Experimental Research on The Coupling Effect of Hole Plate Size and Initial Pressure on The Pressure of Methane-Air Explosion

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Abstract: In order to study the effects of different orifice sizes and initial pressures on the explosion process of methane-air mixture, the explosion tests of methane-air mixture were carried out under different orifice sizes (16mm-160mm) and initial pressures (0kPa-50kPa) using PTB pipeline experimental device. The experimental results show that with the decrease of orifice size and the increase of initial pressure, the maximum explosion pressure of methane-air increases. The maximum explosion pressure is 5 times of the minimum explosion pressure in the limit state. The coupling effect of orifice size and initial pressure on explosion pressure is greater than effect of single factor. Finally, the influence surface is drawn to describe the relationship between the size of orifice plate and the initial pressure and the maximum explosion pressure of methane-air mixture.

1. Introduction
In the mine, the explosion-proof door divides the roadway into small doors to connect the passage. In the shell of the explosion-proof equipment, the explosion-proof chamber is divided into small holes connected by the wire plate for convenient wiring. These connected channels or cavities will affect the propagation of methane explosion. When the explosion passes through the explosion-proof door or wire plate, the flame shape, flame propagation speed, flow field structure and explosion pressure will change significantly, and the unburned cavity will be pre-pressed [1-4]. Therefore, it is of great significance to study the coupling effect of orifice size and initial pressure on methane-air explosion pressure to effectively reduce the loss of gas explosion disaster and improve the strength of flameproof shell. In this paper, with the help of explosion-proof test system of Fushun Mine Equipment Testing and Inspection Center for National Safety Production, the explosion test of methane-air mixture was carried out on PTB pipeline experimental device. The explosion pressure process of methane-air mixture with methane volume concentration of (9.80±0.05)% under different orifice plate sizes (16mm-160mm) and initial pressures (0kPa-50kPa) was measured, and the size of orifice plate was studied.

2. Experimental System and Method
The explosion test of methane-air mixture was carried out with the experimental device of Fushun Mine Equipment Testing and Inspection Center of National Safety Production. The flow chart of the system is shown in Figure 1. From Figure 1, it can be seen that the experimental system is mainly composed of experimental tank, gas distribution unit, vacuum pump, ignition unit, control unit and pressure...
acquisition unit. The PTB pipeline experimental device is shown in Figure 2. The outer diameter of the pipeline is 285mm, the inner diameter is 160mm and the length is 750mm. The intake port, ignition point and pressure measuring point $P1$ are set on the left side of Chamber A, and the outlet, ignition point and pressure measuring point $P2$ are set on the right side of Chamber B. Different orifice sizes are obtained by changing the size of the middle orifice. The corresponding relationship between orifice plate number and intermediate orifice is shown in Table 1. During the experiment, the initial pressure was 0kPa, 10kPa, 20kPa, 30kPa, 40kPa and 50kPa.

![Figure 1 Flow chart of explosion test system](image1)

![Figure 2 PTB pipeline experimental device](image2)

| Number | Intermediate hole Φd(mm) | Number | Intermediate hole Φd(mm) |
|--------|---------------------------|--------|---------------------------|
| 1#     | 16                        | 6#     | 96                        |
| 2#     | 32                        | 7#     | 112                       |
| 3#     | 48                        | 8#     | 128                       |
| 4#     | 64                        | 9#     | 144                       |
| 5#     | 80                        | 10#    | 160                       |

The tightening moment of each bolt is 64.0Nm and clearance are is 0.10mm in PTB pipeline test device. The ignition energy is 10J, and the concentration of methane in the mixture of methane and air is $(9.80\pm0.05)\%$[5]. The influence of ambient temperature, humidity and methane concentration on the experimental results is ignored [6-7]. In order to study the effect of maximum explosion pressure on methane-air mixture, the ignition point at Chamber B was selected to ignite [8].

3. The influence of single factor of orifice size and initial pressure
3.1. Effect of Orifice Size on Explosion Pressure Process

At atmospheric pressure, experiments were carried out on the 3# orifice plate. The results of the explosion pressure of methane-air mixture are shown in Figure 3. From Figure 3, it can be seen that the values of pressure measuring point \( P1 \) and \( P2 \) are basically the same within 120ms. From 120ms to 160ms, the value of \( P1 \) is gradually larger than that of \( P2 \). This is because the orifice did not affect the methane-air explosion process before 120ms.

Figure 3 3# Explosion pressure process of methane-air mixture in orifice plate

From 120ms to 160ms, the orifice plate interrupted the continuous propagation of methane-air explosion, pre-pressed the chamber A, and caused the explosion pressure to rise in the chamber. The Chamber A and Chamber B pressures of the two chambers are basically the same after the pressure point \( P1 \) and \( P2 \) reach their maximum values. As can be seen from Figure 4, when the size of the hole in the orifice plate is 160mm, the explosion pressure value can be the minimum is 0.297MPa, and the maximum explosion pressure is 1.129MPa when the hole size is 16mm, which is 280% higher than the minimum. The effect of orifice plates with single serial number on methane-air explosion is shown in Figure 5. It is clear from Figure 4 and 5 that the maximum explosion pressure of methane-air mixture decreases with the increase of orifice size.

Figure 4 Maximum methane-air explosion pressure in different orifice plates

3.2. Effect of Initial Pressure on Explosion Pressure Process
The explosion pressure curves of methane-air mixtures of 0kPa, 10kPa, 20kPa, 30kPa, 40kPa and 50kPa are obtained by changing the initial pressure with the size of the middle hole of the orifice plate being 48mm, as shown in Figure 6. From Figure 6, with the increase of initial pressure, the maximum explosion pressure of methane-air mixture increases gradually, from 0.591MPa to 0.812MPa, and the value increases by 37%.

Figure 6 Methane-air explosion pressure processes at different initial pressures

4. Coupling Effect of Orifice Plate and Initial Pressure

In order to comprehensively analyze the influence of orifice plate and initial pressure on the explosion of methane-air mixture, a curved surface of the maximum explosion pressure varying with orifice plate size and initial pressure is obtained by taking orifice plate size as X axis, initial pressure as Y axis and methane-air explosion pressure as Z axis, as shown in Figure 7. As can be seen from Figure 7, the effect of orifice size and initial pressure on explosion pressure of methane-air mixture is superimposed. When the orifice size decreases and the initial pressure increases, the explosion pressure of methane-air mixture increases. The effect can be observed more intuitively from the surface of Figure 7.

Figure 7 Coupling effect of orifice plate and initial pressure on explosion pressure

The maximum explosion pressure of methane-air mixture under the experimental conditions can be predicted by using the fitting function (1)[9-10]. The parameters of the fitting equation are shown in Table 3.

\[
z = \frac{z_0 + A_{01} \times x + B \times y + B_01 \times y^2 + B_02 \times y^3 + B_03 \times y^4}{1 + A_1 \times x + A_2 \times x^2 + A_3 \times x^3 + B_1 \times y + B_2 \times y^2}
\]

(1)

Table 2 Parameters of fitting function

| z | x | y | A_{01} |
|---|---|---|---|
| Pressure/0.1MP | Orifice size/mm | Initial pressure/kPa | -0.0761 |
| a | B_{01} | B_{02} | B_{03} | A_1 |
| 0.2194 | 0.0048 | -1.01×10^{-4} | 0.1643 | A_2 |
| 0.2194 | 0.0048 | -1.01×10^{-4} | 0.1643 | A_2 | B_1 |
| 0.2194 | 0.0048 | -1.01×10^{-4} | 0.1643 | A_2 | B_1 | A_3 | B_2 | B_3 |
5. Conclusion

The experimental results show that the size of orifice plate and the change of initial pressure all affect the explosion process of methane-air mixture. When the orifice size is decreased, the explosion pressure of methane-air mixture is increased. When the initial pressure is increased, the explosion pressure of methane-air mixture is increased. When the two factors is the combined effect, the explosion pressure of methane-air mixture is stronger than effect of a single factor.

Although the experimental results in this paper can be used for reference to reduce the loss of gas explosion disaster and improve the strength of flameproof shell, in order to understand the explosion process of methane-air mixture, the coupling of other factors and the role of flame propagation process in explosion development should also be studied.

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