The above tests indicated that the design 7 burner was not as efficient as design 6 burner, probably because the coal stream was not interrupted as effectively. It also appeared that, although design 6 burner gave satisfactory results within a limited range of reactant ratios, using a primary-zone construction such as existed for run 23, the burner was unduly sensitive to minor changes in reactant rates and reactor geometry. A new design 9 burner (fig. 13) was fabricated and used for test runs 30 through 34. Its distinctive features included a ring of 6 ports in the coal tube 1-1/4 inches from the burner tip designed to admit about 20 percent of the steam-oxygen mixture to the coal stream. The ports at the burner tip were staggered in two concentric circles as close as possible to the coal tube, so as to provide better mixing with the coal stream. Overall burner operation was very satisfactory during test runs 30 through 33. The gasifier refractory remained in excellent condition, and good requirements figures were obtained. Each burner was changed once during the 295-hour extended run 34. Burner B had given some evidence of trouble, since it had been necessary to blow out B coal feedline frequently during the first part of the run. Inspection of burner B after removal showed that its coal tube was badly eroded near the tip. In view of the erosion of burner B and to gain additional experience in changing burners, burner A was changed about the middle of the run. The new A and B burners were continued in operation for the balance of the run.

Both sets of A and B burners were found to be badly eroded for the 1-1/4 inches of distance from the auxiliary steam-oxygen ports to the tips. These results, based on perhaps 120 to 150 hours of operation per burner, indicated that the method of adding the auxiliary steam-oxygen mixture used with design 9 burners would not give satisfactory burner life. However, new reactant-burner designs have been developed, which have proved very satisfactory in later runs, and refractory erosion has been almost completely eliminated.

Coal-feeding system

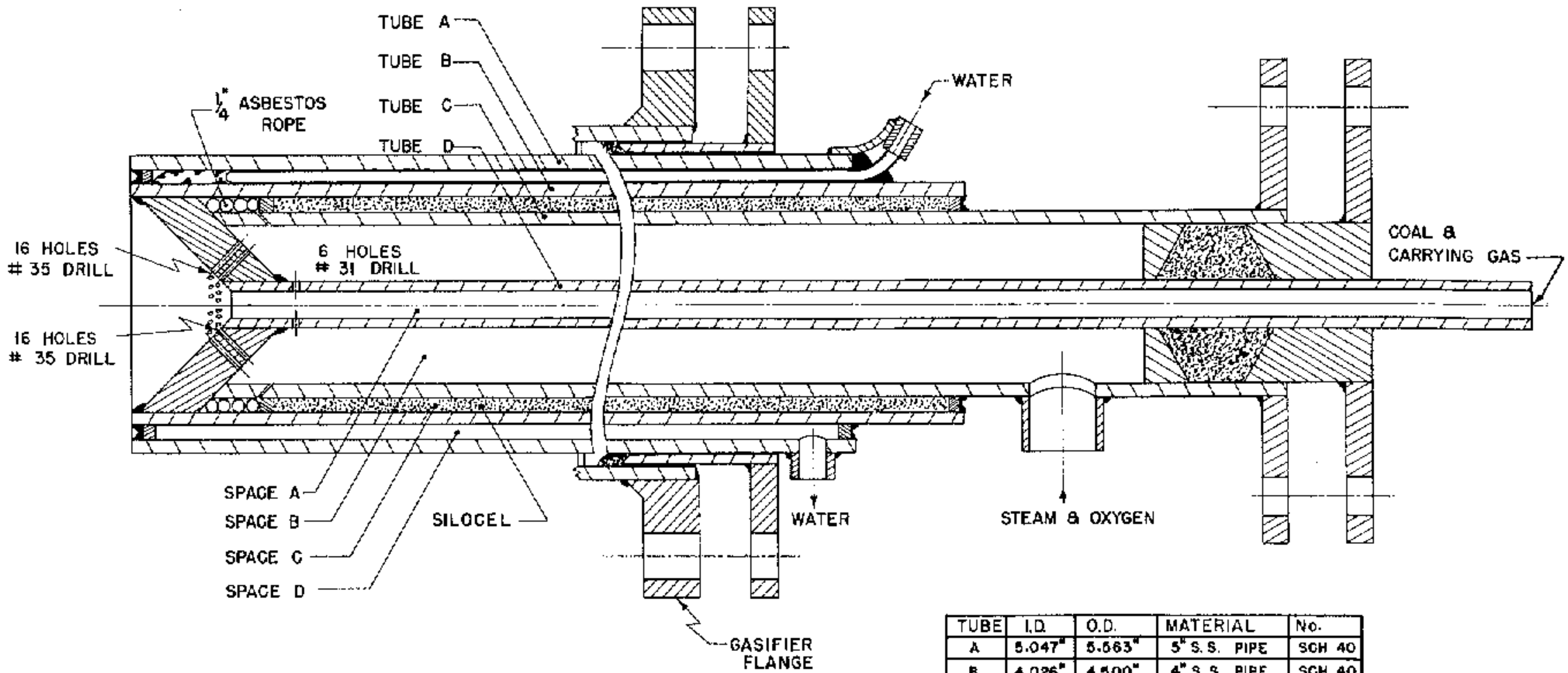
The coal-feeding system from the batch feeder to the gasifier was essentially the same as that used earlier for atmospheric gasifier 2 and described in a previous report.[13] During this investigation on gasifier 4, the coal-feeding system was made semiautomatic from the coal crusher to the batch feeder and the barrel-handling method of charging the batch feeder was eliminated. The flow of coal from the coal pile to the gasifier is shown schematically in figure 14.

The raw coal is crushed to minus-3/4-inch size in a commercial-type hammer mill, conveyed using a bucket elevator to a 4,000-pound-capacity storage hopper, and fed by gravity to a Raymond roller mill. The coal is ground in the roller mill at about 2,500 lb. per hr. for the finer size of 90 percent through 200-mesh, and at a slightly greater rate for the coarser size of 70 percent through 200-mesh.

The pulverized coal is conveyed by air to a cyclone separator, with the main stream then fed by gravity to a Syntron-vibrator scalper-screen and the oversize returned to the roller mill for further grinding. A screw conveyor carries the pulverized coal from the vibrator to 1 of 4 storage hoppers, each with a capacity of about 3,000 pounds of coal.

Coal in the storage hoppers is fluidized as needed, using air or inert gas, and is transferred to either one of two 2,500-pound-capacity transfer (or weigh) hoppers mounted on scales. Coal in a transfer hopper is fluidized a few minutes before needed and transferred to the 1,000-pound-capacity batch feeder as needed, using air or inert gas. Each time coal is transferred to or from the transfer hopper the hopper weight is recorded so that the coal-consumption rate can be determined.

13/ See work cited in footnote 4, p. 11.



TUBE	I.D.	O.D.	MATERIAL	No.
A	5.047"	5.563"	5" S.S. PIPE	SCH 40
B	4.026"	4.500"	4" S.S. PIPE	SCH 40
C	3.390"	3.500"	3 1/2" BWG TBG.	16
D	0.622"	0.840"	1/2" S.S. PIPE	SCH 40

Figure 13. - Reactant injection nozzle for gasifier 4, design 9, runs 30 through 34.

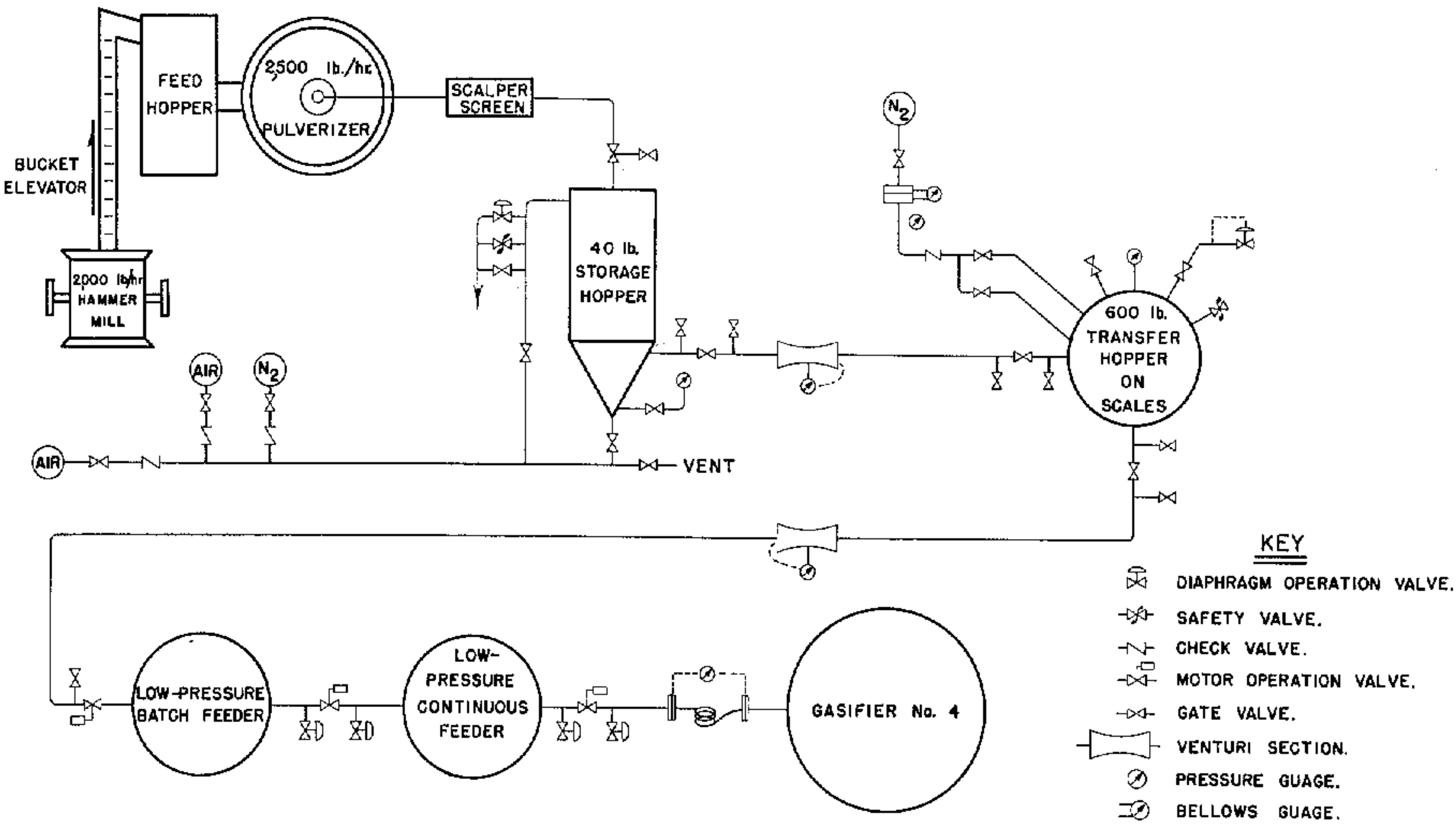


Figure 14. - Coal handling flowsheet for atmospheric gasifier 4.

Experimental work has been carried out for various runs on the moving-bed coke filter.16/ When the coke filter is used, about 1,000 to 2,000 std. c.f. per hr. of product gas is passed through the filter to ascertain the dust-removal efficiency of the equipment with synthesis gas.

TEST PROCEDURES USED

The test procedure was an outgrowth or development of that used during test runs on gasifier 2.17/ In general, each run consisted of a heatup portion and a gasification portion. The gasification portion was further divided into preliminary periods, during which the desired flow rates and refractory temperatures were sought, and data periods of relatively constant conditions, during which numerical test data were collected.

A typical heatup operation commenced about 4 p.m. and continued until about 8 a.m. the next morning. During this time the air and natural-gas flows to the heatup burners were increased gradually so that temperatures indicated by thermocouple 9 (primary-zone refractory) followed on "example" time-temperature curve and temperatures indicated by other thermocouples remained within specified limits. The final temperature for thermocouple 9 was a predetermined safe operating limit of about 2,250° F. Product-of-combustion gases were vented out the stack at the top of the gasifier. Enough water flow was used to maintain the temperature of the water leaving the burner jackets, the heat-trap coils, etc., at about 150° F. About 2 hours before scheduled start of coal gasification, the coal feeder was pressurized, and coal in the feeder was fluidized. At the same time heating of the steam superheater was begun, using settings to give the specified steam rate and temperature, with the superheated steam vented to the outside.

During the next 2 hours the gasifier vent was closed, superheated steam was sent to the gasifier, inert gas was sent through the reactant-burner coal tubes and to various parts of the dust train, and spray-water flows in the dust train were adjusted. A suction of 2 inches of water at the top of the gasifier was maintained, using the Sutorbilt exhauster, to pull hot product-of-combustion gases through the dust train to bring it to the desired temperature.

When spot analyses of gas samples from the dust train showed the system to be properly purged of oxygen, coal and oxygen flows were begun. The Sutorbilt exhauster was set immediately to maintain 6 inches of water pressure at the top of the gasifier, heatup burners were turned off as soon as ignition was verified, purges were discontinued, and a spot analysis of product gas was obtained as soon as possible.

The next 1 to 3 hours made up the first preliminary period. This time was used to check equipment operation, establish reactant rates, as indicated by temperatures, gas analyses, and visual observations, and to allow the gasifier to approach equilibrium operation.

As soon as reasonably steady equilibrium was attained, the first data period was begun. Each data period was continued for 3 to 8 hours if possible, longer intervals being used for some periods of test 34. Temperature, pressure, and flow data were recorded, most readings being taken once every 30 minutes for a typical test

16/ Egleson, G. C., The Design and Operation of a Moving Bed Filter for the Removal of Dust from Gases: Submitted for Master of Science degree, Depart. Chem. Eng., West Virginia University, 1949, 81 pp.
17/ See work cited in footnote 4, pp. 13-18.

run. (Although nearly all these data were also recorded on recording-type instruments, periodic inspection of these readings provided quick indications of abnormal conditions and use of data sheets expedited the later calculations of test results.)

Grab samples of product gas were taken each 1/4 hour after the product-gas flowmeters. Spot analyses for CO_2, O_2, and CO were made on every other sample for control purposes, and complete analyses were made on selected samples among those remaining for report purposes. A composite sample also was collected at the same location for the duration of the data period. Samples of slag-pot vent gas were taken when considered necessary, generally 2 or 3 times per test run.

The slag pot was flushed out periodically, generally once each 1/2 hour, and the slag was retained for weighting and analysis. Sludge-tank overflow water was metered and sampled periodically for residue content, and residue samples were obtained from the seal pot, slag-pot overflow water, etc. Product-gas sulfur samples were generally obtained, and the gas was sampled for dust and moisture content for many of the runs.

If the coal feed was interrupted for any reason, the oxygen flow was turned off, and inert gas was passed through the reactant-burner coal tubes to prevent them from overheating. At the conclusion of any data period, except the last one of a multi-period run, the settings would be changed to those desired for the next data period and gasification would be continued throughout a stabilizing interval - generally 1/2 to 2 hours - before the next data period.

At the conclusion of a normal test run, the oxygen and coal flows were discontinued, inert gas was passed through the burner coal tubes, the heatup burners were turned on, and the dust train was purged with inert gas. After gas samples showed satisfactory purge conditions, the gasifier was vented at the top, the steam and inert-gas flows to reactant injection burners were discontinued, and the heatup burners were turned off. During this time the water flows to coils and sprays were continued as needed to prevent local overheating.

During the course of these 34 test runs, the operating procedure was modified as required by new equipment and suggested new techniques. For example, the steam-oxygen superheater, the coal preheaters, and the capacitometer were first used with run 10, and the new oxygen plant supplied oxygen for the first time for run 30. Also, after installation of a recycle water pump, part of the water used in the heat-trap coils was recirculated, and the water exit temperature was increased to 220° F. Several improvements in gas- and residue-sampling techniques were worked out.

Operability of plant

The gasifier has operated very well throughout all tests made to date. Techniques have been developed to permit passing hot product gas through the heat trap without excessive buildup of fly ash on the coils. The material requirement per unit of product gas has been greatly reduced since the initial run. Refractory erosion has been virtually eliminated in the later runs. Installing the support coil was a distinct improvement, since it permitted operating over a range of temperatures in the primary zone without eroding the refractory at the upper throat.

Installation of the steam ejector in the slag-tap gasline increased operability of the equipment by permitting slag gases to be pulled through the slag tap so that the throat temperature could be brought up high enough for suitable slag flow. It as been found that the amount of slag-tap gas required to be drawn through the lower aroat decreases as the coal rate increases. Much better efficiency is obtained rom the equipment if the slag tap is kep small; a throat 6 to 8 inches in diameter as given the best results to date.

Slag-pot changes have been made from time to time to improve slag removal. riginally a flat bottom was used. The present type has a semiconical bottom uipped with a good water-washout system. Provisions have been made for rodding t the slag pot should slag hang up there, but since this bottom has been installed rodding has been required. Tests were made using a spray ring in the slag pot d a water-jacketed wall, but these were both removed as they kept the temperatures the slag tap too low and caused the slag to build up and block the slag tap. The ag pot is now lined with a 4-1/2-inch thickness of K-30 insulating brick down to e water level. Shell coils were installed in the primary zone as a safety feature. ould any portion of the refractory be severely eroded, the coil section adjacent the refractories would prevent burning through the shell.

Much experience in operation has been gained. It is now possible, while holding fixed coal-feed rate, to vary both the oxygen-coal and steam-coal ratios, maintain od material requirements, virtually eliminate refractory erosion, and maintain good agging conditions. Fear that an explosion would occur in the system because of a nporary excess oxygen supply has been eliminated. It has been found that, should ugging of the coal feedline cause the coal flow to stop temporarily, it is not cessary to shut off the oxygen flow instantantly. Ample time can be permitted to tempt to free the blockage, but after a few seconds, if the coal cannot be again i to the gasifier, a normal shutdown must be made.

A great improvement in the safety of the operation was elimination of the coal veying oxygen. Approximately 20 percent of the oxygen had been admitted at the ht glasses on the coal feedline. While this method had been used occasional shbacks occurred at the sight glasses, causing at least temporary shutdowns in tests until the glasses could be replaced.

After test 9 the conveying oxygen was removed, and the coal was carried with rt gas. All the oxygen is now fed in through the burners and reacts with the coal the burner tips. No difficulties have been encountered in this method of feeding, the efficiency of the gasifier has not been affected by the small quantity of rt gas used to carry the coal.

Methods of measuring reactant and product quantities

Flows of oxygen and steam to the gasifier, and product gas from it, are measured standard orifice-type flowmeters, with flow rates, temperatures, and pressures orded in the pilot-plant instrument room. A second oxygen meter in series with first checks the oxygen rate, and a positive-displacement-type Roots-Connersville er checks the product-gas rate. The coal-feed rate (as mentioned earlier) is ermined by measuring the pressure drop across a precalibrated coil. The probably uracy of these various measurements is discussed later in the section on accuracy results.

The oxygen piping is so installed that, should the oxygen flow be shut off for reason, the system is automatically purged with CO_2.

Stability of refractory linings

In the early stages of the experimental work with this gasifier, it was presumed the life of the refractories, particularly in the primary reaction zone, would

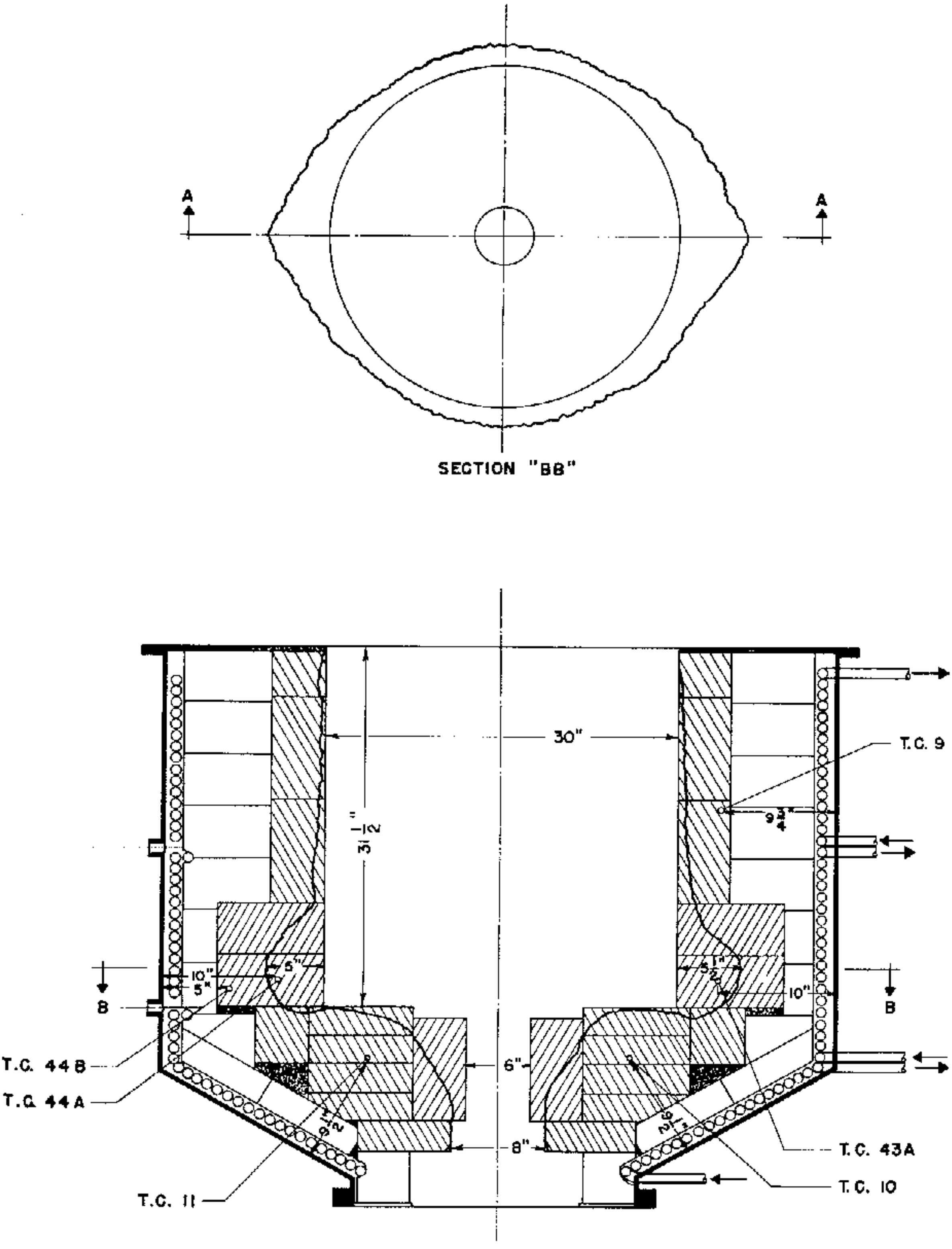


Figure 15. - Atmospheric pressure gasifier 4; primary reaction zone after run G4-34.

be short. During development of suitable operating procedures and reactant-injection-burner design it was expected that the lining would be subjected to unusually severe temperature conditions. Also the optimum positioning of the burners and correct diameter-length relationships for the reactant chamber were not known.

Consequently, the original lining was made with a good-grade, comparatively low cost, standard firebrick, B & W No. 80 brand. Experience soon demonstrated that the refractory in the secondary reaction zone is not subjected to any severe condition; the original lining is still in use. It was found that the refractory in the throat between the two zones would have, at least during the development stage, only a very short life, because very high temperatures were developed near the burner ends, when certain reactant ratios and burner designs were used. To protect the refractory in the throat and to prevent loss of any of the refractory in the upper zone a water-cooled coil was placed as shown in figure 3. Since this coil was installed no further maintenance on the upper throat brickwork has been necessary. The bottom side of this coil is studded and covered with refractory cement, which is patched as needed.

Before run 24 there were several occasions when hot spots developed on the shell of the primary zone. These were in the area opposite the reactant burners, where the vertical wall of the primary zone meets the sloping bottoms. Such erosion of the brickwork could cause a hazardous condition by weakening the shell so that gas could escape. To prevent this, the primary-zone shell was protected by a water coil (fig. 4). The heat loss from such a coil was calculated to be about 75,000 B.t.u. per hr., or about 1.5 percent of the heat in the coal at a 500-lb.-per-hr. rate. For 11 tests the average loss has been measured at 72,630 B.t.u. per hr. at an average coal-feed rate of 450 lb. per hr., or 1.3 percent of the heat in the coal.

To determine the rate at which erosion was occurring at the two points opposite the burner ends, thermocouples were installed, as shown in figure 15. Thermocouples 10 and 11 were 9-1/2 inches from the shell and couples 43A and 44A, 10 inches. In the extended test run 34, erosion was rapid during the first few days of the run, as evidenced by a rapid rise in temperature on couples 43A and 44A. These couples were burned out, and thermocouple 44A was replaced by thermocouple 44B, as shown in figure 15. The opening for thermocouple 43A was plugged with cement. There was a slow rise in temperature for a few days on thermocouple 44B, and the rise on 10 and 11 also continued. Then about 4 to 5 days before the end of the test these temperatures stabilized, indicating that refractory equilibrium conditions had been obtained. The fact that the brickwork condition has stabilized, as shown in figure 15, was further confirmed by analyses of the slag tapped at various times during the test. In the early stages of the run slag flowed sluggishly and the temperatures in the throat, as indicated by couples 10 and 11, and the amount of gas pulled through the slag tap were higher than had been thought necessary. Samples of this slag showed a definite refractory content. When the temperatures on thermocouples 10, 11, and 44B had stabilized, the slag was flowing more freely at lower slag-tap temperatures. Samples of this slag showed it to be virtually all coal ash. After this run the two eroded areas (fig. 15) were patched up. This Allmul refractory lining has been in use, as of April 1953, for 320 hours of heatup time and 530 hours of coal-gasification time. This covers a period of 19 tests with the usual cooling down of the gasifier between tests. With the exception of replacement of the slag-tap brick no other repairs have been needed for this lining.

Because of the constant flow of slag through the slag tap there is slow erosion of the refractory, with consequent increase in slag-tap diameter. On the present gasifier, the slag-tap brick is replaced when necessary to keep the diameter at 6 to 8 inches. These replacements are not frequent.