Experimental study on the effect of the Coupling of Ignition Energy and pressure on the explosion limit of Coal-bed methane

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Abstract. Coal-bed methane(CBM) was a natural gas occurring in underground coal seams, which was mainly composed of methane. In order to study the effect of ignition energy and pressure on the explosion limit of CBM, a special environment 20L explosion characteristic test system was used. The explosion limit of methane under different ignition energy (10~400J) and pressure (0.1~1.2MPa) was studied experimentally. The results show that with the increase of ignition energy and initial pressure, the upper limit of methane explosion was obviously increased, the lower limit of explosion was decreasing, and the range of explosion limit was enlarged. Compared with the lower limit of methane explosion, the effect of ignition energy and initial pressure on the upper limit of methane explosion was more obvious. The coupling effect of ignition energy and initial pressure on the explosion limit of methane was greater than that of a single factor, and the effect of ignition energy and initial pressure on the explosion limit was more significant than that of a single factor.

1. Introduction

There are abundant CBM resources in China, and the proved reserves of shallow layer over 2000m are \( (30 \sim 35) \times 10^{12} \text{m}^3 \), which was equivalent to the reserves of natural gas \(^1\). Therefore, the development and utilization of CBM resources have broad prospects. Methane as the main component of CBM, its explosion risk also represents the explosion risk of CBM. Explosion limit was an important risk parameter, so it is necessary to understand the variation of explosion limit of methane in order to better exploit and utilize coal bed methane. According to the influencing factors of methane explosion limit, domestic and foreign scholars have done some research. According to the influencing factors of methane explosion limit, domestic and foreign scholars have done some research. Wang Hua et al. \(^2\) have studied the influence of initial pressure on explosion characteristics of mine unit and multi-component combustible gas through experiments. The experimental results show that the increase of initial pressure broadens the explosion limit range of flammable gas. And the influence on the upper limit was more significant. Gao Na et al. \(^3\) concluded that the coupling effect of initial temperature and initial pressure...
on the upper and lower limit of methane-air mixture explosion was much greater than that of single factor. The results of Xiao Dan [4] show that with the increase of initial temperature, initial pressure and coal dust concentration, the lower limit of gas explosion decreases, the upper limit increases and the limit range expands. Huang [5] analyzed the influence of inert gas, pressure and temperature on the explosion limit, and concluded that the pressure had more effect on the explosion limit than the temperature.

In this paper, the explosion limit of methane was measured under different ignition energy and initial pressure by the special environment 20L explosion characteristic test system, and the influence of ignition energy and environmental pressure coupling on the explosion limit of methane was analyzed. In order to provide a reference for methane explosion risk assessment and do basic research for the development and utilization of coal-bed methane.

2. Test system and conditions

2.1 Test system

The test was carried out in the test system of 20L explosion characteristics under special environmental conditions. The system was mainly composed of explosion tank, ignition system, data acquisition system, gas distribution system, heating system and humidifying system, etc. The ignition energy was emitted by the high energy EDM energy generator in the ignition system, which can generate 10~450J energy spark discharge and trigger the data acquisition system at the same time for real-time data acquisition. Structural schematic diagram shown in Fig. 1.

![Experimental System Diagram](image)

Figure 1. Schematic diagram of experimental system

2.2 Experimental conditions

Under different ignition energy (10J~400J) and initial pressure (0.1~1.2MPa), the explosion limit test was carried out separately from the lower limit test. The law of the upper limit of explosion under the coupling of ambient temperature and ignition energy was first tested, and then the variation of the lower limit of gas explosion was studied. The upper limit of the explosion and the lower limit of the explosion shall be the same test method.

3. Single factor effect of ignition energy and initial pressure

Fig. 2 shows that the methane explosion limit varies with the ignition energy. When the ignition energy was 10J, the explosion limit was 5.28%, the explosion limit was 14.9%, and the explosion limit was 9.62%. When the ignition energy was 400J, the lower limit of explosion was 4.7%, the upper limit of explosion was 16.8%, the limit range was expanded to 12.1%, and the percentage of explosion limit was 25.78%.
Fig. 3 shows the change of methane explosion limit with initial pressure. At room temperature, when the ignition energy was 10J, the initial pressure increases from 0.1MPa to 1.2 MPA, the upper limit of methane explosion rises to 21.8%, the lower limit decreases to 4.67%, and the limit range extends to 17.13%. The expanding percentage of explosion limit was 78.06% when compared with normal temperature and normal pressure. Compared with ignition energy, the influence of initial pressure on methane explosion limit was more obvious.

By comparing the fitting curves, it can be seen that with the increase of ignition energy and initial pressure, the effect of ignition energy and initial pressure on the upper limit of methane explosion was greater than that on the lower limit of methane explosion, and the lower limit of methane explosion reaches a certain concentration. The downward trend has become slow. The main reason was that when the methane concentration was about the lower limit of the explosion, the methane concentration was small at this time, the specific gravity of the air increases, and the air will have an inert effect on the methane explosion reaction, which will hinder the reaction. It reduces the likelihood that the reaction will occur. Therefore, although the lower limit of methane explosion was decreased with the increase of temperature and pressure, the influence degree of methane explosion was smaller due to the presence of excess air.

According to the fitting results, the upper limit of methane explosion was basically linear with ignition energy and initial pressure, as shown in formula (1). The upper limit parameter values of methane explosion are shown in Table 1.

\[ y = a + bx \]  

When \( x = E/J \), \( 10 \leq x \leq 400 \); when \( x = p/\text{MPa}, \ 0.1 \leq x \leq 1.2 \).
Table 1. Parameters of fitting function

| % | \( x \) | \( a \) | \( b \) | \( R^2 \) |
|---|---|---|---|---|
| UEL | \( E_0/J \) | 15.09746 | 0.00457 | 0.88788 |
| | \( P_0/\text{MPa} \) | 14.08149 | 6.73798 | 0.95978 |

With the increase of ignition energy or initial pressure, the lower limit of methane explosion decreases more and more slowly. As shown in formula (2). The lower limit parameter values of methane explosion are shown in Table 2.

\[
y = A_2 + \left( A_1 - A_2 \right) / \left[ 1 + \left( x / x_0 \right)^p \right]
\]

(2)

When \( x=E/J, 10 \leq x \leq 400 \); when \( x=p/\text{MPa}, 0.1 \leq x \leq 1.2 \).

Table 2 Parameters of fitting function

| % | \( x \) | \( A_1 \) | \( A_2 \) | \( x_0 \) | \( p \) | \( R^2 \) |
|---|---|---|---|---|---|---|
| LEL | \( E_0/J \) | 7.6737 | 4.25907 | 0.52003 | 0.28832 | 0.99588 |
| | \( P_0/\text{MPa} \) | 23.65098 | 4.61766 | 0.0033 | 0.97413 | 0.99613 |

4 Coupling factors of ignition energy and pressure

4. 1 Methane explosion upper limit

The comparison between Fig.4(a) and Fig.4 (b) shows that the effect of pressure change on the upper limit of methane explosion was more obvious than that of ignition energy. At the same initial pressure, the effect of the increase of unit ignition energy on the upper limit of explosion decreases gradually.

When the ignition energy was 10J, the upper limit of methane explosion was 14.9%, when the ignition energy was raised from 10J to 400J, the upper limit was only 6.04%. When the ambient temperature was at room temperature and ignition energy was 10J, when the initial pressure increases from 0.1MPa to 1.2MPa, the upper limit increases by only 46.3 percent. When the ignition energy was up to 400J and the initial pressure increases to 1.2MPa, the upper limit of the explosion increases to 25.6%, and the range of increase was almost 71.81%. It can be seen that the change amplitude of the upper limit of methane explosion under the coupling action of ignition energy and pressure was much larger than that under the influence of a single factor, and it was much larger than the sum of the variation amplitude under the influence of a single factor.
methane explosion more intuitively, the initial pressure was used as the x axis, the ignition energy as the y axis, and the methane explosion upper limit as the z axis. The curve of explosion upper limit varying with initial temperature and initial pressure was obtained by fitting, as shown in Fig. 5. The Gauss equation with the change of ignition energy and environmental pressure was obtained by fitting, as shown in formula (3).

\[ z = z_0 + a \exp \left[ -\frac{1}{2} \left( \frac{x-b}{c} \right)^2 - \frac{1}{2} \left( \frac{y-d}{e} \right)^2 \right] \]

(3)

When \( x=E/J, 100 \leq x \leq 400, 0.2 \leq y \leq 1.2. \)

| Z   | X    | Y    | Z₀   | a    |
|-----|------|------|------|------|
| UEL | p/MPa| E/J  | 4.06977 | 23.77595 |
| LEL | p/MPa| E/J  | 4.595   | 0.01996  |
|     | b    | c    | d    | e    | R²   |
| 1.37453 | 2.16669 | 664.67761 | 615.6154 | 0.98844 |
| 2.45419 | 0.0037  | 766.50413 | 599.78615 | -0.5 |

### 4.2 Lower limit of methane explosion

The change in the lower limit of the methane explosion with the ignition temperature and the initial pressure coupling was shown in Fig.5. As can be seen from the figure, when different ignition energy was used, the lower limit of the explosion of methane decreases with the increase of the pressure; under the different conditions of the initial pressure, the lower limit of the methane explosion decreases with the increase of the ignition energy.

![Figure 5](image-url)  

It can be seen that the change amplitude of methane explosion lower limit under the influence of ignition energy and initial pressure coupling was larger than that of single factor, but it was smaller than the change amplitude of explosion upper limit. The variation amplitude of methane explosion lower limit under the influence of ignition energy and initial pressure coupling was basically consistent with the sum of the two single factors. Fig.7 was a fitting surface diagram of the upper limit of methane explosion under the condition of coupling ignition energy and initial pressure. It can be seen more intuitively how the lower limit of methane explosion changes with the increase of ignition energy and environmental pressure. The Gauss equation with the change of ignition energy and environmental pressure was consistent with the Gauss equation obtained from the explosion upper limit, as shown in formula (3) above.

According to this formula (3), the limit of methane explosion in the range of experimental conditions can be obtained, and the parameters of the fitting function are shown in Table 3.

### 5. Conclusions

The change of ignition energy and initial pressure will affect the explosion limit of methane. When the
ignition energy or initial pressure increases, the lower limit of explosion of methane decreases, the upper limit of explosion increases, and the range of explosion limit expands. The upper limit of methane explosion has a linear relationship with ignition energy and initial pressure, and the lower limit of explosion has a curve relationship with ignition energy or initial pressure, and with the increase of ignition energy or initial pressure, there was a linear relationship between the explosion limit and ignition energy or initial pressure. The lower limit of explosion of methane was decreasing more and more slowly.

The effect of ignition energy and initial pressure on the coupling of upper and lower limit of methane explosion was much greater than that of single factor. The coupling effect of the two on the upper limit of the explosion was much greater than the sum of the single effect of the two, and the effect on the lower limit of the explosion was almost the same as the sum of the single effect of the two. The relationship between temperature and pressure and the upper and lower limit of explosion can be described by Gauss's surface equation.

By fitting the experimental data, the variation rule of methane explosion limit under different ignition energy and initial pressure was obtained, as shown below,

\[ z = z_0 + a \exp \left[ -\frac{1}{2} \left( \frac{x-b}{c} \right)^2 - \frac{1}{2} \left( \frac{y-d}{e} \right)^2 \right] \]

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