SUMMARY AND CONCLUSIONS

The continuous gasification of lignite in an externally heated alloy-steel retort was investigated by the Bureau of Mines, Grand Forks, N. Dak., from 1945 to 1951. The main objective of the long-term experimental program was to obtain data on the mechanical performance of this type of gasification retort, particularly the alloy-steel heat-transfer surface of the retort, when operated on large pilot-plant scale. At the same time, extensive experimental data were obtained concerning the effect of process variables and the effect of a limited number of design modifications on gasifier performance.

In the period covered by this progress report 4 pilot-plant runs totaling 2,879 hours of operation were completed with the rolled-plate, 310-alloy reaction tube. Over 30 million cubic feet of gas, having H_2-CO ratios from 2.1 to 4.4, was made by the partial gasification of 636 tons of 1-1/2- by 3/8-inch natural lignite. Rates of gas generation were from 8,200 to 14,300 cubic feet per hour. Three of the four runs were carried out with the lowered gas offtake or continuous-annulus design modification of the gasification retort. In the final run of the series, gasification of lignite from seven different mines in North Dakota and Saskatchewan, Canada, was investigated at similar combustion-space temperatures and lignite and steam feed rates.

In development work on the externally heated gasifier, the aim was to use the maximum temperatures for heat supply that were consistent with satisfactory tube life. Maximum temperatures, measured in the combustion space near the outer wall of the retort, were from 1,925° F. at the lower end of the retort and heating furnace to 1,600° F. at furnace outlet. In general, during the 4 runs, average temperatures over the length of the combustion space were from 1,720° F. to 1,790° F.

Results of the gasification runs show that performance of the rolled-plate, 310-alloy retort tube was satisfactory at the combustion-space temperatures used. With completion of the work reported here, the 310-alloy tube has been tested in over 4,700 hours of operation. Measurements made after each run showed continuing radial deformation of the retort tube as a whole; however, the successive measurements indicate that this deformation was not necessarily progressive. Some localized deformation was also observed in the zone of highest temperature. The results indicate that deformation could probably be lessened and gas-making capacity increased by changing the design to maintain a more uniform temperature distribution along the length of the retort, using higher temperatures opposite the upper drying zone of the retort. Continuing chemical attack of the inside of the retort tube also occurred on a limited scale, but this does not appear to be a significant factor in determining tube life.

Comparison of design modifications of the gasification retort in terms of the continuous vs. divided annulus showed relatively minor differences in gasification characteristics. With increasing lignite feed rate at equal combustion-space temperatures and steam-lignite feed ratios, a trend was indicated to higher percent carbon gasified and rate of gas production with the continuous annulus arrangement.

In the comprehensive investigation of gasification process variables, a series of steam feed rates was used up to 535 pounds per hour, corresponding to a maximum feed ratio of 1.8 pounds of steam per pound of moisture- and ash-free lignite. Two test periods were run without adding process steam and with only the natural lignite moisture content available for gasification. Total water content of the lignite as charged, including water of formation, was normally about 0.85 pounds per pound of moisture- and ash-free lignite.

In general, the results show that addition of process steam had a significant effect on carbon gasified. With the continuous annulus, increase in steam feed rate from zero to 0.7 pounds per pound of moisture- and ash-free lignite increased the carbon gasified and rate of gas generation by about 30 percent at equal lignite feed rates and combustion-space temperatures. At the higher rates of steam addition, a large part of the total water available passed through the retort without reaction. The increased concentration of steam in the total gas passing through the retort had the principal effect of altering gas composition and increasing H_2-CO ratio by water-gas shift.

Lignite feed rates from 309 to 681 pounds per hour were used in the 4 gasification runs. Carbon gasified varied over a wide range, from 47 to 86 percent. When lignite feed rate was increased, at equal combustion-space temperatures and steam-lignite ratios, the percent carbon gasified dropped but gas production increased, because the first fractions of carbon in the lignite were gasified more readily than succeeding portions. In a representative series of experiments, carbon gasified dropped from 82 to 68 percent and gas produced increased from 11,600 to 14,100 cubic feet per hour when lignite feed rate was increased from 454 to 681 pounds per hour. At the lower percent carbon gasified, it is evident that the gasification process approaches a carbonization operation, involving mainly the release and cracking of volatiles. In plant practice, operation at low percent carbon gasified would necessarily depend on possibilities for secondary utilization of residual char from the gasification process.

In the final run of the series, lignite from seven different mines was gasified at similar combustion-space temperatures and lignite and steam feed rates. Wide differences in gas-making capacity were observed, gas produced ranging from 14,300 to 9,500 cubic feet per hour at the same nominal feed and operating conditions. Differences in gas produced appear to be associated primarily with heat-transfer effects rather than differences in lignite reactivity, the main effect being heat-transfer limitation from gradual buildup of ash deposits at the wall of the alloy tube. Previous data had showed little or no evidence of variation in heat transfer or gasification characteristics with time. The formation of bonded ash deposits resistant to heat transfer in this run appears to be related to low ash fusibility of lignites charged in the early part of the run, in conjunction with use of high, constant combustion space temperatures. Ash-softening temperatures of lignites charged during this run were as low as 2,150° F., compared to an average ash-softening temperature of 2,400° F. for the lignite used in previous experimental work. The results indicate that a high ash-fusion lignite is required to operate at high temperature and maximum gas-making capacity in the externally heated gasifier. Gasification data after ash buildup to approximate steady state indicate that size variation of the lignites tested was an important secondary factor in determining gasification rate, again primarily through effect on heat transfer.

With the completion of the series of runs reported here, the externally heated, alloy-retort gasification unit as a whole had been operated over 8,700 hours, including 4,700 hours of satisfactory operation for the rolled-plate, 310-alloy retort tube, and process variable data had been obtained over a wide range of operating conditions. The large pilot-plant investigation of this gasification process was therefore concluded. This final progress report on the experimental work, includes a summary of the earlier results (Section II), together with several general correlations of the overall gasification data obtained during the 6-year experimental program (Section III).

The investigation was carried out in a large pilot plant of commercial scale, and complete data on cost of construction and operation were collected. This cost information has been prepared for publication as a separate report (7).[4]

INTRODUCTION

Since February 1945, the Bureau of Mines has operated an externally heated retort for the continuous gasification of lignite on the campus of the University of North Dakota. When the project was begun, interest centered on the use of the product gas as a reducing agent for beneficiating low-grade iron ores. The synthesis gas produced by this process, containing 70-80 percent (H_2+CO), is also adapted to use in a number of important and potentially large-scale synthesis applications, including production of liquid fuels and chemicals by Fischer-Tropsch synthesis and manufacture of synthetic organic chemicals by the Oxo process and as a source for hydrogen for coal hydrogenation and ammonia synthesis.

This progress report on the gasification project, the fifth of a series, covers the period from July 1, 1950, to December 31, 1951, during which time the gasification unit was operated nearly 2,900 hours to produce 30 million cubic feet of gas under various experimental conditions. Previous publications have presented in detail the history and development of the gasification process (12, 13), theoretical aspects of gasification of lignite in externally heated retorts (5, 6), and data and observations for 5,770 hours of operation (3, 4, 13). A principal objective of the large pilot-plant experimental program has been to test the alloy-steel, heat-transfer surface of the externally heated gasifier during full-scale operation. In addition, as part of the testing program, a comprehensive study has been made of the effect of process variables on gasifier operation.

ACKNOWLEDGMENTS

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Baukol-Noonan, Inc.
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Dakota Collieries Co.
Knife River Coal Mining Co.
Truax-Traer Coal Co.
Western Dominion Mines, Ltd.

Free transportation of the lignite was provided by the Great Northern Railway, Northern Pacific Railway, and Minneapolis, St. Paul & Sault Ste. Marie Railroad.

4/ Underlined numbers in parentheses refer to items in the Bibliography at the end of this report.

SECTION I. EXPERIMENTAL WORK: JULY 1, 1950, TO DECEMBER 31, 1951

Description of Commercial-Scale Pilot Plant

Descriptions of the Grand Forks gasification unit and methods of operation and obtaining data have been reported previously (3, 4). Essentially, the gasifier consists of two concentric metal cylinders separated by a 3-inch-wide annular space in which gasification occurs. Lignite screened to 1-1/2 by 3/8 inches descends by gravity flow through the annular space where the carbon of the lignite is converted to gas by reaction with steam. Heat for the endothermic process is supplied through the outer metal cylinder. A residue or char consisting of ash and ungasified carbon is removed continuously at the bottom of the retort.

In the large pilot-plant retort, the outer cylinder, across which heat required for gasification is transferred, is 48-1/2 inches inside diameter, with a heated length of 16-1/2 feet. After earlier trials with other materials, including alloy-clad and centrifugally cast alloy cylinders (4, 13), a 310-alloy, rolled-plate tube one-half inch in wall thickness has been used in the recent experimental work (3).

A flow diagram of the gasification unit and auxiliary equipment is shown in figure 1. The alloy-tube retort is heated by tangentially mounted burners placed in an external furnace. There are 6 burners at the first level in the furnace and 3 burners at each of the two higher levels. A relatively low flame temperature and low B.t.u. gas are required for heating. In experimental operations product gas diluted with products of combustion was used to heat the retort. Primary air and recycled products of combustion were preheated in an alloy-tube recuperator. Products of combustion going to the stack were used to preheat steam fed to the gasifier. A bleed stream of products of combustion was cooled and used as purge gas in the lignite-feed and char-discharge systems.

Product gas left the retort through the inner retort tube and passed to the scrubbing system, where any blowover dust or tar entrained in the gas were removed by water and oil scrubbers, followed by a coke-packed shavings scrubber to remove oil mist. In pilot-plant experimental work, part of the clean gas was used for retort heating and the remainder was piped over to the adjacent University of North Dakota power plant.

Retort Arrangement

Detailed arrangement and dimensions of the gasification retort during runs 14, 15, 16, and 17, the four runs covered in this progress report, are shown in figure 2.

During most of the previous experimental work with the annular-retort gasifier (3, 4), steam for gasification was introduced both at the top and bottom of the annular reaction space. Product gas left the retort through an outlet about one-third of the way up on the inner wall. This arrangement of the gasifier, designated as the divided annulus arrangement, was continued in run 14.

A basic change in retort design was made after run 14 when arrangement of the metal cylinders was converted from a divided to a continuous annulus similar to that previously used for runs 7 and 8 (4). In the continuous annulus arrangement, the gas outlet is shifted to the bottom of the retort. Both the inner and outer cylindrical walls of the annular reaction space are continuous along their full length. All process steam is fed to the top of the retort. This retort arrangement was used in runs 15, 16, and 17.

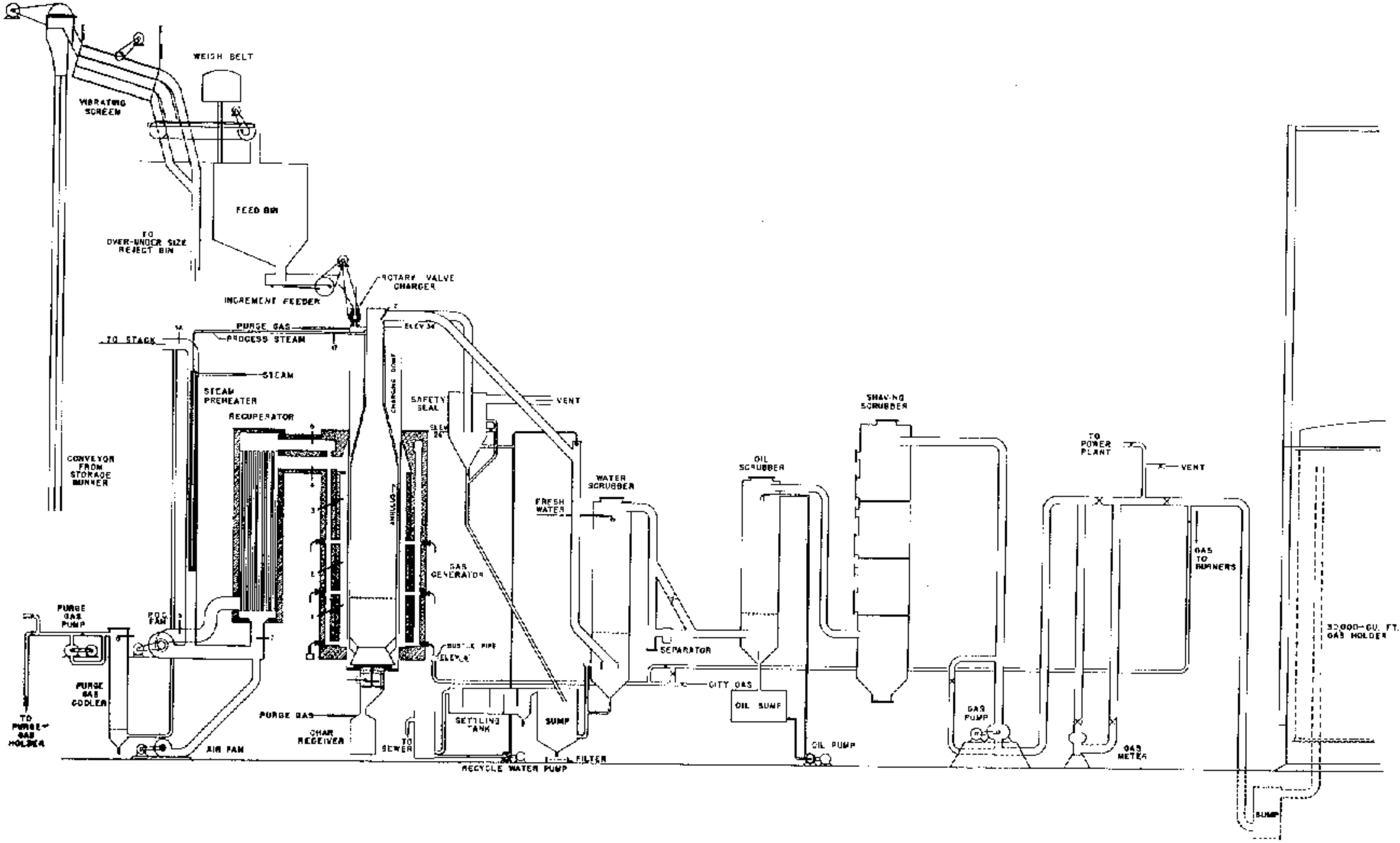

Figure 1. - Flow diagram of commercial scale pilot plant for gasifying lignite. Bureau of Mines, Grand Forks, N. Dak.

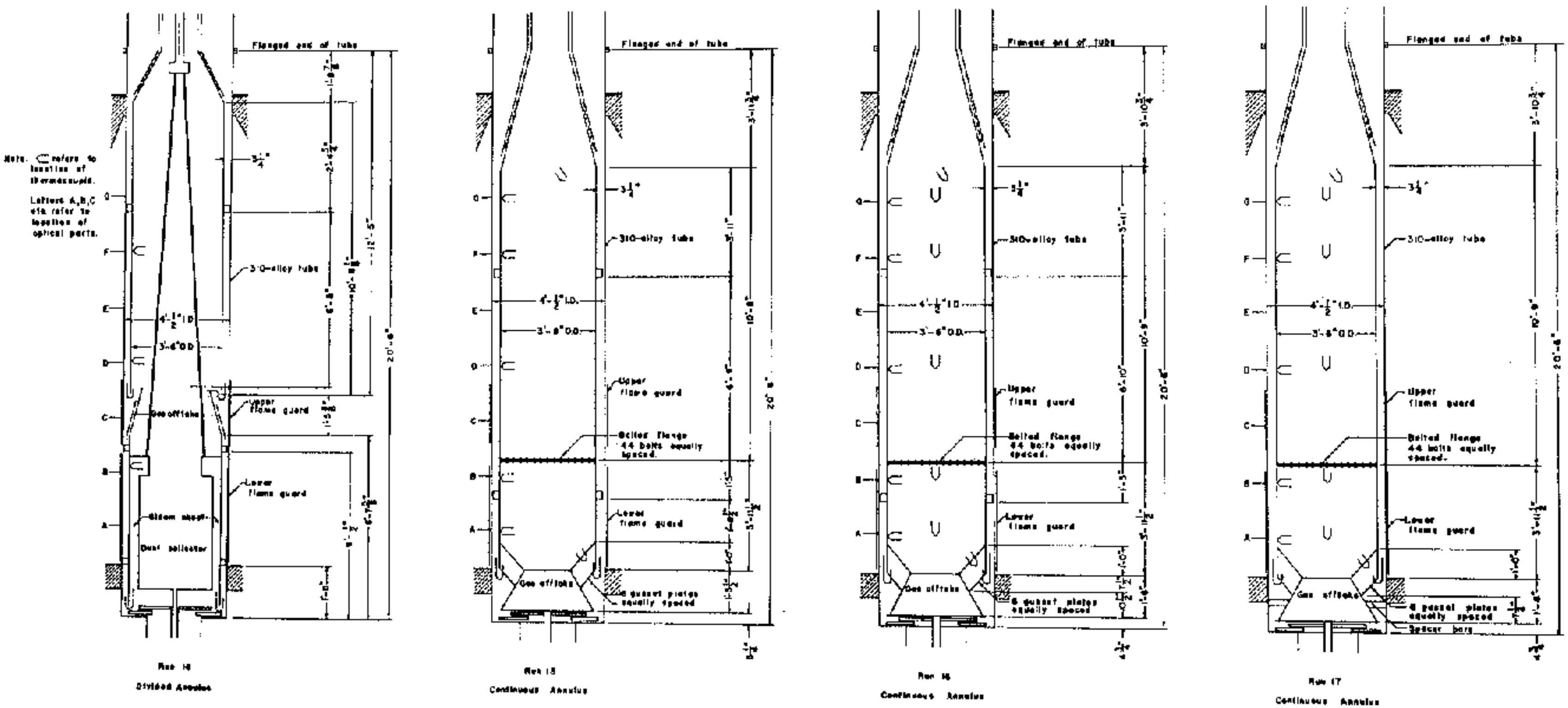

Figure 2. - Arrangement of gasification retort during runs 14, 15, 16, and 17.

Minor modifications in design of retort and auxiliary equipment for the individual runs were as follows:

Run 14

Previous to run 14, a new 23-12-alloy, steel tube nest was installed in the recuperator. In the gasification retort, the lower row of spacer bars welded to the outside of the inner tube was replaced by a stiffener ring welded to the inside 9 inches from the bottom. These two changes were reported in the last progress report (3). To improve performance of the lignite-feed system, a trip-feeder mechanism consisting of a small quick-acting counterbalanced hopper was placed between reciprocating feeder and rotary feed valve. The trip was synchronized with the rotary feed valve so that the increment of lignite being charged dropped directly into the chamber of the valve, thus preventing lignite from falling on the surface of the revolving plug. This change retarded abrasion and lengthened the serviceable life of the rotary feed valve.

Run 15

Beginning with run 15, the gasification unit was converted to the continuous annulus arrangement, as shown in figure 2. A new, mild-steel inner tube was fabricated. Other changes such as lengthening of the steam distribution cone, and installation of additional thermocouple stations on the inner wall, at the gas offtake, and at the center of the inner tube are also indicated on figure 2. To reduce carryover of dust particles, the area of the gas offtake was increased from 3.6 square feet to 6.7 square feet. Changes in the construction of the inner tube and steam distribution cone reduced the total length of the annular reaction space by 2 feet.

Run 16

The diameter of the gas offtake cone at its base was increased from 40-3/8 inches to 42 inches, reducing space for discharge of the gasification residue or char. This change reduced char removal for each revolution of the discharge scraper from 23-24 pounds to 18-19 pounds, permitting better control of char discharge at low rates of discharge and high percent gasification.

Several additional thermocouple stations were installed along the center line of the inner tube of the gasification retort to measure gas temperatures at locations corresponding to thermocouple stations at the wall of the inner tube.

Run 17

All spacer bars were removed from the inner tube. Four new spacer bars were attached to the gas offtake cone perpendicular to the outer alloy tube, as shown in figure 2.

In the product-gas line, the multiple-baffle entrainment separator following the water scrubber was replaced by a separator of simpler design containing a single impingement plate. A moveable, ring-cleaning device was installed at the first water spray head in the gas-scrubbing system to permit removal of dust accumulations. In the lignite feed system, the intermediate feed hopper, which holds the weighed lignite, was rebuilt to improve gravity discharge of the lignite.

Operating Procedure

On the basis of 5,772 hours of previous operating experience with the annular-retort gasifier, the following final procedure was established for startup and for operation of the gasifier at various test conditions during runs 14 through 17:

Startup

The unit was air pressurized at about 60 inches of water and checked for leakage. Instruments for recording the principal data were calibrated. The gasification retort and charging dome were filled with metallurgical coke crushed to 1/2- by 1/4-inch. The 30,000-cubic foot gas holder was filled with a propane-air mixture having a heating value of about 1,000 B.t.u. per cubic foot. The primary air fan was turned on, and three equally spaced burners in the bottom row of the heating furnace were ignited. Additional burners in the first, second, and third rows were ignited as required to maintain a temperature rise in the heating space of 50° to 60° F. per hour.

When temperatures over 1,000° F. were reached at points 1 and 2 in the heating space, process steam was added to the retort at a rate of 100 pounds per hour. Char discharge and lignite feed were then started at low rates. Process steam rate was increased to about 200 pounds per hour when temperatures at points 1 and 2 in the heating space were approximately 1,800° and 1,600° F., respectively, and lignite feed and char discharge rates were gradually increased. Normally, enough product gas was being generated to allow burners to be switched from propane-air mixture to product gas approximately 36 hours after lighting burners. After this change, the desired experimental conditions of lignite feed rate, steam feed rate, and combustion-space temperatures were established as required for the test. After apparent equilibrium was reached, operating data were recorded during a 24-hour test period. About 78 hours was required from lighting burners to the start of the first test period.

Test Periods at Constant Conditions

Each experimental run was divided into a number of test periods, each at a different operating condition. Tests were approximately 24 hours in length. To insure equilibrium at the specific test conditions, each test was preceded by a preliminary stabilizing or transition period of about 24 hours. In run 17, during which 7 different lignites were tested, the transition period between official tests on different lignites was extended to 48 hours.

Experimental conditions were changed at the beginning of a transition period, and only adjustments necessary to maintain selected operating conditions were made during transition and test periods. Usually only one major variable such as steam-lignite ratio, lignite feed rate, or temperature distribution in the combustion space was changed between successive tests. Indicating instruments were read and data recorded at periodic intervals during transition and test periods. Samples of gas, lignite, char, and other materials were taken as required.

To shut down the gasifier after completing the testing schedule for a given run, the lignite feeder was stopped while char discharge was continued to remove the material in the retort. When inner tube temperatures near the top of the reaction zone (points F and D) increased rapidly, indicating that the level of charge had passed, the top row of burners was closed. After the charge level had dropped below the mid-point of the retort, the remaining burners were closed and bustle pipe purged to the atmosphere. When gas production dropped below that required to maintain operating pressure at the gas offtake, the gas was vented to the atmosphere through the lowered water seal. The remaining char was then removed and the gas system vented. Auxiliary equipment was turned off and the gasifier slowly cooled by running the primary air and stack-gas fans.

After the retort had cooled, the deposits of ash and scale that had formed on the inside of the alloy retort tube were removed and weighed.

To minimize deformation and possible influence of uneven heating, the retort tube was rotated a quarter turn between runs.

Instrumentation and Methods of Obtaining Data

Extensive instrumentation was used in the pilot plant to collect operating data and to assist in process control. Because of the continuous nature of the process, emphasis was placed on measurement of flow rates.

Product gas was measured directly with an integrating Roots-Connersville positive-displacement meter installed immediately after the gas-scrubbing system (see fig. 1). This meter had a guaranteed accuracy of 0.5 percent. A recording orifice meter was used for operational control. Rates of addition of process steam to the gasifier were determined with calibrated indicating-type Foxboro orifice meters after pressure reduction from 125 p.s.i.g. line pressure to 30 p.s.i.g. with a Cash regulator. Weight of lignite fed to the gasifier was measured with a belt-type Weightometer. The weighbelt was calibrated before each run, and corrections for variation in integration or "creep" were calculated for each loading of the feed bin. Weight of char was determined by direct weighing on a platform scale. Purge gas rates to the lignite feed and char-discharge systems were measured with calibrated orifices.

Other secondary flow rate data, such as flow rates of primary air, heating gas, recycled products of combustion, and water to the gas-scrubbing system, were measured for control purposes with uncalbrated orifices.

Temperatures were measured at various points in the gasification unit (see figs. 1 and 2 for measurement locations) with chromel-alumel thermocouples and recorded with a 16-point Micromax potentiometer. Combustion-space temperatures were determined at four points covering the tube length and furnace outlet with chromel-alumel thermocouples and recorded by a Brown electronic potentiometer. Air, steam, water, and product- and heating-gas temperatures were measured with dial-face bimetalic thermometers. Alloy-tube surface temperatures were measured at intervals by optical pyrometer.

Each test or transition period was ended with the lignite level in the charging dome at a standard height and the weighed-lignite storage bin empty to insure accurate cutoff point for the determination of lignite feed rate. Final readings of all integrating instruments for calculating experimental results were also taken at this time. Data from indicating instruments were recorded at periodic intervals, usually every 2 hours. Printed records of recording instruments were retained. Averaged data from these sources were used for summary reports and calculations.

Carbon dioxide content of product gas and products of combustion were indicated and recorded continuously for control purposes by Republic meters. Specific gravity of the product gas was measured with a Ranarex meter, and heating value was measured