# The suppression effect of ultra-fine water mist on methane/air explosion in the closed Vessel

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## Abstract

Expeimental investigation of the suppression effect of ultra-fine water mist on methane/air explosion was carried out in a cloesed vessel. The effects of water mist on the overpressure and the flame propagation show that the the suppression effect would improve with the increase of the mist amount and it can be attributed to the combined action of physical mechanism and chemical mechanism.

## 1 Introduction

Fine water mist has got the concern of more and more researchers for its applications on suppressing combustions and explosions of gas, dust, and explosives such as trinitrotoluene(TNT) and Destex [1-3]. The fine water mist may have two opposite effects on the explosions, namely enhancement or inhibition, due to the droplet diameter, velocity and concentration, which are related to the atomizing method. There are mainly three methods for generating water mist, which are the pressure atomization, the ultrasonic atomization and explosion induced atomization.

Among the atomizing methods, the mist generated through pressure atomization has a droplet size over 20 μm and a relatively high velocity. Wingerden and researchers[4-6] conducted expmerimental investigations in confined spaces of 1.5m$^3$ and 50 m$^3$ on the two kinds effects of enhancement and suppression of water mist on gas explosion. They pointed out that the turbulence caused by the mist will enhance explosion, and it is possible to realize the suppression of gas explosion only when the force was large enough to make the droplet decomposition. And the conclusion was that when the droplet diameter was less than 20 μm, the explosion suppression effect was better. Similaily, Hargrave[7] and Gieras[8] also proposed that the turbulence, which would be accelerated by the disturbance of the droplet, can increase the flame area and promote the combustion.

The explosion induced atomization is a passive water mist generating method. The interaction between the induction effect of the explosion shock on the water atomization and the suppression effect of the water mist on the flame propagation, was experimentally studied on a 5.1m long open pipe (Edwan[9] and Catlin[10]) and theoretically analyzed (Adiga[11]) by researchers. The results indicated that the droplets generating process largely depended on the early explosion, and then the so-

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produced mist would conversely affect the followed explosion, which made the suppression mechanism of the explosion more complex and uncertain.

In recent years, the ultrasonic atomization technology has attracted a lot of attention, due to its characteristic of low momentum and that similar to gases. Ingram of South Bank University investigated the effect of ultra-fine water mist generated by ultrasonic technology on the burning rate of hydrogen flame[12] and the overpressure of hydrogen explosion[13]. Their results show that ultrasonic water mist can make hydrogen explosion strength decrease, in decreasing the maximum explosion overpressure and the rate of pressure rising. At the same time, some researchers[14, 15] also carried out numerical simulations of the inhibitory effect of mist on the explosion process. Compared to other mathods, the disturbance caused by ultrasonic atomization to the flow field inside the container is much smaller. The research of the suppresion mechanism of it on gas explosions would provide a basis for understand the action mechanisms of other suppression method by water mists.

In our previous works, the atomizing methods of pressure atomization and ultrasonic atomization were both investigated[16-18]. And the methane/air explosion was found enhanced and suppressed respectively by the two kind of atomizing methods. In this paper, we focus on analyzing the suppression process of ultra-fine water mist on the methane/air explosion. The effects of water mist amount on the overpressure and the flame propagation were presented and discussed.

## 2 The overpressure of the explosions

The experimental research of the suppression effect of ultra-fine water mist on methane/air explosion were conducted on the apparatus shown in Figure 1, which mainly consists of a closed vessel, a gas preparation system, a ultrasonic atomization system, an ignition system, a high speed camera, and a data acquisition and control system [16].

Figure 2 presents the pressure histories under four different spraying conditions, namely no spraying, spraying 3.75ml, 7.50ml, and 11.25ml. The results show that with the increasing of the mist amount, the maximal overpressure decreased and the time for the pressure running up to the maximum was delayed, which indicated that the increase of the mist amount can promote the suppression effect. At the same time, it also can be seen from Figure 2 that the decreasing of the maximal overpressure with the increase of the mist amount reduced gradually. That is to say, the suppression effect can't be improved endless by spraying more ultrafine water mist, which may results from the saturation in humidity of the mixed gases.

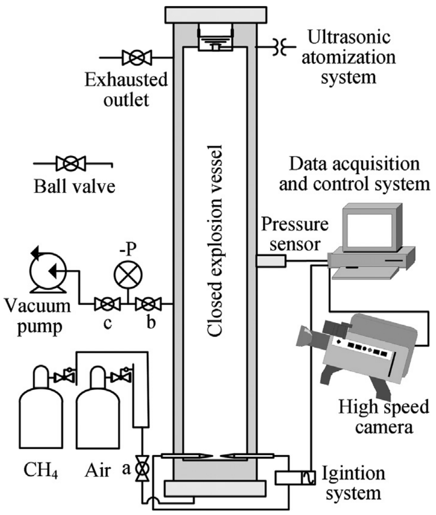



Figure 1. The experimental apparatus

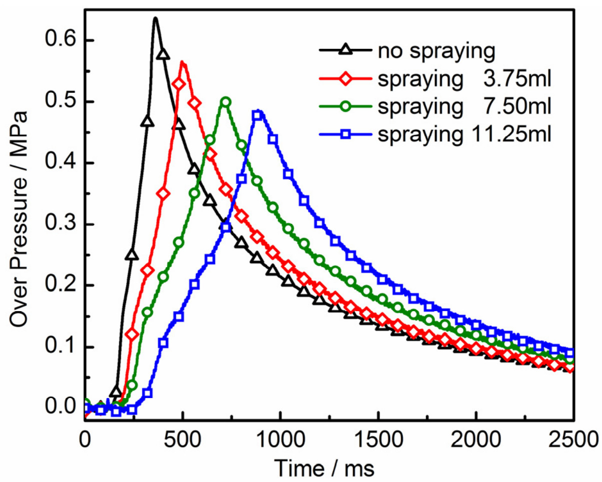
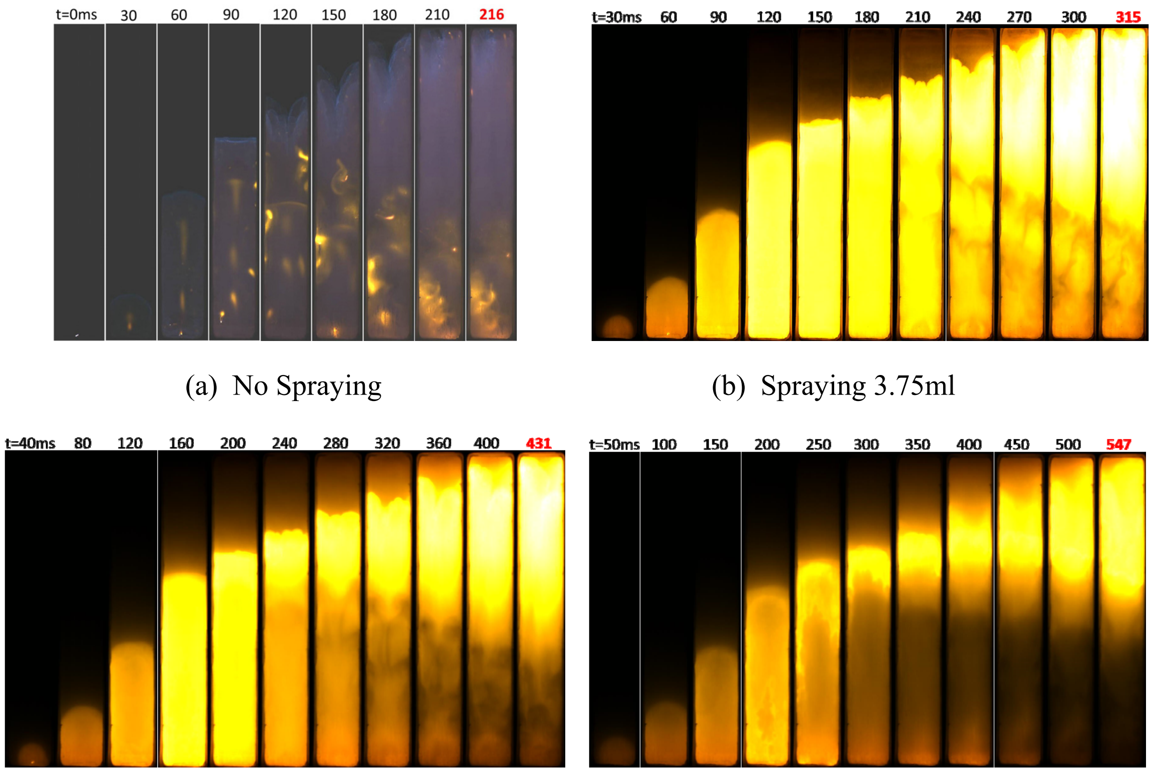



Figure 2. Pressure histories under different spraying conditions

# 3 The flame propagation of the explosions

Figure 3 shows the flame propagation process of the explosions under the four spraying conditions. It presents the developing traces of the flame from the ignition point at the bottum of the vessel to the top of the vessel. From the pictures we can obtain the following informations: (i) the time for the flame front reaching the top of the vessel was prolonged for the explosions under no spraying, spraying 3.75ml, 7.5ml and 11.25ml in turn; (ii) the tulip flame became less and less obvious until almost disappear in the atmosphere of 11.25ml ultrafine water mist. These informations indicated that: (i) the flame speed was cut down from the adding of the ultrafine water mist; (ii) the compression wave caused by the slowed forward moving flame front, weakening with the increase of the mist amount till having little reverse drag effect on the center of the flame front.




(a) No Spraying

(b) Spraying 3.75ml

(c) Spraying 7.5ml

(d) Spraying 11.25ml

Figure 3. Flame propagating process from the ignition point at the bottum of the vessel to the top of the vessel

# 4 Discussion and conclusions

The decrease of the flame speed shown in the flame propogation pictures indicated that the energy transfered from the burning gas to the unburned gas for ignition was reduced. And it can be attributed to the cooling effect during the vaporization of the micro droplets and the blocking of the radiative heat transfer by the generated vapour. Seen from the results of the pressure history, the decrease of the delayed maximal overpressure reflected that the adding of the ultrafine water mist not only slowed down the spread of the explosion reaction, but also weakened the chain reaction strength. This may be due to the participation of the micro droplet and the vapor generated from it in the chain reaction of the explosion by affecting the propogation of the chain and causing the inhibition and termination of the reaction.

In summary, the suppression of the gas explosions by the ultrafine water mist can be attributed to the physical mechanism of cooling and blocking the radiative heat transfer, as well as the chemical mechanism of inhibiting and terminating the chain reaction. Under this mechanism, the suppression effect would improve with the increase of the mist amount. But affected by the saturation effect, it would improve no more when the mist amount increased to a certain extent.

## References

[1] Oleszczak P, Gieras M, Kałużny M, et al. (2007). Dust explosions suppression by means of water spray and suppressing powder novel extinguisher design. Proc. 5th Int. Semin. Fire Explos. Hazard. 237.

[2] Willauer HD, Ananth R, Farley JP, et al. (2009). Mitigation of TNT and Destex explosion effects using water mist. J. Hazard. Mater. 165: 1068.

[3] Adiga KC, Hatcher Jr RF, Sheinson RS, et al. (2007). A computational and experimental study of ultra fine water mist as a total flooding agent. Fire Safety J. 42: 150.

[4] Van Wingerden K, Wilkins B. (1995). The influence of water sprays on gas explosions. Part 1: water-spray-generated turbulence. J. Loss Prevent. Proc. 8: 53.

[5] Van Wingerden K, Wilkins B, Bakken J, et al. (1995). The influence of water sprays on gas explosions. Part 2: mitigation. J. Loss Prevent. Proc. 8: 61.

[6] Van Wingerden K. Mitigation of gas explosions using water deluge. (2000). Process Saf. Prog. 19: 173.

[7] Hargrave GK, Jarvis S, Williams TC. (2002). A study of transient flow turbulence generation during flame/wall interactions in explosions. Meas. Sci. Technol. 13: 1036.

[8] Gieras M. (2008). Flame acceleration due to water droplets action. J. Loss Prevent. Proc. 21: 472.

[9] Edwan BCR, Moatamedi M. (2002). Induced water atomization devices for gas explosion suppression[J]. Process Saf. Prog. 21: 164.

[10] Catlin C. (2002). Passive explosion suppression by blast-induced atomisation from water containers. J. Hazard. Mater. 94: 103.

[11] Adiga KC, Willauer HD, Ananth R, et al. (2009). Implications of droplet breakup and formation of ultra fine mist in blast mitigation. Fire Safety J. 44: 363.

[12] Ingram JM, Averill AF, Battersby PN, et al. (2012). Suppression of hydrogen–oxygen–nitrogen explosions by fine water mist: Part 1. Burning velocity. Int. J. Hydrogen Energ. 37: 19250.

[13] Battersby PN, Averill AF, Ingram JM, et al. (2012). Suppression of hydrogen–oxygen–nitrogen explosions by fine water mist: Part 2. Mitigation of vented deflagrations. Int. J. Hydrogen Energ. 37: 19258.

[14] Holborn PG, Battersby P, Ingram JM, et al. (2012). Modelling the mitigation of lean hydrogen deflagrations in a vented cylindrical rig with water fog. Int. J. Hydrogen Energ. 37: 15406.

[15] Holborn PG, Battersby PN, Ingram JM, et al. (2013). Modelling the mitigation of a hydrogen deflagration in a nuclear waste silo ullage with water fog. Process Saf. Environ. 91: 476.

[16] Zhang PP, Zhou YH, Cao XY, et al. (2014). Mitigation of methane/air explosion in a closed vessel by ultrafine water fog. Safety Sci. 62: 1879.

[17] Zhang PP, Zhou YH, Cao XY, et al. (2014). Enhancement effects of methane/air explosion caused by water spraying in a sealed vessel. J. Loss Prevent. Proc. 29: 1873

[18] Cao XY, Ren JJ, Zhou YH, et al. (2015). Suppression of methane/air explosion by ultrafine water mist containing sodium chloride additive. J. Hazard. Mater. 285: 311