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# Explosibility Characteristics of Philippine Coal Dust

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**Abstract:** The explosion behaviour and physical characteristic of Philippine coal dust was analyzed. Experiments for explosibility were performed to measure the overpressure,$P_{max}$, deflagration index, $K_{st}$ and flammability limits of Philippine coal dust/air mixtures in a standard 20 L spherical bomb. The coal dust/air mixture was ignited by chemical ignitor of 5 kJ. From the explosibility test, it is found that the maximum overpressure attained for coal dust/air explosion was 10.4 bar at 750 g $m^{-3}$ concentration. However, at lower concentration i.e., 200 g $m^{-3}$, there is no sign of explosion observed, contrary on what have been reported in literature for coal dust explosibility behaviour i.e., at 200 g $m^{-3}$ Pittsburgh coal gave 5.3 bar. The minimum concentration for obtaining a coal dust explosion that propagated in the spherical bomb was 315 g $m^{-3}$. In order to further analyze the coal dust characteristic, proximate analysis using thermogravimeter and furnace (according to ASTM E1131 and British Standard Method of analysis of coal and coke) were carried out. From the result, it showed that moisture content and ash content of Philippine coal are relatively high, 11.32 % and 6.7%, respectively as compared to Pittsburgh coal which was 1 and 6%, respectively. This study concluded that the Philippine coal is hardly exploded at lower concentration, however it could pose a dangerous hazard at high concentration and it should be taken into consideration for storage or vessel design.

**Key words:** Philippine coal, coal explosibility, deflagration index, maximum overpressure, minimum explosion concentration

## INTRODUCTION

Dust explosion involving coals have been a threat to humans and property for a long time, either operation in coal mining or in various unit operations. Therefore, detailed experimental and theoretical studies of the physics and chemistry of dust cloud generation and combustion need to be done for prevention and mitigation of the explosion. Knowing the minimum explosible dust concentration is very important as an explosible dust cloud may be formed during operation or transportation of the dust. The maximum explosion overpressure, $P_{max}$ is obtained from the highest corrected value of explosion overpressure over a wide range of fuel concentration (Cesana and Siwek, 2000). The $K_{st}$ value is derived from multiplying the maximum rates of pressure rise, $(dP/dT)_{max}$ by the cube root of the explosion chamber volume. This concept is introduced for scaling the maximum rates of pressure rise to larger volumes by normalizing them. It is also known as deflagration index or volume-normalized maximum rate of pressure rise (Amyotte and Eckhoff, 2010). The result of explosion severity may be used to design the basis for explosion protection and mitigation such as explosion relief venting and explosion suppression but it depends entirely on the validity of the cube root law (Reyes *et al*., 2011; Eckoff, 2003). The lowest fuel concentration limit or also known as lean flammable limit is the lowest concentration of dust cloud dispersed in air that can propagate an explosion upon ignition (Ebadat, 2010; Going *et al*., 2000). When the concentration level of dust flammable dust cloud below minimum explosibility concentration during operational condition or other conditions cannot be avoided, other safety practices must be in place to control the formation of hazardous dust cloud such as safe housekeeping practices and minimize or completely remove the presence of ignition sources (Abbasi and Abbasi, 2007).

Even though no coal mining industry is commercialized in Malaysia, there is a risk of having coal dust explosion due to transportation, storage and uses of coal in power generation industry, cement industry and other manufacturing industries. There are numerous

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publications regarding dust explosion in confined area, but to the author's knowledge, there is limited data on physical and chemical characteristics of coal dust from Asia. It is crucial to know the physical characteristics and dust behaviour in order to apply an effective protection and safety systems available to prevent and mitigate the dust explosion in industries and this paper will provide fundamental information on explosion severity characteristics and minimum explosion concentration of Philippines coal.

## MATERIALS AND METHODS

**Sample preparation:** Samples used in the research were coal dust from Philippines. The Preparation of samples included grinding and sieving the coal dust to particle with size diameter of <45 μm. After grinding process with grinder, the sample would be sieved to get the particle sizes to be below 45 μm. After that, the samples would be stored in a tight container to minimize the loss of moisture. Upon the explosion test, the samples would be dried in an oven at 75°C for 2 h.

**Coal dust explosion:** The flammability and severity characteristics data was obtained by using the Siwek 20 L spherical chamber. Instrumentation included a sensitive strain-gauge pressure transducer to measure the partial pressures as the gases were added and mixed and a higher capacity strain-gauge pressure transducer to monitor the explosion pressure. The strain-gauges had a response time of 1 m sec. Two 5-kJ ignitors were used as the standard ignition source. The ignition delay time, $t_{ig}$ was fixed at 60 m sec. The pressure transducers were mounted on the wall of the chamber. In the experiments, dusts were directly loaded to the storage container and would be dispersed with the rebound nozzle using compressed air at 20 bar. The dust concentration would be started at 15 g before gradually decreased until constant pressure is achieved. The same method would be used to determine the lean limit concentration by gradually stepped down by step change of 2 g until there was no explosion/flame propagation shown on data captured. The bomb was interfaced with a computer, which controls the dispersion/firing sequence and data collection. As part of the experimental programme, two repeat tests would be performed on each test and these demonstrated good reproducibility, with peak pressures varying by less than±5% in magnitude.

**Proximate analysis:** The characteristic of the sample was further investigated through proximate analysis by drying and combustion in the oven or furnace for moisture, ash and volatiles. The analysis was carried out according to British Standard 1016 Part 6; Analysis and testing of coal and coke: Proximate analysis of coal (British Standard, 1999). As for moisture, an empty glass crucible (diameter of 6 cm) was weighted. Then, approximately 1±0.1 g of the sample was added to the crucible. The new weight of the crucible and the sample was recorded. The crucible and contents were placed in an oven for one hour at a temperature of 105±5°C as a drying process. The crucible was then cooled in a desiccator and reweighed. The amount of moisture in the sample was then calculated using Eq. 1:

$$\%\text{of moisture} = \frac{\text{Mass of water removed (g)}}{\text{Mass of original sample (g)}} \tag{1}$$

For analysis of ash content, a clay crucible (2 cm in diameter) was placed in the furnace for one hour at a higher temperature (750°C). The crucible was then cooled at room temperature for approximately 1 minute and then put in the desiccator. Finally, the sample was reweighed and % of ash was determined by using Eq. 2:

$$\%\text{of ash} = \frac{\text{Mass of residue after combustion (g)}}{\text{Mass of original sample (g)}} \tag{2}$$

To determine the volatile matter in the coal, the weight of empty crucible (3 cm in diameter) with lid was first measured. Then, approximately 1±0.1 g of the sample was added to the crucible. The new weight of the crucible with lid and the sample was recorded. The crucible was then placed in high temperature furnace (preheated to 925°C) for 7 min. After that, the crucible was removed from furnace and then cooled at room temperature for approximately 1 minute and then put in the desiccators and cooled to room temperature before being reweighed by using Eq. 3:

$$\%\text{ volatile} = \left(\frac{\text{Mass loss of sample after heating (g)}}{\text{Mass of original sample (g)}} \times 100\right) - \%\text{ moisture} \tag{3}$$

The proximate analysis of the coals was also determined by using thermogravimetry analysis (TA instruments-Waters' TGA Q 500). The samples were heated at a heating ramp of 50°C per minute in a nitrogen atmosphere until the temperature reach 850°C. Then the inert gas is switched into oxygen gas at a heating ramp of 50°C per minute until the temperature reach 950°C (ASTM, 2008). The proximate data was then analysed to get moisture content, ash, volatility and carbon content of the coals.

## RESULTS

**Coal dust explosibility at ambient condition:** Figure 1 showed the pressure time profile on Philippine dust explosion. The highest $P_{max}$ was obtained at 10.4 bars for 750 g $m^{-3}$. Figure 2 showed the maximum pressure of different dusts as a function of dust concentration. The studied coal dust was compared to others i.e Pittsburgh coal, hvb coal, South African coal and Prince coal. The $P_{max}$ of Philippine coal dust is higher about 3 bars as compared to others. From Fig. 2, $P_{max}$ for both Prince coal and hvb coal was approximately 6.7 bar and South African coal is 5.8 bar. The value of MEC obtained was 315 g $m^{-3}$. As shown in Fig. 3, the value of $K_{st}$ for Philippine coal was 52.39 bar.m/s. Figure 3 also shows the $K_{st}$ from Cashdollar (2000) and Amyotte *et al.* (1991) as comparison with Philippine coal in this study. $K_{st}$ for both coals were approximately 43 and 37 bar.m/s respectively. It meant that Philippine coal dust could pose more danger compared to both coals reported, valuing from Kst value higher than both coals.

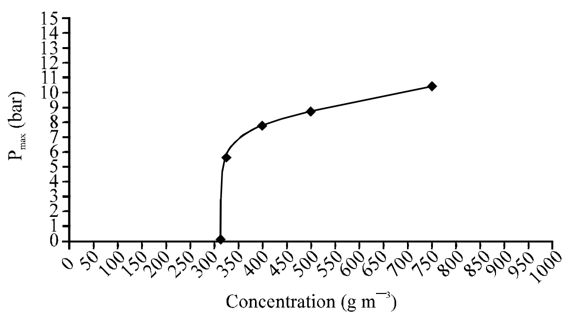


Fig. 1: Explosion overpressures of Philippine coal versus nominal dust concentration

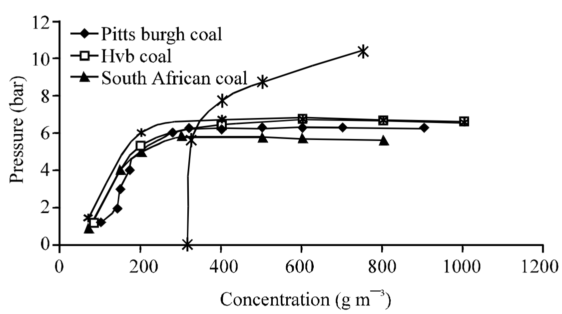


Fig. 2: Overpressures versus dust concentration for 7 µm Pittsburgh coal, 23 µm high volatile bituminous coal, 53 µm South African bituminous coal, 23 µm Nova Scoatia Prince coal and <45 µm and Philippine coal (Hertzberg *et al.*, 1981; Cashdollar 2000; Continillo *et al.*, 1991; Amyotte *et al.*, 1991)

## DISCUSSION

The explosion test was stopped at concentration 750 g $m^{-3}$. Further test on higher coal concentration was not continued for safety reason; the 20 litre sphere chamber is tested up to 39 bar but design for test pressure jacket is only at 14.3 bar. High result obtained for $P_{max}$ of Philippine coal is due to high volatility as shown in Table 1. Table 1 showed the proximate analysis of the coal dust and indicated that the coal dust volatility content is about 40%. This postulated that the increase of volatile content, the coal could pose more hazardous on the process and environment. This is because, the flame propagation during dust explosion starts with devolatilization then followed by a vapour phase combustion (Amyotte, 2006).

The explosion profile of Philippine coal dust was different from others due to higher moisture content (~10%), bigger and non-uniform particle size and higher combustible material content. Higher combustible material content and high volatility are assumed to be the driving factor for the studied coal dust giving higher $P_{max}$ and Minimum Explosibility Concentration (MEC). Further, the high result of $P_{max}$ obtained from Philippine coal was due to overdriving as the strong ignition used in smaller vessel may overdrive the explosion of certain dusts and hence, the overpressure and rate of pressure rise are overestimated (Continillo *et al.*, 1991; Chawla *et al.*, 1996; Dastidar *et al.*, 2001).

The physical properties of the Philippine coal dust of high moisture content of ~10.6% could lead to higher

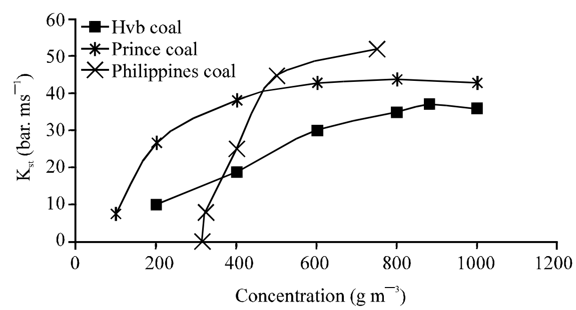


Fig. 3: $K_{st}$ versus dust concentration of Philippine coal, 23 µm high volatile bituminous coal and 23 µm Nova Scoatia Prince coal (Cashdollar, 2000; Amyotte *et al.*, 1991)

Table 1: Proximate analysis of Philippines sample with particle size <45 µm

| | Moisture | | Volatility | | Combustible material | | Ash | |
|---|---|---|---|---|---|---|---|---|
| Percentage | Oven | TGA | Oven | TGA | Oven | TGA | Oven | TGA |
| Philippines sample | 11.32 | 9.95 | 40.95 | 36.85 | - | 43.03 | 6.70 | 7.16 |

MEC and geographical factor could be one of the parameters to be considered. Philippine is a part of South East Asia countries and this region is experiencing high humidity climate. Woskoboenko (1988) stated that moisture may acts as inertant that would reduce the effectiveness of solid-air interfacial surface area and moisture content is dominant for the very fine dust. However, even though ignition energy of 10 kJ was used in the test, the MEC of Philippine dust obtained is quite high as compared with MEC of Pittsburgh coal using the same 20 L chamber and ignition energy of 10 kJ. It might be the reason why the coal hardly exploded at concentration below 315 g $m^{-3}$ and the non uniform dust particles would create inhomogeneous particle dispersion in the air-dust condition, leading to the difficulty of explosion at lower concentration.

$K_{st}$ normally will increase with the increase of $P_{max}$ The result obtained does not have much difference with other coals from previous study as compared with result of $P_{max}$.

## CONCLUSION

The analysis on physical and explosibility of Philippine coal dust was carried out. In the study, it is found that the maximum overpressure of studied coal dust gave highest $P_{max}$ of 10.4 bars, 3 bars higher compared to typical coal dust explosion. Further, MEC of the Philippine coal dust is 315 g $m^{-3}$, higher about a factor of 7 compared to Pittsburgh coal dust of 50 g $m^{-3}$. This study indicates that Philippine coal is hardly exploded at lower concentration however it could pose a dangerous hazard at high concentration. This is due to higher volatility, higher moisture content and different geological factor as South East Asia is experiencing high humidity. The higher the value of $P_{max}$ and $K_{st}$, the more violent the hazard and risk of dust. The parameters studied also depend on other influent factors such as the dynamics state of the dust clouds, oxygen content, dust concentration as well as physical and chemical properties of the dust. By understanding the possible hazard posed by $P_{max}$ and $K_{st}$ on dust clouds, the appropriate method of protection and mitigation may be applied accordingly and effectively.

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