proved beneficial, not only for removing slag lumps but also for inspection of the gasifier interior and heat trap during short shutdowns, using a periscope designed for this purpose.

4. A spray ring was installed below the slag tap for a twofold purpose. First, it cooled the slag gases before entering the piping from the slag pot. Second, it was felt that, by passing the slag through a fine spray of water, the slag would be shattered and broken into small pieces.

5. The water-jacketed vent line leaving the slag pot was replaced with a non-jacketed stainless-steel line so that the vent line would be operated at a higher temperature and would not plug off from water condensation. Condensation had taken place in this line during previous runs, eventually plugging the line with moist fly ash or carbonaceous material, which prevented pulling any vent gas through the slag tap.

During the next two runs it appeared impossible to set reactant rates or ratios so as to eliminate the presence of char in with the slag. Although it was believed that the new reactant burners were less satisfactory than the previous ones, it was though that the 20-percent reduction in primary zone volume might have adversely affected gasifier capacity. Consequently, after run 25 the primary zone diameter was increased to its original 30 inches by removing part of the refractory lining. At the same time, the spray ring was removed from the slag pot, as it had been responsible for too much cooling at the slag tap.

Although the conical section of refractory cement (fig. 3) aided materially in removing slag from the slag pot, it eroded away after a few runs. A new conical section fabricated from steel plate proved much more successful, but after a time the slag tended to bridge over at the top of this piece. It was then replaced with a semiconical steel section, and the slag pot was equipped with better washout facilites.

No more changes were made to the gasifier until after run 32. By this time the bottom coil of the heat trap had developed a leak, and the top of the gasifier was removed so that the bottom coil could be replaced by a coil of different design. At the same time the top section of the gasifier was modified as shown in figure 5, to give quick access to the heat-trap coils.

No other major changes were made to the gasifier through run 34.

## Reactant injection burner designs

Operation of atmospheric gasifier 2[12] indicated that continued exposure of refractory linings to around 3,000° F. in the presence of slag was detrimental to the linings. Also, when coal and oxygen were introduced through one burner and steam through another, localized hot spots developed with resultant refractory damage. During long test runs horizontal injection tubes were sometimes blocked by slag flowing down refractory walls.

With atmospheric gasifier 4, the injection burner for all reactants was designed to control flame lengths and temperatures so that slag could be kept fluid without subjecting the refractory to temperatures as high as 3,000° F. The first reactant burner tested - design 1 (fig. 6) - consisted of four concentric tubes. The 2 outer tubes, 3-1/2 inch o.d. and 3-inch o.d. stainless-steel tubing, formed the burner water jacket. The tube inside of which steam flowed was 2-1/4-inch stainless steel, and the coal tube was 1/2-inch stainless steel covered by a 1-inch stainless-

---

[12] See work cited in footnote 4, p. 2.

steel shield. Both the steam and coal tubes were adjustable to permit different premixing of reactants. (Column 3 of table 1 and table 7 (see pp. 17 and 31 gives information on burners used for the 34 test runs.)

The original settings for the reactant burner were determined by trying out the burner in a "mockup" combustion chamber. This was done by moving the steam and coal tubes forward and backward in the burner while the character of the flame was studied through observation ports. Test run 1 was made using what appeared to be the most favorable settings. Examinations during and following this run indicated that temperatures at the slag tap were never up to those required for proper slag flow. The residue obtained in the slag pot consisted of a considerable volume of coal char but no slag.

Run 2 was made with the same reactant burner, the only change being in the method of mixing of reactants. Only half of the steam was sent through the reactant burner, and the balance was sent into the primary zone through a tangential port. Examination after this run showed that the slag tap did not reach slag-removal temperatures, but the refractory around the tangential steam inlet was badly eroded.

To secure better temperature conditions run 3 was made, using two design 1 burners set opposite each other and positioned so that the flames would strike the floor of the primary reaction zone. The tangential steam inlet in the primary zone was plugged up with refractory cement. Examination showed the refractory to be badly eroded, with the eroded section about 2 feet lower in the primary zone than in run 2. Considerable char and very little slag were found in the slag pot. Figure 7 shows the sausage-shaped char formations obtained during this run. These shapes indicated definitely that mixing was very poor and that neither the steam nor oxygen stream was breaking the coal stream as it left the burner tip.

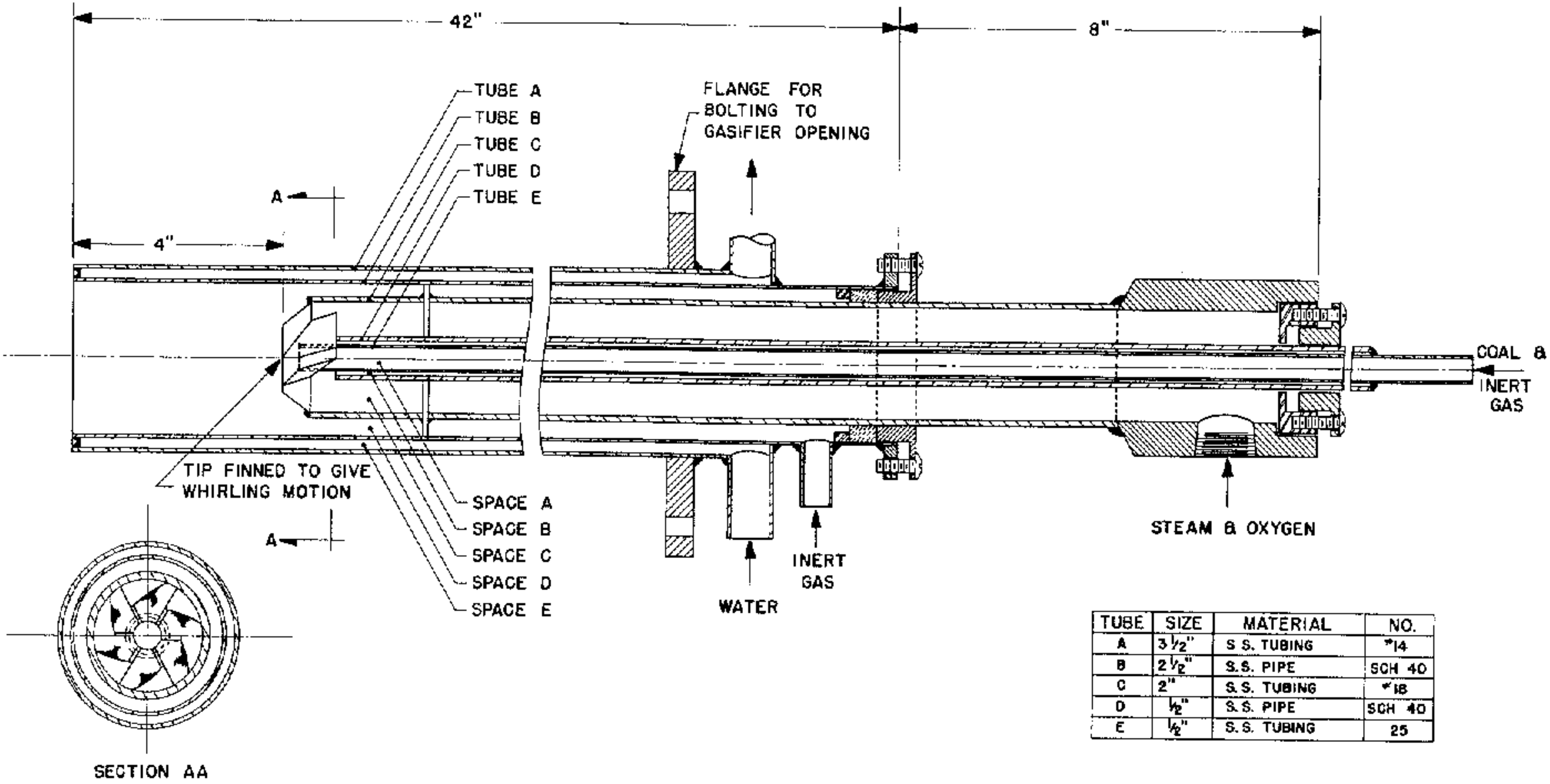
The first three runs showed that reactants would have to be mixed better for satisfactory gasification. Therefore, it was decided to attach vanes to the ends of the steam tubes to give a swirling motion to the steam and assure better mixing of steam and coal. These new design 2 burners, used for the next six test runs, indicated that the swirling action was definitely a step in the right direction; gasification was improved, temperature control was better, and refractory erosion was reduced.

Tests 4 through 9 also indicated the need for considerable development before the burners could be regarded as satisfactory. Refractory erosion was now centered near the ends of the burners, and flashbacks continued to occur at the coal-feedline sight glasses, where conveying oxygen was added to the system. After run 6 both burners were lengthened to project slightly past the interior vertical refractory lining and thus minimize erosion around the burners. It was also thought that the lower temperatures at the burner tips would help eliminate flashbacks in the coal feedlines.

The above change in burner location effected some improvement in conditions. With oxygen introduced around the outer annular space, temperatures remained higher than desired around the ends of the burners and refractory erosion was not eliminated. Also, even with low oxygen-coal ratios and low carbon gasification, the upper throat gradually increased in temperature and eventually became too hot. Considerable char was still produced, and mixing could not be regarded as satisfactory.

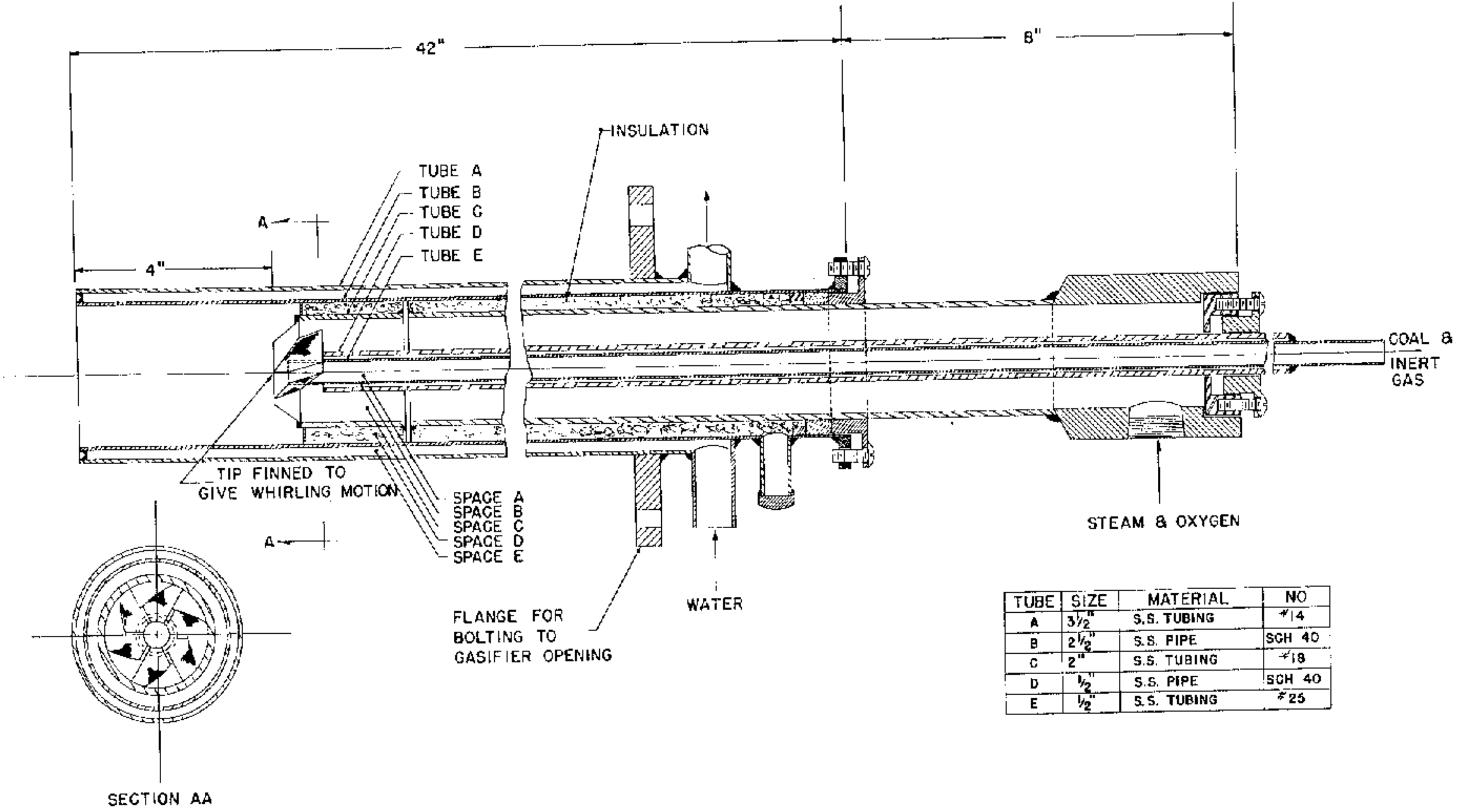
Commencing with run 10, the steam and oxygen were preheated together to about 600° F., and the coal was preheated to about 300° F. Figure 8 shows the design 3 burner used for run 10. Coal was admitted through the central tube as before, and

Figure 7. - Atmospheric gasifier 4, char formation obtained using nozzle design l.



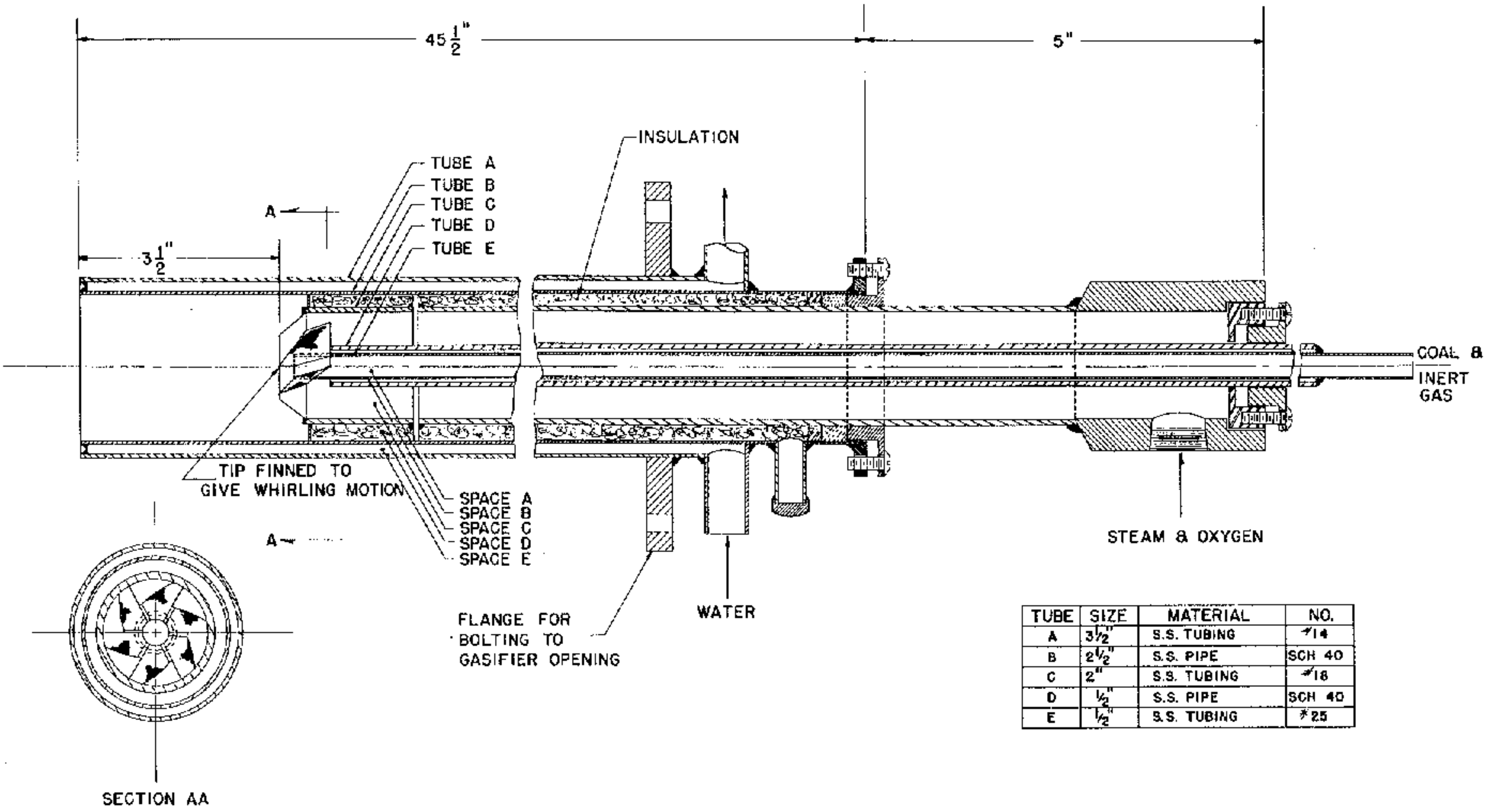
| TUBE | SIZE | MATERIAL | NO. |
|---|---|---|---|
| A | 3 ½" | S S. TUBING | #14 |
| B | 2 ½" | S.S. PIPE | SCH 40 |
| C | 2" | S.S. TUBING | #18 |
| D | ½" | S.S. PIPE | SCH 40 |
| E | ½" | S.S. TUBING | 25 |

Figure 8. - Reactant injection burner for gasifier 4, design 3, run 10.



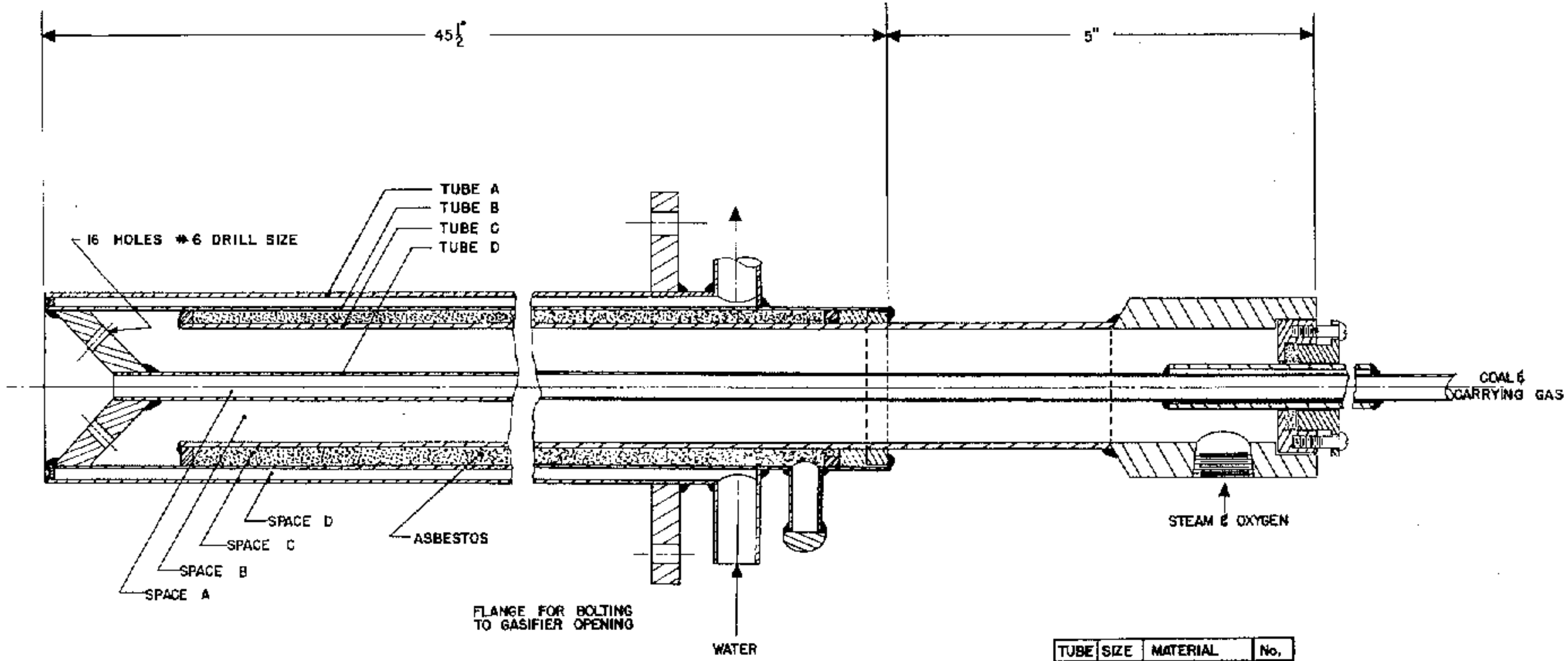
| TUBE | SIZE | MATERIAL | NO |
|---|---|---|---|
| A | 3½" | S.S. TUBING | #14 |
| B | 2½" | S.S. PIPE | SCH 40 |
| C | 2" | S.S. TUBING | #18 |
| D | ½" | S.S. PIPE | SCH 40 |
| E | ½" | S.S. TUBING | #25 |

Figure 9. - Reactant injection burner for gasifier 4, design 4, runs 11 and 12.



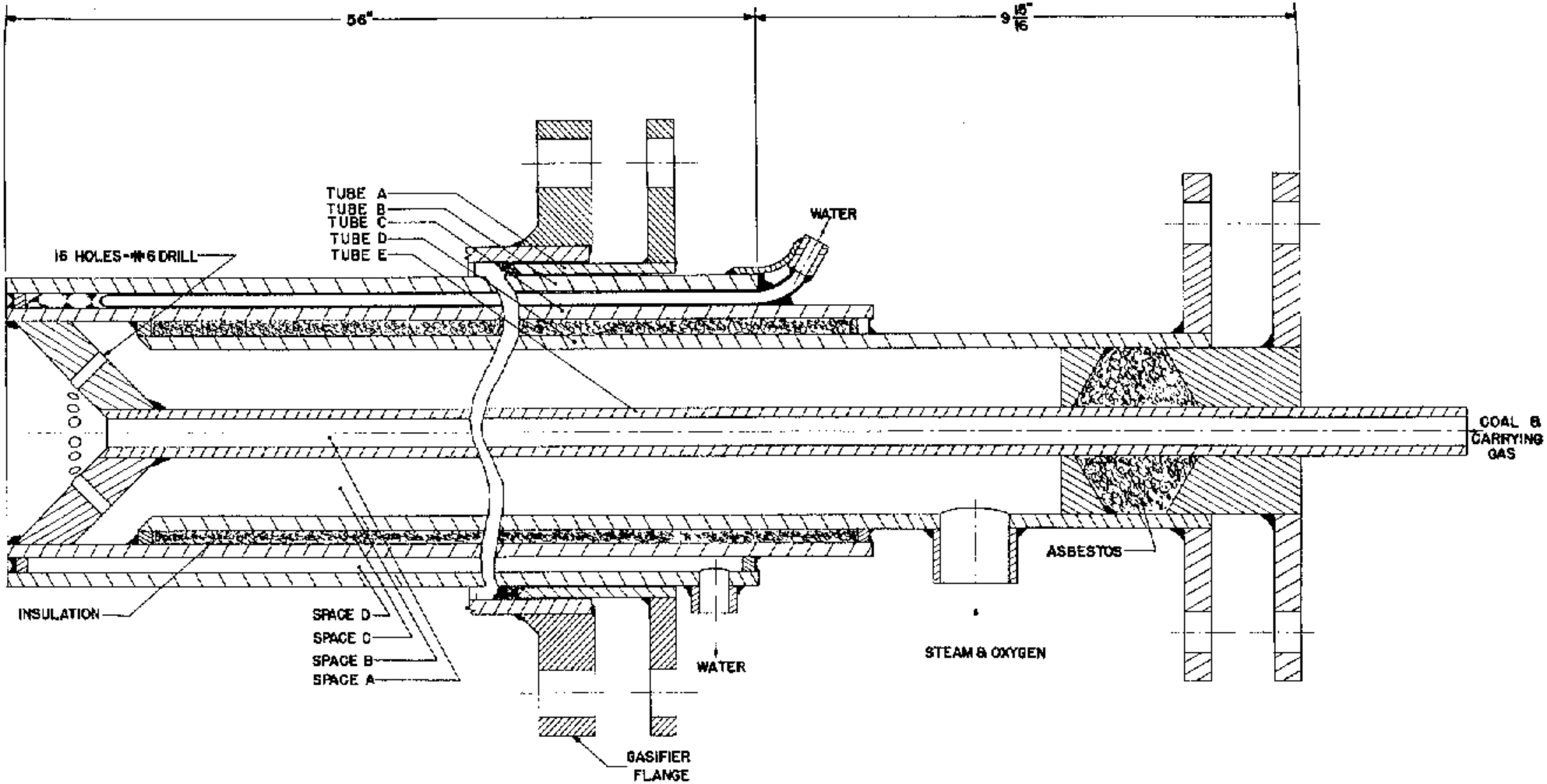
| TUBE | SIZE | MATERIAL | NO. |
|---|---|---|---|
| A | 3½" | S.S. TUBING | #14 |
| B | 2½" | S.S. PIPE | SCH 40 |
| C | 2" | S.S. TUBING | #18 |
| D | ½" | S.S. PIPE | SCH 40 |
| E | ½" | S.S. TUBING | #25 |

Figure 10. - Reactant injection burner for gasifier 4, design 5, runs 13 through 20.



| TUBE | SIZE | MATERIAL | No. |
|---|---|---|---|
| A | 3½" | S.S. TUBING | 14 |
| B | 2½" | S.S. PIPE | SCH 40 |
| C | 2" | S.S. TUBING | 18 |
| D | ½" | S.S. TUBING | 25 |

Figure 11. - Reactant injection burner for gasifier 4, design 6, runs 21, 22, 23, 28, 29.



| TUBE | SIZE | MATERIAL | NO |
|---|---|---|---|
| A | $5\frac{5}{8}$" x 6" | BRASS | — |
| B | 5" | S.S. PIPE | Sch.40 |
| C | 4" | S.S. PIPE | Sch.40 |
| D | $3\frac{1}{2}$" | S.S. TBG. | 14 |
| E | $\frac{1}{2}$" | S.S. PIPE | Sch.40 |

Figure 12. - Reactant injection burner for gasifier 4, design 7, runs 24 through 27.

the steam-oxygen mixture was admitted through the annular space surrounding the coal tube. This design brought the reaction hot zone closer to the slag tap and away from the refractory wall. It reduced erosion around the burner tips, permitted slag tapping with less vent gas, and allowed higher carbon utilization without overheating of the upper throat. Material requirements remained high, however, and a small quantity of product gas leaked through the packing gland in the annular space formerly used for oxygen, causing minor explosions as the gas seeped out into the atmosphere.

Design 4 burner (fig. 9) used for runs 11 and 12, differed from the design 3 only by having the annular space surrounding the steam-oxygen tube filled with shredded asbestos to prevent leaking of product gas back through this space. Overall results indicated that steam-coal ratios under 0.8 lb. per lb. could not be used without excessive refractory temperatures near the burner tips.

After run 12 the water-cooled support coil (mentioned earlier) was installed in the upper throat refractory to permit operating over a wide range of reactant ratios without damaging the upper throat, and the burners were lengthened to protrude through the support coil. These design 5 burners (fig. 10) were used for runs 13 through 20. Run 13 and the next few runs demonstrated the value of the support coil for protecting the upper throat and secondary-zone refractory and indicated the lower materials requirements possible with lower steam-coal ratios. Some refractory erosion near the burner tips occurred during those tests with the lower steam-coal ratios.

Design 6 burners (fig. 11 ) were employed for tests 21 through 23, for a total of over 100 hours of operating time. Overall results were very encouraging. No refractory damange was observed from test 21, but some incipient erosion on the sloping surfaces opposite the burners occurred during test 22, and considerable erosion occurred here during test 23. Excellent material requirements were obtained at steam-coal ratios of 0.4 and 0.5 lb. per lb.

After run 23, the cooling coil (fig. 4) was installed in the primary zone to permit operation over a wide range of reactant ratios without excessive erosion in the primary zone. New design 7 burners (fig. 12) were installed at the same time. Larger coal tubes were used to decrease the coal-stream velocity from about 50 to 30 ft. per sec., and the burners were equipped with packing glands to permit varying the distance of projection into the gasifier. However, the distance of the steam-oxygen ports from the coal stream was increased. Design 7 burners, used in runs 24 through 27, proved less satisfactory than the design 6 burners. During the first two tests large quantities of char formed along with the slag, and no reactant rates or ratios tried were successful in eliminating this char formation. Results still were not satisfactory for run 26, even though the primary zone had been increased to its original diameter and the velocity of the coal stream was increased to about 50 ft. per sec. (by adding inert gas at the coal feedline sight glasses). For test 27 the burners were pulled back so that their projection was the same as for tests 21 through 24, but no appreciable improvement was noted.

Following run 27, the design 6 burners were reinstalled and were used for the next two tests. No appreciable improvement was noted for run 28, and it was found after the run that burner A had projected farther into the gasifier than intended. During run 29 the burners were alined as for run 24, using minimum projection into the reaction zone. Test periods were run using normal flow of water to the reactant burner jackets and using no flow to the primary-reaction-zone wall coils; some improvement in requirements was noted for the second condition. Refractory examination aften the run showed considerable erosion in the primary zone across from burner A.