

CHEMISTRY AND PHYSICS OF  
ENTRAINED COAL GASIFICATION

R. L. Zahradnik  
National Science Foundation  
Washington, D. C.

R. J. Grace  
Bituminous Coal Research, Inc.  
Monroeville, Pennsylvania

INTRODUCTION

The BI-GAS process <sup>2,3\*</sup> for the production of synthetic natural gas is being developed by Bituminous Coal Research, Inc. under the joint sponsorship of The Office of Coal Research and The American Gas Association. The key features of the process are illustrated in Figure 1. Fresh coal is introduced into the upper section (Stage 2) of a two-stage gasifier at system pressures of 70 to 100 atm. Here, it contacts a rising stream of hot synthesis gas produced in the lower section (Stage 1) of the gasifier and is partially converted into methane and more synthesis gas. The residual char is swept out of the gasifier together with the gas; the char is separated from the gas stream and returned to the bottom section of the gasifier. Here, the char is completely gasified under slagging conditions by reaction with oxygen and steam, producing both the synthesis gas required in the upper section of the gasifier and the heat needed to complete the endothermic reactions.

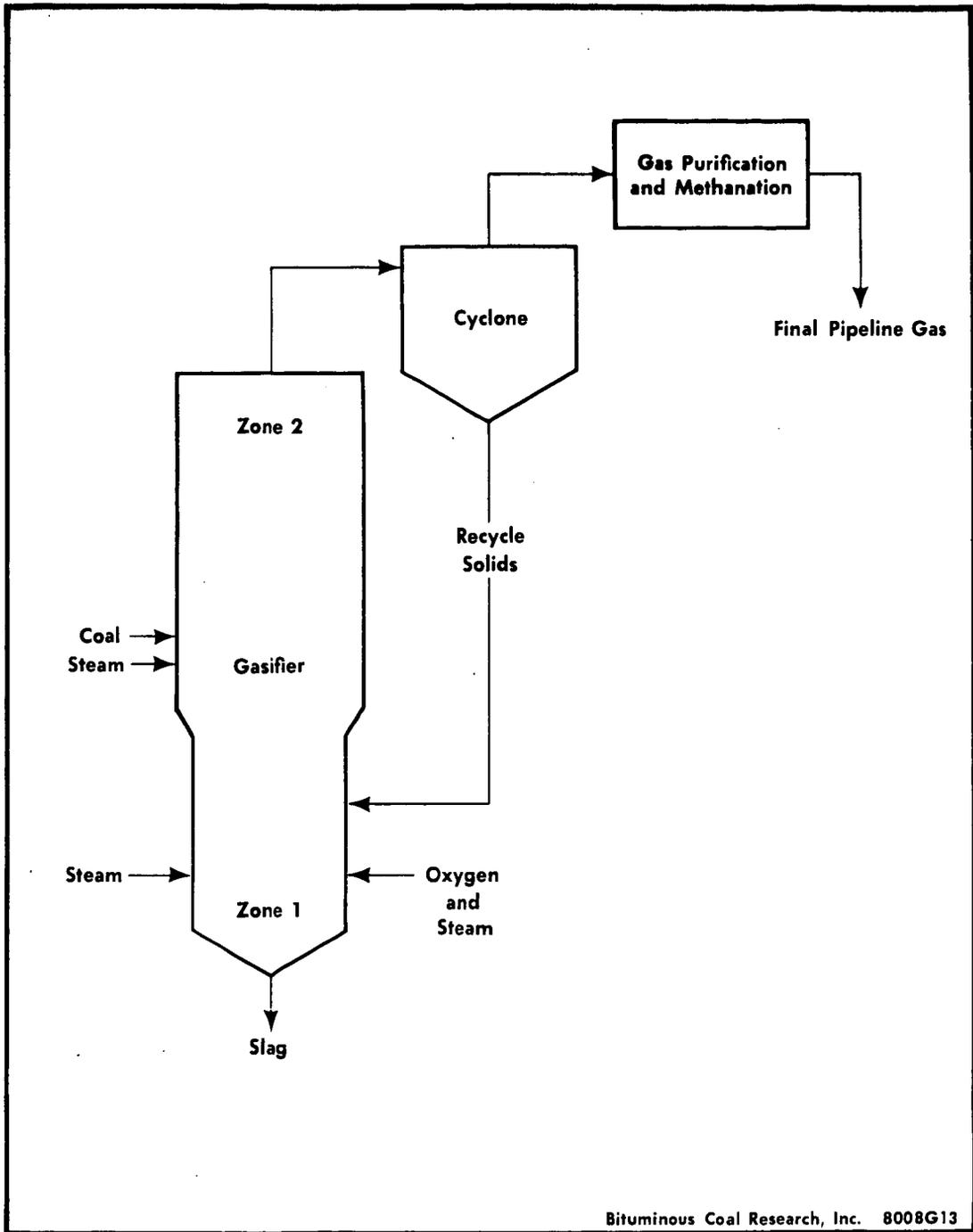
To meet pipeline specifications, the product gas requires further processing. It is cleaned and subjected to partial water gas shift to adjust its  $H_2/CO$  ratio; it is scrubbed to remove acid gases ( $CO_2$ ,  $H_2S$ ); and finally it is subjected to catalytic methanation to raise the heating value to pipeline quality.

The basic component of the process is the entrained two-stage gasifier. The major emphasis of the BCR program to date has been to develop data sufficient to optimize the operation of Stage 2 of the gasifier. Initial experiments were carried out with coal slurries in rocking autoclaves at pressures of 3000 to 4000 psig and temperatures 1380 F to 1400 F.<sup>1</sup> These experiments showed that large amounts of methane could indeed be produced from the contact of coal with superheated steam. However, the tests were of necessity batch in nature and involved relatively slow heating rates and long residence times. Consequently, the results could not be applied directly to an integrated entrained gasifier, and data from experiments under more realistic conditions were sought.

The next step in the BCR program consisted of tests that were continuous in nature and involved a short coal-steam-synthesis gas contact time

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\* Numbers refer to references cited.



**Figure 1. Simplified Flow Diagram for Two-stage Super-pressure Gasifier**

with rapid heating. Over 100 experiments were conducted under conditions simulating those of Stage 2 using a 5 lb/hr continuous flow reactor (CFR). Lignite, a Wyoming subbituminous coal, and Pittsburgh seam high volatile bituminous coal were tested. These experiments showed conclusively that appreciable amounts of methane could be produced during short contact times of 2 to 20 seconds between steam, synthesis gas, and fresh coal at about 1000 psi and 1750 F.<sup>5</sup>

The experiments carried out in the 5 lb/hr unit involved the simultaneous heating of the simulated Stage 1 gas, the superheated steam, and the fresh coal. Because of the limitations of the equipment, the reaction conditions did not exactly duplicate those conditions expected in the integrated gasifier. Nevertheless, the results warranted the construction of a process and equipment development unit in which fresh coal and steam could be contacted with hot Stage 1 gas under conditions that more closely duplicate those in Stage 2. The design features of this PEDU have been given elsewhere<sup>2,6,7,9</sup>. Nearly sixty individual experiments were conducted, using the same series of coals as were used in the CFR. The range of operating conditions for these tests is reported in Table 1; the range of results is given in Table 2.

Initial results from the PEDU using lignite were reported in earlier publications<sup>2,8</sup>. The purpose of this paper is to present data for the gasification of Pittsburgh seam coal in the PEDU and to discuss these data on the basis of the chemistry and physics of entrained gasification.

#### GASIFICATION CHEMISTRY

The physical and chemical processes which take place between the hot synthesis gas from Stage 1 and the fresh coal and steam in Stage 2 are complex and any attempt to model them must be regarded as approximate. Nonetheless, it is possible to develop reasonable correlations in terms of certain basic gasifier variables suggested by the gasification chemistry.

As a result of the very rapid heating of the coal, a significant devolatilization takes place in a matter of milliseconds.<sup>4</sup> This devolatilization step produces a variety of gases including hydrogen and methane.

The remainder of the gasification process may be characterized by the carbon-hydrogen reaction



and by the carbon-steam reaction



The overall methanation process has been described by Moseley and Paterson<sup>10,11,12</sup> as consisting of three steps. The first step is the rapid devolatilization of coal which produces, in addition to volatile products, an active carbon species. This active carbon reacts, in the second step, either with hydrogen to form more methane or with itself in a cross-linking

TABLE 1. RANGE OF OPERATING CONDITIONS FOR 100 LB/HR PEDU TESTS

Coal Feed Rates	43 lb/hr to 108 lb/hr
System Pressure	220 psig to 1,420 psig (15 atm to 96.5 atm)
Outlet Temperature	1,375 F to 2,160 F (746 C to 1,180 C)
Hydrogen Partial Pressure	56 psig to 308 psig (3.8 atm to 21 atm)
Total Steam/Coal Ratios	0.90/1 to 2.78/1
Total Carbon Gasified	32 percent to 68 percent
Total Btu in Gas/Btu in Coal	38 percent to 85 percent
Residence Times	3 sec to 22 sec

TABLE 2. RANGE OF RESULTS FOR 100 LB/HR PEDU TESTS

<u>Coal Tested</u>	<u>Coal Feed Rate (lb/hr)</u>	<u>Methane Yield, Percent</u>	<u>Total Carbon Gasified, Percent</u>	<u>Preformed Methane, Percent</u>
Design Basis	<u>100</u>	<u>15.0</u>	<u>33</u>	<u>62</u>
Lignite	62-108	12-20	32-68	30-79
Elkol	43-104	18-23	39-64	47-86
Pittsburgh	50-77	16-26	33-57	61-84
Lower Kittanning	64-66	14-17	34-38	59-68

polymerization to form an inactive char. The third step involves the slow reaction of hydrogen with the inactive char.

In Stage 2 of the BCR two-stage process, this third step is relatively unimportant. Zahradnik and Glenn<sup>15</sup> have shown that the direct methanation of coal in Stage 2 can be described adequately as a two-step process which is independent of residence time when residence time is greater than a few seconds. On this basis, it is possible to relate the yield of methane, MY, expressed as the fraction of the carbon in coal appearing as methane, to hydrogen partial pressure in the following way.

$$MY = \frac{a + b (P_{H_2})}{1 + b (P_{H_2})} \quad (3)$$

where a and b are kinetic parameters.

Zahradnik and Glenn<sup>15</sup> were able to correlate the CFR data, the data of Moseley and Paterson, and data obtained by the U.S. Bureau of Mines with this expression. Data obtained in the 100 lb/hr PEDU for lignite were also shown to be correlated by Equation (3)<sup>8</sup>, demonstrating its validity for larger sized equipment.

For data correlation purposes, Equation (3) can be written as:

$$\left( \frac{MY-a}{1-MY} \right) \frac{1}{(P_{H_2})} = b \quad (4)$$

On the basis of earlier tests, the value of a is taken to be 0.08 and is assumed to depend on temperature in an Arrhenius manner. Thus, a plot of the natural logarithm of the left-hand side of the above equation, as a function of reciprocal temperature, should yield a straight line. Figure 2 is such a plot for Pittsburgh seam coal, under comparable physical and geometrical configurations, and for residence times between 14 and 17 seconds. The correlation is quite good.

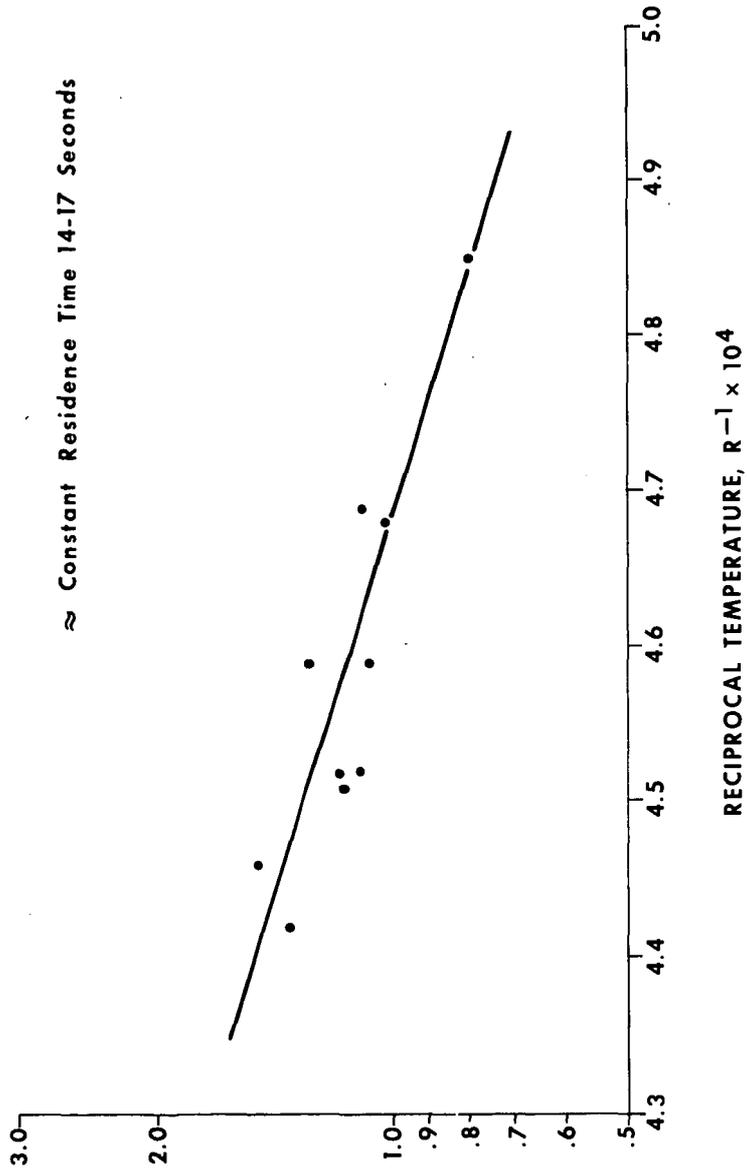
A complete tabulation of the data on which Figure 2 is based is given in Reference 2. The experimental and analytical techniques used to obtain these data were reported in a previous publication by Grace, Glenn, and Zahradnik<sup>8</sup>.

Not all the data points from the PEDU experiments with Pittsburgh seam coal fell on the correlating line of Figure 2, however. A more detailed explanation of their behavior is in order.

#### METHANE DECOMPOSITION

Experiments in the externally heated 5 lb/hr CFR showed that methane, once formed, did not decompose under the Stage 2 simulation achieved with this unit. However, because of the higher mixing temperatures attained in the PEDU, such decomposition is possible. In order to test whether methane does decompose, tests were conducted whereby a stream of methane was injected

$$\left(\frac{MY-a}{1-MY}\right) \frac{1}{(PH_2)}, \text{ atm}^{-1} \times 10^2$$



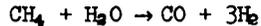
RECIPROCAL TEMPERATURE,  $R^{-1} \times 10^4$

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Figure 2. Methane Yield per Atmosphere of Hydrogen Partial Pressure as a Function of Reciprocal Outlet Temperature at Constant Residence Time for Pittsburgh Seam Coal

into the simulated Stage 1 gas. It was noted that the methane experienced partial decomposition.

The exact nature of the destruction of methane is not clear. However, it is most likely that the steam in the Stage 1 gas promotes the reforming reaction:



Analysis of the material balance data from the methane decomposition tests suggests that the latter reaction is occurring. One of the tests was carried out at 200 psig in order to permit observation of the mixing temperature by an ultra-violet pyrometer. The results can be explained by assuming that methane decomposes at a rate proportional to its concentration, i.e.:

$$\frac{d[\text{CH}_4]}{dt} = k[\text{CH}_4]$$

Although it is likely that the reaction rate is influenced by steam, hydrogen, and carbon monoxide partial pressures, these did not vary significantly during the tests, and their effect cannot be determined at this time.

Integration of the rate expression gives:

$$\ln [1 - f] = -k\tau \quad (5)$$

where,  $\tau$  = residence time  
 $f$  = fraction of methane decomposed  
 $k$  = reaction rate constant

The residence time of the individual tests was constant. Since the reaction rate constant is temperature-dependent, an Arrhenius plot of  $\ln [1 - f]$  versus the reciprocal of the observed mixing zone temperature should yield a straight line. That this is indeed the case is shown in Figure 3. The temperature effect on the rate of methane decomposition is quite pronounced, corresponding to an activation energy of 30 Kcal/g mole.

The fact that methane injected into the PEDU decomposes to a certain extent suggests that methane formed directly from coal could also decompose. Thus, the methane yield predicted by Equation (3) would have to be modified as in Equation (5). This gives the following equation for methane yield:

$$\text{MY} = \left( \frac{a + b \left( \frac{P_{\text{H}_2}}{P_{\text{H}_2}} \right)}{1 + b \left( \frac{P_{\text{H}_2}}{P_{\text{H}_2}} \right)} \right) e^{-k\tau} \quad (6)$$

Note that this equation indicates that methane yield is dependent upon residence time, but in an unusual and unexpected way.

Because both parameters  $b$  and  $k$  depend on temperature, it is difficult to express the relationship of Equation (6) in a form convenient for graphical display. However, certain first order simplifications and approximations can be made.

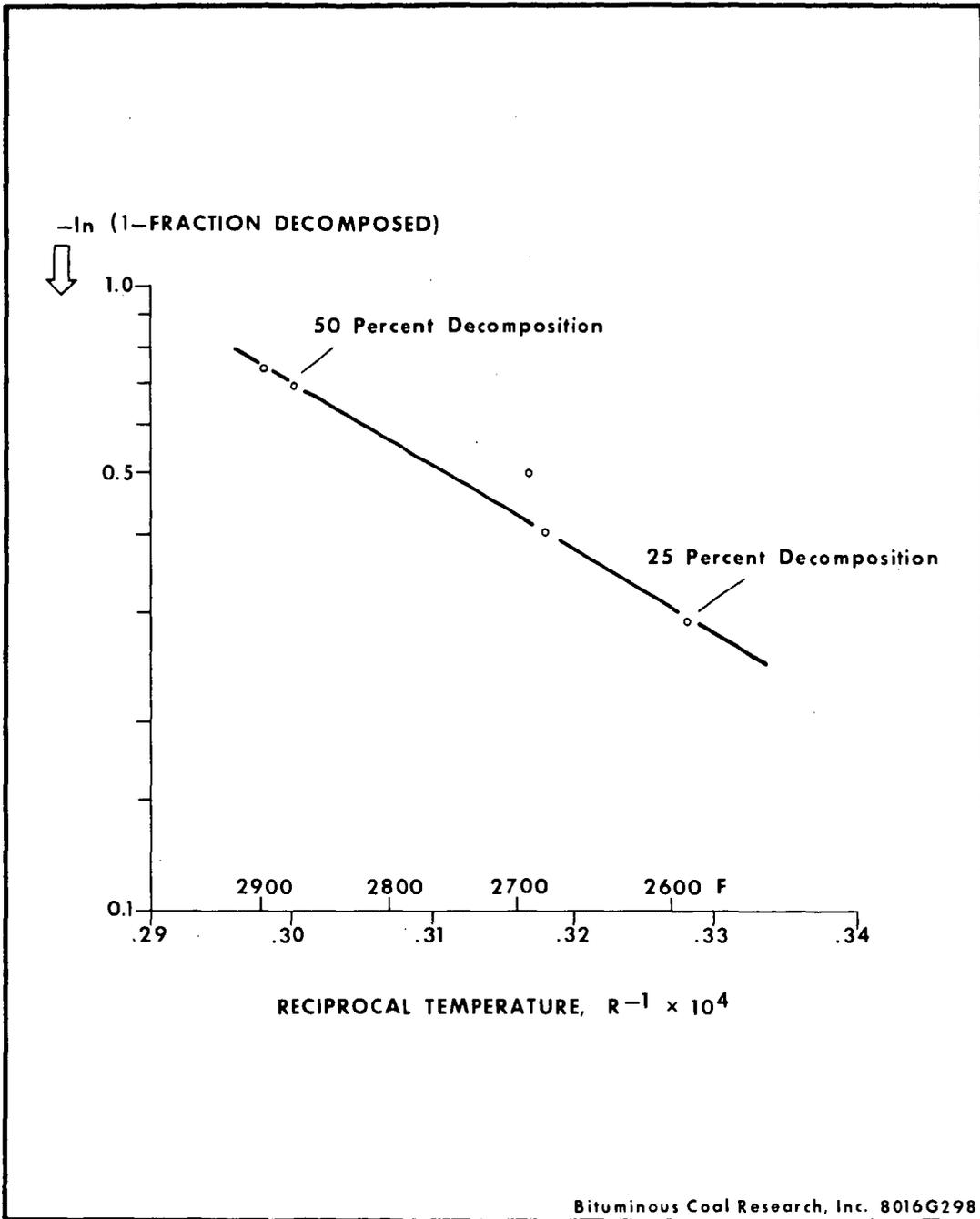


Figure 3. Methane Decomposition in the PEDU

Thus, if we make the following approximation

$$e^{-k\tau} \cong 1 - k\tau,$$

Equation (6) can be written in the following form:

$$\left(\frac{MY - a}{1 - MY}\right) \left(\frac{1}{P_{H_2}}\right) = b - \frac{k\tau[a + b(P_{H_2})]}{(P_{H_2})(1 - MY)} \quad (7)$$

Furthermore, if we note that the group  $\left(\frac{a + b(P_{H_2})}{(P_{H_2})}\right)$  is relatively insensitive to the partial pressure of hydrogen in the range of experiments conducted, then Equation (7) becomes

$$\left(\frac{MY - a}{1 - MY}\right) \left(\frac{1}{P_{H_2}}\right) = b - k_1 \left(\frac{\tau}{1 - MY}\right) \quad (8)$$

Thus, a plot of

$$\left(\frac{MY - a}{1 - MY}\right) \left(\frac{1}{P_{H_2}}\right) \text{ versus } \frac{\tau}{1 - MY}$$

should give a straight line, provided temperature is constant. Figure 4 is such a plot for those Pittsburgh seam coal tests whose exit temperature was in the range 1720 to 1800 F. The trend is unmistakable. Although Equation (8) is the result of a number of assumptions and mathematical simplifications, it does provide a format for displaying and correlating the PEDU methane yield data. In addition these data do suggest that methane formed in the direct methanation process is destroyed in its passage through the remainder of the PEDU. The percent decomposition indicated by Equation (8) ranges from 10 percent at the low residence time tests to 25 percent at the high residence time tests.

If the correlating line in Figure 4 is extrapolated to zero residence time, a value is obtained for the b parameter in the methane yield equation:

$$b = 0.0165$$

An extension to higher temperatures of the Arrhenius plot for b obtained by Zahradnik and Glenn shows this value to correspond to a temperature of 2240 F<sup>15</sup>. This is probably a reasonable estimate of the mean reaction temperature of the methanation process taking place in the PEDU, when the exit temperature is between 1720 and 1800 F.

At a temperature of 2240 F, the methane decomposition correlation (Figure 3) gives a value for  $k\tau$  of 0.085. The residence time in the methane decomposition tests was 7.5 seconds, so that a k value can be calculated.

$$k = \frac{0.085}{7.5} \text{ sec}^{-1} = 0.0113 \text{ sec}^{-1}$$

A k value can also be obtained from the gasification tests, since from

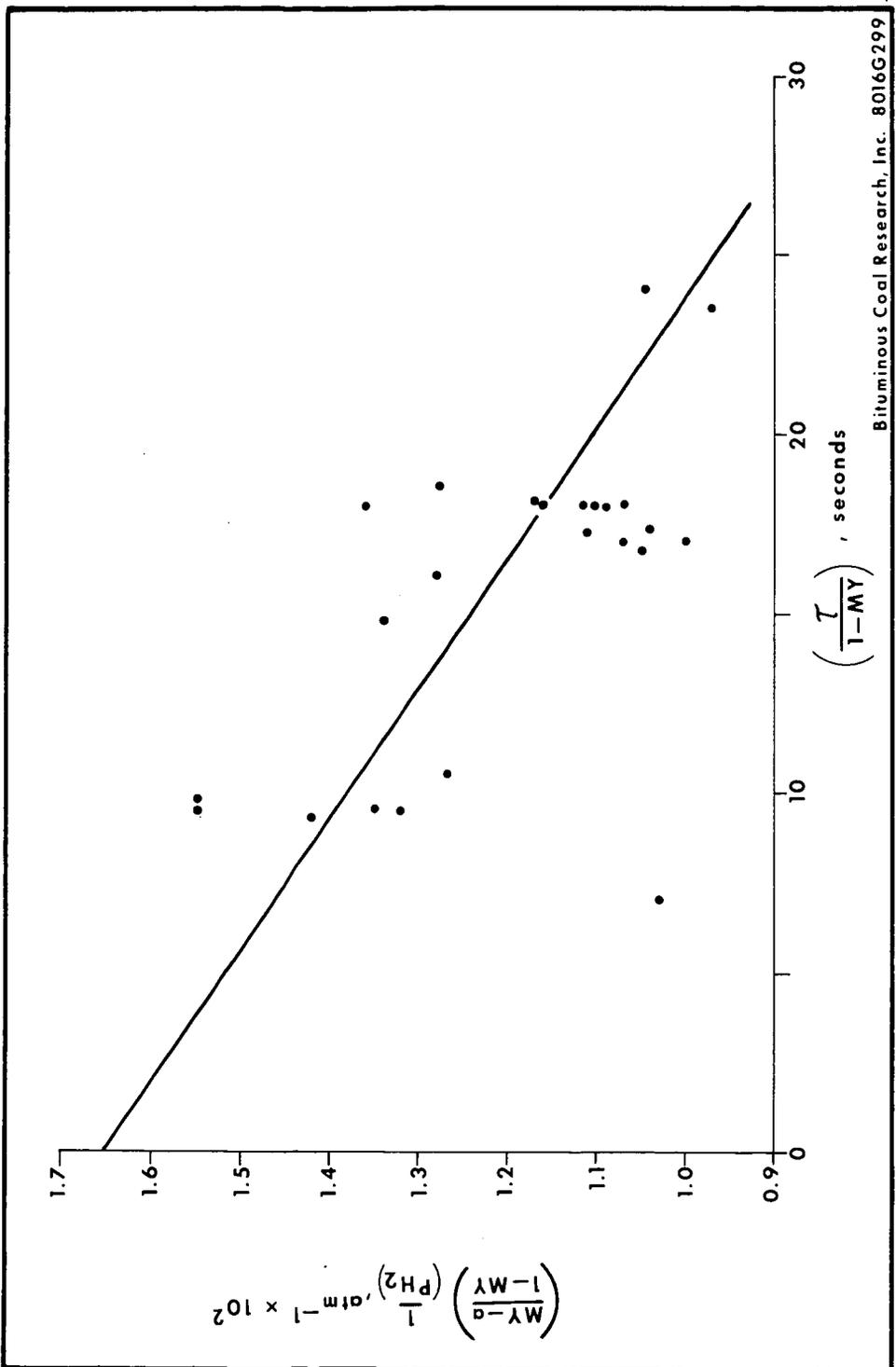


Figure 4. Methane Yield per Atmosphere of Hydrogen Partial Pressure vs. Residence Time for Pittsburgh Seam Coal

Equation (8) the slope of the correlating line of Figure 4 is

$$\text{slope} = k \left( \frac{a + b \left( \frac{P_{H_2}}{P_{H_2}} \right)}{\left( \frac{P_{H_2}}{P_{H_2}} \right)} \right)$$

The value of this slope is 0.000275. If  $b = 0.0165$  and the average hydrogen partial pressure is 15 atm, the value of  $k$  can be calculated:

$$k = \frac{0.000275 \text{ sec}^{-1}}{\frac{0.08 + 0.0165 (15)}{(15)}} = 0.0126 \text{ sec}^{-1}$$

This value,  $0.0126 \text{ sec}^{-1}$ , is remarkably close to the value of  $0.0113 \text{ sec}^{-1}$  at 2240 F estimated from the methane decomposition tests.

A complete and consistent model for methane production in the PEDU may now be given. The following equation can be written for any temperature and contact time:

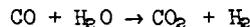
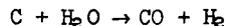
$$\left( \frac{MY - a}{1 - MY} \right) \left( \frac{1}{\left( \frac{P_{H_2}}{P_{H_2}} \right)} \right) = b - k \left( b + \frac{a}{\left( \frac{P_{H_2}}{P_{H_2}} \right)} \right) \left( \frac{\tau}{1 - MY} \right) \quad (8)$$

For a given reaction temperature,  $b$  can be estimated from the paper by Zahradnik and Glenn<sup>15</sup> and  $k$  from Figure 3 and Equation (5). Then a plot of reduced methane yield per atmosphere of hydrogen partial pressure as a function of reduced residence time can be constructed, as in Figure 5. Notice that as temperature increases, the decomposition rate increases, thereby reducing the contact time required to destroy the methane. Moreover, for a given residence time, there is a "best" temperature at which to operate, best in the sense of yielding the highest methane yield per atmosphere of hydrogen partial pressure. This "best" temperature is shown as a function of residence time in Figure 6.

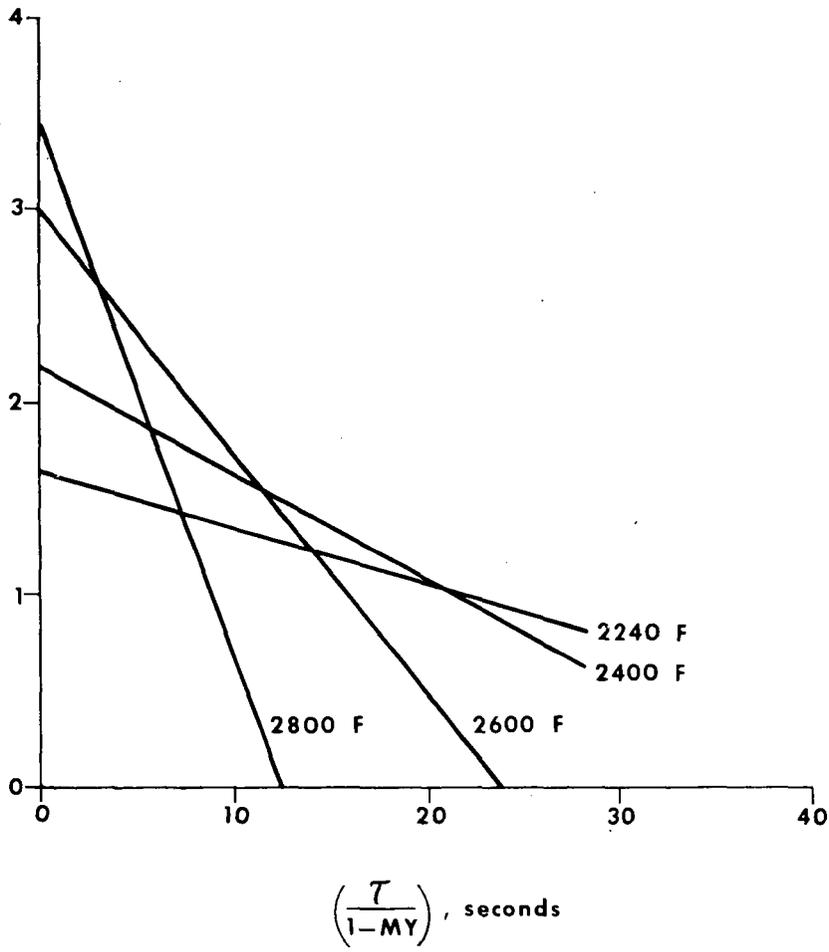
The results shown in Figures 5 and 6 are specific to the PEDU operation and involve numerous assumptions. Moreover, the temperature values are estimated reaction temperatures which combine the total effect of temperature profiles and gas mixing patterns. As in all the correlations presented here, they should be regarded as phenomenological and suggestive--not as the consequences of strict mechanisms. Nonetheless, they do underscore the effect of residence time and temperature on the yield from Stage 2.

#### STEAM-CARBON REACTION

The yield of carbon oxides from coal in Stage 2 has been attributed to the steam-carbon reaction and water-gas shift.



$$\left( \frac{MY - a}{1 - MY} \right) \left( \frac{1}{P_{H_2}} \right), \text{ atm}^{-1} \times 10^2$$



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Figure 5. Residence Time and Temperature Effect on Methane Yield

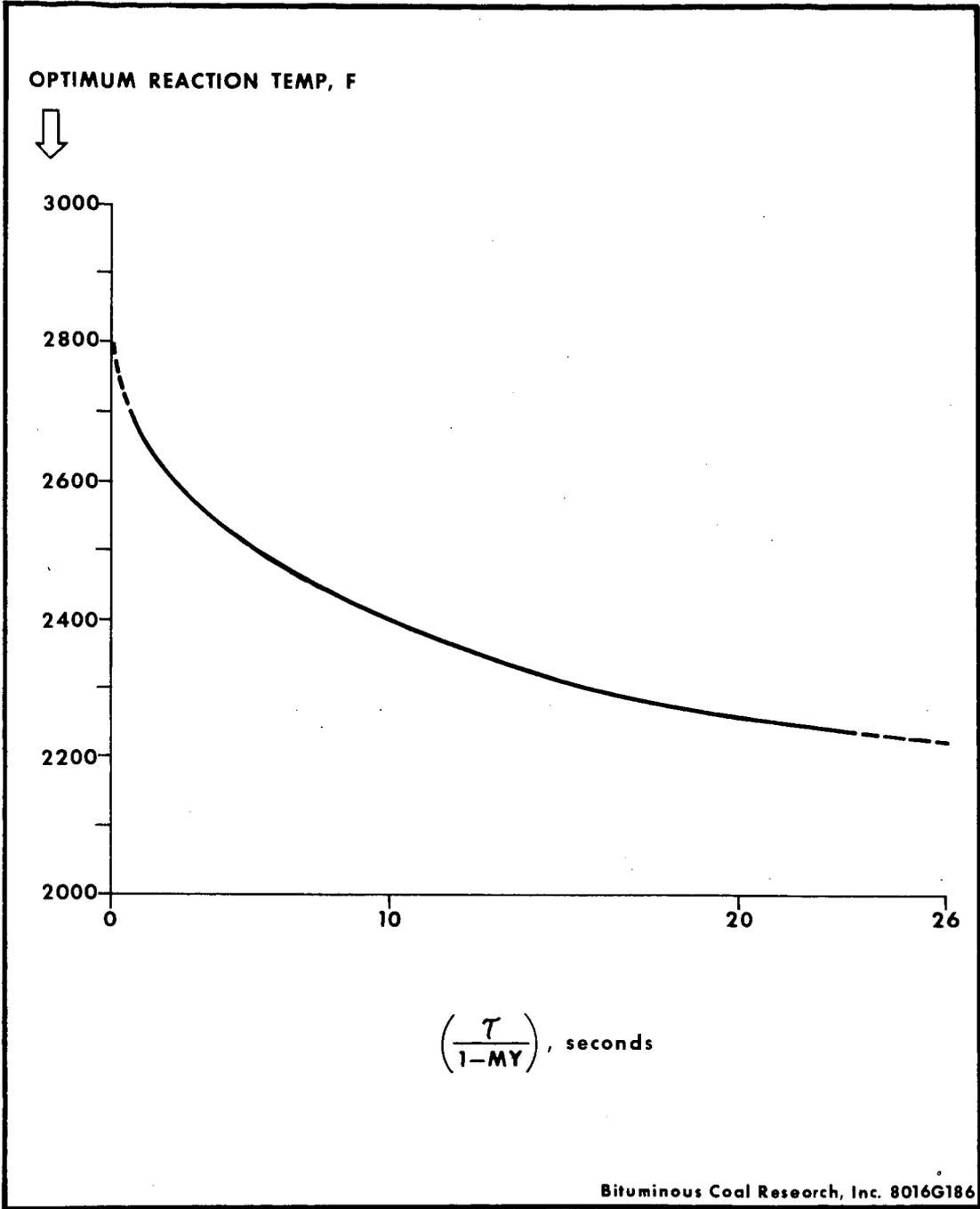


Figure 6. Optimum Temperature for Methane Production vs. Residence Time

The rate of production, under Stage 2 conditions, is to a first order approximation

$$\text{rate} = k' \frac{(P_{H_2O})}{(P_{H_2})}$$

where  $k'$  is an effective rate constant. Proper integration of this equation would have to take into account the temperature and composition paths, which are unknown. However, if outlet conditions are used to approximate the appropriate integrated equation, the following expression is obtained

$$\frac{CY}{\left(\frac{P_{H_2O}}{P_{H_2}}\right)_\tau} = k' \quad (9)$$

where  $CY$  = fraction of carbon in coal gasified to carbon oxides.

Figure 7 is a plot of the natural logarithm of the carbon oxide yield expression from Equation (9) versus reciprocal outlet temperatures for all the data for Pittsburgh seam coal. The overall fit is fairly good, indicating that the various assumptions required to arrive at Equation (9) are not unreasonable.

#### GASIFICATION PHYSICS

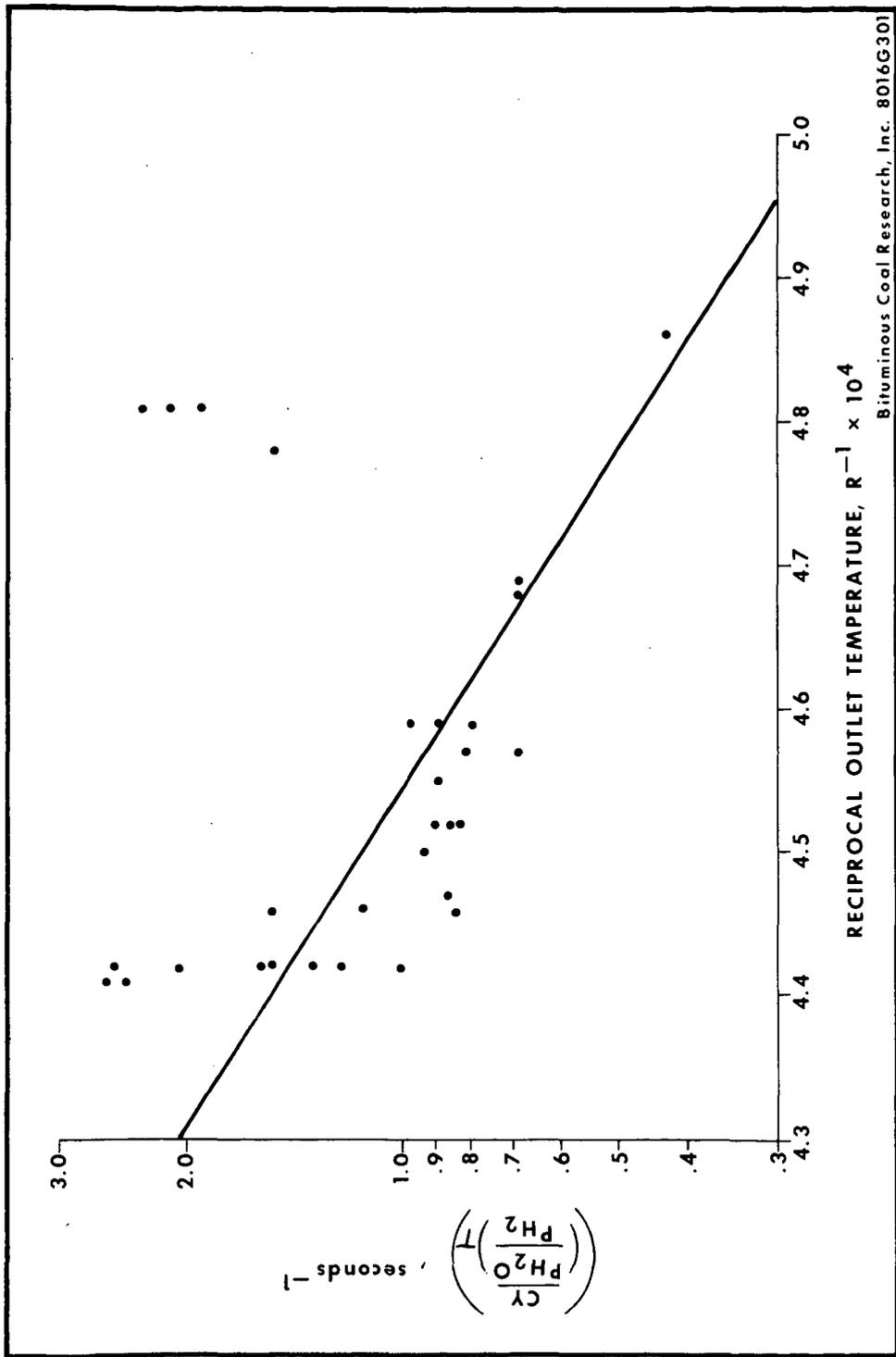
The physical processes taking place during entrained gasification are as complex as the chemical ones. Complete modelling of the physics would have to include the expansion of the jet of coal into the hot synthesis gas, particle-particle collisions; particle heat up, etc. Many of these physical processes have been examined by BCR in an attempt to understand entrained gasification. However, in the light of the previous discussion concerning the recirculation reformers set up by the coal feed, the most significant physical process affecting methane yield is the mixing between the coal feed and hot Stage 1 gases.

Although it is not possible to predict or even infer the exact mixing patterns in Stage 2 of the PEDU, some insight into these flow patterns can be obtained by considering certain idealized conditions. If only the expansion of the coal feed jet into Stage 2 is considered, the fluid mechanics of turbulent jets predicts that the coal stream would strike the wall at a distance  $X_p^{13,14}$ , where

$$X_p = 5.85 L$$

and  $2L$  is the Stage 2 diameter (ft). In the absence of reaction or other influence from the Stage 1 gases, the coal feed jet would strike the wall of the 8-inch diameter PEDU about 2 ft below its entrance.

As the coal feed jet slows down from its nozzle velocity, it entrains surrounding fluid in order to conserve its axial momentum and thereby sets up recirculation currents. The mass rate of material recirculated,  $m_r$ , per



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Figure 7. Carbon Oxides Yield Group vs. Reciprocal Outlet Temperature for Pittsburgh Seam Coal

mass rate of material fed,  $m_o$ , can be estimated from the following equation proposed by Thring<sup>14</sup>.

$$\frac{m_r}{m_o} = \frac{0.47}{\theta} - 0.5 \quad (10)$$

Where

$$\theta = \frac{m_o}{L(\pi \rho_a G)^{1/2}}$$

and  $\rho_a$  = density of surrounding fluid (lb/ft<sup>3</sup>)

$G = m_o \times v_o$  = mass velocity at nozzle (ft lb/sec<sup>2</sup>)

Typical values for PEDU operation are:

$\rho_a = 0.6$  lb/ft<sup>3</sup> (22 molecular weight gas, 1020 psia, 2700° R)

$m_o = 100$  lb/hr =  $\frac{1}{36}$  lb/sec

$v_o = 50$  ft/sec

$G = \frac{50}{36}$  ft lb/sec<sup>2</sup>

Hence

$$\theta = \frac{\frac{1}{36}}{\left[ \frac{1}{3} \pi (0.6) \left( \frac{50}{36} \right)^2 \right]^{1/2}} = 14.5$$

And a typical recirculation ratio is:

$$\frac{m_r}{m_o} = \frac{0.470}{0.069} - 0.5 = 6.4$$

Operation at this ratio would result in the first two feet of Stage 2 being fairly well mixed. According to Thring, recirculation into the jet begins at a distance  $X_n$ ,<sup>14</sup>

$$X_n = 6.25 \theta L$$

which in this case is 1.7 inches. Entrainment into the jet continues until a distance  $X_1$ ,

$$X_1 = 3.12 (0.94 + \theta) L$$

which is about 13 inches. From this point onward disentrainment occurs, reaching a maximum at about 16 inches.

These dimensions are summarized on Figure 8, which is a schematic of the PEDU.

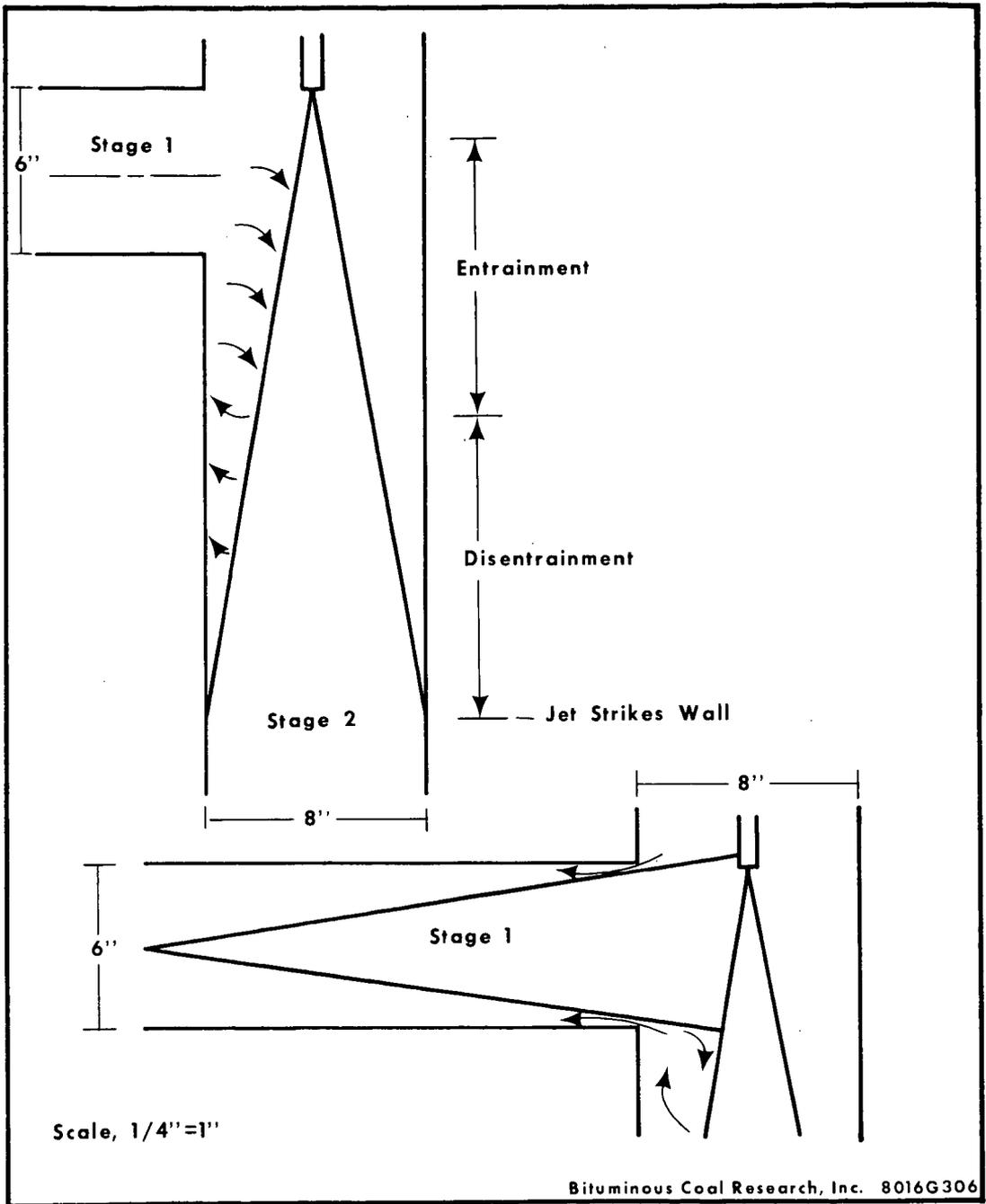


Figure 8. Typical Entrainment, Disentrainment Distances in the PEDU

The high recirculation rate and the fact that entrainment is taking place in the region where the hot Stage 1 gas enters Stage 2 indicate that product decomposition could occur in the PEDU. And as we have seen in the previous section, this does indeed occur.

When Stage 1 and Stage 2 are operating in concert, the mixing patterns are unquestionably more complicated. The Stage 1 zone is 18 inches long and its diameter is 6 inches. For these dimensions, it might be expected, on the basis of cold jet mixing, that the Stage 1 gases would strike the walls of the sidearm just prior to their entrance into Stage 2. However it has been reported that the jet half-angle in a furnace flame is about 4-1/4 degrees. At this angle the distance for the jet to strike the Stage 1 chamber walls,  $X_p$ , would be<sup>4,14</sup>

$$X_p = \cot (8.5^\circ) (3'') = 20''$$

Since this distance exceeds the length of the Stage 1 Zone, recirculation into Stage 1 from Stage 2 would be expected. From the previous arguments, it must be concluded that this would include both product gas and char. In actual fact, considerable insufflation into Stage 1 did occur, since extensive slag deposits were observed along the entire bottom of this zone. With this concept of PEDU circulation in mind, some tests were conducted in which hydrogen was used for coal transport. Low pressure operation was also employed. In these cases, nozzle velocities exceeded 100 ft/sec, and in some cases approached 300 ft/sec. Since  $\theta$  is proportional to

$$(m_0/v_0)^{1/2}$$

and if all other variables were held constant, an increase in nozzle velocity to 200 ft/sec would decrease  $\theta$  from the previously considered value by a factor of 1/2 to  $\theta = 0.035$ . Using this value, the mass recirculated ratio then would become

$$\frac{m_r}{m_0} = 12.9$$

The locations of the entrainment and disentrainment areas would remain relatively the same and, ideally, the jet would strike the Stage 2 chamber walls at about the same 2-ft level.

Under such operation, one would expect that a considerably higher degree of backmixing or recirculation would occur, although, of course, the average residence time of the gases in this part of the reactor would be dictated by overall flow rates. It is possible that the considerable backmixing leads to a higher inventory of char, particularly in the high temperature region exposed directly to Stage 1 input. This would lead to proportionately higher char gasification (to carbon oxides) than in less well-mixed tests.

Figure 9 presents the results of the high nozzle velocity tests for Pittsburgh seam coal. It can be seen that the carbon oxide yields are indeed higher than expected.

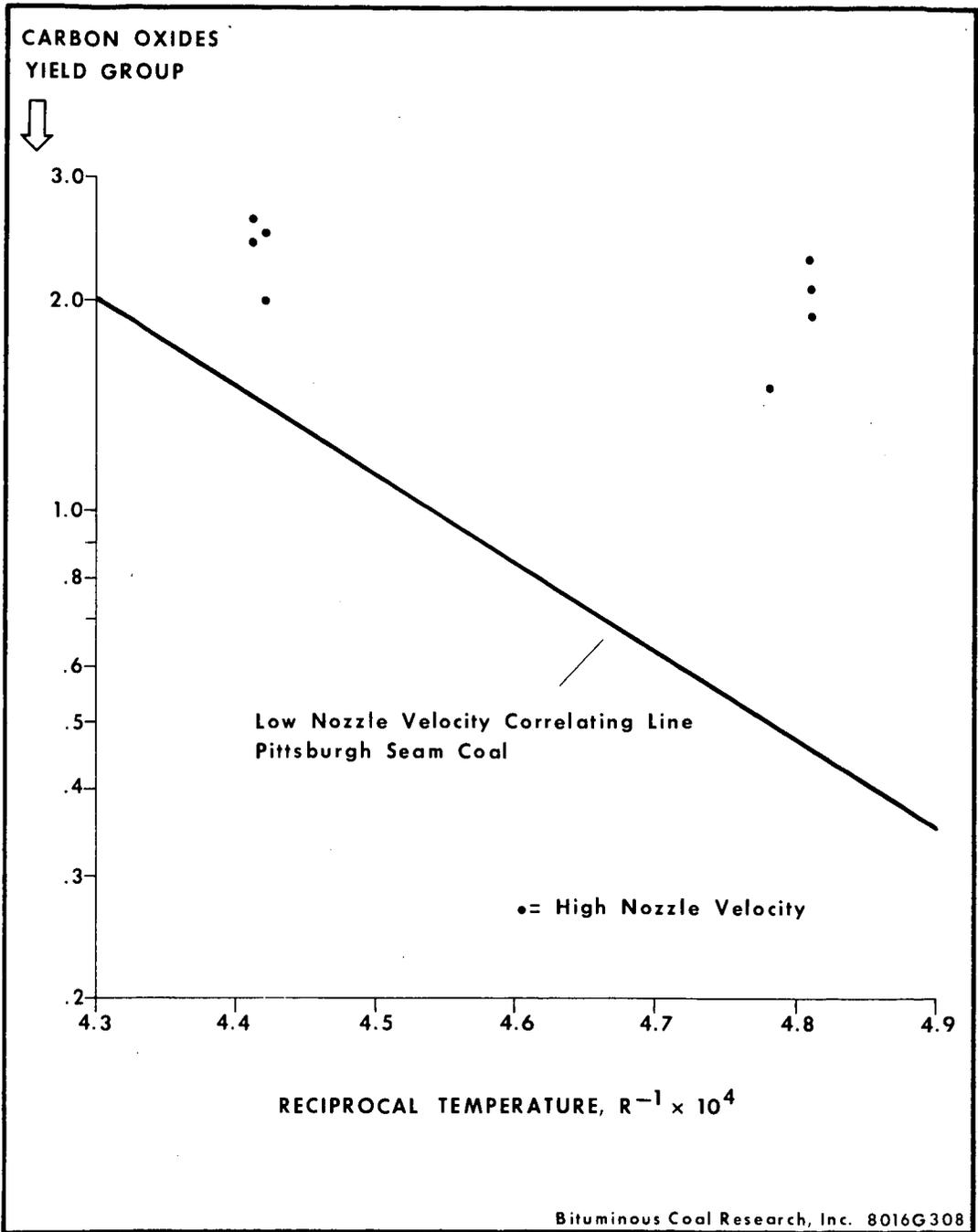


Figure 9. Effect of High Nozzle Velocity on Carbon Oxide Yield Group for Pittsburgh Seam Coal

The methane yields for these tests correlated in the same way as did those for the lower nozzle velocity tests and are included in Figure 4. This is as expected since the reactivity of char to direct methanation by hydrogen is considerably less than the active form of carbon produced in the initial heat-up of coal. Consequently, a higher char inventory, even in the high temperature region, would not produce higher methane yields.

#### DISCUSSION

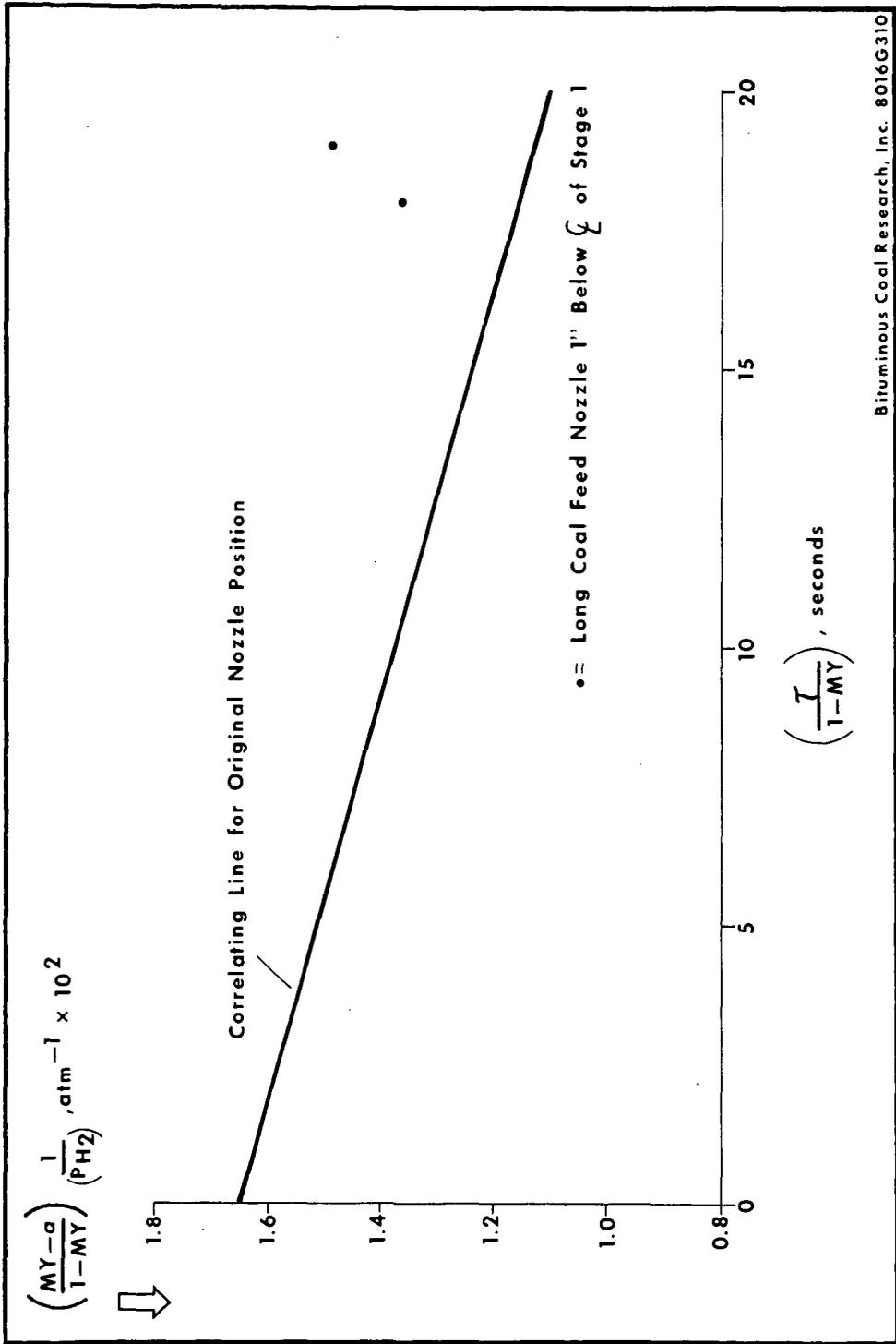
It must be remembered that the results and correlations expressed in the previous sections are specific to the geometry and conditions of the PEDU. They do not represent fundamental limitations on the entrained gasification of coal, but are to be taken as guidelines to basic understanding of the process. Thus, if the flow patterns set up by the PEDU geometry result in destruction of a portion of the methane, it should be possible to alter this geometry to improve methane yields. For example, if the coal feed nozzle were lowered into Stage 2, the back mixing of coal and product gases into the hotter regions of the gasifier would be reduced.

In order to test this idea, arrangements were made to extend the coal feed nozzle to various lengths inside Stage 2. The best location of those tested occurred with the nozzle one inch below the Stage 1 center line. With Pittsburgh seam coal as feedstock and the nozzle in this position, a methane yield of 25 percent was obtained for an outlet hydrogen partial pressure of 16 atmospheres. This exceeds the correlation established for the original nozzle position shown in Figure 10 and emphasizes the importance of proper flow patterns in Stage 2.

Carbon oxides yield for this nozzle position was less than expected from earlier correlations, as shown in Figure 11. In this case, the product methane and char which were recirculated would have been exposed to less severe temperatures and hence contributed less to the yield of carbon oxides.

The correlations discussed in the previous sections can therefore be viewed as conservative. With proper design to avoid recirculation of product methane into zones of high temperature, the next generation two-stage gasifier can be expected to produce methane yields in excess of those obtained in the PEDU.

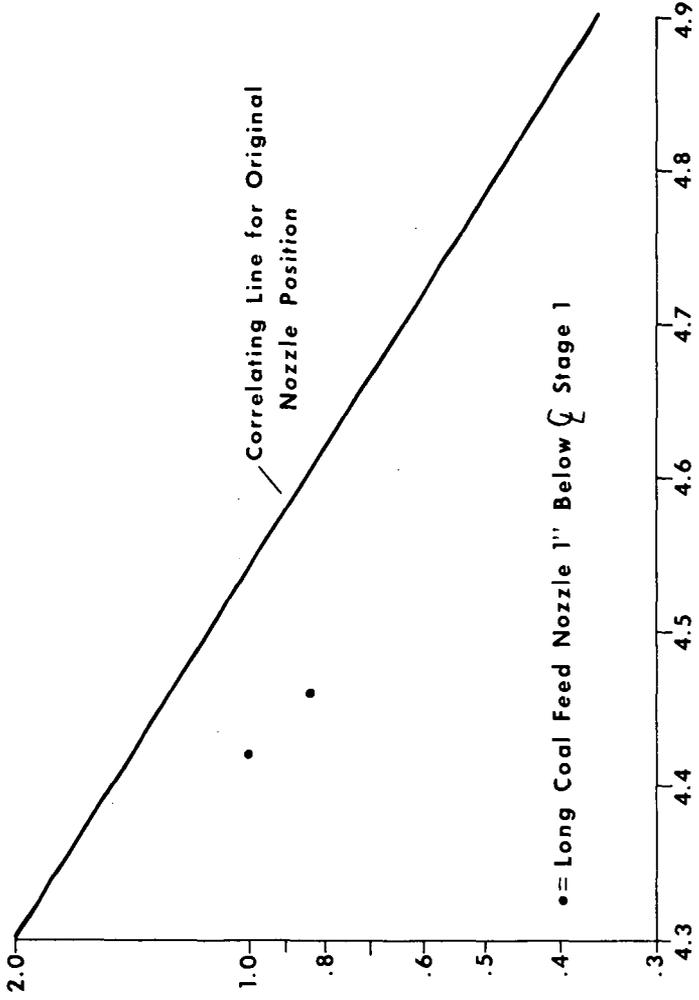
The PEDU tests discussed here have provided considerable information on the effects of temperature and residence time on the process. We have shown in this paper that simple ideas of gasification chemistry and physics can be combined into expressions adequate for correlating these data. Extrapolation of these expressions gives estimates for the methane yields which might be obtained from the entrained gasification of coal. For example, the extrapolations of Figure 6 indicate that if residence times could be limited to 2 seconds and effective temperatures of 2800 F were attained while maintaining 20 atmospheres of hydrogen partial pressure, methane yields of 38 percent could result. Even at effective temperatures of 2240 F, which we know we can achieve, methane yields in excess of 30 percent could be obtained if residence times could be kept to 1 or 2 seconds.



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Figure 10. Effect of Location of Coal Feed Nozzle on Methane Yield Using Pittsburgh Seam Coal.

CARBON OXIDES  
YIELD GROUP



RECIPROCAL TEMPERATURE,  $R^{-1} \times 10^4$

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Figure 11. Effect of Location of Coal Feed Nozzle on Carbon Oxide Yield Group Using Pittsburgh Seam Coal

Whether the exact nature of the rapid, high temperature gasification of coal is properly captured by the correlations of this paper to allow such extrapolations to be validly made is of course open for discussion. Whether gasifiers with proper geometrics can be designed to attain these high yields remains to be seen. But on the basis of the analysis proposed in this paper, the promise is there.

#### ACKNOWLEDGEMENT

This paper is based on work carried out at Bituminous Coal Research, Inc. with support from the Office of Coal Research, U.S. Department of the Interior, under Contract No. 14-32-0001-1207, and the American Gas Association. The authors also acknowledge the advice and encouragement of Dr. Ernest Donath.

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