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Title: Experimental Studies on Group Ignition
of a Cloud of Coal Particles

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by

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OVERVIEW

Objectives for November 16, 1989 to February 15, 1990

1. Investigate the effect of particle size on ignition.
2. Investigate the effect of particle size on ignition temperatures.
3. Submit Annual Report #1.

Activities during November 16, 1989 to February 15, 1990

1. The effect of particle size on ignition times was investigated.
2. The effect of particle size on ignition temperature was studied.
3. The report covering the results for the period August 16, 1990 to February 1990 was submitted as Annual Report #1 to Mr. Thomas D. Brown. This report is based on MS thesis of Mr. Miguel Ruiz and the model results of Mr. Ryan.

Objectives for February 16, 1990 to May 15, 1990

1. Since an invitation was received from Professor Chigier, Editor Prog. Energy and Comb. Sc., for an article in the area of interactive combustion, efforts will be directed in collecting the literature on the interaction combustion of a cloud of drops and a cloud of coal particles.
2. Since Mr. Miguel Ruiz, a MS student has graduated in December, 1989 efforts will be directed in recruiting another student. This period will be used in writing the review paper.
3. Write the papers for presentation at Combustion Institute Meeting, Central States Section, May 1990.

1. Effect of Particle Size on Ignition Time

The effect of particle size was studied for three different particle average sizes. Experimental conditions for these tests were as those of the base case except for the particle diameter. The comparative results for average particle diameters 39, 64, and 90 μm are shown in Fig. 1 where the ignition times are plotted against mass flow rates. The scatter appears to suggest that the data may be inconclusive. However, whenever larger particles (150 to 300 μm) were fed into the reactor, ignition could not be obtained within the reactor. Thus ignition time must have increased with increase in particle size. Further the data points were fitted with third order polynomial curves. The polynomial curves are shown in Fig. 2 for the three different sizes. The curves show that the ignition time generally increases for the increased particle diameter at low and high mass flow rates. Figure 2 shows the same results as Fig. 1 but ignition time is represented as a function of the fuel volume fraction and the overall equivalence ratio. The increased ignition time is generally due to increased heat up time for each particle in the cloud. For the individual particle ignition times, the time increases as square of particle diameter. For clouds, however, it is apparent that the ignition time is not that sensitive to particle size since the ignition time is dominated by the heat up time of the cloud. For a change in average diameter from 39 to 90 μm , for example, it is seen that the increase in the ignition time is in the range from 4 (dilute regime) to about 10 ms (dense regime). For an increase in diameter from 39 to 64 μm the increase in ignition time is very small, ranging from about 2 ms in the dilute region to almost 5 ms in the denser region. In the intermediate mass flow rate range (from 4 to 8 g/min) a decrease in ignition time is experienced for transition of the particle size from 39 to 64 μm .

2 Ignition Temperature

Results for the ignition temperature as a function of mass flow rate were obtained for three different particle sizes. Figure 3 presents the results. It is seen from Fig. 52 that there is a decrease in the ignition temperature with the increase in mass flow rate. The effect of the particle size is to decrease the ignition temperature as particle diameter increases in the dilute regime (heterogeneous ignition regime). This confirms the individual particle ignition theory. However, the dependence of the ignition temperature on the particle size is less sensitive at larger mass flow rates.

Figure 1. Effect of Particle Diameter on Ignition Time, Experimental Results

Figure 2. Ignition Time as a Function of Fuel Volume Fraction and Overall Equivalence Ratio at Various Particle Sizes

Figure 3 Ignition Temperature Dependence on Mass Flow Rate for Various Particle Sizes

Up to about 10 g/min for average particle size of 64 μm , the ignition temperature decreased from 920 to 820 K. For the same mass flow rate range and average particle diameter of 90 μm the change was from 870 K to 800 K. For mass flow rates larger than 10 g/min the ignition temperature remains approximately constant or even slightly increases. For the smallest particle diameter the sensitivity of the ignition temperature to the mass flow rate is more significant, decreasing from 945 K to 800 K continuously for a mass flow rate range from 0.5 to 24 g/min.

Figure shows also the dependence of the ignition temperature on fuel volume fraction. It is apparent that the ignition temperature of the coal cloud is more sensitive to the mass flow rate at lower fuel volume fraction (dilute regime). For higher fuel volume fraction (dense regime) the ignition temperature remains constant or slightly increases.

When the cloud is lean the behavior of the ignition temperature is similar to that of a single particle. Further, as shown earlier the ignition is believed to be heterogeneous since the flammable mixture can't be formed readily in the gas phase. Thus high temperatures are required in order to heat up the particles and ignite them heterogeneously. As the number of particles increase, more volatile are released and it is more likely that a flammable mixture can be formed in the hotter gas phase outside the cloud. Beyond certain cloud concentration, however, the particles in the middle of the cloud do not contribute significantly to the production of volatiles but rather act as heat sinks slowing down the heating rate of the neighboring particles. Only a small layer of the cloud adjacent to the hot ambience seems to participate in the ignition process and hence the ignition temperature is essentially constant.

VI.4 Comparison with Group Ignition Theory

Ignition times found by Ryan (1988) range from about 130 to 200 ms for a spherical coal cloud radius of 1.0 cm, secondary air temperature of 1500 K, an oxygen concentration of 23%, initial cloud temperature of 300 K, and particle diameter of 100 μm . However the radius in the experiments is only 0.24 cm which will reduce the ignition time by an order of magnitude. Further the experiments were on a cylindrical stream of particles, with particles surrounded by secondary gas containing 10% oxygen. Although the experimental times are found to be much less than those reported by Ryan, his model predicts the basic behavior in that there appears to be a minimum ignition time at a particular cloud denseness.

The model assumes a quiescent spherical coal cloud in a hot environment, such that there is no air entrainment inside the cloud, which could cause a more rapid heating of the fuel and hence a shorter ignition time. The range of particles sizes used in the experiment are smaller than the 100 μm diameter particle used in the theoretical model. Heating rate and hence volatile matter release rates are greater for smaller particles, which would render the ignition time slightly shorter. On the other hand, the cloud radius used in the experiments is of the order of 2.4 mm compared for a cloud of 10 mm presented in the theoretical study. The heat up time for a small cloud is less than that of a larger cloud. Finally, Ryan neglects radiation, and radiation particularly from the hot honeycomb can play a very important role in the thermal ignition of the coal particles.

Summarizing, the difference between theoretical and experimental results can be ascribed to the difference in the conditions and assumptions used by the model, while the general basic trend is well correlated.

The autoignition temperatures at high mass flow rates merge to a single value, i.e. the ignition temperature does not depend on the particle size. This is in agreement with the theoretical results of Rumanov and Khaikin (1969) for a system involving homogeneous ignition. The decrease in ignition temperature is steeper for smaller sized particles than for larger sized particles. These results are similar to the observations of Cassel and Liebman (1959) for particles of Mg and Mg-Al alloy. For a batch of coal particles dropped into a hot ambience, (Chen *et al.* (1984)) the minimum temperature of the gas at which the particles ignite was determined to be 680 K for a bituminous coal of 60 μm diameter, while the ignition temperature for an initially cold stream of coal particles as found in the present experiments was of the order of 920 K for a dilute stream of similar size.

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