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Ignition behavior of pulverized coals in lower oxygen content O_2/CO_2 atmosphere

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High speed camera is employed to capture the transient images of the burning particle in a flat-flame entrained flow reactor. Some characteristics of the burning particle, such as the optical intensity and the residence time, are obtained through the analysis of transient images. The ignition behavior of different rank coals at 1670K, 1770K and 1940K over a range of 2~30% O_2 in both N_2 and CO_2 diluent gases is researched. The results indicate that with the gas temperature increased, the ignition delay time for the lower oxygen concentrations cases decreased. The presence of CO_2 increases the ignition delay time at 2% oxygen content. And with the particle concentration and the volatile content increasing, the ignition delay time decreased. These trends are similar to those obtained from the testing at higher oxygen concentrations. But 40ms later, when the coal particles were ignition, the particle optical intensity in 2%O2/CO2 is larger than that in 2%O2/N2. This phenomenon is inconsistent with the previous results observed in the high oxygen concentrations.

Keywords: Coal; Ignition; High speed camera; Flat-flame entrained flow reactor; lower oxygen content; O_2/CO_2

1. Introduction

MILD-Oxyfuel combustion is a new technology, which integrated MILD combustion into Oxyfuel. It is activity being investigated because of its potential to resolve the problems, which Oxyfuel combustion has been on security and stability. But the MILD combustion has been used on the gaseous/liquid fuel only. The ignition and burnout characteristics of the solid fuel in MILD-Oxyfuel condition (low temperature and high CO_2) haven't been started. In this paper, ignition behavior of pulverized coals in the environment with lower oxygen content and high temperature will be studied.

In previous studies, most studies of pulverized coal particle ignition have been performed, but most of these have focused on the minimum gas temperature for ignition of particles, irrespective of residence time. This steady-state analysis has less applicability to the determination of flame holding in coal burner. Transient ignition phenomena have not been widely investigated (C.R.Shaddix 2009). The earliest reports were that W.J.Mclean(1981) and W.R.Seeker(1981) respectively used the high speed shadowgraph and holography to study the thermal decomposition of pulverized coal particle in a laminar flow reactor. In recent years, C.R.Shaddix(2009) employed the Sandia's optical entrained flow reactor facility to capture the transient image of the burning particle, studied the ignition and devolatilization of bituminous and subbituminous coal at a gas temperature of 1700K over a range of 12~36% O_2 in both N_2 and CO_2 diluent gases. Zhang(2010) employed the high speed camera to capture the particle images in the

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DTF, investigated the combustion of a brown coal at 1073K and 1273K over a range of 21~36% O_2 in both N_2 and CO_2 diluent gases. We can find that the related research has focused on high oxygen content.

In the work reported here, the photography technology was used for the direct observation of coal particle ignition during pulverized coal combustion in a flat-flame entrained flow combustion reactor. Emphasis in this study was placed on ignition behavior of pulverized coals in the environment with lower oxygen content and high temperature.

2. Experimental Section

2.1 Coal Combustion Facility

A flat-flame entrained flow combustor coupled with an 74mm i.d. transparent quartz reactor were employed for coal combustion. A schematic of the facility is shown in fig.1. The furnace operated at 1atm and used a McKenna flat-flame burner to provide high-temperature gas that rapidly heated the injured coal particles. The particle feeding rate was kept low (5g/h or 2.5g/m) to guarantee that the gas temperature and velocity profiles were not affected by particle combustion and the particle ignited and burned as isolated particle.

Three different burner temperatures were investigated, such as 1940K, 1750K and 1670K. The gas temperature profile along the reactor centerline was measured with a type B thermocouple and corrected for radiation losses.(Shaddix 1999) The combustion atmospheres were over a range of 2~30% O_2 in both N_2 and CO_2 diluent gases.

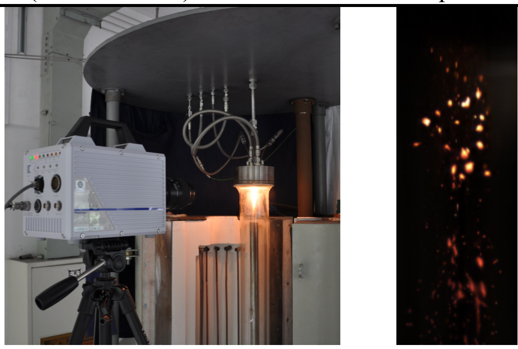

Fig.1. Schematic diagram of the flat-flame entrained flow reactor and the Transient image

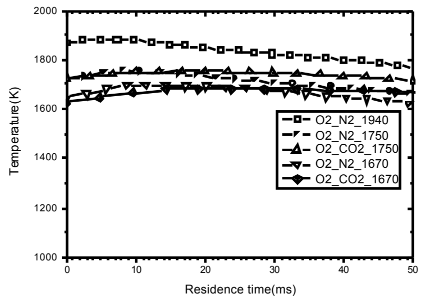

Fig.2. Measured centerline gas temperature profiles in the entrained flow reactor

2.2 Coal Properties

Two characteristic Chinese coals were investigated: DT bituminous coal and DQ lignite coal. The bituminous coal contains 24.78wt% volatile matter and 28.31wt% ash on dry mass basis. And the lignite coal contains 34.11wt% volatile matter and 22.62wt% ash on dry mass basis.

2.3 Particle imaging

A high speed camera (Photron FASTCAM SA1.1; see figure 1) was employed for phenomena observation, which was mounted with 105mm Micro lens and an anti-blooming CMOS sensor. The camera focus was set on the centerline of the reactor. The effective pixel size is 57μ m; the shutter speed was set to 5000fps and the exposure time was 200 μ s.

The image of the first 30mm of the reactor was recorded, saving 200 pictures. Image processing for the properties of discernible spots and volatiles cloud/flame was conducted the use of Matlab, which is able to simultaneously count and measure size. Luminosity represents a level of grayness or brightness, ranging in value from 0 denoting completely black to 255 for a completely white object in an 8-bit gray scale image. Which not confirmed if proportional to thermal radiation, apparently provides direct evidence on the oxidation intensity of char particle and volatile cloud. The brighter the particle is, the more intense it ignition/oxidation is, or the higher its temperature is.

In this paper, we assumed that the ignition spot was the first pixels whose gray values aren't equal to zero in the 8-bit gray scale image.

3. Result and Discussions

3.1 Ignition characteristic at the different conditions

Statistical analysis of more than 200 pictures for coal combustion quantified the ignition behavior in the environment with lower oxygen content and high temperature. For the O_2/N_2, the ignition delay decreases with the temperature and oxygen concentration increasing. It is similar to previous conclusion in the lower temperature. Fig.3. show the ignition delay for DT coal in the different conditions. Comparison of the ignition delay time, the presence of CO_2 increases the ignition delay time at 2% oxygen content. And the difference between O_2/N_2 and O_2/CO_2 decreases with the increase of temperature. This is because the auto-ignition time of coal particles increases linearly with the increasing volumetric heat capacity of bulk gases, according to adiabatic thermal explosion theory for a one-step overall reaction. The trends are similar to those obtained during testing at higher oxygen concentrations.

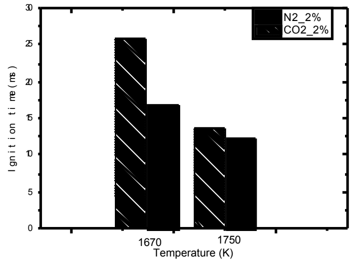

Fig.3. DT coal particle ignition delay time (ms) versus temperature for various O_2/N_2 and O_2/CO_2 gas mixtures

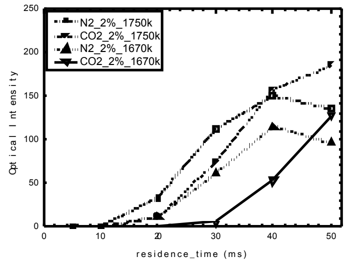

Fig.4. DT coal particle optical intensity versus residence time for various O_2/N_2 and O_2/CO_2 gas mixtures

3.2 Influence of particle concentration and coal property on ignition delay

It has been established that neither temperature nor the mechanism of ignition are inherent properties of coal, and that they depend on the surrounding gas, the heating rate of the particle and the particle concentration. In order to study the Influence of particle concentration and coal property on ignition delay. Two feeding rates are investigated: 2.5g/h and 5g/h. Relative to the actual concentration of pulverized coal furnace, the two particle concentrations are in the scale of single particle reaction.

From the view of the heat transfer, the main heat source to ignition come from the convection heat transfer in the flat-flame entrained flow reactor. During the experiment, the feeding rates are small; the absorbed heat of coal is negligible. With the increase of particle concentration, the volatile matter in the environment increased, which resulted in shortening of the ignition delay time. Similarly, the ignition of the high-volatile lignite coal is shorter than that of the bituminous coal. The trends are similar to those obtained during testing at higher oxygen concentrations.

3.4 Optical Intensity along the centerline of reactor

In the early stage of the reactor, their optical intensity in O2/N2 is higher than that in O2/CO2. Because of replacing N2 by CO2 caused noticeable delay in coal ignition. But after the 40ms when the coal particles were ignition, the particle optical intensity in 2%O2/CO2 are larger than those in 2%O2/N2. This phenomenon is inconsistent with the previous results observed in the high oxygen concentrations. The diffusivity of O2 in CO2 is lower than in N2, this difference might result in a lower reaction rate in CO2 environments. But the effect of the difference isn't significant in lower oxygen concentration. And the gasification between CO2 and the char produce more CO in the CO2 environment, CO diffuse to the outside, at the same time of O2 diffusing to the inside. It leads to the intensification of the reaction in the last stage.

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