SUMMARY AND CONCLUSIONS

This is a report on experimental work on development of a gasification process operating at near atmospheric pressures and using finely pulverized coal entrained in oxygen and steam.

The gasifier was designed by The Babcock and Wilcox Co. in cooperation with engineers of the Bureau of Mines Morgantown station. The test work discussed in this report covers the first 34 tests made in the pilot plant in which a strongly coking Sewickley-bed coal, ground to either 70 or 90 percent through a 200-mesh screen, was used.

A range of reactant ratios has been tested and procedures developed so that economical reactant requirements, per thousand standard cubic feet of ($CO + H_2$), as compared with other processes, have been obtained along with an indicated satisfactory refractory lining life. The entire pilot plant has operated very well, and continuous operation has been possible, tests being terminated voluntarily in the majority of cases.

Since the major emphasis of the program during these tests was on the development of an operable process, the results given in the tabulated data cover a range of operating variables. Several designs of burners for injecting the reactants have been tried, and the gasifier itself was modified several times during testing. These modifications to the gasifier consisted mainly in shell construction, which introduced variable heat losses between series of tests.

Within the limits of satisfactory refractory life it has been possible to obtain a considerable range, 0.72 to 1.15, of H_2-CO ratios. Although it is not possible to state optimum operating conditions exactly for various reactant ratios, typical results obtained under conditions of satisfactory refractory life are given below.

Typical material requirements per M std.c.f. of ($CO + H_2$) produced, using Sewickley-bed coal ground to 70 percent through 200-mesh screen

Oxygen to coal ratio, std.c.f./lb.	Steam to coal ratio, lb./lb.	Material requirements per M std.c.f. of ($CO + H_2$)			Carbon in coal gasified, percent
		Oxygen, std.c.f.	Coal, lb.	Steam, lb.	
8.75	0.60	350	40	24	82.0
8.75	.40	333	38	15	84.5

Experimental work is continuing, and a wide variety of coals is being tested. From the work reported here and that done later, it is possible to estimate that in a full-scale plant using a similar coal, results would be somewhat improved because of decreased heat losses.

INTRODUCTION

This report gives further information on the work being done by the Bureau of Mines to develop processes for low-cost production of synthesis gas directly from raw coal. The Synthesis Gas Branch is carrying on this program under a cooperative agreement with West Virginia University.

The particular pilot-plant work reported here was done in cooperation with the Babcock & Wilcox Co. The gasifier was designed by this company and Bureau of Mines engineers and was fabricated in Babcock & Wilcox Co. shops, incorporating all that was learned in earlier work done by the Bureau.[4] This design[5] now allows the economic production of synthesis gas using oxygen and steam superheated to 1,000° F. Superheaters for this temperature range are standard items of boiler-plant equipment and can be adapted for use as heat-recovery units in gasification.

The flexibility of this gasification process, as regards types of coals and ash content, which was indicated by the previous work,[6] has been verified in the test program with this pilot plant. Because of time limitations in preparing a report of this kind, the test work described here was all done with Sewickley-bed coal; however, later tests have been made with satisfactory results using a sub-bituminous C coal from Lake de Smet, Wyo., and bituminous coals from the States of Washington and Kentucky.

ACKNOWLEDGMENTS

This investigation was conducted at the Synthesis Gas Branch, Bureau of Mines, Morgantown, W. Va., on the campus of West Virginia University, under the general direction of J. D. Doherty, acting chief of the Synthetic Liquid Fuels Branch, Bureau of Mines, Washington, D. C. The authors wish to acknowledge the fine cooperation and assistance of P. R. Grossman, R. W. Curtis, N. W. Eft, J. A. Danko, and H. P. Markant of the Babcock & Wilcox Co. The last two, as resident engineers on the project, have been very helpful in expediting the test program and in evaluating the results.

DESIGN OF GASIFIER AND ITS EFFECT ON EXPERIMENTAL PROGRAM

Various design features of the gasifier and explanations of the reasons underlying their adoption have been dealt with in other reports.[7] It will only be necessary in this report to indicate their influence on the development of the experimental program.

Earlier work[8] showed that gasification of pulverized coal by entrainment in steam and oxygen was practical. Although, as then reported, tests demonstrated that

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4/ Strimbeck, G. R., Holden, J. H., Rockenbach, L. P., Cordiner, J. B., Jr., and Schmidt, L. D., Pilot-Plant Gasification of Pulverized Coal with Oxygen and Highly Superheated Steam: Bureau of Mines Rept. of Investigations 4733, 1950, 41 pp.

5/ Grossman, P. R., Schmidt, L. D., and Curtis, R. W., Design and Performance Characteristics of a Pilot-Plant Slagging Gasifier Operating at Atmospheric Pressure with Powdered Coal, Oxygen and Steam: pres. 119th ann. meet. Am. Assoc. Advancement Sci., St. Louis, Mo., Dec. 26-30, 1952.

6/ See footnote 4.

7/ See footnote 5.

8/ See footnote 4.

the use of highly superheated steam, 2,500° F. to 3,000° F., would effect a large saving in oxygen, it became apparent that generation of steam at these temperatures involved mechanical difficulties that largely offset the saving in oxygen cost, at least under some conditions. As the program developed, improvements were made in commercial processes for producing oxygen with consequent lower costs, so that analyses of overall costs involved in producing synthesis gas showed that, in general, use of steam at 1,000° to 1,400° F. with unheated oxygen would result in an economical process. Equipment for producing steam in this temperature range could be adapted to the recovery of heat from the gasification process.

The combination of the use of pulverized fuel, slag tapping, and heat recovery by waste-heat boilers immediately suggests the similarity of this gasification process to steam generation in modern boilers using slag-tap furnaces. The design of this gasifier represents the combination of the experiences of the Babcock & Wilcox Co. in the designs of such boiler units with the experience of the Bureau of Mines with the early pulverized-fuel gasifiers.[9/10/]

The work with this gasifier has indicated that the reactant-injection-burner design is one important feature in determining the overall efficiency of the gasifier. Within certain limits and with all other factors being kept constant the performance of a given gasifier can be radically varied by changes in burner design. This parallels the experience in boiler-furnace development work and that in the fields of oil- and gas-burner design. Although much has been learned regarding proper burner design, there is still much work to be done in this field, as noted later in this report.

It can be said now that proper reactant-burner design will provide for:

a. Quick, intimate mixing of the reactants (steam, coal, and oxygen).

b. A degree of control over the point of maximum heat release in the reactant chamber.

c. A reasonable "turndown" ratio, or variance in reactant feed rates over a range.

d. Freedom from flashbacks into the reactant feed lines.

Combined with proper placement or orientation of the reactant burner in the gasifier a good design will:

a. Prevent or keep at a minimum the direct impingment of the coal-oxygen stream on the reaction zone wall, and

b. Keep the area, in which the slag tap opening is located, at a temperature adequate for slag tapping,

The correct location of the reactant burner will prevent any buildup of slag or ash that can distort the flame pattern and disrupt adequate gasification of the fuel. In refractory-lined units such distortion of the flame pattern may result in serious refractory erosion and consequent difficulty in slag tapping. This difficulty in slag tapping results from the fusion characteristics of the slag-refractory combination.

9/ Sebastian, J. J. S., Edeburn, P. W., Bonar, F., Bonifield, L. W., Schmidt, L. D., Laboratory-Scale Work on Synthesis Gas Production: Bureau of Mines Rept. of Investigations 4742, 1951, 41 pp.

10/ See footnote 4.

As the program has developed, it has been demonstrated that with this particular type of gasifier and suitable refractories, refractory erosion can be controlled and an economical refractory life obtained. The refractories originally used in the gasifier, B&W No. 80 brick, backed up by K-30 insulating firebrick, were not expected to have a long life, since they would undoubtedly be subjected to overly severe temperature conditions during the early orientation work. However, they have performed very satisfactorily in the upper or secondary reaction zone. In the lower zone the Allmul lining backed up by water cooling eroded in the early stages of test 34 and then stabilized at a thickness of about 8 to 9 inches. This is described more fully later in the report, and the overall and localized heat losses from the unit are discussed under Results.

In small-scale apparatus for gasification work the effect of heat losses is greatly exaggerated compared to that in large-scale units. One method of compensating, at least in part, for the exaggerated effect of the heat losses in small units is to introduce as much preheat as possible into the entering reactants. This procedure is justifiable, even if a complete evaluation of the economics of such preheat in larger units should show it to be impractical. It appears that a B.t.u. of preheat is exactly equivalent to saving a B.t.u. of heat loss, as far as gasification performances are concerned. Preheating process steam to 1,000° to 1,200° F. is, of course, practical for both large and small units, and such superheated steam is used in this gasifier. The problem of preheating the oxygen is not so simple and its net value in large-scale operation is questionable because of mechanical difficulties involved.

Work done at the Morgantown Station on preheating fluidized coal streams11/ had demonstrated that noncaking coals could be heated to about 900° F., using air as a carrying gas and that caking coals, such as the Sewickley-bed coal, could be heated to about 300° F., without trouble from caking, and possibly as high as 800° F. Consequently, coal preheaters were built to use the available plant steam to heat the coal to about 300° F. Equipment is now being installed to preheat the coal to the higher temperatures.

DESCRIPTION OF PILOT PLANT

Reactant and product flows

The reactants used for all the test runs herein reported were steam, oxygen, and pulverized Sewickley-bed coal. Initially, the steam was superheated to about 1,000° F., and the oxygen and coal were unheated. The reactants were mixed at the injection reactant burner or burners, 1 burner being used for tests 1 and 2 and 2 burners beginning with test 3. The coal was pulverized to a fineness of approximately 90 percent through 200-mesh for tests 1 through 18 and to approximately 70 percent through 200-mesh for the other tests. In test 2, half of the process steam was fed tangentially into the primary zone. This method of feeding steam was eliminated after one trial because of the excessive refractory erosion around the inlet.

Commencing with test 10 and continuing through test 31, steam and oxygen were premixed in a steam-oxygen superheater to about 600° F. to introduce more heat with the reactants; the pulverized coal was heated to about 300° F. in the coal preheaters. The coal was mixed with the steam-oxygen mixture at the tip of the burners. A somewhat different system of heating reactants was used for tests 32 through 34. Steam

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11/ Stenger, W. J., Heating Characteristics of Powdered Coal in Fluidized Transit: Dissertation for doctorate, West Virginia University, 1952, 137 pp.

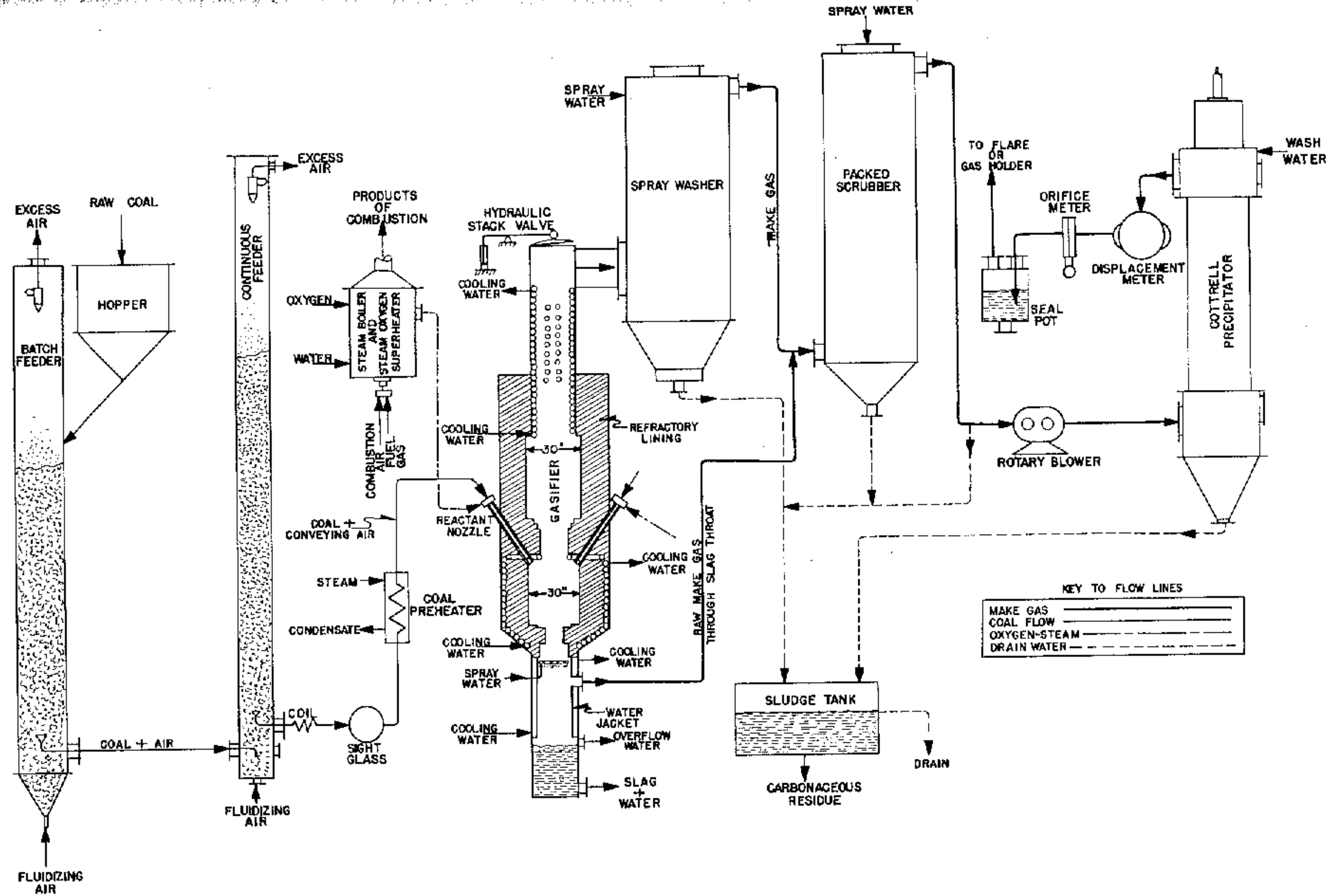


Figure 1. - Pilot-plant flowsheet for atmospheric pressure gasification.

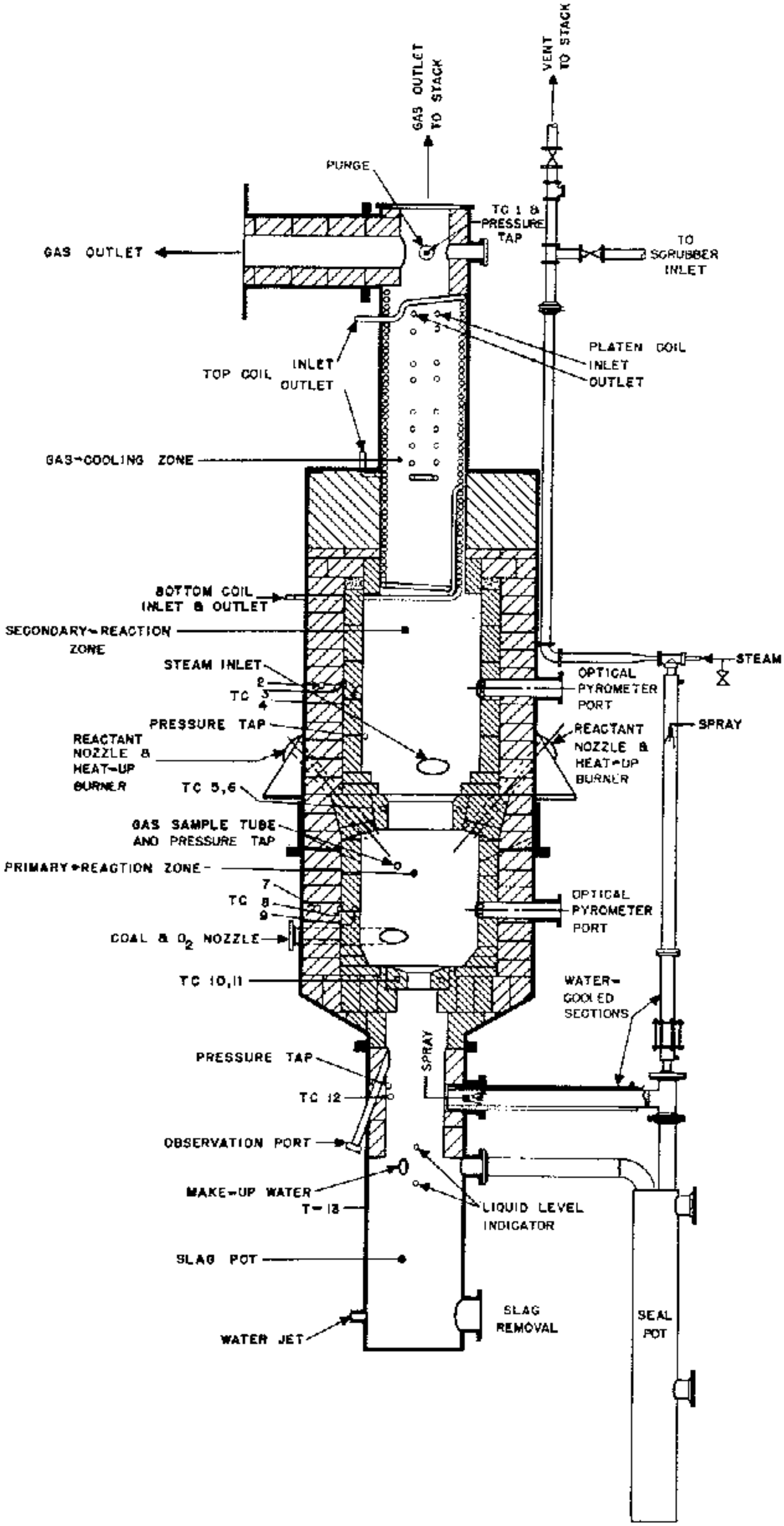


Figure 2. - Atmospheric pressure gasifier 4, design I.

was superheated to about 1,000° F. in a new superheater and mixed with unheated oxygen just before entering the reactant burners, giving a mixture temperature of about 450° F. Coal was preheated to about 300° F., as before.

The flowsheet (fig. 1) shows the pilot plant as it was operated for runs 10 through 31.

Gasifier construction details

The gasifier consists essentially of four units: A heat trap or cooling zone at the top, an upper or secondary reaction zone, a lower or primary reaction zone, and a slag pot at the bottom. The original design (fig. 2) was used for the first 12 test runs. Minor changes were made during these runs, but none of the changes altered the gasifier design appreciably.

Slag removal equipment

The slag pot (fig. 2), a cylindrical container 78 inches high and 15 inches inside diameter, was designed to permit continuous slag removal from the primary zone during gasification. During operation the slag pot is filled with water to the indicated water level to permit continuous slag quenching. Slag was to be flushed out periodically through the indicated washout line, 8 inches from the bottom of the pot. An overflow pipe allowed continuous removal of any light ash that remained on the surface of the water. This ash was washed into a seal pot where it was sampled as part of the gasifier residue.

Three observation ports, approximately equally spaced, were positioned on the slag pot to permit observation up through the lower throat and into the primary reaction zone. Any slag obstructing the slag tap could be rodded out through an observation port without interrupting gasification. The tip of each reactant burner could be inspected during brief shutdowns. A purge of nitrogen or inert gas (carbon dioxide and nitrogen) was used when sighting through an observation port.

A water-jacketed product-gas vent line permitted withdrawing up to 20 percent of the product gas down through the slag tap and returning this gas to the purification system just ahead of the water scrubber. This was done to keep the slag tap hot enough for proper slag flow.

Primary reaction zone

The primary or lower reaction zone consisted of a refractory-lined cylindrical section 30 inches inside diameter and 34-5/8 inches high, having a volume of approximately 14 cubic feet. The inner refractory lining was of B&W No. 80 firebrick, 4-1/2 inches thick, backed by 9 inches of K-30 insulating firebrick. This section contained the heatup burners and the reactant injection burners and was the one to which the reactants were fed and in which initial gasification took place. In order that no slag buildup should occur across the upper throat, it was necessary that product gases leave the primary zone at an estimated temperature of about 2,500° F. Any fly ash carried with the gases would be plastic at this temperature.

The upper throat consisted of a refractory-lined section approximately 9 inches in height. The upper throat and slagtap sections were both constructed to permit having a thickness of at least 9 inches of B&W No. 80 firebrick in the throat area to aid in decreasing refractory erosion through this area. The upper throat was designed to protect the reactant burners and heat-up burners from slagging over during test runs and after shutdowns and to help prevent recirculation of gases from the secondary zone back into the primary zone.

The slag tap was designed to permit slag removal at the bottom of the primary zone. Its original diameter was 6 inches.

Secondary reaction zone

This zone was designed to give more retention time in the gasifier. It permitted partial cooling of the product gases and entrained fly ash, so that the fly ash would be in a dry or nonplastic condition when it reached the water-cooled section at the top of the gasifier. This meant cooling to an estimated temperature of about 2,100° F. for these tests on Sewickley-bed coal. The secondary zone is 30 inches in diameter and 48-1/2 inches high and has a volume of approximately 19 cubic feet. The refractory in this section is identical to the primary zone, having an inner lining of 4-1/2 inches of B&W No. 80 firebrick backed by 9 inches of K-30 insulating firebrick.

Heat trap or cooling zone

The heat trap or cooling zone at the top of the gasifier was designed to simulate conditions that would exist in a commercial unit using a waste-heat boiler to recover part of the sensible heat of the product gases without excessive buildup of slag or fly ash on the tubes. This heat trap consisted of two cylindrical coils. The larger of these coils, fabricated from 1-1/2-inch o.d. steel tubing, was 17-3/4 inches inside diameter and 73-7/8 inches high. The smaller or platen coil was made from 3/4-inch standard steel pipe and had an overall height of 44 inches.

Modifications in gasifier construction

No major changes were made to the gasifier during the first 12 test runs. It was found, however, from these runs that temperatures at the upper throat were higher than had been expected. Following run 12, a flat "support coil" was fabricated from 1-inch o.d. steel tubing and was installed in the upper throat refractory. This change (fig. 3) greatly reduced refractory erosion at the upper throat, as was demonstrated beginning with run 13. It was possible to pass all the product gas through the secondary zone without damage to the upper throat. Later tests showed that a wide range of operating temperatures could be used in the primary zone without affecting the upper throat refractory.

Extensive changes to the gasifier were made after run 23. These alterations, shown in figures 3 and 4, included the following:

1. Wall coils, fabricated from 1-inch o.d. steel tubing, were installed in the vertical and sloping sections of the primary zone, just inside the gasifier shell. This was intended as a safety precaution to protect the shell, should the refractory be burned through. After these coils were installed, the primary zone was relined as before, using B&W No. 80 firebrick, backed by K-30 insulating firebrick. With this relining the diameter of the primary zone was decreased from 30 to 27 inches, giving a decrease in volume of approximately 20 percent.

2. The flat bottom of the slag pot was changed by casting a conical section of refractory cement inside the steel shell. The slag washout line was changed from its original height of 8 inches above the bottom to the bottom of the conical section. This change improved slag removal considerably, since a buildup of slag in the slag pot was no longer required before slag could be flushed out.

3. An 8-inch quick-access flange was installed close to the bottom of the slag pot to permit removal of any large pieces of slag that might fall from the slag tap. These pieces could be removed during a temporary shutdown. The flanged opening

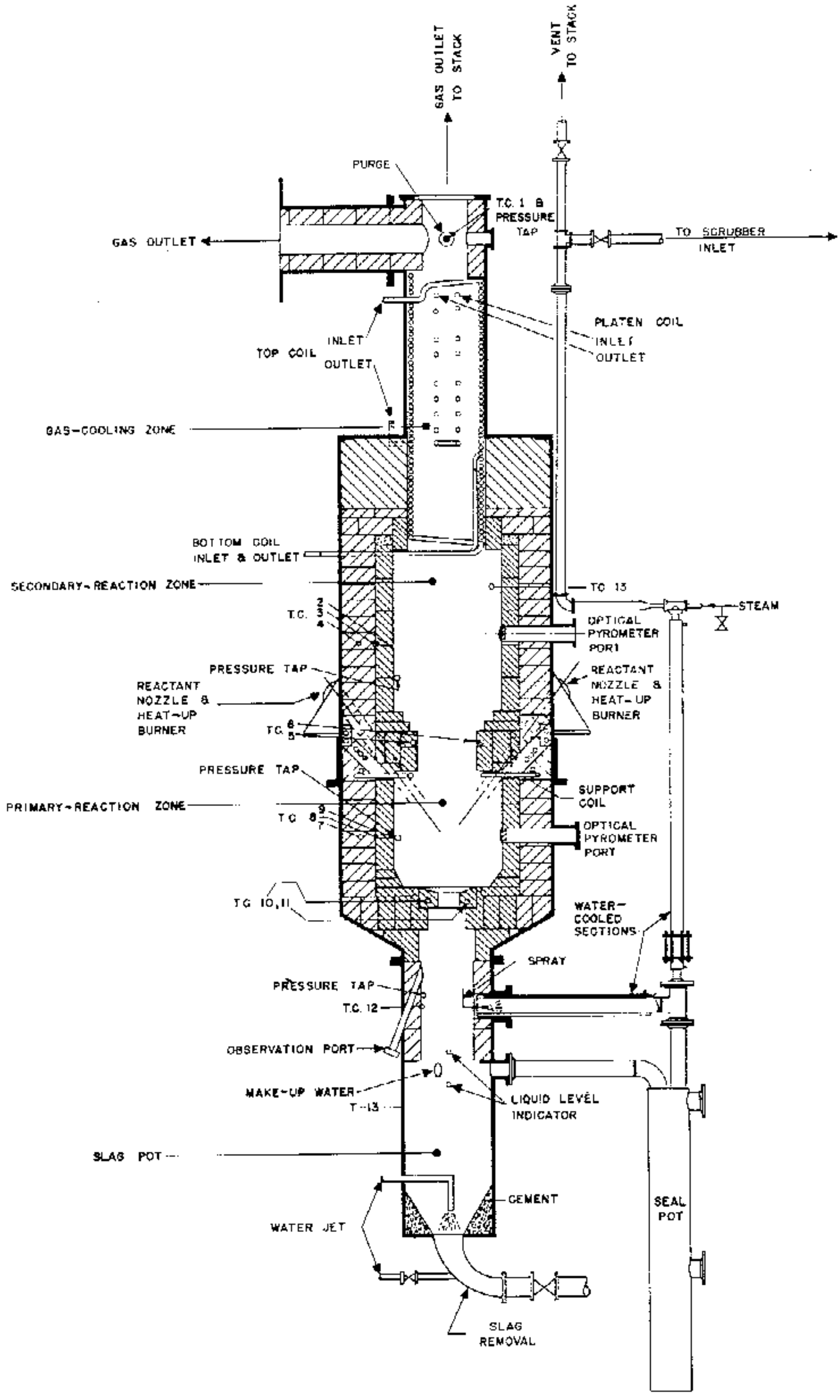


Figure 3. - Atmospheric pressure gasifier 4, design 2.

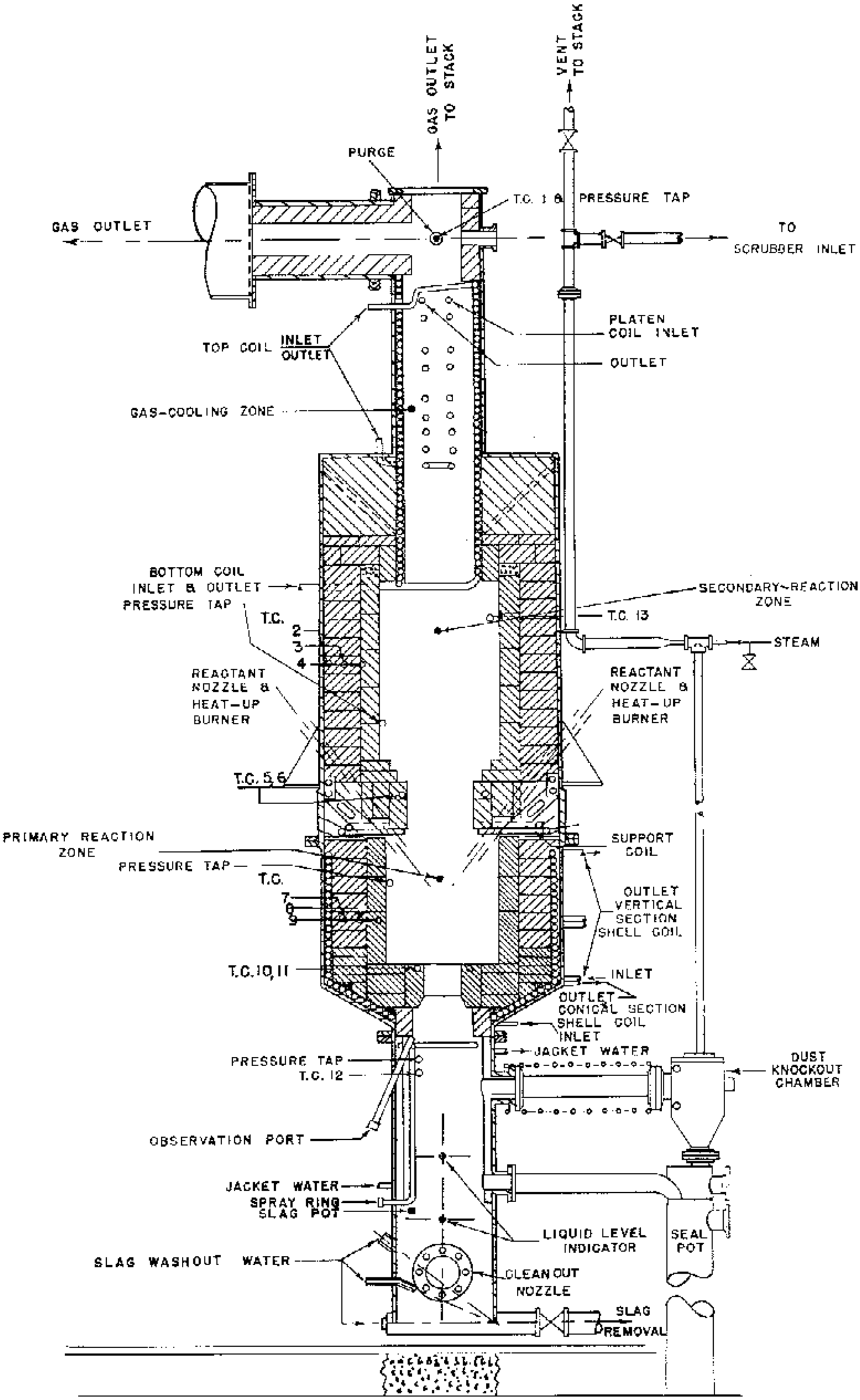


Figure 4. - Atmospheric pressure gasifier 4, design 3.

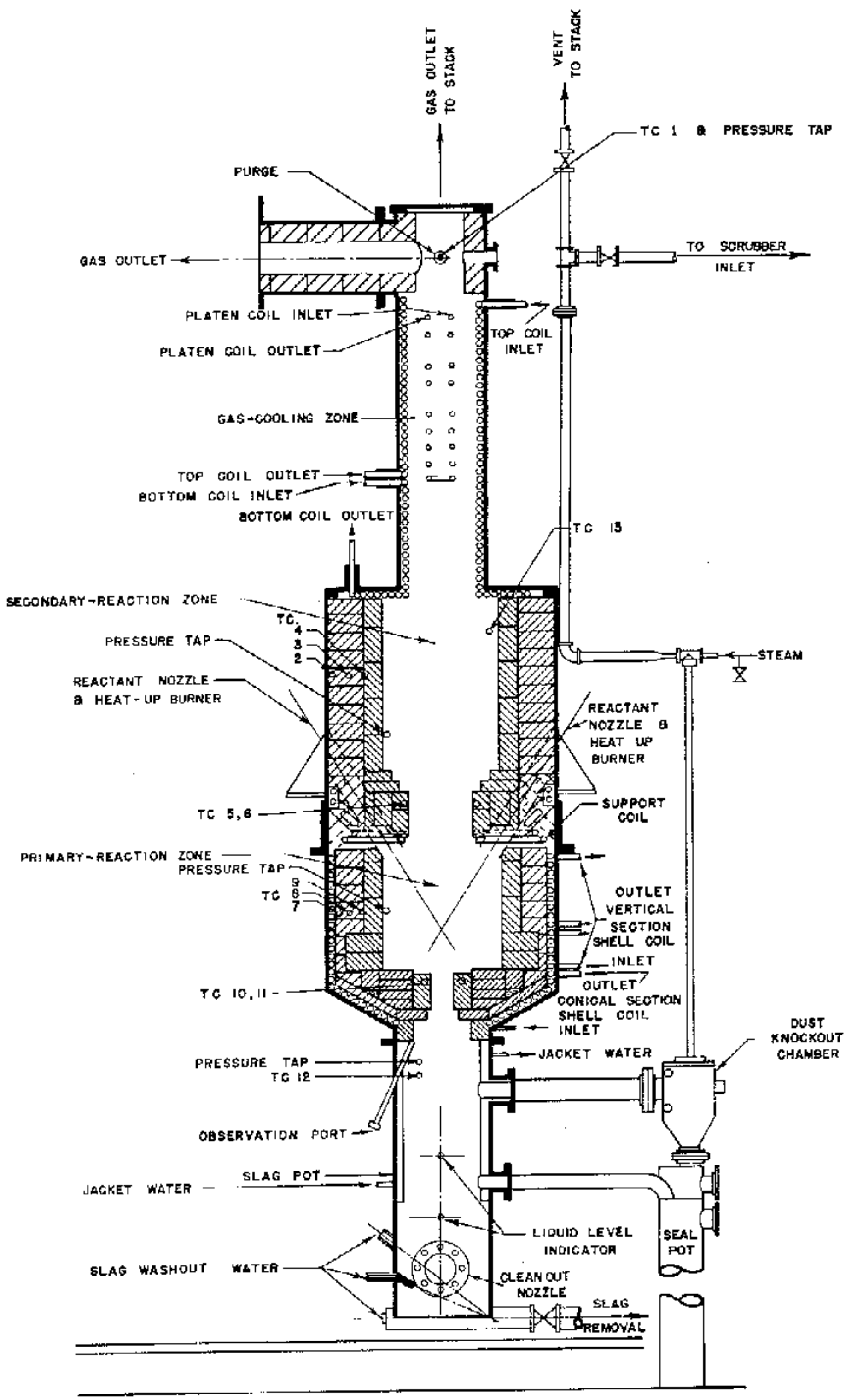
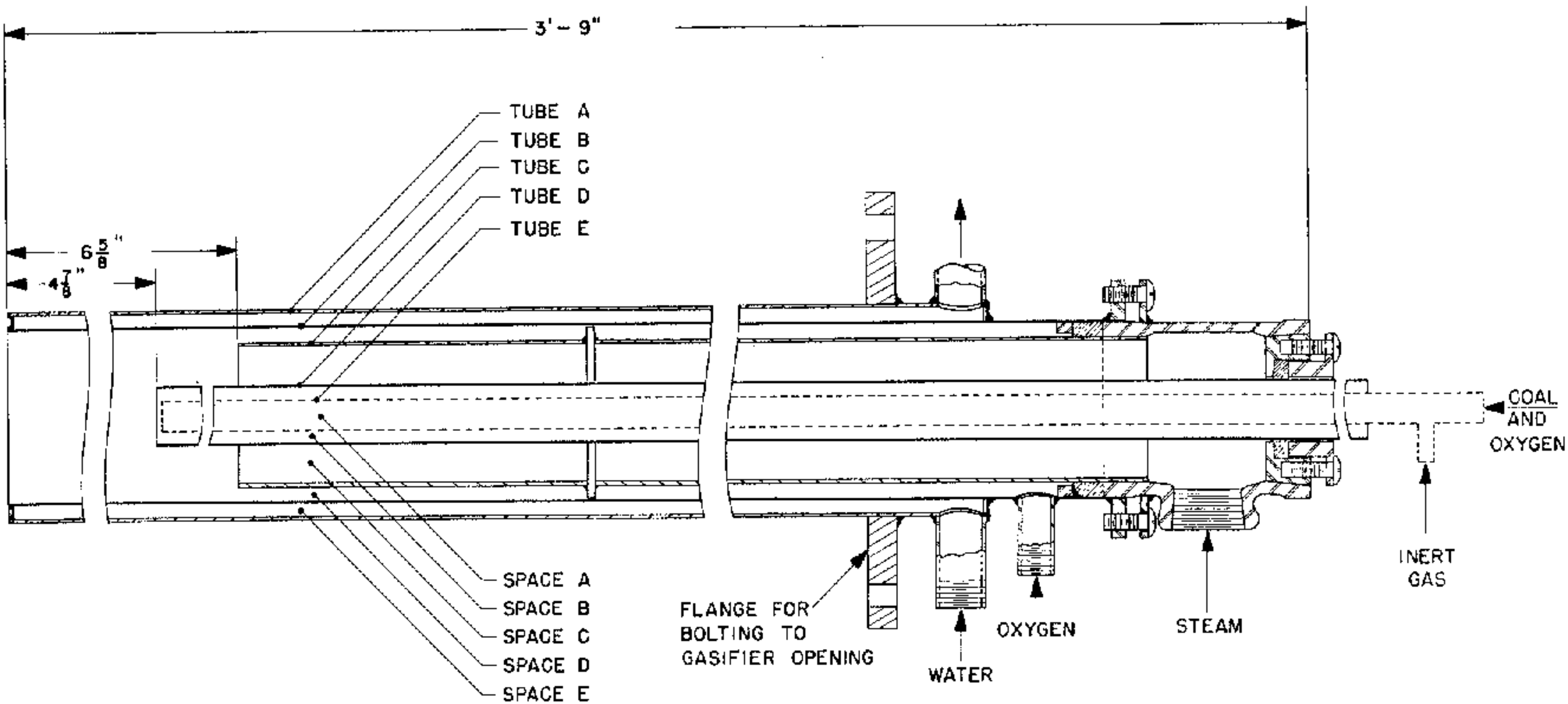


Figure 5. - Atmospheric pressure gasifier 4, design 4.



TUBE	SIZE	MATERIAL	NO.
A	3 1/2"	S.S. TUBING	#14
B	3"	S.S. TUBING	#17
C	2 1/4"	S.S. TUBING	#16
D	1"	S.S. TUBING	#18
E	1/2"	S.S. TUBING	#25

Figure 6. - Reactant injection burner for gasifier 4, design 1, run 1.