The effect of water spray temperature on effectiveness of water mist fire suppression systems

Amir Hossein Mahdavi, Amir Omidvar*, Reza Mehryar
Department of Mechanical and Aerospace Engineering, Shiraz University of Technology, Shiraz, Iran
(*Presenting Author: Tel/Fax: +98 711 7264102, Email: omidvar@sutech.ac.ir)

Abstract
There has been considerable interest in the last few years in developing enhanced water mist fire suppression systems. In this study the impact of initial droplet temperature on water mist effectiveness has been investigated. A simple Lagrangian model has been developed to study the dynamics and evaporative characteristics of the water mist droplets. The mathematical model has been verified by some experimental results where a good agreement was found. Results indicate that, the preheating of the water droplets can considerably improves the evaporative characteristics of the water mist technology.
Keywords: water mist, evaporation, fire suppression

1. Introduction

At present, there is a significant interest in water based suppression systems such as sprinklers and water mist. For certain fires, applying water in the form of ultra fine spray or mist can be particularly effective and reducing water usage. Water mist fire suppression systems are attractive as their high cooling capacity, low cost and less environmental impact. Hence, a vast amount of researches has been done to improve the efficiency of the water mist systems [1,2,3]. The water-mist absorbs a considerable amount of the explosive energy from the fire and surrounding area through vaporization. In fact, evaporative cooling and oxygen displacement by the resulting vapor suppresses the flames. It is clear that the injected droplet sizes have a major effect on spray effectiveness and its cooling rate [4]. Smaller droplets have a relatively high surface area, resulting in enhanced heat transfer and more quick vaporization. Droplet sizes can be controlled by atomization and breakup processes. These processes are strongly influenced by surface tension forces which are intensely depends on initial droplet temperature. In the present study the impact of initial droplet temperature on water mist effectiveness has been investigated. For this aim, the evaporation rate of droplets with different initial diameters and temperatures has been studied.

2. Theoretical Analysis

For the simulations performed in this paper, we are interested in water spray atomization characteristics and the droplet vaporization rate. In order to simplify the atomization process we assume that the water is already fully atomized at the nozzle exit. The distribution of droplet sizes can be calculated by mathematical functions [5]. The initial Sauter Mean Diameter (SMD) of droplets at the nozzle exit can be approximated by [5]:

$$SMD = 2.25\sigma^{0.25}\mu_l^{0.25}\dot{m}_l^{0.25}\Delta p^{-0.5}\rho_g^{-0.25} \quad (1)$$

where, σ, μ_l and $\dot{m}_l$ are the liquid surface tension, liquid viscosity and injection mass flow rate, respectively. In this equation, Δp is difference of injection pressure and the environment pressure and ρ_g is the ambient gas density.

The Lagrangian method was used to track the water droplets trajectories leaved the nozzle exit. The equation of motion for any moving droplets is described by Newton’s second law considering drag force [6].

It is also assumed that Basset force and the fore due to fluid pressure gradient are negligible.

The mass evaporation rate from water droplet surface can be calculated by a zero dimensional model described in [7]. It is derived from the equilibrium of vapor mass fraction boundary condition at the surface of the droplet with respect to time.

3. Results and discussion

In order to validate the mathematical model, the simulation results are compared with the experimental data reported in Ref. [7]. As shown in Fig. 1, the calculated data for droplet evaporation are in good agreement with the mentioned experimental values.

In this section a specified mass of water is injected to the quiescent environment with various temperatures. It is evident that the size distribution of water droplets at the vicinity of the injection hole is influenced by the initial temperature of water drops. The particle size of the water droplets in the mist is a critical parameter as this directly influences the effectiveness of the spray.

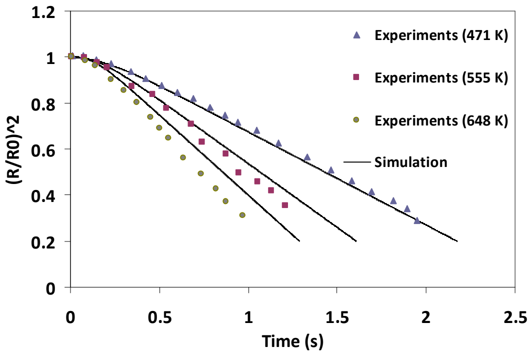

Fig 1. Comparison of simulated and experimental data [5] for (P=1.0 bar)

A plot of relative Water Vapor Mass Fraction (WVMF) of a water spray for various initial droplet temperatures has been shown in Fig. 2. WVMF expresses the ratio of mass of vaporized water to the total injected mass. In order to facilitate the comparison of the results, in Fig. 2 the relative WVMF has been introduced and depicted. Relative WVMF is defined as the ratio of WVMF of the heated droplets to a reference value (WVMF at T=280 K). It can be observed from Fig. 2 that the WVMF of liquid droplets increases with increasing of initial droplet temperatures. In other words, preheating of the injected water can improve the evaporative performance of the water mist technology.

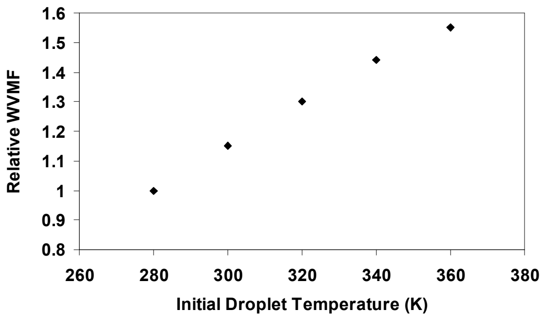

Fig. 2. Relative Water Vapor Mass Fraction (WVMF) for various initial droplet temperatures

Fig. 3 demonstrates the relative evaporative power (E.P.) of fine water droplets under various initial temperatures. In this paper E.P. is defined as:

$$\text{E.P.} = \frac{\text{Absorbed Energy by Evaporation of Water Droplets}}{\text{Evaporation Time Scale of the Droplets}}$$

Similar to the definition of relative WVMF, the relative EP is defined as the ratio of EP of the heated droplets to a reference value (E.P. at T=280 K).

As shown in Fig. 3, the evaporative power of the water mist droplets increases by preheating the water.

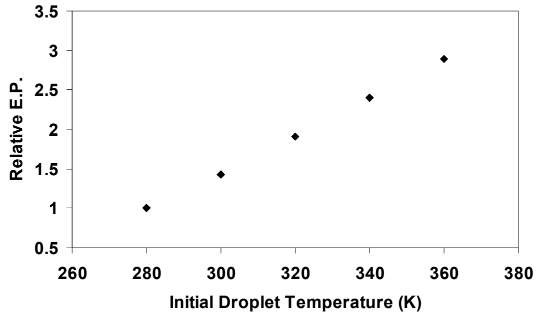

Fig. 3. Relative Evaporative Power (E.P.) for various initial droplet temperatures

4. Conclusion

In this study the impact of initial droplet temperature on water mist effectiveness has been investigated. Results show that, preheating of the injected water significantly improves the evaporative characteristics of the water mist.

5. References

[1] Z. Xiaomeng, Z. Biao, J. Xiang, Study of fire-extinguishing performance of portable water-mist fire extinguisher in historical buildings, J. Cultural Heritage 11 (2010) 392-397.

[2] W.Y. Chang, P.K. Fu, C.H. Chen, Y.L. Shu, Performance evaluation of a water mist system in semiconductor wet bench fires, Process safety and Environmental Protection 86 (2008) 213-218.

[3] L. De-pin, C. Zu-ming, Numerical simulation of water mist fire suppression technology, Procedia eng. 11 (2011) 205-209.

[4] P.E. Santangelo, Characterization of high-pressure water-mist sprays: Experimental analysis of droplet size and dispersion, Experimental Thermal and Fluid Science 34 (2010) 1353-1366.

[5] C. Baumgarten, Mixture formation in internal combustion engines, Germany, Springer 2006.

[6] Y.F. Li, W.K.Chow, Study of water droplet behavior in hot air layer in fire extinguishment, Fire technology 44 (2008) 351-381.

[7] S.S. Sazhin, W.A. Abdelghaffar, E.M. Sazhina, M.R. Heikal, Models for droplet transient heating: Effect on droplet evaporation, ignition, and break-up, Internal. J. Thermal science 44 (2005) 610-622.