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Experimental Study on Influence of Ignition Energy on Gas Explosion Reaction Characteristics

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Based on both the theoretical analysis and laboratory test, the influence of ignition energy on the parameters such as gas explosion pressure and ignition delay time etc. was studied in this paper. The research results show that ignition energy is linearly proportional to the gas explosion pressure and pressure increase rate; the ignition energy in the 0.1-1J range has the greatest impact on the gas explosion pressure and pressure growth rate, and in the 10-100J it is the smallest. The methane explosion of gas is essentially a process in which the C-H chemical bond breaks to form the free radical, and this process requires a lot of energy. The greater the ignition energy, the more free radicals generated by the C-H breakage and the more complete the explosion reaction, which further allows the gas explosion to be completed in a shorter time. Besides, the greater the ignition energy, the larger the heated area of the gas, the more gas will participate in the explosion at the same time, and then the ignition delay time of the gas explosion will be smaller. With the initial concentration of gas 10% as the optimal concentration, the delay time at the time of explosion is 37ms at the minimum, the explosion pressure can reach a maximum value of 0.713MPa, and the increase rate of explosion pressure is a maximum of 17.1MPa/s.

1. Introduction

Gas explosion in mines is the most serious mine accident (Yang et al., 2014). It is an extremely complex chemical phenomenon, so the study of gas explosions requires the basic theories of multiple disciplines, including: comprehensive explosion mechanics, chemical kinetics, and computational fluid dynamics etc. (Lei et al., 2012; Pang et al., 2012; Zhang, Han and. Wang, 2009). At present, researchers have studied the characteristics of gas explosions, the influence of high temperature conditions on gas explosion, and the propagation and attenuation law of gas explosion (Oh et al., 2001; Li, Huang and Si, 2013; Jiang et al., 2012; Ning et al., 2006; Jiang et al., 2012) and theoretically deduced the explosion limits of gas mixtures, but due to the relative ideality of the relevant parameters, the research conclusions cannot be applied in practice. The influence of temperature, pressure, and ignition energy on gas explosions still requires further analysis (Zhu et al., 2010).Ignition energy is the main factor affecting gas explosion. Related literature studies have shown that ignition energy has a significant impact on gas explosion pressure, explosion limit, and ignition delay time, etc. (Meng et al., 2014; Qiu et al., 2011; Benedetto et al., 2012; Ajrash et al., 2016). However, there are still very few quantitative researches on the influence of ignition energy on gas explosions, and related theoretical research results have lag far behind on-site engineering experience (Cui et al., 2016; Dumitrache et al., 2015; Shmelev, 2009). An in-depth analysis of the gas explosion mechanism is of great significance for the safe coal mining.Based on the theoretical analysis and laboratory test, this paper studies the influence of ignition energy on the parameters such as gas explosion pressure and ignition delay time etc. The conclusions provide good references for coal mining standard revision and accident prevention etc.

2. Experimental methods

The 20L gas explosion experimental facilities shown in Figure 1 were used to study the explosion characteristics of gas. The test equipment is mainly composed of the explosion tank, pressure sensor, ignition

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source, vacuum pump, computer, etc. When the pressure in the explosion tank rapidly rises, it is determined that the gas explosion has been ignited successfully. The release range of energy value for energy source is 0-500J.

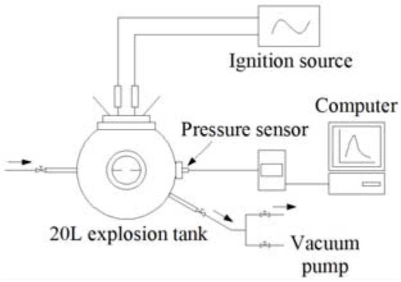


Figure 1: 20L gas explosion test equipment

3. Test results and analysis

3.1 Influence of ignition energy o gas explosion pressure

First, the influence of ignition energy on gas explosion pressure was studied. Under the condition of room temperature, the gas concentration in the explosion tank was kept at 10%, and the maximum explosion pressure value and the fitting curve of the gas explosion at the three ignition energy levels were shown in Figure 2. It can be seen from the figure, within the range of three ignition energy levels, the ignition energy is directly proportional to the gas explosion limit pressure; the fitting curve shows that the ignition energy and gas explosion limit pressure are approximately linear. In all three cases, the correlation coefficient of the fitting curve reached 0.89 or more, with good fitting effect. Besides, the slope values of the three fitting curves are y1>y2>y3, indicating that the ignition energy has the greatest impact on the gas explosion pressure in the range of 0.1-1J, and the ignition energy has the smallest in the range of 10-100J.

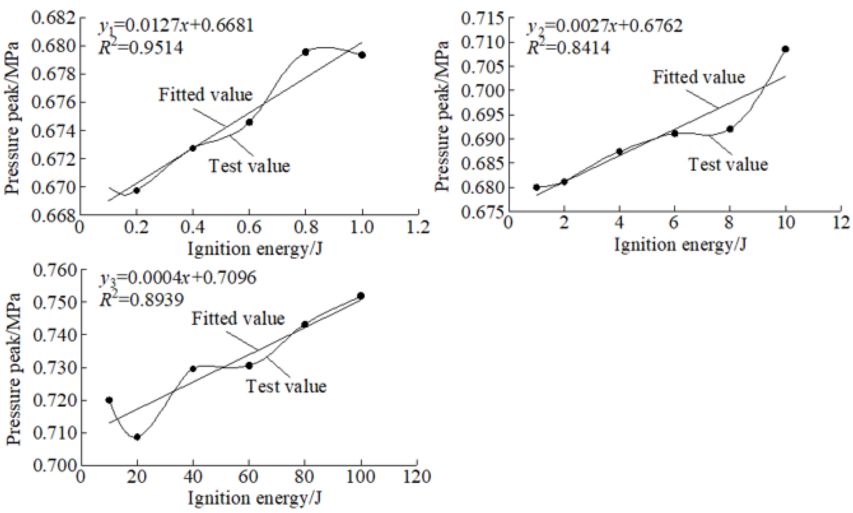


Figure 2: Maximum explosion pressure value and fitting curve of gas explosion at three ignition energy levels

Figure 3 shows the relationship between gas explosion pressure increase rate and the ignition energy in the three ranges of ignition energy levels. It can be seen from the figure that the ignition energy and the gas explosion pressure increase rate are also approximately linearly proportional to each other, but the correlation coefficient is relatively low. The slope of the fitting curve is y4>y5>y6, which indicates that the ignition energy has an effect on the increase of gas explosion pressure: the ignition energy has the largest influence in the range of 0.1-1J, while it has the smallest in 10-100J. The gas explosion pressure and pressure increase rate are affected by many factors. In general, the larger the ignition energy, the greater the heated area of the gas and the more unstable the gas. When a spark occurs in the range of gas, a very high-temperature volumetric volume shall appear around the spark, which exchanges heat with the neighboring environment to form the spherical travel path similar to the combustion wave, as shown in Figure 4.

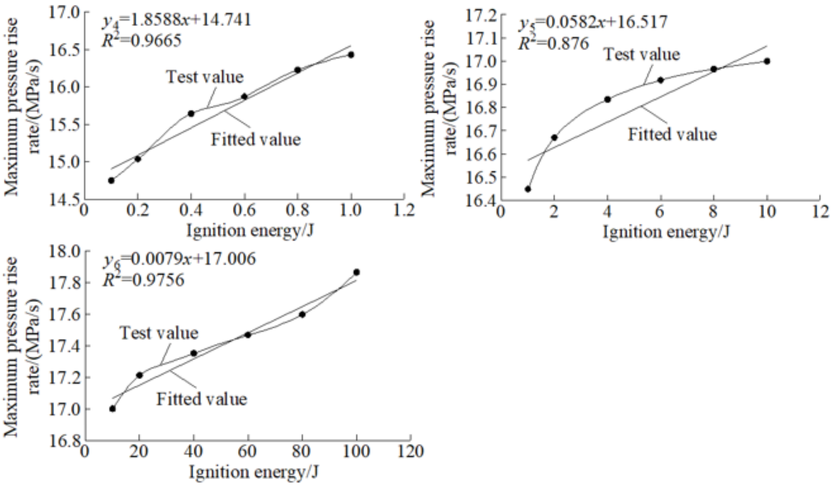


Figure 3: The relation between the increase rate of gas explosion pressure and ignition energy in the range of three ignition energy levels

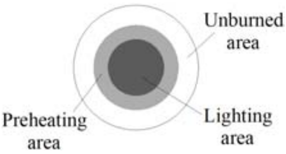


Figure 4: Flame combustion model

Gas explosion can be regarded as the chain reaction process of several chemical reactions combinations. The explosion of methane in a gas is essentially the process in which a C-H chemical bond breaks to form the free radical, and this process requires a lot of energy. The greater the ignition energy, the more free radicals generated by the C-H breakage and the more complete the explosion reaction, which further allows the gas explosion to be completed in a shorter time.

3.2 Influence of ignition energy on gas explosion ignition delay time

After the gas is ignited, there is a slight delay of explosion pressure from 0 to the start of rise. This delay time is related to the gas concentration, the degree of explosion chemical reaction and other factors.
Figure 5 shows the relationship between ignition energy and ignition delay time of gas explosion, at the initial concentration of gas 8%. It can be seen from the figure that the larger the ignition energy, the smaller the ignition delay of the gas explosion. When the ignition energy is 1J, the ignition delay time is 79ms, and when the ignition energy is increased to 350J, the ignition delay time is sharply reduced to 36ms, which is a reduction of 119% compared to 1J. The greater the ignition energy, the greater the area of gas heating, and the more gas involved in the explosion reaction at the same time.
The scatter points were fitted to obtain the fitting formula (Formula 1). The ignition energy and the gas explosion delay time have an approximate exponential functional relation.

$$y = 33.94 + 42.48\exp\frac{-\left(x - x_0\right)}{150.3} \tag{1}$$

Figure 6 shows the relationship between the initial gas concentration and the ignition delay of the gas explosion. It can be seen from the figure that with the increase of gas concentration, the ignition delay time of gas explosion shows a trend of decreasing first and then increasing. At a gas concentration of 10%, the delay time reaches a minimum of 37ms; but, when the concentration is too small (6%) or too large (15%), the delay time will increase dramatically, reaching more than 300ms.

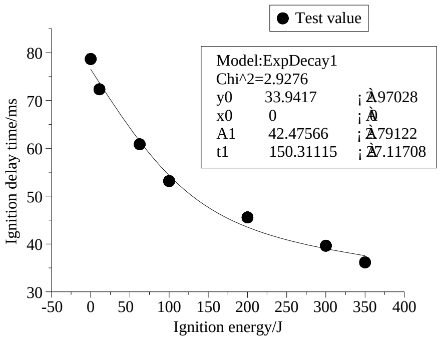


Figure 5: Relationship between ignition energy and ignition delay time of gas explosion

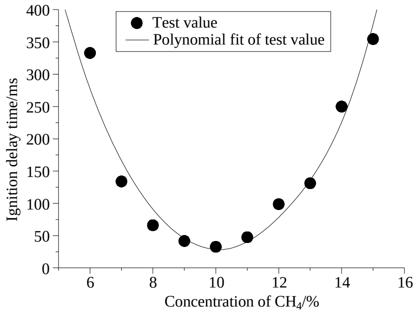


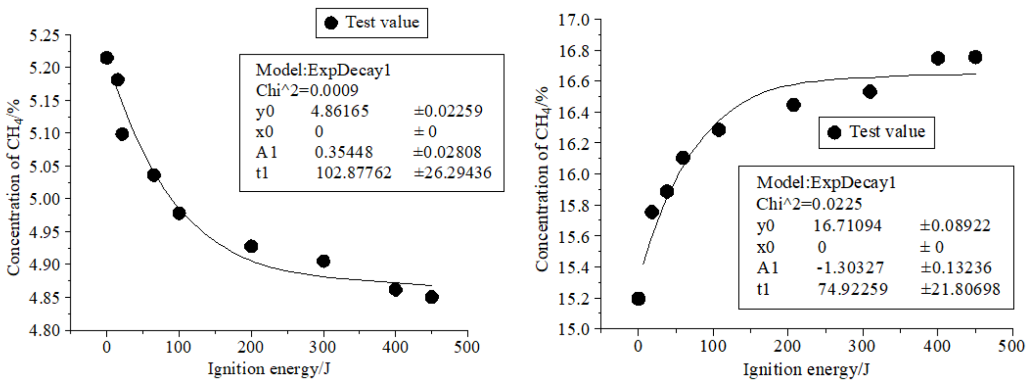
Figure 6: Relationship between initial gas concentration and ignition delay time of gas explosion

The fitting curve can be expressed as:

$$y = 14.53x^2 - 295.7x + 1534.9 \tag{2}$$

3.3 Influence/ of ignition energy on the limit of gas explosion

Figure 7 shows the influence of ignition energy on the upper and lower limits of gas explosion. It can be seen from the figure that with the ignition energy increasing, the lower limit of gas explosion first shows a rapid decrease and then slowly decreases; when the ignition energy reaches 450J, the lower explosion limit is 4.79%. The upper explosion limit of gas explosion first shows a rapid increase and then increases slowly; when the ignition energy reaches 450J, the upper explosion limit is 16.9%. That is, when the gas concentration exceeds 16.9%, the gas will not be able to produce an explosive reaction because of no enough oxygen; when the gas concentration is less than 4.79%, no gas explosion will occur due to lack of gas.



(a) Lower explosion limit (b) Upper explosion limit

Figure 7: Relationship between ignition energy and gas explosion limit

3.4 Influence of initial gas concentration on gas explosion pressure

Based on the section above, the influence of different initial gas concentrations on the gas explosion pressure and the explosion pressure increase rate was further discussed, as shown in Figure 8 and 9. It can be seen from Figure 8, the initial gas concentration and gas explosion pressure are approximately quadratic functional relation. The fitting relation is expressed as:

$$y = -0.0205x^2 + 0.4185x - 1.4417 \quad R^2 = 0.9836(6\% \leq x \leq 15\%) \tag{3}$$

It can also be seen from the figure that at the initial gas concentration of 10%, the gas explosion pressure can reach a maximum value of 0.713 MPa. Under too large or too small initial concentrations, the gas explosion pressure will rapidly decrease.

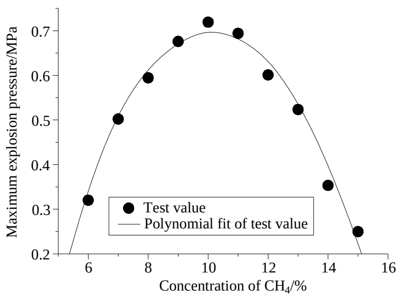


Figure 8: Relationship between gas concentration and gas explosion pressure

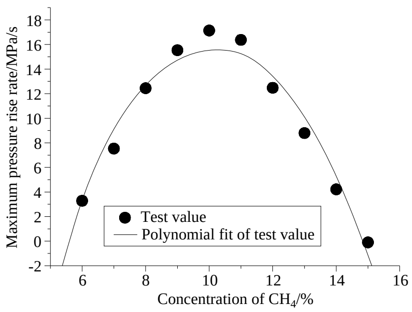


Figure 9: Relationship between gas concentration and gas explosion pressure increase rate

Figure 9 shows that the initial gas concentration and the increase rate of gas explosion pressure are also quadratic functional relation. The fitting function is given as:

$$y = -0.7329x^2 + 14.921x - 58.899 \quad R^2 = 0.9727(6\% \leq x \leq 15\%) \tag{4}$$

At the initial gas concentration of 10%, the gas explosion pressure increases at a maximum rate of 17.1 MPa/s.

4. Conclusions

Based on the methods of theoretical analysis and laboratory test methods, this paper studies the influence of ignition energy on the parameters such as gas explosion pressure and ignition delay time etc. The related conclusions are as follows:

(1) The ignition energy is linearly proportional to gas explosion pressure and gas explosion pressure increase rate. The ignition energy in the range of 0.1-1J has the greatest influence on the gas explosion pressure and pressure increase rate, and in 10-100J has the smallest. The methane explosion in the gas is essentially a process in which a C-H chemical bond breaks to form a free radical, and this process requires a lot of energy. The greater the ignition energy, the more free radicals generated by the C-H breakage and the more complete the explosion reaction, which further allows the gas explosion to be completed in a shorter time.

(2) The larger the ignition energy, the larger the heating area of the gas, and the more gas involved in the explosion at the same time, the smaller the ignition delay time of the gas explosion. With the initial

concentration of gas 10% as the optimal concentration, the delay time at the time of explosion is 37ms at the minimum, the explosion pressure can reach a maximum value of 0.713MPa, and the increase rate of explosion pressure is a maximum of 17.1MPa/s.

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