fire-brick baffle extending through the middle of the legs from wall to wall with an opening for the bottom of the U.

Experiments 7 and 8 were made with this retort. A final enlargement of the retort increased its capacity to about 8,300 pounds. Experiments 9, 10, and 11 were made with this last retort (see fig. 51). Use of the last two retorts resulted in the most successful experiments of the series.

Several of the experiments were ended because of various operating difficulties before much of the charge in the retort had been gasified. These residues were examined and scale drawings constructed in an effort to determine the way in which the fuel was being consumed. Examinations showed the extent to which the charge was carbonized and the location of the reaction zones at the time the experiment was discontinued. They also clearly indicated that a "coke pipe" was formed around the channel originally built through the charge to the retort. As the reaction progressed the dimensions of the coke pipe increased. The majority of the ash remaining after the gasification of the fuel was deposited on the floor of the retort.

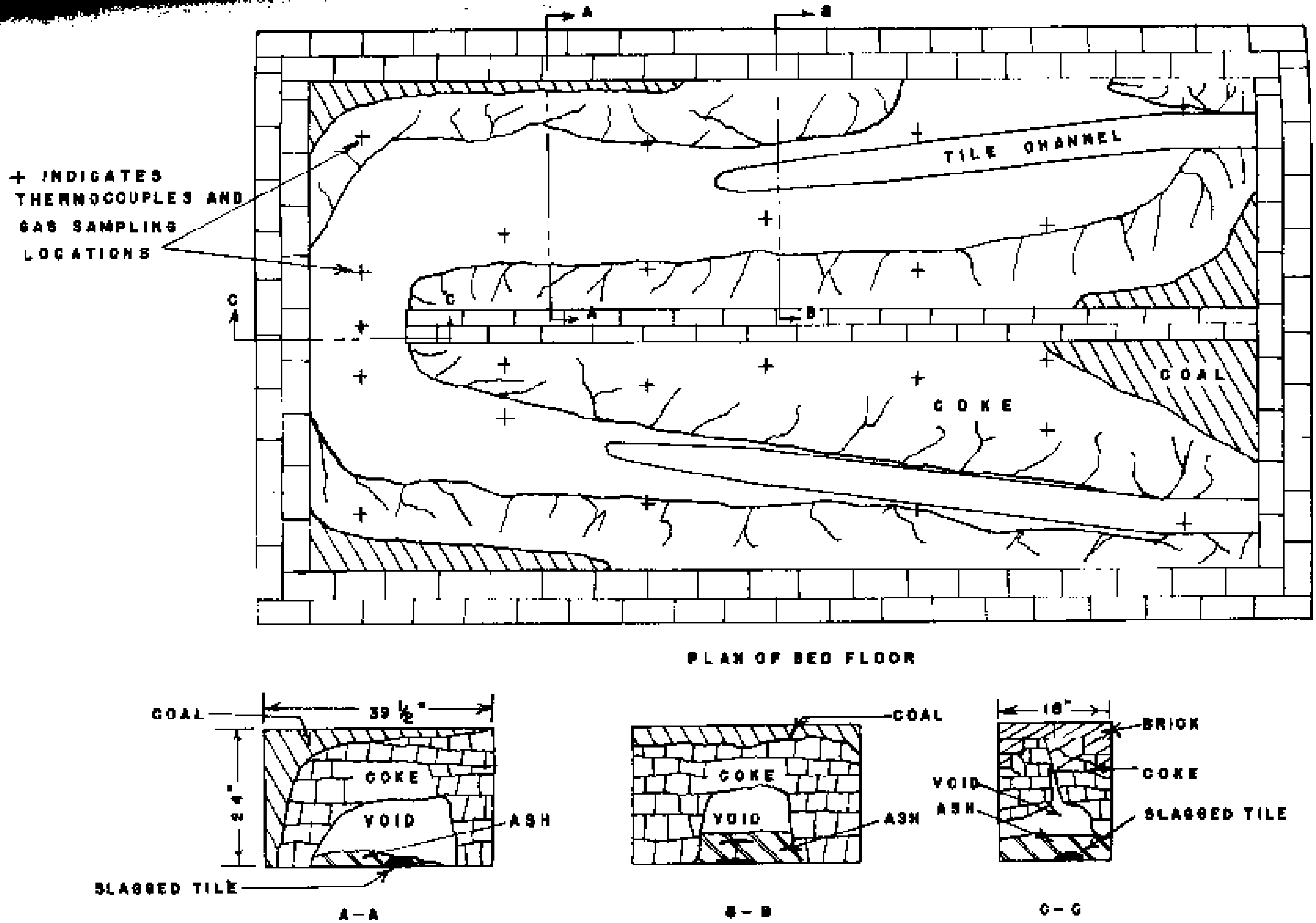

Figure 51. - Residue found in laboratory model underground-gasification unit following run no. 10.

Data from experiments 7, 9, 10, and 11 have been grouped in table 12 for comparison.

TABLE 12. - Results of laboratory experiments

Experiment	7	9	10	11
Wt. of charge...lb.	5,180	8,730	8,185	8,030
Wt. of residue...do.	1,453	4,920	4,717	2,002
Percent consumed	72	44	43	75
Max. air flow...cu. ft. per hr.	2,350	3,642	4,600	2,940
Analysis of charge:				
Hydrogen...percent	4.6	4.2	4.2	4.5
Carbon...do.	75.9	75.6	78.2	76.6
Nitrogen...do.	1.2	1.3	1.3	1.4
Oxygen...do.	6.1	5.6	4.7	6.2
Sulfur...do.	.9	1.3	.9	.9
Ash...do.	11.3	12.0	10.7	10.4
Heating value...B.t.u. per lb.	13,220	13,010	13,390	13,250
Length of run...hr.	109.25	83.5	46.3	124.5
Gasification period...do.	31.5	52.0	20.3	22.5
Ave. gas analysis:				
CO_2...percent	8.7	10.2	7.7	7.7
Ill. ...do.	.2	.6	.5	.3
O_2...do.	.2	.2	.5	.4
CO...do.	19.9	12.1	14.7	20.9
H_2...do.	4.3	9.5	10.7	4.5
CH_4...do.	1.0	2.4	2.0	2.3
N_2...do.	65.7	65.0	63.9	63.9
Heating value...B.t.u. per cu. ft.	92.4	106.1	111.6	111.4
Cold-gas efficiency...percent	55.6	75.0	80.9	64.5

Pilot Unit for Use of Superheated Steam and Oxygen

This project was undertaken in cooperation with Dr. Albert DeSmaele, chairman of the board, SOCOGAZ, Belgium, to study the underground gasification of coal with highly superheated steam and oxygen in an experimental pilot unit. Conditions underground in the gasification of coal seams are to be simulated in the two units under construction at Morgantown. As underground gasification is essentially gasification of coke resulting from the devolatilization (carbonization) of coal by intense heat, it was decided to study the gasification of run-of-oven, high-temperature coke cemented into a strong circular wall of about a 2-foot thickness.

The pilot units constructed are cylindrical steel chambers 10 feet in length and 4 feet in diameter, each holding about 2 tons of coke with a 4-inch-diameter channel along their axis in the middle. A large (2-million-B.t.u.-per-hr.)-capacity burner using natural gas and oxygen will be employed to blast the charge from the top. The products of combustion - steam and carbon dioxide - will be mixed with enough additional steam in such a way that all of these reactants will be introduced through the 4-inch channel at 4,000° F.

Products of gasification will move downward and pass into an 8-inch stack. The ratio of steam and oxygen to carbon will be varied to determine the optimum choice of operating variables for efficient and economical gasification of coal in underground seams.