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Research Paper

Flame thickness and propagation characteristics of premixed methane-air explosion with a small filling ratio in an open-ended steel pipe

Chen Lv [a,*], Zongzhi Wu [a,b]

[a] Faculty of Resources & Safety Engineering, China University of Mining & Technology (Beijing), Beijing 100083, China
[b] China Academy of Safety Science and Technology, Beijing, China

HIGHLIGHTS

- Flame thickness of methane explosion with a 20% filling ratio was revealed.
- Increasing the distance from ignition source decreased the flame thickness.
- Flame speed presented a trend of increasing and decreasing with distance.
- Maximum overpressure followed a trend of decreasing, increasing and decreasing.

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ABSTRACT

Through establishing a non-adiabatic open-ended steel pipe with a length of 20 m and a cross-sectional area of 0.08 m × 0.08 m, the changing rules of flame propagation and flame thickness of premixed methane/air explosion with a 10% fuel concentration and a 20% filling ratio were revealed. The experimental results show that the flame arrival time increased gradually with the increase of the distance from the ignition source, the maximum flame signal value initially increased along the pipe but then dropped. The flame thickness at a certain point could be measured by the time differences between vanishing moment and initial rising moment of flame signal at this point. With the increase of the distance from the ignition source, the flame thickness gradually decreased, the flame propagation speed presented a changing trend of increasing and decreasing, while the maximum overpressure followed a trend of decreasing, increasing and decreasing. The research results provide the scientific experimental basis for the reasonable setting mine explosion-resistant device, it is of great significance to effectively restrain the spread of explosion flame surface and avoid accident enlarging of gas explosion in coal mine.

1. Introduction

Now, in the case of gas explosion, the most explosion-resistant device achieve the aim of preventing continuing gas explosions by releasing suppressant into flame propagation region to restrain the spread of explosion flame surface. The release time and duration time of suppressant is critical to the effective suppression of the spread of explosion flame surface, it not only depends on the time of flame surface reaching the explosion-resistant device, but also relates to the duration time of flame surface, the flame thickness can be measured generally by the flame duration time, therefore, the experimental study of flame thickness has important practical significance for the prevention and control of methane explosion.

It is generally known that, the research of methane explosion propagation is the theoretical basis to prevent explosion disaster, and many scholars have done a great deal of theoretical and experimental studies. Lee et al. [1] firstly relative comprehensive summarized the process of flame acceleration and being transformed into detonation. Ciccarelli et al. [2] summarized systematically the research results of DDT (Deflagration-to-Detonation Transition) process. Dorofeev [3] summarized briefly the mechanism of flame acceleration and the latest achievement of applying it to explosion safety. Lin et al. [4,5] proposed the chief role of obstacles which induced the production of the turbulent flow, and the positive feedback mechanism of explosion propagation was triggered, which could ultimately lead to explosion strength enhancement. Frolov et al. [6,7] found the U-shape pipe could advance greatly the process of SDT (Shock-to-Detonation Transition) by the research of propagation characteristics of explosion and detonation in the U-shape pipe. Sha [8] carried out the explosive experiment

* Corresponding author.
E-mail address: 827400414@qq.com (C. Lv).

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in pipe, its diameter was 125 mm and 300 mm, the decay factor of air shock wave in bend and bifurcation pipe was obtained.

The previous published work focused on the fields of deflagration-to-detonation transition and attenuation characteristics in the bend and bifurcation pipe, but there have been few reports on the research of flame propagation and flame thickness of premixed methane and air explosion with a small filling ratio. In this work, the author uses the non-adiabatic steel pipe to establish the premixed gas explosion test equipment of small amounts of methane and air, the flame propagation and the change rules of flame thickness in the pipeline are studied after the methane explosion, in order to guide the prevention and control of methane explosion.

2. Experimental apparatus and procedure

The schematic diagram of experimental apparatus is shown in Fig. 1. This apparatus mainly consisted of an explosion pipe, a gas distribution device, a vacuum pump, a high-energy ignitor, a dynamic data acquisition system, etc. The explosion pipe was a square steel tube with a cross-sectional area of 0.08 m $\times$ 0.08 m and a length of 20 m, and it could withstand a pressure of 20 MPa. The pipe was closed at one end and open at the other end. In the closed end, the high-energy ignitor was installed, and its ignition energy was 20 J. The gas distribution device included the gas bags, the methane gas source, the reducing valves, the methane detectors, etc, which could obtain the premixed methane and air of different fuel concentrations. At the distance of 4 m away from the closed end, there was a valve which was used for isolating flammable gas and air, indicating that the filling rate was 20%. The fuel concentration was 10% in these experiments. The dynamic data acquisition system included the pressure sensors (see Fig. 2), the flame sensors (see Fig. 2), the data acquisition instrument and computer, etc. The position of each flame sensor from the ignition source was shown in Table 1, and the position of each pressure sensor from the ignition source was presented in Table 2.

3. Results and discussion

In order to study the flame propagation characteristics of gas explosion in the steel pipe which is filled with partial fuel, the flame signal curves obtained by the flame sensors are shown in Fig. 3.

According to the flame signals, we can clearly see that flame propagates with the distance from the ignition source, indicating that there is a clear flame propagation phenomenon. The initial rising moment of flame signal increases with the distance increases. Compared with the flame signals at 3.2 m and 3.9 m away from the ignition source, it can be seen that the moment of strongest flame signal at 3.2 m is later corresponds to the time at 3.9 m, so the moment of the strongest flame signal is not strictly increasing with the increase of distance from the ignition source.

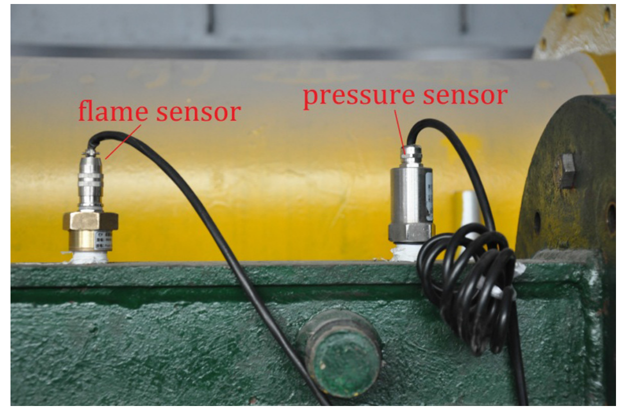

Fig. 2. Flame and pressure sensors.

The flame arrival time at each point can be obtained by the flame signal curves, which are collected by the flame sensors. There are two ways, namely, the initial rising moment of flame signal and the moment of the strongest flame signal. As we know, the structure of one-dimensional flame front is made up of preheating zone and reaction zone, the change of temperature and concentration is mainly due to the effect of heat-conduct and diffusion in preheating zone, the fresh premixed methane-air is heated in this zone, but the chemical reaction occurs at a high temperature slightly below the combustion temperature. The reaction speed, temperature and concentration of activation center reach their maximum values in the reaction zone. The moment of strongest flame signal corresponds to a certain moment in reaction zone of the flame front, which is not suitable as the flame arrival time. The initial rising moment of flame signal is close to the initial moment of flame front in the preheating zone, so it can be selected as the flame arrival time.

The flame arrive time and the time of the strongest flame signal is shown in Figs. 4 and 5, respectively. As the distance from the ignition source increases, the flame arrival time increases gradually. The time of the strongest flame signal presents an increasing trend on the whole.

According to the Fig.5, we can notice that the maximum flame signal at zero distance arrives significantly later than the location of 1.1 m, on the one hand, it fully verifies the correctness of the judgment that the moment of the strongest flame signal cannot be used as the flame arrive time; on the other hand, after preliminary analysis, the author thinks the reason for this phenomenon is that the flame front spreads from 0 distance to 1.1 m in the process of transmission, the negative pressure suction of the closed end results in back propagation of partial flame, making the

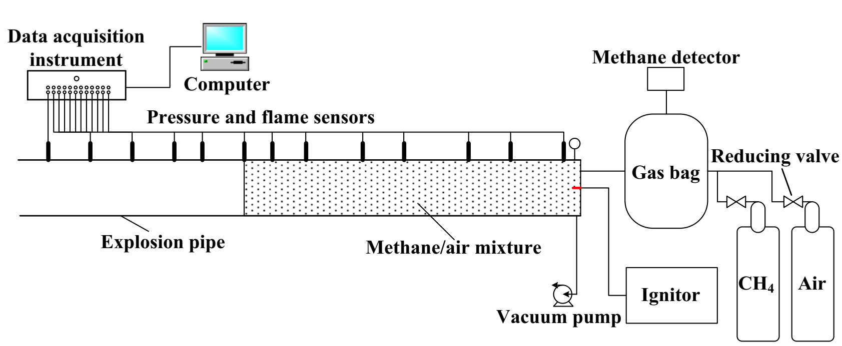

Fig. 1. Schematic diagram of experimental apparatus.