Slag was hoed out from the ash-leg water seals every day. The total weight amounted to 892 pounds or 3-1/2 percent of the ash in the coal charged.

The remainder of the ash, associated with the unreacted carbon, was conveyed with the gas through the mains, waste-heat boiler, cyclone, and washer-cooler, where most of it was scrubbed out. Only a few grains of dust per 100 cubic feet were left in the gas beyond this point. Some of the dust settled in the mains or was trapped in the boiler and cyclone before the gas went to the washer-cooler. This accumulation was satisfactorily removed with water sprays and steam jets located at advantageous points.

As previously described, the fouled scrubbing waters flowed to settling basins for clarification. Each of these basins has a working volume of about 5,000 cubic feet. Some 12,500 cubic feet of sludge was collected in these during the run. Thus, the basins had to be cleaned out during the run. The weight of the solid matter (ash plus carbon) was about 125,000 pounds. Apparently in continuous operation disposal of this low-density refuse will involve a handling problem.

The gasifier lining was inspected twice daily during the run. Little serious erosion was noted during the course of the run. There was some increased vertical furrowing on the east wall of the north cone, some miscellaneous furrowing in the south cone, and some slag buildup on the steam ring. The main body of the gasifier appeared unchanged. For the conditions of operation employed, which were more moderate than for the majority of the previous runs, it appears that the lining would have performed satisfactorily in routine operation.

Miscellaneous Auxiliary Studies

Gasifier Heat Losses

The gasifier heat losses were studied to aid in the thermal analysis of the operations. An example of this analysis was given in a preceding section, Data and Calculations for a Typical Run, and demonstrates the need for the heat-loss information established by this study.

Heat losses from the gasifier, other than in sensible heat in the exit products, occurred at the internal water-cooled elements in the gasifier and through its walls and shell. The water-cooled elements accounted for about 90 percent of the total of these losses.

Six heat-loss tests were made during gasification runs and one while the gasifier was on "standby" heating with natural gas and air.

Heat Losses to Water-Cooled Elements. - The main water-cooled ducts in the gasifier are the explosion riser, hot-gas outlet, and the three ash legs. There are also twenty-five 2-inch-diameter peepholes. However, the jackets for these do not extend through the full thickness of the lining, as the others do, and the losses here have been found to be very small.

In addition to these elements, there are the two water-cooled burner nozzles. Different lengths have been used in the gasification runs, but in these tests, with one exception, the nozzles with 4-inch projections into the gasifier were used.

The cooling water for the gasifier was softened water. The individual flows are indicated in figure 19. Each of the numbered lines, except as indicated, runs

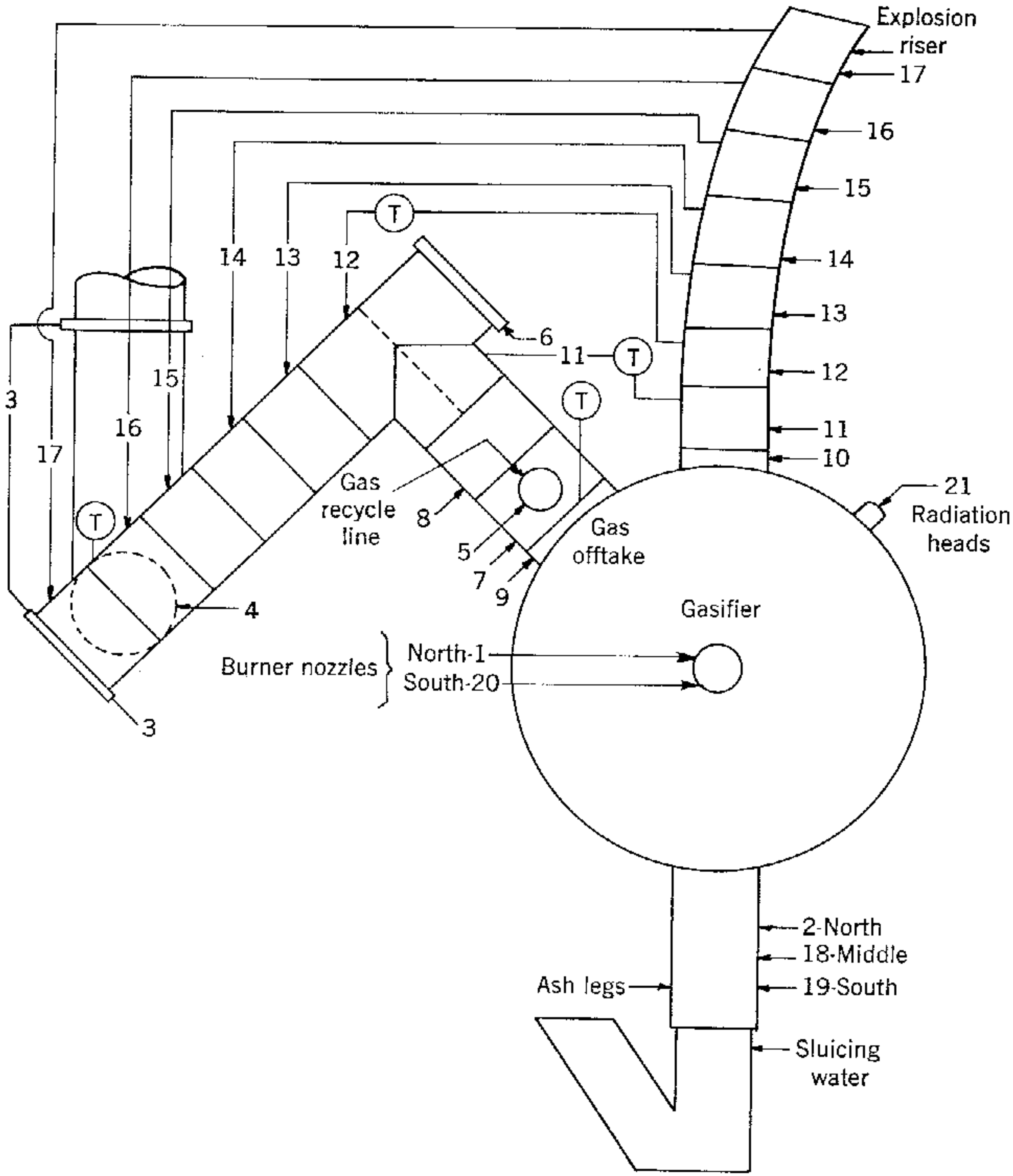

Figure 19. - Schematic diagram of flow to water-cooled gasifier elements.

individually to a collecting tank, where all the exit streams join. The gas-main cooling jackets are compartmented and served by the separate flows as indicated. Rates for the different lines were obtained by timing and weighing the cooling-water exit flow.

The temperature of the water in and the temperatures out of the various cooling points were obtained. With this and the flow information, the heat pick-up was calculated directly. At the explosion riser no heat pickup was found in the sections above 12 (13 to 17). Heat picked up in the hot-gas outlet in the sections serviced by lines 7 and 9 was used as a measure of the radiation loss to this duct. This was not entirely rigorous but served as a compromise selection. Actual radiation loss from the gasifier would extend at least to section 8, but this quantity will be accounted for to some extent by heat picked up in sections 7 and 9 from the hot-gas flow, which is not a heat loss from the gasifier. Theoretical heat loss by radiation from the gasifier to this duct (see table 7) actually indicated a loss somewhat lower than that obtained from cooling waters from sections 7 and 9. Other heat losses to water-cooled elements will be apparent by inspecting the sketch. In addition to their water jackets, the ash legs dip down into a trough through which sluicing water is run; the heat pickup by this water was found to be negligible. Thus, lines 1, 2, 7, 9, 10, 11, 12, 18, 19, 20, and 21 were used to calculate the total measured internal heat losses from the gasifier. The losses to cooling waters during the seven tests are presented in table 6.

Heat Losses From Shell. - These were estimated from skin temperatures and by heat conduction through the gasifier brickwork. Both methods gave a loss of about 100,000 B.t.u. per hour. This varied little with the operating rate or the range of internal temperatures obtained in the gasification work.

Losses from skin temperatures were calculated, using a method proposed by Trinks.9/ The heat loss is obtained from equation $Q = UA\Delta T$, where Q = total heat loss, B.t.u. per hour, A is the area of the shell, and ΔT is the difference between the shell and atmospheric temperatures. A plot is presented for values of the heat-transfer coefficient, U, versus the difference between skin temperatures and that of the surrounding air. Still air is assumed.

Skin temperatures were obtained from thermocouples welded on the shell. They ranged from 140° to 170° F. with the gasifier operating. A heat loss was computed for each area surrounding the thermocouple. The total shell area was 480 square feet. A total of these shell heat losses was around 100,000 B.t.u. per hour for run 38B. A second test was run in which the gasifier was heated by natural gas and "idled." The loss was then 92,000 B.t.u. per hour. In this test the internal temperature was about 500° F. lower than in a normal coal-gasification operation.

The heat loss by conduction through the brickwork was calculated, using equation

$$Q = \frac{A\Delta T}{\left(\frac{L}{k}\right)_1 + \left(\frac{L}{k}\right)_2 \text{ etc.}},$$

where Q is the total heat transferred, A is the mean area between the interior and exterior of the gasifier, and ΔT is the difference between interior and shell temperatures. L and k are the thickness of the particular refractory and its heat-transfer coefficient, respectively. As the gasifier was not lined uniformly, the calculation was made for several locations.

9/ Trinks, W., Industrial Furnaces: John Wiley & Sons, Inc., New York, 3d ed., vol. 1, 1934, p. 81.

TABLE 6. - Summary of gasifier heat loss data

Date	Conditions	Coal feed rates, lb. per hr.	Gasifier heat losses - B.t.u./hr.							Highest cone temperature, °F.	Measured exit gas temperature, °F.	Thermal balance temperature, °F.
			Explosion outlet	Ash legs	Hot gas outlet	Burners	Radiation heads	Skin	Total (to nearest 5,000)			
Nov. 4, 1949	Run 35--flush burners (6) 1/	2,295	71,000	88,500	526,000	193,000	12,000	100,000	990,000	2,650	2,315	2,435
Jan. 25, 1950	Run 40B--4-inch burners (5)	1,970	62,500	64,500	549,000	230,000	5,800	100,000	1,010,000	2,470	2,275	2,320
Feb. 3, 1950	Run 41A--4-inch burners (6) Superheated steam blast on burner	2,380	50,000	67,500	581,000	290,000	1,300	100,000	1,090,000	2,490	(2/)	2,260
Apr. 10, 1950	Run 43--4-inch burners (5)	2,150	50,500	27,500	461,000	211,000	20,500	100,000	870,000	2,575	(2/)	2,320
Apr. 11, 1950	Run 43--4-inch burners (6)	2,750	45,500	24,500	469,000	216,000	12,400	100,000	870,000	2,620	(2/)	2,370
Apr. 13, 1950	do.	2,670	65,000	32,000	518,000	249,000	18,900	100,000	985,000	2,560	(2/)	2,380
Nov. 18, 1949	Gasifier idling, heated with natural gas and steam--4-inch burners	None	36,500	76,000	283,000	231,000	--	92,000	720,000	1,700	1,555	--

1/ Number of coal feed pipes in use during the run.

2/ Instrument out of order in these runs.

The sum of the shell loss and losses to the internally cooled elements is called the heat loss from the gasifier. These data plus gasifier temperatures and coal-feed rates for the test periods are presented in table 6.

The thermal balance temperatures are presented also. Note that they are lower than the cone temperatures but higher than the exit gas temperatures. Calculations on heat loss by radiation to the cold wall of the gas main (water cooled) indicate that the exit gas thermocouple temperature could be 100° to 200° F. low.

After the gasifier heat losses had been calculated, the thermal balance temperature was determined as the temperature needed to give the gasifier products the degree of sensible heat, which, with the heat loss and heating value of the gaseous products, would balance the total heat put into the system. It is considered to be the one most truly representing the equilibrium operating temperature in the gasifier.

In the range considered in this study the gasifier heat losses show no clear trend as a function of the operating (thermal balance) temperature. The spread in the heat losses probably represents the limit of accuracy of the work. In view of these considerations, a total heat loss of 1 million B.t.u. per hour from the gasifier has been used in all gasification thermal calculations, other than those for which the losses were specifically measured.

Heat Radiation Losses to Water-Cooled Elements. - The heat lost to internal, water-cooled elements in the gasifier by direct radiation was checked by the basic formula,

$$\text{Radiant heat, B.t.u./hr.} = 0.173\ (A)\ (E) \left[\left(\frac{T}{100}\right)^4 - \left(\frac{T_1}{100}\right)^4\right],$$

where, A = heat receptive area, square feet,
E = emissivity of area A,
T and T_1 = temperatures, °R., of hot body and area, A, respectively.

The receptive area of each water-cooled duct was taken to be that of its cross section - this representing the maximum area for radiant-heat transfer from the furnace to ducts leading from it. The total exposed surface of the burners in the gasifier was used for their area. The emissivities of the surfaces were unknown factors and were assumed to be 1.0. T was the gasifier operating temperature. The thermal balance temperatures (table 6) were used. T_1 was the temperature of the cold wall. This was taken to be 10° F. higher than the cooling water in the jackets.

Run 40B was selected to compare measured versus theoretical heat losses to the water-cooled elements. The data are presented for the heat-loss points and their effective areas. The operating temperature was 2,320° F. Table 7 presents these data.

TABLE 7. - Heat loss to water-cooled elements

Heat-loss point	Effective area, sq. ft.	Theoretical heat loss, B.t.u./hr.	Measured heat loss, B.t.u./hr.
Explosion outlet	1.397	144,000	62,500
Hot-gas outlet	4.275	440,000	549,000
Burners	1.572	161,000	230,000
Ash legs	6.546	673,000	64,500
Total	13.790	1,418,000	906,000

The figures for the hot-gas outlet and the burners are of the same order of magnitude. Actual heat loss was probably higher than the calculated value, owing to convection transfer from gas flow.

Examination of the surface of the explosion outlet after shutdown showed it to be heavily crusted with rust. This probably reduced the emissivity factor considerably, which would help explain the lower measured loss.

It was noted during and after operations that the ash legs were thickly coated with slag. Heat loss to them was probably controlled by the heat-transfer rate through a slag crust, which would be considerably less than by radiation to a cool steel surface.

Inspection of Gasifier Lining

The gasifier interior was inspected through peepholes after each short run and twice daily during extended run 43. When it was shut down and cooled off, the interior was entered and carefully examined.

A temperature of 1,700° F. or higher was maintained continuously in the gasifier from the time of its first heatup, April 1949, until after the last run, April 1950. At this time the gasifier was cooled down over a 3-week period.

The total operating time for the 46 runs was 420 hours. During these periods temperatures of 2,200° to 2,900° F. were measured in the gasifier. The highest temperatures obtained were in the cones. These normally ran 2,400° to 2,600° F., but sometimes reached 2,900° F. As might be expected, the cone linings showed the most severe attack. The main cylinder of the gasifier, except for some furrowing below the water-cooled gas exit duct, was virtually unaffected.

Up to run 36 only slight roughness in the cone linings and wear in the brick joints had been noted. After run 36 some vertical furrows were observed on the east wall of the north cone. After run 38 similar furrows were noticed on the east wall of the south cone. In run 36 the temperature in the attacked zone rose above 2,800° F., but it was lower in run 38.

After extended run 43 the erosion in the north cone appeared to be somewhat deeper. There was considerable rounding of the edges of the brick, and there were some random furrows along the top of this cone.

The previous erosion in the east side of the south cone appeared to be unchanged, but some washing had developed on the west face.

The next few runs after 43 were very short, and the lining appeared to have undergone no change during them. Thus, its condition at the time of shutdown was substantially the same as after extended run 43.

A description of the interior inspection and pictures taken after cooling the gasifier follow.

North Cone. - The north cone (fig. 20) shows considerable furrowing on the east side. There are 6 distinct grooves running almost the full semicircle, which are about 2 inches deep and wide. The rest of the cone and its face appear to be in good condition.