Test on methane flame velocity in horizontal tube with obstacles

TAN Ying-xin (谭迎新), YU Cun-juan(尉存娟)
(*School of Chemical Engineering and Environment, North university of China, Taiyuan 030051, China*)

Abstract: To test flame propagation velocity of gas explosion in a horizontal tube, a set of flame velocity testing system is designed. The system is composed of two parts: a horizontal tube used for methane burning and a flame detection system. The effect of obstacles on flame propagation velocity of methane explosion is tested. Methane volume density is 10% in the tube. The obstacle is the circular ring, 2 mm thick. Its blockage ratios are 40%, 50% and 60%, respectively. The number of obstacles put in the tube is 1, 3, 5 and 7. Experimental results show that the obstacle has obviously accelerating effect on flame wave of gas explosion. As the number and blockage ratios of the obstacles increase, flame accelerating became more obviously. When there are seven obstacles, the maximum average flame velocity reaches over 351.2 m/s. When the blockage ratio of three obstacles is 60%, the maximum average flame velocity is 238.9 m/s.

Key words: gas explosion; obstacle; flame velocity; horizontal tube; methane

CLD number: O643.2 **Document code**: A
Article ID: 1674-8042(2012)04-0320-03 **doi**: 10.3969/j.issn.1674-8042.2012.04.004

In modern coal industry, the structural damage accidents resulting from methane explosion are mainly caused by pressure wave[1]. Therefore, it is greatly significant to study the moving velocity of methane burning flame. Flame velocity is also an important factor to study the combustion and explosion characteristics of the methane and coal dust in tunnel[2-4]. When methane explodes, its flame will change suddenly[5]. Besides, because the industrial equipments are often connected by tube, the propagation pattern of flame in the tube has become a focus of the explosion study.

In this paper, a flame velocity testing system with horizontal tube that imitates mine tunnel is designed. Methane flame velocity is tested by photoelectric way. In the tube, there are four transparent holes as observation windows to receive flame signals. When the flame passes through the light hole in turn, the photoelectric sensors become photosensitive and transducers output the voltage into data analysis instrument. Then tested data are recorded into waveform memorizer. According to the recorded time between two photoelectric transducers, the flame propagation velocity could be calculated.

1 Test system composition

The testing system is composed of two parts, one of which is a horizontal tube used for methane burning and the other is a flame detection system.

1.1 Horizontal tube

Explosion characteristics of coal dust are often tested in closed vessel[6]. An example of the 20 L laboratory test chamber designed by Siwek R[7] has been in wide use in Europe and elsewhere. In order to simulate coal mine tunnel, main part of the device is designed as a horizontal pipeline in the paper. The testing device is shown in Fig. 1.

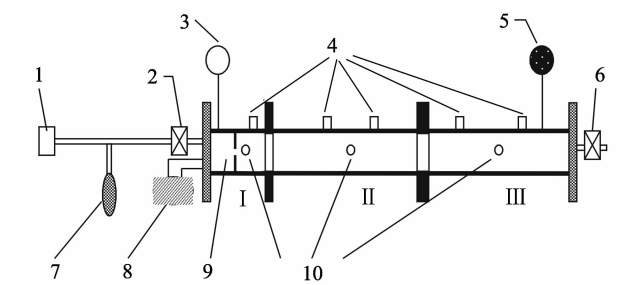
Fig. 1 Test device

The material of horizontal tube is high intensity steel. It has an internal diameter of 139 mm and a length of 9 700 mm. Thickness is 10 mm. Whole tube is fixed on "V" cement slot away 0.5 m from

* **Received data**: 2012-06-18
Foundation item: International Technical Cooperation Projects of Shanxi Province (No. 2012081014)
Corresponding author: TAN Ying-xin (fang9178@sina.com)

the ground. There are 13 holes in the tube. They are a pressure meter, a safety valve, a gas inlet, a gas outlet, a pair of electrodes, three observation windows and five fixed sensors. A pair of 2-mm spark gaps with stainless steel electrodes are placed in the 700-mm horizontal pipeline. To observe the experimental process, three 40 mm diameter observation windows are fixed to the wall of the horizontal pipeline.

The schematic drawing of the horizontal pipeline is shown in Fig. 2.



1:Vacuum pump; 2: Valve; 3: Pressure meter; 4:Sensors; 5: Safety valve; 6:Valve; 7:Methane; 8: Air expenses machine; 9: Electrode; 10: Windows

Fig. 2 Schematic drawing of the horizontal pipeline

1.2 Flame detection system

The flame detection system is composed of the phototransistor sensor and the single chip computer time-measurement circuit. The former is a kind of flame probes, and it can accurately collect flame signals generated by premixed methane-air explosion from a great amount of theoretical analyses and researches. The latter is the flame testing circuit.

When the flame burns in the pipeline, the photoelectric sensor inducts the signals of the specific ray from the flame front. The phototransistors is installed in the metal shell with 2-mm thickness and is put on observation windows. The collector and emitter of the photoelectric sensor are connected with the signal wire and the ground wire of the metal shield wire, respectively.

1.3 Single chip time-measurement circuit

The single chip computer time-measurement circuit can receive the two phototransistors' signals from gas burning flame. When the first phototransistor receives the flame signal, it conducts rapidly and produces an electrical signal to single chip time-measurement circuits. Then it becomes a standard signal after shaped by Schmitt trigger. The output terminal is connected with $P_{3.2}$ inside the microcontroller and is used as a start trigger signal to record the time. When the second phototransistor receives the flame irradiation, it also inputs a control signal to the single chip time-measurement circuit and is connected with the $P_{3.3}$ inside the microcontroller. This signal stops the time from being recorded. So the time when gas burns in the tube is got. The average velocity can be worked out by making this time value divided by the measured distance.

Fig. 3 shows the phototransistors designed by ourselves[8]. Fig. 4 shows the observation windows of the horizontal tube.

Fig. 3 Phototransistor

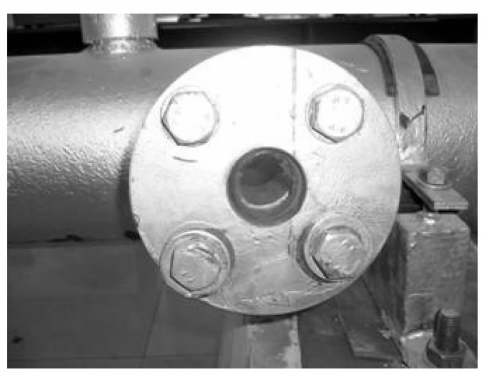


Fig. 4 Observation windows

1.4 Experimental conditions

In this experiment, the gas sample is methane, Its volume density is 10% in tube. Obstacle is the circular ring, 2 mm thick. Its blockage ratios are 40%, 50% and 60%, respectively. The number of the obstacles put in tube is 1,3,5 and 7.

The obstacles are installed at 180 mm away from the igniter electrode. The distance between two flame detectors is 2.2 m. All the experiments are done at normal temperature and pressure.

2 Experimental results

The main work of this experiment is to contrastively study the obstacles' effects on the flame propagation velocity of gas explosion. Test results are shown in Table 1 and Table 2. The average flame propagation velocity is the average of the five experimental tests.

Table 1 Effects of obstacles' blocking ratios

Obstacle number	Blocking rate/%	Velocity/(m·s^{-1})
0	0	29.2
3	40	179.2
3	50	184.6
3	60	238.9

Table 2 Effects of the number of obstacles

Obstacle number	Blocking rate/%	Velocity/(m·s^{-1})
0	0	29.2
1	60	179.9
3	60	238.9
5	60	335.8
7	60	351.2

From Table 1 and Table 2, it can be seen that the maximum average flame propagation velocity of gas explosion is 29.2 m/s without obstacles in the tube. With the increase of the blockage ratio from 40% to 60%, the average flame propagation velocity also increases, the maximum average flame propagation velocity is 238.9 m/s.

For a circular ring obstacle with 60% blockage ratio, the maximum average flame propagation velocity of gas explosion is 351.2 m/s. When obstacles' number increases from 1 to 7, the flame propagation persistence is enhanced.

The existence of obstacles aggravates the turbulent flow. It can enlarge the propagation velocity of gas explosion.

3 Conclusions

This paper presents a flame velocity testing system. After an amount of experiments and analyses, conclusions are given as follows:

1) By this velocity testing equipment, the flame propagation velocity of gas explosion with obstacle can be tested.

2) The obstacle has an obviously accelerating effect on gas explosion flame velocity. Only one obstacle can make the flame velocity in the tube increase about six times in comparison with zero obstacle.

3) The obstacle number has a distinguishing effect on the flame propagation velocity of gas explosion. With obstacle number increasing, the turbulence in tube enhances and flame propagation velocity also increases. When there are seven obstacles, the maximum average flame velocity reaches over 300 m/s.

4) The blockage ratio has a distinguishing effect on flame propagation velocity of gas explosion. When the blockage ratio of three obstacles is 60%, the maximum average flame velocity is 239 m/s.

References

[1] YU Bu-fan. Technology handbook of prevention and use methane disaster in mine. Beijing: Coal Industry Publish, 2005.

[2] LUO Zhen-min, DENG jun, WEN Hu, et al. Experimental study on flame propagation characteristics of gas explosion in small-scale duct. China Safety Science Journal, 2007, 17(5): 106-109.

[3] LIN Bai-quan, CHANG Jian-hua, ZHAI Cheng. Analysis on coal mine safety situation in china and its countermeasures. China Safety Science Journal, 2006, 16(5): 42-46.

[4] TAN Ying-xin, BO Tao. Explosion pressure testing of coal dust inducted by shock wave, China Safety Science Journal, 2009, 19(5): 80-83.

[5] LUO Zhen-min, DENG jun, WEN Hu, et al. Experimental study on flame propagation characteristics of gas explosion in small-scale duct. China Safety Science Journal, 2007, 17(5): 106-109.

[6] Dunn-Rankin D, Mccann M A. Overpressures from Non-detonating, Baffle-Accelerated Turbulent Flames in Tubes. Combustion and Flame, 2000, 120(4): 504-514.

[7] LIN Bai-quan, CHANG Jian-hua, ZHAI Cheng. Analysis on coal mine safety situation in china and iits countermeasures. China Safety Science Journal, 2006, 16(5): 42-46.

[8] MA Li. Research on the testing system of flame speed of gas pipeline explosion. Taiyuan: North University of China, 2009: 15.