with the superheated steam at the inlet to the reactant-injection burner. Operations proceeded satisfactorily under this arrangement. The steam superheater operated normally, but after run P-59 the temperature of the processed steam was not permitted to exceed 900° F.

Figure 16 shows the valve for controlling the outlet of the heater. This valve is designed for high-temperature, high-pressure, steam-oxygen service. The valve body is stainless steel, but brass rings were installed on the rubbing surfaces so that the stem would not contact like metal. Thus, incidence of galling was reduced. The rings act merely as stem spacers and do not affect the mechanical strength of the valve.

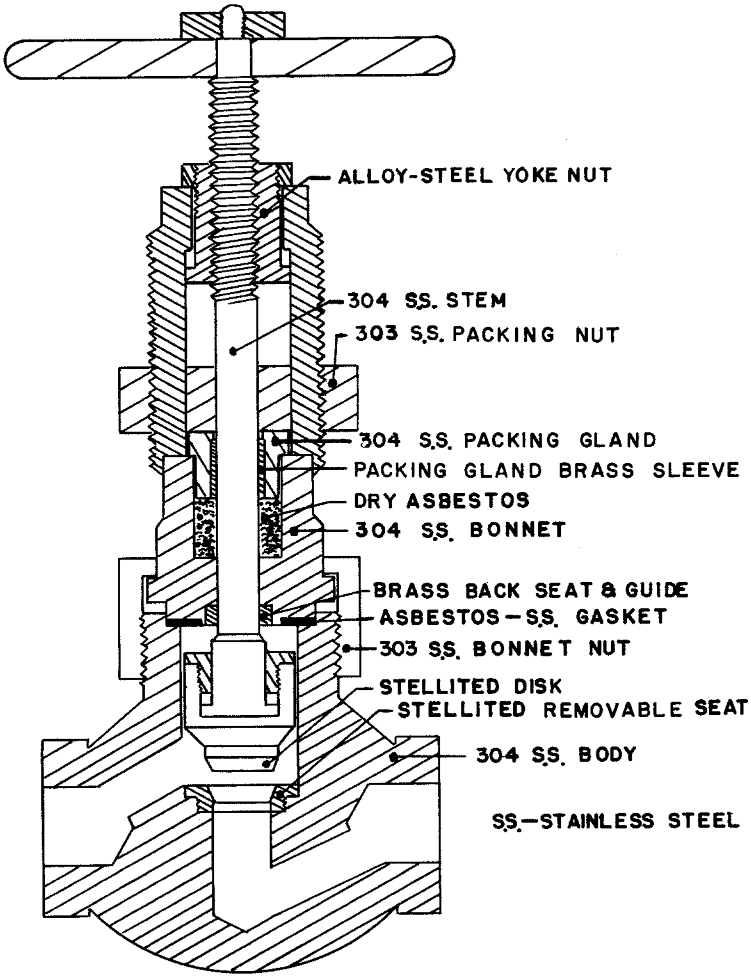


FIGURE 16. - 1,500 p.s.i.-1,000° F. Valve for Steam or Steam-Oxygen Service.

## Reactant-Injection Burner

The reactant-injection burner, which was similar to that used in the final runs previously reported,11/ consists of three concentric pipes. The center pipe delivers a jet of fluidized, powdered coal. Surrounding the center pipe is another pipe containing the high-velocity, oxygen-superheated steam mixture. The burner fires downward along the vertical axis of the gasifier. The mixture of oxygen and steam escapes through radially drilled ports at the burner tip and discharges into the coal stream in a pattern of converging, high-velocity jets. The third concentric pipe, which is provided with a water-cooled jacket, serves as insulation.

During runs P-23 to P-32, design 4 burner (fig. 17) was used as a natural gas-oxygen burner for preheating the gasifier and as a reactant-injection burner. Design 5 burner (fig. 18) was used as a reactant-injection burner for runs P-33, 34, and 35. Burner designs 4 and 5 were based on development work involving gasification of pulverized coal with oxygen and superheated steam in

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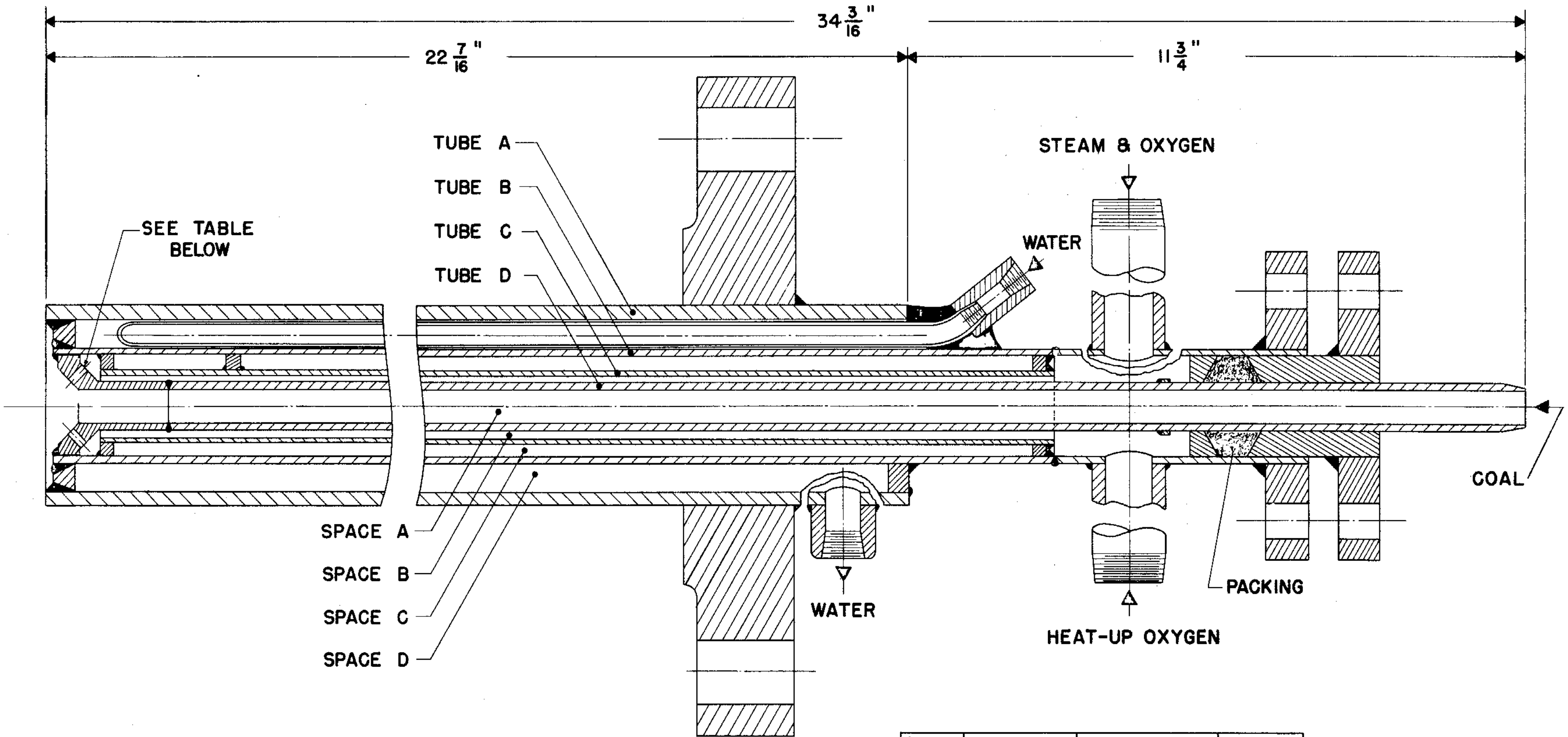
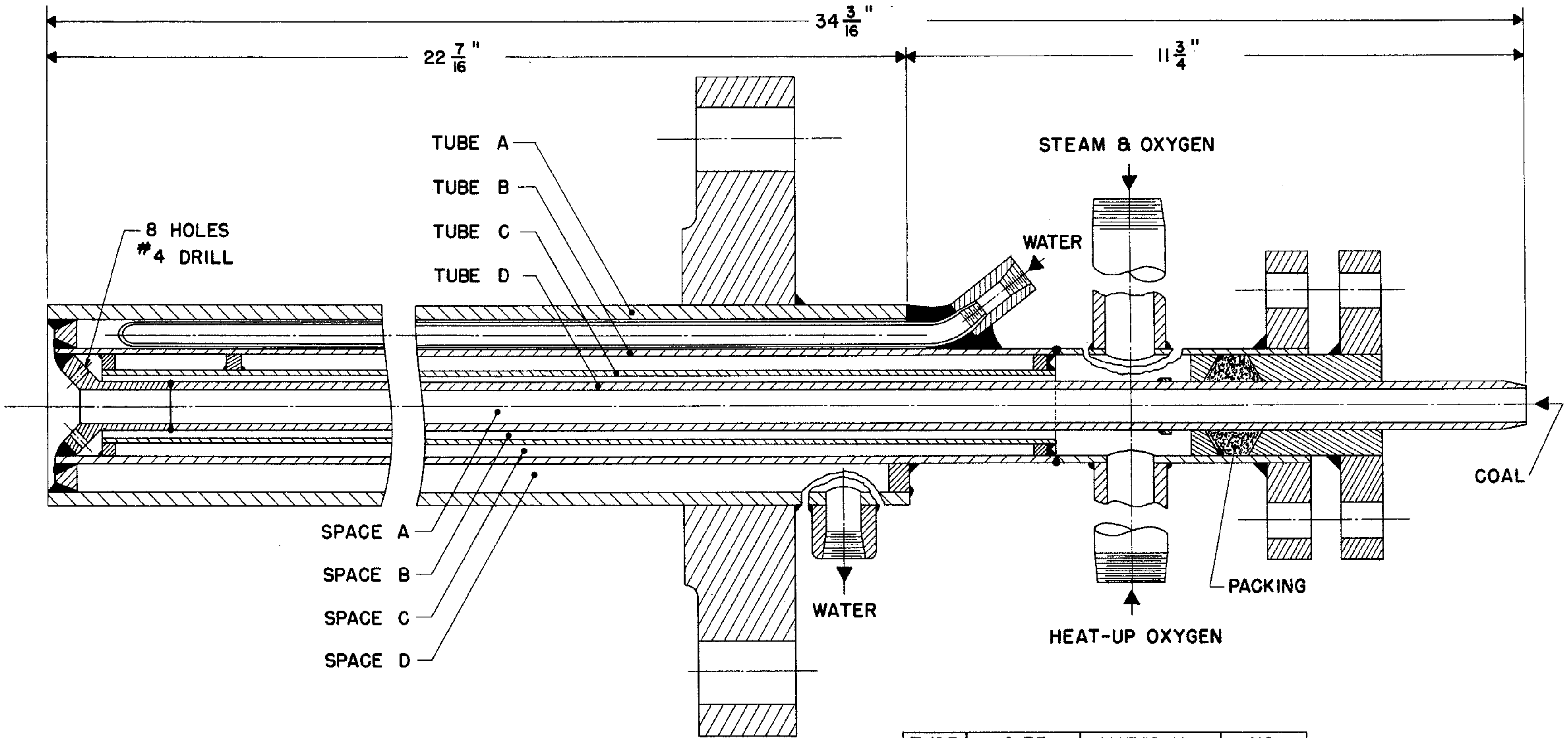
11/ Work cited in footnote 10.




| RUN NO. | NO. PORTS | PORT DRILL-SIZE |
|---|---|---|
| P-21 THROUGH P-22 | 16 | # 41 |
| P-23 | 16 | # 36 |
| P-24 THROUGH P-32 | 16 | # 33 |

| TUBE | SIZE | MATERIAL | NO. |
|---|---|---|---|
| A | 3" | S.S. PIPE | Sch. 40 |
| B | 2" O.D. x 1.75 I.D. | " " | —— |
| C | 1.25" O.D. x 1.15 I.D. | " " | —— |
| D | .50 | " " | Sch. 40 |

FIGURE 17. - Reactant-Injection Burner, Design 4 (Gasifier 3).




| TUBE | SIZE | MATERIAL | NO. |
|---|---|---|---|
| A | 3" | S.S. PIPE | Sch. 40 |
| B | 2" O.D. x 1.75 I.D. | " " | —— |
| C | 1.25" O.D. x 1.15 I.D. | " " | —— |
| D | .50 | " " | Sch. 40 |

FIGURE 18. - Reactant-Injection Burner, Design 5 (Gasifier 3).

an atmospheric-pressure gasifier. This development work was reported previously.[12 13] The two reactant-injection burners differ chiefly in construction of the nose and size of the radially drilled ports. These changes in design were made in an attempt to prevent cracks from developing at the nose. In gasification runs with the redesigned gasifier (the gasifier with the water-cooled liner), designs 6 and 7 burners were used. (See figs. 19 and 20.)

Reactant-injection burners 4, 5, and 6 were not entirely satisfactory. The difference between the thermal expansion of the center (coal) tube and that of the wall of the water jacket caused the nose junctions of tubes B and D (fig. 19) to break and leaks developed. In design 7 burner, a stuffing box was provided for the center tube so that it could expand away from the nose, thus preventing further breaks. This burner design proved satisfactory. Other improvements in burners for high-pressure use included the reduction of localized thermal stresses and provision for easier construction. These improvements resulted from adoption of better welding procedures, use of a fully welded burner-cone construction, and annealing the burner after fabrication.

After a gasification run, microscopic examination of the exposed face of the burner usually revealed surface cracks between the oxygen-superheated steam ports and at other points. (Fig. 21 shows a burner face with its oxygen-superheated steam ports.) These cracks were 1/64 to 1/8 inch deep and were random and discontinous. Incidence of cracks was reduced after the practice of annealing the burner was instituted.

Because of an excess of carbon in the gasifier atmosphere, consideration was given to the possibility that the cracks resulted from carbon penetration. However, excluding the effects of the pressure to which the burner is exposed (20 atmospheres), the influence of the gasifier atmosphere on the austenitic stainless steel of the burner tends to decarburize rather than to carburize. This decarburization is due to the presence of hydrogen and such powerful oxidants as $CO_2$ and excess superheated steam, as well as to the oxygen that is admitted to the gasifier in the same region. The photomicrographs (fig. 22) seem to substantiate this conclusion. These photomicrographs are of etched sections of metal taken from the hot faces of two burners that had been in gasification service for 65 and 160 hours, respectively. Each section shows the effects of thermal conditions, specifically the precipitation of chromium carbide at the grain boundaries--carbide formed from the carbon in the original steel. (The slip and cleavage planes produced by severe stressing are also evident.) Failure due to chromium migration was eliminated by proper annealing after the burner was fabricated. The familiar spherical bubbles of boiling chromium carbide also can be seen; chromium carbide precipitation is characteristic of austenitic stainless steels subjected to prolonged heating

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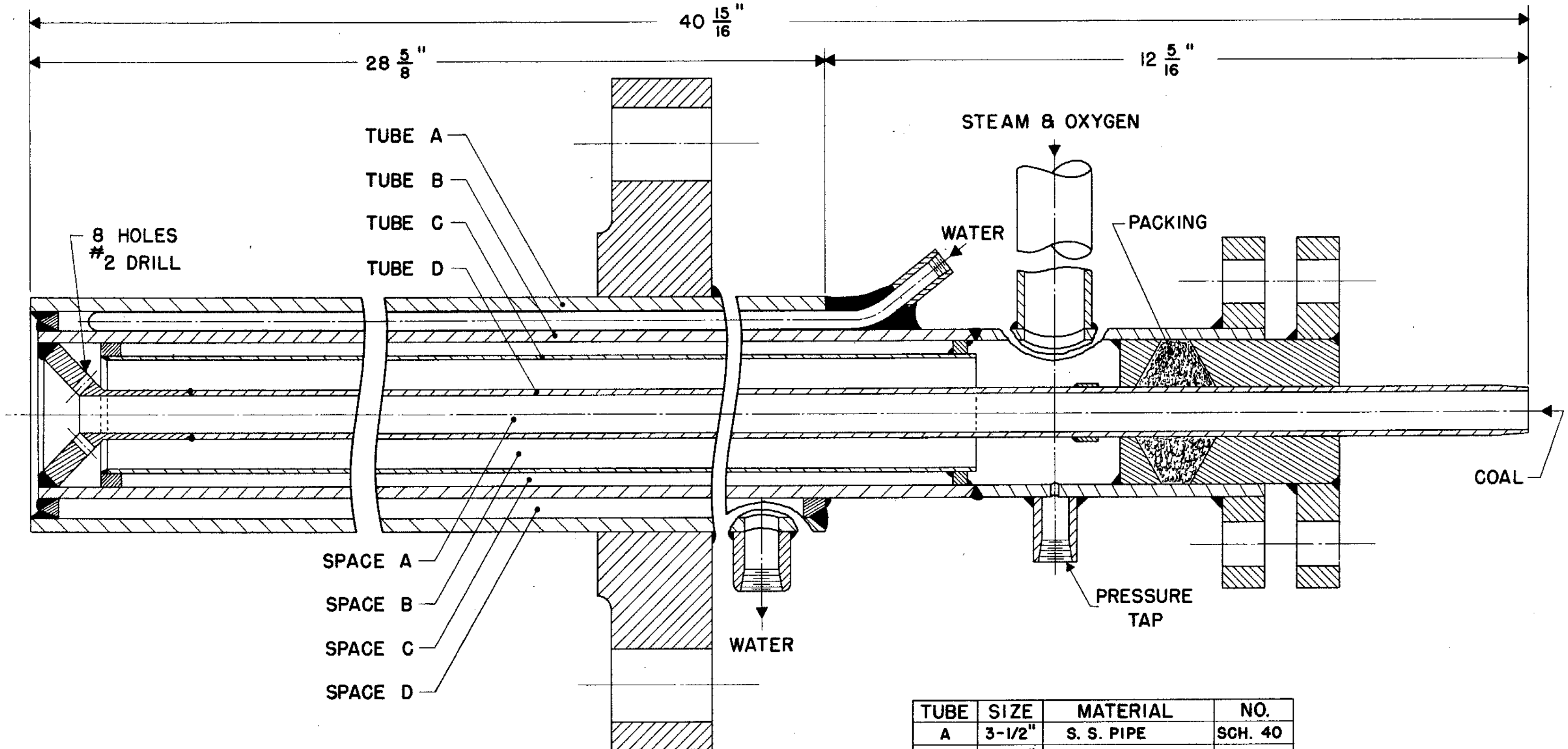
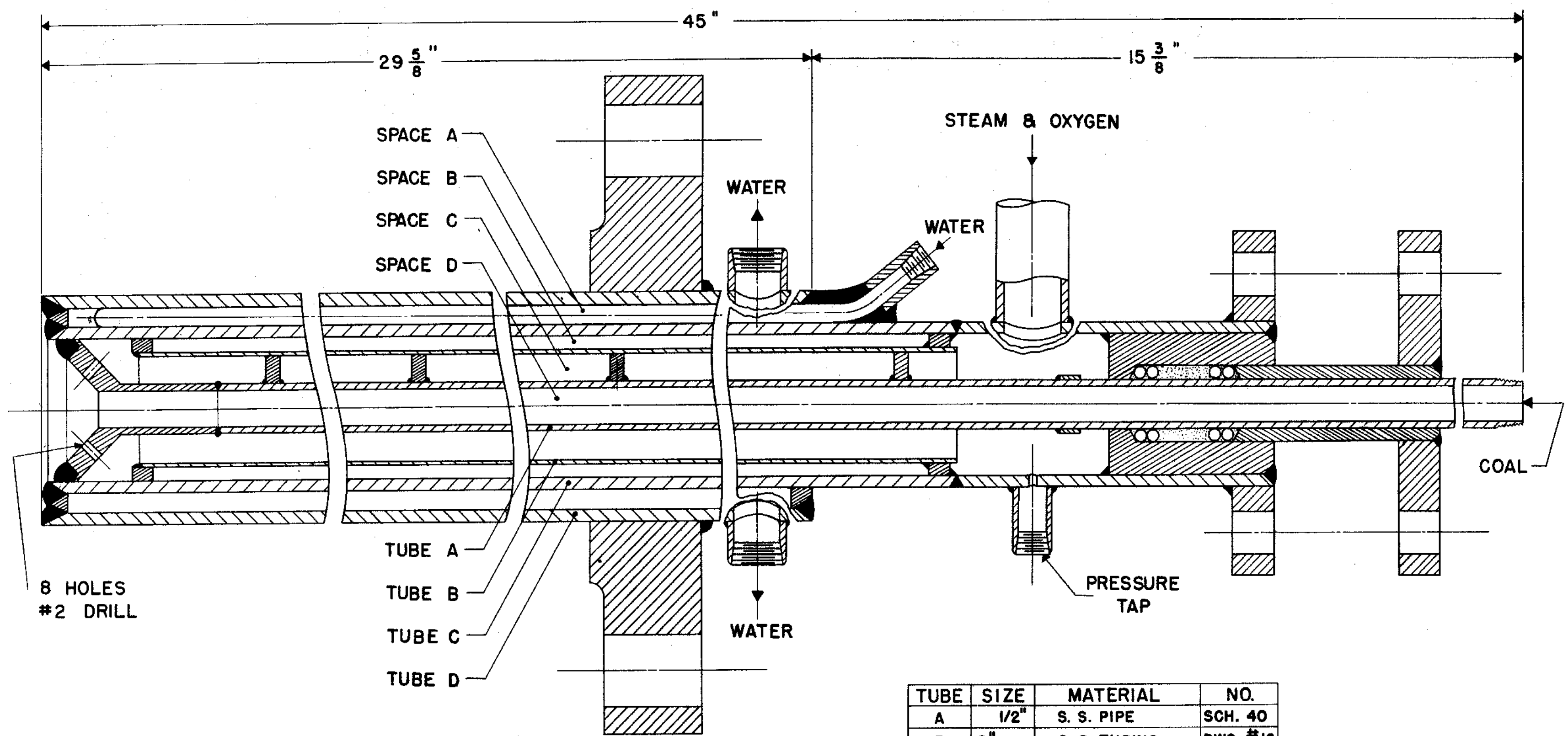
12/ Work cited in footnote 10.

13/ Strimbeck, G. R., Cordiner, J. B., Jr., Baker, N. L., Holden, J. H., Plants, K. D., and Schmidt, L. D., Gasification of Pulverized Coal With Steam and Oxygen at Atmospheric Pressure: Bureau of Mines Rept. of Investigations 5030, 1954, 37 pp.




| TUBE | SIZE | MATERIAL | NO. |
|---|---|---|---|
| A | 3-1/2" | S. S. PIPE | SCH. 40 |
| B | 2-1/2" | S. S. PIPE | SCH. 40 |
| C | 2" | S. S. TUBING | BWG. #16 |
| D | 1/2" | S. S. PIPE | SCH. 40 |

FIGURE 19. - Reactant-Injection Burner, Design 6 (Gasifier 3).




| TUBE | SIZE | MATERIAL | NO. |
|---|---|---|---|
| A | 1/2" | S. S. PIPE | SCH. 40 |
| B | 2" | S. S. TUBING | BWG. #16 |
| C | 2-1/2" | S. S. PIPE | SCH. 40 |
| D | 3-1/2" | S. S. PIPE | SCH. 40 |

FIGURE 20. - Reactant-Injection Burner, Design 7 (Gasifier 3).

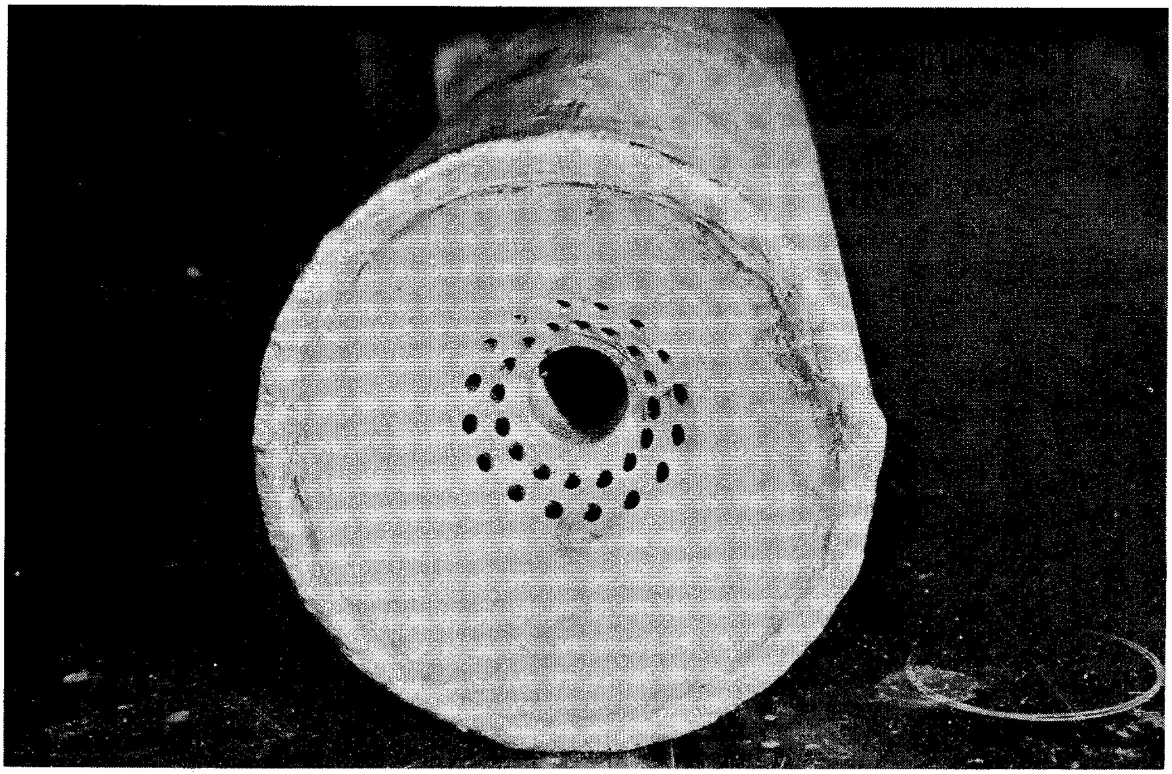


FIGURE 21. - End View of Reactant-Injection Burner.

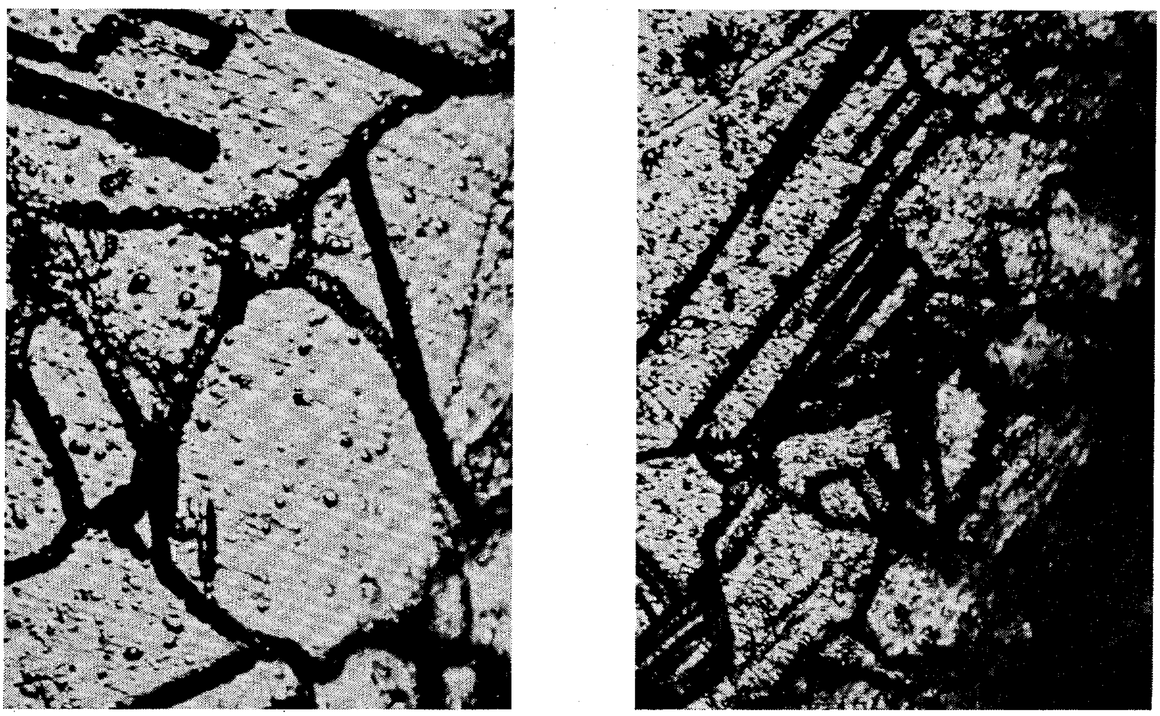


FIGURE 22. - Photomicrographs—Cone Edge of Reactant-Injection Burner.

at gasifier temperatures. As has been pointed out elsewhere,[14] the areas adjacent to the boundaries become partly depleted of the chromium that has migrated to the boundaries as chromium carbide. This leaves the chromium-impoverished areas open to stress corrosion attack.

It has also been reported[15] that these steels often show carbide precipitation when they are received from the steel mill, and sometimes only part of the carbon can be dissolved upon subsequent heat treatment. Thus, a true picture of what is taking place in the burner metal probably can be obtained by annealing the two burners from which the etched sections have been taken and comparing the photomicrographs with the photomicrographs shown in figure 22 and with photomicrographs of the original metal from which the burners were made.

Changes made to the reactant-injection burner during the gasification runs were principally to improve the burner structurally and to eliminate the incidence of gas leaks at the flange. Structural improvements were made principally at the nose of the burner, where water leaks had occurred at the welds and hair cracks had developed in the metal between the radial oxygen-steam ports. When a leak from the burner water jacket was suspected, the burner was removed from the gasifier and pressure-tested. Under these conditions the leaks were very small; however, under the thermal conditions of gasification they must have been considerable, as was indicated by the high $CO_2$ content of the make gas, lower gasification temperature, reduction in the amount of slag, and occasional formation of coke and char in the gasifier.

No attempt has been made to evaluate the effect on gasification results of variations in actual and relative velocities of the intersecting steam-oxygen and coal streams leaving the burner. It is questionable whether the effect is as great as that of some other process variables. In any case, any attempt to assess the effect must await more knowledge of the specific type of flame pattern the burner produces.

In the burner designs used in these runs, an attempt was made to increase mixing through turbulence. Research work with turbulent flames has indicated that flame-generated turbulence (that is, turbulence generated by the expansion of the gases and gasification of the solids passing through the flame front) is much more important than turbulence in the approach flow to the flame.[16] This result would seem to limit the advantage to be gained from approach turbulence.

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14/ Buck, D. C., and others, Corrosion Resistance and Mechanical Properties of Low Carbon Austenitic Stainless Steels; Symposium on Evaluation Tests for Stainless Steels: ASTM, Special Tech. Pub. 93, May 1950.

15/ Brown, Hiram, Carbides in 310 Stainless Steel: Steel, vol. 135, No. 3, July 1954, pp. 106-108.

16/ Lewis, B., Report of Research and Technologic Work on Explosives, Explosions and Flames, Fiscal Years 1951 and 1952: Bureau of Mines Rept. of Investigations 5006, 1953, 66 pp.

Figure 23 shows the calculated velocity of the steam-oxygen mixture as it discharges from the ports of the burner under test conditions. The center

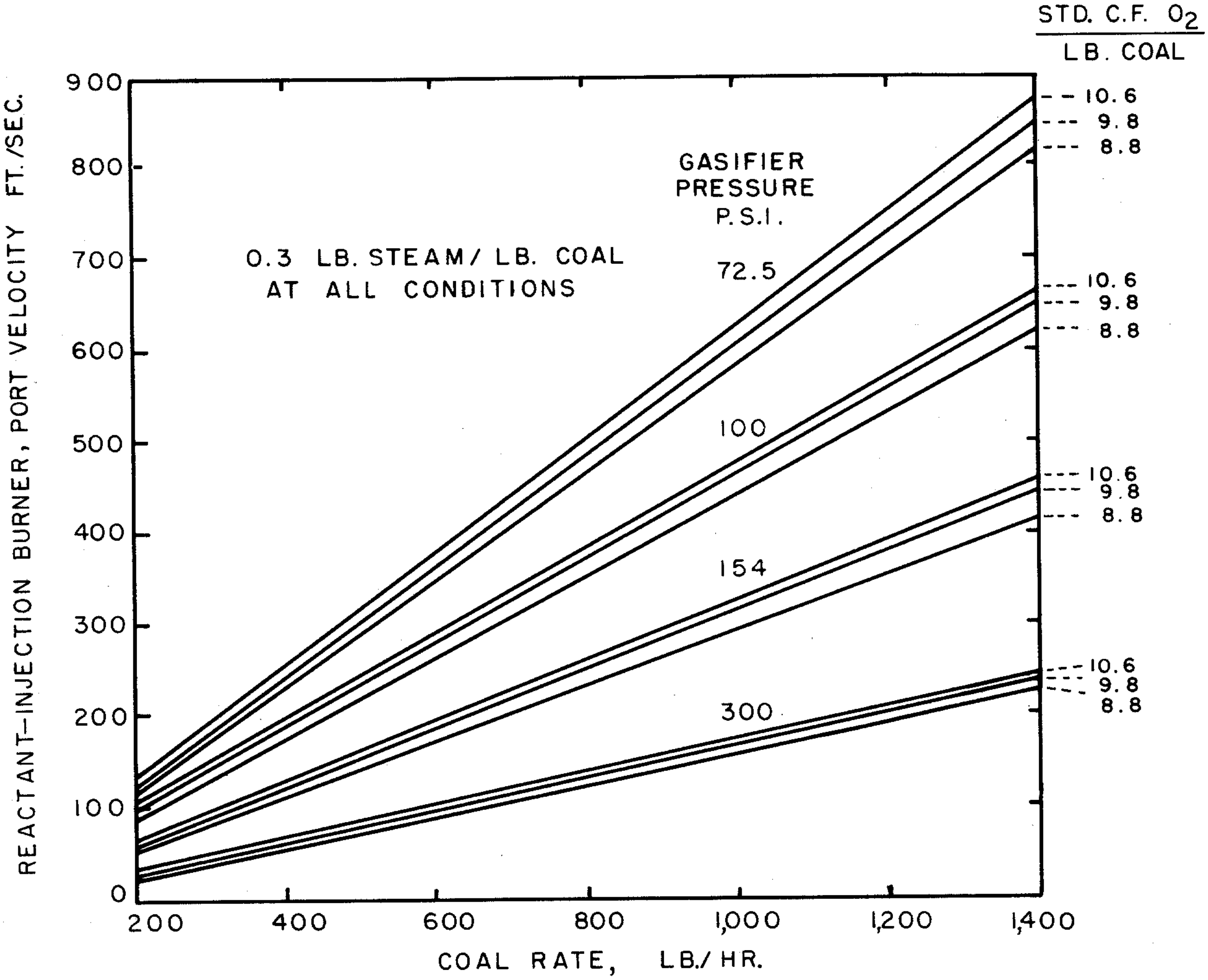
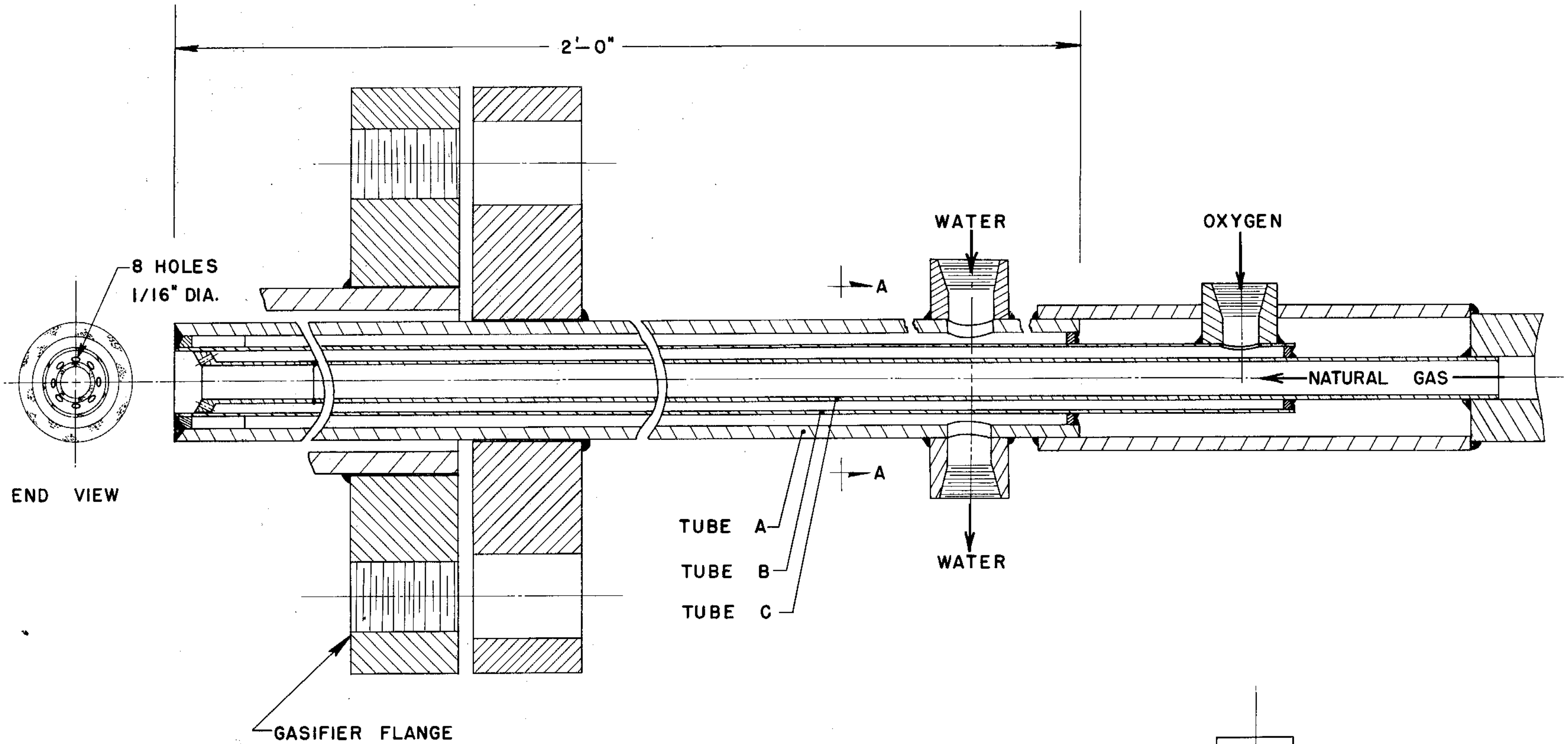



FIGURE 23. - Velocities of Steam-Oxygen Mixtures Entering Gasifier.

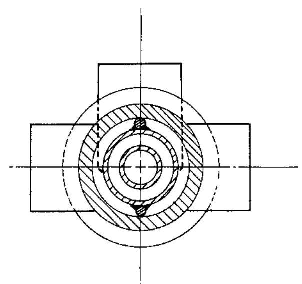
axis of each port intersects the axis of the central coal port at an angle of 45° (see fig. 20). There is evidence, particularly at lower gasifier operating pressures, that the steam-oxygen jets do not actually converge so transversely but are deflected outward so that they intersect the coal stream at a more acute angle and further from the nose of the burner, possibly owing to the thermal and volume expansion occurring at the flame front. The relative port velocities of the steam-oxygen jet and the coal jet range from 20:1 to 28:1, the ratio increasing with decreasing gasifier operating pressure.

## Pilot Burner

After run P-32, a water-cooled, oxygen-natural gas pilot burner (fig. 24) was used in the refractory-lined gasifier, thereby eliminating the necessity




| TUBE | I. D. | O. D. | MATERIAL |
|---|---|---|---|
| C | 0.311" | 0.375" | 3/8" TUBING—304 S.S. |
| B | .561" | .625" | 5/8" TUBING—304 S.S. |
| A | .824" | 1.050" | 3/4" SCH. 40-304 S.S. |



SECTION "AA"

FIGURE 24. - Pilot Burner for High-Pressure Gasifier.

of preheating the refractory wall to start combustion. (The location of the pilot burner in relation to the reactant-injection burner is shown in fig. 3, p. 7.) The burner consists of a central tube for natural gas surrounded by an annular space for oxygen, which, in turn, is surrounded by a cooling-water jacket. The oxygen annulus terminates in a series of eight, equally spaced, radially converging ports.

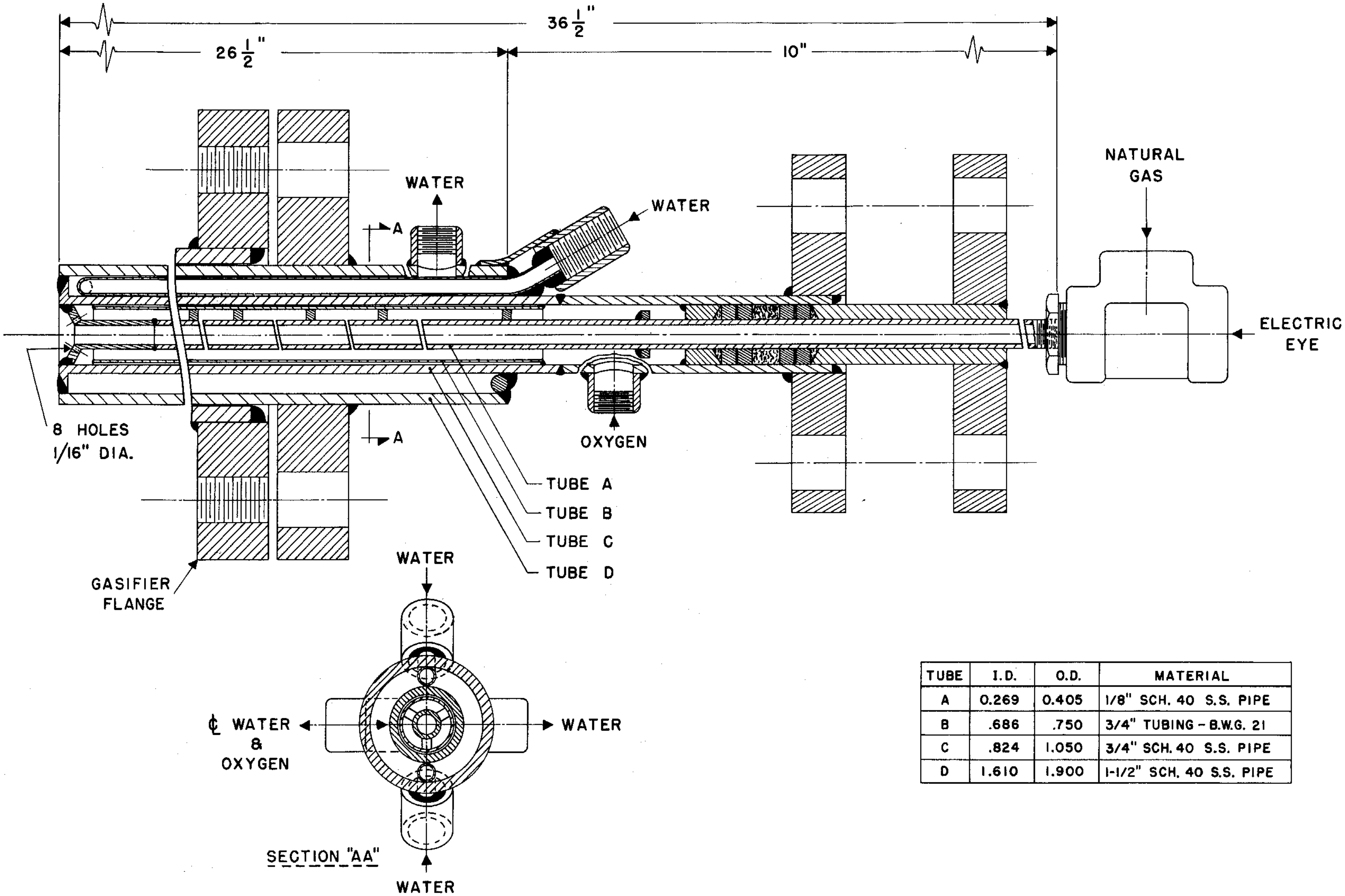
The pilot burner was redesigned for use with the redesigned gasifier; thereafter, the pilot burner (design 4) became the sole means of "triggering" the coal-gasification reactions. The design 4 burner (fig. 25) was practically the same as the design 3 burner, although in some later runs its design was changed to provide for expansion of the central (natural gas) tube in the direction away from the nose of the burner.

A decided advantage was gained by using the pilot burner in conjunction with the gasifier with water-cooled lining. Because of the rapid removal of heat from the reaction zone by the cooling water, it would have been impossible to preheat the reaction zone, as in previous operations, enough to start the coal-gasification reaction.

During the experiments, small leaks developed in the nose of the pilot burner, which is shown in figure 26. The lower picture shows the nose (about 1-inch o.d.) cut in half along its longitudinal axis. The central tube has buckled about midway between the end of the burner and the welded joint, and the thermal stresses causing buckling are assumed to have caused minute fractures in the metal at the end of the water jacket. As already indicated, a pilot burner was designed and put in use (see fig. 25) which provided for expansion of the central tube in the direction away from the nozzle of the burner.

Investigation of the pilot-burner failure showed that phosphorous in the silver solder tended to deposit in the grain boundaries of the parent metal, causing impairment of tensile strength, so copper brazing was used in place of silver soldering for stainless steel. However, copper proved unsatisfactory, and stainless-steel welding material is now used in fabricating these burners. The pilot burner that failed had been in operation over 300 hours, including many startups and shutdowns, which are incompatible with longevity.

The burner ports tended to become coated with slag during gasification. In an attempt to prevent the necessity of removing the burner for cleaning, a slow-diffusion-type burner was installed. It comprised adjacent parallel pipes--one for natural gas and one for oxygen. This burner proved difficult to ignite and to keep ignited; its malfunctioning finally resulted in an explosion, which blew water from the quench zone of the gasifier through the rupture disk, and use of the burner was discontinued. It was then found that by periodically introducing a small purge stream of inert gas into the original pilot burner its ports could be kept free from slag. This modification required no change in design of the pilot burner.




| TUBE | I.D. | O.D. | MATERIAL |
|---|---|---|---|
| A | 0.269 | 0.405 | 1/8" SCH. 40 S.S. PIPE |
| B | .686 | .750 | 3/4" TUBING - B.W.G. 21 |
| C | .824 | 1.050 | 3/4" SCH. 40 S.S. PIPE |
| D | 1.610 | 1.900 | 1-1/2" SCH. 40 S.S. PIPE |

FIGURE 25. - Pilot Burner, Design 4, Gasifier 3.