Determination of the explosion characteristics of methanol - Air mixture in a 20-l sphere

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Abstract

In this work, the effects of ambient temperature and methanol temperature on the explosion characteristics of methanol droplet were investigated by performing experiments in a 20-l closed sphere at different equivalence ratios. The ambient temperature and methanol themselves temperature were varied from 298.15K to 318.15K, respectively. Results show that, the explosion range of methanol droplets in the 20-l closed sphere is 118.8-594.0 g/cm^3. Compared with the explosion range of pure methanol vapor (78.6-628.6 g/cm^3), the explosion range of methanol droplets is narrower, and the sensitivity of the droplets is lower than that of pure methanol vapor. As the ambient temperature in the 20-l closed sphere increases, the explosion range of methanol droplet becomes wider. When the methanol temperature or the ambient temperature in the 20-l closed sphere remains unchanged, the corresponding explosion characteristics firstly increase, and then decrease at the inflection point of Φ=1.8. When Φ=1.8, there is a maximum explosion pressure in the methanol droplet explosion. The increasing ambient temperature and methanol temperature can improve the evaporation and atomization of methanol, and then promote the transient physicochemical process in the 20-l closed sphere. However, the effect of ambient temperature is more significant than the factor of material temperature on the explosion characteristics of methanol droplet explosion. The ambient temperature and equivalence ratio both affect the explosion index of methanol droplet explosion. When Φ=1.8 and the ambient temperature is 303.15K, the intensity of methanol droplet explosion is greater than the intensity of methanol gas explosion.

Keywords: Methanol; 20-l closed sphere; Ambient temperature; Explosion pressure; Rate of pressure rise.

Introduction

Methanol has attracted significant attention as an alternative, environmentally and economically fuel. Over the past decade, methanol combustion within a confined space has been investigated extensively, including fundamental experiments, kinetic parameter studies and kinetic models [1, 2]. Saeed et al [3-5]

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investigated the combustion characteristics of methanol-air mixtures under initial high temperatures, pressures and concentrations in a constant volume vessel to obtain a better understanding of the fuel combustion process in engine.

As is known, methanol is also an important chemical raw material for fine chemicals. During its manufacture, storage and transport, if leakage, in a fire or heated, a pressure increase will occur and the methanol container may burst, and then methanol evaporation and mixing with air may actually take place, with the risk of a subsequent explosion [6-8]. It is easily understood that explosion of methanol becomes especially severe at temperatures higher than its boiling point (337.15K) [9]. At temperatures higher than the flash point (284.15K), methanol evaporation may not be so apparent. Here the concentration of the pure methanol vapor in a constant volume vessel is small and the liquid phase accounts for a large proportion. Many accidents happened under ambient conditions as a result of ignition of flammable mixed clouds (the so-called "vapor-liquid two-phase explosion"), causing casualties, property damage, and environmental damage [7, 8]. However, up to now limited information can be obtained from previous studies. From the perspective of industrial safety, the explosion hazard of methanol under ambient conditions should be addressed and investigated to assess the potential industrial hazard of methanol.

In this work, an experimental study on the characteristic parameters of methanol explosion was performed in a 20-l closed sphere with central ignition, at different initial conditions (ambient temperatures, methanol themselves temperatures, equivalence ratios). The initial ambient temperature and methanol themselves temperature were varied from 298.15K to 318.15K, respectively. The equivalence ratio was varied from 0.2 to 3, and at constant pressure (101.325kPa) within the 20-l closed sphere.

Experiment

Experiment Sample

Methanol (CH_3OH, 99.5% pure, Sinopharm Chemical Reagent Co., Ltd.) was used without further purification.

Experimental Setup and Method

The experimental setup consists of a spherical reactor with additional modules: ignition module, spray droplets module, pressure measurement module, temperature module and data acquisition module. The principle of the setup has been described in detail by Beeckman [1]. The spherical reactor, with volume of 20 l, is made of stainless steel (Fig. 1). A series of induction sparks generated between stainless steel electrodes was used as an ignition source. The tips of the electrodes were positioned at the center of the sphere. The distance between the tips was (3 ± 0.1) mm. A high voltage transformer (root mean square: 10–12 kV; short circuit current: 15-25 mA) was used for producing the series of ignition sparks. A timer was used to set the required discharge time of 0.1 s. The ambient temperature inside the sphere can be controlled by the oil bath sandwiched between the two layers stainless steel of the spherical reactor. In order to study the effect of methanol themselves temperatures on the characteristic parameters of methanol explosion, the methanol themselves temperatures can be controlled by the material temperature control system (Fig. 2). The spray droplets module was allowed creating homogenous methanol droplets in the sphere by spraying methanol sample at a high nitrogen pressure.

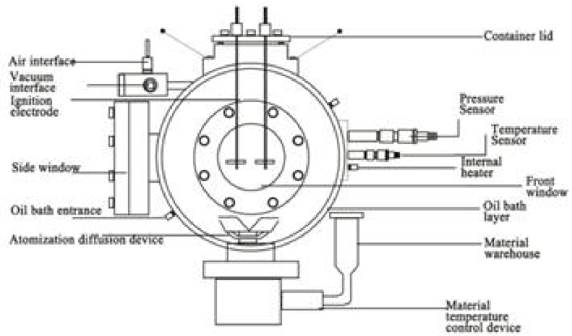


Fig.1. Schematic of the experimental setup.

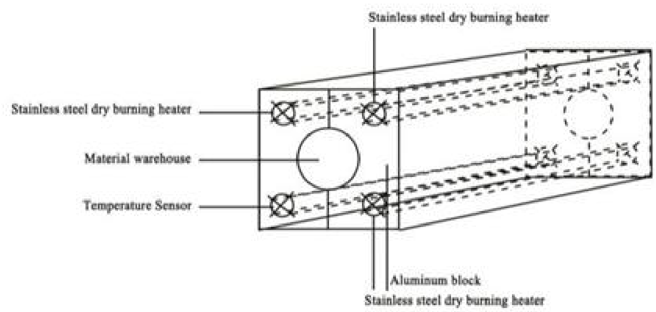


Fig.2. Schematic of the methanol temperature control system.

Results and Discussion

The development of the methanol droplet explosion could be approximately divided into four stages, which was marked as initial stage, ignition stage, accelerate stage and decay stage. A typical evolution of the methanol droplet explosion was observed in the experiment as shown in Fig.3. Taking initial stage (0-76ms) for example, at the beginning methanol is sprayed by high nitrogen pressure to form a jet in the bottom of the closed sphere, and then the flashing jet moves relative to the gas, the gas will act on the surface of the methanol droplet to cause deformation and fragmentation of the methanol droplet. Methanol droplets will gradually split into smaller droplets under the action of airflow disturbance. Because methanol droplets are subjected to air resistance, surface tension, and viscous dissipation, their velocity decays rapidly with time, and the atomization process decays more slowly. Then the methanol droplets continue to diffuse under the action of aerodynamic drag, and the turbulent flow with the airflow finally forms a droplet cloud in closed sphere, the radial radius of the droplet cloud no longer expands, the atomization of the droplet becomes more completely.

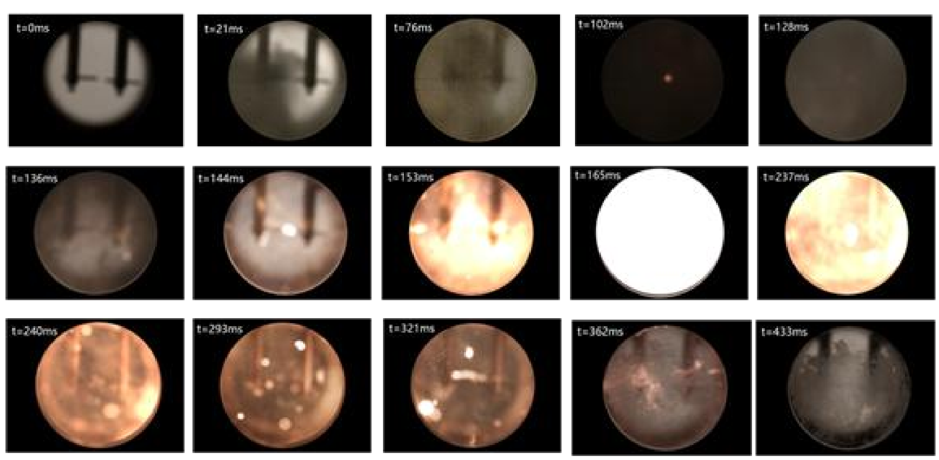
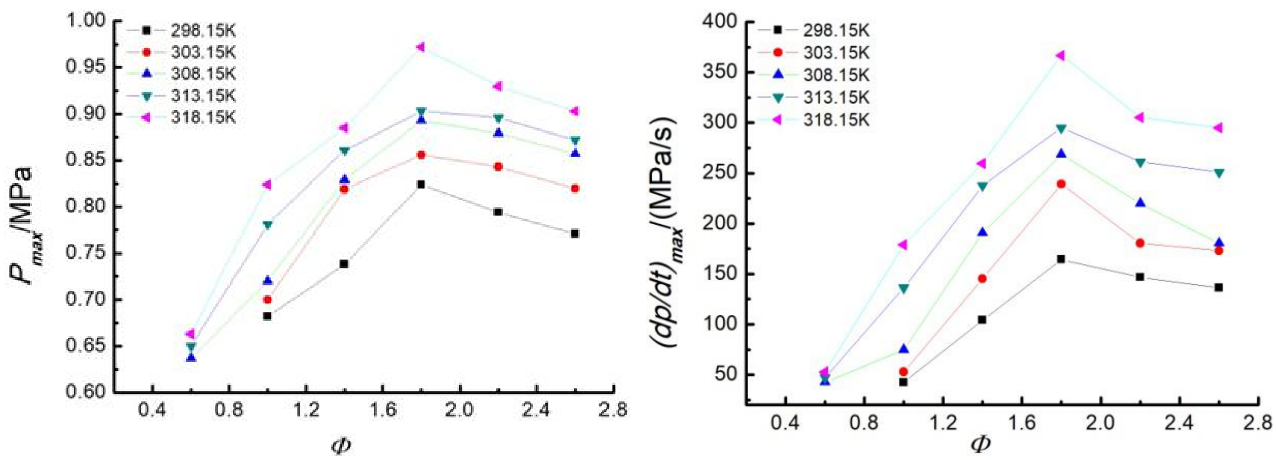


Fig.3. Captured images of the methanol droplet explosion at an equivalence ratio of 1.8; P = 101.325kPa and T = 308.15 K.

Effect of Ambient Temperature in 20-l Closed Sphere on Methanol Explosion Range

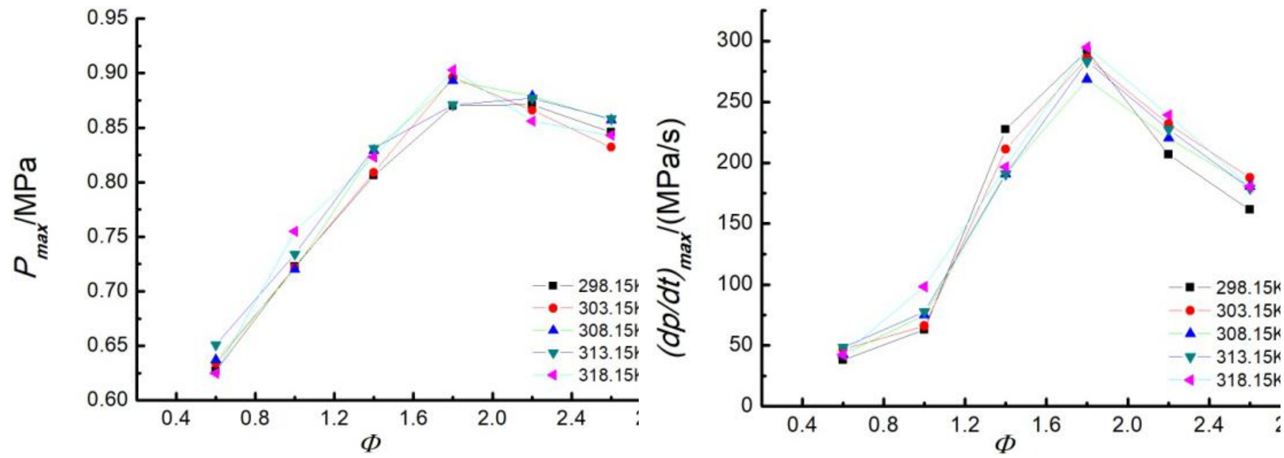
The experimental study of droplet explosion is different from gas explosion and dust explosion, and up to now its test methods and related standards have not yet been formed [10]. This paper intends to use ASTM standard to study the effect of ambient temperature on the explosion range of the methanol droplet under the same methanol temperature (298.15K).

It is well known that gases and vapors are only ignitable within their explosion range, and the explosion range varies with various factors, such as temperature, pressure, humidity. According to the methanol chemical safety specification, the explosion limit of methanol vapor is 5.5-44% under the initial pressure (101.325 kPa), and the corresponding explosion range is 78.6-628.6 g/cm3 in the 20-l closed sphere. According to the experiment, under the initial pressure (101.325 kPa), the explosion range of methanol droplets in the 20-l closed sphere is 118.8-594.0g/cm3. It can be concluded that the methanol droplets have lower explosion sensitivity than pure methanol vapor, and the effect of elevated ambient temperature on methanol droplet evaporation is limited.



(a) (b)

Fig.4. Effects of ambient temperature and equivalence ratio on explosion characteristics of methanol explosion when methanol temperature is 308.15K; P = 101.325kPa. (a)Maximum explosion pressure; (b) Maximum rate of explosive pressure rise.



(a) (b)

Fig.5. Effects of methanol temperature and equivalence ratio on explosion characteristics of methanol explosion when ambient temperature is 308.15K; P = 101.325kPa. (a)Maximum explosion pressure; (b)Maximum rate of explosive pressure rise.

The trend of maximum explosion pressure with temperatures was found to be the same from the experimental explosion measurements in this work. The increasing ambient temperature and methanol temperature can improve the evaporation and atomization of methanol, and then promote the transient physicochemical process in the 20-l closed sphere. However, the effect of ambient temperature is more significant than the factor of material temperature on the explosion characteristics of methanol droplet explosion.As shown in Fig. 4, when the ambient temperature in the 20-l sphere is 308.15K, with the increase of Φ value (0.6~2.6), the maximum explosion pressure of methanol is 0.637MPa, 0.720MPa, 0.829MPa, 0.893MPa, 0.879MPa, 0.857MPa, respectively, and the maximum explosion rate of pressure rise is 42.547 MPa/s, 74.824 MPa/s, 190.728 MPa/s, 268.486 MPa/s, 220.07 MPa/s, 180.458 MPa/s, respectively. The peak of Pmax、 dP/dtmax reached at equivalence ratio of 1.8. With the increase in ambient temperature, Pmax、 dP/dtmax found to increase in the lean side and decreases in the rich side. It can be seen in Fig. 5 that the effects of the methanol temperature on the characteristic parameters of methanol explosion is less pronounced.

Explosion index is usually used to characterize the explosion intensity of gas and dust [10]. At present, there is no classification standard for droplet explosion in confined space. As shown in figures, it can be seen that the ambient temperature and equivalence ratio both affect the explosion intensity of methanol droplet. As is well known, methane is a symmetrical molecule with a central carbon atom with 4 hydrogen atoms, and the methanol and methane both have the same carbon atom, so in this work the explosion index of methane gas was used as evaluation criterion. Compared to the explosion index of methane (55MPa.m/s), with elevated ambient temperature (313.15~318.15K), the explosion intensity of methanol droplet is greater than that of methane explosion. When Φ=1.8 and the ambient temperature is 303.15K, the intensity of methanol droplet explosion is greater than the intensity of methane gas explosion.

Conclusion

In this paper, the effects of ambient temperature and methanol temperature on the explosion characteristics of methanol droplet were studied by performing experiments in a 20-l closed sphere at different equivalence ratios. Results show that, the methanol droplets have lower explosion sensitivity than pure methanol vapor. The peak of Pmax、dP/dtmax reached at equivalence ratio of 1.8. With the increase in ambient temperature or methanol temperature, Pmax、dP/dtmax found to increase in the lean side and decreases in the rich side. Compared to the role of the ambient temperature, the effect of the methanol temperature on the characteristic parameters of methanol explosion is less pronounced. Therefore, in a real enterprise, temperature of storage and transportation environment for methanol is very important and the prevention of external ignition source is also important.

Acknowledgements

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