Experimental study on flame propagation characteristics of premixed gas in gas pipeline

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Abstract. The serious accident is usually accompanied by combustion and explosion of premixed combustible gases in petrochemical industry. The local combustion flame that occurs in the gas pipe will accelerate the propagation and may become to a detonation. The flame propagation characteristics of premixed methane/air were investigated by experiment. Three different sizes of gas pipeline and five different concentrations of methane were considered. The flame shape, the speed of the flame propagation and the reaction pressure were tested and discussed. And then the influences of gas pipeline sizes on the premixed combustion development were analyzed. The conclusions are expected to provide the basis data for the design of combustible gas transport in the petrochemical industry.

1. Introduction

The combustible gas was widely used in the petrochemical industry, and major security incident are usually accompanied by combustion and explosion of combustible gases. Gas pipeline is the main equipment in petrochemical production and gas transportation. The local combustion flame that occurs in the gas pipe will accelerate the propagation and may become to a detonation, and then causing a serious accident, due to the closure of the long enough gas pipeline. The combustion and explosion of the combustible gas is an extremely complex physical and chemical process, which includes complex mechanisms of multidisciplinary intersection, such as thermodynamic, chemical kinetics, hydromechanics, heat and mass transfer and turbulent media. It is very difficult to accurately descript the reaction process. Only the simulated experiment with a similar condition is the essential method to study the combustion and explosion characteristics of combustible gas.

The kinetic theory of laminar flame gas, the emergent property of the flame front and the constant flame theory of square pipes were discussed in the early 1950s[1-2].The propagations of gas explosion wave in the open system were also focused as follow[3-4].Since the new century, the studies of the flame propagation characteristic of premixed gas in the closed system were also get some new progresses[5-6].But the investigation about the influence of constraint system size on the combustion development of premixed combustible gas is not enough. It has very important practical significance, and is the key of whether the premixed combustion can become an explosion accident. And also has a guiding significance to the gas pipeline design in petrochemical industry.

Natural gas is the most typical combustible gas in petrochemical industry, and methane is the mainly component of it. In this paper, the influence of pipe size on methane/air premixed combustion was concerned, based on the theory of flame dynamics and pressure change. The tulip flame and the pressure fluctuation were also tested.

2. Premixed combustion of methane/air

The suitable gas concentration, enough oxygen and ignition source with energy are the condition of gas combustion. The process of combustion and explosion are due to the chemical reaction flow. The explosion occurs when the reaction flow and pressure increase constitute an effective feedback loop, as shown in figure 1.

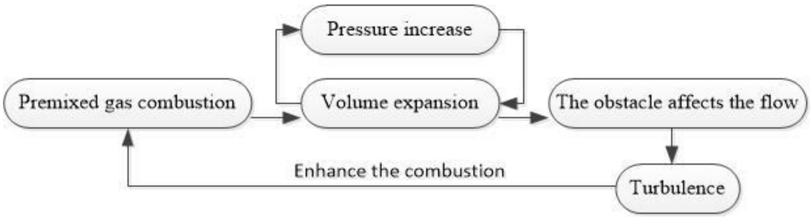

Fig. 1 An effective feedback loop of gas explosion

The following combustion chemical reaction occurs, when methane is ignited.

$$CH_4+2O_2 \rightarrow CO_2+2H_2O \quad (1)$$

or $CH_4+2(O_2+3.76N_2) \rightarrow CO_2+2H_2O+7.53N_2$ (2)

The chemical measured concentration of methane is about 9.48%. In this paper, five different methane concentrations were chosen around the measured concentration, they are 8.5%, 9%, 9.5%, 10% and 10.5%.

3. Experimental system

The experimental setup is shown as in Fig. 2, which consists of a automatically gas supply system, a high explosive pressure test system, a high-speed photography system, a high-voltage ignition system and a pressure relief channel. The simulated pipes used in the experiment were made by polymathic methacrylate tubes. The inner diameters of the tubes were 78mm, 108mm and 148mm, respectively, with a uniform length of 1.2m. A relief channel is set on the side of the pipeline to ensure the safety. The ignitions were charged by high voltage spark discharge. The reaction pressure and the flame propagation were recorded by the pressure sensors and high-speed camera.

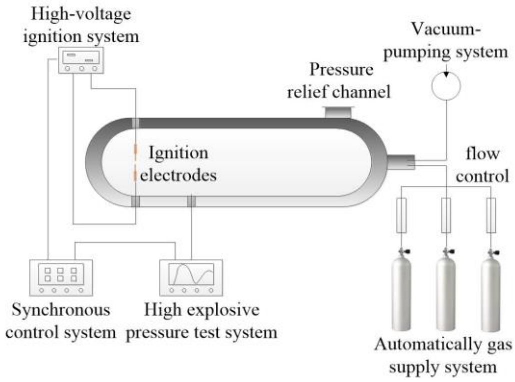

Fig. 2 Schematic of the experimental setup

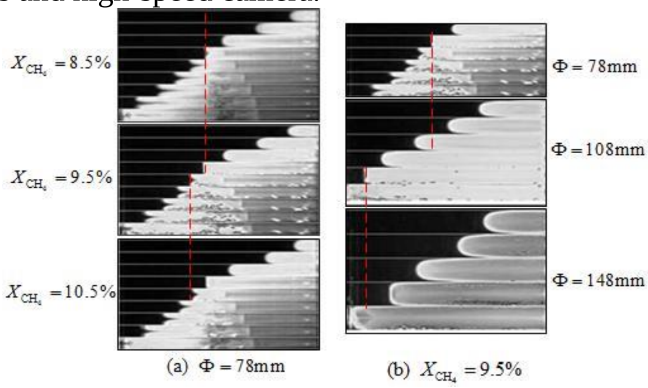

Fig. 3 The images of the flame propagation

4. Results and discussion

4.1 Flame shape

The flame propagation was recorded by the high-speed camera, the typical records as shown in Fig.3. According to the records, the propagation of flame goes through three typical kinetic processes: the fingertip flame caused by the flame-acceleration, the flat flame which is accompanied by deceleration of flame and the tulip flame with the flame front turning to the combusted area.

Fig. 3 gives the experiment records about the flame propagation process in different pipeline and with different methane concentration. In the 78mm pipe, the tulip flame appears in all the different methane concentrations, and earliest under the situation of $X_{CH_4}=8.5\%$. Fig. 3(b) gives the situation of $X_{CH_4}=9.5\%$ premixed gas burned in different inner diameter pipes. In 78mm pipe, the tulip flame shape is clearly visible. In 108mm pipe, the irregular surface of the flame front is observed at the end of the pipe, which indicates that the flame is transformed from flat to tulip. But in 148mm pipe, there is no tulip flame until the end of the pipe. That means the formation of tulip flame in a closed system depends on the size of cross-section, more specifically, the length and diameter ratio.

4.2 The speed of flame propagation

The speed of flame propagation is defined by the velocity of the combustion reaction wave front propelling forward. The effects of different methane concentrations and different pipe sizes on the speed of flame propagation were discussed. The results are shown in Fig. 4. The propagation speed of the flame in the pipe increased with the flame front propelling, and then decreased after the peak. It is consistent with the evolution of the flame shape recorded by the high-speed camera. The pipe size has a significant effect on the peak speed of flame propagation. The peak value of the speed appears in the 108mm pipe for the range of consider methane concentration. But, by contrast, the flame propagation was advanced effectively in the smaller size pipe (78mm) to achieve the peak speed earlier.

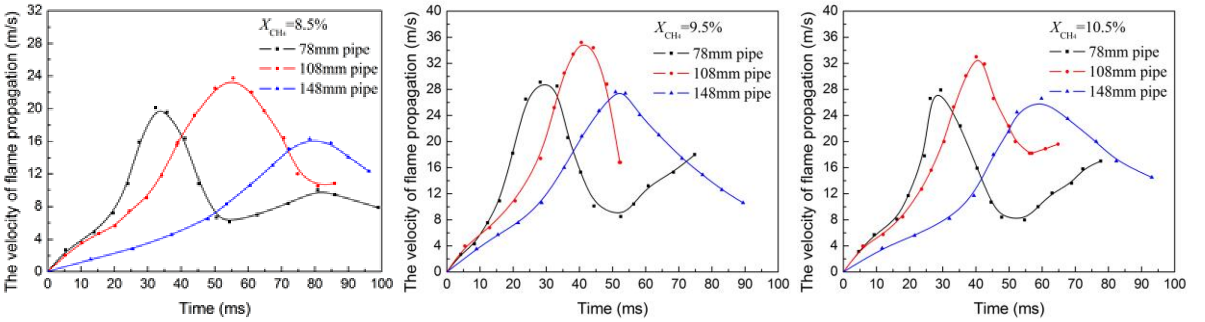

Fig. 4. The flame propagation speed curves of pipelines with different inner diameters: (a) $X_{CH_4} = 8.5\%$; (b) $X_{CH_4} = 9.5\%$;(c) $X_{CH_4} = 10.5\%$

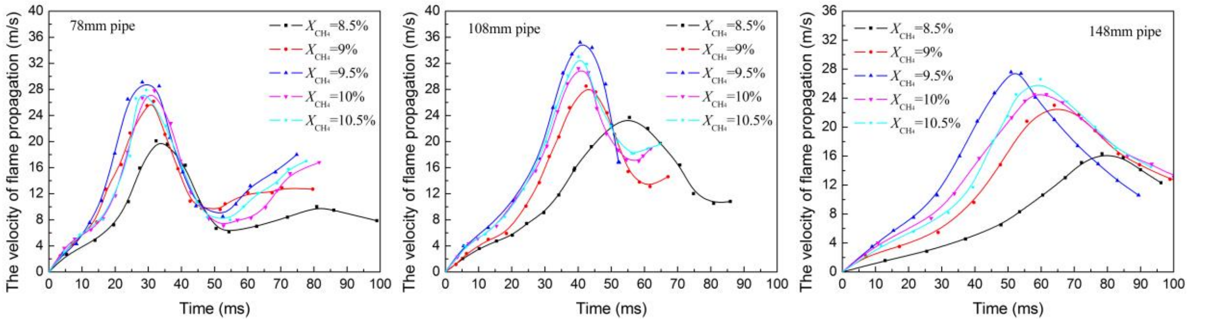

Fig. 5. The flame propagation speed curves of different methane concentrations: (a) for 78mm pipe; (b) for 108mm pipe ;(c) for 148mm pipe

The flame propagation speed curves under different methane concentration in 78mm, 108mm and 148mm pipe are shown in Fig. 5, respectively. The flame propagation in the pipeline is related to the combustible gas concentration. In the same pipe, the flame propagation speed increases with the increasing of methane concentration, but the largest speed appears around the chemical measured concentration ($X_{CH_4} = 9.5\%$), which is consistent with the theoretical calculation. For 78mm pipe, the flame propagation speed had a second increase, which caused by the tulip flame. The surface of the flame increased due to the flame front reversed to combusted zone, as clearly shown in Fig. 5(a).

4.3 The reaction pressure

The typical pressure curve was shown in Fig. 6, which was recorded by the pressure sensor. There are three obvious peak pressures: relief pressure, reaction peak pressure and tulip pressure. The relief pressure indicated that the pressure relief channel had been broken. So, the pressure down followed the relief pressure peak. The second peak pressure is the real reaction peak pressure. And then, the third peak pressure caused by the reaction acceleration of the tulip flame, which called as tulip pressure. Table 1 gives the relief pressure and the peak pressure. In 108mm pipe, the reaction had the maximum pressure peak; the combustion reaction was most intense.

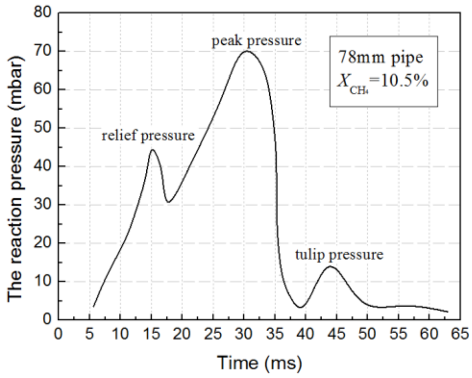

Fig. 6 Typical reaction pressure curve

Table 1 The relief and peak pressure for different X_{CH_4} and pipe sizes

Relief / peak pressure	X_{CH_4}				
	8.5%	9%	9.5%	10%	10.5%
78mm pipe	37.1 / 40.1	39.7 / 53.2	46.1 / 70.4	40.2 / 65.9	45.1 / 69.9
108mm pipe	35.5 / 51.2	36.3 / 66.3	42.4 / 80.5	38.4 / 72.3	40.1 / 79.7
148mm pipe	21.1 / 29.9	23.3 / 39.9	26.8 / 55.1	23.8 / 49.6	24.9 / 52.3

5. Summary

The size of the gas pipeline and the methane concentration has very important influence on the propagation of premixed combustion flame. The fingertip flame, the flat flame in 108mm and 148mm pipelines were appeared for five different methane concentrations. But the well-defined tulip flame was only occurred in 78mm pipeline. The maximum speed of flame propagation and the reaction peak pressure were all happened in the 108mm pipeline. The result shows that the smaller pipe is more conducive to the accelerate deformation of the combustion flame front. But the growth of combustion reaction speed and pressure were promoted by a moderate size of the gas pipeline.

Acknowledgements

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