ESTIMATION OF VOLATILE CLOUD DENSITY FOR SINGLE COAL PARTICLES USING MICROGRAVITY CONDITION.

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ABSTRACT

Single coal particle's volatile cloud density has been estimated by employing a microgravity condition. The volatile yield was found to decrease with pressure while the density was found to increase, indicating that volatiles occupies less space when under pressure and hence causing some volatiles to be retained within the particle. The volatile cloud density was also found to increase with volatile yield suggesting volatile composition changes with yield. The effect of heating rate on volatile yield was found to be the same as reported by other investigators where the yield increased with heating rate.

INTRODUCTION

The use of microgravity as a tool for studying or simplifying various phenomena has increased recently and advantages associated with it has been reported [1,2]. Studies involving single coal particles have been undertaken focusing on various behaviors, mainly the effect of volatiles concentration in the particle vicinity and how it affects the ignition and combustion process [3,4]. Coal devolatilization has been studied extensively and Saxena [5] has made a comprehensive review of these studies. As far as the effect of pressure on volatile release is concerned, it has been reported that as the pressure increases, the residence time of volatiles within the particle increases and this results in more extensive secondary reactions of certain reactive species such as tar. Secondary reactions, such as cracking lead to the deposition of coke and decreases the yield of volatiles [5]. As for the effect of pressure on volatile product composition, it is reported that pyrolysis under high pressure produces more char, less tar and more hydrocarbons. Another factor affecting the yield as well as the composition of volatiles is the heating rate. It has been shown that the volatile yield increases with the heating rate while the composition is also affected due to the secondary reactions of the escaping volatile species.

The above reported results have been reported with relatively low heating rates (mostly < 10 K/s) and was not possible to take any volumetric measurements of the released volatiles. With the application of microgravity condition which eliminates natural convection, volumetric measurements are made possible since volatiles are retained in the particle vicinity. This work focuses on the effect of heating rate and pressure on the volatile yield and goes a step further in estimation of the volatiles density under the microgravity condition.

EXPERIMENTAL

Shown in **Fig 1** is the schematic diagram of the experimental apparatus used in this

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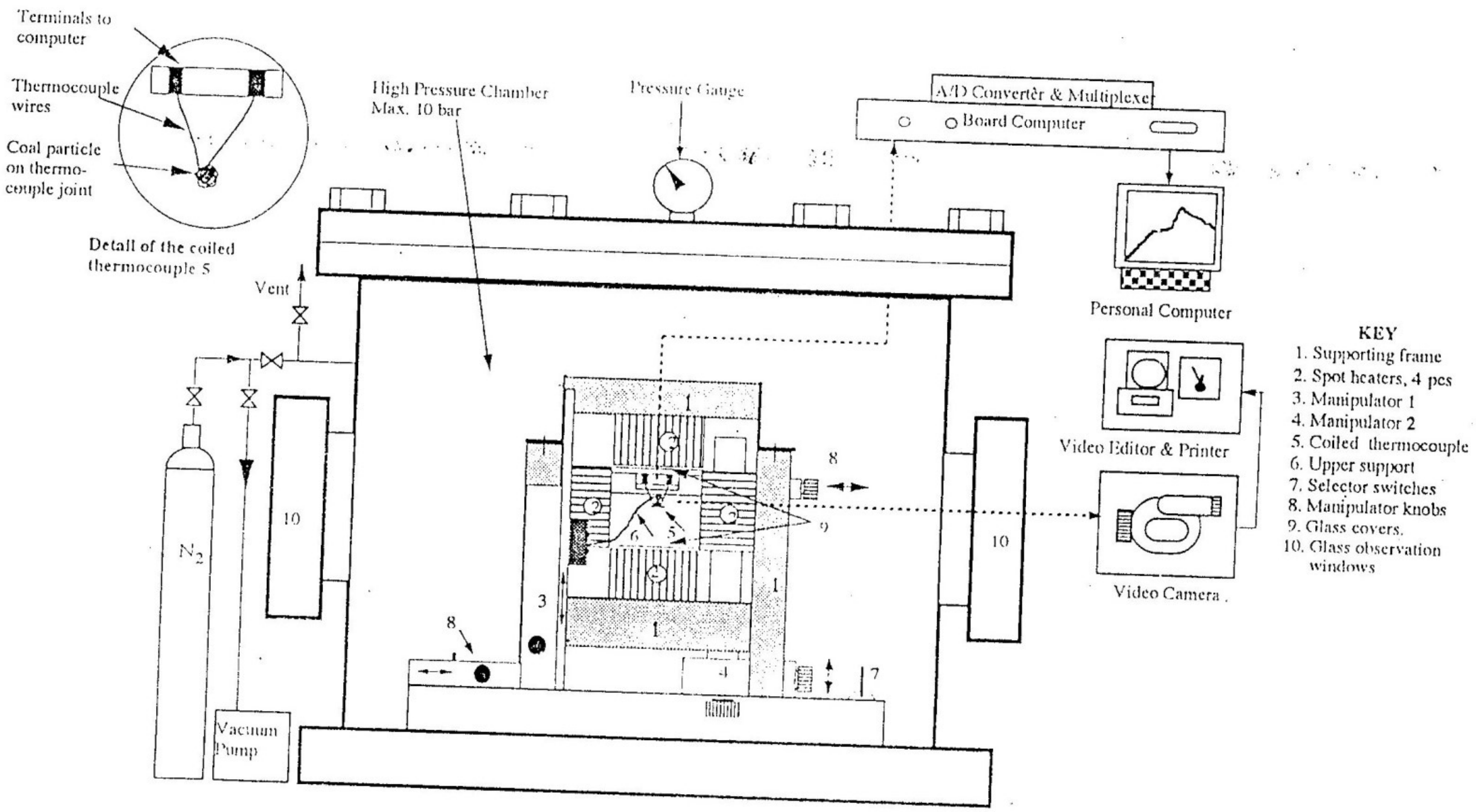

Fig. 1. Schematic diagram of the experimental apparatus

study. A single coal particle was supported on the coiled thermocouple as shown by no 5. The thermocouple saved as a support for the coal particle as well as particle temperature measurement. The coal particle was heated by radiation from the four spot heaters arranged in a square pattern with a common focal point. The spot heater system (details given elsewhere [3]) was placed in an airtight chamber which had four observation windows to allow for the devolatilization process to be recorded by the video camera. The air in the chamber was then withdrawn using a vacuum pump, after which the chamber was filled with nitrogen to the desired pressure. To study the effect of pressure on volatile yield, the experiments were undertaken under normal gravity and coal particles were weighed before they were introduced into the apparatus. The particles were then heated and volatiles released. 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 video images of the devolatilization were also taken. After devolatilization, the particle was taken out of the chamber and weighed again. The difference between the two weight measurements gave the weight of the volatiles released. The experiment was repeated for a number of particles (about 15 particles per set of given conditions). After that, the pressure in the chamber was increased and experiments continued as explained above. Although the chamber could withstand pressures of up to 10 bar (gauge), for safety reasons the maximum pressure used in this study was only 7 bar (gauge). The experiments were done for five types of coal, the properties of which are given in **Table 1**. The heating rates were in the range of 900-1000 K/s.

To study the effect of pressure on the released volatiles under microgravity condition, the same procedure as above was adopted. In this case however, after nitrogen has been introduced into the chamber, the chamber was disconnected from the N_2 cylinder and loaded into a drop tower capsule from which it was dropped to create a microgravity condition [3]. The drop height was 10 m which produced a microgravity time of 1.2 s. During the drop, the particle was heated and volatiles were released. From the video recording, prints were made and the size of the volatile cloud could be measured (from the prints) and their volumes calculated. Knowing the mass of the volatiles, their densities could then be estimated.

Table 1 Properties of coals used

Proximate Analysis

Coal	Mo[a]	Ash	V.M.[b]	F.C.[c]
		[wt%]		
Taiheiyo	5.9	20.1	40.2	33.8
Coal Valley	8.0	9.9	32.5	49.6
Datong	4.3	10.1	26.6	59.0
Mt. Klappan	1.9	5.4	8.0	84.7
Pennsylvania	3.6	8.2	4.4	83.8

Ultimate Analysis

C	H	O	N	S
	[d.a.f.[d]wt%]			
77.5	6.4	14.9	1.1	0.3
79.0	5.0	14.8	1.1	0.3
84.6	4.6	9.1	0.9	0.9
85.6	2.5	3.4	1.1	0.6
85.6	2.6	1.6	1.2	0.5

RESULTS AND DISCUSSION

Effect of heating rate

As expected, the volatile yield increased with heating rate. The observed volatile yields exceeded the volatile matter content values reported in literature (Table 1). The comparison of the standard values (established under low heating rates < 10K/s) and the observed values obtained from this work are given in **Table 2**. It can be seen that, in average, the volatile yield at the current heating rates (900 K/s) is about 15% higher than the standard values. So generally, results from this work agrees well with those previously reported [5,6]

Table 2 Standard and observed volatile matter content values

Coal name	Standard VM values %	Experimental VM values	% Difference
Pennslyvania	4.4	5.1	15.9
Mt. Klappan	8.0	9.2	15.0
Datong	26.0	28.9	11.2
Coal Valley	32.5	38.3	17.5
Taiheiyo	40.2	47.2	17.4

Effect of pressure on volatile yield and volume.

As reported previously, increasing pressure decreases the volatile yield. The same trend was observed for three coal types employed in this study as can be seen in **Fig. 2**. This effect, however, seems to level off as pressure increases and for the case of a Coal Valley coal, the effect seems to be less significant. The anthracite coals were not used here because of their relatively low volatile matter contents.

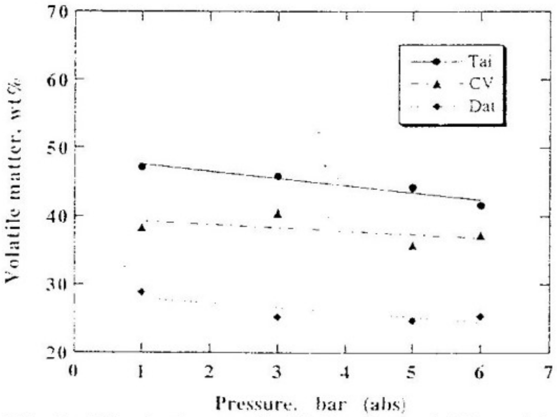

Fig.2 Variation of Volatile yield with pressure for different types of coal(Tai=Taiheiyo, CV=Coal Valley, Dat=Datong coal)

The variation of the volatile cloud diameter with pressure is shown in **Fig. 3**. The volatile cloud diameter measurements were obtained from the video prints as explained above. It can be seen that the volatile cloud diameter decreases with increasing pressure. This is due to the fact that the volatile yield decreases with increasing pressure, hence if the volatile density remains constant, then the volume and hence the volatile cloud diameter will decrease. **Figure 4** shows the variation of the volatile cloud volume with time under different pressures for the same size particle and same coal type. It can be seen that whereas the volatile cloud volume increases fast with time under atmospheric pressure, it remains less than 20% of the size when the pressure is increased to 7 bars (abs). As for time when devolatilization commences, it can be seen that it commences earlier under less pressure than when under higher pressure.

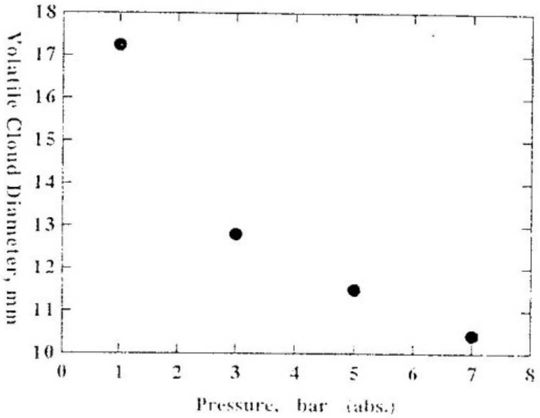

Fig. 3 Variation of volatile cloud diameter with pressure

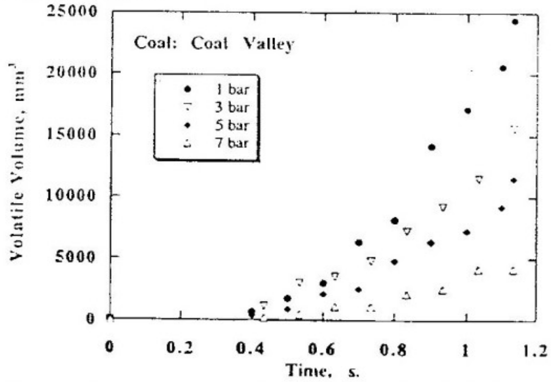

Fig. 4 Change of volatile cloud with time under different pressures for the same particle size

Volatile density.

The mass and volume measurements for the volatiles make it possible to calculate the density of the volatiles in the cloud. It is assumed that volatiles are evenly distributed

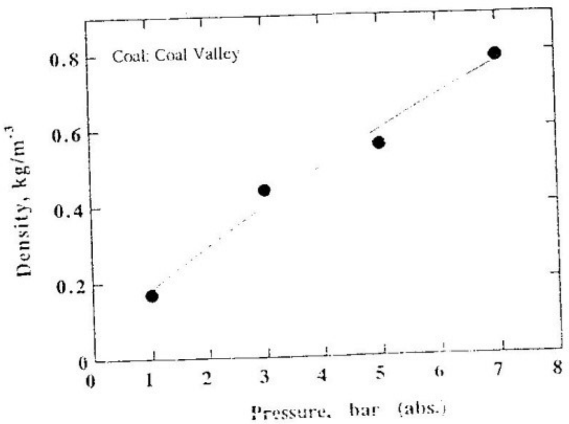

Fig. 5 Effects of pressure on volatile cloud density

within the cloud and the differences between volatile species are neglected. The effect of pressure on the volatile density is shown in **Fig. 5** where the density is seen to increase with pressure. From the effect of pressure on volatile cloud diameter (Fig. 4), the decrease of diameter has been attributed to the fact that less volatiles are released at higher pressure. But this does not appear to be the only reason because here the density is found to change with pressure. It is therefore apparent that the volume occupied by the released volatiles is reduced under high pressure. This is because the distance that the released volatiles can travel away from the particle is reduced when pressure is increased and hence all the volatiles are confined in only a small space. The short distance the volatiles can travel under high pressure is due to the fact that the pressure difference between the inside of the particle and the surrounding, which also is a driving force during volatiles release, is reduced when pressure is increased. So generally, in this case, the volatile cloud volume appears to be compressed when under high pressure. This phenomenon may be applicable not only to volatiles outside the particle but also to those inside the particle. Therefore, the decreasing devolatilization driving force with increasing pressure is one of the factors leading to the decreasing volatile yield with increasing pressure. This may have something to do with increasing the volatiles residence time inside the particle thus leading to secondary reactions taking place, but even if secondary reactions do not take place, still the volatile yield will be affected.

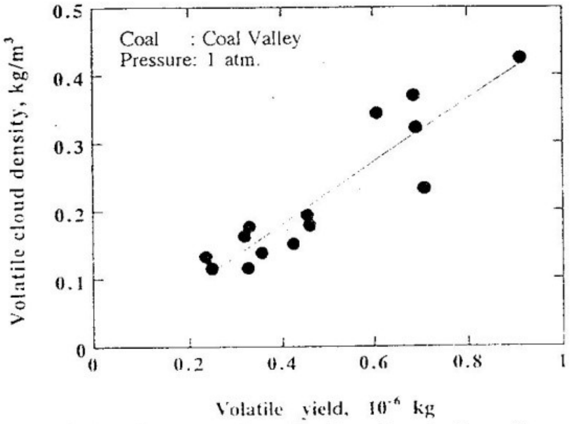

Fig. 6 Variation of volatile cloud density with volatile yield under constant pressure

Therefore the secondary reactions becomes an essential but not a necessary condition to affect the volatile yield, especially if the particle is subjected to a definite heating period. The variation of volatile density with pressure is not linear, as it appears to level off at higher pressures. This could be attributed to the fact that the composition of volatiles change with pressure [5] and lighter volatiles (hydrocarbons) dominates under higher pressures. Secondary reactions can also be one of the reasons leading to this phenomenon.

A striking observation from this work was the variation of volatile density with volatile yield from particles of different sizes under atmospheric pressure as shown in **Fig. 6**. In normal situations, a change in volatile yield would not be expected to have any influence on volatile density. In this work, the amount of volatiles released was found to increase with particle size. However, when the density of volatiles from different particle sizes were calculated, it was found that the density increased with the yield. This suggests that there might be a change in the volatile composition when particle size increases. Saxena [5] reported that the effect of particle size on volatile composition is the same as that of pressure whereby at higher pressure, more char and hydrocarbons and less tar are produced. If this were the case, we would expect to see a decrease in volatile density since tar is the heaviest of all the volatile species. The opposite trend could be caused by either the fact that despite the (relative) decrease in tar production with increasing particle size, the absolute amounts of tar produced could be still higher for larger particles, hence leading to higher densities. Another possible explanation could be that the released tar condenses in the gas phase thus leading to small volatile volumes and hence higher density. Further work on analyzing the volatile composition would be needed to clearly explain this situation.

Conclusion

A method for estimating volatile cloud density using microgravity condition has been presented and the effect of pressure has been studied. Within the limits of the current experimental conditions, the following can be concluded:

1) As expected, increasing pressure decreased volatile yield while increasing heating rate increased the yield.
2) Volatile cloud diameter as well as volume decreased with pressure while the density increased. This could be attributed to the decreasing driving force (pressure difference between inside and outside the particle) as the pressure increases.
3) The volatile cloud density was found to change with volatile yield. This result was unexpected but it suggests the possibility of some volatile species changing phase, possibly the condensation of tar in the gas phase.

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