Thermochimica Acta, 166 (1990) 351–356
Elsevier Science Publishers B.V., Amsterdam

COMBUSTION STUDIES OF COAL DERIVED SOLID FUELS BY THERMOGRAVIMETRIC ANALYSIS. III. CORRELATION BETWEEN BURNOUT TEMPERATURE AND CARBON COMBUSTION EFFICIENCY *

M. ROSTAM-ABADI, J.A. DEBARR AND W.T. CHEN
Illinois State Geological Survey, 615 E. Peabody Drive, Champaign, IL 61820 (U.S.A.)

(Received 9 January 1990)

ABSTRACT

Burning profiles of 35–53 μm size fractions of an Illinois coal and three partially devolatilized coals prepared from the original coal were obtained using a thermogravimetric analyzer. The burning profile burnout temperatures were higher for lower volatile fuels and correlated well with carbon combustion efficiencies of the fuels when burned in a laboratory-scale laminar flow reactor. Fuels with higher burnout temperatures had lower carbon combustion efficiencies under various time-temperature conditions in the laboratory-scale reactor.

INTRODUCTION

The reduction in volatile matter that accompanies most thermal and chemical coal-desulfurization processes influences combustion characteristics such as ignition temperature, flame stability and carbon burnout. The current goals of combustion research at the Illinois State Geological Survey are to obtain combustion characteristics of partially devolatilized coals and to develop methods for predicting combustion performances of fuels in larger combustors using thermogravimetric data.

Nonisothermal thermogravimetry (TG) has been widely used for evaluating burning properties of coals and chars [1–6]. A plot of the rate of weight loss against temperature while burning a sample in air has been referred to as a "burning profile" [3]. Burning profiles obtained under a set of standard conditions provide detailed information from the onset of oxidation to complete burnout and are useful for predicting the relative ranking of fuels with regard to their combustion reactivities. According to published reports

* Presented at the 18th Annual NATAS Conference, San Diego, CA, U.S.A., 24–27 September 1989.

0040-6031/90/$03.50

[3,7], fuels with higher burning profile burnout temperatures (T_B) are more difficult to burn and require longer residence times or higher temperatures to achieve complete combustion in a commercial boiler. Fuels with similar burning profiles have comparable burning characteristics in large coal-fired furnaces [3]. In a recent study [4] a correlation was observed between a fuel's burn-out temperature and its burnout performance in a pilot-scale pulverized coal combustor.

In part I of this series, the effects of sample mass, heating rate, and air purge rate on burning profiles were presented [8]. In part II, the influence of particle size on burning profiles of a coal and three partially devolatilized coals were reported [9]. In this paper, the results of a study to relate a fuel's burning profile burnout temperature to its combustion efficiency when burned in a laboratory-scale laminar flow reactor under conditions representative of pulverized-coal boilers are presented.

EXPERIMENTAL

Samples for this study were derived from sample number 3 of the Illinois Basin Coal Sample Bank (IBC-103, 39.2% volatile matter, dry basis) [10]. This sample is a mine-washed coal and consists of a blend of 20% Herrin (No. 6) and 80% Springfield (No. 5) coals. The analyses of the 38-53 μm size fraction of the IBC-103 coal are presented in Table 1. The partially devolatilized (PD) coals were produced at the United Coal Company's (UCC) pyrolysis pilot plant facility located near Bristol, VA. The parent coal and the three PD samples were subjected to a riffling and grinding procedure [2]

TABLE 1

Analyses of the 38–53 μm IBC-103 coal and PD coals (wt.%)

	Coal	PD-1	PD-2	PD-3
Proximate				
Moisture	2.0	1.6	1.7	1.6
Volatile matter	35.6	25.6	18.4	13.6
Fixed carbon	53.4	61.9	67.8	73.0
H-T ash	9.0	10.9	12.1	11.8
Ultimate				
Hydrogen	5.07			
Carbon	73.21			
Nitrogen	1.82			
Oxygen [a]	8.68			
Sulfur	2.23			
H-T ash	8.99			
Btu/lb	13153	12932	12691	12624

[a] Oxygen was obtained by difference.

to produce five discrete size fractions of each fuel, 38–53 μm, 53–75 μm, 75–105 μm, 105–150 μm, and 150–212 μm. The 35–53 μm size fraction was used in this study. The PD fuels had volatile matter (dry-ash-free basis) contents of 29.3 (PD-1), 21.5 (PD-2), and 15.7% (PD-3). Proximate analyses of the PD coals are given in Table 1.

Burning characteristics of the fuels were obtained with an Omnitherm TGA coupled with an Omnitherm QC25 Program/Controller. The TGA system is interfaced with an IBM PC-XT computer through a Keithley DAS series 500 data acquisition system to provide automatic data collection and storage. In a typical run, a sample mass of about 5 mg was loaded into the platinum pan of the TGA and was heated at a constant rate of 20 °C min^{-1} in a 10% O_2–90% N_2 gas mixture from ambient temperature to 800 °C. The flow rate of reactant gas was 200 cm^3 min^{-1}. Under these conditions thermal runaway, which results from sudden ignition of sample, did not occur. The percent weight of the unburned sample, percent rate of weight loss, and the gas temperature in the vicinity of the sample pan were collected by the computer at 15 s intervals. Percent rate of weight loss data were plotted against temperature to obtain burning profiles. The burning profiles of the size-graded fuels were reported in part II of this study [9].

Carbon combustion efficiency data were obtained in a vertical laboratory-scale laminar-flow tube reactor located at the University of North Dakota Energy and Minerals Research Center. The reactor, referred to as a drop tube furnace (DTF), mimics the time–temperature history of commercial boilers. Tests were performed at two furnace temperatures (900 °C and 1300 °C) and two residence times (0.1 s and 0.8 s). The reacting gas contained 3% oxygen and 97% nitrogen and had a nominal flow rate of 10 l min^{-1}. Original samples and their residues collected from the DTF tests were subjected to TG–proximate analysis to determine the fraction of carbon converted. Approximately 40 mg of sample was heated at 50 °C min^{-1} under argon purge to 825 °C. The weight loss between 110 °C and 810 °C was considered to be exclusively volatile matter in calculations. The percent of fixed carbon in the sample was determined from the weight loss after admitting air at 825 °C. The ash content was evaluated from the weight remaining. The fraction of carbon burned in the DTF was calculated by assuming that all of the ash in the original sample remained in the residue.

RESULTS

Burning profiles of the fuels are shown in Fig. 1. The profiles are offset to avoid overlap. Raw coal exhibits a single-burn profile, while double-burn profiles are observed for PD-1, PD-2 and PD-3 coals. The second burn appears as a shoulder peak for PD-1 and becomes more pronounced for PD-2 and PD-3. The double-burn behavior observed for the PD coals

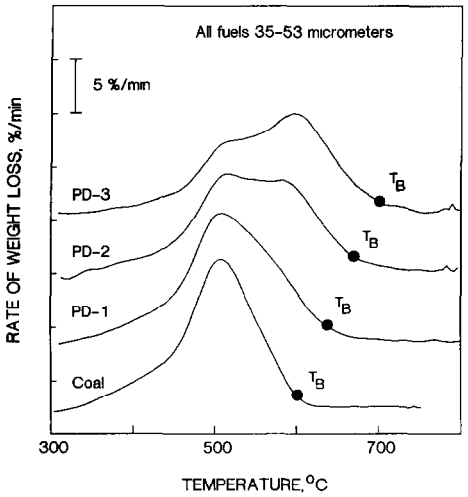

Fig. 1. Burning profiles for 35–53 μm fuels in 10% O_2–90% N_2, 20 °C min^{-1}.

suggests the presence of at least two types of combustibles in the fuels. The two portions of combustibles burn in two distinct stages with peak burn rates at approximately 520 °C and 600 °C. The higher reactivity constituent (low temperature burn) has burning properties similar to coal and was present in larger concentrations in PD-1, followed by PD-2 and PD-3 [2]. TG volatile release profiles of the fuels indicated that PD samples were blends of untreated coal and highly devolatilized coal [2].

Figure 1 reveals that the profiles are shifted to higher temperatures with decreasing volatile matter content. Burnout temperatures, defined as the temperature where the rate of weight loss decreases to less than 1% min^{-1}, are 600 °C, 640 °C, 670 °C and 695 °C for coal, PD-1, PD-2, and PD-3. This indicates that under the conditions used coal is the most readily combusted fuel followed by PD-1, PD-2 and PD-3.

The results of the DTF tests are shown in Fig. 2. Carbon conversions for the coal and PD coals vary from 10% to 75% at 900 °C and from 25% to 100% at 1300 °C. Carbon conversion increases with increasing temperature, residence time and volatile matter content. Data indicate that the effects of volatile matter and residence time on carbon conversion are more pronounced at higher furnace temperatures. Also, the effect of residence time on carbon loss is generally more pronounced for fuels with higher volatile matter content. Data also show that carbon conversion curves at 1300 °C and 0.1 s residence time were identical to those at 900 °C and 0.8 s residence time, indicating that temperature and residence time are interrelated. DTF data reveal similar trends in the reactivity of fuels as those obtained with the TG method.

In Fig. 3, carbon conversions obtained in the DTF for 38–53 μm fuels at 900 °C and 1300 °C and 0.1 s and 0.8 s residence times (values were taken

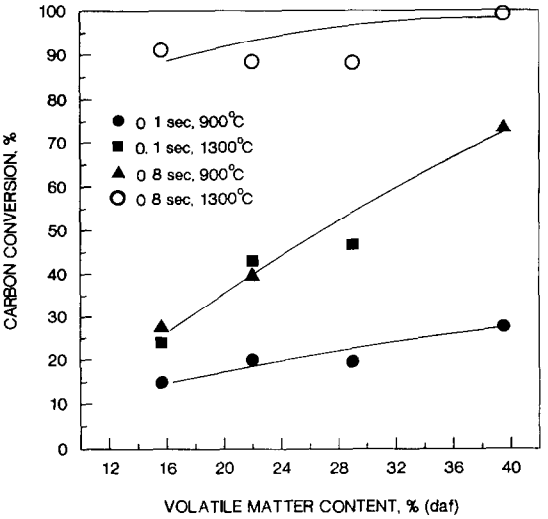

Fig. 2. Carbon conversions obtained in the drop tube furnace.

from the curves shown in Fig. 2) are plotted against values of T_B obtained from burning profiles. Good correlations were observed between burning profile burnout temperatures, which reflect fuel reactivity, and carbon conversions under various time-temperature conditions in the DTF. In all cases, a low T_B corresponded to high carbon conversion.

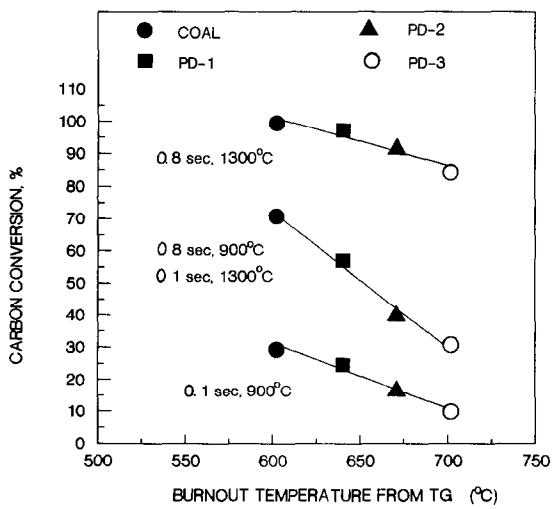

Fig. 3. Relationship between TG burnout temperature and carbon conversion in DTF.

CONCLUSIONS

Correlations such as those shown in Fig. 3 have practical applications when a large database is established for different types of fuels which have been tested under various conditions in the DTF and larger combustors. Burning profiles and burnout temperatures of new fuels, especially those that are not available in sufficient quantities for pilot or full-scale testing, can be compared with those of fuels with known performances to evaluate relative combustion performances of the new fuels under different boiler conditions. The results presented here demonstrate the potential of TG as a rapid and cost effective technique to predict burning characteristics of fuels under conditions representative of coal-fired boilers.

ACKNOWLEDGEMENTS

This work was funded in part by the Center for Research on Sulfur in Coal through the Illinois Coal Development Board. The authors thank Dr. Steve Benson and Dr. Donald McCollor for coordinating DTF experiments at the University of North Dakota Energy and Minerals Research Center.

REFERENCES

1 M. Rostam-Abadi, J.A. DeBarr, C.W. Kruse, D.L. Moran, R.D. Harvey and R.R. Frost, Final Technical Report to Center for Research on Sulfur in Coal, August 1987.
2 M. Rostam-Abadi, J.A. DeBarr, W.-T. Chen, S.A. Benson and D.P. McCollor, Final Technical Report to Center for Research on Sulfur in Coal, August 1988.
3 C.L. Wagoner and A.F. Duzy, presented at Winter Annual Meeting, ASME, Pittsburgh, PA, 12–16 November 1967.
4 P.A. Morgan, S.D. Robertson and J.F. Unsworth, Fuel, 65(11) (1986) 1546.
5 P.A. Morgan, S.D. Robertson and J.F. Unsworth, Fuel, 66(2) (1987) 210.
6 J.W. Cumming, Fuel, 63(1) (1984) 1436.
7 C.L. Wagoner and E.C. Winegartner, J. Eng. Power, April (1973) 119.
8 M. Rostam-Abadi and J.A. DeBarr, in P.J. Kelleghan (Ed.), Proc. 16th Annual North American Thermal Analysis Society Conf., 1987, p. 38.
9 J.A. DeBarr and M. Rostam-Abadi, in C.M. Earnest (Ed.), Proc. 17th Annual North American Thermal Analysis Society Conf., 1988, p. 566.
10 C.W. Kruse, R.D. Harvey and D.M. Rapp, Am. Chem. Soc., Div. Fuel. Chem., Prepr., 32(4) (1987) 359.