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Full Length Article

Experimental investigation on effects of particle size, dust concentration and dust-dispersion-air pressure on minimum ignition temperature and combustion process of coal dust clouds in a G-G furnace

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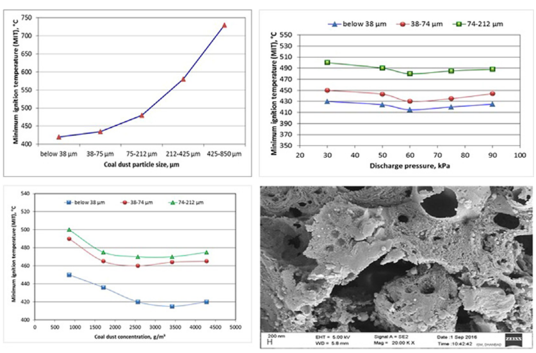
GRAPHICAL ABSTRACT



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ABSTRACT

The present study investigates the effects of three important parameters, namely, particle size, dust concentration and dust-dispersion-air pressure on Minimum Ignition Temperature (MIT) and explosion process of coal dust cloud using Godbert-Greenwald furnace. The coal sample collected from Jharia Coalfield, India was used for experimentation. The effects of particle size and concentration of coal dust on MIT of coal dust cloud were studied at five different particle size ranges, that is, < 38 µm, 38 to < 75 µm, 75 to < 212 µm, 212 to < 425 µm and 425 to < 850 µm. However, the effect of dust-dispersion-air pressure was studied only with the initial three finer particle size ranges, because at coarser sizes it was not possible to maintain a dust cloud of sufficient concentration due to high particle settling velocity and the dust cloud became non-explosive beyond dust-dispersion-air pressure of 30–35 kPa, even at ignition temperature of 1000 °C, which is the limiting temperature of the apparatus. The results indicate that MIT of coal dust cloud increases exponentially from 420 to 730 °C with increase in coal dust particle size. MIT was also found to decrease with the coal dust concentration till a stoichiometric concentration was reached, beyond which MIT slightly increased for the three finer particle size ranges. Nevertheless, in the case of the coarser particle size ranges tested, initially a trivial decrease in MIT was observed only up to certain dust concentration, after which, the MIT increased faintly. The results and the underlying mechanism presented are extremely useful, not only in research and advancement of knowledge on the coal dust explosion process, but also in taking necessary measures for preventing coal dust explosions in underground coal mines.

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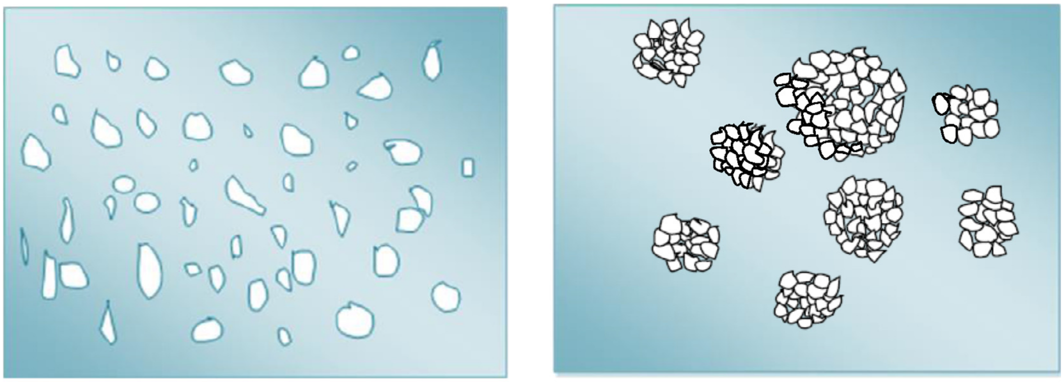

(a) (b)

Fig. 1. Dispersion of fine dust particles: (a) perfect dispersion of non-agglomerated particles (b) poor dispersion of agglomorated particles [2].

1. Introduction

The large quantity of coal dust generated from different mining operations poses a serious explosion hazard in underground coal mines. The coal dust explosions are triggered by various ignition sources of sufficient energy [1] such as smoldering or burning coal dust, mine fires, naked flames (welding, cutting, matches, etc.), hot surfaces (bearings, dryers, heaters, etc.), mechanical impacts, electrical short-circuiting and arcing, frictional sparks, methane explosions, etc. [2–4]. The coal dust explosions are characterized by mechanical destructive effect through the development of dynamic pressure and heat energy leading to the loss of valuable lives and damage to the mine property.

The coal mining industry worldwide and particularly the major coal producing countries, viz. China, U.S.A., India, Germany, etc. have witnessed numerous explosion disasters in the past [5–7]. Therefore, understanding the coal dust explosion process has been an important subject of study since the early 1900s. However, the complex dust explosion phenomenon is yet to be understood completely owing to intertwining of a number of factors affecting the explosion process. Nevertheless, all the continuous efforts and studies conducted so far have made it possible to significantly reduce the occurrences of coal dust explosions in underground coal mines worldwide. But still, it is a credible risk and even one such explosion can lead to the loss of a number of valuable lives and property damage. Hence, efforts still continue to study the explosion process with different types of coal around the world to ward off such explosion hazards completely.

Diverse pre- and post-explosion parameters are being rigorously studied. However, the real problem arises in the correlation of the results obtained from different coals and situations of the investigation. Any professional of this field of research can easily conjure that the data collected from a type of coal dust sample and in a particular situation can never be directly considered for implementation at other circumstances as the conditions are not comparable everywhere. Hence, independent study is quite imperative for every blend of situations. Hence, the effects of some of the inherent characteristics of coal and extraneous parameters that affect the explosibility of a coal dust cloud are investigated in the present study. The parameters considered are particle size, dust concentration, dust-dispersion-air pressure and the effects of their variation on the minimum ignition temperature (MIT) of coal dust cloud.

The minimum ignition temperature (MIT) or thermal ignition point of a coal dust cloud may be defined as the minimum temperature required to ignite the coal dust cloud so that the ignition is self-propagating. It is determined using a Godbert-Greenwald (G-G) furnace [8–11]. MIT is used to evaluate the probability of ignition due to the hot surfaces. Hence, if explosible coal dust is generated in an uncontrolled manner in the vicinity of hot surfaces having temperatures above the MIT, then it will explode and propagate the explosion throughout the dust cloud. Therefore, the knowledge of MIT of coal dust cloud under a particular situation is necessary to take adequate measures to control the temperature of ignition sources within the MIT of dust cloud and prevent the coal dust explosions in underground coal mines.

2. Effects of different parameters on coal dust explosion process

Explosibility of coal dust and severity of coal dust explosions in underground coal mines are intertwined and depends upon various parameters including both the surrounding conditions and properties of the coal dust itself. Particle size is one of the key elements of all dust explosion studies [12,13]. The mechanism of coal dust explosion is extensively governed by the constituent particle size of the coal dust cloud. Predominantly, the dust from bituminous coal deflagrates via homogenous mechanism, in which, the combustion of coal dust particles is preceded by devolatilization [14]. In fact, the explosion process is dominated by the combustion process of the volatile-air mixture [15]. Devolatilization of the coal dust primarily occurs in the homogeneous gas phase and subsequently, the gas phase mixing and gas phase combustion follows [2]. Devolatilization of coal dust particles is a rapid step and is controlled by the rate of combustion of oxygen on the surface of the coal dust which results in the release of volatiles from the coal dust particles. Release of volatiles, which may be due to breaking of chemical bonds [16] and desorption of low molecular weights [17], mainly depends upon the specific surface area (SSA) of the dust particles. It is a well known fact that SSA of a certain amount of dust is inversely proportional to the constituent particle size.

There is a limit to the fineness of dust which can remain suspended in the air independently. Below that particle size, the particles tend to agglomerate and behave as larger particles and consequently their dispersibility is reduced as shown in Fig. 1. If the moisture content of the coal dust is high, then even the bigger sized particles will agglomerate.

The shape of the particle is also a rational component in deciding the agglomeration of the dust particles. Agglomeration will be more if the dust particles are of nearly spherical in shape. Because in such case, the orientation of the particles is not a problem unlike the irregularly shaped particles, wherein their orientation will not allow them to attach with each other effectively as depicted in Fig. 2. The inter-particle forces play a major role in the case of the strongly bonded agglomerates, which require a large shear force to break them. Therefore, the strongly bonded agglomerates are required to be exposed to the high velocity flow fields or high-velocity impacts arising from high dust-dispersion-air pressures for their complete dissociation into smaller primary particles [18].

Large concentrations of finely crushed dust produced in