Several methods of obtaining check weights on water flows to the superheater during runs have been suggested, but none of them appear feasible for this particular installation. Also, no satisfactory method for direct metering of 1,000° F. steam has been found that would fit our installation, nor for the 600° F. steam-oxygen mixture. Hence, no independent method of verifying steam flows during runs is operating at present, and calibration checks between runs must be relied on.

Coal Flow

Instantaneous coal-feed rates are determined by reading the "delta P" across the calibration coil coal-feed line between the coal feeder and the gasifier and referring to the calibration chart (fig. 17) for that coal. The results should be accurate within 3 percent, provided that the same type and size of coal, the same quantity of conveying gas, and the same static pressure were used as during calibration runs. To safeguard against the effect of variations in coal type, carrying gas, pressure, or other conditions, the "hydrostatic head" of the fluidized feeder is read at periodic intervals as a measure of the quantity of the coal remaining in the feeder, and appropriate adjustments are made when necessary. Also, a record is maintained of coal added to the feeder, and the feeder is emptied at the end of the run, and unused coal is weighed. Thus, independents checks of coal consumption are provided, and the adjusted consumption rate should be accurate within 2 percent.

Product-Gas Flow

Product gas flow is determined with an orifice-type meter, whose orifice plate is installed in the exhaust line where the gas is at approximately atmospheric pressure and room temperature. Product-gas flows used in this report are based on theoretical orifice calculations as no independent means was used to calibrate the orifice meter. A positive-displacement-type Roots-Connersville meter is now available and will be used in series with the orifice meter during future runs. Also, plans are underway to calibrate the orifice meter against a critical-flow prover. Irregular operation of the water-letdown valve produced surges in the product-gas flow and undoubtedly affected the accuracy of product-gas measurements. Taking these surges into account and correcting for them by utilizing experience gained from tests on the atmospheric-pressure gasifiers, the results obtained with the uncalibrated orifice meter are probably accurate to about 5 percent. The effects of these errors are discussed later under Comparison of Product Gas-Flow Data and Residue Data.

Residue Measurement

It was mentioned earlier that gasifier residues are collected at the bottom of the gasifier and at the bottom of the scrubber, and the overflow water from the scrubber is metered and sampled for content of solids. Proximate analyses are made for the separate residue samples, and proximate and ultimate analyses for the weighted average composite samples. No systematic sampling for dust content of the exhaust gases going out the stack has been possible. However, such data on the dust content of the gas as has been obtained indicate that it is probably under 5 grains per 100 cubic feet. The effect on material balances of such an amount is negligible. The greatest source of error in residue data probably occurs in measuring the overflow water and sampling this water for solids content. The measurement of residue quantities at the bottom of the gasifier and scrubber is believed accurate within 5 percent. The effects of errors in residue measurements are discussed in the following section, along with the effects of errors in product-gas measurement.

Other Measurements

Other measurements of importance for calculating run results are the measurements of temperature and moisture content of the product gas leaving the gasification chamber, of the interval volume of the gasifier, of temperature relationships within the gasifier, and of moisture and dust contents of the product gas passing out the exhaust stack.

Among these, the direct measurement of the temperature and moisture content of the gas leaving the gasification zone offers the greatest problem; thermocouples rapidly deteriorate in the exit-gas stream, and the dust content of the product gas makes the measurement of moisture content very difficult, especially with the gasifier under pressure. The presence of a "support coil" near the gas outlet rendered the calculated exit-gas temperature even less accurate, and the resulting error may have been as great as 200° F. The error in calculating excess steam (moisture content of product gas) by use of the material balance may be well over 5 percent.

For example, assuming 75 pounds of excess (unreacted) steam or 25 pounds of decomposed (reacted) steam per 100 pounds of process steam introduced, an error of 5 percent in the excess steam would represent 15 percent in the steam decomposed, and the true percentage of steam decomposed would be 25 plus or minus 3.75 percent.

The interior volume of the gasifier, calculated from interior measurements before and after runs (see figs. 7 and 8), should be accurate within 2 or 3 percent. A greater error in calculating the average gasifier volume would occur if the gasifier volume had changed appreciably during the run. Measurements of the moisture and dust content of the product gas passing out the exhaust stack should be accurate to within 5 or 10 percent. For these tests, however, the exit gas was assumed saturated at the exit temperature, and the dust content of the exit gas was neglected in the residue balance. With the exit gas at about normal room temperature, the error from assuming it saturated probably would not exceed that in measuring its moisture content. Also, results from previous runs indicated that the dust content of the gas leaving the exhaust stack represented less than 1 percent of the weight of residue leaving the gasifier.

Comparison of Product-Gas Flow Data and Residue Data

Two general methods have been used for determining carbon gasification and other material balance items, namely, calculations based on direct measurement of product-gas flow and calculations based on residue data and carbon balance. It has been found to be a useful procedure to determine material balances by both these methods, particularly in the early stages of operating the pilot plants. Since originally no exact data were available on which product and reactant flows could be calculated, quite frequently the orifice meters were operated well past their designed ratings. Also, because of space limitations, it has not always been possible to install metering equipment under optimum conditions. Data on the nature of the residues obtained are necessary to determine proper design of scrubbing and waste-disposal systems. By extending the waste sampling procedure, to determine amounts also, an independent check on the results obtained from flow meter calculation is obtained, which has quite frequently detected errors in these measurements that might not otherwise have been noted. To determine the amount of product-gas by the method based on residue data and carbon balance the amount of carbon in the gas is determined by subtracting the amount of carbon in the residue (using residue weight and residue analysis) from the amount of carbon in the coal (using coal weight and coal analysis). The amount of carbon in the gas, so determined, is divided by

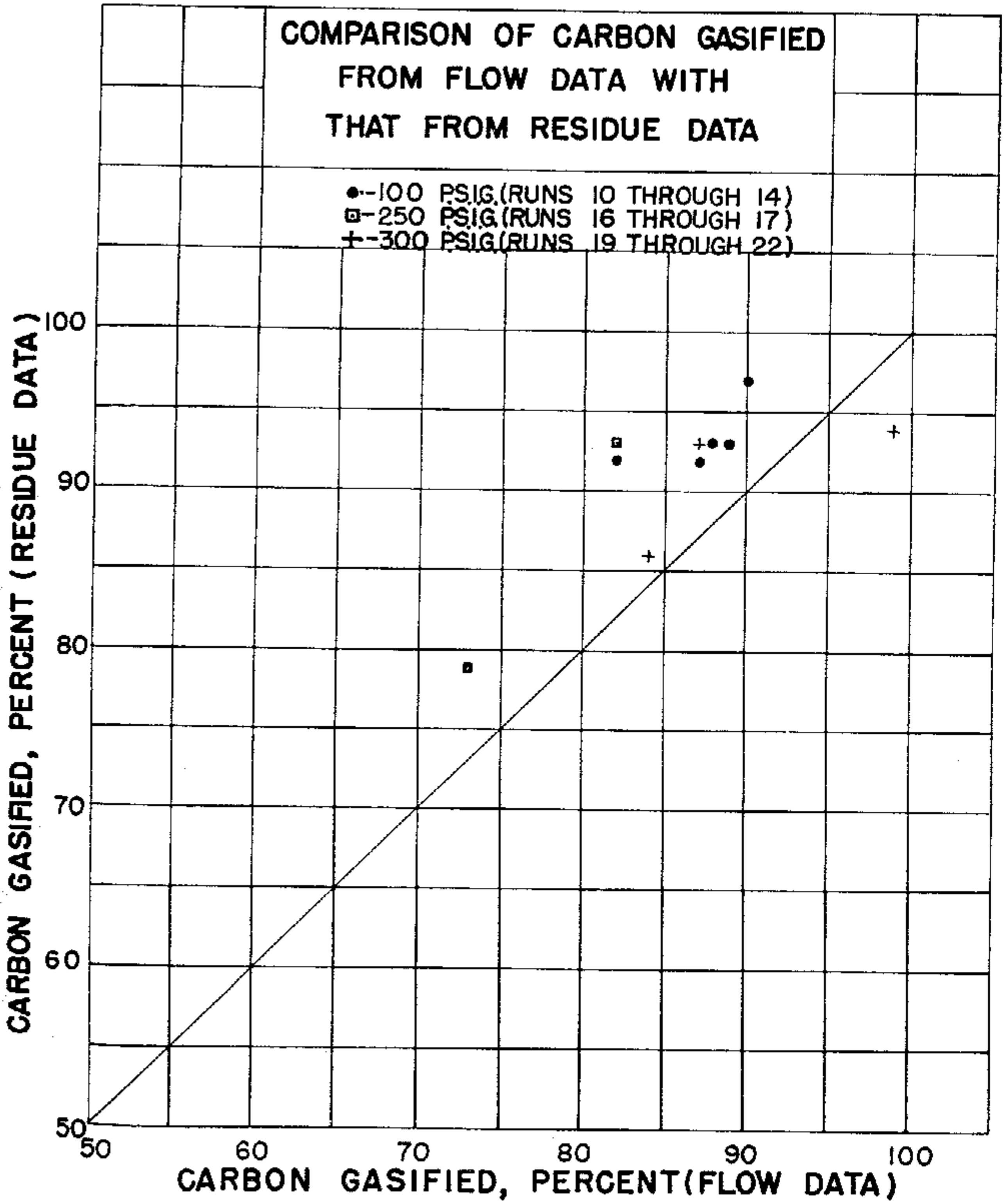

Figure 19. - Comparison of carbon gasified from flow data with that from residue data.

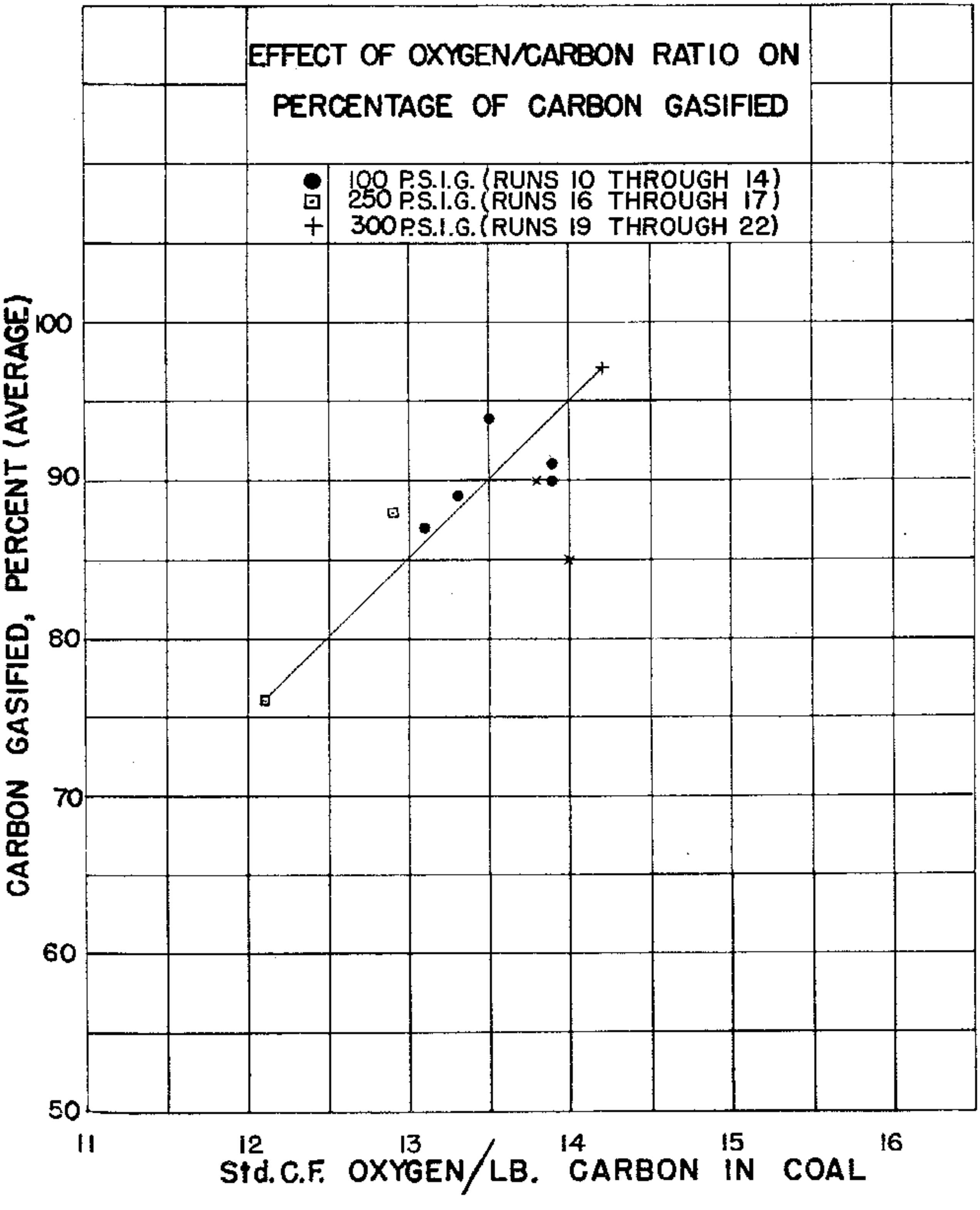

Figure 20. - Effect of oxygen-carbon ratio on percentage of carbon gasified.

the amount of carbon per unit of gas (determined from gas analysis) to find the total amount of gas. Any consistent units may be used. An inert-gas correction is then applied if necessary. Columns 21 and 22 of table 1 were included to provide a comparison of the carbon gasification calculated by these two methods and thus show the overall result of errors in measurements. The same data are expressed graphically in figure 19. Except for run P-21, the carbon gasified, based on residue data, is seen to be higher than that based on gas-flow data.

A probable source of error in the residue data was indicated earlier (in the discussion of table 2) by the fact that, based on ash balance, the actual residue might be one-sixth greater than that measured. This discrepancy was due in part to the irregular operation of the water-letdown valve, which caused surges in the overflow water leaving the scrubber as well as in the product-gas flow. These surges rendered the measurements of flow rates and solids content of this overflow water less reliable. If, however, the full suggested correction of approximately one-sixth (see above) were applied to the amount of residue recovered, the average carbon-gasification figure of about 90 percent (based on residue data) would be changed to 88 percent, a difference of only 2 percentage points.

Most of the remaining discrepancy between results based on flow data and those based on residue data is probably the result of inaccuracies in the measurement of product-gas flow. The greatest probably source of error is the mentioned surges in the product gas, caused by the irregular operation of the water-letdown valve. Preliminary results have shown that with overflow water leaving the scrubber, at about 200° F., the absorption of CO, CO_2, and H_2 has only a relatively small effect on the quantity of product gas metered. The total volume of absorbed gases is about 0.20 percent of the total gas made.

Results based on residue data are believed at least as reliable as those based on flow data for the simple reason that an error in residue measurement has much less effect on the material balance than an error of the same magnitude in flow measurements. Referring to the example cited above, whereas an error of 17 percent in residue measurement would change the carbon gasification by only 2 percentage points, an error of 2 to 3 percent in product-gas flow measurement would have the same effect. Consequently, the averages shown in table 1 will probably tend to be very slightly lower (or poorer) than the true values. Since the preparation of table 1, a new water-letdown valve has been installed, and much better agreement has been shown for results calculated by the two methods.

DISCUSSION OF RESULTS

The limited amount of test data available for this preliminary report and the lack of duplicate or check tests make it difficult to draw final or exact conclusions as to the effect of the operating variables. However, the general trends shown in the graphs are believed to be accurate.

Effect of Oxygen-Coal Ratio

Figure 20 has been prepared to indicate the effect of oxygen-carbon ratio, that is, standard cubic feet of oxygen supplied per pound of carbon in the coal, on the percentage of carbon gasified for runs P-10 through P-22 in the high-pressure gasifier. The data were taken from tables 1 and 2. The oxygen-carbon ratio was used (instead of the oxygen-coal ratio) to eliminate the effect of differences in carbon content of the various batches of Sewickley coal. The solid line shows a substantial increase in carbon gasification with increase in oxygen-carbon ratio, and the general shape of curve is seen to hold for the three gasifier pressures. (The point for run P-19 is out of line owing to the unusual conditions of that run.)

Because of differences in coal-feed rate and types of lining that affect the heat loss for the groups of tests at the different pressures, separate curves have not been drawn for the various pressures. Comparison of these data with those from atmospheric pressure gasifier (No. 2) shows essentially the same curve but with a slightly steeper slope for the high-pressure gasifier, indicating slightly higher carbon utilization for oxygen-carbon ratios above 13 std. c.f. per pound. (The atmospheric-pressure results were with varying steam-coal ratio and pressure-gasification results were at constant steam-coal ratio).

Figures 21 and 22 indicate the effect of oxygen-coal ratio on coal requirement and oxygen requirement, respectively, per 1,000 std. c.f. of ($CO + H_2$) produced. As would be expected, the coal requirement per 1,000 std. c.f. of ($CO + H_2$) decreases with increase in oxygen-coal ratio, and the general shape of the curve holds true for each gasifier pressure. What might not be expected is that the oxygen requirements per 1,000 std. c.f. of ($CO + H_2$) increases only slightly over the range of 9.0 to 10.0 std. c.f. oxygen per pound of coal. The best place to operate depends upon relative costs of oxygen and coal, proper operating temperatures, and overall life of equipment. Inasmuch as all the runs (except P-19) were made at a steam-coal ratio of about 0.3 pound per pound, the optimum oxygen-coal ratio for this steam-coal ratio could be determined from figures 21 and 22 as that ratio giving the lowest total cost of coal and oxygen per unit output of synthesis gas, other conditions being constant.

Relationship Between Pressure and Capacity

In comparing the throughputs of coal and the gas outputs obtained at various pressures, the volume of the refractory-lined space has been used as a base. It is possible that the gasification reaction continues for a short distance below the slag throat, that is, in the space above the spray ring (see fig. 6). It has not been possible to obtain accurate gas temperature records just below the slag throat.

Thermocouples inserted here are quickly coated or damaged by slag and are affected by radiation to the wall coils and spray rings. The few temperature readings that were obtained showed that the spray from the spray ring reached up very close to the slag throat. Consequently, it is very probable that the gasification reaction stops very quickly after the gas stream leaves the slag throat. In any event, the use of this volume does give a relative figure for capacities at various pressures for this particular unit.

Figures 23 and 24 have been prepared as a preliminary indication of the relationship between gasifier pressure and capacity. The dotted line on figure 23 is based on an assumed coal throughput rate of 25 pounds per hour per cubic foot of gasifier volume at atmospheric pressure and 85 to 90 percent carbon gasification, with a theoretical increase in coal throughput rate proportional to the 1.0 power of the absolute pressure. For example, at 450 p.s.i.g. the theoretical coal throughput rate indicated by the dotted line is almost 800 pounds per hour per cubic foot of gasifier volume. Similarly, the dotted line on figure 24 is based on an assumed $CO + H_2$ output rate of 625 std. c.f. per hour per cubic foot of gasifier volume at atmospheric pressure and 85 to 90 percent carbon gasification, with a theoretical increase in $CO + H_2$ output rate proportional to the 1.0 power of the absolute pressure.

These theoretical pressure-capacity values are influenced by recent tests in our atmospheric-pressure gasifier (No. 4) and of the high-pressure gasifier (No. 3), and consequently are higher than those used in the original design of the pressure gasifier.[13] For example, the original calculations were based on an assumed gasification rate of 20 pounds coal per hour per cubic foot of gasifier volume at atmospheric pressure, with an increase in gasification rate proportional to the 0.6 power

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[13] See footnote 4.

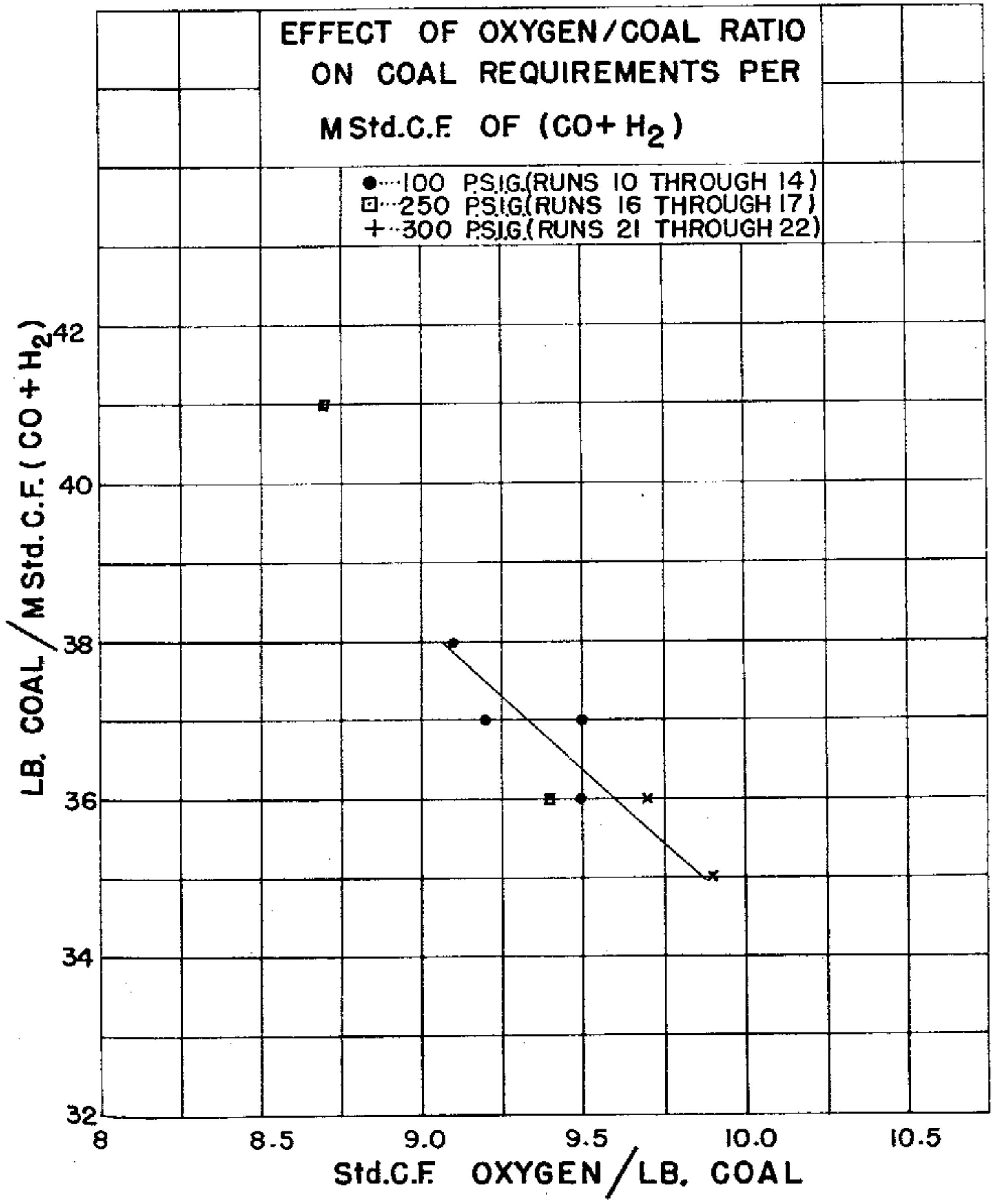

Figure 21. - Effect of oxygen-coal ratio on coal requirements per 1,000 std. c. f. of $(CO + H_2)$.

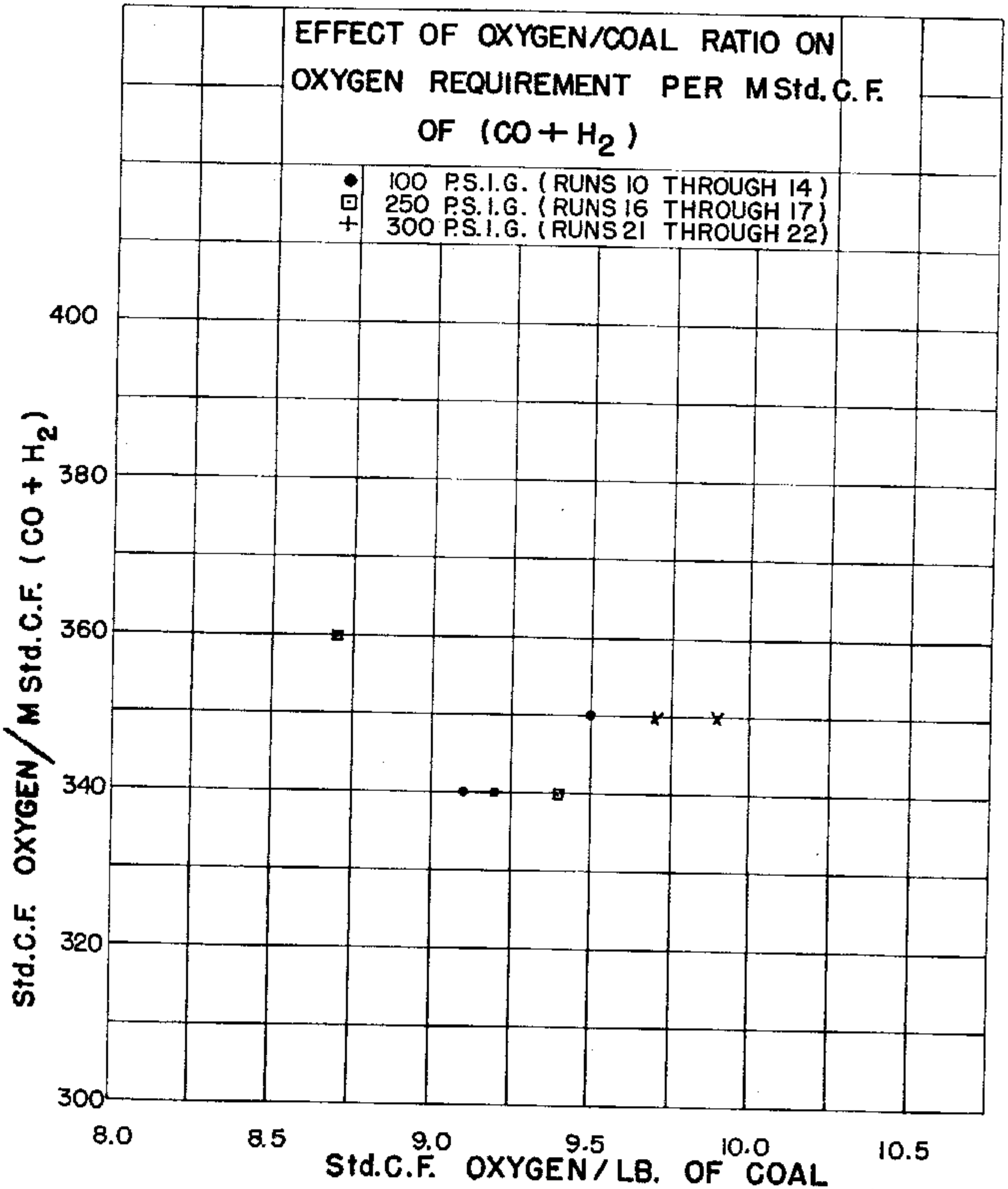

Figure 22 - Effect of oxygen-coal ratio on oxygen requirement per 1,000 std. c. f. of $(CO + H_2)$.

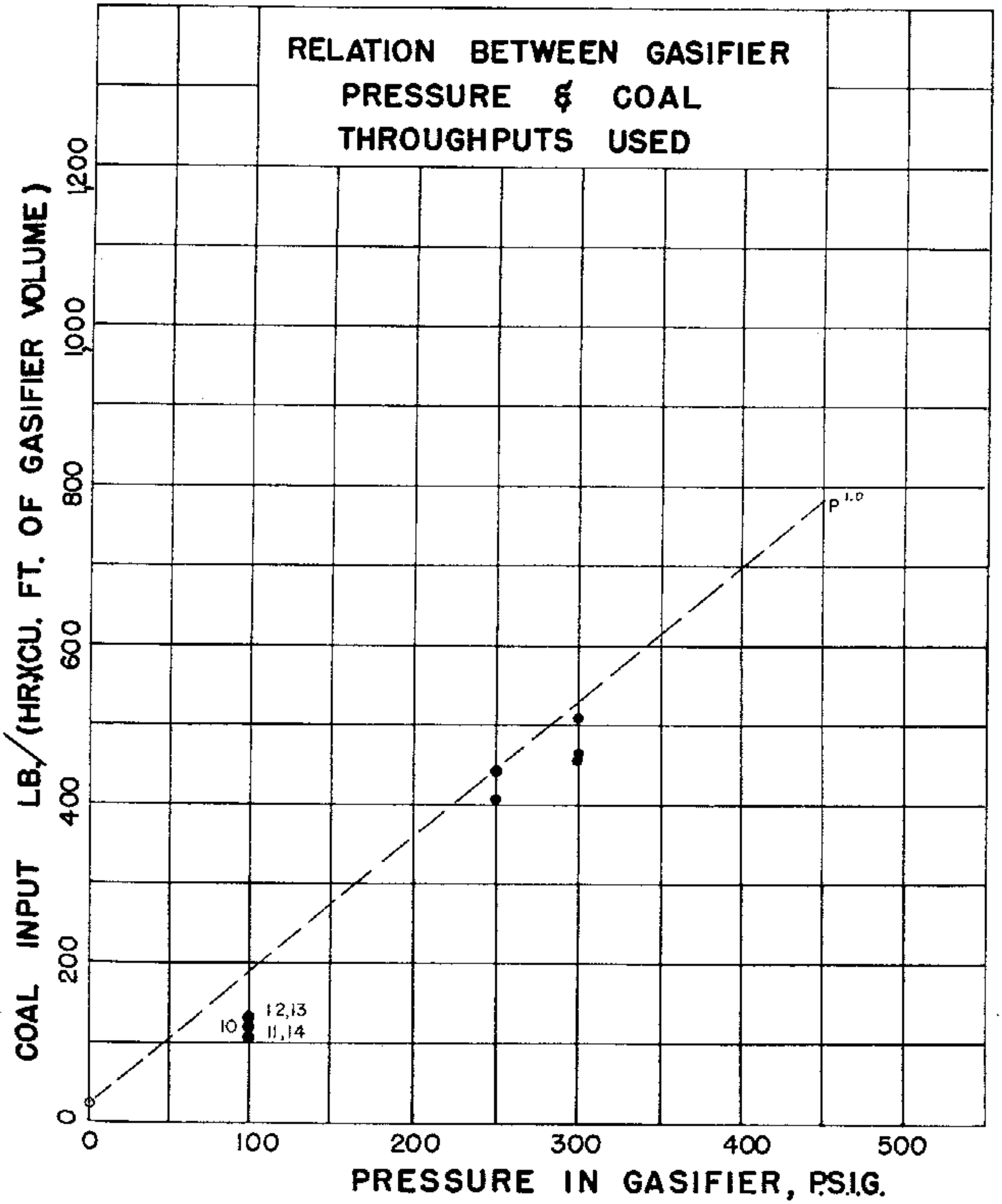

Figure 23. - Relation between gasifier pressure and coal through-puts used.

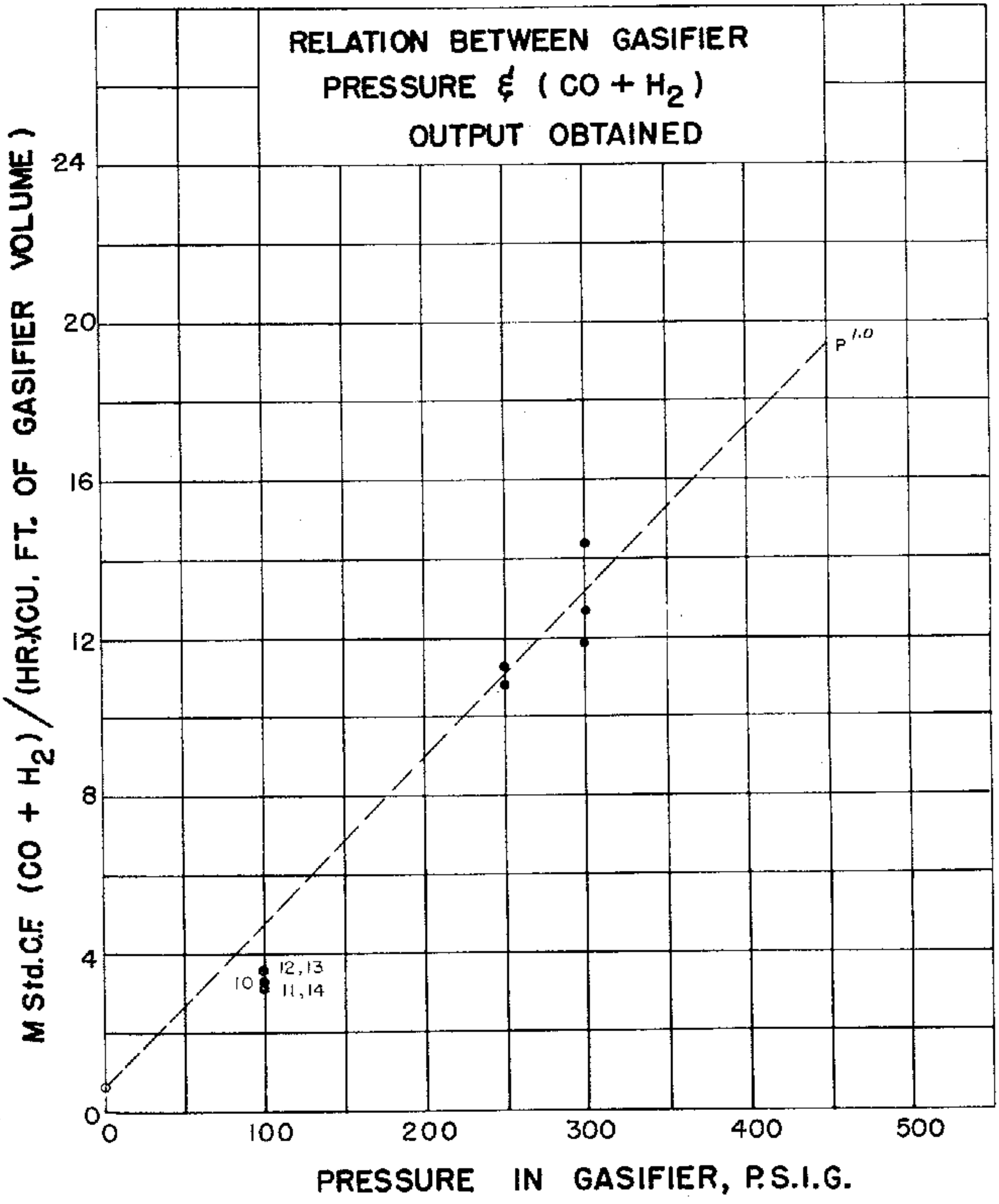

Figure 24. - Relation between gasifier pressure and ($CO + H_2$) output obtained.

of the absolute pressure. At the present time, it is by no means certain that the maximum gasification rate varies with the 1.0 power of the absolute pressure.

Probable Capacity at Higher Pressure

The atmospheric-pressure values in figures 23 and 24 admittedly are based on recent data obtained in the pilot-plant atmospheric-pressure gasifier and do not represent the ultimate that could be obtained with improved gasifier design. Also, the data shown by the dots at 100, 250, and 300 p.s.i.g. gasifier pressure represent actual results obtained in test runs P-10 through P-22 and are not necessarily maximum capacity outputs. So far the capacity has been limited only by the rate at which coal could be charged. No clear-cut relationship has been obtained to date between percentage of carbon gasification and coal throughput. It appears reasonable that, at 450 p.s.i.g. gasifier pressure, actual capacities considerably over 800 pounds of coal or 20,000 std. c.f. of ($CO + H_2$) per hour per cubic foot of gasifier volume are obtainable. In fact, recent runs at 300 p.s.i.g. show capacities considerably above those indicated by the theoretical curves (fig. 23 and 24).

Heat Losses and Probable Economic Effect in Larger Units

The enormous output per unit volume of gasifier obtained with pressure gasification results in lower heat losses when expressed per pound of coal or in percentage of the heat of combustion of the coal. For example, during runs P-15 through P-22, in spite of using high-conductivity silicon carbide refractory throughout and water-cooled shell, the calculated heat loss through the refractory lining represented only 600 to 900 B.t.u. per pound of coal or 5 to 7.5 percent of the heat of combustion of the coal.

The percentage heat losses through gasifier walls could be expected to be much lower, and in fact almost negligible, in larger units. This would make possible the use of water-cooled refractory linings, or even the use of bare water-cooled interior coils on which the coal ash slag would form its own refractory. With this arrangement the maintenance cost of gasifier lining refractory could be reduced to a very low value.

Nature of Sulfur Content of Product Gas

Analyses of product gas for sulfur compounds indicate that no unusual forms of sulfur exist and that the demands made in the purification process will be similar to those encountered in the manufacture of water gas from coke in fixed beds. No special problems in gas purification have been encountered.