Experimental Study on the Interaction of Water Mists with Fires in the Confined Space

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ABSTRACT

Water mist fire suppression system is an attractive candidate as the Halon replacement, and much research has been made on the interaction of water mists with fires. In this paper, the interaction was studied in the confined space with proper ventilation control. The 3D LDV/APV system was employed to measure the water mist characteristics. The Cone Colorimeter was also used to measure the heat release rate, oxygen and carbon monoxide concentrations and other important parameters of the interaction in different conditions.

The water mists suppressed fires in the confined space through oxygen displacement, evaporation cooling and heat radiation attenuation, and oxygen displacement played the very important role. The poorer ventilation, the easier suppression. The water mists took less effect on the smouldering than the flaming fires, and more smoke was produced. However the mists prevented the smouldering from bursting into flaming fires.

KEYWORDS: confined space, water mists, interaction, heat release rate

INTRODUCTION

The use of water mists for fire extinguishment and control is taken as one of the effective candidates as the Halon replacement, and much work has been done to develop this technique. The experiments with water mist fire suppression systems have been reviewed in [1]. The water mists, which have been defined as sprays with water droplet less than 300 microns in diameter, have the different suppression mechanism from the Halon agent. The extinguishing capacity is determined by the drop size distribution, spray location, spray momentum, room geometry, obstructions in the room and fuel types. So it is very important to study the interaction of water mists with fires. A lot of fires occur in the confined space with proper ventilation control, and the fuel always varies. The study on the interaction of water mists with fires in the confined space will enhance knowledge of such processes and be useful for developing the water mist fire suppression system, improving the fire suppression and control efficiency and extending their application field.

The three dimensional Laser Doppler Velocimetry or Adaptive Phase Doppler Velocimetry system (3D LDV/APV system) can measure the velocity, drop size and concentration of the three dimensional multiphase flow at the same time. In this paper, the characteristics of the water mists to suppress the fires were measured with this system. The Cone Colorimeter is the proper equipment to study the interaction of water mists with fires in the confined space, and the gas concentration, temperature, heat radiation flux and heat release rate can be measured automatically before and after the water mist actuation. The experiments have been performed with the liquid and solid fuel samples, and the results were compared with other similar experiments as possible.

EXPERIMENTAL APPARATUS

The experiments were performed first with use of the 3D LDV/APV system, and the characteristics of the water mists were measured. The water mists were generated by the pressure atomizer. The optics theory and the measurement have been described in detail in [2].

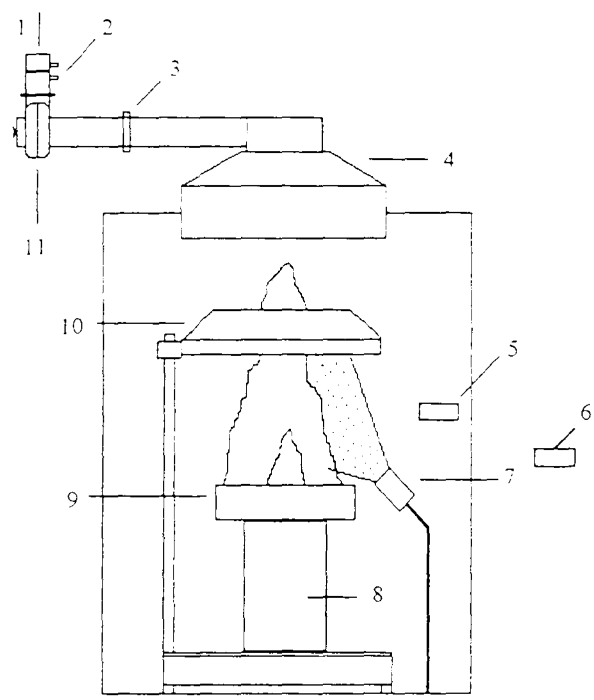

Figure 1. Schematic diagram of the experimental apparatus.

1—exhaust 2—pressure and temperature measure 3—gas sampling tube
4—hood 5—heat radiation flux meter 6—CCD camera 7—water mist nozzle
8—electric balance 9—fuel sample 10—cone heater 11—blower

According to the combustion oxygen consumption theory, the Cone Colorimeter can measure and analyze the combustion product when the oxygen of constant flow rate was provided into the confined space. The combustion characteristics can be gained such as heat release rate, combustion efficiency, burning delay time and gas concentration.

The interaction experiments were performed in the 0.6m×0.6m×0.7m glass-walled enclosure of the Cone Colorimeter shown schematically in Figure 1. The fuel sample was located on the electrical balance, and there was a 200 kW/m^2 cone heater over the sample to keep the combustion stable. The combustion products were all collected by the hood and transferred to measure and analyze. The blower added ambient fresh air into the confined space, and the flow rate could be adjusted. The heat radiation flux meter was located 25 cm away from the flame centerline, and the thermal couples were arrayed along the centerline. The water mists measured with LDV/APV system were injected into the confined space with 45 degree axial angle to the vertical direction. The liquid fuel samples were both ethanol. One weighed 34 g, and the other weighed 100 g. Their height were both 10 mm. The solid fuel sample was a 100 g pine wood, which height was also 10 mm. The system began to record time after the automatic ignition, and the water mists were injected into the confined space at 160 seconds after ignition. All the raw data were processed automatically by computer.

RESULTS AND DISCUSSION

The characteristic parameters of the water mists determined their fire extinguishing capacity. The water mists used in these experiments were generated by the single pressure atomizer under 0.8-1.2 MPa pressure. Figure 2 shows the APV results measured at 20 cm away along the nozzle axis and the pressure is 1.2 MPa. The up left figure shows the relationship between the drop size and the nozzle axial velocity. The up right figure shows the relationship between the drop size and the mean velocity, and the possibility density functions of the volume mean diameter are also shown. The down left and down right figure show axial velocity and drop size histogram respectively. The axial velocity can also be shown with other dimensional velocity.

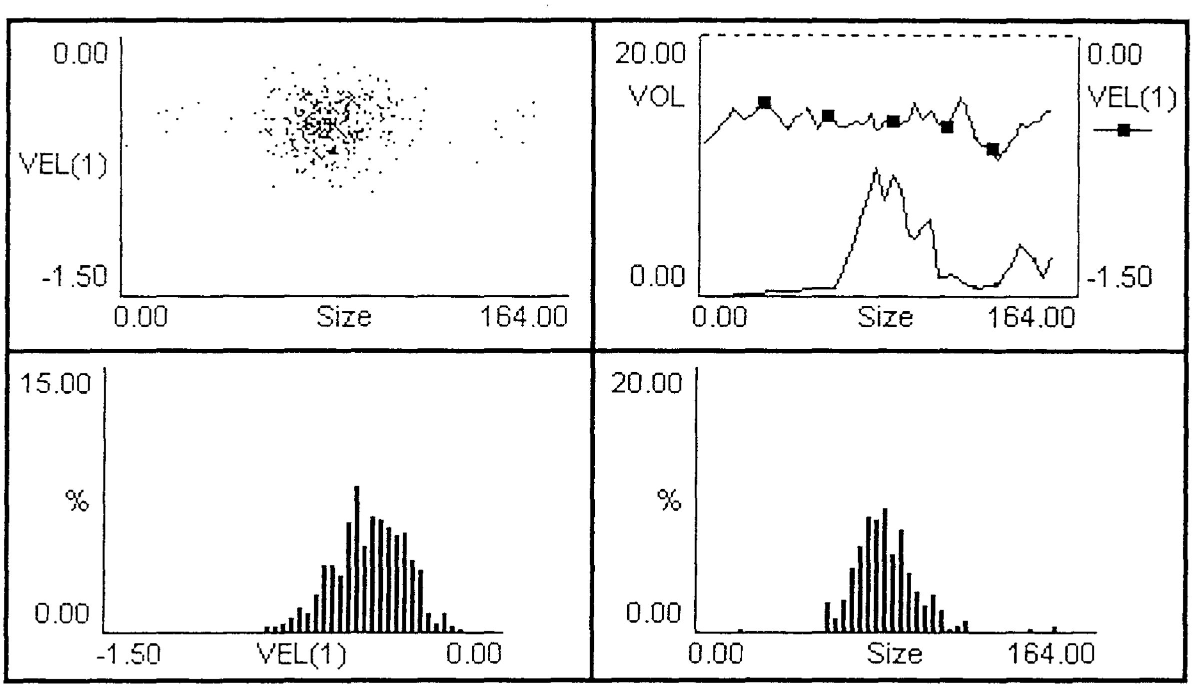

Figure 2. The typical characteristics of the water mists employed to suppress the fires in the confined space

Though the large scale ethanol sample gave out more heat than the small one, its heat release rate was smaller than the small one. Because in the confined space with ventilation control, the oxygen supply was limited (no more than 0.4 l/s)and the large one could not burn thoroughly. On the other hand, the burning surface area of the large one was larger than the small one. so it gave out less heat per unit surface area. When the water mists were applied, the heat release rate decreased immediately. The fires extinguished in no more than one second if the water mists had enough flux. Figure 3 shows the heat release rate for a period of approximately two and half minutes after actuation of the water mists. The heat release rate of the large one decreased more quickly than the small one. The heat release rate deceased more quickly when the oxygen flow rate decreased. The ventilation affected the water mist extinguishing capacity deeply in the confined space. In one sense the large scale fires are more easily suppressed by the water mists than the small ones in the confined space with poor ventilation.

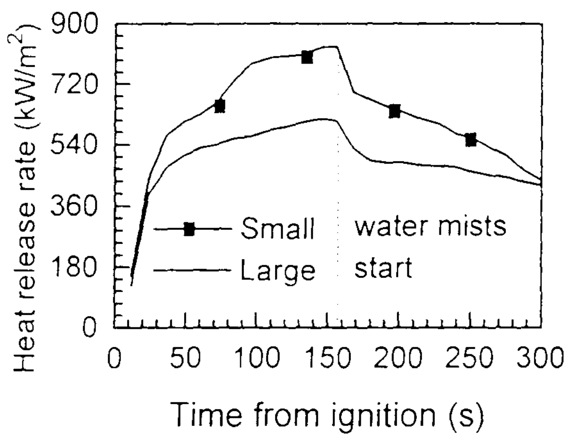

Figure 3. Heat release rate of ethanol samples before and after the water mists start

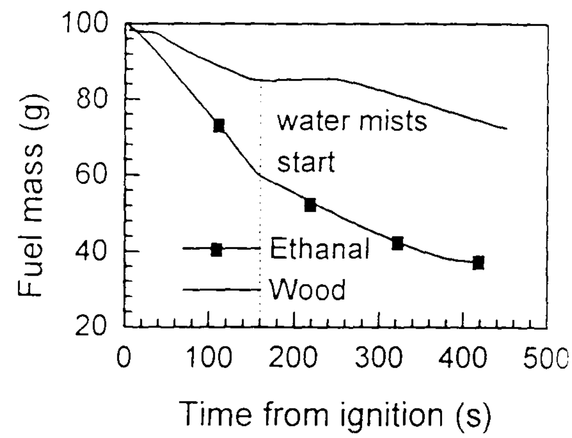

Figure 4. Fuel mass of the samples before and after the water mists start

The experiments have also been made to compare the behavior of the solid fuel with the liquid during the water mist employed period. Here the fuel mass loss was the proper parameter and the results are shown in Figure 4. Both samples had the same weight, and burnt in the same conditions. During the stabilized combustion before the water mist actuation, the fuel mass lost at the constant rate respectively and the solid sample lost more slowly than the liquid one. When the water mists were injected into the confined space, the solid sample was suppressed at once. Although the cone heater was still working, the solid sample mass did not lose obviously. When the water mists were stopped after 100s application, (to the liquid sample, the water mists were applied until the experiments ended,) the solid sample continued to lose its mass under the cone heater. But this time it was a smouldering fire instead of the flaming fire, and its mass loss rate was less than the flaming fire. Because the water mists absorbed much heat and changed into vapor, this prevented the solid sample from being heated and volatilizing gas fuel. After the water mist application, a lot of carbon monoxide and smoke were produced, which were harmful to human and environment. The carbon monoxide concentration and the smoke release rate of the solid sample before and after the water mist application were both shown in Figure 5. At the beginning the smoke release rate reached a peak, because a lot of matter was volatilized from the sample under the cone heater, and the smoke release rate decreased after ignition. During the period of water mist application, the carbon monoxide concentration increased and the smoke release rate deceased. The oxygen displacement will be discussed as follows.

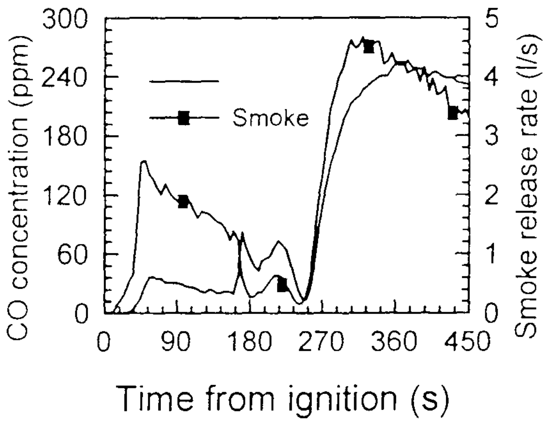

Figure 5. CO concentration and smoke release rate of pine wood sample before and after water mists start (160s to 260s after ignition)

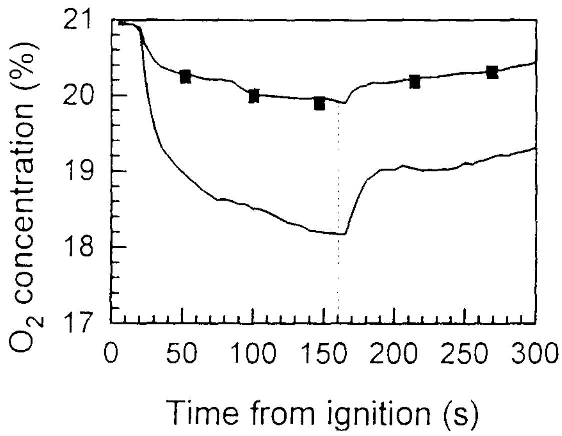

Figure 6. Oxygen concentration of ethanol sample products before and after water mists start (symbols as same as Figure 3)

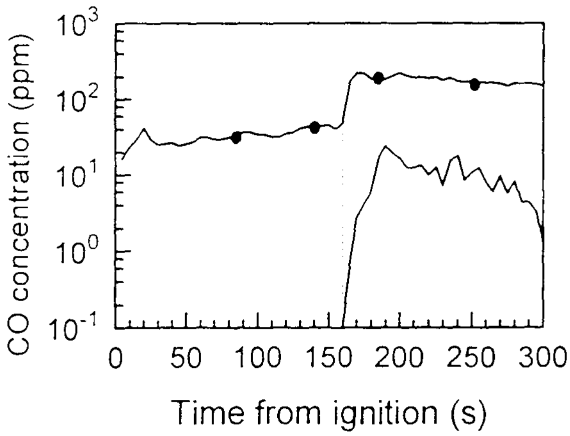

Figure 7. CO concentration of ethanol sample products before and after water mists start (symbols as same as Figure 3)

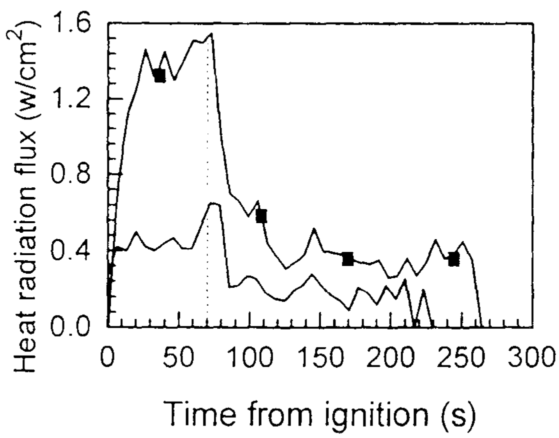

Figure 8. Heat radiation flux of ethanol samples before and after water mists start (70s after ignition) (symbols as same as Figure 3)

Figure 6 and Figure 7 show the oxygen concentration and the carbon monoxide concentration of the ethanol sample products. The oxygen supply rate is 0.4 l/s. The oxygen concentration decreased after ignition and increased quickly after the water mists were injected, although a part of water mists changed into vapor to decrease the oxygen concentration of the products. The carbon monoxide concentration also increased quickly when the water mists were applied. Because when the water mists were injected into the confined space, their surface area were relatively large and they absorbed the heat more quickly than large drops, which slowed the reaction rate down. So the oxygen consumption decreased. On the other hand, when the mists changed into vapor at the reaction zone, their volume increased by almost 1600 times and decreased the oxygen concentration. The combustion could not be supported without enough oxygen and so more carbon monoxide was produced. The more oxygen needed, the more easily the fires were suppressed with water mists and the more carbon monoxide was produced. The smouldering fires depended less on oxygen, and their entraining capacity was less than the flaming fires. The water mists could not be entrained into fires easily to slow down the reaction rate. But the water mists could absorb heat and prevent the smouldering from flaming. These results were supported by direct measurement of oxygen and carbon monoxide concentration at the reaction zone with gas sampling in [3].

The heat radiation flux variations with time of the ethanol sample fire are also shown in Figure 8 . The flux decreased because of not only the reaction rate decreasing, but also the attenuation of the mists and their vapor. The thermal couples located along the flame centerline also indicated the temperature decreasing at reaction zone and plume.

The experiments are also made to study the element influence such as ventilation, spray angle, volume flux, obstruction and disturbance. In the confined space, proper spray angle and volume flux would send the mists into the flame and displace the oxygen to suppress the fires in short time and with very little water. The obstruction affected the suppression capacity deeply, especially on small scale fires, because the weak entraining force could not entrain the mists into flame to suppress fires. When the fires and the mists kept balance, proper disturbance would help to extinguish fires. For example, properly changing the spray angle or flow rate perhaps could break the balance and extinguish the fires.

CONCLUSION

The interaction of water mists with fires in the confined space was experimentally studied The mechanism of the water mist fire suppression system was different from the Halon agent. The water mists did no harm to the environment, cost less than the sprinkle and could suppress some special fires. The water mists took less effect on the smouldering than the flaming fires, and more smoke was produced. In the confined space, the remaining liquid water was very limited. At present study it is found the main suppression mechanism is oxygen displacement, the second is the cooling, and the third is attenuation Although the vapor micro-explosion and the molecular decomposition promote the combustion, in the condition of enough water mist momentum, the suppression effect plays the leading role.

Future work will consider different nozzle types, water mist entrainment, smoke movement and fire spread under the water mist application.

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