GASIFICATION OF COAL BY HOT RECYCLED HELIUM IN A LABORATORY-SCALE EXCHANGER-TYPE GASIFIER[1]

by

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SUMMARY

This report describes Bureau of Mines experiments in gasifying coal in a helium-heated tube-coil reactor. The purpose of this work was to investigate helium as a medium for transferring heat from a nuclear reactor to gasify coal or for use as high-temperature process heat.

A laboratory-scale system was designed and constructed to demonstrate feasibility. In preliminary tests with this system, in which the coal was fed as a water slurry, the helium-heating and recycling equipment operated well. Considerable difficulty was experienced, however, in preheating coal slurry to the desired range of 400°-1,000° F. without plugging the preheaters. Five different preheaters plugged with coke or with salts leached from the coal. The longest operating period was 12 hours. These difficulties were partly due to the relatively small equipment and flow rates.

The gasifier processed 1 pound per hour of low-rank coal at 300 p.s.i.g. and 1,800° F., with the carbon conversion limited to 20 to 30 percent by the short residence time and slow heat-transfer rate.

INTRODUCTION

The Bureau of Mines has already developed entrained-gasification processes[5] [6] for the production of carbon monoxide and hydrogen from coal, steam,

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[5]Holden, J. H., Strimbeck, G. R., McGee, J. P., Willmott, L. F., and Hirst, L. L., Operation of Pressure-Gasification Pilot Plant Utilizing Pulverized Coal and Oxygen, A Progress Report: Bureau of Mines Rept. of Investigations 5573, 1960, 56 pp.
[6]Strimbeck, G. R., Holden, J. H., Bonar, F., Plants, K. D., Pears, C. D., and Hirst, L. L., Gasification of Pulverized Coal at Atmospheric Pressure: Bureau of Mines Rept. of Investigations 5559, 1960, 68 pp.

and oxygen. However, these processes require partial combustion of the coal with oxygen to supply heat for the reaction of coal with steam. The cost of oxygen is significant, so a source of cheaper heat is being sought.

Atomic energy is a potentially cheaper source of heat. Heat from a gas-cooled nuclear reactor, supplied to an externally heated gasifier, offers several advantages over heat from combustion. First, higher operating temperatures might be obtained; temperatures are limited primarily by materials of construction since there is no inherent temperature limitation as in the combustion of fossil fuels. Second, higher operating pressures are obtainable because failure of heat-exchanger tubes at high temperatures can be diminished by supplying the hot-working fluid (gas coolant) from the reactor at the same pressure as the process stream, thus eliminating pressure differential across the hot tube walls. Third, heat can be utilized more efficiently because the unused heat in the working fluid is returned to the reactor; there is no stack loss.

The Atomic Energy Commission and the Bureau of Mines in 1955 began investigating the use of atomic energy as a process-heat source. As part of this program, the Bureau constructed a pilot-scale simulated nuclear system in which heat generated by electrical induction in a bed of graphite spheres is transferred to a pressurized stream of recycled helium.[7] [8] In this system, the hot helium transfers the heat to air or water in an exchanger. Eventually, it is planned to replace this exchanger with one that can gasify coal.

The Bureau has demonstrated that coal can be adequately gasified at atmospheric pressure with heat from an external source[9] and has designed and constructed, on a laboratory scale, a helium-heated exchanger-type gasifier for operation at 310 p.s.i.g. This report describes the laboratory-scale unit and its performance in operating tests.

ACKNOWLEDGMENTS

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BASIC OBJECTIVES AND FUNDAMENTAL DESIGN

The system consists of two basic parts--a helium-recycle section and coal-gasification section. The helium-recycle section simulates, on a small scale, the primary coolant system of a gas-cooled nuclear reactor. The gasifier is

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[7] McGee, J. P., Coates, N. H., and Fasching, G. E., Development of a Simulated High-Temperature Nuclear Loop: Bureau of Mines Inf. Circ. 7981, 1960, 17 pp.

[8] Coates, N. H., McGee, J. P., and Fasching, G. E., Simulated Nuclear Reactor System for High-Temperature Process Heat: 1,000-Hour Demonstration Run at 2,500° F.: Bureau of Mines Rept. of Investigations 5886, 1961, 15 pp.

[9] Konchesky, J. L., Stewart, R. F., and Sebastian, J. J. S., Laboratory-Scale Gasification of Coal-Water Slurries in a Metallic Tube Coil: Bureau of Mines Rept. of Investigations 5704, 1960, 29 pp.

designed to gasify at 1,800° F. and 300 p.s.i.g. 1 pound of pulverized coal per hour in 3 pounds of steam. The coal is fed as a slurry that is preheated to form a steam-coal mixture before it enters the gasifier.

The helium-recycle section is designed to heat 20 std. c.f.m. of helium at 310 p.s.i.g. from room temperature to 2,500° F. Molybdenum-wire elements are used to heat the helium. Because these elements can be used for sustained periods only in an inert atmosphere free from oxidizing impurities, provision is made for completely evacuating the helium-recycle section before helium is introduced. Thus, all external fittings of the loop have to be vacuum tight and able to sustain pressures of 310 p.s.i.g.

No attempt was made to develop a pump for circulating the high-temperature helium because this is one of the objectives of the Bureau's research on the pilot-scale simulated nuclear reactor.[10] Instead, the helium leaving the gasifier was cooled to 100° F. and circulated by a standard blower.

Several methods were considered for feeding coal to the gasifier. These included the slurry, fluidized, and steam-pickup methods. However, emphasis was placed on the slurry-feeding method.

In addition to having the required capacity, the gasifier had to be designed to avoid the stresses caused in the hot tube walls by pressure differential. The unit had to be constructed so that the pressure of the helium on one side of the tubing was virtually the same as the pressure of the steam-coal mixture on the other side, especially throughout the hotter range of the tubing.

DESCRIPTION OF SYSTEM AND OPERATING PERFORMANCE IN PRELIMINARY TESTS

Discussion of the design and operating performance of the laboratory-scale system is divided into two parts, the helium-recycle section and the gasification section.

The helium-recycle section, figures 1 and 2, is a loop containing equipment for circulating and heating helium to 2,500° F. at 310 p.s.i.g. Carbon-steel piping designed for a maximum temperature of 650° F. at 600 p.s.i.g. is used in its construction. All flanges are rated at 600 p.s.i.g. at 650° F.

A flowsheet for the gasification section is shown in figure 3. The gasifier is a coiled tube. Coal-water slurry is vaporized in a preheater, and the coal-in-steam suspension is passed through the tube while hot helium is circulated around the outside of the tube. Details of construction and operation of both sections follow.

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[10]Work cited in footnote 7, p. 2.

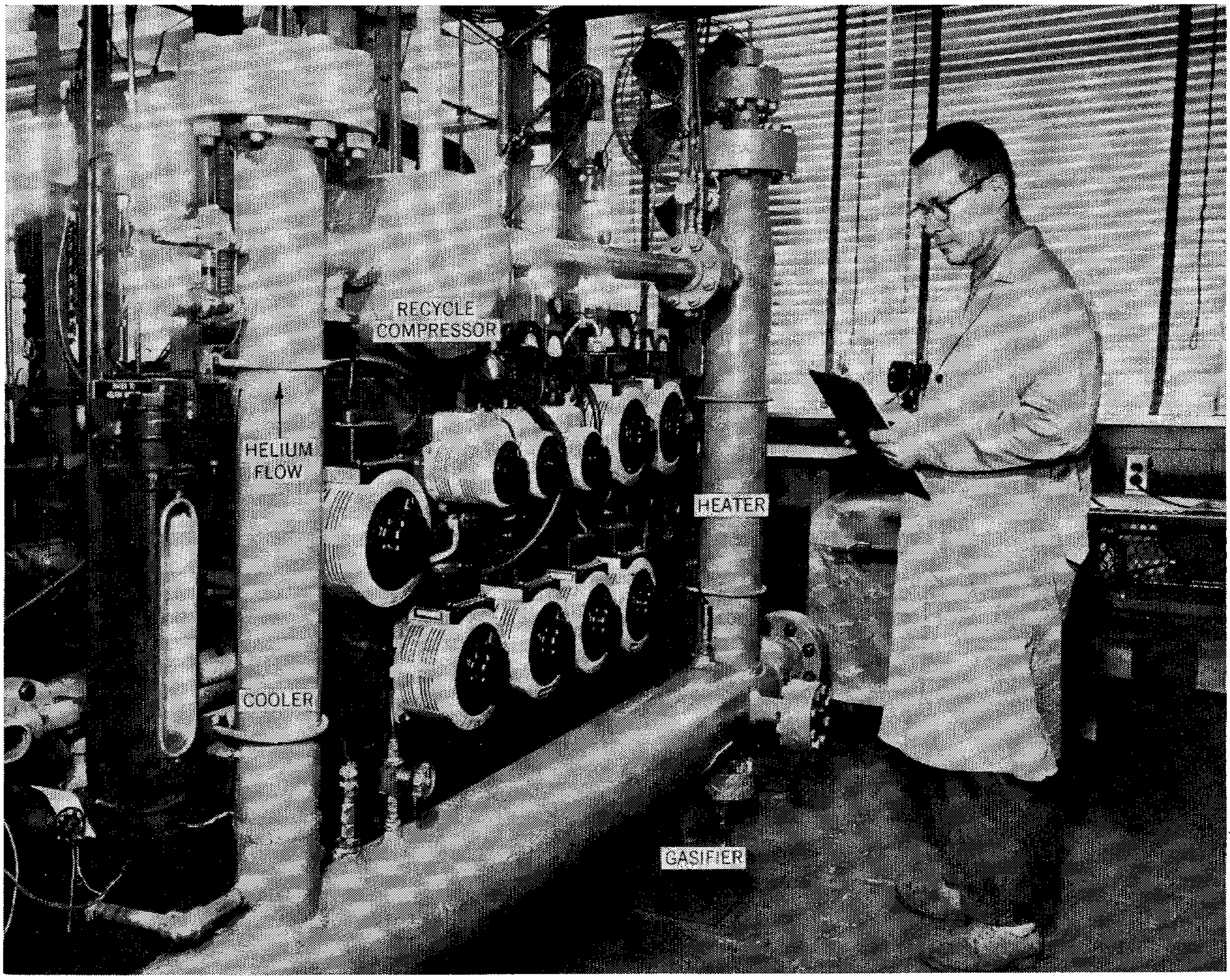

FIGURE 1. - Helium-Recycle System and Gasifier.

Helium-Recycle Section

The helium-recycle section consists of a heater, a test section (such as a gasifier or a reactor) for transferring heat to process streams, a cooler and a circulating compressor. Figure 2 shows these units including a gasifier.

Helium Heater

The helium is heated by electrical-resistance coils in a 46-inch long, 1-1/2-inch-ID, 2-inch-OD zirconia tube encased in Fiberfrax[11] in the shell of the heater (fig. 4). The shell of the heater is 6-inch-diameter schedule-80 pipe. Zirconia is a good insulator and can withstand temperatures up to 4,000° F. Fiberfrax, aluminum silicate fiber used as insulation, can be heated to 2,700° F. without fusing and is easily outgassed.

[11]References to specific brands is made to facilitate understanding and does not imply endorsement of such items by the Bureau of Mines.

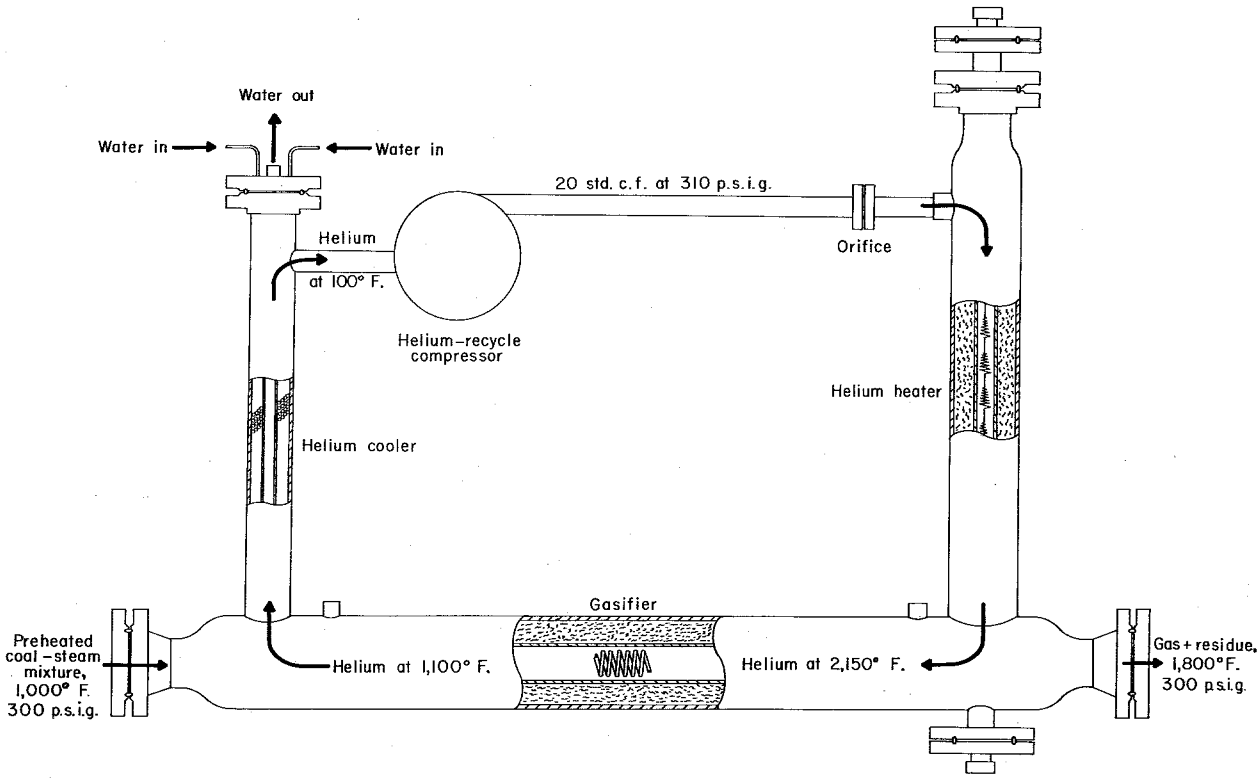

FIGURE 2. - Helium-Recycle Section.

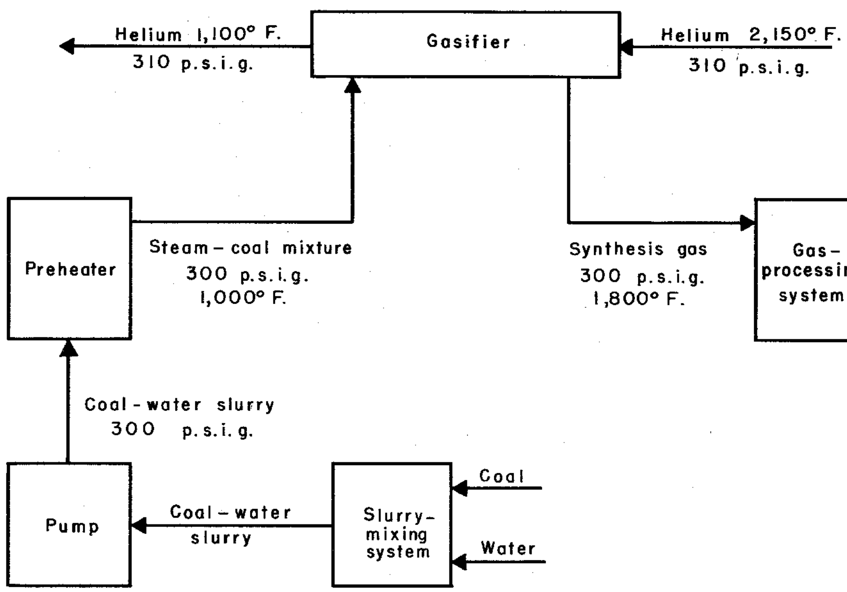

FIGURE 3. - Flowsheet for Gasification of Coal With Hot Recycled Helium.

Details of one of the cone-shaped molybdenum-wire heating coils are shown in figure 5. Electrical contact to the heating element is made through threaded type-304 stainless steel terminal rods (fig. 6) to which the ends of the heating element are attached by lead wires secured in the rods with pairs of set screws. Two additional molybdenum wires are used at the ends of the heating element to connect with the terminal rods. These wires are bound to the end of the heating element with fine molybdenum wire. This reduces the resistance of the leads and prevents heating of the terminal rod.

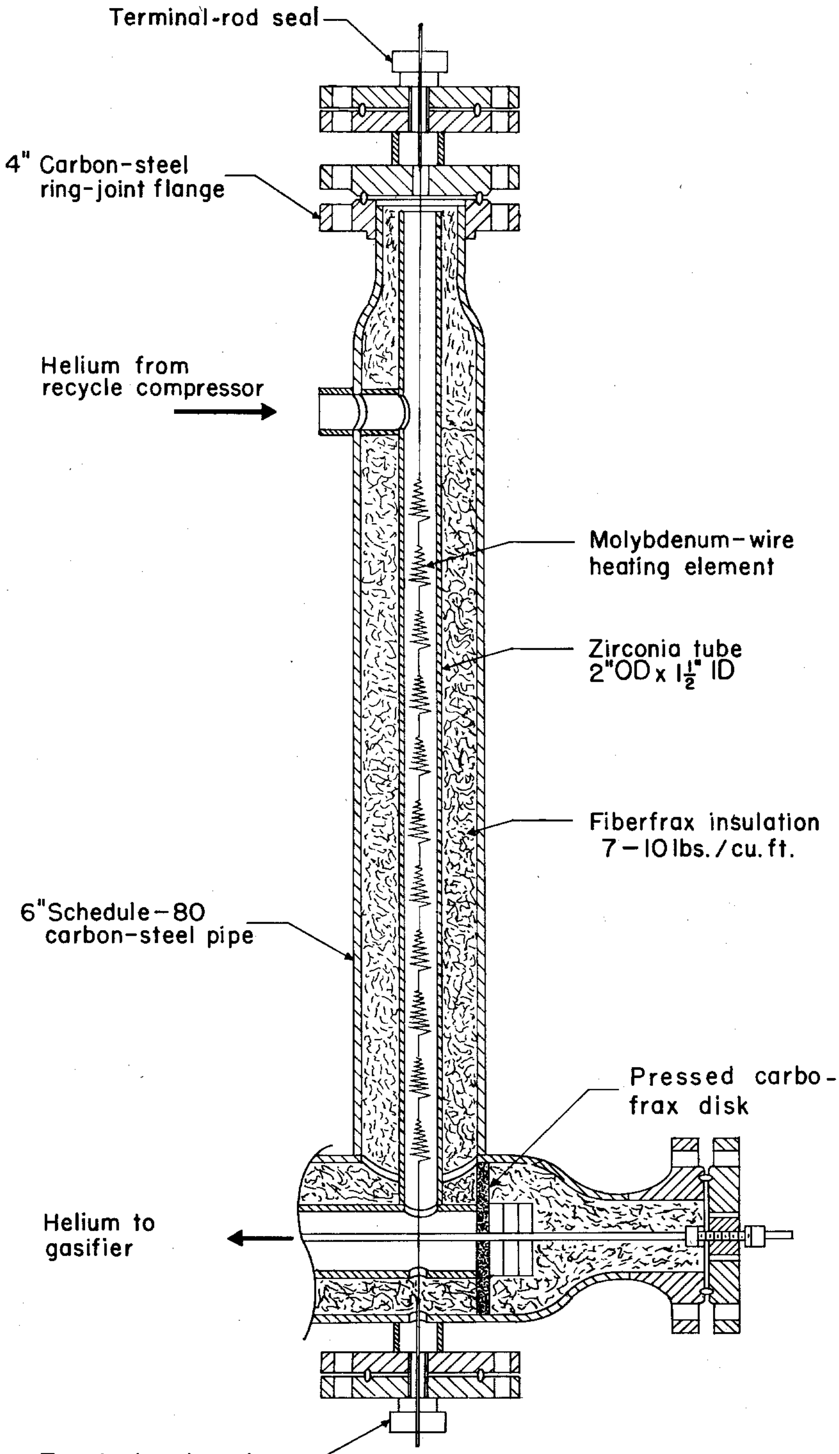

FIGURE 4. - Helium Heater.

Power to the heater is manually controlled by a variable transformer. Normally, 94-99 amperes at 130-160 volts were required when 310-p.s.i.g. helium was circulating through the heater at 20 std. c.f.m. With this load, the temperature of the coil at the hottest section was approximately 2,400° F. The coil's electrical resistance was very sensitive to temperature changes caused by variations in helium-flow rates. Normally, however, the load was relatively constant.

The terminals are 9 inches long. For the first 7-1/2 inches from the external end they are three-eighths inches in diameter and threaded. The remaining 1-1/2 inch of each terminal is one-half in diameter and drilled axially with a 3/16-inch drill to a depth of 1 inch. The first seals used for the terminals were Teflon discs held on both sides of the blind flange by nuts screwed onto the terminal. This seal was not satisfactory and was replaced with the 2-1/2-inch Teflon cone (1-1/2 inches at its largest diameter) seen in figure 6. This type of seal was reasonably effective, but the packing nut had to be frequently tightened.

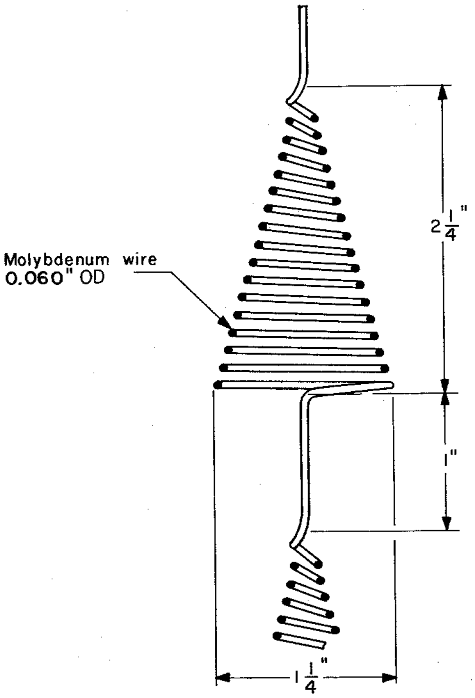

FIGURE 5. - Molybdenum-Wire Coil for Helium Heater.

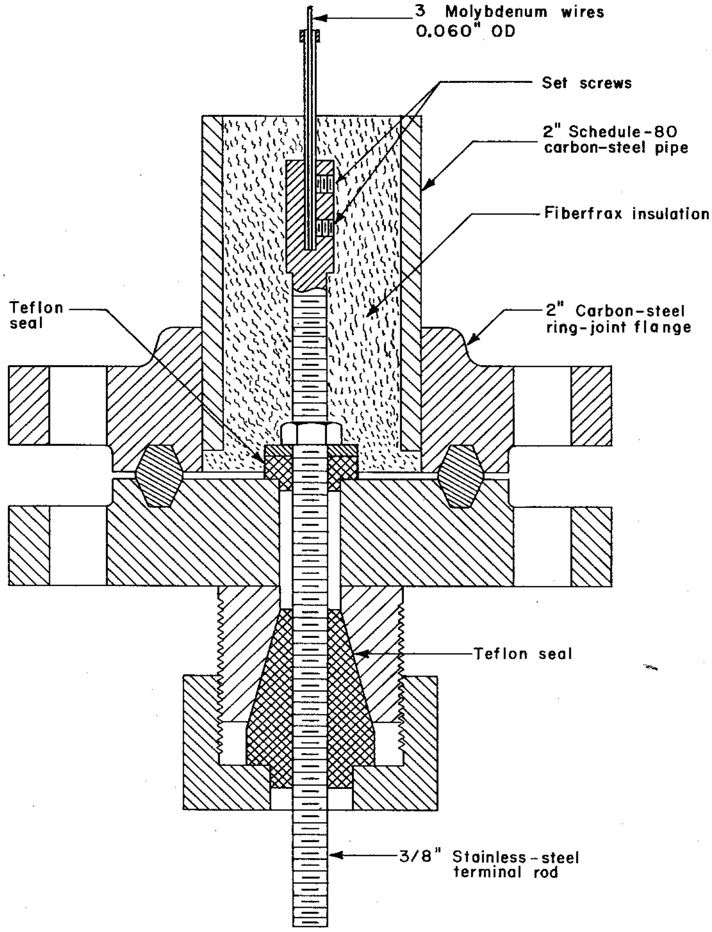

FIGURE 6. - Seal for Terminal Rod of Helium Heater.

Raised face flanges originally were installed on the helium heater, but it was impossible to keep them from leaking. Several types of gaskets were tried, including gaskets made of copper and aluminum, without success. Leaks were considerably reduced by using thick (1/8-inch), narrow annealed copper gaskets, which were forced out between the faces of the flanges as they were tightened. Octagonal ring-joint flanges with aluminum gaskets next were installed, and only traces of helium have since been detected at these flanges.

The molybdenum heating elements proved to be durable, as much as 200 hours of operation having been attained with one element. Oxidation of the molybdenum was inhibited by carefully evacuating the loop, as previously stated, and by adding small amounts of hydrogen to the recycle helium. On the occasions when the heating element failed, the biggest contributing factor was the rapid overheating and sagging of the coils when the helium flow became too low.

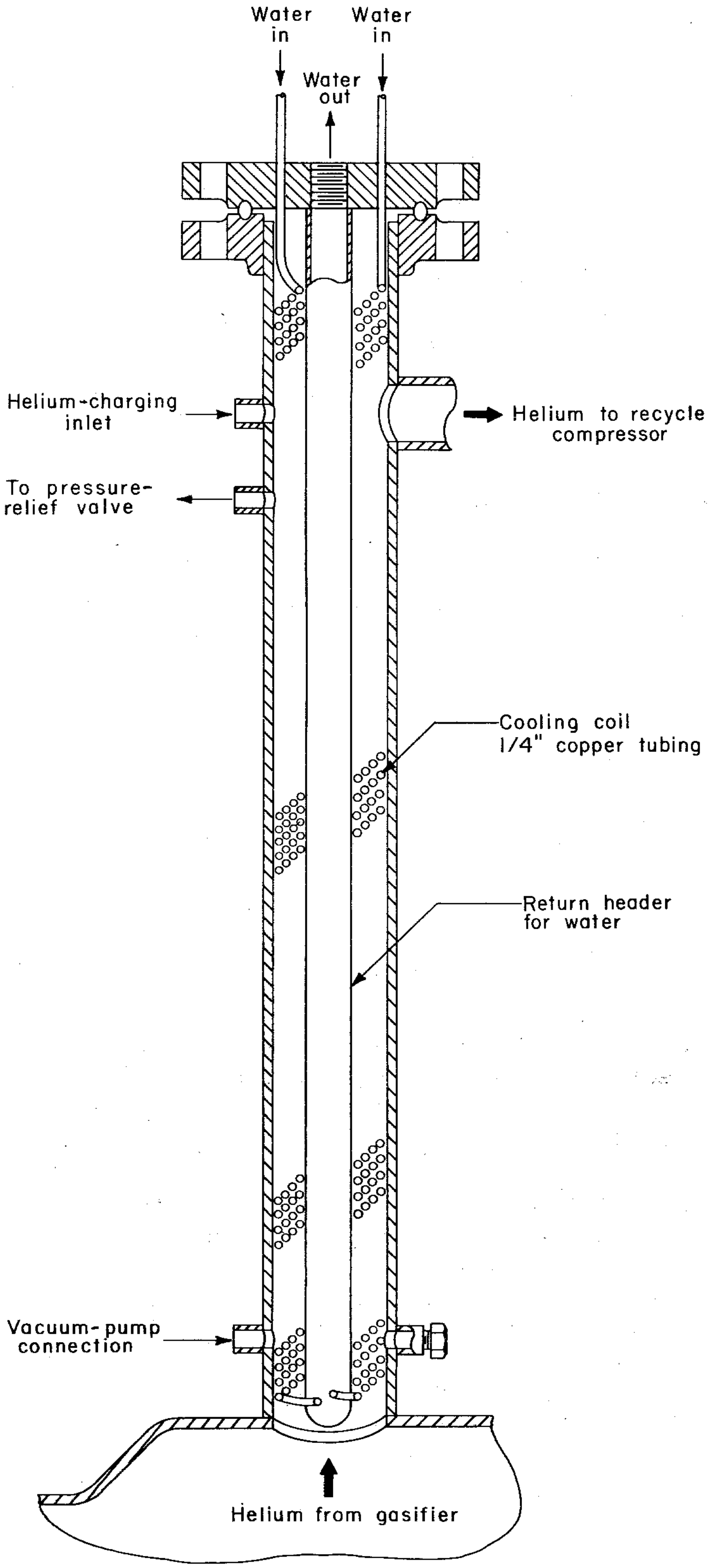

FIGURE 7. - Helium Cooler.

Helium Cooler

The purpose of the helium cooler (fig. 7) is to cool the helium from the gasifier from 1,000° F. to room temperature to avoid damage to the recycle compressor. The cooler is a 47-inch long, 4-inch schedule-80 carbon-steel pipe containing four cooling coils, each made of 40-foot long, 1/4-inch copper tubes, and a 1-inch water-outlet pipe that can be removed from the shell as a unit.

The original cooling coil had only two concentric spirals and did not provide enough cooling. The temperature of the helium to the recycle compressor rose to more than 120° F. and overheated the motor windings. The four-coil cooler, however, keeps the helium entering the blower below 100° F. About 3.5 g.p.m. of water is necessary to cool the 20 std. c.f.m. of helium from 1,400° F. to 100° F.

Helium-Recycle Compressor

The helium-recycle compressor satisfactorily circulates 20 std. c.f.m. of helium at 100° F. and 310 p.s.i.g. Adapted from a portable industrial-type vacuum sweeper, the compressor is a single-stage centrifugal type with a 7-inch aluminum-alloy impeller. The 1-horsepower compressor develops a head of 48 inches of water at 11,500 r.p.m.

The motor and impeller were "canned" to avoid trouble with leaking seals. The "can," which can be seen in figure 1, is a pair of dished heads welded to a short section of