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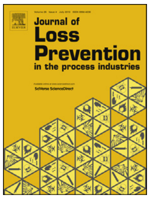

# Optimization of water mist droplet size by using CFD modeling for fire suppressions

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## ABSTRACT

With recent developments in sprinkler technology, water mist system is becoming more and more useful in fire suppressions. However, regulations on water mist system are inadequate, because most of them are based on experimental results. The computational method is an efficient way to make validations and optimize droplet size distribution of water mists. In this work, a computational fluid dynamics (CFD) model and a fire dynamics simulator (FDS) code were used to analyze effects of fire suppression using water mists with different droplet sizes. By using numerical methods, the interaction between water mist and fire could be better understood. The range of droplet size was determined based on the NFPA 750 standard. The fire extinguishing times of different droplet sizes were calculated by running the FDS code. After running the FDS code for different droplet size ranges, the optimal droplet size range was obtained. With the increase of droplet sizes, the fire extinguishing time first fluctuated and then increased. An optimal droplet size range was determined to have the best suppression effectiveness with the shortest fire extinguishing time and less water consumption. It should be noted that there are limitations for the CFD study since the real circumstance of fire is more complicated.

## 1. Introduction

The Montreal Protocol was enacted in 1987 which regulated Halon fire suppressants should be replaced by the start of the 21 century. Since then, water mist fire suppression system has been considered as one of the most effective candidates to replace Halon. According to the current NFPA 750 standard (National Fire Protection Association, 2015), 99% of the water mist droplet size should be less than 1000 μm. Although the standard gives designers a wide flexible range of droplet size, it is not beneficial in real fire scenes because the suppression time usually plays a vital role in eliminating of injury and property loss. In order to have better suppression effects, an optimal droplet size is essential to design a water mist fire protection system.

In order to determine the optimum water mist droplet size, experiments have been carried out by different researchers. Ultra-fine water mists (<10 μm) discharged with multiple floor outlets around a 120 kW gas fire in a 28 $m^3$ compartment have been studied (Adiga et al., 2007). The work indicated that the ultra-fine water mist behaved like a dense gas which could be used in the case of total flooding situation. A two dimensional methane diffusional flame was studied by using a modified Wolfhard-Parker burner along with the mist generation chamber (Ndubizu et al., 1998). The results showed that the gas-phase cooling is more dominant than oxygen dilution with a mean diameter of 60 μm. The size range between 100 and 1000 μm was regarded as the most effective size range for firefighting (Grant et al., 2000). However, the droplet size may be too small (<100 μm) with less weight that could easily spread out by flames and vapors. An advanced concept was suggested that the water droplet size distribution should have a mean diameter of 80–200 μm and 99% of the volume should be smaller than 500 μm (Ramsden, 1996). This definition is more suggestive for providing such a narrower range. Similarly, an optimal mean diameter of 350 μm was proposed theoretically by using the maximum heat transfer coefficient (Herterich, 1960). A summary of the optimum droplet sizes distribution was made which suggested most of the effective suppression droplet sizes are smaller than 500 μm (Andrews, 1992).

It is not always ideal to conduct field experiments of fire suppressions, not only because of a high cost and demand of man

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power for providing real scene situations, but also because of unrecoverable fire damages (Zhang et al., 2015; Gopalaswami et al., 2016). Computer modeling has been recognized as an alternative way in understanding and validating most of the engineering problems. This kind of cost effective and time efficient software could assist the fire protection system design and evaluation. The modeling can show a process in a visual way which could enhance the understanding of fire behaviors. The commonly used models for studying the interaction between water mist and fire are CFD based models. FDS and CFX are two main CFD based software that incorporated most of the necessary elements from thermodynamics and fluid dynamics (Hurley, 2015). As for the studying of some specific attributes of fire and water mist, FDS has been considered as the best simulation tool for fire research with some available built-in fire codes.

A lot of models have been set up by various researchers. A 4.0 m × 4.0 m × 2.3 m enclosed compartment with a fire source and water mist fire suppression system was simulated by using FDS (Kim and Ryou, 2003). The results indicated two kinds of regimes in the smoke layer: initial sudden cooling and gradual cooling. This model was further extended into a study of fire suppression mechanisms of different droplet size water mist (Ferng and Liu, 2010). The results showed that the fire extinguishing time first increased and then decreased with increase in droplet size. The interaction between a heat release rate of 6 MW fire plume and water mist in a 10 m × 10 m × 5 m brick-walled room was simulated by using FDS (Yang et al., 2010). Four water mist nozzles were placed at 4 m height from the floor with a mean diameter of 46 μm and a flue spray was placed 1 m above the floor. The performance between pool fire and water mist suppression inside a 4.3 m × 4.2 m × 3.05 m parallelepiped room was modeled (Jenft et al., 2014). Four water mist nozzles injected the droplets with a sauter mean diameter (SMD) of 112 μm. A hollow cone water mist nozzle on the top of a 2.92 m × 2.92 m × 2.20 m room was simulated by using FDS code (Husted, 2007).

This study will use fire dynamics simulator (FDS) to simulate the fire growth along with water mist in order to study the effects of droplet sizes. In water mist fire suppression system design, droplet size plays a vital role in determine the fire extinguishing time. By studying the effects of droplet size, it will be beneficial for the manufactures to produce the most efficient water mist nozzles for the industries.

## 2. CFD modeling

### 2.1. Heat release rate

The Heat Release Rate (HRR) is the single most important parameter to characterize a fire (Babrauskas and Peacook, 1992). Generally, HRR can be regarded as the driving force of a fire because most other variables always have some relations with it. Methane was selected as the burning fuel, because it is the major component of natural gas. The production of natural gas is abundant, which can be used as the fuel for cooking and for heating of homes and commercial buildings. In this work, 200 kW was used as the HRR of methane fire.

### 2.2. Parameter setup

The scale of the tested room was a compartment with dimensions of 4.0 m × 4.0 m × 3.0 m and four-sided solid concrete walls. The cell size was set up as 0.1 m hence it could be easier to calculate manually in the simulation process (Stroup and Lindeman, 2013). The final mesh was 40 × 40 × 30 with a total of 48,000 cells. A rectangular methane table (HRR of 200 kW) with an area of 1.0 m × 1.0 m was placed 0.5 m above the floor in the center of the room. The water mist nozzle was placed in the center of the ceiling with its cone angle of 60° and the droplet velocity of 5 m/s. It is not related to the flow rate as the flow rate only determines the droplet density at the time when water mist nozzle emits. The flow rates were set up as 5 L/min, 10 L/min and 15 L/min separately in three series of simulations. The droplet particles were defined as water vapor with reference temperature of 50 °C. The reference temperature is the mass fraction of the burning material decreased at its maximum rate. The sampling factor is used to reduce the size of the particle in the output simulation files, the value of which was one. The water mist nozzle started to emit water mist at the time after the fire lasts for 5 s. Three thermocouples were set up in the center of the room above the methane table with heights of 1.0 m, 1.5 m, and 2.0 m from the floor, respectively. A clock was set inside the system in order to make sure the nozzle would start on time after 5 s. The droplet diameter was changed in each of the simulation in order to investigate its influence on the suppression effectiveness. Fig. 1 shows the general schematic of the simulated room. For other parameters in the model, the default values were used as given in the FDS manual.

The limitations of this model are primarily due to the attribute of FDS as it only deals with low-speed, thermally-driven or buoyancy-driven flows. The real circumstance of fire is more complicated than the theoretical model with more uncontrollable variables, such as the destruction of the structure, influence caused by ventilation system, etc. However, by running the FDS code, it could provide some basic preliminary results with the fire scenarios. A typical size range of water mist droplet could be beneficial for the future experimental studies.

## 3. Results and discussion

### 3.1. Temperature distribution

In order to give a general understanding of the simulation in water mist fire suppression, some of the screen shots were captured from the FDS Smokeview. Fig. 2(a) is the temperature profile after the fire started. Fig. 2(b–f) show the interaction between water mist and fire after the water mist nozzle activated. All of these screen shots were taken at the plane of y = 2.0 m with a droplet size of 100 μm and a flow rate of 5 L/min.

As shown in Fig. 2(a) on the temperature reference column, the

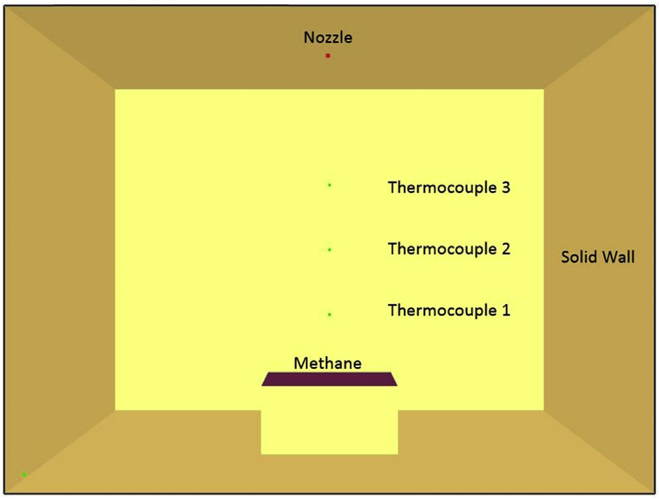

**Fig. 1.** Schematic of the simulated room.

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