flame would flash back through the pipe. The sound of the flashback always prompted the operator to shut off the coal and oxygen immediately, so that no damage was done except that caused to the flame arrestor by the pressure wave. In 1 or 2 instances in actual operation of the gasifier later, the feed was not cut off immediately so that the flame was not extinguished and burned for a short time at the end of the coal screw.

The tunnel tests also furnished opportunity for the operating personnel to become familiar with the panelboard controls and their operation.

Initial Operations

When the construction of the gasifier system was virtually complete, these tunnel tests were terminated and the first trial operation of the gasifier was run on May 4, 1949. To make the conditions as mild as possible, the unit was started with the full steam rate of about 2,000 pounds per hour, heated to a temperature of about 2,000° F. Only the No. 2 coal screw on the south end was used, with a coal rate of about 400 pounds per hour and an oxygen flow of about 3,000 cubic feet per hour. This operation was continued for approximately 2 hours. Temperatures ranged from 1,600° to 1,700° F. About 15,000 cubic feet of gas per hour was produced, containing about 28 percent carbon dioxide with a hydrogen-carbon monoxide ratio of 2.6:1. The high hydrogen and carbon dioxide in this gas were, of course, due to the very high steam-coal ratio employed.

Trial runs were then made in which 2, 3, and 4 coal screws were used, leading to run 4 on June 8, 1949, in which design coal and oxygen rates were reached. The operation of the unit was quite satisfactory. However, during the latter part of run 4 the coal-oxygen flame on the No. 3 screw at the south end flashed back, and after the run evidence of slight slag deposition was observed in the cones around the burner nozzles.

In the next few runs various means were tried to prevent the flashback and to minimize the slag deposition. Previous tunnel combustion tests had demonstrated that to prevent flashbacks a minimum pipe-flow velocity for the coal-oxygen stream of 70 feet per second was necessary. This was not always attained in the early tests, owing partly to the fact that in using multiple tubes for oxygen-coal transport it was difficult to balance the flows exactly. Although the total flow might have provided an adequate velocity when divided equally per pipe, in actual practice it was not so divided, and quite often 1 or 2 of the pipes would operate at a marginal flow rate. To aggravate this situation, some of the pressure surges in the line might have dropped the flow below the 70 feet per second and thus precipitated the flashback.

It was thought that these fluctuations might be due to accumulations of coal on the walls of the pipes, and an attempt was made at systematic pipe rapping during the runs. This effected some reduction in the line surging but apparently did not eliminate the flashbacks, which persisted through run 8.

A particular effort was made to maintain the velocity in the individual coal pipes above 70 feet per second. Also, the oxygen purity dropped from 98-1/2 to 95 percent by dilution with air at the intake of the oxygen booster. No further flashbacks were encountered after this, except in runs 25, 40 and 43 and in run 36, which was made with an extra fine coal grind. No further study of the problem was made, as it was concluded that the most critical factor was the velocity of the oxygen-coal stream in the transport pipes.

However, the oxygen concentration was kept at 95 percent throughout the rest of the work on this unit. This would be about the purity of tonnage oxygen, and it was felt that the results might be more generally applicable.

To prevent slagging around and over the burner nozzles, new burners, which projected 4 inches out into the cones, were installed for run 5. However, the nozzle on the south end developed a cooling-water leak in the course of the run and had to be replaced by one of the original flush burners for run 6. Inspection after this run indicated very clearly that slag deposition on and around the flush burner nozzle was much greater than around the one on the north end with the 4-inch projection. A new 4-inch projection burner was installed in the south end for run 9, and slagging in the cones was reduced after this change.

In these early runs a visual examination of the interior of the gasifier was made after each of the runs through peepholes located in the gasifier shell at strategic points. These permitted observation of the slagging around the burners as well as in the ash legs. It was also noted that the annular steam rings in the cones around the burners had developed definite cracks by run 5. As these rings were designed to whirl the steam out to the gasifier lining and thus assist in protecting it from high-temperature attack, this development was cause for some concern. However, no particular erosion of the lining was noted in these early runs.

Some slagging over of the ash-leg ducts at the floor of the gasifier was also noted in these inspections; but, from its appearance and the small amount of ash, slag, and cokelike material actually withdrawn from the ash legs (through the water seal), the gasifier appeared to be operating in a manner to pass virtually all the mineral matter of the coal out in the effluent gas stream. This material was scrubbed out of the gas with water and sent to the settling basin. Analyses of this ash and a few checks on its volume were later determined. In the early series of runs (through run 12) the ratio of oxygen to coal was kept low (below 8 cubic feet of oxygen per pound of coal) because of the desire to explore cautiously the temperature effects on the gasifier lining. Later, when higher oxygen-coal ratios were employed, the quantity of slag deposited in the gasifier and collected through the ash legs increased appreciably. The coal grind for these first 12 runs was 75 percent through 200-mesh.

Two means of determining coal rates were available - the speed of the previously calibrated coal screws and the weigh-hopper data. Frequently, the two did not agree, and after the first few runs the weigh-hopper data were taken as final.

After run 12 it was felt that enough operating experience had been gained to proceed with the study of process variables in the gasifier performance. A number of minor repairs and alterations were made at this time to improve the facility for operation and collection of data. The data for the first 12 runs are of questionable value because of the exploratory nature of the operations. Consequently, these data are not presented, nor are they considered in the analysis of the gasifier's performance.

Study of Process Variables

Ratio of Oxygen to Coal

The ratio of oxygen to coal is expressed as standard cubic feet[7] of 100-percent oxygen to the pounds of dry coal fed to the gasifier. The coal used in this study (from Rock Springs, Wyo.) was consistent enough in analysis that expression of the results on the basis of oxygen-carbon ratio made no important difference in the results. (See Appendix for coal analyses.)

In this study runs were selected in which virtually the only variable was the oxygen-coal ratio. However, this could not be achieved entirely, owing to variations in the feed of reactants and in the performance of the gasifier itself. For this reason, in classifying the data for analysis arbitrarily selected ranges were chosen for the other variables, such as steam-coal ratio and process-steam temperature. Within these ranges the data were remarkably consistent in demonstrating the effect of the oxygen-coal variable, as noted later. The data from all the runs (after run 12) that met the following requirements were used. Detailed data for these runs and all others after run 12 are presented in Appendix A.

1. Duration of run, 1/2 hour or longer, after operations were stabilized.

2. 6 burners operating.

3. 4-inch- or 16-inch projection burners used.

4. 0.8 to 1.2 pounds of steam per pound of coal.

5. 1,485° to 1,750° F., temperature of process steam.

6. 1,975 to 2,350 pounds per hour, coal-feed rate. Rock Springs, Wyo., coal ground to 85 to 90 percent through 200-mesh sieve.

7. 94-1/2 to 97 percent process oxygen.

Average coal-particle residence time in the gasifier under these conditions ranged from 2-1/2 to 3 seconds.

No attempt was made to control the gasifier temperature. The average of the cone temperatures obtained ranged from 2,375° to 2,665° F.

Table 1 presents data obtained by this selection.

7/ Standard cubic feet for this report stands for dry gas at 60° F. and 30 inches Hg and will be abbreviated to std.c.f.

TABLE 1. - Conversions and temperatures - base runs

Run No.	Std.c.f. 100-percent oxygen per lb. dry coal	Carbon conversion percent	Temperature, °F.	
			Average in cones	Gas exit
14A..	7.6	68.5	2,375	2,110
14B..	7.8	70.0	2,370	2,140
14C..	8.1	71.4	2,460	2,160
23A..	8.9	81.0	2,525	2,335
16...	9.0	78.9	2,520	2,230
40A..	9.1	79.5	2,490	2,260
26...	9.2	81.7	2,595	2,390
17...	9.6	83.1	2,515	2,275
23B..	9.7	85.7	2,650	2,415
18...	9.8	83.6	2,625	2,295
32...	11.0	89.8	2,665	2,405

In figure 4 the carbon conversion is plotted against the oxygen-coal ratio, and in figure 5 the gasifier cone and exit gas temperatures are shown to be functions of the oxygen-coal ratio. Figure 4 is considered a basic performance curve for the Koppers gasifier, and data obtained from runs made under conditions varied beyond the scope of the specified categories will be compared to it.

Another measure of gasification performance is the requirement of coal and oxygen per unit of synthesis gas ($CO + H_2$) produced. These requirements can be combined into an arbitrarily devised "economic factor." This, in effect, expresses the charge for coal and oxygen per 1,000 (M) standard cubic feet of $CO + H_2$. In computing it 10 cubic feet is taken to be equivalent to the cost of a pound of coal. Thus, the economic factor will be the sum of the pounds of coal and one-tenth of the cubic feet of oxygen consumed in producing 1,000 standard cubic feet of $CO + H_2$.

Table 2 gives the coal and oxygen requirements (per M std.c.f. of $CO + H_2$) and the economic factors for the runs previously selected.

TABLE 2. - Materials requirements and economic factors - base runs

Run No.	Oxygen-coal ratio	Lb. dry coal per M std.c.f. $CO + H_2$	Std.c.f. O_2 per M std.c.f. $CO + H_2$	Economic factor
14A....	7.6	45.1	344	79.5
14B....	7.8	44.4	345	78.9
14C....	8.1	43.6	351	78.7
23A....	8.9	38.2	338	72.0
16.....	9.0	38.9	350	73.9
40A....	9.1	37.5	342	71.7
26.....	9.2	38.9	359	74.8
17.....	9.6	38.2	365	74.7
23B....	9.7	37.1	362	73.3
18.....	9.8	37.2	365	73.7
32.....	11.0	36.4	398	76.2

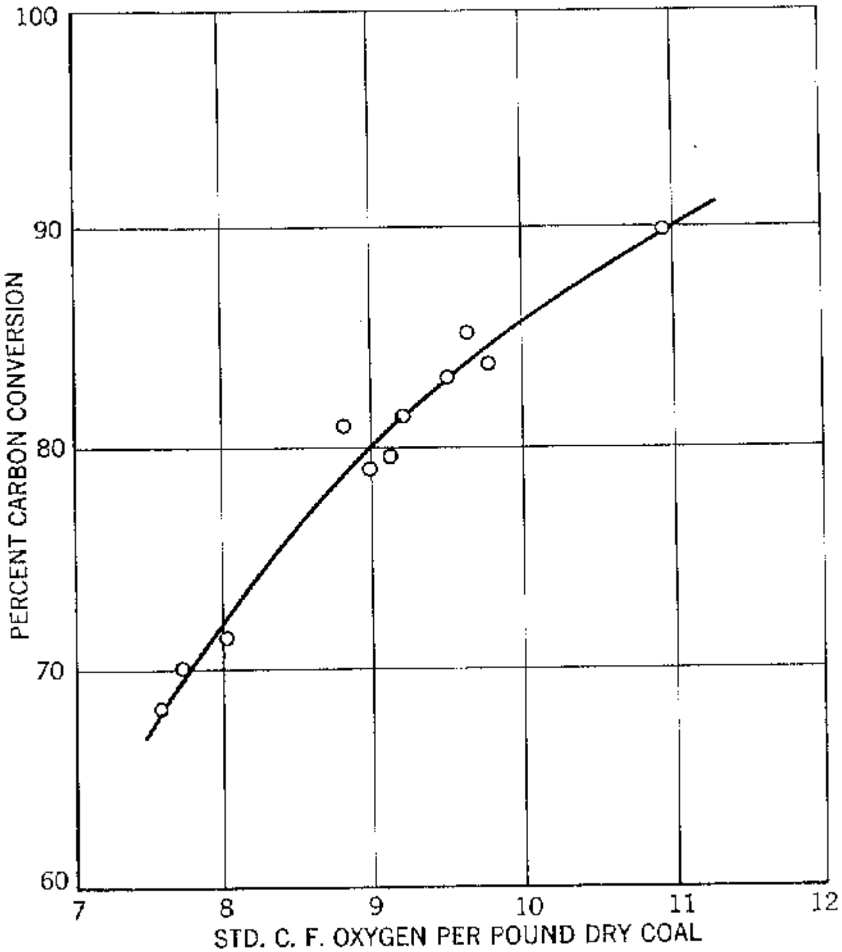

Figure 4. - Effect of oxygen-coal ratio on carbon conversion—base runs.

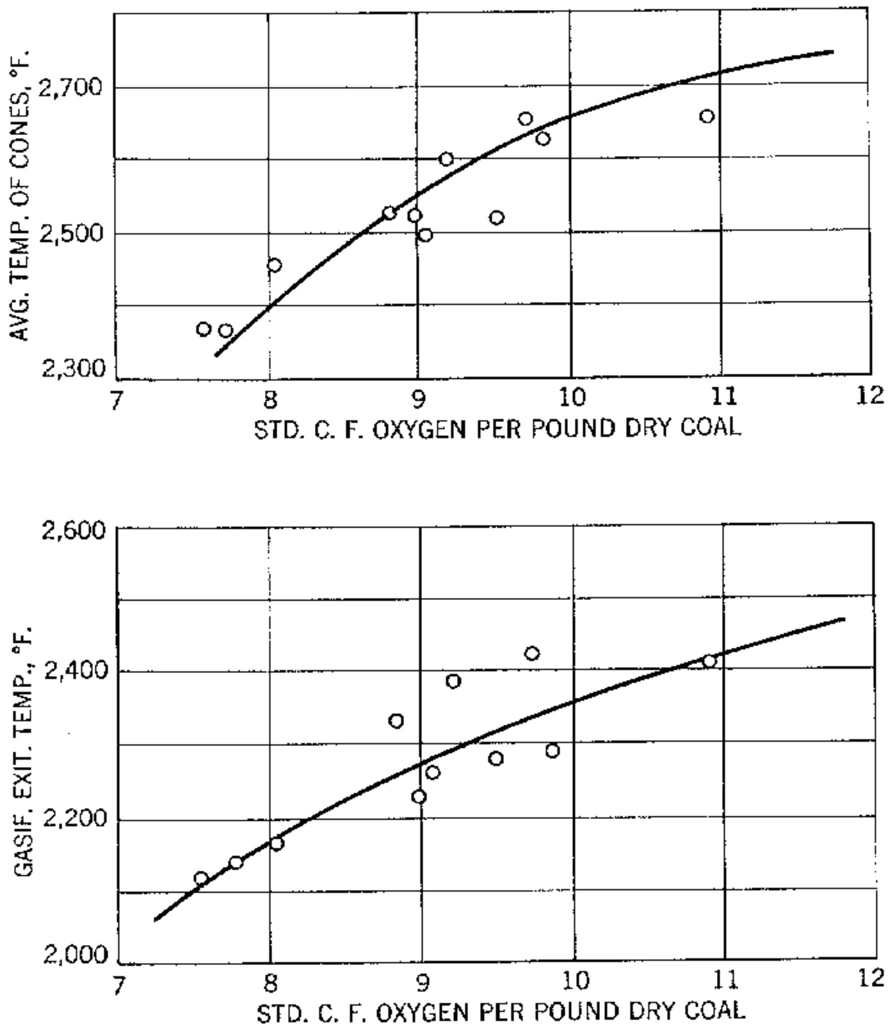

Figure 5. - Effect of oxygen-coal ratio on gasifier temperatures—base runs.

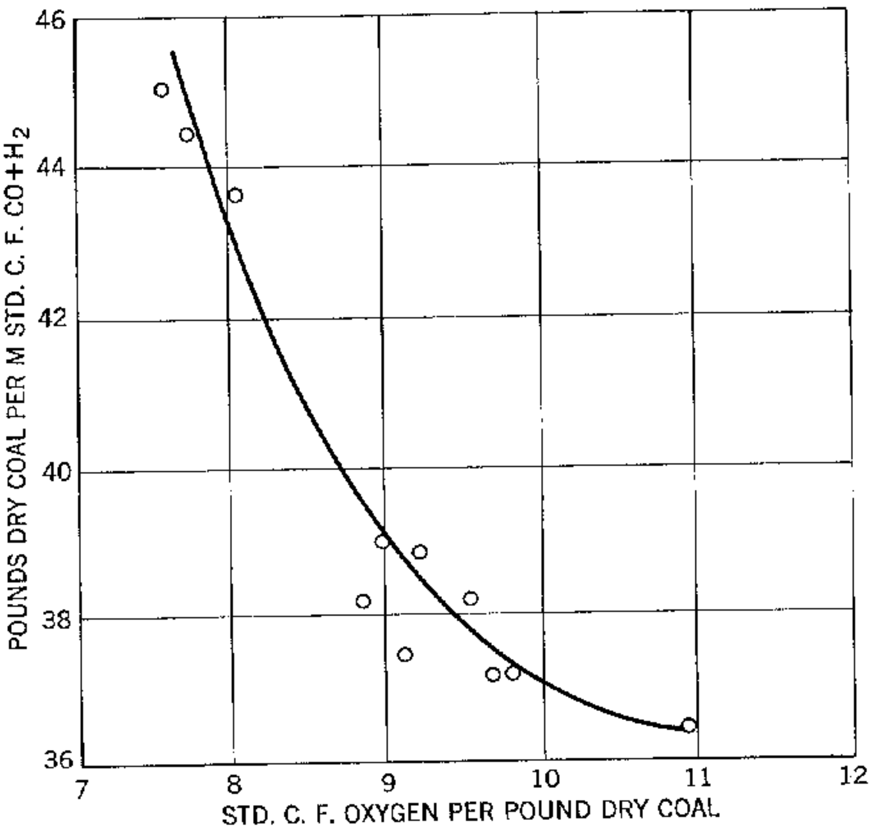

Figure 6. - Effect of oxygen-coal ratio on coal requirements—base runs.

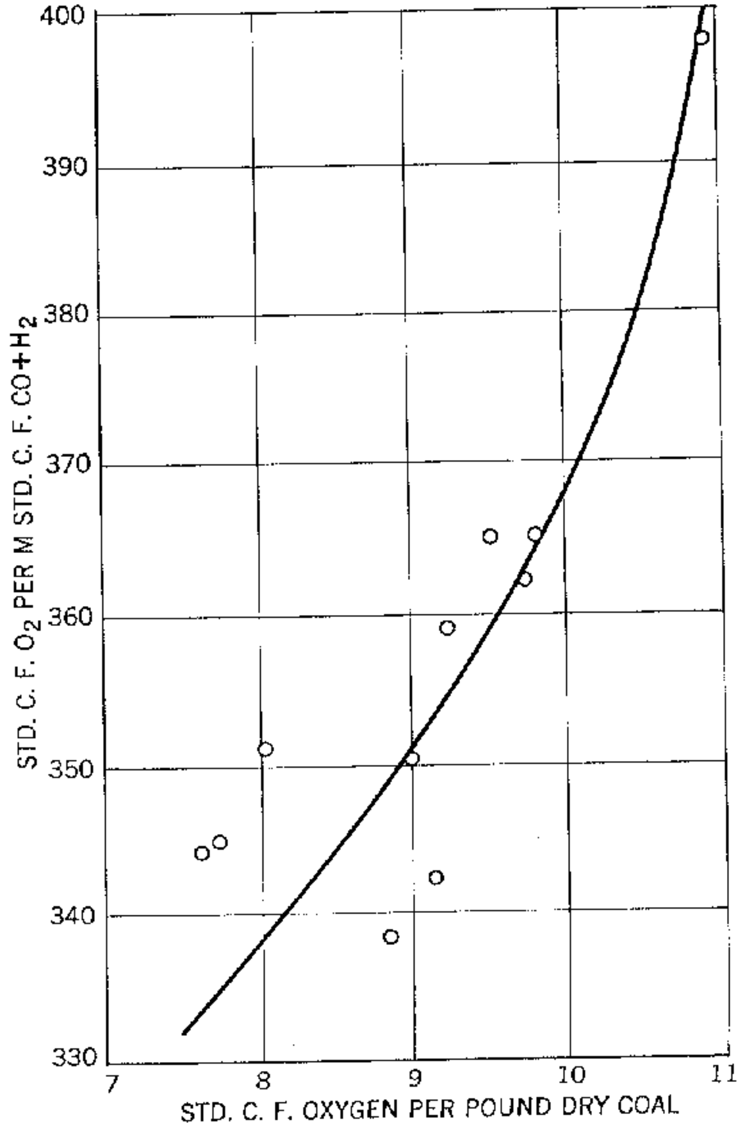

Figure 7. - Effect of oxygen-coal ratio on oxygen requirements—base runs.

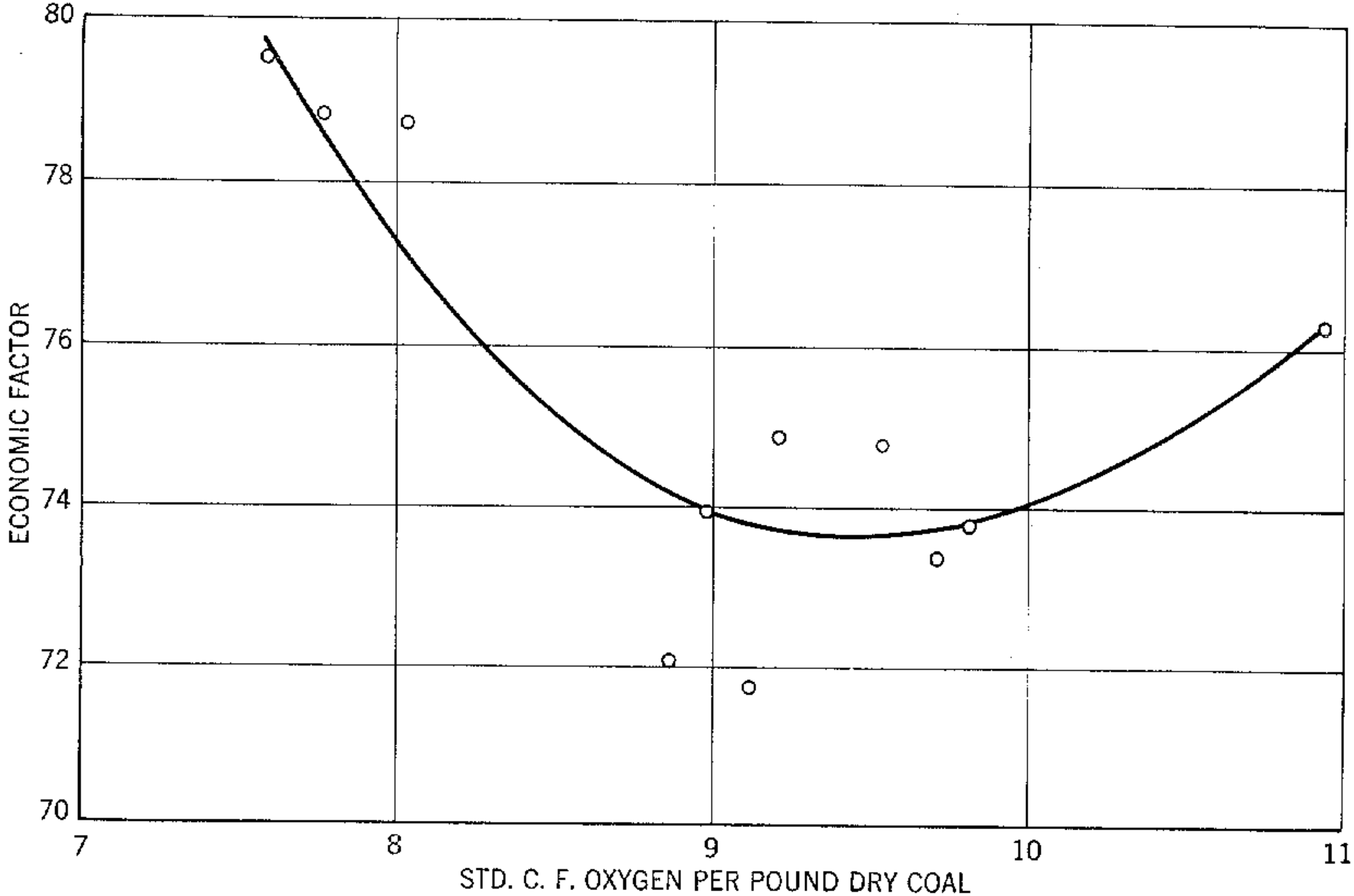

Figure 8. - Relation between economic factor and oxygen-coal ratio—base runs.

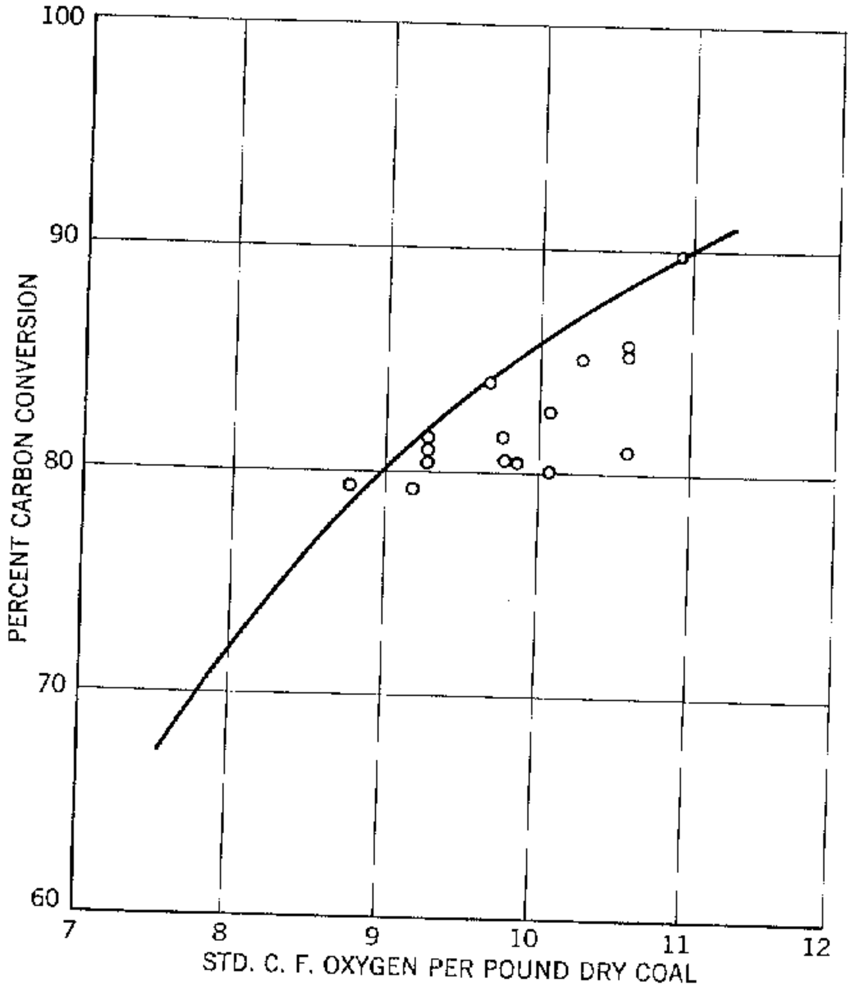

Figure 9. - Effect of varied steam addition on basic relation between carbon conversion and oxygen-coal ratio—points from table 3.

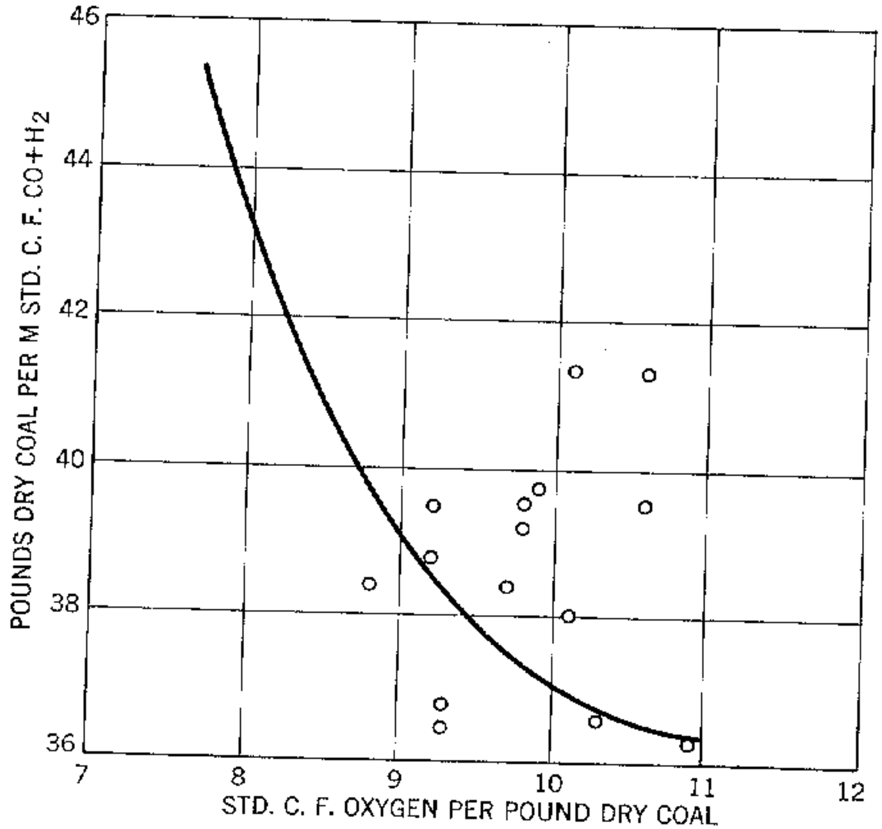

Figure 10. - Effect of varied steam addition on basic relation between coal requirements and oxygen-coal ratio—points from table 3.

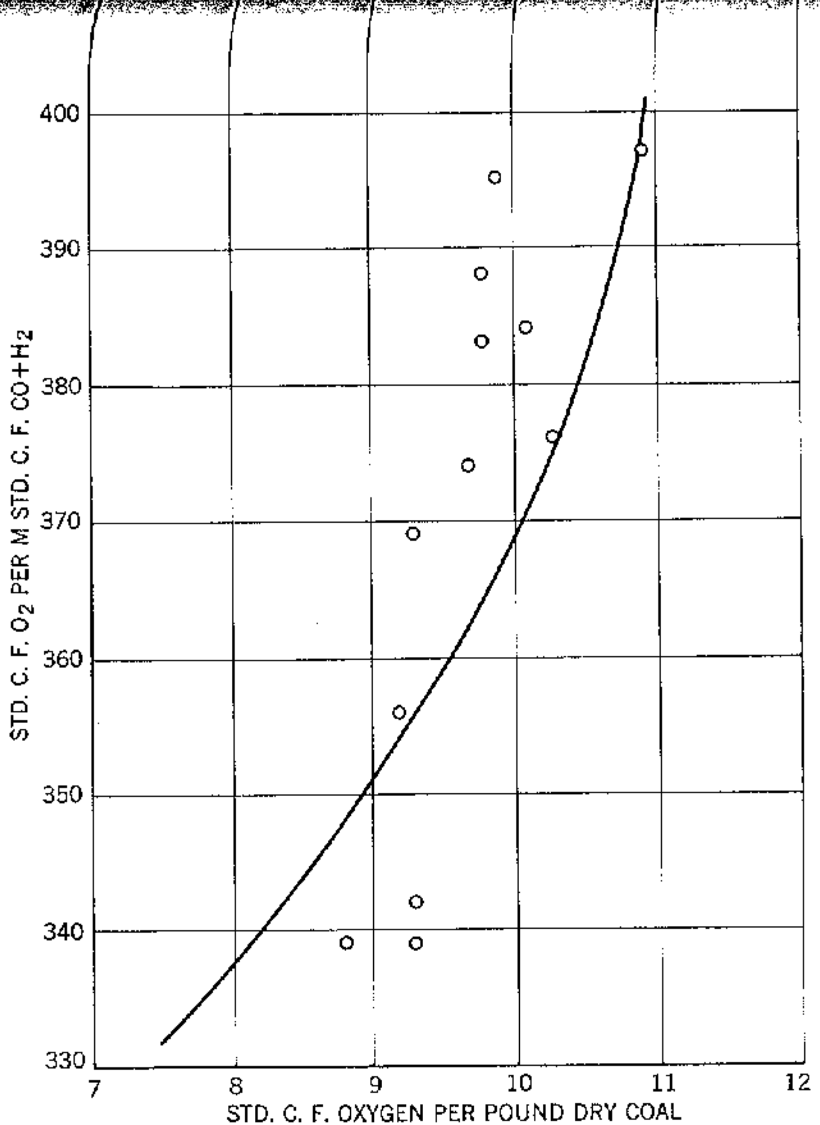

Figure 11. - Effect of varied steam addition on basic relation between oxygen requirements and oxygen-coal ratio—points from table 3.

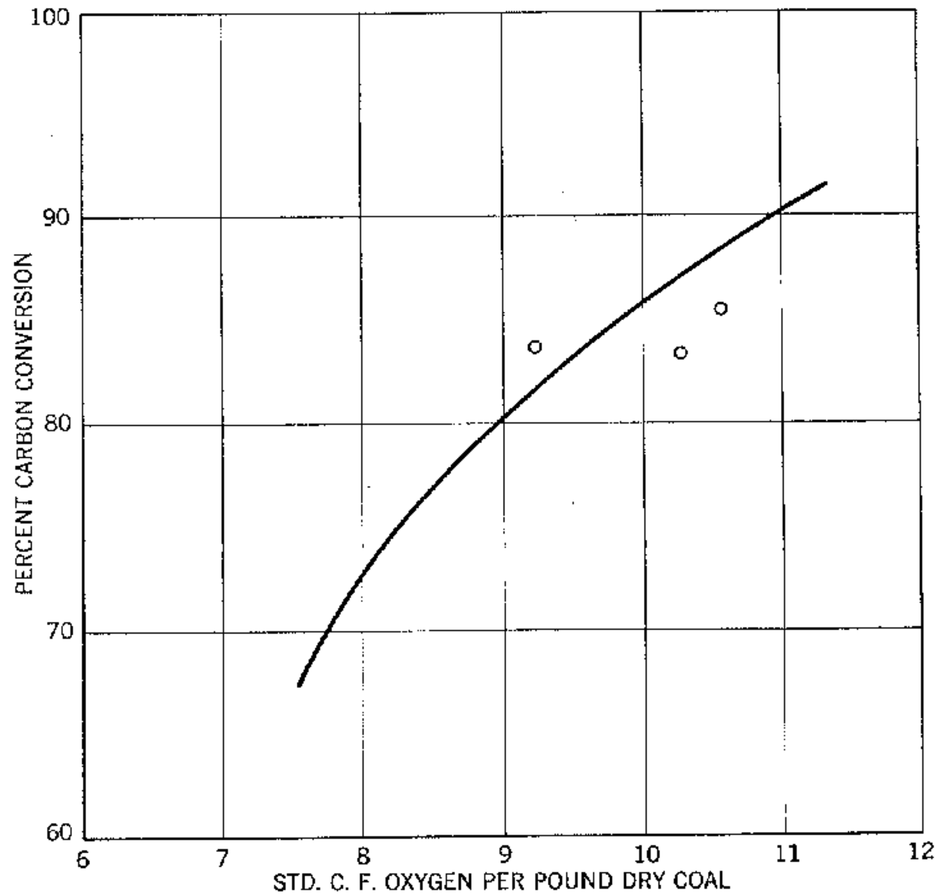

Figure 12. - Effect of burner length on basic relation between carbon conversion and oxygen-coal ratio—points from table 4.