The coal and oxygen requirements and the economic factors are plotted against the oxygen-coal ratios in figures 6, 7, and 8. The coal requirement is probably about the minimum at 11 cubic feet of coal, because when in excess of 12 cubic feet there is enough oxygen to convert all the carbon to carbon monoxide, and any amount beyond this would begin burning synthesis gas. The oxygen requirement obviously goes to infinity as the oxygen-coal ratio is increased to the point where enough oxygen is supplied to burn all the carbon and net hydrogen in the coal to carbon dioxide and steam. This assumes complete conversion of the oxygen in the gasifier, and in none of these data was there evidence to the contrary (see gas analyses in Appendix).

It appears from the plot of the economic factor (fig. 8) that a minimum requirement for Rock Springs, Wyo., coal and oxygen is achieved in the range of a 9 to 10 oxygen-coal ratio. Some of the points for this plot are quite scattered, but the curve indicates the general trend.

The economic factor cannot be used as an index of total operating cost, nor, in general, can it be used to compare this gasifier with others operating under different conditions. It is useful primarily in comparing results of a given gasifier under various operating conditions.

Method of Adding Steam

In attempts to increase the gasification efficiency variations in the method of adding steam to the gasifier were tried. The object was to obtain greater agitation of steam with coal to promote the carbon-steam reaction and thus produce more synthesis gas ($CO + H_2$) per unit of coal and oxygen.

The pertinent data from these runs are presented in table 3. The data are plotted in figures 9, 10, and 11, which also show the curves obtained from the base runs, as noted under Ratio of Oxygen to Coal.

TABLE 3. - Summary of data from runs made with varied steam addition

Run No.	Oxygen-coal	Carbon conversion, percent	Lb. coal per M std.c.f. $CO + H_2$	Std.c.f. O_2 per M std.c.f. $CO + H_2$	Economic factor	Average cone temp., °F.	Exit gas temp., °F.
19	10.1	82.8	38.0	384	76.4	2,620	2,220
20A	10.1	80.0	41.3	417	83.0	2,430	2,230
20B	9.9	80.1	39.7	395	79.2	2,630	2,270
20C	9.8	80.1	39.2	383	77.5	2,640	2,325
21A	9.8	81.5	39.5	388	78.3	1/2,545(N) 1/2,165(S)	2,180
21B	9.7	84.1	38.1	374	75.5	1/2,250(N) 1/2,635(S)	2,250
28A	10.6	85.2	39.5	422	81.7	2,090	2,150
28B	10.6	85.5	39.5	420	81.5	2,075	2,135
28C	10.6	81.0	41.3	439	85.2	2,100	2,180
29	8.8	79.2	38.4	339	72.3	2,470	2,335
31	9.2	79.1	38.8	356	74.4	2,535	2,355
32	10.95	89.8	36.3	397	76.0	2,665	2,405
41A	9.3	81.0	36.8	342	71.0	2,280	(2)
41B	9.3	81.5	36.5	339	70.4	2,240	(2)
44	10.3	85.1	36.6	376	74.2	2,425	(2)
46	9.3	80.2	39.6	369	76.5	2,325	2,210

1/ Large variance due to unbalanced firing rate in opposing cones, "N" being north cone and "S" the south cone.
2/ Temperature recorder out of service.

A description of the runs follow:

Run 19: Steam was introduced through 4 pipes with 1/8-inch nozzles on the tips into the gasifier through sight ports in the barrel. Saturated steam at 50 p.s.i.g. was used. About 50 pounds of steam per hour was passed by each nozzle. Except as noted, in all other respects this run met the requirements used for the selection of data for table 1.

Comparison with the base curves indicates that this run was somewhat poorer with respect to carbon conversion and oxygen and coal requirements. Rather than having increased the steam decomposition, it appears to have acted only as a thermal burden on the process.

Run 20: This run was broken up into a series of three. Except for the auxiliary steam, the conditions were similar to those selected for the oxygen-coal ratio analyses.

A. Auxiliary steam was injected into the gasifier through 1/2-inch tubes in the center of each burner nozzle. These tubes were originally installed for introducing natural gas for heatup. Steam at 275 pound pressure was used and throttled before entering the burner. About 100 pounds of steam per hour was fed into each burner.

It was hoped that by adding the steam in this manner an intimate mixture of steam and coal would be obtained, which would result in increased carbon-steam reaction.

B. This part of the run was a repeat run 19, to check and compare with other sections of its parent run. The same steam lances and quantities of steam were used.

C. This part of the run was made without auxiliary steam for direct comparison with results from the preceding two sections.

Compared with the base curves (see figs. 9, 10, and 11), runs made with the injected steam gave poorer results. The last part of the run (20C) was also poorer for some reason, but still better than 20A and 20B.

After the run the steam ring in the south end of the gasifier was noted to be in poor condition, and it was thought to have had an adverse effect on performance. Both steam rings had been patched in run 8 but depreciated slowly in subsequent runs. However, the north ring was still in fair shape at this time.

Run 21: To test the effect of the broken ring in the south end, this run was made in two sections: (21A) With 3 burners operating in the south end and 1 burner in the north and (21B) with 1 burner operating in the south end and 3 in the north. It was reasoned that if the ring made any appreciable difference, this would become apparent in the overall gasification results. The results, as noted in the summary data, table 3, would indicate somewhat better performance in run 21B. Thus, the broken steam ring may have been beneficial, owing possibly to a more random type of steam introduction. This was tested further in run 29, when the steam ring was removed.

Run 28: This run was one of a special series made with 45-inch burner nozzles. It is analyzed separately in a later section on burner nozzles as a variant. However, the data are presented here to show the effect of steam injection through the center of these burners, as in run 20A. Except for the longer burner nozzles, the run conditions were similar. Run 28A was made with no steam injection, 28B was made with about 40 pounds of steam per hour through each burner, and 28C was made with about 80 pounds per hour per burner. As in previous results with steam injection, the effect seems to have been primarily that of a thermal burden, the overall gasification efficiency declining with steam addition.

Run 29: As noted above for this run, the steam ring was removed from the south end of the gasifier. At the same time a flush burner was installed in this end of the gasifier to more thoroughly mix the steam at this point with the coal-oxygen stream. A 16-inch projection nozzle was installed in the north end, the 45-inch nozzles having been abandoned after run 28. The results from this run are somewhat better than indicated by the base curves, although not enough to be significant.

Runs 31, 32, and following: For run 31 one modified ring was installed in the north end, and in run 32 a modified steam ring was also installed in the south end. These modified rings were designed to impart less spin to the entering steam. Run 31 was otherwise similar to run 29. For run 32 the flush burner in the south end was replaced with a 16-inch burner.

No effect of the steam-ring modification was detectible. These rings were therefore used in all later runs, and no differentiation was made in the data analysis between these runs and those made with the original ring.

Run 41: For this run steam superheated in a gas-fired coil was introduced into the gasifier, using a 1-inch pipe, which was run through the center of the north burner nozzle, ending flush with the nozzle face. In run 41A, 450 pounds of steam was used per hour, superheated to enter the gasifier at 1,000° F. The calculated inlet velocity was about 2,000 feet per second. In run 41B the added steam was 270 pounds per hour at 1,100° F. Velocity in this run was 1,300 feet per second. In all other respects the conditions of this run conformed to the requirements for the runs listed in table 1.

It was thought that the high-speed jet of superheated steam, firing directly through the core of both oxygen-coal flames might aid in mixing steam with carbon particles to promote gasification. The results seem to indicate some improvement. However, after the run slag was found to be plastered well back in the south cone. Obviously, continued operation under these conditions was not feasible. This line of test work was therefore discontinued, although the results indicated some possibility for improved gasification by modification of the method of introducing steam. Perhaps, more fundamentally, this may have indicated an effect to be obtained by truly increased agitation of the reactants.

Runs 44 and 46: For these runs superheated steam was injected into each oxygen-coal pipe at a point before the pipe entered the burners. Much difficulty was experienced with erratic operation and flashbacks. Run 44 was terminated with a flashback that burned out a feed pipe. The next 2 runs were then made with 5 burners. Operation during run 45 was so erratic that no calculations were attempted. Actually, steady operating conditions were never attained during the runs, as the steam-injection rates were still being increased when shutdowns occurred.

However, "on stream" data for runs 44 and 46 were reported for comparison. These data indicate no improvement in gasification over the basic operating performance of the gasifier.

Although many data in this series are erratic, it was concluded that variations of the method of steam injection had little effect on the gasification process except where violent agitation could be obtained. Mechanical difficulties blocked further studies of this nature.

Coal Mesh Size

The runs from which data for the base curves were selected were made with coal ground to pass 85 to 90 percent of the total through a 200-mesh sieve. It was reasoned that an improved gasification efficiency might result from an increase in surface area per pound of coal.

The existing coal-grinding system was modified to recycle coarse coal from the cyclone hopper to the ball mill. Thus, only the fines that carried from the cyclone to the bag filters were collected for gasification. This procedure resulted in a coal grind with a mesh analysis of 92 percent through 325-mesh. Almost 100 percent of the coal passed the 200-mesh sieve.

This coal was gasified in run 36. Four-inch burners were used with the modified steam rings. Other conditions of the run, except for the coal mesh, conformed to the requirements for the base runs (table 1). Although the coal feed, as indicated by pressure in the feed tubes and cone temperatures, appeared to be erratic, the run was made without incident. Pertinent data, compared with base-run data made at comparable oxygen-coal ratios, follow:

		Base runs	
	Run 36	18	23B
Duration of run .... hr.	3	3	3/4
Oxygen-coal ratio,std.c.f. per lb.	9.8	9.8	9.7
Carbon conversion .... percent	89.0	83.6	85.7
Pounds coal per M std.c.f. $CO + H_2$	35.1	37.2	37.1
Std.c.f. O_2 per M std.c.f. $CO + H_2$	342	365	362
Economic factor	69.3	73.7	73.3
Average cone temperature.......°F.	2,535	2,625	2,650
Exit gas temperature ....do.	2,395	2,295	2,415

This comparison indicates that a real improvement in performance was achieved, but the results of only one run cannot be taken as conclusive.

Several attempts were made to repeat this run, but these were terminated by a series of flashbacks. This probably developed from the erratic feed characteristics of the very fine coal. It may have fluidized at times and flowed through the screws rather than having been impelled. Apparently, only good luck permitted the first run to be made without incident. There appeared to be no way of solving the difficulty with the screw feed system, so no further studies were made with the fine-mesh coal.

Length of Burner Nozzles

The original purpose of projecting the burner nozzles out into the gasifier from a position flush with the steam rings was to eliminate the problem of slag drip over the face of the nozzles, which had caused some trouble in the early runs. Later, in studying variables in gasifier performance the question of the effect of burner-nozzle length on gasification efficiency was considered.

Results of several runs made with 4- or 16-inch nozzles indicated that these two were interchangeable as far as the effects on gasification efficiency itself were concerned. In the data analysis they have been so considered.

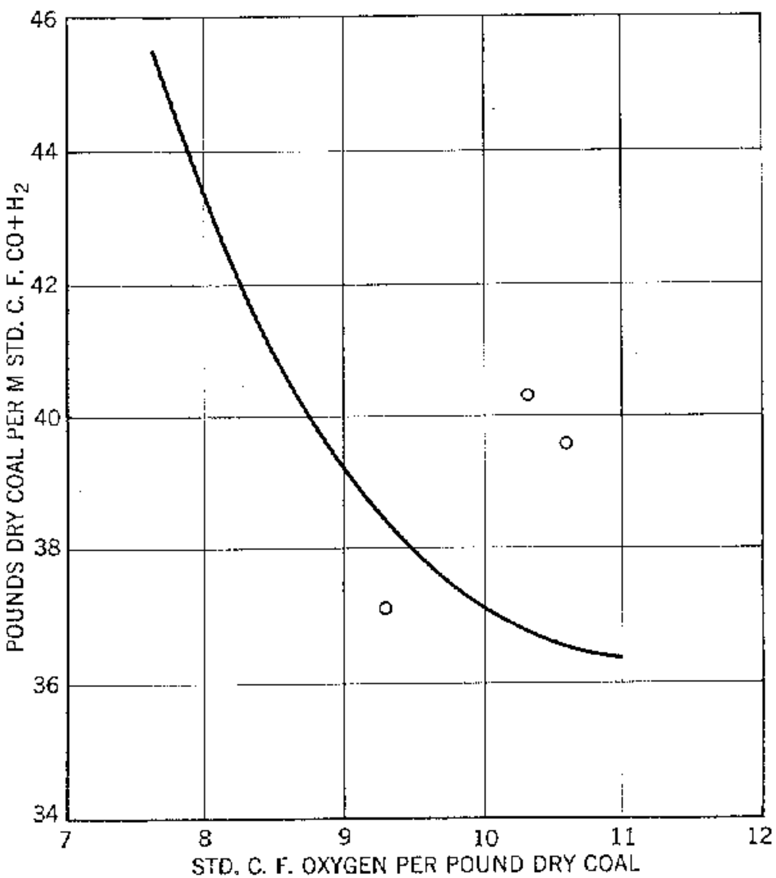

Figure 13. - Effect of burner length on basic relation between coal requirements and oxygen-coal ratio—points from table 4.

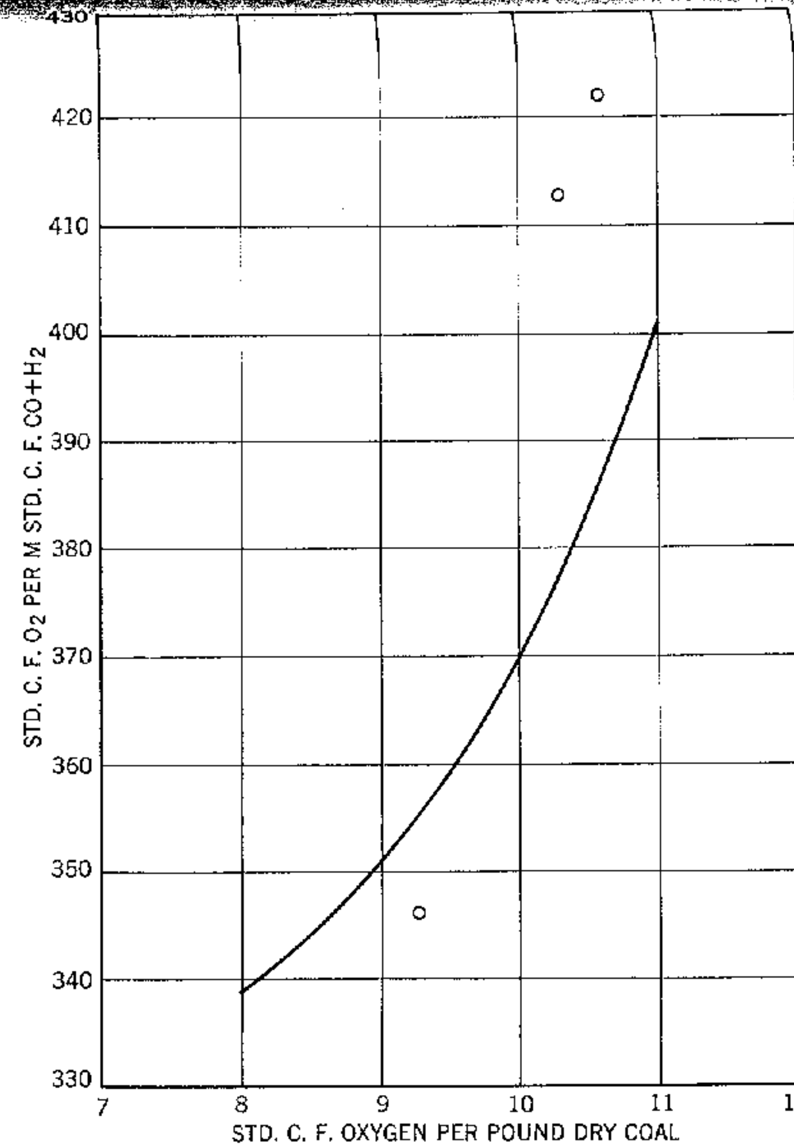

Figure 14. - Effect of burner length on basic relation between oxygen requirements and oxygen-coal ratio—points from table 4.

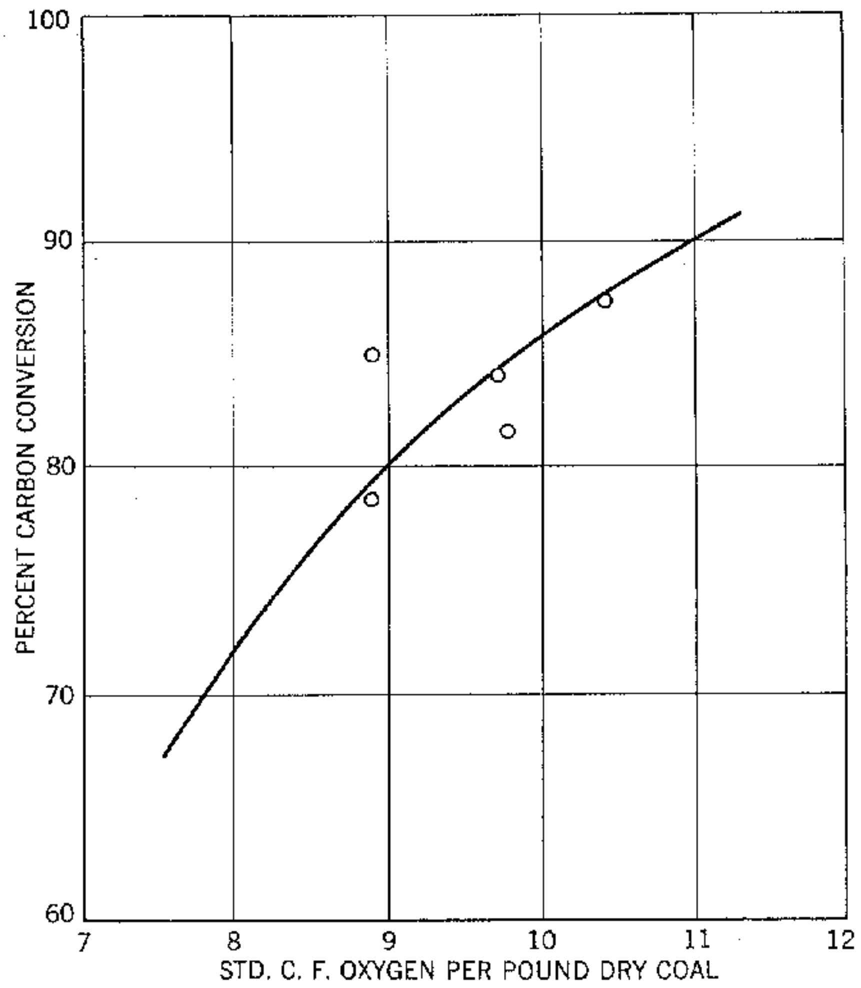

Figure 15. - Effect of steam-coal ratio on basic relation between carbon conversion and oxygen-coal ratio—points from table 5.

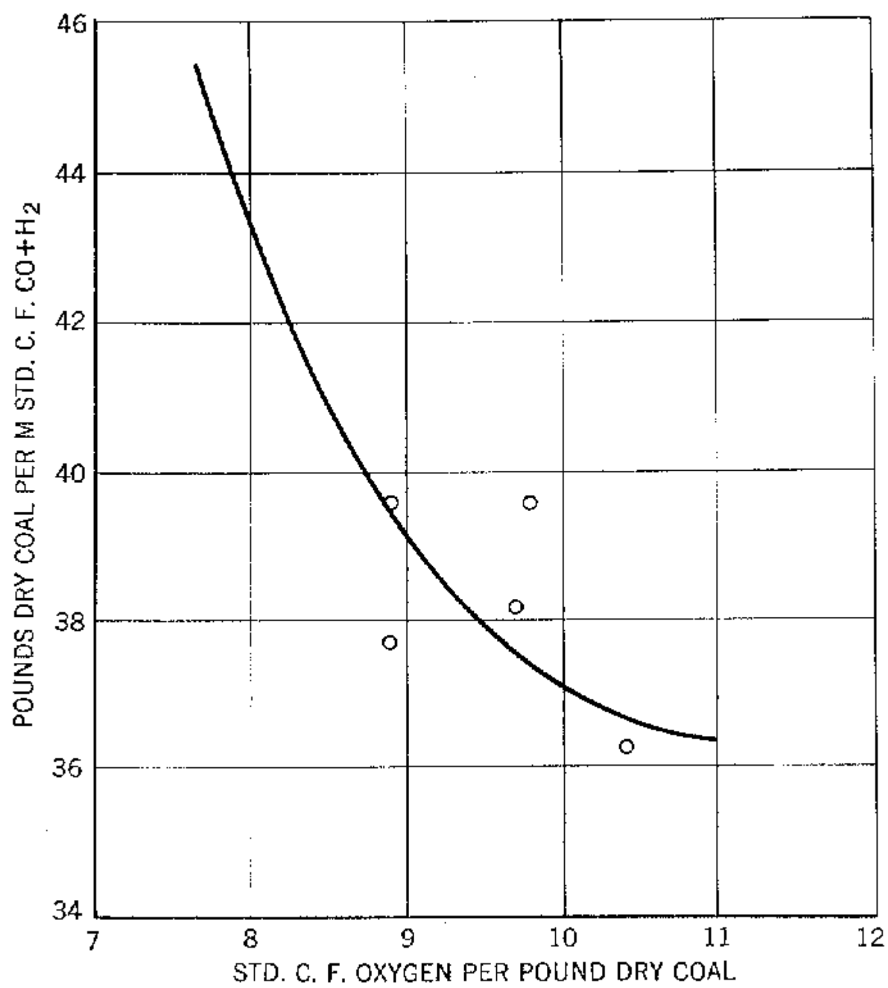

Figure 16. - Effect of steam-coal ratio on basic relation between coal requirements and oxygen-coal ratio—points from table 5.

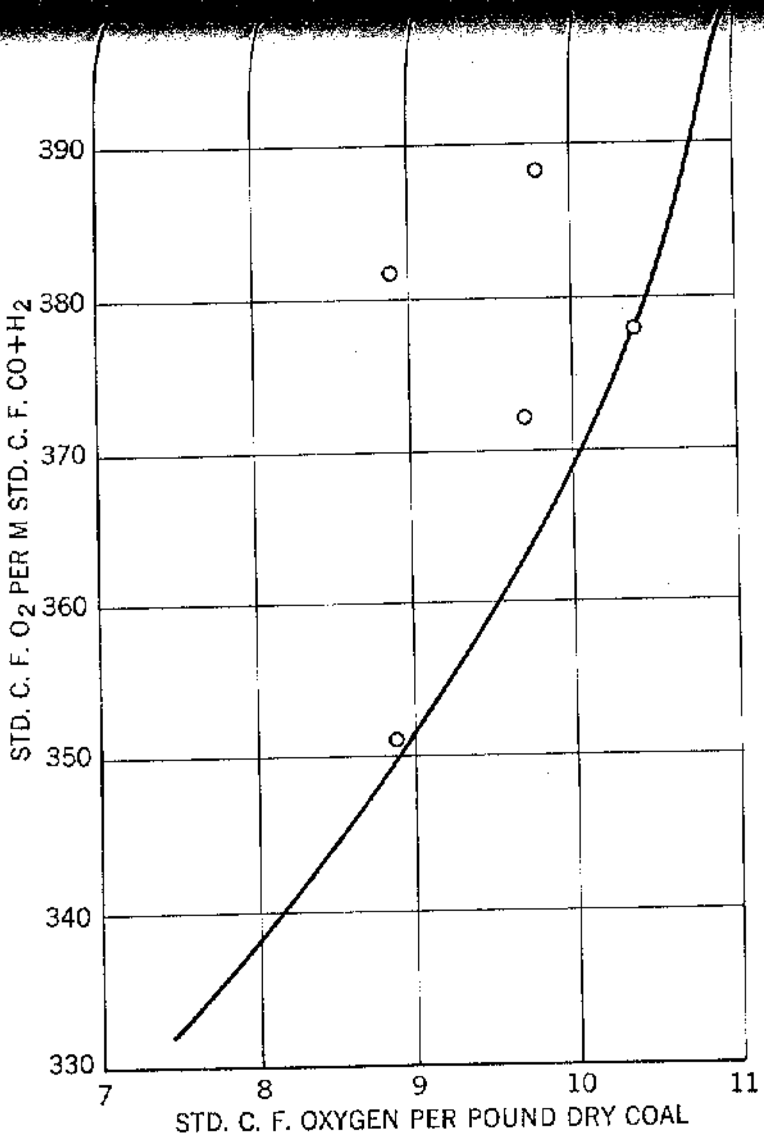

Figure 17. - Effect of steam-coal ratio on basic relation between oxygen requirements and oxygen-coal ratio–points from table 5.

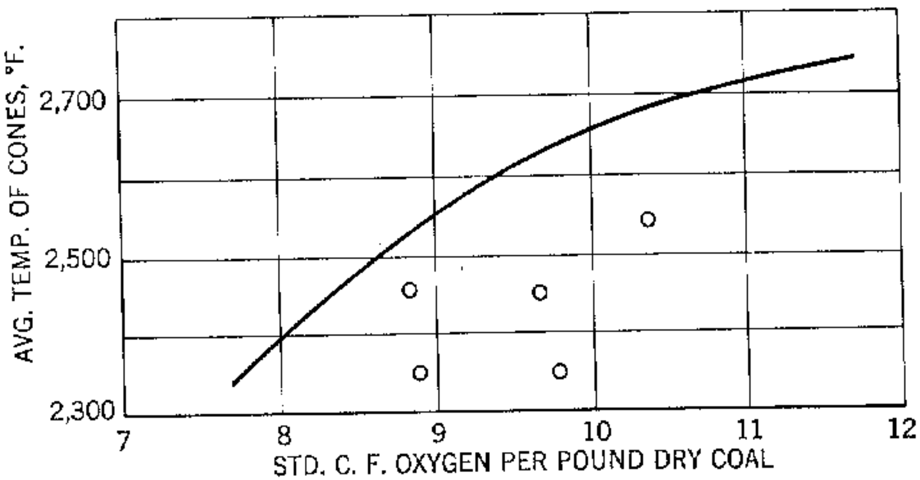

Figure 18. - Effect of steam-coal ratio on basic relation between cone temperatures and oxygen-coal ratio–points from table 5.

Burner nozzles projecting 45 inches into the gasifier were tested in runs 27 and 28. This amount of projection carried the nozzle face to a point about even with the base of the gasifier cones. The nozzle was otherwise similar in construction to the shorter length units used in the earlier runs. Runs 27 and 28A were made under conditions conforming to those selected for the base runs (table 1). Run 28 has already been presented in the section on Method of Adding Steam. In runs 28B and 28C auxiliary steam was injected. For this reason only 28A will be considered in this section.

One run (35) was made with flush burners to check the effect of this variable, but further work was not pursued with the flush burners, owing to the recurrence of slagging on the nozzle faces. Data from these runs are presented in table 4.

TABLE 4. - Summary of data from runs made with varions lengths of burner nozzles

Run No.	Nozzle	Oxygen-coal ratio	Carbon conversion, percent	Lb. coal per M std.c.f. $CO + H_2$	Std.c.f. O_2 per M std.c.f. $CO + H_2$	Economic factor	Average cone temp., °F.	Exit gas temp., °F.
27	45-inch	10.3	83.1	40.3	413	81.6	2,000	2,200
28A	45-inch	10.6	85.2	39.6	422	81.8	2,100	2,150
35	Flush	9.3	83.4	37.1	346	71.7	2,600	2,315

The 45-inch burner runs show a marked drop in gasification efficiency, and no further work was done with them. It was postulated that the greater possibilities for short circuiting of the coal through the gasifier and the increased thermal load added from the extended water-cooled surfaces of these burners contributed to the poorer performance. Somewhat improved performance was obtained in run 35 but not enough to justify further work in the face of the slagging problem. The data from these runs are plotted relative to the base curves (fig. 12, 13, and 14).

Ratio of Steam to Coal

The weight ratio of steam to dry coal selected for the base runs was 0.8 to 1.2. In two runs (21 and 24) this range was exceeded, and a summary of the data may be of interest for comparison. These runs were made with only 4 burner nozzles but with a steam four around 2,000 pounds per hour, normally used in the 6-burner runs because it was easier to adjust the coal feed than the steam flow. However, in one run (33) employing from burner nozzles the steam rate was reduced. A summary of the results of this and the other two runs is presented in table 5. They are plotted in figures 15, 16, and 17 with the base curves.

The lower coal rates in these runs resulted in reduced operating temperatures (table 5); they are plotted in figure 18 with the base-data curve. Higher steam temperatures in runs 24 and 33 helped to offset the effect of the higher relative heat loss at the reduced operating rates.