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Effects of Catalytic Mineral Matter on CO/CO₂ Ratio,
Temperature and Burning Time for Char Combustion

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Introduction

The high temperature oxidation of char is of interest in a number of applications in which coal must be burned in confined spaces. These include: the conversion of oil-fired boilers to coal using coal-water slurries, the development of a new generation of pulverized-coal-fired cyclone burners, the injection of coal into the tuyeres of blast furnaces, the use of coal as a fuel in direct-fired gas turbines in large-bore low-speed diesels, and entrained flow gasifiers. In addition, there is a need to better understand the temperature history of char particles in conventional pulverized-coal-fired boilers in order to better understand the processes governing the formation of pollutants and the transformation of mineral matter.

The temperature of a char particle burning in an oxygen containing atmosphere is the product of a strongly coupled balance between particle size and physical properties, heat transfer from the particle, surface reactivity, CO/CO₂ ratio and gas phase diffusion in the surrounding boundary layer and within the particle. In addition to its effects on burning rate, particle temperature has major effects on ash properties and mineral matter vaporization. Measurements of the temperature of individual burning char particles have become available in recent years and have clearly demonstrated large particle to particle temperature variations which depend strongly on particle size and on particle composition. These studies, done with pulverized coal, do not allow direct determination of the CO/CO₂ ratio produced at the char surface or the catalytic effects of mineral matter in the individual char particles and it has generally been assumed that CO is the only product of the carbon-oxygen reaction and that CO₂ is formed by subsequent gas phase reaction. More recent work, however, has pointed out the need to take CO₂ production into consideration in order to account for observed particle temperatures.

The importance of the CO/CO₂ ratio of carbon oxidation products is illustrated by examination of the heats of reaction for formation of these two products

The heat released by formation of CO₂ is a factor of 3.5 higher than for CO so the temperature of a particle will depend strongly on the CO/CO₂ ratio produced. If gas diffusion through the boundary layer is fast, increased direct production of CO₂ produces a higher temperature and a higher burning rate. If the supply of oxygen to the surface is limited by diffusion through the boundary layer, production of CO₂ consumes half as much carbon as production of CO so carbon consumption rate is reduced even though temperature may be somewhat higher. Models of these complex interactions have been developed; however, the CO/CO₂ ratio produced by the carbon-oxygen reaction must, at present be assumed or inferred from measurement of particle temperature.

CO₂/CO ratios can be strongly influenced by catalytic material in the carbon and by the char temperature. In this program we are measuring the CO₂/CO ratio for both catalyzed and uncatalyzed chars over a wide range of temperature. These results will then be used to develop predictive models for char temperature and burning rates. The electrodynamic balance has been successfully used to make such measurements for single 200 μm spherocarb particles. This work has been previously reported (progress reports 1 and 2). The electrodynamic balance has been rebuilt to improve its performance including:

1. Better control of gas flow and composition
2. High pressure operating capability
3. Advanced imaging system for size measurement and position determination
4. Capability of high and low temperature measurement

5. Better position control
6. Fast computation and memory facilities
7. Better laser power control

In this report, progress on the calibration of the imaging system, the laser power control system, and calibration of the mass flowrate controller are reported.

Results

The construction of the new system is about to be complete, and the entire diagram of the EDB system is in Fig.1. The preliminary calibration of the size measurement has been done, and the work on the laser power control system is on the way.

A. Calibration of the Image on the Screen

The usual method of measuring the size of the particle is using measurements of aerodynamic drag and particle weight. But that method requires particles of known size and density, and the accuracy is not that high enough due to the fact that it is an indirect method. By the development of the high resolution imaging system, it is now possible to measure the diameter of the particle directly.

The method is simple. A fine microscope scale (AZI Co. 100 parts/ 10mm) was inserted in the center of the chamber. A 3-way adjustable stand with a holder is used for centering. Also the microscope was used to verify that the scale was centered. The shape of the scale is in Fig.2a. The one scale of the picture is equal to 100 μm . The Image-Pro Plus program (Media Cybernetics) and AT386 have been used for image processing. The shape of the particle is shown in Fig.2b. And the size of the particle is 223 μm . The accuracy of this method can be estimated. The error from centering the scale

is less than 1 mm and the focal length of the convex lense is 10 cm, so the relative error is about 1 %. Because the image of the particle is not perfectly sharp, the measurement by the imaging program results in 1-3 pixels uncertainty. The number of the pixels over the diameter is about 120. We can reduce the uncertainty by trying as many measurements as we want. On the average, the error coming from the imaging program is about 2%. Therefore, the total error is about 2.24% maximum, which is comparable to the one from the aerodynamic method. But this method is much quicker and easier.

B. Laser Power Control System

The circuit diagrams for the laser control system are in Fig.3a and Fig.3b. The laser power control system is consists of three components. As we can see in Fig.1, the temperature of the particle is measured by the two color pyrometer. The signals go through the set of amplifiers to remove noise and AC component. One of the signals comes into the computer for recording, and the other signal comes into the laser power control box, which goes through the circuits in Fig. 3 to generate the control signal of the laser power by the algorithm of Proportional, Integral, and Differential control. And the TTL (a series of 0-5V square wave signal) signal generated goes into the power supply of the CO₂ Laser to control the laser power. The variable resistance for each control needs to be set by calibration. The need for the power control is clear if we see the laser power fluctuation in Fig.4. Therefore correct set of the resistances should be determined to get the desired temperature of the particle. This could be achieved by tracing the temperature fluctuation of the particle as a function of the resistance knob value. The fine tuning of the knob is on the way.

C. Mass Flowrate Controller Calibration

The calibration of the mass flowrate controller is necessary to measure the density of the particle by the aerodynamic drag method. Because if we plot the

volumetric flow rate vs voltage change , we get the product of the density and the diameter square, we can calculate the density of the particle. And if we want to verify the accuracy of the new method of measuring particle diameter by the aerodynamic drag method, we need exact values of the flowrate. The calibration is performed by the use of bubble meter, and the rising time of the bubble surface is measured. The result is in Fig.5, and the linearity is confirmed by the four nine digits correlation factor. And the whole gas flow system and MFC are shown in Fig 6.

Future Progress

During the next quarter the preliminary calibrations and experiments including aerodynamic density measurement should be completed and the main experiments of temperature profile of char oxidation will be studied. The temperature history of the particle will be modeled including gas phase boundary layer reactions. The CO_2/CO ratio of the catalyzed spherocarb is expected to be studied.

Fig.1 Schematic diagram of the Electrodynamic Balance System

Fig. 2a The Image of the Scale (100 parts/ 10mm)

Fig. 2b The Image of a Spherocarb

Fig. 3a Electric circuit diagram for
Log-ratio conversion unit

Temperature log-ratio box

Fig. 3 b Electric circuit diagram for PID control unit

PID Control Box

Fig.4 The Laser Power vs Time

Fig.5 Calibration of Mass Flowrate Controller

Fig.6 Gas flow system

Gas Flow System

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