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Research on characteristic parameters of coal-dust explosion

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Abstract

The parameters of explosive characteristics of the coal-dust are assessed systematically with the test device of minimum ignition temperature of dust clouds and 20L sphere explosion test units. The minimum ignition temperature of dust is a main safety index when handling combustible dusts in industrial production, and while hazard evaluation, the maximum explosion pressure and the explosion index are key parameters. Five kinds of coal-dust with different particle diameters were tested in order to determine the temperature sensitivity and the ferocity under the given conditions, which can be used as the criteria to classify dust explosion hazards. The experiment results indicate that the minimum ignition temperature of coal-dust cloud reduces with the decrease of particle diameter under temperature of (293±5) K and powder spraying pressure of 0.08MPa, and when the particle size reduces to (25-48) μm, the minimum ignition temperature is between (793-803)K; Besides that, the results can also show that minimum explosive concentration of coal-dust cloud is between 20 $g \cdot m^{-3}$ and 30 $g \cdot m^{-3}$ under temperature of (293±5) K, powder spraying pressure of 2MPa and ignition energy of 10kJ, the maximum explosion pressure is 0.45MPa and the maximum explosion index is 11.14 $MPa \cdot m \cdot s^{-1}$, which classifies coal-dust explosion hazards to Level I. The conclusions drawn from the experimental results are of great significance to the safe application of these combustible substances.

Keywords: coal-dust explosion; minimum ignition energy; minimum explosive concentration; explosion pressure; explosion index

Nomenclature

L	litre
K	thermodynamic temperature
g	gram
m	meter
MPa	million pascal
kJ	kilo joule
P_{max}	maximum explosion pressure
K_{st}	maximum explosion index
Greek symbols	
μ	micro

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1. Introduction

Dust explosion is the most common safety risks in coal, metallurgy, chemicals, wood, food processing, explosives and other industries [1-3], of which coal-dust explosion phenomena is more serious. Compared with the developed countries, in our country, the studies on the coal-dust explosion started relatively later and the awareness on harm of coal-dust explosion are lack. In China, coal production accounts for about 37% of the world total production, but the death toll accounts for about 70% of the world's. The severity of coal mine accidents should be paid more attention [4], especially the accident of gas and coal-dust explosion, which is one of the major malignant coal mine accident. In addition, the participation of coal-dust makes the explosion more destructive and causes more casualties and property losses [5].

Recently, with the gradual improvement of the safety consciousness, the harm of coal-dust explosion had been researched by some domestic research institutions and enterprises, and some progress in research had been made according to various coal-dust of different composition [6-8]. During transport, storage of coal, and preparation processes of coal-dust, large amounts of coal-dust suspend in the air. If these coal-dust cloud meet high temperature of the environment, they will be very likely to cause coal-dust explosion, and the explosion shock wave will make the accumulation of coal-dust raised, which will cause subsequent explosion by distributing spark and radiate heat. Finally, the whole area of dust is damaged [9-12].

The coal-dust explosion factor is an important basis for explosion risk assessment and explosion protection, mainly including the minimum ignition temperature of cloud (MITC), the lower explosive limit (LEL), the maximum explosion pressure (P_{max}) and the maximum explosion index (K_{st}) [13-15]. MITC is mainly used for the assessment of the environmental minimum temperature of ignition of coal-dust cloud, which is an important basis to prevent the burning of coal-dust. LEL is the maximum concentration of dust allowed in environment not to cause explosion. Explosion can be prevented by controlling the coal-dust concentration below LEL, which, furthermore, can be used to estimate the dangerous threshold of coal-dust layer thickness and accumulation. P_{max} and K_{st} are the important parameters to reflect the explosive ferocity [16-19], which are used for explosion pressure relief, explosion inhibition, protective isolation and dust risk classification. Taking coal-dust as test material, this paper systematically analyzed characteristics parameters of coal-dust, such as LEL, MITC, P_{max} and K_{st} and determined the effect of environmental temperature and coal-dust concentration to the coal-dust explosion, in order to gain certain understanding to coal-dust combustion and explosion, which will be used as a guide for explosion prevention, explosion relief, explosion suppression, protective isolation, and coal-dust explosion hazard classification [20].

2. Sample preparation and test methods

2.1. Coal-dust sample and test equipment

Coal-dust samples: according to the MT/T934-2005 standard about test method and the judgment of safety of permissible explosive in grime and inflammable gas, coal-dust should contain volatile content more than 35%, ash less than 12% and moisture content less than 3%. Five samples of different particle size were tested for study, and the particle size of samples, which were dried at the temperature of 50℃ for 24 hours before experiment, range from 250μm to 500μm , 150μm to 250μm, 75μm to 150μm, 48μm to 75μm, and 25μm to 48μm.

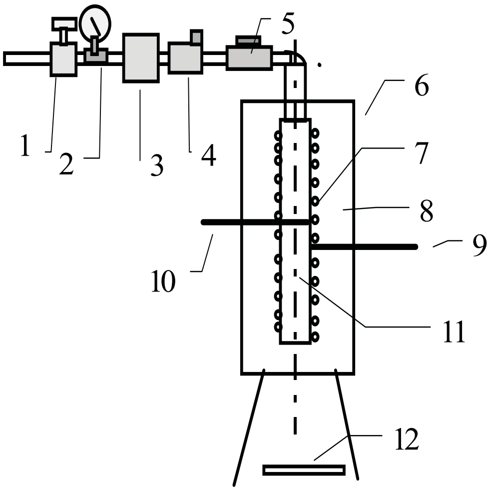
Chemical electric igniters: 10 kJ of total Ignition energy, which contains 2.4g ignition agent, including 0.96g activity zirconium powder (Chemical pure, Shanghai Lingfeng Chemcal Reagent CO., LTD), 0.72g $Ba(NO_3)_2$ (Chemical pure, Shanghai Lingfeng Chemcal Reagent CO., LTD) and 0.72g BaO (Chemical pure, Shanghai Lingfeng Chemcal Reagent CO., LTD).

- MITC test device

Coal-dust cloud minimum ignition temperature is the lowest temperature at which the coal-dust cloud suddenly changes when the mixture of coal-dust and air are heated, which is determined in Godbert-Greenwald furnace (Fig 1). Quartz furnace tube, the bottom of which is open, is major part of Godbert-Greenwald furnace. Inside of the quartz furnace, the resistance wire is around the wall, sparse in middle but dense at both ends in order to guarantee the temperature is equal throughout the furnace, the volume of which is 0.27L. The dust sample in the powder room is dispersed into the quartz furnace tube to form a uniform dust cloud by compressed air. Through the mirror below the furnace can observe whether catch fire.

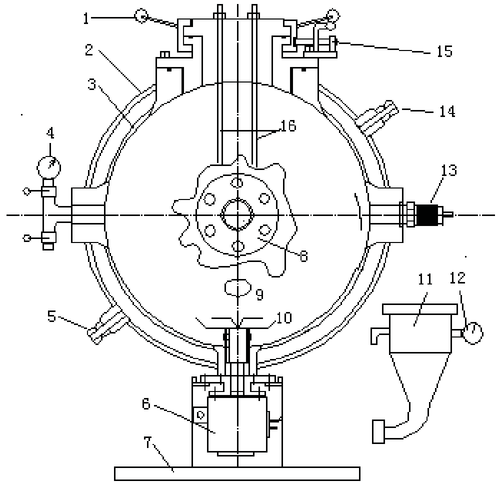
- Test device of P_{max}, K_{st} and LEL

The change process of pressure within the 20L spherical (Fig 2) vessel turns into electrical signals though the pressure sensor and the transmitter, collected by the data acquisition system and stores in the computer. Test explosion limit concentration, maximum explosion pressure and explosion index can be got by analyzing pressure-time curve. Based on the different dust concentration or different gas composition of a series of explosion test, a series of explosion pressure and index are got, which can make the relevant curves of P_{max}, K_{st} and the LEL.



1-needle valve; 2-pressure gauge; 3-powder room; 4-solenoid valve; 5-deposit powder room; 6-furnace shell; 7-heating resistance wire; 8-insulation materials; 9-fire galvanic for temperature controlling; 10-fire galvanic for wall temperature recording; 11-quartz furnace tube; 12-reflector

Fig. 1. MITC test device.



1-the operating handle; 2-the outer wall; 3-The inner wall; 4-vacuum table; 5-cooling water inlet; 6-fast opening valve; 7-base; 8-observation window; 9-inlet; 10-dust dispersed valve; 11-gas chamber; 12-electric contact pressure gauge; 13-pressure sensor; 14-cooling water outlet; 15-Security lock

Fig. 2. Test equipment 20 liter sphere.

2.2. Test methods

- Determination of the minimum ignition temperature of coal-dust cloud

The coal-dust with five different particle size of (250-500) μm, (150-250) μm, (75-150) μm, (48 -75) μm and (25-48) μm were test respectively at the environmental temperature of (293 ± 5) K and powder spraying pressure of 0.08MPa. Minimum ignition temperature of dust cloud could be gained by changing the concentration. Each group of test should repeat 10 times until 100% explosion probability, if temperature was higher than 573K, 20K should be subtracted, if not, 10 K should be subtracted [13].

- Determination of 20L sphere

Coal-dust were put in storage tank and pressurized in the environmental temperature of (293 ± 5) K, powder spraying pressure of 2MPa. According to the state equation of ideal gas to ensure that the explosion chamber pressure was in 10^5 Pa when ignited. Coal-dust were scattered to the container by high pressure gas through dust dispersion system when Open the valve. The energy of 10 kJ chemical igniter detonated in the container center 60ms after the valve open. Changing concentration of the dust, the pressure of different concentration in the container was recorded by the pressure sensor which was installed in the wall. Explosion limit concentration, explosion pressure and maximum rate of pressure rise $(dp/dt)_m$ could be reached by analyzing the pressure-time curve, according to the formula $K_{ST} = (dp/dt)_m \times \sqrt[3]{V}$ to calculate explosion index [13-15].

3. Effects of temperature and concentration of coal-dust on the explosion characteristic parameters

3.1. Minimum ignition temperature of coal-dust cloud

Powder spraying pressure of test is 0.80MPa. Test results are given in Fig 3.

Fig 3 shows the test result of minimum ignition temperature on the five kinds of coal-dust cloud with different particle size at the constant dust dispersing pressure but different temperatures. The concentration of 190g·m^{-3}, 300g·m^{-3}, 370g·m^{-3}, 740g·m^{-3}, 1100g·m^{-3} and 1850g·m^{-3} coal-dust cloud were trialed 10 times respectively, then calculate the probability of explosion.

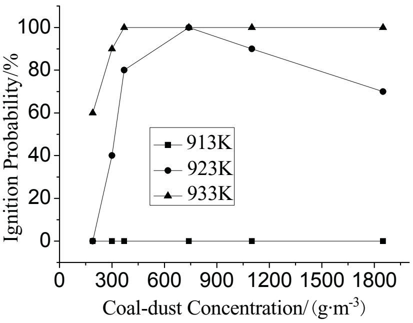
(1) Six kinds of concentration of coal-dust cloud are not ignited with particle size (250-500) μm and at temperature of 913K. The result indicates that the temperature is too low, not enough to ignite coal-dust cloud.

(2) At the temperature of 923K, with the increase of concentration, the ignition probability of coal-dust cloud first increases and then decreases, and ignition probability reached 100% when the concentration of coal-dust is $740 g\cdot m^{-3}$, which is the best ignition concentration.

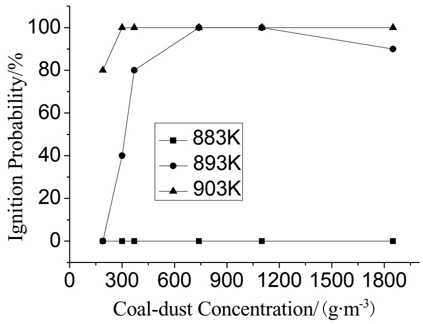
(3) Five kinds of concentration of coal-dust cloud are all ignited at temperature of 933K, which indicates that it is high enough to ignite the concentration of coal-dust within $(190\text{-}1850) g\cdot m^{-3}$ when the temperature reaches 933K. Therefore, Minimum ignition temperature of coal-dust clouds is between (893-903)K at the particle size between 250μm to 500μm.

Similarly, the particle size between 150μm to 250μm with minimum ignition temperature between (863-873)K. the particle size between 75-150 μm with minimum ignition temperature between(853-863)K; the particle size between 48μm to 75μm with minimum ignition temperature between (833-843)K. the particle size between 25μm to 48μm with minimum ignition temperature between (793-803)K. The best concentration of coal-dust clouds concentration is between (740-1100) $g\cdot m^{-3}$.

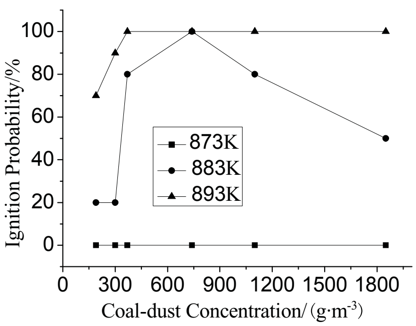
(4) With the decrease of the coal-dust particle size, coal-dust cloud minimum ignition temperature reduces gradually.



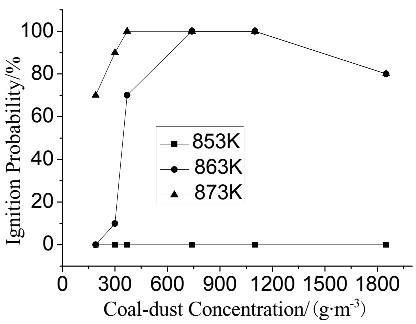
（a）Particle size（250-500）μm



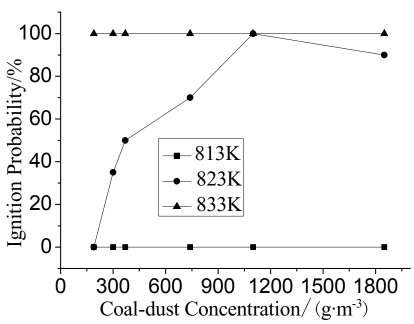
（b）Particle size（150-250）μm



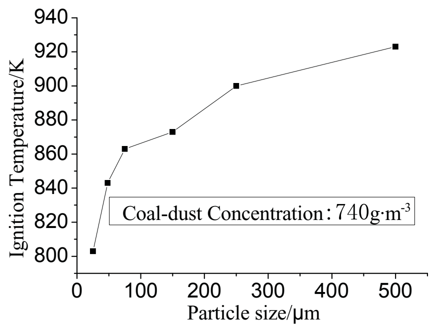
（c）Particle size（75-150）μm



（d）Particle size（48-75）μm



（e）Particle size（25- 48）μm



（f）Relationship between dust concentration and explosion pressure

Fig. 3. Coal-dust cloud minimum ignition temperature test diagram.

3.2. Effects of concentration of coal-dust on minimum explosive concentration, explosion pressure and explosion index

When coal-dust particle size is between (25-48)μm and chemical ignition energy is 10 kJ, the results are as follows.

Fig 4 shows the test result of the minimum explosive concentration on the six kinds of different concentration of $10g\cdot m^{-3}$, $20g\cdot m^{-3}$, $30g\cdot m^{-3}$, $40g\cdot m^{-3}$, $500g\cdot m^{-3}$ and $60g\cdot m^{-3}$ coal-dust at constant temperature and ignition energy. No explosion has happened at the concentration of $10g\cdot m^{-3}$, $20g\cdot m^{-3}$ and the explosion pressure is 0.11MPa. At the concentration of $30g\cdot m^{-3}$, the explosion pressure is 0.17MPa which is 0.6MPa more than the pressure of ignition, which indicated that coal-dust exploded. The explosion pressure rises gradually with the increasing of dust concentration, so the minimum explosive concentration of coal-dust concentration is within (20-30) $g\cdot m^{-3}$.

Fig 5 shows the test result of the explosion pressure on the six kinds of different concentration of $60g\cdot m^{-3}$, $125g\cdot m^{-3}$, $250g\cdot m^{-3}$, $500g\cdot m^{-3}$, $750g\cdot m^{-3}$ and $1000g\cdot m^{-3}$ coal-dust at constant temperature and ignition energy. Explosion pressure rises gradually from 0.3MPa with the increase of concentration, and reaches the peak of 0.45MPa at concentration of $250g\cdot m^{-3}$. The explosion pressure decreases with the increase of concentration ranging from $250g\cdot m^{-3}$ to $1000g\cdot m^{-3}$ and explosion pressure drops to 0.24MPa at the concentration of $1000g\cdot m^{-3}$.

Fig 6 shows test result of explosion index on the six kinds of different concentration of $60g\cdot m^{-3}$, $125g\cdot m^{-3}$, $250g\cdot m^{-3}$, $500g\cdot m^{-3}$, $750g\cdot m^{-3}$ and $1000g\cdot m^{-3}$ coal-dust at constant temperature and ignition energy. Explosion index rises gradually from 2.92 $MPa\cdot m\cdot s^{-1}$ with the increase of concentration, and reaches to peak of 11.14 $MPa\cdot m\cdot s^{-1}$ at concentration of 500g m^{-3}. The explosion index decreases with the increase of concentration ranging from $500g\cdot m^{-3}$ to $1000g\cdot m^{-3}$ and explosion index drops to 6.63 $MPa\cdot m\cdot s^{-1}$ at the concentration of 1000 $g\cdot m^{-3}$. The coal-dust explosion risk (K_{st}), less than 20 $MPa\cdot m\cdot s^{-1}$should be classified to level Ⅰ according to the dust explosion risk classification standard, while K_{st} between 20 to 30 $MPa\cdot m\cdot s^{-1}$ should be levelⅡ, and when K_{st} more than 30 $MPa\cdot m\cdot s^{-1}$should be level Ⅲ.

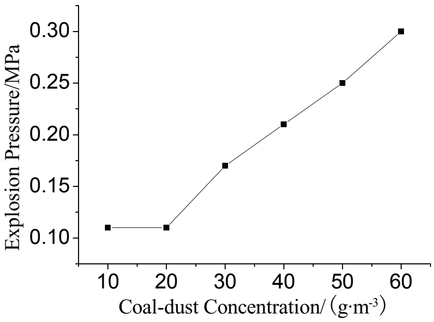


Fig. 4. Relationship between dust concentration and explosion pressure.

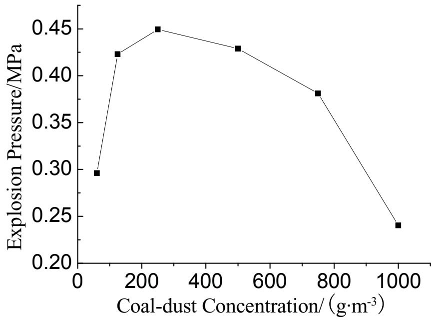


Fig. 5. Relationship between dust concentration and explosion pressure.

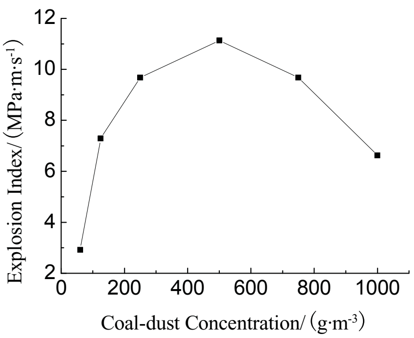


Fig. 6. Relationship between dust concentration and explosion index.

4. Conclusions

(1) The optimum ignition concentration of coal-dust cloud is between (740-1100)$g\cdot m^{-3}$ at an ambient temperature of (293±5) K and dusting pressure of 0.08MPa. Smaller the coal-dust partical size is, more easily the dust is ignited, and lower the minimum ignition is, which is between (793-803) K at the particle size of (25-48)μm.

(2) Explosion limit concentration of coal-dust is between (20-30) $g\cdot m^{-3}$at an ambient temperature of (293±5)K and dusting pressure of 2MPa. With the increase of coal-dust concentration, dust explosion pressure and explosion index showed a trend of first increase and then decrease. Coal-dust explosion pressure achieved maximum of 0.45MPa at the concentration of 250 $g\cdot m^{-3}$, and explosion index achieved maximum of 11.14 $MPa\cdot m\cdot s^{-1}$at the concentration of 250 g m^{-3}.

(3) Dust explosion performance parameters can be affected directly by the effective dust particles per unit volume. On one hand, only enough dust involved in reaction, is the flame and shock wave propagation velocity accelerated and do reach a critical value, which makes deflagration of the dust ignited by the chemical igniter to detonation transition rapid, and then the explosion increases gradually, the corresponding explosive parameters can increase to peak rapidly; on the other hand, when the dust is of excessive, the air in the reaction vessel can not supply, which will make chemical reaction incomplete, and inhibit the explosion to a certain extent.

(4) Coal-dust has dust explosion hazards and classification of explosion danger is level I. Appropriate security protection is necessary in actual production.

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