COMBUSTION OF PULVERIZED CHAR

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Introduction

The increasing demand for natural gas stems from its freedom from emissions of particulate matter and sulfur oxides and its adaptability to relatively inexpensive and automatic combustion equipment. Many studies of fuel resources in the U.S. have indicated an impending shortage of natural gas. Fish[1] concludes that development of coal gasification is essential for the survival of the gas industry and indicates wellhead prices of natural gas will reach 50¢/MCF within 15 years.

Several coal gasification processes are being developed for production of pipeline gas. These generally yield a char residue that must be recovered for use as a solid fuel. The heating value in the char residue can amount to 50% of the heating value of the coal feed, depending on the process.

The combustion properties of chars are quite variable. A study based on the Coal Research Laboratory Reactivity Indices[2] shows a close correlation with the volatile matter content of cokes, reactivity decreasing with decreasing volatile matter content. The reactive properties of chars may differ, for material of the same volatile matter content, from those of cokes to those of active carbons. The reactivity of char residues from gasification will probably be nearer that for coke.

Walker[3] reported that chars from a fluidized bed process can be burned in pulverized form in furnaces normally used for anthracite, or in conventional bituminous-type units with supplemental fuel. Craig and Smith[4] have burned the product of fluidized-bed coking of petroleum fractions in a slagging furnace without supplemental fuel. The furnace used opposed firing inclined downward to give flame impingement on the slag pool and very stable ignition.

Experience is limited, but indicates that char residues from gasification can be burned efficiently provided the furnace is designed for the particular fuel or an auxiliary fuel is used.

Tests such as those for the CRL Reactivity Indices or burning profiles, developed by Wagoner and Duzy[5] can be used to estimate relative ease of combustion, but may not be sufficient to predict combustion efficiency in a particular type of unit not designed primarily for handling low-volatile matter fuels. Also, the tests are not standardized nor are they generally available. This has resulted because data have not appeared that justify standardized reactivity tests in consideration of the close correlation between reactivity indices and the proximate analyses of solid fuels.

The present paper reports on the combustion experience with three chars of different volatile matter contents in a front-wall-fired, dry-bottom furnace capable of burning 500 lb of bituminous coal per hour.

Supplemental fuel was needed for stable combustion of low-volatile-matter chars in this unit. The proportion of supplemental fuel required, other operating variables held constant, is then a measure of the combustion properties of the given char. The percent carbon conversion in gasification should be optimized in relation to utilization of fuel value in the residual char, which in turn depends upon combustion properties of the char.

Experimental Apparatus

Combustion research has long been hampered by the unavailability of suitable equipment which could be used for experimental purposes. Present day industrial furnaces are too large, costly, and unwieldy to be used for experimentation, while results obtained from smaller experimental combustion units are difficult to interpret and extrapolate for use on full-scale furnaces. To overcome these liabilities, a multipurpose combustion unit was designed to simulate the performance of an industrial steam-generating furnace. The combustor, a dry bottom unit, is capable of burning 500 lbs of pulverized fuel per hour with an exit gas temperature of 2000°F. A photograph of the furnace is shown in Fig. 1. A simplified flowsheet of the combustion system including the pulverizing and feeding system is shown in Fig. 2. A cross-sectional view of the principal components, the combustor, convective heat transfer section, a duct designed for emission measurements, and a recuperative air heater is shown in Fig. 3. A detailed description of the furnace has been reported earlier.[6]

Operation

The four front-wall burners were designed to fire natural gas and/or pulverized solid fuel. Prior to each test period, the experimental furnace was fired with natural gas to preheat the refractory and to provide a source of preheat for the secondary air. During this period, combustion air flows were established and necessary secondary-air swirl adjustments were made to provide flames that were attached to the burners, but not drawn into the burner tubes. Preheating was then continued until the secondary air temperature reached about 550°F. Natural gas flow to each burner was then reduced by 50%, and pulverized-char feed was started at a rate of about 250 lbs per hour. From this point, oxygen content of the flue gas was used as a guide in the changeover. As the char feed rate was increased, natural gas to each burner was decreased to maintain a constant oxygen level in the flue gas. All of the chars fired in this investigation required supplemental fuel to provide stable flames. Since the burners are capable of burning pulverized solid fuels and natural gas, the latter was used as the supplemental fuel. Thus, the next operation was determination of the minimum amount of natural gas to provide stable flames.

When the desired char feed rate, nominally 400 lbs per hour, was reached, natural gas provided about 25% of the total thermal input to the furnace. Natural gas feed to each burner was then gradually decreased to the minimum amount necessary to produce stable flames, as determined by observation of the burners. Final adjustments were then made on char feed rate and secondary air to provide the desired excess air level for the test period.

Char used in this investigation was produced in an entrained carbonizer using Utah King HVBA as the parent coal. About 50 tons of coal were processed in 3 batches, each batch yielding a different volatile-level char, nominally 5, 12, and 15 percent by weight. During each combustion test, a char sample was taken from the primary air-fuel stream using a small cyclone sampler, the tip of which extended into the center of the recirculation loop. A typical analysis of char of each volatile level and of the parent coal is given in Table I.

TABLE I.- Typical analyses of chars and parent coal

	Low volatile char	Medium volatile char	High volatile char	Utah King mine coal
Proximate, wt-pct, as received				
Moisture	0.8	2.8	2.6	4.9
Volatile matter	5.1	12.0	15.1	44.0
Fixed carbon	80.9	73.2	72.0	45.9
Ash	13.2	12.0	10.3	5.2
Ultimate, wt-pct, as received				
Carbon	81.6	75.9	75.5	72.3
Hydrogen	1.0	2.3	3.0	5.8
Nitrogen	1.4	1.7	1.8	1.3
Sulfur	0.5	0.6	0.6	0.5
Oxygen	2.3	7.5	8.8	14.9
Ash	13.2	12.0	10.3	5.2

Discussion of Results

Supplemental fuel requirements varied for each volatile level and, to a lesser degree, for each set of combustion conditions within a volatile level. Minimum fuel requirements, determined as percent of total enthalpy input are shown graphicly in Fig. 4. The plot shows that minimum supplemental fuel depends somewhat upon the amount of preheat in combustion air. Extrapolation of the curves indicates that volatile matter content in excess of 20% is required for combustion of this char without supplemental fuel addition.

Combustion tests were performed according to a factorially designed program using three independent variables, each at two levels, as follows:

Variables*	Levels
Excess air	5 and 20%
Secondary air preheat	600° and 700°F
Degree of pulverization	80 and 95% thru 200 mesh

*Supplemental fuel, as percent of total heat input, was also a variable, but as indicated above, it was not an independent variable.

When minimum auxiliary fuel requirements were met, chars of each volatile level burned with very stable flames. Table II is a summary of the experimental data from the combustion tests. Carbon combustion efficiencies greater than 99% were obtained with char containing 15% volatile matter. Even with the more undesirable combustion variables--low air preheat, low excess air, and large fuel particle size, the low volatile char yielded about 94% carbon combustion efficiency.

Figure 5 shows the effect of volatile matter content on carbon combustion efficiency, with excess air and fuel particle size as combustion parameters. While the experiments were factorially designed for each volatile level of char individually, the data were subjected to regression analysis, since this type of analysis permitted addition or transformation of variables, and analyses of all of the data as a single block. The analyses yielded an equation as follows:

TABLE II. - Summary of experimental data

Observation No.	Excess air, pct	Degree of pulverization, pct, thru 200 mesh	Air preheat temp., °F	Volatile matter content percent, as fired	Carbon combustion efficiency, pct	Percent of total heat input in natural gas
31	19.6	95.2	700	5.2	97.5	15.4
32	5.4	95.2	695	5.2	95.5	15.0
33	10.6	94.9	600	4.7	97.2	14.6
34	5.4	94.9	600	4.7	95.2	15.2
35	19.0	80.1	605	5.0	95.3	15.2
36	4.9	80.1	600	5.0	93.8	14.8
37	19.6	80.3	690	5.6	95.7	15.2
38	4.9	80.3	695	5.6	94.0	14.7
91	19.6	95.1	700	12.5	98.7	12.0
92	4.9	95.1	695	12.5	97.5	11.9
93	20.2	95.0	605	11.9	98.3	13.0
94	5.0	95.0	600	11.9	97.2	13.2
95	20.3	79.8	600	12.1	97.3	13.9
96	4.9	79.8	600	12.1	95.7	13.8
97	20.3	80.2	690	11.5	97.5	11.8
98	4.9	80.2	690	11.5	96.0	12.3
151	19.6	95.0	700	15.3	99.8	8.9
152	5.4	95.0	700	15.3	99.5	9.6
153	18.2	94.9	600	16.0	99.5	10.9
154	4.9	94.9	600	16.0	99.2	10.4
155	18.9	79.9	600	14.9	99.1	10.8
156	4.9	79.9	600	14.9	98.1	11.0
157	19.6	80.0	705	14.9	99.4	9.2
158	4.9	80.0	695	14.9	98.5	9.5

$$\text{Carbon combustion efficiency} = 85.5 + .077A + .067B + .00347C + 1.3 \times 10^{-6} D^2 + .0007E$$

where A = excess air, percent
B = degree of pulverization, percent thru 200 mesh
C = heating value of volatile in char, Btu/lb char as fired
D = (C - 1400)
E = thermal input in preheated air, Btu/lb char.

Heating value of volatile in the char, C, was calculated by difference in the heating value of the char and the heating value of the fixed carbon in the char, assuming 14,500 Btu/lb of fixed carbon.

Of interest in the equation is the absence of a term showing the effect of the natural gas used to provide flame stabilization. As the volatile matter content of the char was decreased, it was necessary to increase the percent of total heat input supplied by natural gas in order to maintain a stable flame. The percent of heat input supplied by natural gas was not an independent variable. Accordingly, the effect of natural gas is included in the effect of the heating value in the volatile of the char.

Analyses of the data indicate that excess air, degree of pulverization, heating value of the volatile in the char, and the quadratic effect of the heating value of the volatile in the char are about equally important, while air-preheat temperature is of marginal significance. Over 95% of the variation in carbon combustion efficiency is explained by the equation.

Conclusions

The combustor used in this investigation simulated the operation of a dry-bottom, horizontally-fired, pulverized-coal furnace. When fired in this unit, chars with about 5% volatile matter yielded 94-97.5% carbon combustion efficiency, while 12% volatile char yielded 95.7-98.7%, and 15% volatile char yielded 98.1-99.8% carbon combustion efficiency. The ranges of carbon combustion efficiency were the effect of the combustion parameters--excess air, fuel particle size, and secondary air preheat. As expected, higher excess air and higher preheat with fine particle size yielded higher efficiencies. All of the chars fired required supplemental fuel to provide flame stabilization. The amount required, based on percent of total enthalpy input, was about 10, 13, and 15% natural gas for chars containing 15, 12, and 5% volatile matter, respectively. It appears that a volatile matter content in excess of 20% is necessary for combustion of these chars without supplemental fuel.

References

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Figure 1.- Pulverized-Coal-Fired Combustor.

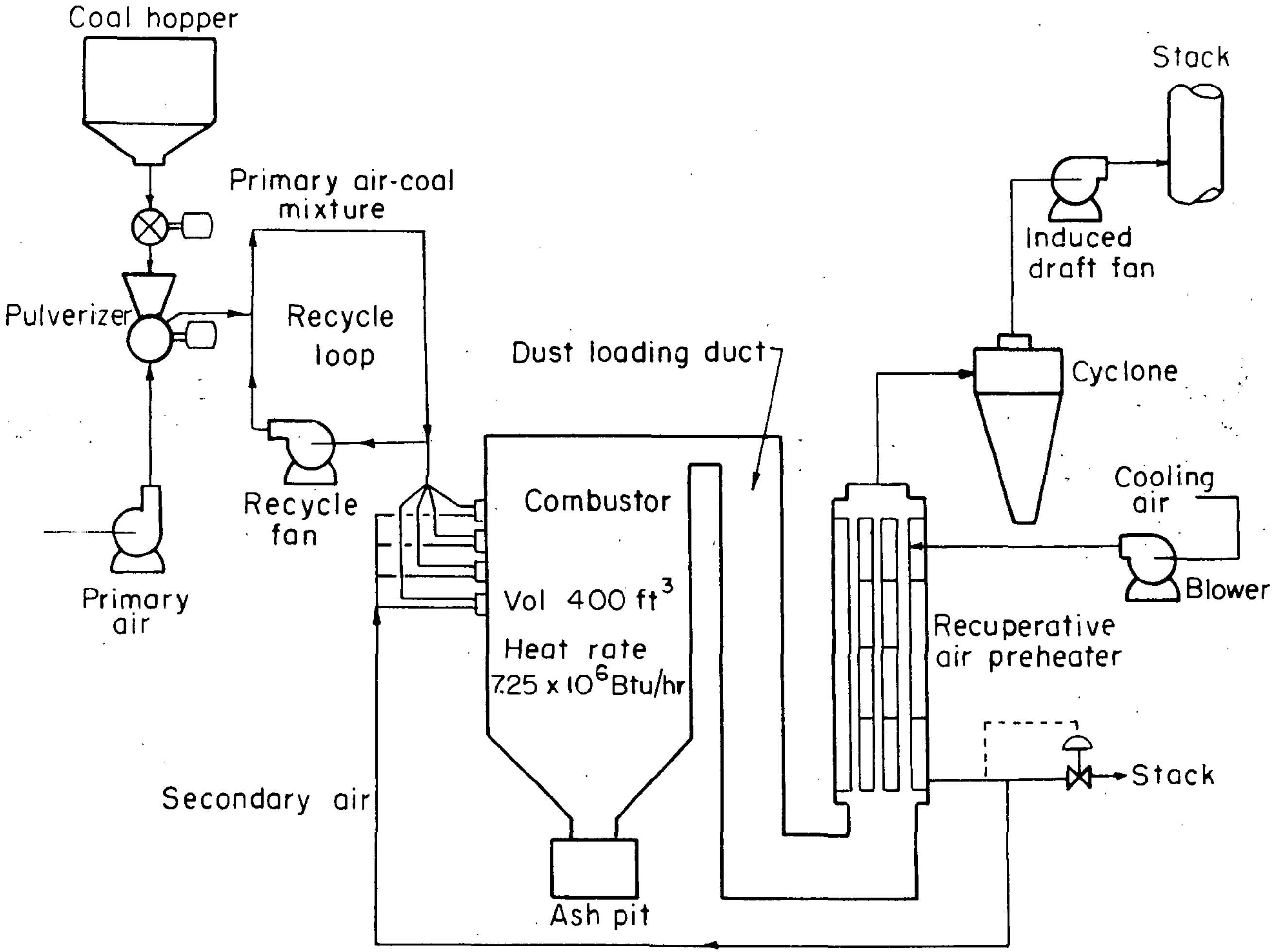

Figure 2—Simplified flowsheet of 500 lb/hr pulverized-fuel-fired furnace.
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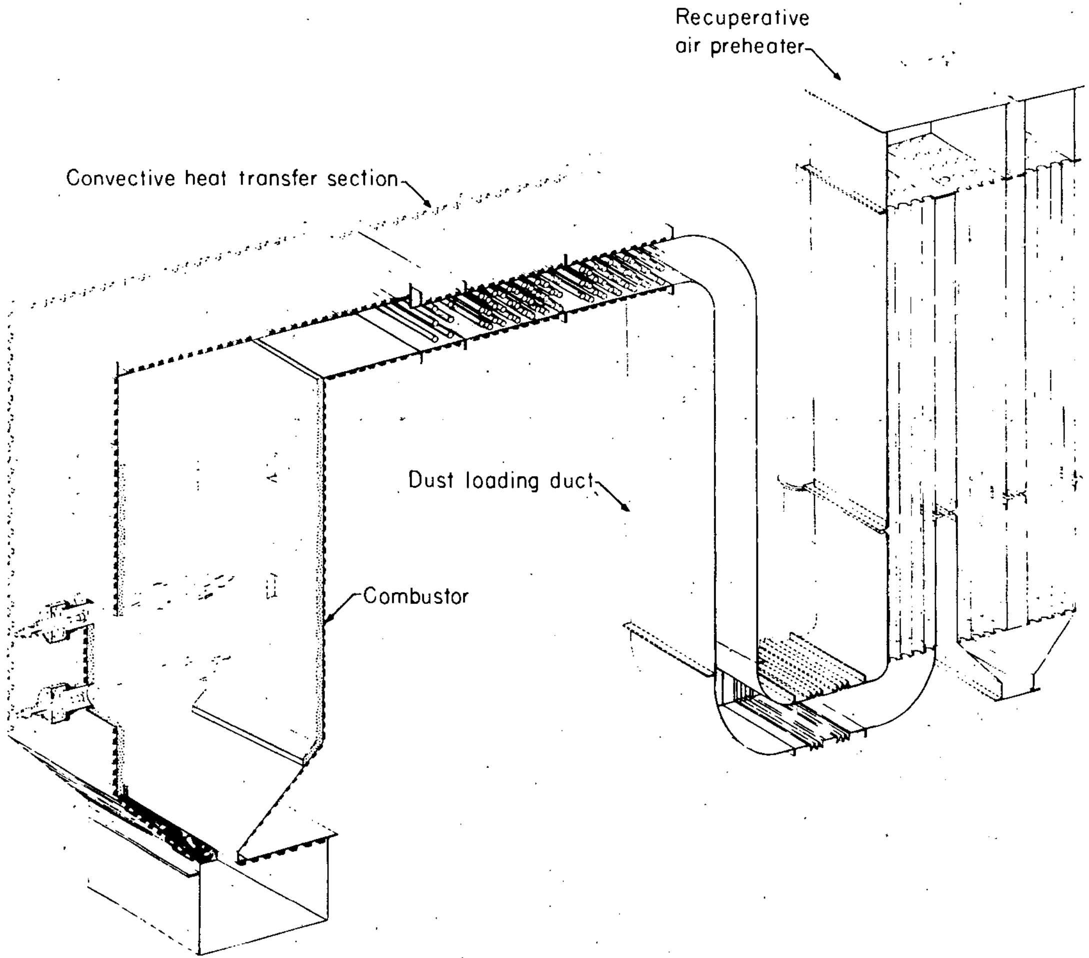

Figure 3.- Cross-sectional view of 500 lb/hr pulverized-fuel coal combustor.

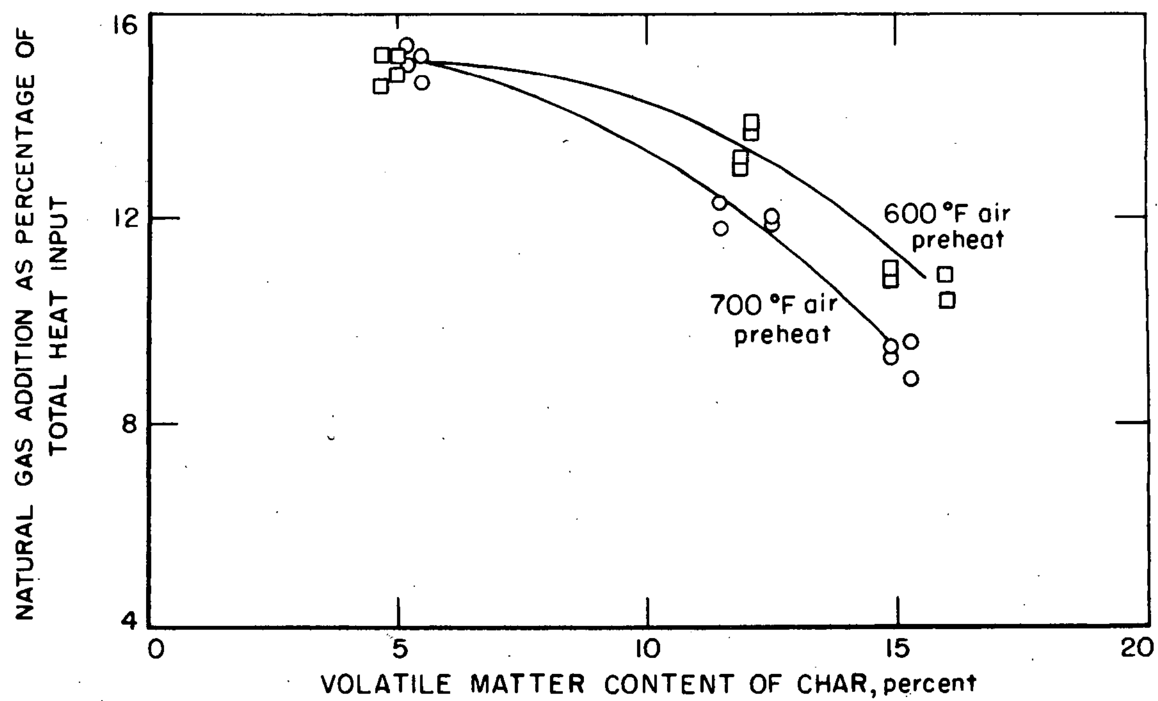

Figure 4—Supplemental fuel requirement as a function of volatile matter content.

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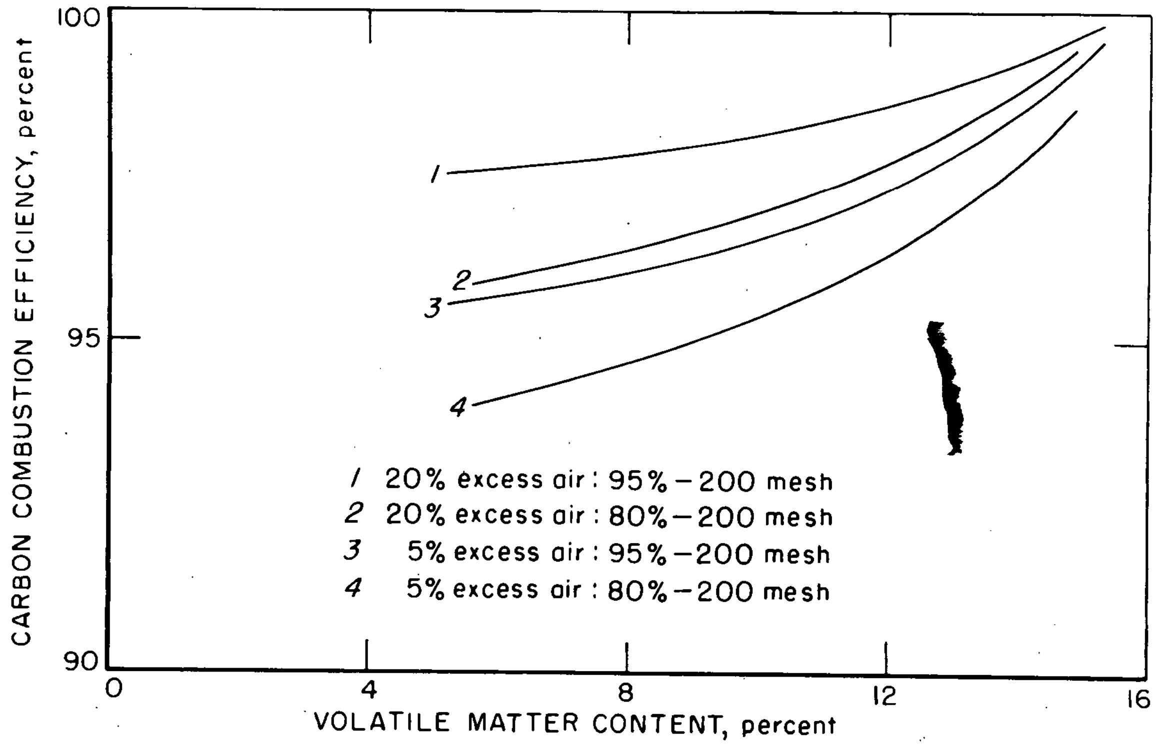

Figure 5—Carbon combustion efficiency as a function of excess air with 700° F preheat.[1]

[1] Sufficient natural gas added to stabilize combustion (See figure 4)

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