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Influence of bend structure on high-temperature flow after gas explosion

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ABSTRACT

In order to study on the influence of bend structures on high-temperature flow of gas explosion in laneways/tubes, a set of experimental facility for gas explosion in tubes with bend structures of different angles and a transient temperature and pressure test system were set up, with the help of which, the variation process of unsteady temperature field when high-temperature flow of methane–air explosion going through the bend structure was studied. The study results show that the bend structure has little influence on high-temperature flow before the bend and has relatively great influence on that after the bend. The bigger the bend angle is, the greater the thermal loss at the bend will be and then the greater the temperature attenuation of the high-temperature flow going through the bend structure will be. In addition, the attenuation of peak temperature after the bend compared with that of corresponding location in the straight tube presents a linear distribution with the bend angle. The above conclusions provide reference basis for compound hazard effect assessment of gas explosion in a complex structure as well as corresponding accident investigation and analysis.

1. Introduction

Coal laneways, underground warehouses, tubes and other complex buildings are all composed of various simple basic structural units such as straight laneways, variable cross-section structures and bend and bifurcation structures, which provide convenience for resource exploitation, transportation and storage. Nevertheless, these basic structural units probably aggravate the complexity and diversity of combustible gas explosion accidents in underground confined building structures such as gas explosion in coal laneways and explosion caused by hydrogen leakage in underground warehouse. Therefore, it is necessary to study on the role these units play in gas explosion, thus to provide basis for hazard assessment of gas explosion in a complex structure and accident investigation.

There are various hazardous factors generated by gas explosion in a confined space and the hazard effect is complex. Shock wave is one of the most critical and the most direct dangerous and hazardous factors of gas explosion in a confined space, while the accompanying high-temperature hazard can not be ignored as well, for the high-temperature flame front generated by gas explosion is extremely apt to cause damages to the respiratory system and skin. Another high-temperature hazard of gas explosion derives from the high-temperature flow generated after the gas explosion. This flow carries plenty of heat as well as poisonous and harmful gaseous products and moves slowly towards the exit of the building structure, which brings about certain piston effect under the influence of negative pressure of the shock wave. For this reason, this kind of high-temperature flow presents longer action time and more severe hazardous effect. Currently, a lot of studies related to gas explosion in a confined space have been carried out, mainly focusing on explosion process [1–6], flame propagation [7–13], and propagation characteristics of explosion wave and air shock wave [14–17], etc. Besides, with the development of computation technology, numerical simulation based on advanced computational method has been used for the gas explosion in confined spaces. For example, novel positivity-preserving high order discontinuous Galerkin method [18] and high order numerical boundary treatment [19] were proposed to investigate gas explosion, and the results demonstrated the designed high order accuracy, stability, and good performance for problems involving detonation diffraction and complicated interactions between detonation/shock waves and solid boundaries. These studies, though obtained certain research achievements, have obvious deficiencies. On the one hand, experiments or numerical models of existing studies are mostly based on straight laneways/tubes, without considering complexity of actual building structures; on the other hand, though they have investigated the high-temperature hazard characteristics of flame front generated after gas explosion, the hazard

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effect of high-temperature flow generated by gas explosion was ignored to a large extent.

Bend structure is one of the most basic structural units in a complex structure, so it is of great significance to study on the influence law of bend structures on hazard effect of gas explosion. In recent years, there have been a small number of researchers starting to pay attention to the influence of bend structures and other complex structures on hazards of gas explosion, but mostly concentrating on distribution of explosion wave, flame and air shock wave at the complex structure. For instance, Zhai et al. [20] have studied the qualitative influence law of bend structures on flame of gas explosion and propagation of explosion wave through model experiments and numerical simulations, pointing out that bend structures can boost turbulent flow and flame propagation. Wang and Li [21] have performed experiments and obtained the attenuation ratio of air shock wave during propagation in laneways with a right-angled bend, and also have acquired the waveform and flow-field charts of propagation of air shock wave before and after the bend of 90° by virtue of numerical simulations.

The shock wave is repeatedly reflected on the wall, generating a turbulence area when running through the bend structure. The attenuation ratio of shock wave after it goes through the bend laneway can be described with impulse attenuation in percentage, and the impulse attenuation of shock wave will rise with increase of the bend angle [22]. After the shock wave goes through the bend structure at a relatively high speed for a while, high-temperature flow with plenty of heat and poisonous gaseous products will gush towards the exit of the laneway at a relatively low speed. Low flow velocity may weaken the reflection of air flow on the wall but meanwhile lengthen the action time of high-temperature air flow to human body. So far, there has been no report on the propagation law of high-temperature air flow of gas explosion going through the bend structure, and the influence of the bend structure on the high-temperature flow of gas explosion is still unknown. Therefore, this paper established an experimental system for gas explosion in tubes with bend structures and studied the influence law of bend structures with different angles on high-temperature flow after gas explosion, thus to provided basis for exploration of compound hazard effect of gas explosion in a complex structure as well as accident investigation and analysis.

2. Experimental system

2.1. Tubes

This tube system consisted of multiple segmental structures and corresponding supporting components, including of straight connection sections, 45° bend connection section, 90° bend connection section, 135° bend connection section, ignition connection sections, flanges, seal discs, washers, sensor hole plugs, and discharge electrodes, etc. Tubes was all 45# seamless steel tubes subject to cutting and welding with inner diameter of 199 mm, outer diameter of 219 mm, wall thickness of 10 mm and the maximum design pressure of 3 MPa. Tubes can be connected by flanges to form various tube networks of complex structures. Each connection section was provided with sensor holes and vent holes. The ignition connection section was provided with an air valve to which the vacuum pump and the exhaust system can be connected.

2.2. Temperature and pressure test system

The designed gas explosion test system was composed of hardware and software. The hardware included thermocouple temperature sensors, piezoelectric pressure transducer, easy signal conditioning, data acquisition card, PXI mainframe-box and controller, and so on. Thermocouple temperature sensors were the temperature sensing elements, and the test system was set up on the basis of virtual instrument technology. After the temperature signal was modified by the easy signal conditioning and was input into the data acquisition card, it was transformed into digital signal through A/D conversion.

Fast thermocouple WRe5–WRe26 (type C) made by Nanmac Corporation is very good, having a response time less than 10 μs, but it is expensive. In general, a thermocouple can be used only once in test under the conditions of high pressure and high temperature generated from gas explosion. In view of the experimental cost and specific experimental environment, fast naked thermocouples of type K were self-manufactured in this work, and were calibrated by means of the WRe5–WRe26 (type C) taking as the standard thermocouple. The pressure variation was recorded with a piezoelectric pressure transducer (Kistler 211M), connected to a Charge Amplifier. The signals of the easy signal condition and the Charge Amplifier were recorded with the data acquisition system, by means of an acquisition card type NI PXI-5922, at 5×10^5 signals/s.

3. Experimental scheme

Four sets of experimental facilities were set up respectively with connection sections of straight tubes, ignition connection sections and bend connection sections as well as other auxiliary components, namely, 0° straight tube, 45° bend tube, 90° bend tube and 135° bend tube. For example, experimental facility diagrams of straight tube and 45° bend tube are shown in Fig. 1. Equivalent axial length of all of the four sets of experimental facilities was 5.5 m with the maximum length–diameter ratio of 27.5 and all their ignition connection sections are filled with flammable gas. In this paper, pure methane gas with concentration of 99.9999% was selected to be experimental material. A polyethylene film was clamped by the ignition section and the adjacent straight tube first when methane gas was filled, thus to prevent the filled methane gas from leaking to tubes at the back end. The melting point of the polyethylene film is much less than the temperature of the gas explosion flame face. When the flame face arrives at the film, the film breaks immediately and has no influence on the latter flame and shock wave propagations. The ignition section was placed aside for a period of time after filling to let methane mix fully with air. Detect the methane concentration with a methane gas concentration detector. The ideal methane concentration for this experiment was 9.5%, i.e. the chemical equivalent concentration of methane explosion. For the three bend tubes with different angles, a thermocouple was arranged respectively before and after the bend, shown as black dots in Fig. 1. Distance from both thermocouples to the tube bend was 5 times of the cross section diameter of the tube. In order to compare with the bend tube experiment results, two thermocouples were arranged at corresponding

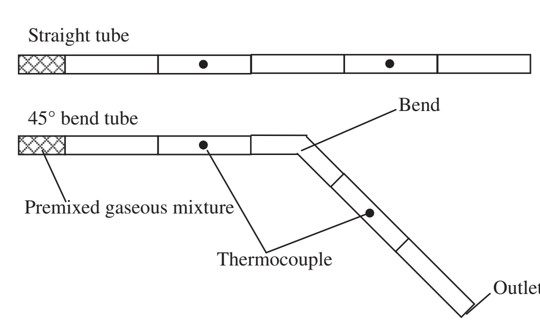

Fig. 1. Experimental facility diagrams of 0° straight tube and 45° bend tube.