Experimental Studies of Explosion Venting in a Cylindrical Vessel

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Abstract: Experiment investigations were carried out for the explosion venting in a 0.025m^3 vertical cylindrical vessel. Mixtures of 4.1% propane air were used with central bottom spark ignition. When venting occurs at different failure pressure through different vent areas, pressure histories and flame propagating photos were obtained. Possible mechanisms responsible for vented explosion are discussed.

Key words: explosion; explosion venting; flame propagation; turbulence;

1 Introduction

As well known, venting technique is a popular and effective method to reduce the possible explosion damages of flammable gases, liquids or powders [1].

Venting process is a very complicated unsteady turbulent reacting flow problem. Explosive material properties, vessel shape and size, ignition position, venting position, area and strength etc. are all factors entering into the problem. The design of venting parameters requires an understanding of the venting process for a given vessel under considered boundary conditions. The key is to be able to elucidate the interaction between venting induced flow (and turbulence) and the on going chemical reaction.

The current state of investigation on venting problems, either of spherical or cubic vessels observed quite detailed processes of flame front evolution[2] and pressure variations[3]. Some analysis and vent design calculation methods were also proposed[4, 5, 6].

Venting studies of cylindrical vessels with large aspect ratios (L/D) are very useful because such vessels are of great industrial application importance. The combustion characteristics for closed cylindrical vessels with large aspect ratios (L/D>4) have some features different from those specific for vessels with small aspect ratio. Three-stage flame development [7, 8, 9] and tulip flame front evolution [9, 10] are among these features.

The objective of the present study is to obtain basic information on flame development and pressure variation throughout venting processes for a cylindrical vessel with large aspect ratio (L/D=5.6) under various initial and boundary conditions.

2 Experiment

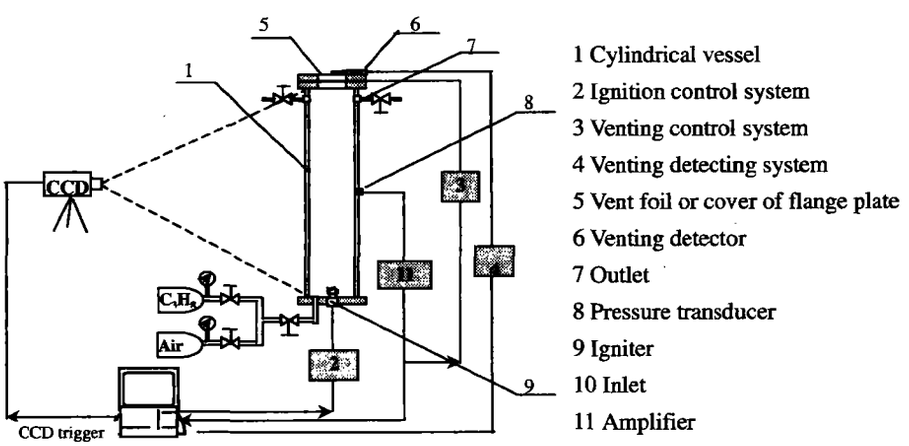

Fig.1 Schematic diagram of the experimental arrangement

Experimental facilities include gas mixer, cylindrical venting vessel, igniter and controller, pressure transducer, high-speed CCD camera and data transmission /storage system, signal amplifier and process timer, venting; probe and so on. The system is sketchily shown in Fig.1.

Both constant volume and venting combustion experiments were conducted in a transparent cylindrical vessels of 1m long and 0.18m in diameter made of perplex glass. The igniter was set at the center bottom end of

the tube, and the circular vent was located at the top end of the tube opposite to the ignition bottom end. The ignition and venting were executed precisely at the specified moment by means of specially designed electronic circuit. High-speed CCD camera was used to record the events at 250~500 frames per second and the data were transmitted to the storage. The mixtures of 4.1% propane-air and 9.5% methane-air were employed in the experiments.

In the present study, the examined parameters were mainly vent area and vent pressure. Three different vent diameters of 50, 80, 100mm were used in the experiments. The ratios of vent area to the cross-section area of the vessel (δ) were 7.7%, 19.7%, 30.8% respectively. The examined venting pressures were in the range of 0~0.18MPa, which is in agreement with safety engineering interests.

3 Experimental Results

3.1 Basic Measurements of Constant Volume Combustion Experiments

Fig.2 shows the photo sequence of flame propagation in 4.1% propane- air mixture, which indicates the "three-stage" behavior of flame front evolution in closed cylindrical vessel [7, 8, 9]. During the first stage of its propagation from t=0 to t_{A1}=56ms, the flame front evolves from a semispherical surface into an elongated semi ellipsoidal one (Fig. 2, from a to e). At the beginning of the second stage, the flame front touches the vessel wall, it suddenly decreases its surface, and heat from the combustion gases is transferred to the wall (Fig.2, from e to g).

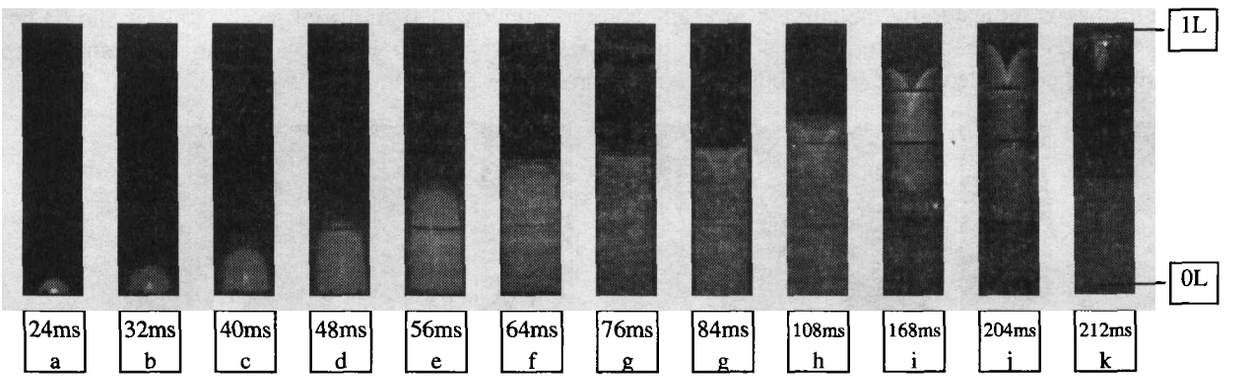

Fig.2 The flame propagation in constant volume explosion

From the beginning of the third stage (t_{A2}=76ms) the flame front is deformed drastically into a typical tulip shape and kept so through to the end of combustion.

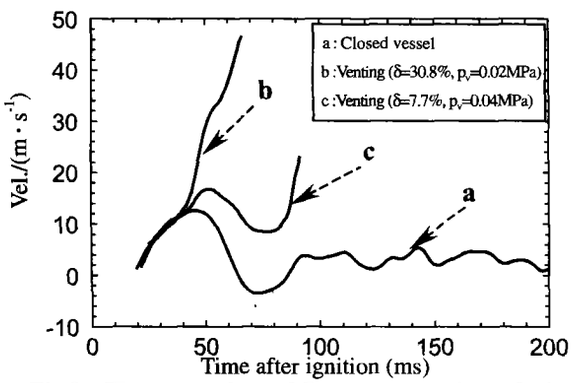

Fig.3 The comparison of flame propagation velocity

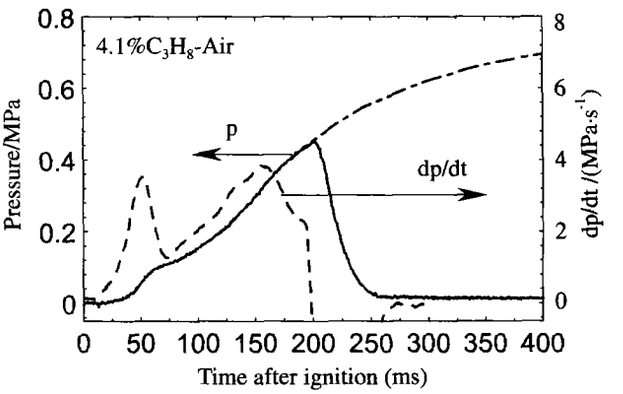

Fig.4 Pressure history and pressure rise rate in constant volume explosion

Typical examples of flame front propagation velocity and pressure evolution as a function of time, taken from constant volume experiments with 4.1% propane– air mixture, are shown in Figs.3 and 4, respectively.

3.2 Combustion–venting Experiments

3.2.1 Venting from " big " ratio of δ=30.8%

An example of the pressure- time history related to venting combustion process with the biggest venting ratio of δ=30.8% is shown in Fig.5. Curves a, b, c, d correspond to different venting pressures of 0.005, 0.02, 0.05 and 0.08MPa, respectively. The experimental results show that during the period from ignition to venting, the curve of pressure rise is in line with that of constant volume combustion process. The pressure starts to decrease almost immediately after the vent opening. Soon after that pressure starts to increase and decrease again and finally reachs the environmental value forming a second pressure peak.

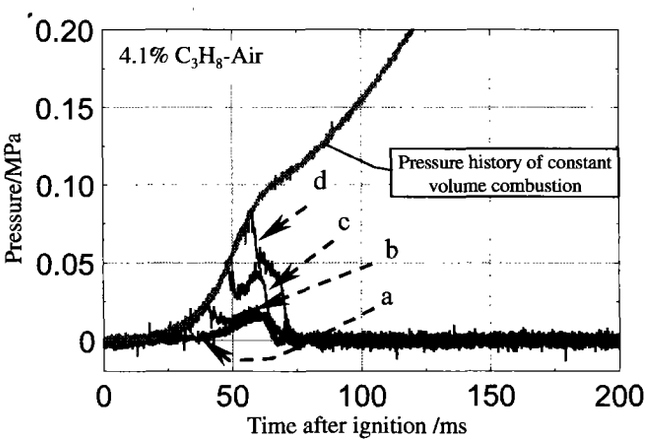

Fig.5 Pressure histories at different failure pressures (vent diameter is100mm)
(P_v MPa: a—0.005 ; b—0.02 ; c—0.05 ; d—0.08)

Flame propagating through the vessel at a venting pressure of 0.02MPa is shown in Fig.6. The corresponding pressure history is indicated by the curve b in Fig.5, and the velocity of flame front propagation is shown by the curve b in Fig.3. By comparison of the experimental results shown in Figs.3, 5 and 6 one can see more quantitative and complete picture of combustion–venting process.

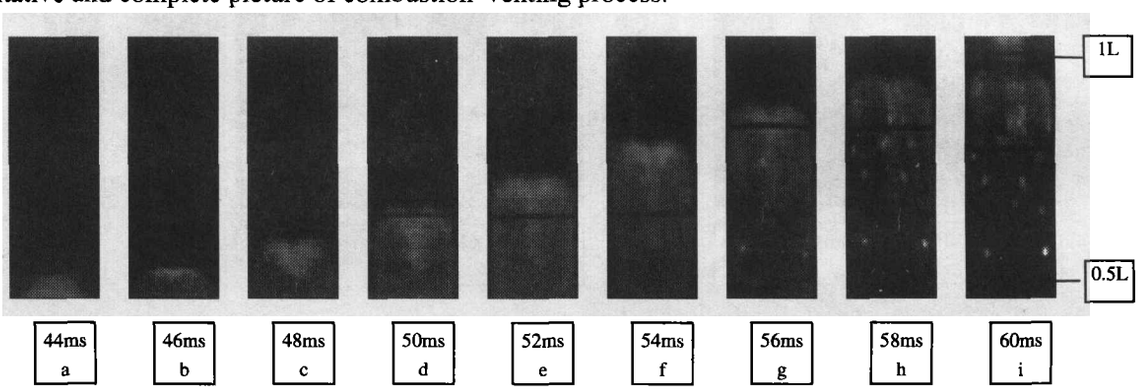

Fig.6 The flame propagation during venting with vent diameter 100mm
4.1% C_3H_8-air , Pv=0.02MPa, tv=42ms δ=30.8%

3.2.2 Venting from "small" ratio of δ=7.7%

The pressure histories of venting combustion processes from the smallest vent ratio of δ=7.7% under various venting pressures are shown in Fig.7. The related venting pressures for four pressure curves were 0.005, 0.02, 0.05 and 0.08MPa, respectively. The common feature of four curves is the fact that pressure in vessel kept increasing after venting, contrary to the pressure behavior in the case of big ratio of vent area. In most cases of this kind of venting the pressure curves have only one pressure peak which is at a certain lag from the venting moment.

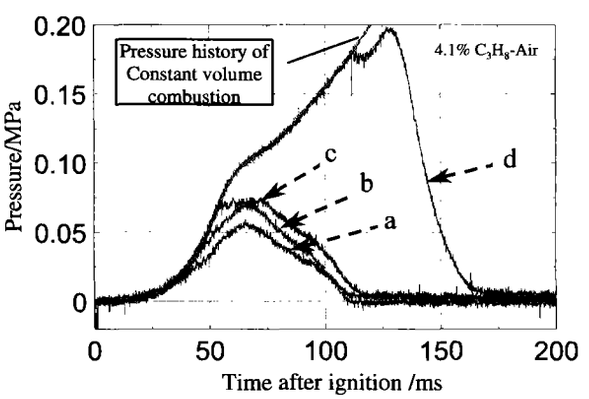

Fig.7 Pressure histories at different failure pressures
when vent diameter is 50mm
(P_v MPa: a—0.02 ; b—0.04 ; c—0.07 ; d—0.18)

Fig.8 shows the photos of the flame traversing through the vessel at a venting pressure of 0.04MPa. The corresponding pressure history and flame front propagation velocity are indicated by the curve b in Fig.7 and curve c in Fig.3.

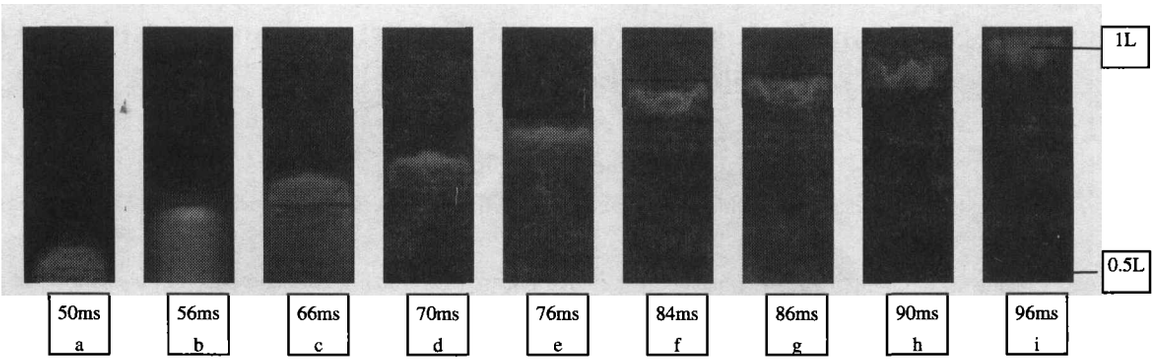

Fig.8 The flame propagation during venting with vent diameter 50mm
4.1% C_3H_8-air , Pv=0.04MPa, t_v=48ms δ=7.7%

4 Discussions

The pressure development of a venting process as a main concern in the safety-engineering point of view, is the consequent manifestation of two competing factors. One is the gas production rate due to combustion, which is mainly determined by the flame surface and burning velocity and the other is the out flowing rate of gases from the vent, which is mainly determined by vent area and venting pressure.

4.1 "Big" Vent

From the experimental results described above, one can see two features of this kind of venting: (1) It can be seen from flame photos as shown in Fig.6 that the flame front soon transformed into tulip shape after venting. Drastic deformation of the flame front and their blurred edge indicate a rather intensive influence of venting-induced flow and turbulence. (2) As seen from curve "b" of Fig.3, the flame propagated with rather high and monotonic acceleration.

Though the big vent allow a rapid decrease of pressure yet the flow/turbulence intensified combustion can raise the gas production rate over the rather high out flowing rate. The existence of the second pressure peak is an evidence. Flame photos showed the situation where the flame clearly ran out of the vessel. One can reasonably suggest that the large quantity of unburned gases and the out going flame may create some new hazard i.e. outside burning. This is something worth of notice when large vent designing is adopted.

4.2 "Small" Vent

The photos of flame propagation process shown in Fig.8 indicate that during a venting process of "small" vent case, the flame kept its clear, smooth and regular configuration. No obvious turbulent disturbance has been seen at the front of flame, suggesting that venting-induced turbulence might be weak. The flame transformed into typical tulip shape and its propagation velocity is limited in most of time before it ran out of the vessel as indicated by curve "c" in Fig.3. The pressure kept increasing after venting till the flame approached the vent and then pressure drops quickly to the environmental value forming a pressure peak around the moment while the flame is close to the vent.

The value of maximum pressure peak can be much higher than that of venting pressure. The difference between the value of venting pressure and maximum pressure peak increases as the venting pressure decreases; namely the earlier in the first combustion stage venting the greater room there will be for pressure to rise. Therefore, the maximum pressure should be carefully anticipated for "small" vent case.

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