Characterization of an Effervescent Atomization Water Mist Nozzle and Its Fire Suppression Tests

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Abstract: A gas-outside-liquid-inside water mist nozzle based on effervescent atomization technology is designed, characterized and tested in this paper. The droplets size distribution and velocity under different operation pressures and gas-liquid-ratios(GLR) are measured with a Phase Doppler Analyser(PDA). The gas flow rate, liquid flow rate of the nozzle with one or seven orifices are also characterized under different operation pressure and GLR conditions, respectively. The results show that all of above parameters are mainly influenced by GLR, i.e., the larger the GLR is, the smaller the droplet size will be, and the liquid mass flow rate is exponentially increased with the increasing of GLR. The test results of fire suppression show that this gas-outside-liquid-inside effervescent atomizer works well for fire extinguishment except the cases where the liquid flow rate is less than about 70 kg/h or the gas pressure is lower than 0.3MPa.

Keyword: Effervescent atomization; Two-phase flow; Water mist; Fire suppression

1. Introduction

It is well known that the use of water mist for fire suppression was sparked since the first version of the Montreal Protocol which was introduced in 1987. This international commitment to protect the earth's ozone layer from further damage by chlorinated fluorocarbons (CFC's) , has driven about 20 years of testing to develop alternative fire suppression technologies to replace the chlorine- or bromine-based gaseous fire suppressants known as Halons. Water mist is not associated with such dangers to people in occupied areas and has received considerable attention as one of the potential methods for replacement of Halon 1301 and 1211 [1,2].

Fire suppression mechanisms of water mist are rather complex. The main mechanisms can be identified as fuel surface cooling, flame cooling and oxygen dilution and displacement. The sub-mechanisms include blocking of radiant heat transfer, reducing mixing concentration ratio of combustibles and oxygen, and dynamical influences [3-8]. The characteristics of mist droplets, such as droplet size distribution, velocity and spray density, are key factors which may mainly influence the fire suppression efficiency of a water mist system [9]. Generally, in order to produce relatively smaller mist droplets, traditional water mist nozzles, such as pressure jet nozzles and impingement nozzles, are applied with higher working pressures. Otherwise, coarser mist droplets should be produced, which may cause poor fire suppression effectiveness. However, effervescent atomization technology can generate finer water mist under relatively lower pressures.

Effervescent atomization technology is one of the twin-fluid atomization methods while it has better performance in terms of smaller drop sizes and/or lower injection pressures [10]. Roesler and Lefebvre conducted experiments to visualize the two-phase flow inside an effervescent atomizer as it approaches the exit orifice and the near-nozzle liquid break-up mechanism [11,12]. Huang et al. visualized the two-phase flow patterns inside the effervescent atomizer and studied the effects of superficial liquid velocity and GLR on transition between the flow patterns, known as bubbly flow, annular flow, and intermittent flow [13]. Sovania et al. had discussed the mechanisms of effervescent atomization and studied the effects of ambient pressure on its spray cone angle [14,15]. However, there is few studies have been performed focusing on characterization and its fire suppression efficiency of an effervescent atomization based water mist nozzle. Therefore, a gas-outside-liquid-inside effervescent atomizer was developed, characterized and tested for fire suppression under different operation pressure and GLR conditions in this work.

2. Experiment apparatus

As shown in Fig.1, the PDA system manufactured by TSI Co. in USA is used for mist droplet size and velocity measurement. A 5W Innova70 Ar^+ laser is used by the system and the light is splitted to 514.5nm, 488nm and 476nm by a Colorburst unit, so 3-D velocity of the droplet passing through the measurement volume can be obtained. A 7-hole plain-orifice with 1.5mm diameter effervescent atomizer was manufactured and used for fire suppression tests, while the case with only one orifice was considered for its characterization with PDA system, where other six orifices were blocked up. The overall length of the atomizer is approximately 160mm. The containment tube has the inner diameter of 40mm and 5mm wall thickness. The mixing tube has 6mm inner diameter and 2mm wall thickness. Twenty four gas injection holes with 1mm diameter are designed for injecting gas into the mixing tube. Each ring is spaced 8mm apart and rotated 45° from the neighboring ring. The last ring with the injection holes is located 80mm upstream of the exit orifice.

Fig.2 shows the schematic diagram of the water mist generation system with an effervescent atomizer. Two flowmeters and two pressure sensors coupled with some valves are used for determining flow rate of the nozzle under different operation pressure and GLR conditions.

Fire suppression tests were performed in a 3m×3m×3m confined space as shown in Fig.3. Six K-type thermocouples are directly placed above the fuel pan to obtain the flame temperature history before and after the application of water mist. A 0.22m diameter pan with a lip height of 0.04m is used for test of diesel pool fire suppression. Extinguishing time is determined by using a stop-watch which with a resolution of 1/100s. At the same time, a JVC DVM801 CCD camera was used to record the extinguishment processes for subsequent frame-by-frame analysis.

3. Results and discussion

3.1. Characterization of the effervescent atomization nozzle

The droplet size and velocity were measured by the PDA system, where the measurement volume was located 0.4m away from the orifice of the atomizer. Fig.4 and Fig.5. show the Sauter mean diameter (SMD) and its droplets size distribution of the atomizer with one orifice measured under different gas operation pressure (P_g) and GLR conditions, respectively. Fig.6 shows the axial and radial mean velocity of the droplets. The results obviously show that both of the droplets size distribution and the mean velocity are mainly influenced by the GLR, i.e., the droplet size will decrease and its mean velocity will increase as the GLR is increased, especially when the GLR is lower than 0.06.

The liquid and gas mass flowrate of the effervescent atomizer with one or seven orifices under different operation pressures and GLRs are determined, respectively.

As shown in Fig.7 and Fig.8, both of the liquid and gas mass flow rate are increased with increasing of the gas operation pressure, while the liquid mass flow rate is exponentially decreased with the increasing of GLR. Based on these experimental data, the relationship among the liquid mass flow rate, the GLR and the gas operation pressure can be derived [16]. To the case with one or seven orifices, the relationship can be expressed in Eq. (1) and Eq.(2) , respectively. Fig.9 gives the calculated results with these two equations.

$$M_l = 7.44 + 19.2P_g + (15.7 + 6.29\, e^{P_g/0.191})\, e^{-GLR/(0.0411+0.00113 e^{P_g/0.156})} \tag{1}$$

$$\begin{aligned} M_l = {} & 22.1 + \left(73.0 + 268P_g - 241P_g^2\right) e^{-GLR/(0.0556+0.0349 e^{P_g/0.256})} \\ & + \left(186 + 65344\, e^{-P_g/0.0360}\right) e^{-GLR/\left(-0.0266+0.275P_g-0.232P_g^2\right)} \end{aligned} \tag{2}$$

3.2 Fire Suppression Tests with the effervescent atomization nozzle

Tests of diesel oil fire suppression were conducted using the effervescent atomization nozzle with seven orifices. High pressure nitrogen was adjusted to 0.2MPa, 0.3MPa and 0.4MPa as gas operation pressures. The nozzle was set 1.50m, 1.75m and 2.00m above the fuel surface. Fig.10 gives the fire extinguishment time under different gas operation pressures and water flow rates, where the distance between the nozzle and the fuel surface is about 2.00m. Fig.11 gives a summary of the fire suppression test results which were averaged with at least 3 data. It is obviously shown that, to same gas operation pressure, the larger the distance is, the more difficult the fire can be extinguished. And to same distance, the fire can be extinguished easily when the gas pressure is higher. In addition, the results show that an optimization value of the water flow rate for fire extinguishing exists, and this value increases as the gas operation pressure increases.

Fig.12 shows the video pictures of the diesel oil fire before and after the interaction of water mist. Unlike the extinguishing process with a single fluid water mist nozzle, the flame can be enlarged at the beginning of water mist injection as shown in Fig12 (b). This can be explained that the stirring of the nitrogen gas and the evaporative expansion of water mist droplets enhance the mixing of the fuel vapor and the fresh air which being entrained by the injecting water mist. So the combustion will be enhanced before the temperature of the fire plume is cooled down. Generally, the fire can be extinguished within one minutes except the cases under which the nitrogen pressure or the water flow rate is not large enough. For instance, to the test cases of this work, it is difficult to extinguish the fire when the water flow rate is less than about 70 kg/h or the gas pressure is lower than 0.3MPa.

4. Conclusions

A new kind of effervescent atomization based water mist nozzle was designed and its fire suppression eficiency was tested in a 3m×3m×3m confined space. The droplets size distribution and velocity was measured with a PDA system, while the flowmeters and pressure sensors coupled with some valves were used for determining of the flow rate. Following conclusions can be drawn from the experimental results: (1) Both of the droplets size distribution and the mean velocity are mainly influenced by the GLR, i.e., the droplet size will decrease and its mean velocity will increase rapidly as the GLR is increased, especially when the GLR is lower than 0.06. (2) The liquid and gas mass flow rate are increased with increasing of the gas operation pressure, while the liquid mass flow rate is exponentially decreased with the increasing of GLR. (3) To the test cases of this work, there is an optimum water flow rate with which the fire suppression effectiveness is best, and when the water flow rate is less than about 70 kg/h or the gas pressure is lower than 0.3MPa, the fire can not be extinguished.

Acknowledgments

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References

[1] R.L.Alpert, in: A.N. Kathy and H.J. Nora (Eds.), Water Mist Fire Suppression Workshop, Report No. NISTIR 5207, Building and Fire Research Laboratory, 1993, p. 3l-36.

[2] A. Jones, P.F. NoIan, J. Loss Prevention Process industries 8(l)(1995)17-22.

[3] C. Cdubizu, R. Ananth, Fire Safety Journal 31(1998)253-276.

[4] X. Huang, X.S. Wang, X. Jin, G.X. Liao, J. Qin, J. of Fire Sciences 25(3)(2007)217-239.

[5] J.R.Mawhinney, B.Z. Dlugogorki, A.K. Kim，Proc. International Association for Fire Safety Science (IAFSS), Ottawa, Canada, 1994, p. 47-60.

[6] K. Prasad, C. Li, K. Kailasanath, Fire Safety Journal 33(1999)185-212.

[7] X.S. Wang, G.X. Liao, B. Yao, W.C. Fan, W.P. Wu, J. of Fire Sciences 19(1)(2001)45-61.

[8] X.S Wang, G.X. Liao, J. Qin and W.C. Fan, J. of Fire Sciences 20(4)(2002)279-295.

[9] W.D. Bachalo, in: A.N. Kathy and H.J. Nora (Eds.), Water Mist Fire Suppression Workshop, Report No. NISTIR 5207, Building and Fire Research Laboratory, 1993, p.75-92.

[10] T.C. Roesler, *An experimental study of aerated-liquid atomization*. PhD thesis, Purdue University, West Lafayette, 1988.

[11] T.C. Roesler, A.H. Lefebvre, Int. J. Turbo Jet Engines 6(1989)221-230.

[12] T.C. Roesler, A.H. Lefebvre, Proc. of the Meeting of the Central States Section of the Combustion Institute, Indianapolis, Indiana, 1988, Paper 3.

[13] X. Huang, X.S. Wang and G.X. Liao, Journal of Visualization 11(4)(2008)299-308.

[14] S.D. Sovania, P.E. Sojka, A.H. Lefebvre, Progress in Energy and Combustion Science 27(4) (2001)483-521.

[15] S.D. Sovania, E. Choua, P.E. Sojka, J.P. Gorea, W.A. Eckerleb and J.D. Croftsb, Fuel 80(3) (2001)427-435.

[16] X. Huang. *Study on the fire extinguishing efficiency of water mist produced by effervescent atomizer*. PhD thesis, University of Science & Technology of China, Hefei, P.R. China, 2007(in Chinese).

Figures

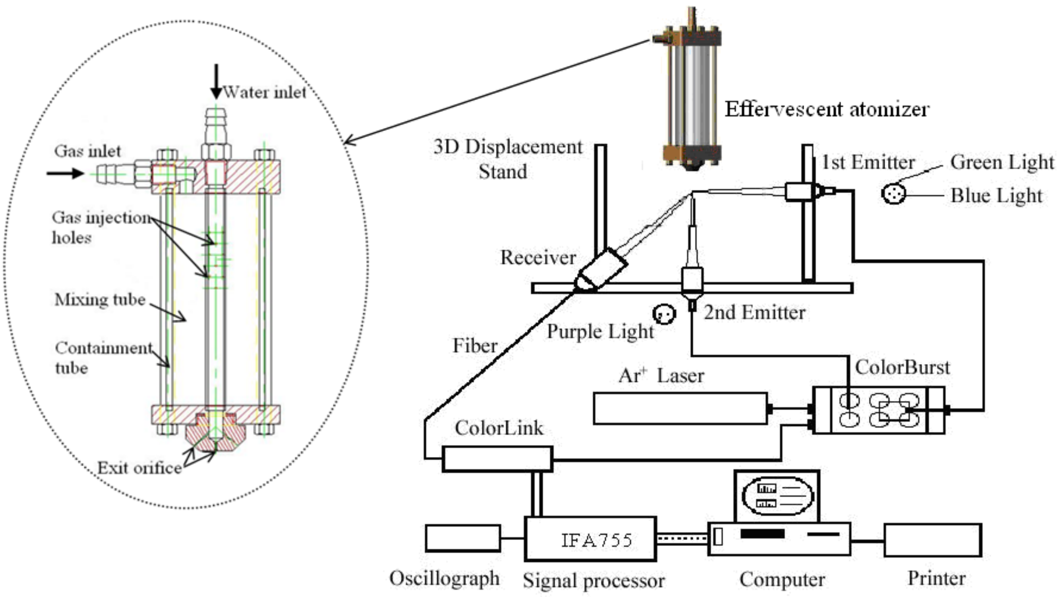

Fig. 1. Schematic diagram of mist droplet characterization with PDA system

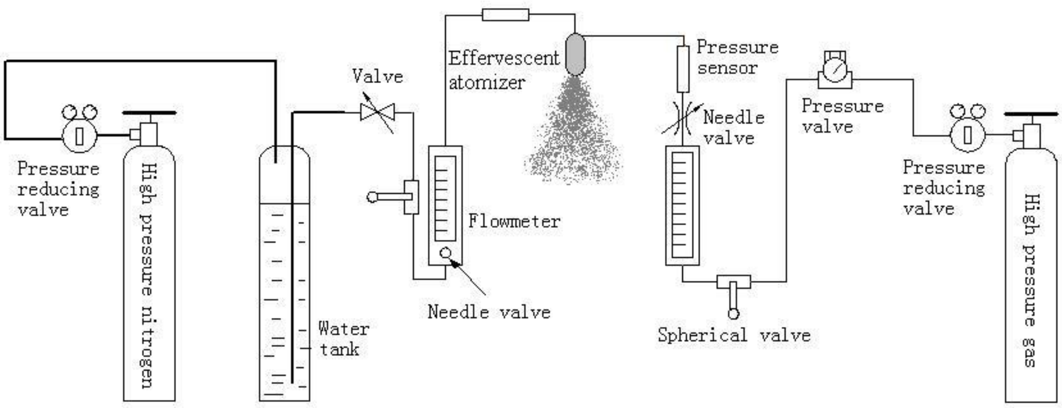

Fig.2. Schematic diagram of the water mist generation with an effervescent atomizer

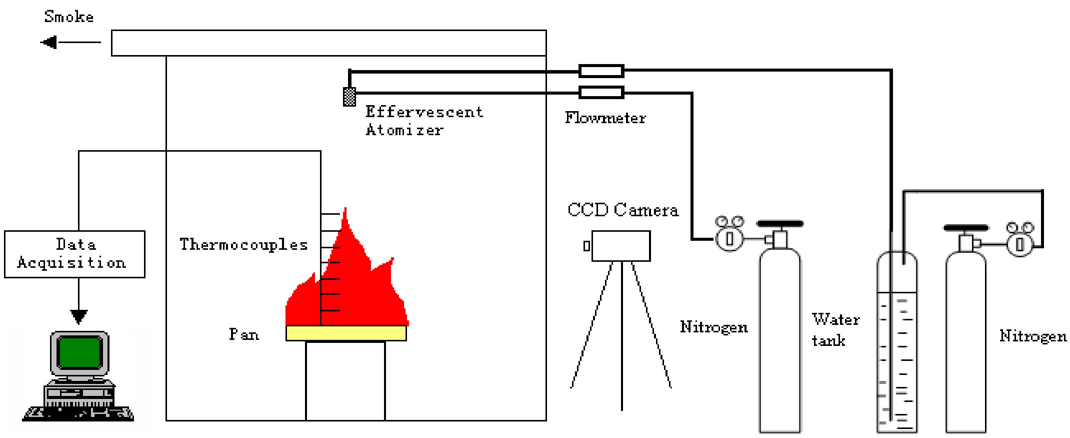

Fig.3. Schematic diagram of water mist fire suppression test with effervescent atomizer

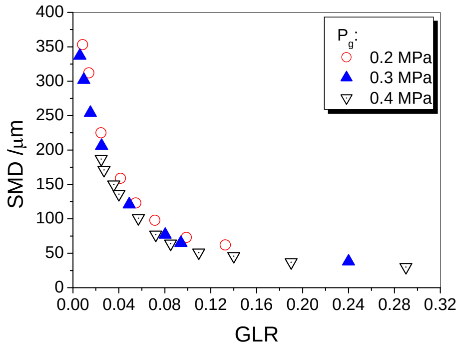

Fig.4. The Sauter mean diameter measured with PDA under different GLR conditions

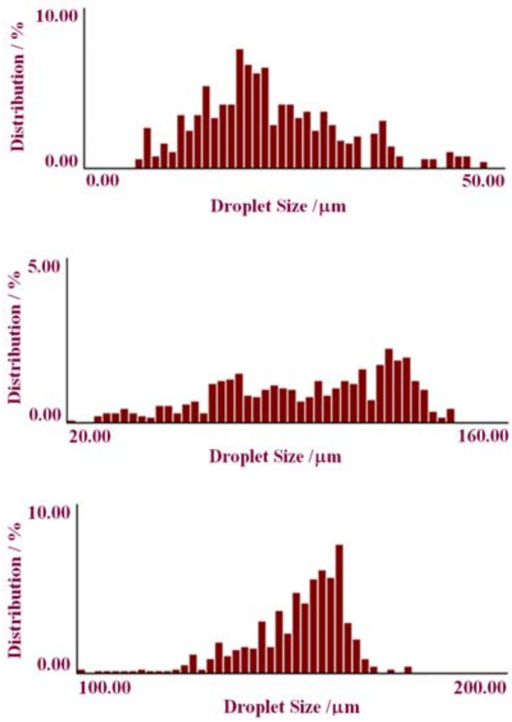

Fig.5. Droplet size distribution measured with PDA system: (a) Pg = 0.4 MPa, GLR = 0.29, (b) Pg = 0.4 MPa, GLR = 0.057, (c) Pg = 0.4 MPa, GLR = 0.036

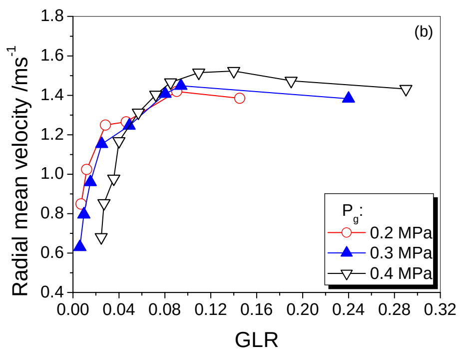

Fig.6. The axial and radial mean velocity of the droplets measured with PDA system:(a) Axial mean velocity, (b) Radial mean velocity

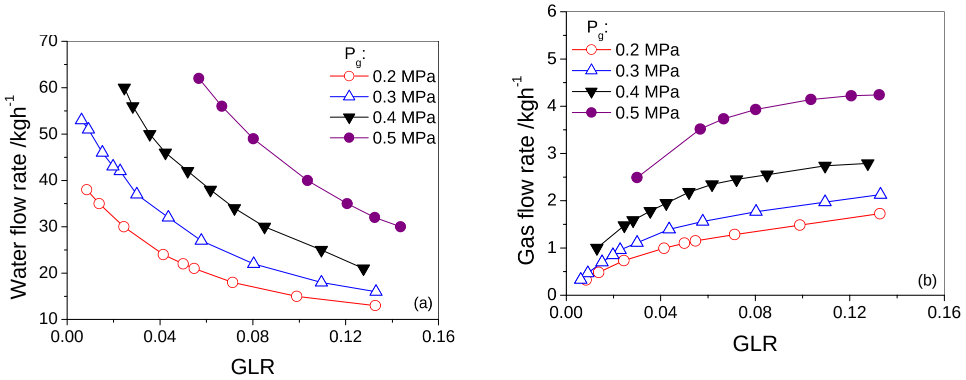

Fig.7. Flow rate of the effervescent atomizer with one orifice:(a) Water flow rate, (b) Gas flow rate

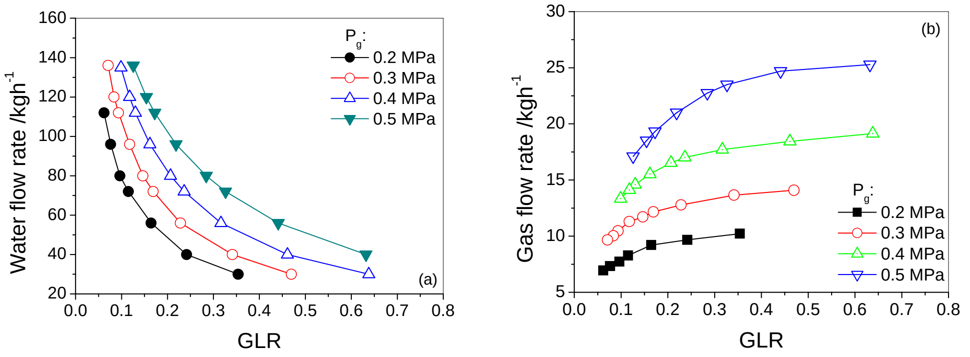

Fig.8. Flow rate of the effervescent atomizer with seven orifices: (a) Water flow rate, (b) Gas flow rate

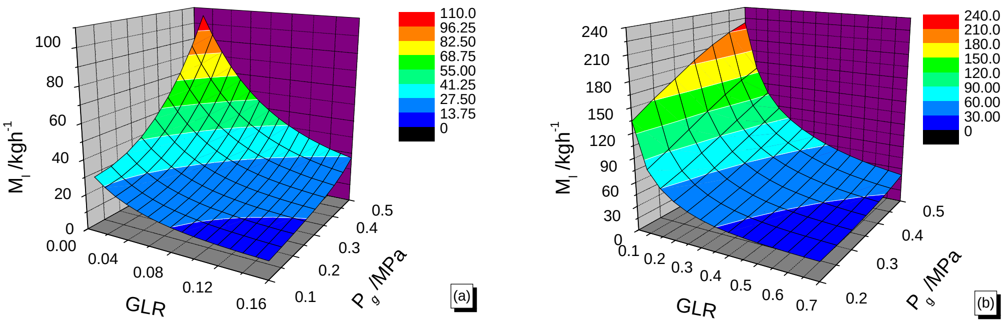

Fig.9. Calculated liquid flow rate the effervescent atomizer: (a) With one orifice, (b) With seven orifices

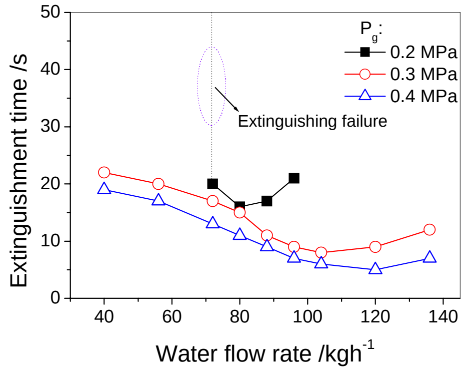

Fig.10. Extinguishment time under different gas operation pressures and water flow rates

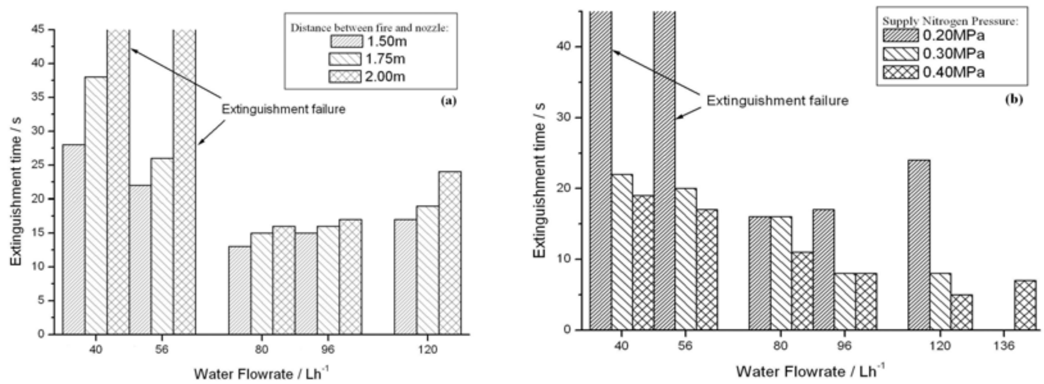

Fig.11. Test results of fire suppression with different water flow rates: (a) gas operation pressure is 0.20MPa, (b) distance between the fire and nozzle is 2.0m

Fig.12. Diesel pool fire behavior before and after the injection of water mist (gas pressure: 0.30MPa, distance: 2.00m, water flow rate: 80kg/h): (a) before water mist injected, (b) water mist injection started, (c) 6s after water mist injection, (d) 11s after water mist injection, (e) 14s after water mist injection, (f) 16s after water mist injection

Figure Captions

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Fig.3. Schematic diagram of water mist fire suppression test with effervescent atomizer

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(a) Water flow rate, (b) Gas flow rate

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