THE EFFECT OF SYSTEM AND OXYGEN PARTIAL PRESSURE ON SINGLE COAL PARTICLE HETROGENOUS IGNITION TEMPERATURE UNDER CONDITIONS OF NEGLIGIBLE CONVECTION; EXPERIMENTAL OBSERVATION

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Abstract

Under conditions of high volatile concentrations, the influence of oxygen concentration on single coal particle ignition becomes more significant. The high volatile concentration conditions have been simulated by employing a microgravity environment. Results show that under these conditions, the heterogeneous ignition temperature decreases faster with increasing oxygen concentration than under normal conditions. The ignition temperature also decreases with increasing system and oxygen partial pressure under both conditions. Generally, the system and oxygen partial pressure show similar and complimenting effects on ignition temperature.

Introduction

A substantial amount of work on single coal particle ignition under microgravity conditions has been undertaken [1,2]. The work so far has only addressed atmospheric conditions as far as pressure and oxidants are concerned. Since the work simulates operations, which are sometimes subjected to high pressures and different types or concentrations of oxidants (e.g. pressurized fluidized bed combustors), it was deemed important to address these issues under this special condition. A major factor affecting the ignition of single coal particles has been shown to be volatile matter. Lu [3] has reported on the effect of pressure on volatile release as well as the effect of O_2 partial and total pressure. Although his work mainly focused on devolatilization rate, his findings have a direct influence on coal particle ignition as well as combustion. A thorough review on coal devolatilization was presented by Saxena [4] who also showed that the volatile yield was significantly reduced when pressure is increased, especially for bituminous coals.

As far as particle ignition mechanism is concerned, it is now generally agreed that coal particle ignition can be a multistage process [5]. In the primary ignition, the particles can ignite either homogeneously, by prior pyrolysis and subsequent ignition of the volatiles (Faraday mechanism), in the case of large particles heated up slowly; or they can ignite heterogeneously, by direct oxygen attack on the whole coal particle, in the case of small particles heated quickly. In this context, large is taken to be greater than 100μm and slowly has been taken to be less than 100 K/s. It has also been shown that ignition mechanism depends more or less on coal type (nature) and oxygen concentration.

Homogeneous ignition is believed to be a two-stage process, and heterogeneous ignition can involve three stages. In homogeneous ignition, the primary step is the ignition of volatiles. Following this, the combustion of volatiles, in circumambient flame like an oil drop, is presumed to prevent char reaction by screening the solid from access of oxygen; secondary ignition of char then occurs as pyrolysis terminates. Heterogeneous ignition can involve three stages. The primary ignition is by direct attack of the reactant gas on the solid. This solid is the whole coal and not only char, and the heterogeneous reaction removes material that would otherwise be expelled as volatiles. As a parallel to the homogeneous case, this reaction can sometimes be quenched as pyrolysis becomes appreciable, even if the volatiles do not burn. Secondary ignition, when it occurs, is that of the volatiles, and this may be followed in the

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due course by a re-ignition of char at the end of pyrolysis.

From above, it is clear that with the presence of volatiles in the particle vicinity, homogeneous ignition precedes heterogeneous one in most cases. Under conditions of negligible convection, the volatile accumulation in the particle vicinity is the largest. In this case, the oxygen concentration, in or around the volatile cloud plays a more significant role in determining how fast homogeneous ignition and volatiles combustion will take place and hence allow the heterogeneous ignition to occur. The rates of ignition and combustion of volatiles in turn influences the ignition time and temperature.

This study therefore, intends to investigate the effect of oxygen partial pressure on the heterogeneous ignition temperature under conditions where there is a substantial concentration of volatiles in the particle vicinity. Since conditions under which natural convection is eliminated makes it possible for volatiles to accumulate surrounding a particle, a microgravity environment (which eliminates the effect of natural convection) has been adopted for the purpose.

Experiments

The experimental apparatus used in this study is shown schematically in Fig. 1. A single coal particle was supported on the coiled thermocouple which saves both as a support for the coal particle as well as particle temperature measurement. The coal particle was heated by radiation from four spot heaters arranged in a square pattern with a common focal point. The spot heater system (details given elsewhere [[1]) was placed in an air-tight chamber which had four observation windows to allow for the ignition process to be recorded by the video as well as the high speed camera. The air in the chamber was withdrawn using a vacuum pump, after which the chamber was filled with a mixture of oxygen and nitrogen to the desired oxygen concentration and pressure. In case of ignition under atmospheric oxygen concentration, a compressor was used to fill air in the chamber to the required pressure. The particles were then heated and ignited. At this moment, the particle temperature measured by the coiled thermocouple was recorded in the board computer and latter transferred to another computer for further processing. The high-speed pictures as well as video images of the ignition process were also taken. The experiment was repeated for a number of particles (about 10 particles per set of given conditions) whose results average makes one data point. After that, the pressure and oxygen concentration in the chamber was changed and experiments continued as explained above. In this study, oxygen concentration was varied between 10-50% while the system pressure was varied between 1-7 bar (gauge). Only one representative coal sample was used, namely Coal Valley which has a volatile matter content of 32.5%. For comparison purposes, ignition experiments were undertaken under both normal and microgravity conditions.

For microgravity experiments, the same procedure as above was followed. In this case however, after the required oxygen concentration has been introduced into the chamber, the chamber was disconnected from the N_2 and O_2 cylinder and loaded into a drop tower capsule from which it was dropped to create the microgravity condition [1]. The drop height was 10 m which produced a microgravity time of 1.2 s. During the drop, the particle was heated and ignited. From the video recording and high-speed camera, volatile release, combustion and char ignition could be analyzed.

Results and discussion

Effect of O_2 partial pressure on char ignition

The effect of oxygen concentration on ignition of coal particles has been investigated extensively as summarized by Essenhigh [5]. The predicted heterogeneous ignition temperature has been shown to decrease with increasing oxygen concentration, while the homogeneous ignition has been shown to increase [5]. Also, the experimental results reported for heterogeneous ignition has shown the same decreasing trend with increasing oxygen concentration [5]. Results from this work, presented in Fig. 2, have shown the same trend as also reported by Lu [3]. Further, the effect seems to level off as the oxygen concentration increases. When the effect was

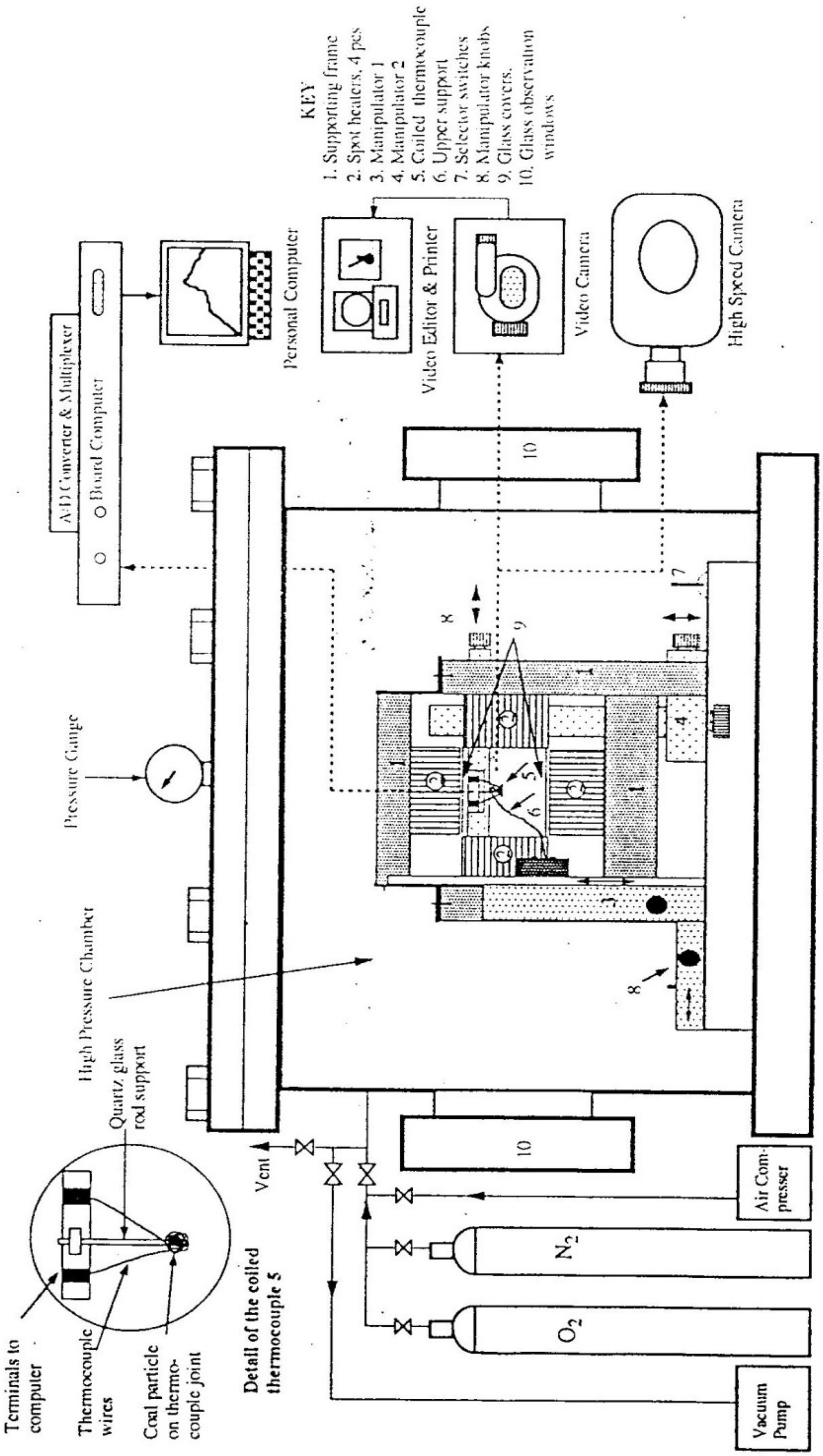

Figure. 1. Schematic diagram of experimental apparatus

investigated under microgravity conditions, the same trend as that under normal gravity was observed. However, the rate of decrease of ignition temperature with increasing oxygen concentration was much faster under microgravity than under normal gravity. It should be noted that each experimental data point in this work was obtained from the average of at least ten experiments (i.e. 10 particles per set at given conditions). As it has been reported before [1], one of the reasons responsible for the delay of char ignition under microgravity condition is the volatile cloud surrounding the particle. This cloud screens the particle from receiving oxygen from the surroundings. In the absence of convection, oxygen can then be delivered only by diffusion. In this situation, the oxygen concentration gradient is formed between the volatile cloud surface and the particle. Depending on the oxygen concentration, the slope of this gradient will change, and the higher the oxygen concentration, the steeper the gradient will be. When this gradient is high, the volatiles in the particle vicinity are combusted faster and hence the heat feedback to the particle becomes larger, thus making it possible for the particle to ignite at lower temperature when oxygen concentration is high. Almost the same argument can be applied to the case of ignition under normal gravity. However, in this case the amount of volatiles in the particle vicinity is reduced by convection, hence the heat feedback to the particle is less and this could influence the ignition temperatures. It

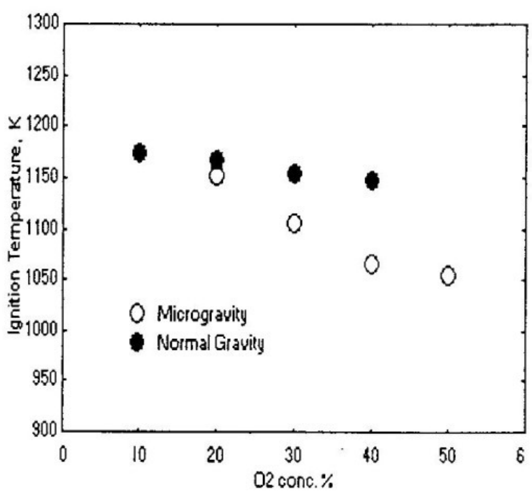

Fig. 2 Effect of O2 partial pressure on char ignition temperatureunder normal microgravity condition

should be noted that in Fig. 2, the cases of normal and microgravity ignitions are plotted together only for the purpose of comparing their rates of change of ignition temperature with increasing oxygen concentration. The comparisons of ignition temperatures under these two conditions have been undertaken before [1,2]. Here, the trend looks opposite because much smaller particles were used in the case of the microgravity condition hence resulting into lower ignition temperatures [6].

Effect of system pressure on ignition temperature.

The heterogeneous ignition also decreases with pressure under both normal and microgravity conditions as depicted in Figs. 3 and 4. The combined effect of oxygen partial pressure and the system's total pressure lowers the ignition temperature even further as shown by the increasing difference between the two oxygen concentrations. When the comparison between normal and microgravity conditions is done, it can be seen that under both conditions, ignition temperature is lower at higher oxygen concentration at any given pressure. It can also be seen that the difference between ignition temperatures at a given system pressure is smaller under microgravity condition than under normal gravity condition. The possible reasons for the decrease in ignition temperature with increasing system pressure includes:

a) The yield of volatiles is reduced under high pressure thus resulting into a smaller volatile cloud. The smaller volatile cloud then makes it possible for the oxygen to reach the particle earlier, thus ignition taking place at a lower temperature.

b) Influence on the composition of the volatiles: Pyrolysis at high pressure produces more char, less tar and more hydrocarbons. The yield of water also decreases substantially with increase of pressure. The presence of less tar and more hydrocarbons makes it easier for volatiles to ignite and burn faster thus allowing an early ignition of char.

c) Influence of diffusion coefficients: From point b above, the change in the volatile composition may have an influence on diffusion coefficients thus affecting the rate of oxygen supply to the particle.

d) Apart from the effects caused by volatiles, increased system or oxygen partial pressure accelerates chemical reactions in any process. This is partly due to the fact that under higher pressure, reactants are brought closer to each other thus making it easier for the reaction to take place.

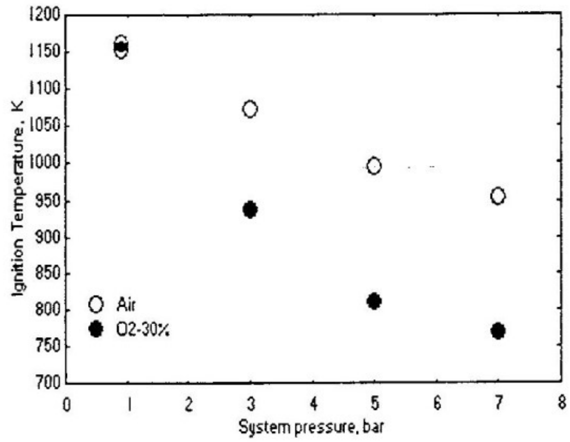

Fig. 3. Variation of ignition temperature with system pressure for different oxygen concentrations under normal gravity condition

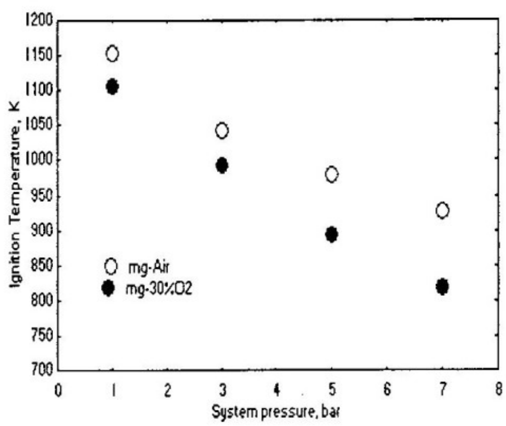

Fig. 4 Effect of total pressure on ignition ttemperature for different oxygen concentrations under microgravity

Generally, the system and oxygen partial pressure seems to have similar and complimenting effects on ignition temperature. This can be demonstrated by the fact that the ignition temperature under atmospheric pressure and 30% oxygen concentration is about 1500 K. However, the ignition temperature at the same oxygen concentration and three atmospheres is about 940 K. This value can not be attained under atmospheric pressure even if the oxygen concentration is increased to 100%.

As for the effect of oxygen partial pressure at higher system pressures, it can be seen from Figs. 3 and 4 that the ignition temperature is almost equal for a given calculated partial pressure (i.e. system pressure times oxygen concentration). But a closer look reveals that there is a limited agreement on ignition temperatures between air and a 30% oxygen in the case of normal gravity where the same

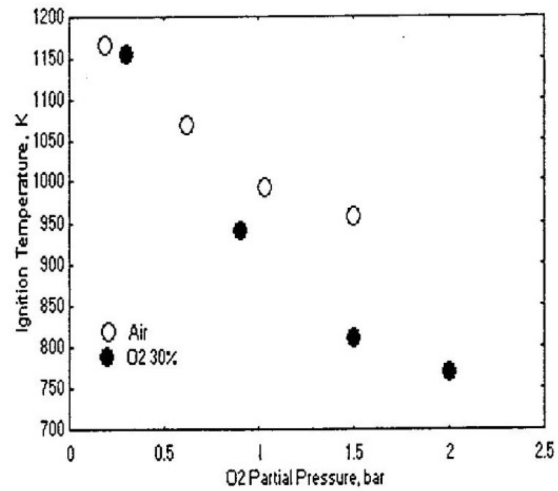

Fig. 5 Variation of ignition temperature with oxygen partial pressure under normal gravity condit

(calculated) partial pressure gives a higher ignition temperature for air than for a 30% oxygen concentration. This is substantiated in Fig. 5 where ignition temperature is presented as a function of oxygen partial pressure for the two oxygen concentrations. For the case of a microgravity condition, however, the results are found to be in a closer agreement between air and a 30% oxygen concentration as also depicted in Fig. 6. This indicates that in the presence of natural convection, the effect of oxygen partial pressure is somehow influenced. Further studies may be required to obtain more information about this. Apart from this, the effect of system and oxygen partial pressure on ignition temperature under conditions of negligible convection is more or less the same as that under normal conditions.

Conclusions

The effect of system and oxygen partial pressure on the heterogeneous ignition of single coal particles has been presented. Within the scope of this investigation, the following can be concluded.

1) The heterogeneous ignition temperature decreases with increasing oxygen partial pressure under both normal and microgravity conditions. This is attributed by the fact that higher oxygen partial pressures makes the oxygen concentration gradient in the volatile cloud surrounding the particle much steeper thus the volatile flammable mixture is easily formed, and volatiles burning rate becomes faster.

2) The heterogeneous ignition temperature also decreases with system pressure under both normal and microgravity conditions. The combined effect of system and oxygen partial pressure lowers the ignition temperature even further.

3) At high system pressures, the effect of oxygen partial pressure between normal and microgravity condition differs slightly. This could be attributed to the presence of natural convection under normal gravity.

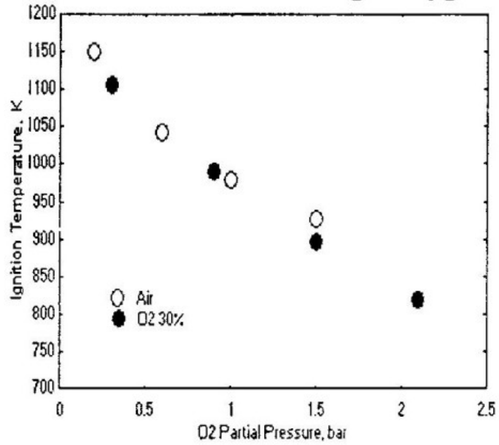

Fig. 6. Variation of ignition tenperature with oxygen partial pressure under

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