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EXPERIMENTAL STUDY ON EXTINCTION OF A POOL FIRE WITH WATER MIST

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ABSTRACT

The mechanisms and effectiveness of water mist, used to extinguish pool fires, were examined in a series experiments conducted in an open space. Fire sources were contained in small-scale circular stainless steel pans of 13 cm and 20 cm diameter, and the fuels used were alcohol and kerosene. Before and after the application of water mist, K-type thermocouples along the pool centerline and an infrared thermography were used to measure and visualize flame temperature. A thermogauge and a turbine flux sensor were used to measure the flame radiant heat flux and the application rate of water, respectively. The experimental results revealed that neither the flames of alcohol or kerosene could be extinguished in most cases when the water mist supply pressures were lower than 0.4 MPa. The distance between the flame and the nozzle, and the application rate of water are the two main factors influencing the effectiveness of the extinction of a pool fire when the working pressure is low. The test results also show that the larger the pool diameter is, the easier the flame can be extinguished.

INTRODUCTION

Pollution-free, safe and effective methods for fire suppression and extinction are widely required, because many traditional techniques and chemical agents have been shown to produce toxicity and asphyxiation effects. Water as a means of fire suppression has been in use from ancient times, and the use of water mist for fire suppression was first studied in the 1950s[1]. Renewed interest in this old technology was sparked when the first version of the Montreal Protocol was introduced in 1987[2,3]. This international commitment to protecting the earth's ozone layer from further damage by chlorinated fluorocarbons (CFC's), has driven almost a decade of testing to develop alternative fire suppression technologies to replace the chlorine- or bromine-based gaseous fire suppressants known as Halons. Water mist has been defined as a water spray for which the $Dv_{0.99}$, as measured at the coarsest part of the spray in a plane about 1m from the nozzle, at its minimum design pressure, is less than 1000 microns[4]. Water mist is regarded as not only an effective fire suppression and extinction method, but also a cheap one. Therefore, the use of water mists for fire extinguishment and control is currently receiving a considerable attention as one of the potential methods for replacement of Halon 1301 and 1211 which can damage the earth's ozone layer[5-11]. Several studies have examined the application of water mist in practical fires associated with aircraft cabins, military radar, computer rooms, communication equipment cabinets, especially in Canada, Britain and America[12].

Based on earlier studies, the mechanisms of fire suppression or extinction with water mist are already known, including gas-phase cooling, oxygen dilution, fuel surface cooling and radiation attenuation. It is very difficult to separate the effects of these mechanisms in a given fire. However, Ndubizu et al.[2] observed that the oxygen dilution effect is the dominant mechanism for suppressing large fires in an enclosed space. And when the enclosed fire is small (compared with the enclosure) or a large fire is in the open, the situation may be different. Studies on the interactions of water mist with small-scale pool fires in confined spaces with a hollow cone nozzle can be seen elsewhere[13,14].

The purpose of this study was to examine the relative contributions of the distance between the nozzle and fuel surface, the application rate of water injection, the working pressure, the pool size and fuel type in an open space with a low pressure water mist system (1.2 MPa or less). The experiments were performed in a 4.5 × 10 m^2 testing room (Appendix A). Similar to Yong's work[15], the fuel was contained in a small-scale circular stainless steel pan, 4 cm deep with a diameter of 13 cm. A larger pan, 20 cm in diameter, was also used in tests so that the influence of pool size could be evaluated. Although heptane, diesel or crude oil pool fires are usually used in fire suppression testing[14,16,17], alcohol and kerosene were used as fuels in this study. The results of tests were compared to previous work, where the tests were conducted in confined or enclosed spaces[13-15]. Before and after the application of water mist, some K-type thermocouples and an infrared thermography were used to measure and visualize flame temperature, a thermogauge and a flow sensor were used to measure the flame radiant heat flux and the application rate of water, respectively.

EXPERIMENTAL APPARATUS

The experimental equipment consisted of three main parts. The first was a water mist generation system (placed in a pump room 4.5 × 2 m^2), the second a measurement system for data acquisition and processing (placed in a controlling and measuring room 4.5 × 3 m^2), and the third was an experiment model (placed in a 4.5×10 m^2 testing room) (Appendix A). The first part used a six-level pressure pump and a variable frequency controller to produce constant pressure, and the pressure was adjusted from 0 to 1.2 MPa. A water tank with volume 3 m^3, some pipeline and electromagnetic valves, and some water filters were also used. A *1-7N-SS26* spray nozzle (produced by spray system Co. in USA) was used in this work, and the nozzle had capacities of 0.46, 0.66, 0.81, 0.95, 1.05, 1.19 L/min at the pressures of 0.13, 0.26, 0.39, 0.52, 0.65 and 0.80 MPa, respectively. The *7N* series FogJet nozzle consisted of a nozzle body and seven removable atomizing spray caps, each cap having an internal core which was easily removed for cleaning or replacement. The nozzle produced a shower-like full cone spray pattern of very fine droplets and it's photo and the spray dimensions can be seen in Figure 1. The second part included some pressure sensors, turbine flux sensors and a radiant heat flux sensor, some K-type thermocouples along the pool centerline and infrared thermography (TVS-2000ST) were used to measure and visualize flame temperature. The last part included the pools and a steel stand, whose height could be changed from 20 cm to 180 cm with a 20 cm step. Hence, the distance between the fuel surface and the spray nozzle could be changed by steps of 20 cm in experiments. The nozzle operated at pressures of 0.4, 0.6, 0.8 and 1.0 MPa , which was altered by adjusting a variable frequency controller. The water mist was injected into the pool fire directly downward and the fire was located directly under the nozzle.

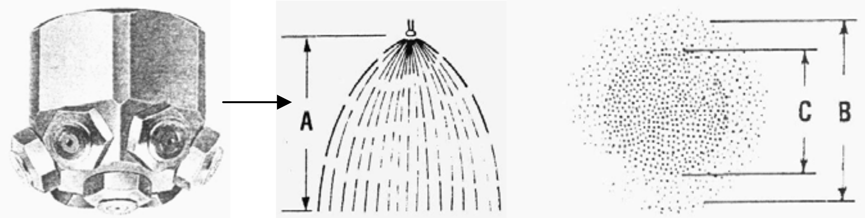


Figure 1: *1-7N-SS26* spray nozzle pattern *A*,*B* and *C* are 0.9,3.0 and 1.8 m, respectively.

The tests were conducted in the testing room (4.5 × 10 m^2), and all of the doors and windows were closed during pre-burn and mist application. All systems began to work after the automatic ignition started. The fire was allowed to burn for about 100 s to create quasi-steady burning before the water mist injection. All the raw data were saved and processed automatically by the computer.

In addition, certain characteristics of the water mist including droplet size distribution and velocity were measured by an Adaptive Phase Doppler Velocimetry (APV) system. The fundamental techniques and configuration of the APV system have been described in detail elsewhere[18,19,20]. Based on these measurements, most larger droplets were found at the outside, and most smaller droplets on the inside, of the water jet. Some larger droplets, about 1 mm in diameter, were also measured inside the spray cone. The typical measurements were performed along the radius 1.0 and 1.5 m from the nozzle, and the SMD (Sauter Mean Diameter) was in the range 450 to 600 μm.

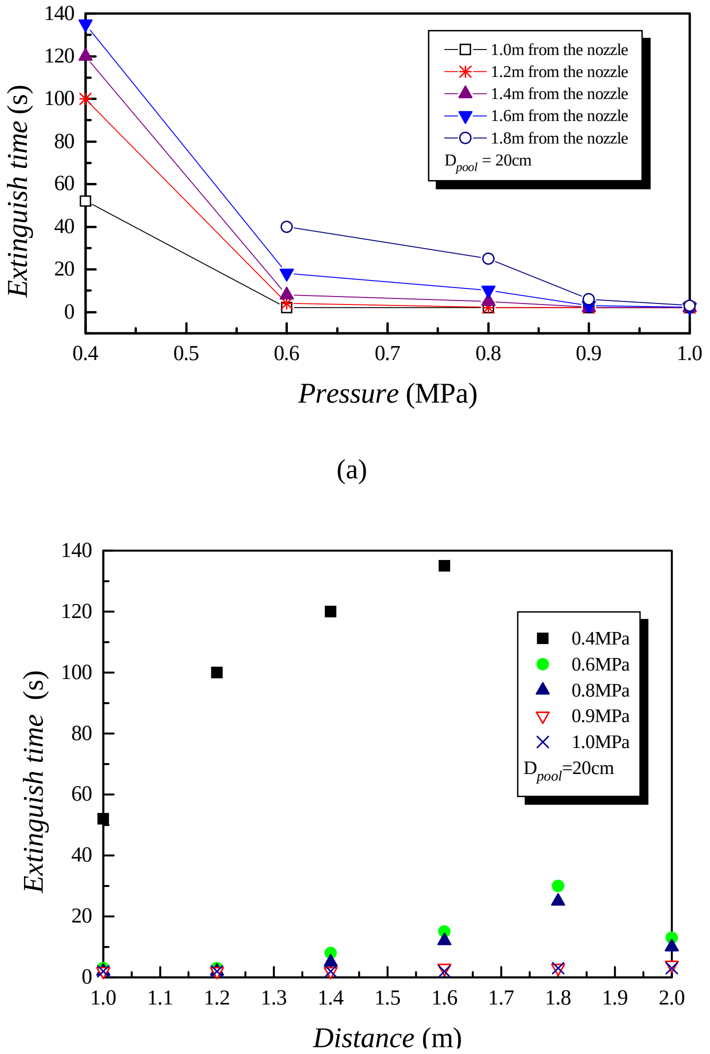
RESULTS AND DISCUSSION

A series of experiments were conducted to study the mechanisms and effectiveness of pool fire extinction with water mist. Of specific interest were the effects of the distance between the fire and the nozzle, the pressure, the pool size and the fuel type on the efficiency of fire extinction with water mist,. Test conditions included different distances (1.0,1.2,1.4,1.6 and 1.8 m) between fire and spray nozzle, different pressures (0.4, 0.6, 0.8 and 1.0 MPa), small and large diameter pools (13 and 20 cm), and different fuels. Table 1 gives some details of the experiments using alcohol fires, where D_{pool} is the pool diameter, H is the distance between fuel surface and mist nozzle, P is the working pressure, F is the application rate of water, and T_e is the extinction time. The details of kerosene fires were omitted in order to save space.

Table 1: Alcohol pool fire extinction with water mist under different conditions.

D_{pool} = 13 cm				D_{pool} = 20 cm			
H (cm)	P (MPa)	F (l/h)	T_e (s)*	H (cm)	P (MPa)	F (L/h)	T_e (s)*
200	1.0	132.0	-	200	1.0	132.0	3
	0.8	118.8	Pulse		0.8	118.8	25
	0.6	98.0	pulse		0.6	98.0	40
	0.4	76.0	Pulse		0.4	76.0	pulse
	0.2	-	pulse		0.2	-	pulse
180	1.0	132.0	-	180	1.0	132.0	3
	0.8	118.8	14		0.8	118.8	10
	0.6	98.0	pulse		0.6	98.0	16
	0.4	76.0	pulse		0.4	76.0	pulse
	0.2	-	pulse		0.2	-	pulse
160	1.0	132.0	-	160	1.0	132.0	2
	0.8	118.8	50		0.8	118.8	12
	0.6	98.0	Pulse		0.6	98.0	15
	0.4	76.0	pulse		0.4	76.0	135
	0.2	-	pulse		0.2	-	pulse
140	1.0	132.0	6	140	1.0	132.0	2
	0.8	118.8	12		0.8	118.8	5
	0.6	98.0	pulse		0.6	98.0	8
	0.4	76.0	pulse		0.4	76.0	120
	0.2	-	pulse		0.2	-	pulse
120	1.0	132.0	2	120	1.0	132.0	2
	0.8	118.8	8		0.8	118.8	2
	0.6	98.0	30		0.6	98.0	3
	0.4	76.0	Pulse		0.4	76.0	100
	0.2	-	Pulse		0.2	-	pulse
100	1.0	132.0	2	100	1.0	132.0	2
	0.8	118.8	2		0.8	118.8	2
	0.6	98.0	30		0.6	98.0	2
	0.4	76.0	pulse		0.4	76.0	52
	0.2	-	pulse		0.2	-	pulse

∗ “ pulse ” indicates that the fire was extinguished with pulse injection of water mist when the fire cannot be extinguished with water mist in continuous injection within a certain time.



(a)

(b)

Figure 2: Extinction time via different pressures and distances.

Figure 2 shows the effects of *H* on fire extinction with water mist under different pressures. The results of the 20 cm diameter pool fire are shown. It is obvious that at a given pressure, the larger the *H* the more difficult it is to extinguish the fire, and this effect will grow even larger when the pressure is less than 0.6 MPa. In addition, for a given *H*, the fire can be more easily extinguished when the pressure is higher. But when the pressure is larger than 0.9 MPa, both the pressure and the separation distance have less effect on the fire extinction. Similar results can be seen in Figure 3 for different application rates of water, as it is directly related to the pressure, i.e., the higher the pressure, the larger the application rate.

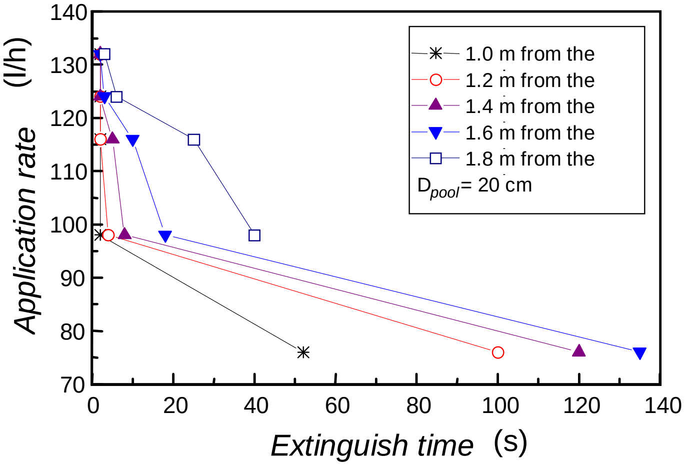
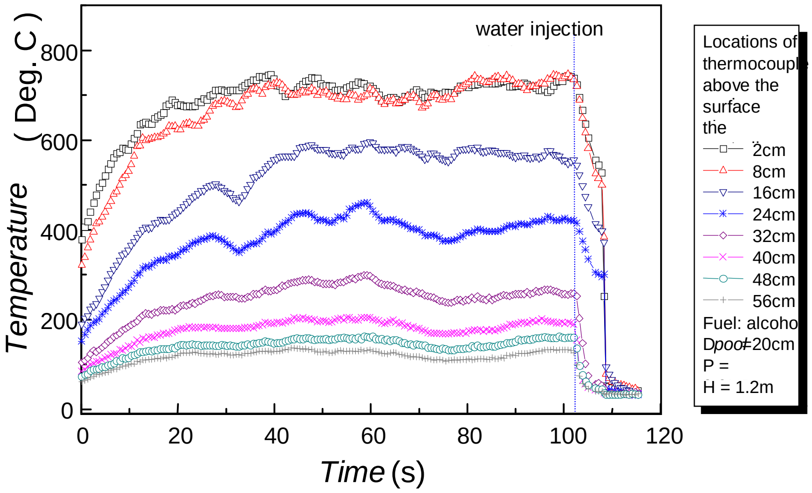
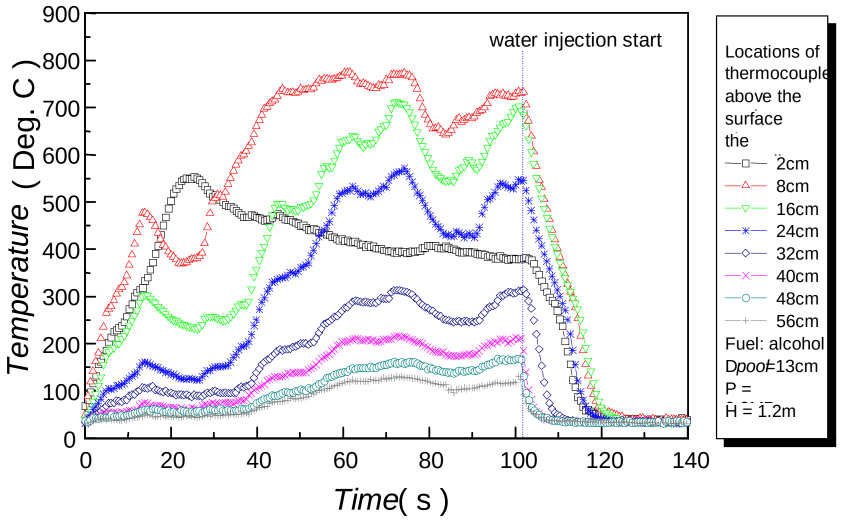


Figure 3: Effects of the application of water on fire extinction.

Figure 4 shows the temperature history of a pool fire before and after the application of water mist. The working pressure was 0.6 MPa and the distance *H* was 1.2 m. Both the results of 13 and 20 cm diameter pools are illustrated. Temperature at different locations above the fuel surface reduced rapidly after the water mist was injected, and it reduced more quickly for the 20 cm pool than for the 13 cm pool. These results indicate that the larger the pool fire is, the easier it is to extinguish as long as the application range of water mist is larger than the fire volume. These results are similar to those of Hanauska[21]. Similar results also can be seen in Figure 5 based on the flame radiant heat flux measurements. The thermogauge was located 5 cm above the pool surface and about 40 cm from the centerline.



(a)



(b)

Figure 4: Temperature history of alcohol pool fire before and after the application of water mist.

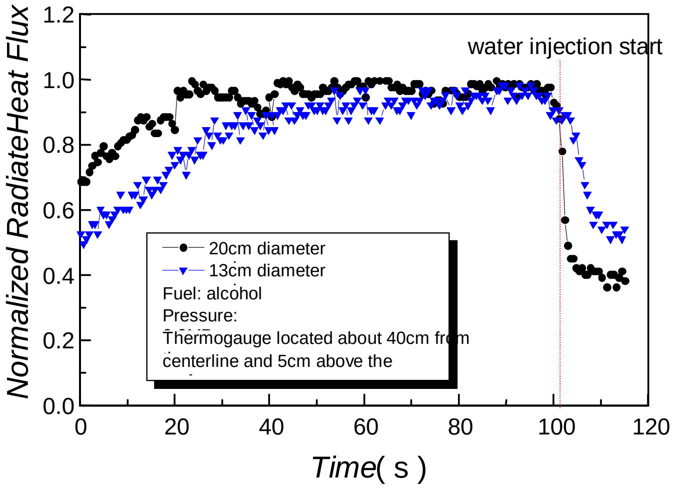
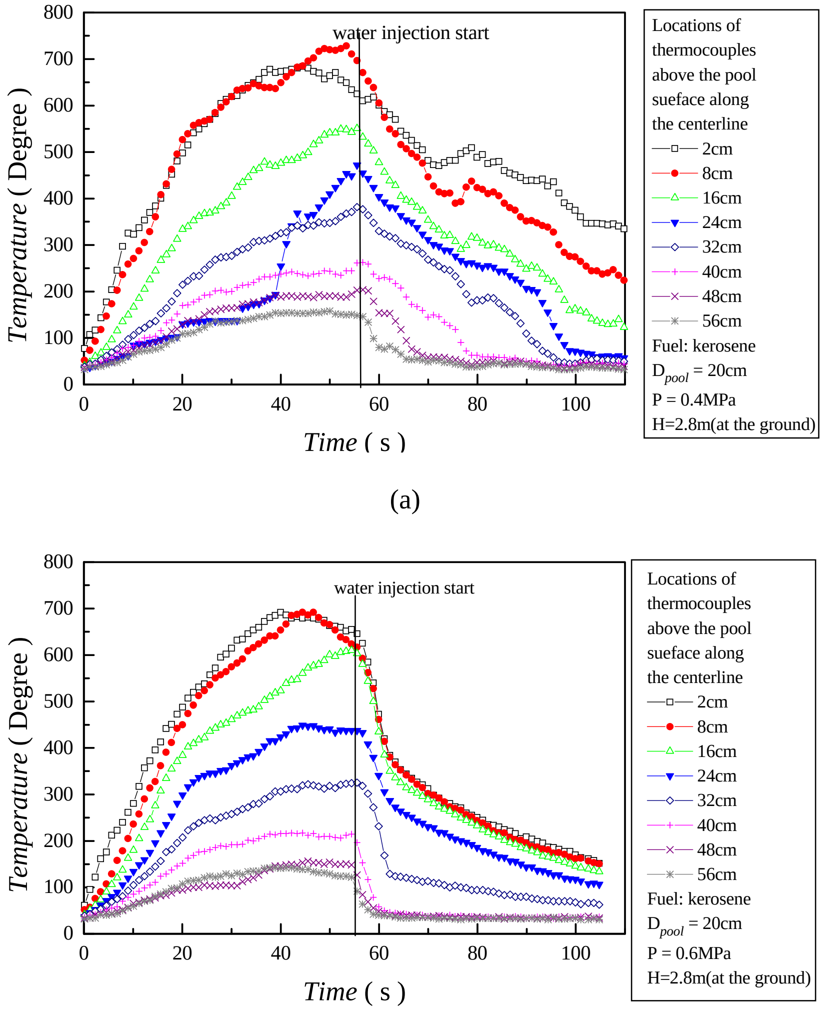


Figure 5: Normalised radiant heat flux of alcohol pool fire before and after the application of water mist.

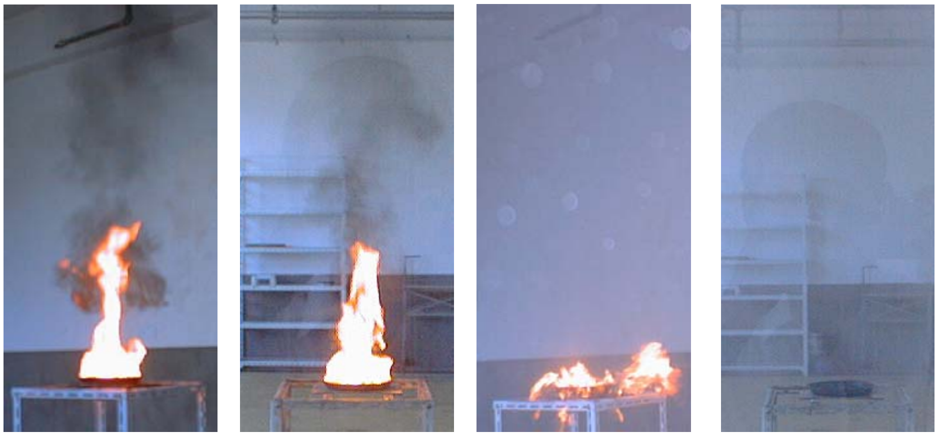
In order to study the extinction efficiency of water mist for different fuel fires, experiments on the interaction of water mist with kerosene pool fires in open spaces were performed. Because of heavy smoke production by the kerosene flames, the water injection was started about 60 s after the ignition. The results show that kerosene pool fires can be extinguished easier than alcohol fires at each working pressure for both 20 cm and 13 cm pools. For instance, when the distance *H* exceeded 200 cm, most alcohol fires could not be extinguished for many minutes using low pressures. However, kerosene fires were extinguished quickly with low pressures (0.6 and 0.4 MPa) even when the pool was located on the ground, i.e., *H* was about 2.8 m. These results are quite different from previous work conducted in a confined space with a hollow cone nozzle[13,14]. Figure 6 shows the temperature history of a kerosene pool fire before and after the application of water mist with *H* of 2.8 m. These results may indicate that the hollow cone nozzle is unfit for sooty fire suppression, or a high flux of water mist was needed for kerosene fire suppression. In all of the experiments, the flame was extinguished within a few seconds and these results are given in Figure 7 where the pool diameter was 20 cm, the pressure was 0.6 MPa, and *H* was about 2 m. Further tests for effects of fuel dilution were conducted after the fires were extinguished in every case, and the fuel could be ignited as for the original ignition. This may mean that the fuel dilution contributes less to fire extinction when water mist is used.



(a)

(b)

Figure 6: Temperature history of kerosene pool fire before and after the application of water mist.



(a) with no water mist (b) 10s after injection started (c) 25s after injection started (d) extinguished 34s after injection started

Figure 7: Visualisation of the interaction of water mist with kerosene pool fire.

CONCLUSIONS

This study has focused on the effectiveness of pool fire suppression with water mist, and a series of experiments were conducted for extinction tests of alcohol and kerosene fires under different conditions. Variables included different pressures, distances between fuel surfaces and nozzles, and different pool diameters. The following conclusions can be drawn from the experimental results: (1) the larger the distance between the fuel surface and the nozzle, the more difficult the fire extinction, and the effect grows even larger when the pressure is less than 0.6 MPa, (2) pressure and application rate of water have similar effects on fire suppression, but when the pressure is larger than 0.9 MPa, both the pressure and distance have less effect on fire extinction, (3) a larger pool fire is easier to extinguish than a small one as long as the fire lies within the spray cone, (4) a kerosene pool fire can be extinguished easier than an alcohol fire when a 1-7N-SS26 spray nozzle is used, (5) pulsed injection of water mist can improve its effectiveness because pulsed flow can provide increased droplet velocities and energies. Future work will focus on water mist characterization with a developed PIV (Particle Image Velocimetry) system and fire suppression with water mist produced by a high pressure system.

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REFERENCES

1. Braidech, M.M., Neale, J.A., Matson, A.F.,et al., The mechanisms of extinguishments of fire by finely dividedwater, Underwriters Laboratories Inc. for the National Board of Fire Underwriters, New York, 1955, p.73.

2. Ndubizu, C.C., Ananth, R., Tatem, P.A., et al., On water mist fire suppression mechanisms in a gaseous diffusion flame, Fire Safety Journal, 1998, 31:253-276.

3. Prasad, K., Li, C., Kailasanath, K., Optimizing water-mist injection characteristics for suppression of coflow diffusion flames, 27th Symposium (Int.) on Combustion, The Combustion Institute, 1998, p.2847-2855.

4. Mawhinney, J.R., Vollman, C.L., et al., NFPA 750 Standard on Water Mist Fire Protection Systems, 1996 Edition, p.750-5.

5. Mawhinney, J.R., Engineering criteria for water mist fire suppression systems, NISTIR 5207, March 1993, p.37-73.

6. Alpert, R.L., Incentive for Use of Misting Spray as a Fire Suppression Flooding Agent, Proceedings of Water Mist Fire Suppression Workshop, 1993, p.31-36.

7. Jones, A. and Nolan ,P.F., Discussions on the Use of Fine Water Sprays or Mists for Fire Suppression, J.Loss Prev, 1995, 8(1):17-22.

8. Mawhinney ,J.R., The role of fire dynamics in design of water mist fire suppression systems, Proc. the Seventh International Fire Science and Engineering Conference, Cambridge England, 1996, p.415-424.

9. Grosshandler, W.L. et al, Suppression within a simulated computer cabinet using an external water spray, Annual Conference of Fire Research: Abstracts, NISTIR 5499, 1994, p.75-76.

10. Gerard, G.B., Robert L.D., Joseph, T.L., Full Scale Tests OF Water Mist Fire Suppression Systems for NAVY Shipboard Machinery Spaces, Proc. the Seventh International Fire Science and Engineering Conference, Cambridge England, 1996, p.435-457.

11. Downie , B., Polymeropoulos ,C. and Gogos ,G., Interaction of Water Mist with a Buoyant Methane Diffusion Flame, Fire Safety Journal, 1995, 24:359-381.

12. Mawhinney, J.R. et al, Water-Mist Fire Suppression Systems for the Telecommunication and Utility Industries, A publication of NCR’s Institute for Research in Construction, 1994, 74:1-3.

13. Yao Bin, Fan Weicheng ,Liao Guangxuan ,Interaction of Water Mists with a Diffusion Flame in a Confined Space, Fire Safety Journal, 1999, 33:129-139.

14. Wang Xishi, Liao Guangxuan, Yao Bin, Fan Weicheng, et al., Preliminary Study on the Interaction of Water Mist with Pool Fires, J. of Fire Sciences, 2001,19: 1-17.

15. Yong Shik Han, Myung Bae Kim and Hyun Dong Shin, Experiments on The Interaction of Water Spray with Pool Fires, International Symposium on Fire Science and Technology, 1997,518-525.

16. Smith, A.C., and Lazzara, C.P., Water Mist Suppression of Fires in Underground Diesel Fuel Storage Areas, NISTIR 6242, 1998, 111-112.

17. Mawhinney, J.R., Engineering Criteria for Water Mist Fire Suppression Systems, NISTIR 5207, 1993, 37-74.

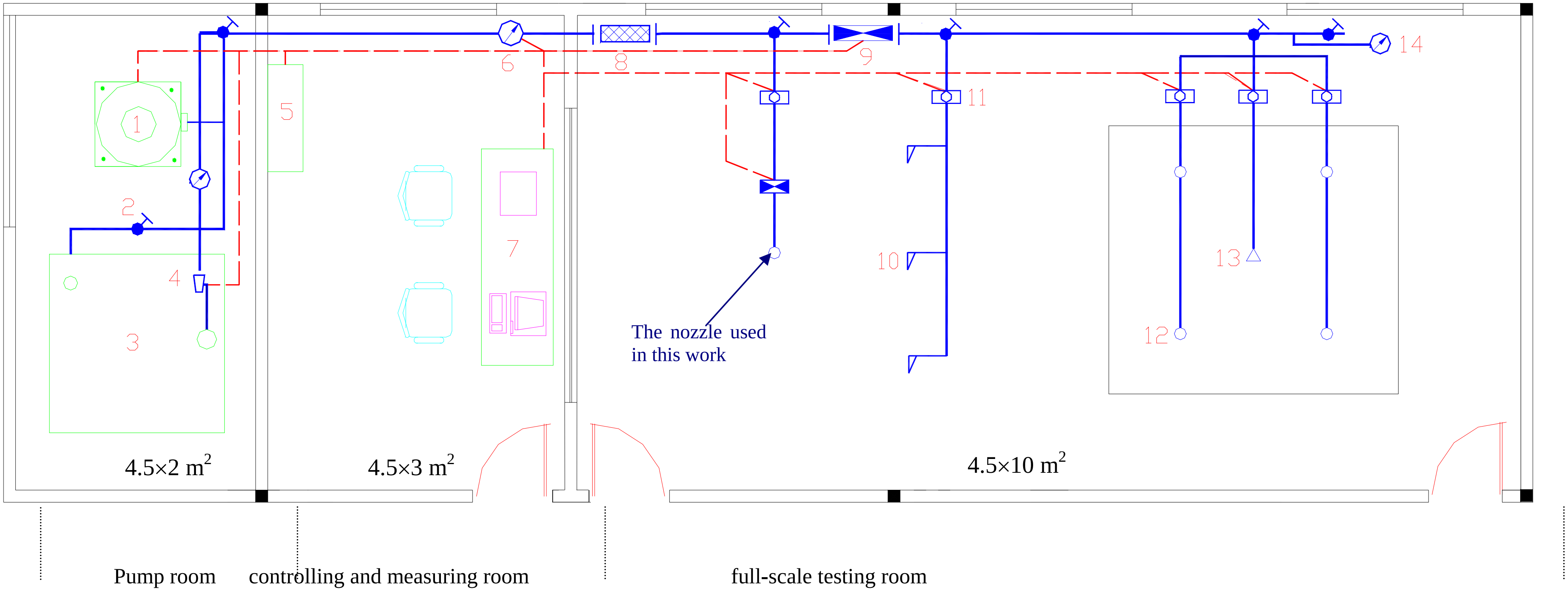
18. Bachalo, W.D. and Houser, M. J., Phase Doppler Spray Analyzer for Simultanous Measurements of Drop Size and Velocity Distribution, Optical Engineering, 1984, 23:583-586.

19. Qin, Jun., Yao, Bin., Liao, Guangxuan, Wang, Xishi, APV System for Flow Field Laser Diagnoses and Its Application, Fire Safety Science, 1999, 8(2):37-42.

20. Qin, Jun, Yao, Bin, Liao, Guangxuan, Wang, Xishi, Study on Volume Flux Measurement of Water Mist Field with APV System, J. of China University of Science and Technology, 1999, 29(3):320-325.

21. Hanauska, C.P., Back, G.G, Halon alternative fire protection systems, An Over View of Water Mist Fire Suppression System Technology, Hughes Associate Inc., Columbia, MD, 1993.

APPENDIX A: A plane figure of an experimental rig for fire suppression with water mist in State Key Lab. of Fire Science, USTC.



1 six-level pressure pump; 2 pipeline valve; 3 water tank; 4 floating ball; 5 variable frequency controller; 6 pressure sensor; 7 console; 8 water filter

9 turbine flux sensor 10 water curtain nozzle 11 electromagnetic valve 12 water mist nozzle 13 water spray nozzle 14 water pressure gauge