

Experimental Studies on the Effect of Humidity on Methane Explosion Characteristic in Confined Spaces

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Abstract: The limit of methane explosion and the characteristics of methane explosion pressure under different conditions of humidity ($\leq 15\%RH$ 、 $63\%RH$ 、 $92\%RH$) are studied by using the test system of 20L explosion characteristics in special environment. It is concluded by the study that when the other conditions remain unchanged, with the raise of environmental humidity, the upper limit of methane explosion becomes smaller but lower limit of it becomes larger. And the range of explosion is lessening. Furthermore, compared with the influence of ignition energy, temperature and pressure on the explosion limits, the humidity has a little effect. Maximum explosion pressure and the pressure rise rate are parabolic distribution taking the optimum explosion concentration as the symmetry axis and under the condition of different humidity, both of them show equal scaling trends within the limit of explosion. The conclusion provides an important theoretical basis for preventing gas explosion accident effectively in mines and utilizing coal-bed methane safely.

Introduction

Humidity is a measure of the amount of water vapor contained in a certain volume of gas under the condition of certain temperature and it is a parameter to measure the drying degree of gas. The explosion characteristic of methane gas with certain humidity is more complex than that of the mixture of methane and air. In the existing experimental studies, people have not paid so much attention to the methane gas explosion related to environmental humidity that there are few studies on the methane explosion characteristics. This paper makes experimental studies on the methane explosion characteristics under certain humidity conditions.

Experimental Configurations

The experimental system of 20L explosion characteristics in special environment is the main equipment to complete the experiment of gas explosion features in airtight vessels. And the relevant measurements are important references for the damage process and degree of explosion pressure. The physical map of experiment device is shown in Fig. 1 and the diagram of experimental system composition is shown in Fig. 2. The experimental system is mainly composed of gas distribution system, vacuum-pumping system, ignition system, temperature control system, data acquisition

system and so on. The explosion container is not only connected with a pressure sensor and temperature sensor but control system that controls heating system, gas distribution system and ignition system through a sequence circuit and is linked to high frequency data acquisition system through a wireless monitoring transmitter. The whole system is for digital control, visualization and high integration automatic collection device, which makes the operation of the experiment more accurate and convenient. The main technical indexes of the experimental system are shown in Table 1.

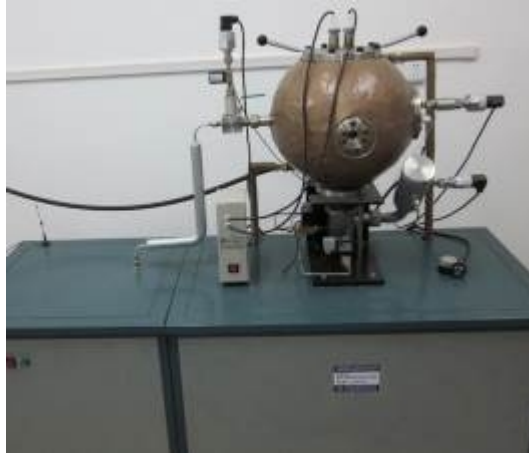


Fig. 1 The Experimental Device of Gas Explosion Characteristics in Special Environment

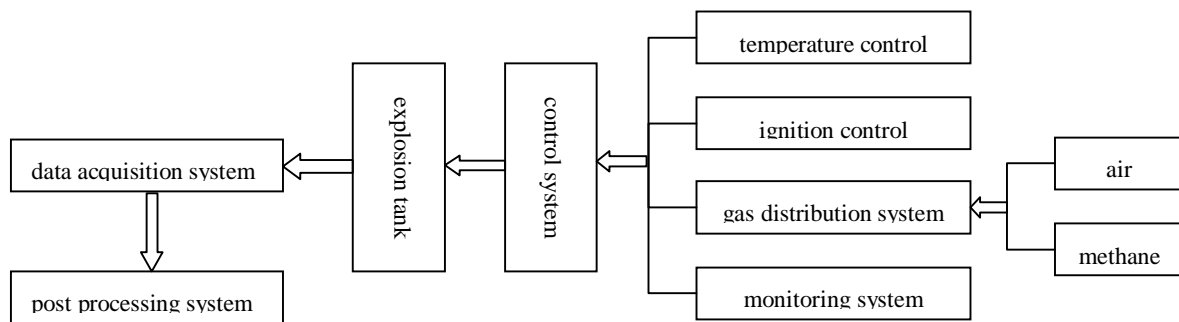


Fig. 2 The Diagram of Experimental System Composition

Table 1 Technical Index of the Test System of 20L Explosion Characteristics in Special Environment

Serial Number	Systematic Technology	Technical Index
(1)	Explosion tank	20L/globular
(2)	Maximum working temperature	200°C
(3)	Pressure measuring range	-0.1~ 4MPa; resolution: 0.01 MPa
(4)	Range of temperature measurement and control	Room temperature~ 200°C; resolution: 0.1°C
(5)	Ignition mode	High-tension ignition: 10J
(6)	Gas distribution mode	Gas distribution according to the proportion of vacuum
(7)	Gas distribution accuracy	±0.1%
(8)	Gas distribution circuit	3 circuit

Preparation of Mixed Gas

In the study of the explosion characteristics of methane gas under the condition of environmental humidity, it is necessary to produce methane-air mixture with different humidity to control the humidity of the mixed gas. Gas humidity recorder, humidifier and other instruments should be equipped in the process of preparation to quantify the humidity of explosion gas. The gas humidity recorder is shown in Fig. 3. The methane-air mixture that is what the experiment needs is made up by the mixture of bag of gas distribution and then measured by the humidity recorder.



Fig. 3 Gas Humidity Recorder

Gas distribution mainly mixes dry methane with air under different humidity (fixed humidity value) so that obtains mixed gas with relatively stable humidity:

(a) Different concentration of gas is mixed by dry compressed gas of methane and dry compresses air. After the test, the humidity value of the mixed gas is between 15% and 25% RH (the average is about 22%RH).

(b) Different concentration of gas is mixed by dry compressed gas of methane and damp air. After the test, the humidity value of the mixed gas is between 62% and 70%RH (the average is about 65%RH). In addition, in the same batch of experiment (based on the volume of air bag, filling with fresh air after the 20L is drawn out to reduce the concentration of the methane volume), the humidity value of mixed gas increases slowly.

Changing the humidity of the mixed gas can be achieved by changing the air humidity in the experimental environment. The methods that we can use are as following.

(c) Humidifier can be used to change the humidity of the room. Increasing the humidity of compressed air in the compressor to high humidity air that is greater than 90% RH is to produce methane-air mixture that the humidity value is between 77% and 85%RH (the average is about 80% RH). In this way, the humidity of methane-air mixture can close to saturation and the experiment proves that the humidity value of it is about $(93 \pm 3)\%$ RH.

(d) Using indoor desiccant equipment to reduce the indoor air humidity (or carrying out the experiment in relatively dry weather) is to get the air that the compressed gas humidity value is about 50%RH in the air compressor, which is used for making methane-air mixture that the humidity value is between 40% and 52%RH (the average is about 45%RH).

According to the principle of the effect of air temperature on humidity, adjusting the humidity of gas in the experiment is feasible by changing the experimental environment temperature.

(e) About 80%RH methane-air mixture can be made at a higher ambient temperature by using method (c). Then the methane-air mixture that is under the condition of close to saturation ($\geq 92\%$ RH) can be produced by reducing the heat of environmental environment.

(f) About 20%RH methane-air mixture can be made at a lower ambient temperature by using method (a). Then the methane-air mixture that is under the condition of close to dryness ($\leq 15\%$ RH) can be produced by rising the temperature of environmental environment.

To sum up, the humidity value used for making methane-air mixture in the laboratory is between $\leq 15\%RH$ and $\geq 92\%RH$.

Experimental Data and Analysis

Explosion Limits

In order to explore the methane explosion under extreme circumstances, three groups of experiments that the explosion limits of methane are in different relative humidity are carried out. The different humidity conditions are close to dryness ($\leq 15\%RH$), close to saturation ($\geq 92\%RH$) and environmental temperature in laboratory ($(63 \pm 5)\%RH$). The experimental data is shown in Table 2.

Table 2 Measured Values of Explosion Limits

Serial Number	Relative Humidity/%RH	Lower Explosive Limit/%	Upper Explosive Limit/%
1	≤ 15	4.91	14.86
2	63 ± 5	4.97	14.71
3	≥ 92	5.02	14.55

It is concluded from the table that the range of methane explosion concentration is between 4.91% and 14.86% under the condition of closing to dryness ($\leq 15\%RH$) while it is between 5.02% and 14.55% under the condition of closing to saturation ($\geq 92\%RH$). The corresponding variations of upper and lower explosive limit are increased by 0.11% and decreased by 0.31% respectively. Correspondingly, we can conclude that when the humidity of methane-air mixture changes from dryness to saturation, the concentration range of methane explosion lessens as well as the lower explosive limit over the same period rises by 2.2% and the upper explosive limit over the same period falls by 2.1%. Compared with ignition energy, pressure and other environmental factors^[1] as well as environmental factor of ignition temperature^[2], the amount of gas explosion limit that only accounts for 2% is relatively so small for the whole explosion range that it is almost. Compared with the influence of ignition energy, temperature and pressure on explosion limit, the influence of humidity is smaller.

Maximum Explosion Pressure and Maximum Pressure Rise Rate

Maximum explosion pressure is the maximum value of P-t curve. And maximum pressure rise rate occurring in the transient state of the most rapid combustion reaction is the maximum value of (dP/dt)-t curve. It is an important parameter to measure the rate of chemical reaction and a parameter that is related to flame propagation velocity of gas combustion^[3]. The experiment is carried out in the humidity of 15%RH, 63%RH and 92%RH. The data of maximum explosion pressure and maximum pressure rise rate under different conditions of humidity is shown in Table 3.

Table 3 Numerical Values of Explosion Pressure Characteristic

Serial Number	Concentration %CH ₄	Humidity(15%RH)		Humidity(63%RH)		Humidity(92%RH)	
		P_{\max}	dP/dt_{\max}	P_{\max}	dP/dt_{\max}	P_{\max}	dP/dt_{\max}
1	5.0	0.107	0.21	0.119	0.15	0.128	0.15
2	6.0	0.443	2.54	0.415	1.03	0.371	1.01
3	7.0	0.642	8.95	0.596	7.73	0.574	6.73
4	8.0	0.732	16.37	0.670	11.97	0.663	12.70
5	9.0	0.765	21.12	0.738	16.15	0.724	17.38
6	10.0	0.802	23.28	0.774	19.82	0.739	18.24
7	11.0	0.766	15.87	0.728	15.07	0.686	12.99
8	12.0	0.639	9.82	0.674	8.24	0.618	6.01
9	13.0	0.497	1.97	0.501	1.12	0.481	1.03
10	14.0	0.347	0.67	0.361	0.53	0.367	0.59
11	15.0	0.104	0.13	0.105	0.15	0.105	0.09

Figure 4 shows the rule of maximum explosion pressure and maximum pressure rise rate with the change of methane volume fraction in three environmental humidity groups.

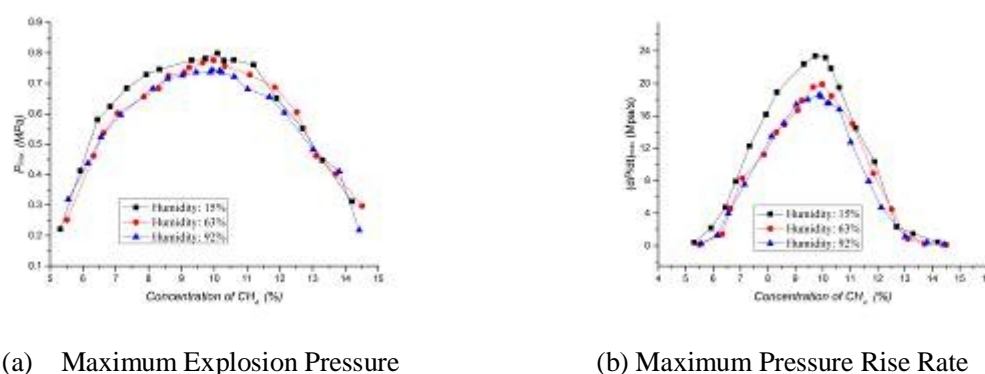


Fig. 4 Methane Explosion Pressure Characteristic Parameters

For a constant volume vessel oil combustion phenomenon, there is a best explosion concentration in reactant components, namely the volume fraction when the fuel is fully reacted with oxygen in theory. Once lacking of fuel or oxidant, there are inhibitory process in chemical reactions. What we can know from the Fig. 4 is that maximum explosion pressure and maximum pressure rise rate are parabolic distribution taking the optimum explosion concentration as the symmetry axis. What's more, the decay process of explosion pressure in the condition of lacking of oxidant is obviously faster than that of lacking fuel. Under the condition of different humidity, maximum explosion pressure and maximum pressure rise rate show equal scaling trends within the limit of explosion. The obvious peak of maximum pressure rise rate can be seen from Fig. 4(b), which is relevant to Fig. 4(a) that maximum explosion pressure maintains a higher stress level ($\geq 90\%P_{\max}$) in a long concentration range (9% ~ 11%).

Fig. 5 shows the curve that the explosion pressure and pressure rise rate of the best explosion concentration change with time. The explosion pressure rises rapidly and then falls slowly after a short delay. The corresponding pressure rise rate also rises and falls rapidly and then it is at a weak level of unloading in long terms. The continuous time of the whole loading process is less than 100ms.

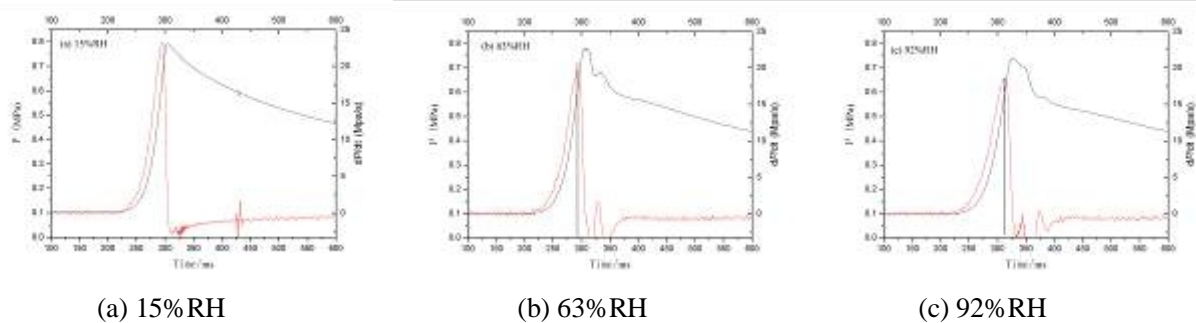


Fig. 5 Gas Explosion Pressure and Pressure Rise Rate Curve of the Best Explosion Concentration

Conclusion

(1)The difficulty of the experiment is producing methane-air mixture of certain humidity. Methane-air mixture that humidity value is between $\leq 15\%RH$ and $\geq 92\%RH$ can be made through a certain operating method in the laboratory.

(2)The humidity of methane-air mixture has influence on explosion limit of mixed gas: with the increase of relative humidity of mixed gas, its lower explosion limit rises, upper explosion limit falls and the concentration range of explosion lessens. Compared with the influence of ignition energy, temperature and pressure on explosion limit, the influence of humidity is smaller.

(3)Under the condition of different humidity, maximum explosion pressure and maximum pressure rise rate show equal scaling trends. The obvious peak of maximum pressure rise rate can be seen. And maximum explosion pressure maintains a higher stress level ($\geq 90\%P_{max}$) in a long concentration range ($9\% \sim 11\%$).

(4)The explosion pressure rises rapidly and then falls slowly after a short delay. The corresponding pressure rise rate also rises and falls rapidly and then it is at a weak level of unloading in long terms. The continuous time of the whole loading process is less than 100ms.

Acknowledgements

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