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A Fundamental Study on Coal Dust Cloud Auto Ignition and Methane Flammability Limit in Ventilation Air Methane (VAM)

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Abstract--The Deflagration and explosion of dust cloud and flammable gases are a major concern in process industry. A combustible cloud could explode at certain concentration and environment conditions. Tests were conducted at the University of Newcastle by VAM project researchers to determine the minimum Auto Ignition Temperature (MAIT) of coal dust cloud and the lower flammability limit of methane at the humid condition and different environment temperatures. The goals of this work are: (a) Investigate the minimum auto ignition temperature for coal dust in cloud form presents in the VAM stream. (b) Investigate the influence of humidity and the temperature effects on methane lower flammable limit and pressure change the results of this work indicate, the influence of particles size on MAIT of coal dust cloud increase as reduce the concentrations. Also, the pressure rise of at the LFL in independent of temperature and more related to the flame shape. Finally, No influence of humidity observed on the LFL of methane

Index Terms-- Dust explosion, Deflagration index, dust layer ignition, ASTM E2021, ASTM E1491, ASTM, E1226

I INTRODUCTION

Coal dust explosions and methane flash fires are the major safety concerns in coal mines and petrochemical industries [1,2]. For Ventilation Air Methane Capture Duct (VAMCD) the understanding of dust explosions is one of several key factors to design the dust explosion prevention measures [3]. Amongst all minimum auto ignition temperature of dust cloud is one of the critical factors in designing the VAM capture duct. The MAIT for dust cloud has been investigated in the past by number of researchers. Cao[4] investigate the MAIT of coal dust , he make tow conclusion , first, the 740 g/m^3 of coal dust is the best concentration to achieve explosion in the form of dust cloud. Second, the MAIT increases from 800 °C to 930 °C as the particle size increases from 250 to 500 micron. Gummer [5] built a large vertical scale apparatus to investigate the MAIT for coal dust particles. He showed that MAIT increases significantly as the particle size increases. Torrent [6] investigated the effect of coal dust properties on the MAIT in cloud form. He used 21 different coal dust samples in his investigation;

His research outcomes showed that the MIAT for dust cloud is a function of coal dust physical and chemical properties.

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Sweis (1987) used a Godbert Greenwald- Furnace (GG) to examine the MAIT for dust clouds. His outcomes were agreed with particles had reverse proportion with MAIT [7].

In terms of methane flammability limit, there is less open literature in the regard of humidity and temperature influence on the lower flammability limits. Garcia [8], investigated the pressure rise and the flammable limit of methane by using a 20L apparatus. Instead of using chemical ignitors, Garcia et al. used an electrical spark. The spark ignition system consisted of a spark generator capable of providing 15kV and two electrical rods (2mm in diameter) with the distance between the ends being 6mm (as described in KSEP 320).

Bartknecht 1993 [10], did similar work that done by Garcia et al. ,and the out coms agreed with data tableted NFPA 1998[9].The pressure rise for both NFPA and Bartknecht reports were much lower than for Garcia data. The difference is due to two important points. Firstly, NFPA and Bartknecht used other apparatus to investigate the explosion limit for methane. Secondly, the types of ignitors used in the Garcia study were not the same as that used in NFPA and Bartknecht reports.To get accurate view in terms of potential hazardous such as ignition, fire and explosion in VAMCD, a set of experiments has carried out in the University of Newcastle to investigate MAIT of dust cloud, also, investigating the humidity and temperature effects on the LFL of methane.

II COAL DUST MAIT

The experimental set up (Godbert Greenwald apparatus) used in this study to determine the MAIT for coal dust samples (see Fig.1). This set up includes a vertical tube furnace, compressed air storage, data logger, image and recording device, thermocouples and computer system. All experiments carried out according to the ASTM 1491[12]. Over four hundred experiments carried out for three different coal samples from different coal mines.

Fig.1. Godbert Greenwald Apparatus (ASTM1241).

An analytical scale was used to measure the precise quantity of coal dust required for each experiment according to the experimental schedule. The coal dust then placed in the coal dust injector and injected into the pre-set temperature tube furnace by using the compressed air. If no ignition observed for that set point the temperature is increased by if 50°C until ignition achieved. Upon achieving ignition then the temperature regulated down by 20°C increments to identify the lowest temperature at which ignition not occurring below that. To stablish the exact set point each experiment repeated 3 times. If the ignition occurs, then that temperature is considered as the MAIT for that coal dust sample under that given conditions. In the cases where no exact set point temperature can be pin pointed then the MAIT defined in a range temperature (somewhere between the temperature the ignition take place and the lowest temperature that ignition did not occur).

The ignition-non ignition temperature data for the coal particles size below 74 µm is shown in Fig.2.

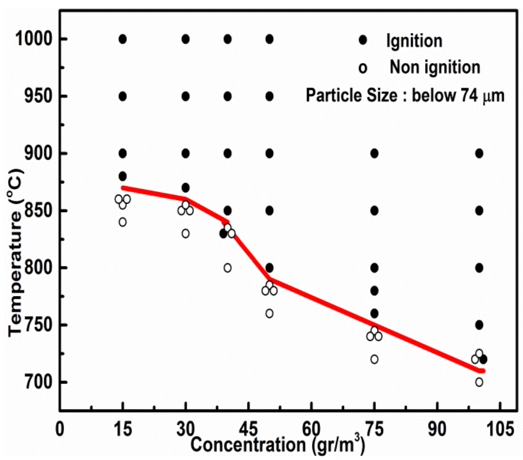

Fig.2. MAIT for Particles Size in The Range of 0-74µ M

The first interesting outcome is that even at low concentration (15 g.m^3) , the second outcome is the MAIT reduce with increasing the concentration in an agreement with the literature review, and the curve sharply decrease (by 50°C) when increase the concentration from 40 g.m^3 to 50g.m^3.

The ignition-non ignition temperature data for the coal particles size in the range of 74-125 µm is shown in Fig.3

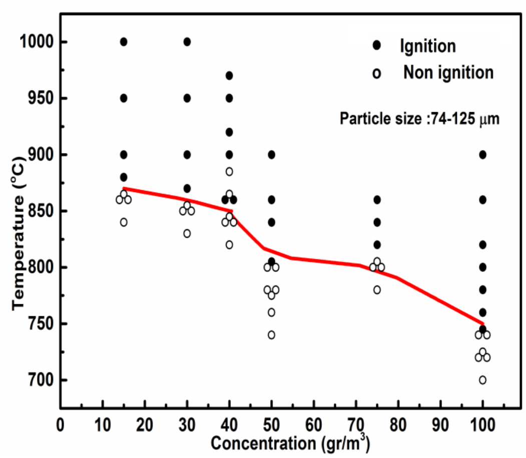

Fig.3. MAIT for Particles Size in The Range of 74-125 µm

Similar the coal particles size below 74 µm, the MAIT significantly dropped when increase the coal dust concentration from 40 g.m^3 to 50 g.m^3. Also it has been observed that the MAIT for the concentrations below 50 g.m^3 are close to the MAIT for coal particles size below 74 µm, but for the concentrations higher than 50 g.m^3 the MAIT is obviously higher than for 74µm.

The ignition-non ignition temperature data for the coal particles size in the range of 125 µm-212 µm is shown in Fig.3

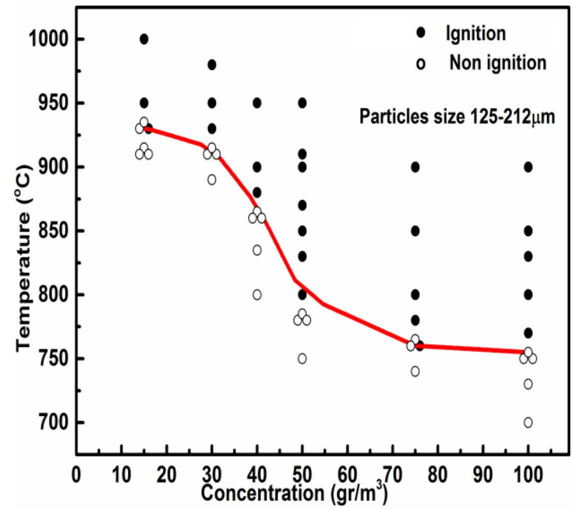

Fig.4. MAIT for Particels Size in The Range of 125-212 µm

In the coal particle size in the range of 125 µm-212 µm (see Fig.4), the MAIT is significantly higher than for coal particle size below 74µm (by about 100°C) for the concentration in the range 15 to 40 g.m^3.In higher concentration (in the range betwee 50 to 100 g.m^3), the MAIT is higher by about 50°C.

Previous results (Fig.2Fig.3Fig.4) showed even low coal dust concertation is able to produce flame and combust in the system, additionally, the MAIT are close for the particles size range below 74 µm and for the coal particles size in the range of 74 µm -125 µm, but for coal particle size in the range of 125 µm - 212 µm is much higher than for the coal particles size below 74µm.

This fact is due to liberation of volatile matter and gases from fine particles more rapid than for coarse particles which allows the volatile matter and gases to oxidizes on the surface of particles. While for coarse particles more time is needed for heating to release the volatile matter from the particles and allow to oxygen to attack the active sites. Additionally, the oxidations are of fine particles are higher than for the coarse particles. All these result in the fine particles in the form of dust cloud ignited with less energy especially for the particles size over 125 µm.

III Methane Flammability Limit

The flammability limits of fuels in the VAM stream may change under various conditions such as temperature, pressure and moisture. To determine the variations of the LFL for different environmental conditions a series of comprehensive investigations were carried out in the laboratory by using an apparatus so called FL-Range. Fig.5 shows this apparatus placed in the lab. This apparatus consists of an enclosure with a transparent door enabling one to see inside the enclosure. A vacuum pump, electrical igniter, temperature and pressure sensors, heating system (up to 150 °C), magnetic stirrer to homogenise the fuel-air mixture, 5 liter flasks made of glass, data logger, computer and remote trigger system. All experiments were conducted according to ASTM E681[15].

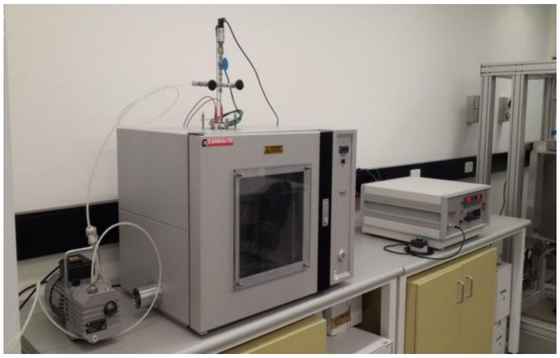

Fig.5. FL-Range Limit Set up (ASTM E681)

The influences of temperature and humidity on methane LFL are studied in this work. In terms of temperature effects, the lower flammable limit was investigated over a temperature range of 25 to 144°C, to reduce the error each test repeated twice. Fig. 6. LFL vs Temperature shows the variations of the methane LFL with temperature. As observed the methane LFL significantly decreases from 4.2% at 25°C to approximately 3.2% at 144 °C. This represents a drop of 20 percent.

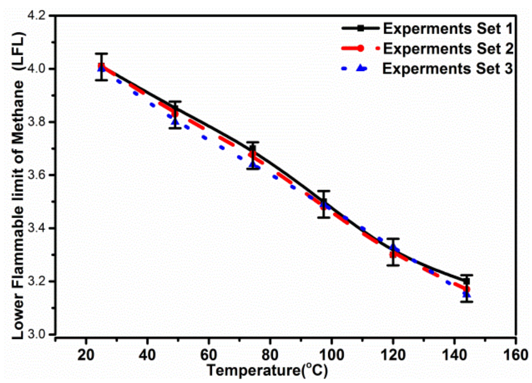

Fig. 6. LFL vs Temperature

The effect of temperature on the pressure rise at LFL concetration is shown in Fig.7.

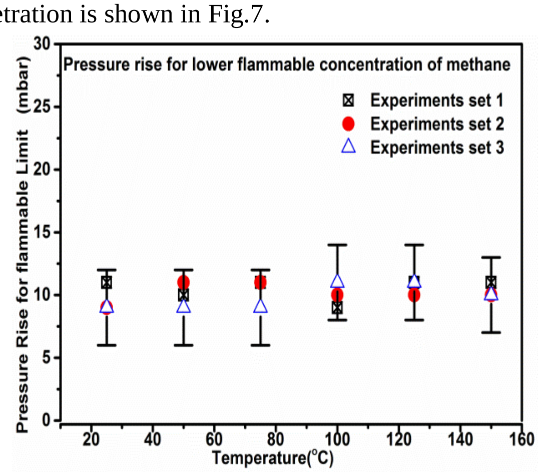

Fig.7. Pressure Rise for Lower Flammable Concentration of Methane

The result shows that upon increasing the temperature the pressure rise due to reaction is negligible (about 0.09% to 0.011%).

The observations show the shape of flame was not affected by the temperature, however, the pressure rise match the flame behaviour at all temperatures. Fig. 8 shows the flame propagation with pressure change.

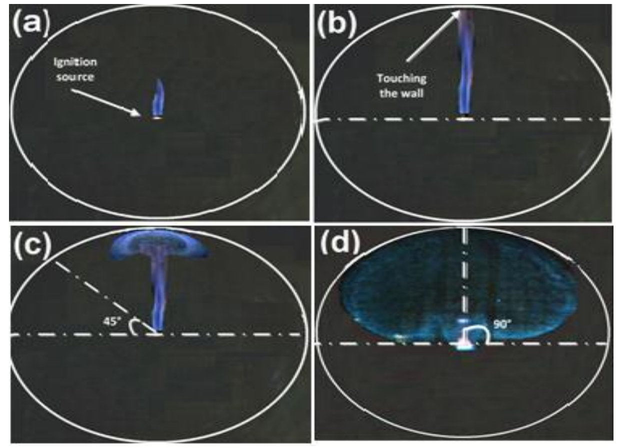

Fig. 8. Flame Propagation at Different Pressure Rise (A) 5-7 Mbar, (B) 8-11 Bar, (C) 12-16 Mbar and (D) 17-25 Mbar

According to the definition of flammable materials in ASTM E681[15], the gases or flame become flammable when the flame is able to propagate from the source of ignition (which is located at the centre of vessel) to the wall. Hence, the case a in Fig. 8 does not represent a flammability status in spite of it traveling through the vessel. The pressure rise recorded ranged from 4 to 7 mbar. As can be seen in Fig. 8(b),the flame touches the top wall of the vessel, the pressure rise recorded ranged from 8 to11 mbar at all temperatures. With a small increase in the concentration of methane, the flame consists of a small ball at the top of the vessel. The pressure rise recorded for this was in the range of 12 to 16mbar. The size of flame increases as the concentration or the temperature increases with the flame forming at 90° angle to the source of ignition , the pressure rise ranging from 17-25 mbar (see Fig. 8d) . Finally, as the concentration of methane at 25 °C increases up to 4.8%, the flame will travel to the top of the vessel and down to the centre of vessel. This is considered as an explosion, at this circumstance the pressure rise will be more than 26mbar.

The vissel has humidifid to 80% R.H (the mass of moisture relative to 25°C). The results dosen't show notable influence on the LFL of methane, on the other hand it has observed color of flame siltly changed.

IV CONCLUSIONS

- In all three particles size groub (below 74µm,74-125µm and 125-212µm), 15 g.m^3 is the lowest concetration that caol dust ignited in the cloud form.
- The influence of coal particles size on the MAIT significantly appears at lower concentration (in the range between15-50g.m^3 the gap is about 100°C). Increasing the concentration will reduce the gap of MAIT at reach about 50°C at 100 g.m^3.
- The lower flammable limit of methane significantly reduced as increase the temperature and reached to only 2.9% at 144°C.

- No effect of 80% R.H on the LFL of methane.
- The pressure of flammable concentration ranged from 8-11 mbar for all temperatures. As increase the temperature or concentration of methane, the flame changed from straight flame upward the top surface to small ball formation and the ball at the end of flame ,then big ball reach the centre of ignition, and finally the flam will travel up and downward which considers explosion.

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