## SUMMARY AND CONCLUSIONS

The design and operation of the Koppers powdered-coal gasifier and its auxiliaries at Louisiana, Mo., are described. This unit was designed to convert 1 ton of coal per hour with oxygen and superheated steam into synthesis gas - primarily carbon monoxide and hydrogen.

The first run was made on May 4, 1949. After this, 44 short runs (less than 8 hours each) and 1 long run (lasting 11 days) were made. Total gasification time was 420 hours. The gasifier was not cooled down during the year when these runs were made.

After an initial period of test operations and equipment proving, during which 12 runs were made, the effect of numerous variables on gasifier performance was studied. The long run was made primarily to check the equipment in sustained operation. Detailed data from these runs are presented.

Inspections of the gasifier lining while hot after runs and cold after shutting it down showed some erosion in the conical end sections.

From the performance of the gasifier the following conclusions were reached:

(1) The prime operating variable is the ratio of oxygen to coal. The increase in conversion of carbon is nearly linear with increase in oxygen-coal ratio.

(2) The combined oxygen and coal requirements per unit of synthesis gas reach a minimum in the range of 9 to 10 cubic feet of oxygen per pound of coal.

In this range the carbon conversion was 80 to 85 percent.

(3) Some indication of an improved gasification efficiency was obtained when using a very fine coal grind or increased turbulence through the use of steam jets. Mechanical difficulties prevented further studies of this nature.

(4) Other mechanical and process variables tried had either little or an adverse effect on performance.

(5) With some alterations, the unit could be operated for sustained periods at the oxygen-coal ratios that were indicated to give the most efficient gasification.

The operating results indicated that, due to short circuiting, more of the coal had been passing unreacted from the gasifier than otherwise would have been the case. It was believed that a change in the geometry of the gasifier to minimize short circuiting would improve performance. Work done at the Morgantown, W. Va., station of the Bureau of Mines supported this contention, and, because of this and as a result of refractory studies that had been made, it was decided to interrupt further work on the Koppers unit and construct a vertical, cylindrical up-flow gasifier lined with high purity aluminum oxide refractory.

## ACKNOWLEDGMENTS

The work reported herein is the result of the combined efforts of many people. The contributions of personnel of the Koppers Co., Inc., and of the Heinrich Koppers Co. were numerous and important. Bureau of Mines employees at Louisiana in the Operating, Planning, Analytical, and Engineering Sections all played their part in this project.

## INTRODUCTION

Under Public Law 290 the Bureau of Mines at Louisiana, Mo., was charged with the responsibility of building plants to demonstrate the conversion of coal to oil - first, by means of coal hydrogenation and, second, by means of gasification of the coal, followed by Fischer-Tropsch synthesis. An important part of the Gas-Synthesis Demonstration Plant is the coal-gasification step. At the time that this work was undertaken Bureau of Mines engineers made an intensive study of the information available, which was then mainly of German origin. On the basis of this study, they reached the decision that the gasification of coal dust in suspension with oxygen and steam was best suited for the needs of the program and best adapted to demonstration-scale operation. It was recognized at that time that pressure gasification might be the ultimate solution but that the end result might be achieved more economically and more rapidly if the first gasification work were done at atmospheric pressure and, with the primary problem solved, the process adapted to pressure operation later.

A Linde-Frankl oxygen plant of approximately 1-ton-per-hour capacity, which had been transported to this country, reconditioned, and erected at Louisiana, Mo., as a part of the demonstration plant, was available for this work. The oxygen-plant capacity then established the basis for sizing the coal-gasification unit, and all design was based on the use of a maximum of 1 ton of oxygen per hour. The process for coal-dust gasification in suspension developed by the Heinrich Koppers Co. in Germany was chosen for several reasons: Results reported by Totzek and by the Heinrich Koppers Co. concerning the performance of this unit were very favorable, and it was found that the Koppers Co., Inc., Pittsburgh, Pa., was already well advanced on the preliminary engineering of a pilot plant of a size comparable to that proposed for Louisiana, Mo. It was agreed that it would be beneficial to both parties to take advantage of the design and engineering work already done and the material purchases that had in some instances already been made. On this basis, a contract was let on March 17, 1948, for the engineering and construction of the entire Gas-Synthesis Demonstration Plant. Construction was begun on the gasification section in June 1948. The plans were drawn to permit completion of the plant section by section and to make possible the testing and preliminary operation of one while construction was still in progress on the others. Because less information was available on the gasification step, this unit was chosen as the first to be constructed and tested. To save further time, it was decided that the initial construction would bypass the waste-heat boiler and cyclone-type dust remover, which were planned for the final installation, and proceed with the operation without waiting for the completion of these units. The construction was virtually complete by June 1, 1949. The initial run on the unit actually was made on May 4, 1949.

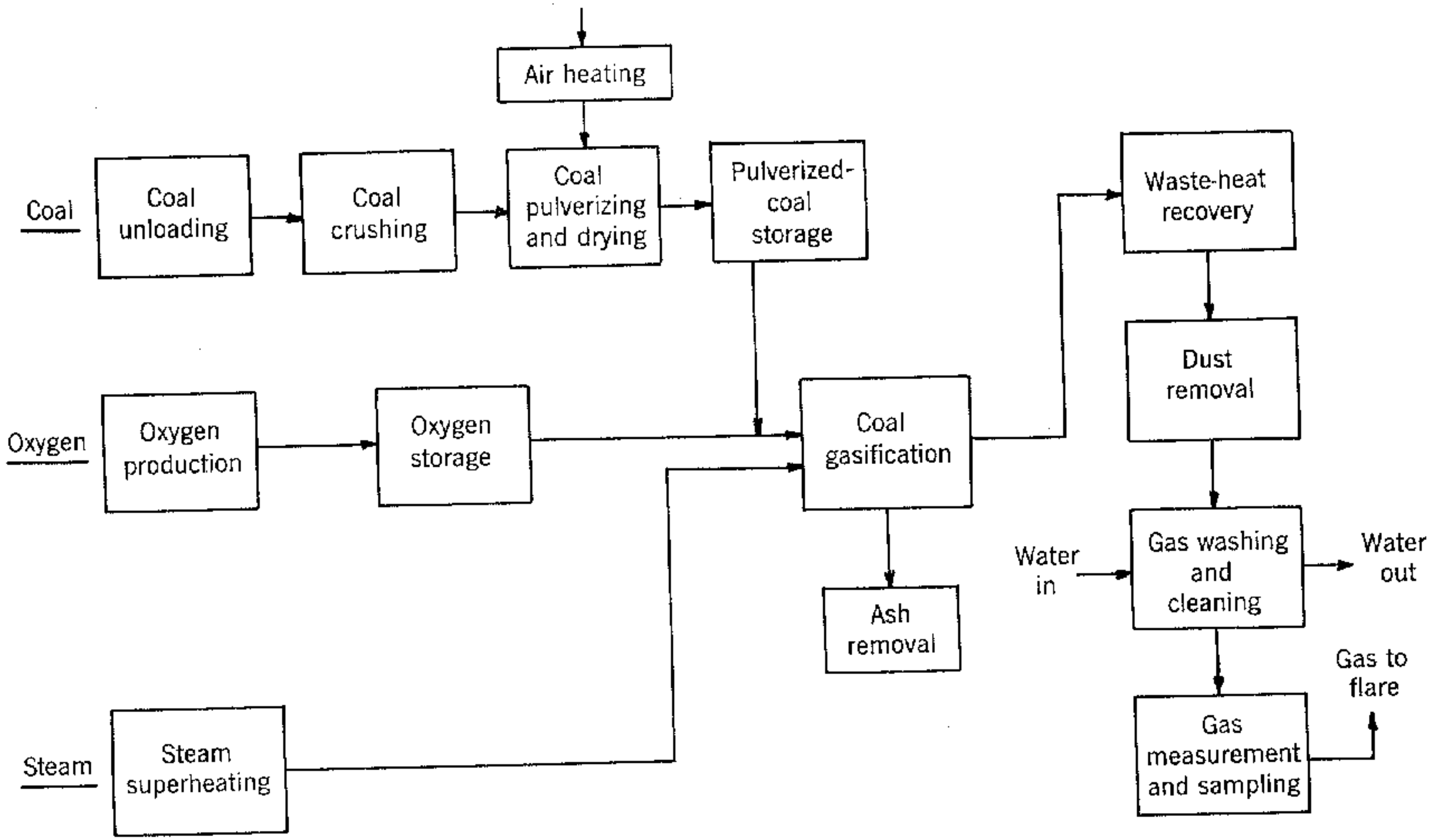


Figure 1. - Block flow diagram of coal-gasification unit.

## DESCRIPTION OF EQUIPMENT

Figure 1 is a block diagram showing the flow of material through the system. The coal is received by rail and fed from a track hopper on conveyor belts either to field storage or to the primary crusher. This is an American Ring mill, which reduces the coal to 3/4-inch top size. The crushed coal is raised in a bucket elevator to an overhead storage bin of approximately 80 tons capacity. From this hopper the coal is fed at a rate controlled by a table feeder into a Babcock & Wilcox wind-swept ball mill (type B, No. 138) in which it is dried as pulverization proceeds. Approximately 4,500 cubic feet per minute of fresh air is drawn through a steam heater and then through a gas-fired heater in which the temperature is raised to about 400° F. Firing on this heater is controlled by the temperature of the air-coal mixture out of the mill. The pulverization can be regulated for various throughputs and size consists, but most of the work reported here was done on coal ground to 65 or 90 percent through 200-mesh. The air-coal mixture passes from the top of the mill to a primary cyclone and then to five Dracco bag filters in parallel. The separated air is exhausted from the system by an induced-draft fan, with a damper in the discharge, regulated to control the air flow through the mill. The coal is fed from the bottoms of the cyclone and the bag filters through star-wheel feeders on a common drive shaft to a screw conveyor, which discharges into the pulverized-coal storage hopper. This hopper is divided at the lower part, and each leg supplies a coal system feeding one end of the gasifier; the two systems are duplicates.

The first unit in the system is a weigh hopper, which is in an automatic sequence-control system that discharges weighed coal as required by its feed hopper, and after a suitable time lag the closing of the discharge gate actuates a star-wheel feeder, which puts a new charge of coal into the weigh hopper until a microswitch on the scale beam stops the feeding when the predetermined weight has been reached. Normal batches are about 500 pounds. The feed hoppers have a working capacity of about 1,500 pounds each. The level is indicated by a high and low "Bindicator." The upper one actuates the charge mechanism when the coal level falls below this point. The lower one operates an emergency shutdown when the coal reaches a dangerously low level. The coal is carried from the bottom of this hopper by three parallel screws of a special design operating from a common drive shaft, whose speed is remotely controlled from the panel board. The coal fed from the ends of the three screws is picked up by separate streams of process oxygen and carried through three 1-1/4-inch copper pipes to a three-port, water-jacketed burner nozzle set through the steam duct into the end of the gasifier.

The process steam is superheated in a moving-bed pebble heater fired with natural gas. A description of this unit and information concerning its operation have been published.[6] The heater consists of two vertical sections - the upper one approximately 3 feet i.d. by 10 feet high and the lower one 33 inches i.d. by 7-1/2 feet high, connected by a restricted throat 3 feet long and 4 inches i.d. The pebbles are heated by firing with natural gas and air in the combustion section, which surrounds the bed just above the restricted throat. The products of combustion pass from the combustion section through radial ports into and up through the pebble bed in the upper section. The heated pebbles pass down through the throat into and through the lower section against an upward flow of low-pressure steam. The superheated steam leaves by ports at the top of the superheater section, from which it passes into the steam duct to the gasifier. The pebbles, cooled by the incoming steam, are discharged from the bottom of the superheating section at a rate controlled by a variable-speed table feeder into a pipe to the boot of the bucket elevator. At the top of the elevator the pebbles are

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6/ Batchelder, H. R., and Ingols, H. A., Performance of a Pebble Heater Steam Superheater: Bureau of Mines Rept. of Investigations 4781, 1951, 8 pp.

delivered to an inclined pipe, which feeds them into the top of the heating section, thus completing the cycle. In this delivery pipe there is provision for sweeping the pebbles with part of the flue gas, which then goes through a cyclone separator to remove pebble dust and back into the main flue-gas stack. The main stream of flue gas passes through a control damper operated by a differential pressure controller to maintain a preset pressure differential across the throat between the combustion and superheating sections.

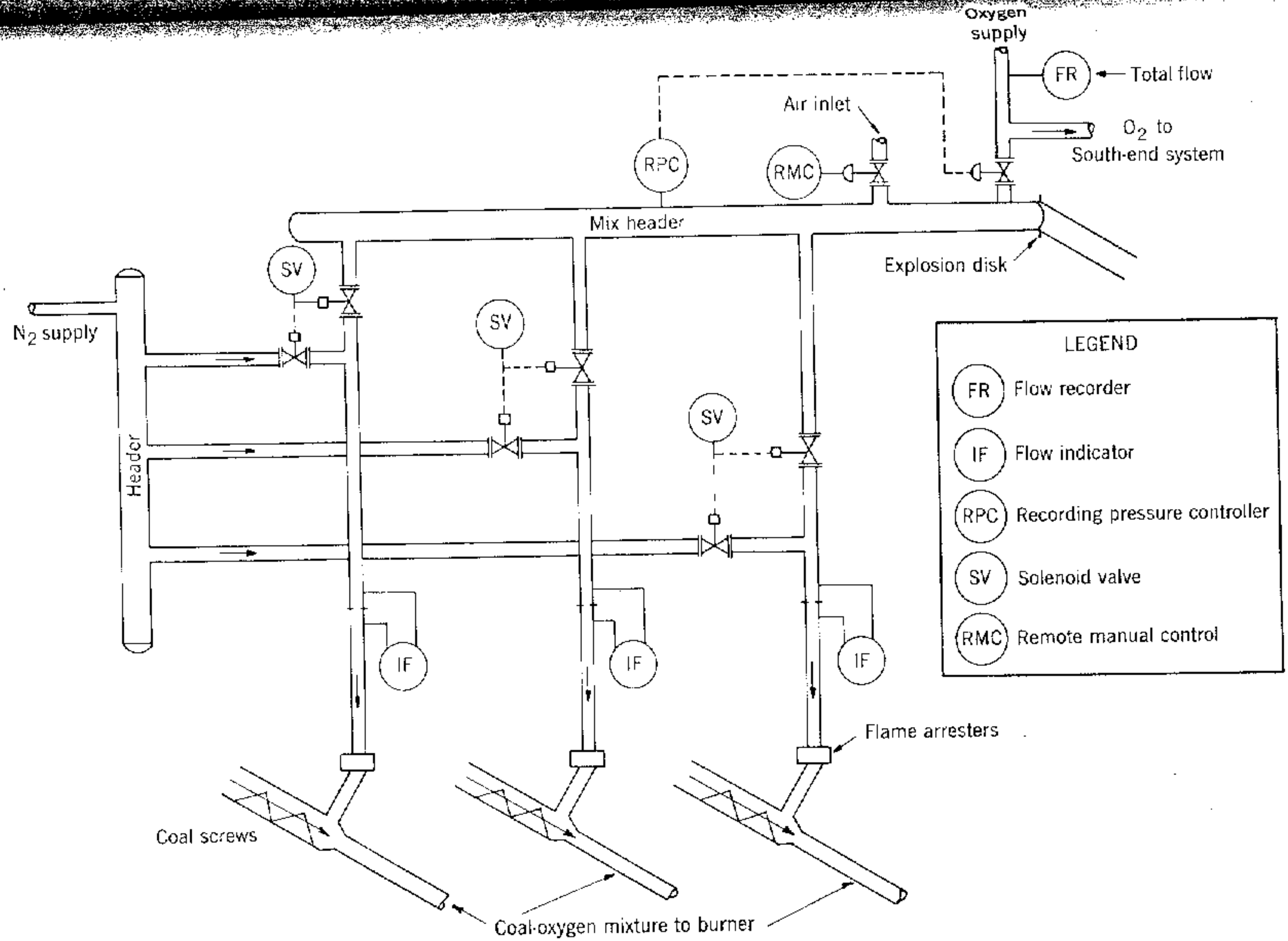
The steam flow is controlled by a recording flow controller. The temperature of the steam leaving is controlled by a recording temperature controller working on the combustion air to the furnace section. The fuel-gas flow is regulated by a ratio flow controller in preset relation to the air flow. The steam duct leaving the pebble heater is divided into 2 sections leading to the 2 ends of the gasifier.

The oxygen plant, as was mentioned above, was originally operated at Hochst, Germany, for about 4 years before it was brought to this country. It is in most respects a conventional Linde-Frankl plant and need not be described in detail here. A special feature of the plant is a secondary column for further purification of part of the nitrogen produced. From this, approximately 7,000 cubic feet per hour of nitrogen containing less than 1/2 percent oxygen is available. This nitrogen is used for maintaining an inert atmosphere in the pulverized-coal bins and for purging various process lines in emergencies. The oxygen, which is produced at a 98-1/2-percent purity, is sent to a 50,000-cubic-foot storage holder, from which the gasifier is supplied. For pumping the supply oxygen there is a Nash Hytor (type K5) booster.

The oxygen is normally supplied at pressures of 5 to 9 pounds per square inch through a recording flowmeter. The stream is then divided and is admitted to the 2 control headers to maintain a preset pressure on each through 2 recording pressure controllers. From each control header separate lines run to each of the three coal screws feeding that end of the gasifier. A schematic diagram of the oxygen feed system is shown in figure 2. Equalizing orifices are installed in each individual oxygen line to divide the flow to the 3 screws at a rate controlled by the pressure on the header. An indicating flowmeter is installed at each orifice to give visual indication of the flow in each line. A flame arrestor is installed just upstream from the coal screws. Each oxygen line is equipped with a solenoid valve, which cannot be opened unless the coal-screw drive motor is running and the clutch on that particular screw is engaged. Paired with these are solenoid valves in a nitrogen supply system, which automatically open if the oxygen solenoid valves are closed. This arrangement provides an immediate and automatic purge of the system in the event of any trouble.

The gasifier proper is a refractory-lined, horizontal steel sheel, fired at each end on the horizontal axis of the cylinder; the gas leaves approximately from the top center. Figure 3 is a drawing of this unit. The shell is lined on the inside with 2 courses of silica brick backed with 1 course of first-quality firebrick and 1 course of Super X asbestos magnesia insulation, making a total wall thickness of approximately 15 inches.

The inside diameter of the brickwork is 6 feet 6-3/4 inches. In the lower part, as may be seen from the drawing, the sides of the cylinder are straightened somewhat to lead to the three ash-removal legs. These legs are spaced evenly along the longitudinal axis of the gasifier, are 20 inches i.d. and are separated by silica piers, which slope uniformly toward each of the adjoining ash legs. Cones are fitted on each end of the cylinder with lining similar to that of the main barrel and approximately 3 feet i.d. at the wide end and 13 i.d. at the small end. The length of the




Oxygen system—Schematic flow North end (South end opposite hand)

Figure 2. - Schematic flow diagram of oxygen system.

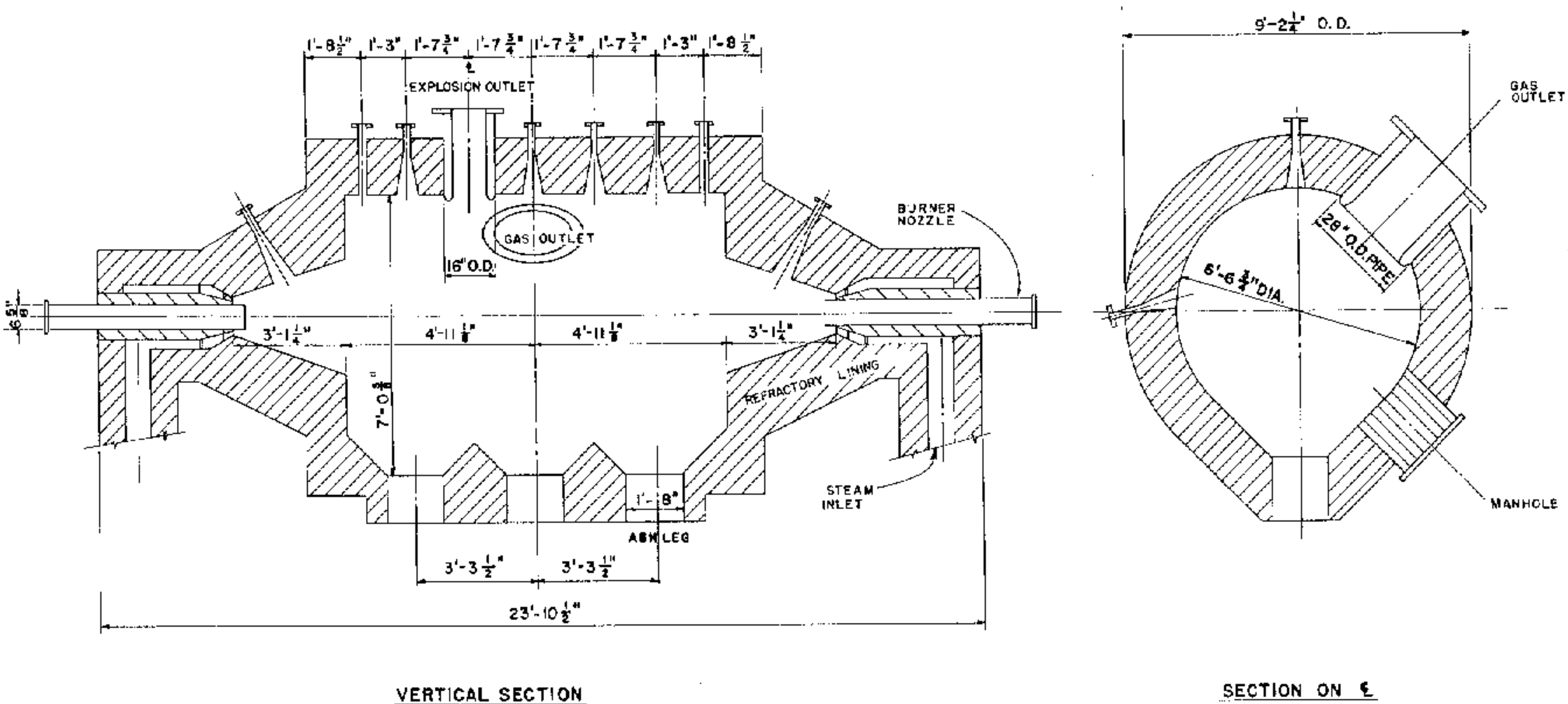



Figure 3. - Gasifier sections.

cylindrical section is 9 feet 10-1/4 inches, and each cone is 3 feet 1-1/4 inches deep. The internal volume of the gasifier is 380 cubic feet. The steam ducts discharge into the small ends of the cones through annular rings constructed of silicon carbide. The center of each ring is occupied by a water-jacketed burner nozzle carrying the coal-oxygen mixtures. The outside of the ring is fitted with silicon carbide vanes to impart a twisting motion to the incoming steam. The gas offtake is a water-jacketed, 24-inch i.d. steel pipe, centered on and at 90° to the axis of the cylinder but at an angle of 45° to the vertical. In the brickwork are various ports for inserting temperature-measuring devices and for observing the interior. A 12-inch water-jacketed pipe capped with a hinged cover leads outside the building for explosion relief.

The make gas leaves the gasifier through a water-jacketed pipe leading to the bottom of a brick-lined vertical dust leg. Immediately after leaving the gasifier a stream of washed and cooled recycle make gas is added, amounting usually to about 60 percent of the make volume. The purpose of this addition is twofold. First, it serves to reduce without undue heat loss the temperature of the hot gas before it enters the rest of the system; make gas leaving at 2,200° to 2,300° F. is reduced to about 1,800° F. by this addition. Second, it provides combustible material to react with any oxygen that might be present as a result of a coal-feed failure. In the early work the make and recycle gases went from this dust leg directly to the washer-cooler. In later operations it went from the dust leg through the waste-heat boiler, in which the temperature of the gas was reduced to about 700° F.; through a cyclone for removal of dust; and then to the washer-cooler. This is a wooden-hurdle-packed tower, 6-1/2 feet i.d. by 61 feet high, through which water is pumped at a rate of approximately 200 gallons per minute. An exhauster takes suction on the washer-cooler gas outlet and discharges the gas through an orifice-type flowmeter to the storage holder or to the flare stack for disposal. The exhauster is a Spencer turbine-type with a rated capacity of 2,400 cubic feet per minute at 35 inches water-column differential. A butterfly valve in the discharge of this exhauster is actuated by a pressure controller to maintain ±0 inch water column on the gasifier proper. The waste-heat boiler and washer-cooler thus normally operate under slight vacuum. The make-gas recycle line to the gasifier outlet is taken off the exhauster discharge just ahead of the pressure-control damper. There is provision for admission of purge gas both to the washer-cooler and to the gasifier (using the recycle line) as a safety measure in the event of trouble.

The water for the washer-cooler is pumped from a cooling tower to the top of the washer-cooler. The warm, dirty water is then used for sluicing ash and dust from the ash legs, cyclone discharge, and other points. From these it flows to two settling basins, each 6 feet deep, 14 feet wide, and 80 feet long. These are equipped with decanting baffles and with graded sand filter and under-drain system. The dirty water can thus be decanted or filtered depending on the character of the dust and ash it contains. The cleaned warm water is pumped over the cooling tower, and the cycle is repeated. Periodically, the settling basins are drained and cleaned of the accumulated refuse.

The gasifier unit was kept hot between operating periods with air-natural gas burners firing into the steam duct from the pebble heater to the gasifier, and, in general, the pebble heater was kept at normal operating loads.

Before each scheduled period of operation the pebble heater was brought to the desired steam flow and outlet temperature. Enough purge gas was admitted through the emergency flooding line to permit starting the exhauster and placing it on automatic pressure control. The coal- screw motors, which activated the panelboard controls, were then started. With the speed control set at zero, the clutches were engaged on the screws that were to be operated. Enough air flow was established through the mix headers and the oxygen pipes to the gasifier to maintain a velocity of at least 70 feet per second through the oxygen-coal pipes. The coal screws were then brought to a low rate, and in successive steps the air was displaced by oxygen and the coal screws were brought to the desired rate. When the heatup burners were shut off, the brickwork temperature dropped steadily. It was necessary that the preliminaries be completed and coal sent to the gasifier before the brick temperature had dropped below about 1,700° F. Above 1,700° F. ignition of coal from the hot brickwork was reliable.

Most runs were begun with 1 screw only on 1 end of the gasifier, then 3 screws on the other end, and finally 3 screws on each end. During the run period the temperatures were maintained by adjusting the coal or oxygen feed rates. Readings were taken of the temperatures, pressures, and flows throughout the system periodically, and samples were taken of the coal and oxygen fed and the gas produced. At the end of the scheduled period of operation the unit was shut down either by a reversal of the startup procedure or by shutting off the coal-screw motors, which automatically interrupted the oxygen supply and admitted purge gas to the system. The standby burners were then relighted, and the unit was held for the next operation.

The make-gas samples were analyzed by mass spectrometer and the oxygen samples by absorption in cuprous chloride. It was found, in general, that after not more than 2 hours' operation the temperatures, rate of gas production, and gas composition were constant. Calculations were usually made covering the period from this point to the end of the run.

## OPERATIONS

### Initial Heating

When the interior brickwork had been completed, natural gas burners were inserted through the cones at each end to dry the brickwork and bring it to operating temperatures. The pebble heater also was started on a very low rate of air through the steam section to carry additional heat into the gasifier and remove the moisture. Because of the silica lining, particular care was necessary to avoid spalling as the temperature passed through the silica transition points. Heating was first commenced on March 21, 1949, and by May 1 the temperature had been raised to 1,500° F. From this time until the shutdown of the unit on April 27, 1950, the temperature of the brickwork was maintained at 1,500° F. or above without interruption.

### Preliminary Tests

While the rest of the unit was being completed, preliminary tests were made - first, to calibrate the coal screws for delivery rate as a function of speed, and, second, to test the oxygen transport of coal and the actual combustion of the oxygen-coal mixture. A brick tunnel was constructed outside the building, approximately 2-1/2 feet square by 15 feet long, in 1 end of which 1 of the water-jacketed burner nozzles was inserted, fed by 1 coal and oxygen pipe from the No. 2 screw on the south end. These tests furnished much information regarding the minimum allowable velocity in the transport pipes, the allowable oxygen-coal ratios, etc. It was found that if the velocity in the coal pipes dropped below about 70 feet per second, the burner