# CHAPTER 1

# INTRODUCTION

## 1.1 Background

Since 1960, Halon system has been used as a fire extinguishment in computer rooms and communication equipments. Since then, Halon becomes a common-used fire suppression agent because of its non-electric conduction, quick extinguishing of fire and no harm on protection objects, etc. However, such agents are being phased out due to their destructive effects of halogen atoms on the atmospheric ozone layer and were banned on the Montreal protocol in 1987. Therefore, scientists and engineers have made a lot of efforts on the researches and developments for the new fire suppression agents, such as water mist, compressed-air-foam, and aerosol and gas produced by generators, as replacements for the existing equipments. The present work is interesting in the application and performance evaluation of water mist system.

The term “water mist” refers to fine water sprays, in which 99% of the volume of the spray droplets is with the diameters less than 1000 microns. However, [1] clarified that this value must be determined from a measurement of “flow-weighted” cumulative volumetric distribution, but not a single point measurement. The study and description of the fundamental principles of extinguishment of solid fuel fires by water mist can be traced back to the mid-1950s in the work of Braidech et al. [2]. They identified flame cooling and oxygen displacement as the dominant mechanisms in water mist fire suppression. Recent investigations by Mawhinney et al. [3], however, suggested that there are additional mechanisms in water mist fire suppression, such as the provided radiation attenuation, dilution of flammable vapors, and direct impingement wetting and cooling of the combustibles. In full-scale tests, some fires were extinguished predominantly through heat extraction (cooling) and others predominantly via displacement of oxygen. The difference depends on whether the fire was poorly or well ventilated and the properties of the fuel.

Water mist fire suppression systems have demonstrated a number of advantages, such as good fire suppression capability, no environmental impact, and non-toxicity [4]. For these reasons, water mist had been considered as an ideal alternative for halon. However, water mist dose not behave like a total flooding agent, thus the fire suppression effectiveness of water mist depends on the potential size of the fire, properties of the combustibles, and the degree of obstruction, as well as the water mist characteristics.

In the high buildings, shopping centers and hospitals etc. have machinery spaces or generator rooms, which are usually located on the basement of buildings. When fire is occurred in the place, the self-activating fire extinguishing systems on the building are the only fire protection means. For the reason, the fire extinguishing performance of fire suppression system becomes very crucial at such space. The main sources of potential fire in machinery spaces are the Class B flammable or combustible liquids used in various processes or pumps. Examples of machinery spaces include test cell for internal combustion engines fueled by gasoline or diesel fuel, electrostatic coating, dipping or cleaning processes using flammable liquids, pumps, piping, containers under pressure that might be used for hydraulic pumping equipment, generators or chemical processes. In summary, the hazards of machinery spaces are classified as the areas that contain flammable processing hazards with Class 1, 2, or 3 of flammable liquids, specified in NFPA 325 [5] and incidental Class A combustibles.

Since 1990, a number of manufacturers and research organizations have been involved in developing water mist technology for the protection of machinery compartments. For an example, the combined efforts of engineering and research disciplines by FMRC have enabled kept it up with the demands from the sector of water mist system manufacturers for an increasing number of approved water mist applications. The company is continually developing new application tests to help the expansion in the use of water mist fire protection systems into new areas, such as the turbine enclosures, machinery enclosures, industrial oil cookers, computer rooms, etc.

## 1.2 Literature Review

The extinguishing performance of water mist system in this kind of space is mainly determined by fire size, the degree of obstruction, ventilation conditions, compartment geometry, spray characteristics of the water mist systems and their configuration in the compartment. Pepi [6] showed that the large spray fires of 6 MW at low pressure were extinguished much faster than the smaller fires of 1 MW at low pressure.

The extinguishing times ranged from 23 to 175 s for large fires and from 5 min 24s to 21 min 10s for smaller ones, depending on the type of nozzle used and compartment size. The tests carried by Bill et al. [7] showed that, when the nozzles are installed at a 5m height and 1.5 m spacing in a large test facility (2800 $m^2$ area and 18m height), without any additional enclosure surrounding the nozzles, or only a ceiling being placed directly over the nozzle, fires (1 to 6 MW shielded and unshielded spray fires, a wood crib fire and a 2 $m^2$ pan fire) are not extinguished by either high pressure (69 bar) or low pressure (12 to 15 bar) water mist systems, even if the number of the nozzles is increased from 30 to 100. They also showed that increasing in the engine-room volume and ceiling heights reduces the effectiveness of water mist in fire suppression, because it is difficult to deliver a sufficient concentration of fine spray to the fire location.

The full-scale tests carried by Back et al. [8] in a 960 $m^3$ space showed that the extinguishing performance of the water mist system is improved by installing the nozzles at two elevations in the compartment. In such arrangement, the water mist system is capable of extinguishing all of the unventilated fires in less than 25s by using less than 100 liters of water. The study on the feasibility of local water mist applications for machinery protection by Hansen [9] showed that water mist system located above the fires has a better extinguishing performance than that of one located beside the fire (90 percent of successful spray fire extinguishment verses 5 percent). Furthermore, the nozzles located directly below the overhead have the better extinguishing performance than these of 2m below the overhead. It because that with such arrangement, more water vapors can be produced in the hot layer and the steam and vitiated gases in the upper layer are redirected more effectively back to the fire which reinforce the water mist capability against the fires.

The water mist effectiveness is further affected by an opening in the compartment due to the leakage of steam and hot gases and the inflow of fresh air. However, water mist still can demonstrate a better effectiveness in extinguishing ventilated fires than that of gaseous agents, such as halon, $CO_2$ and gaseous halon replacements. Dundas [10] indicated that a 37% of failure rate for total flooding Halon or carbon dioxide systems was attributed to the leakage of extinguishment agents from the protected compartment through the openings or vents.

Studies on low-pressure water mist systems of Pepi [11] showed that the ventilation fires can be extinguished eventually but the extinguishing time is increased by 30% to 70%. By increasing the number of nozzles in doorway from 2 to 4, the water mist effectiveness against ventilation fire is increasing due to an increase in the density of water mist around the opening. The full-scale tests carried by the U.S Navy [12] showed that when three doors in the compartment are kept open, the extinguishing time has a slight increase for small fires whereas it has no change for large fires. Zhigang Liu et al. [13] showed that the ventilation influence on the effectiveness of water mist is dependent on the fire location in the compartment and the characteristics of the water mist system used. For the single-fluid/high pressure water mist system, which can produce strong dynamic mixing by its high water spray momentum, only the fire extinguishment near the opening area are influenced by the opening door. On the other hand, the extinguishment of other fires located far from the door is not affected by the opening. For the twin-fluid/low pressure water mist system, producing a lower water spray momentum, the air from outside of the compartment can penetrate more deeply into the compartment and influence the extinguishment process, resulting in an extension of extinguishing time.

Scientists [14] in the Fire-Risk Management Program at the National Research Council of Canada's Institutes for Research in Construction have concluded a preliminary study. It shows that if the water mist is cycled on and off, the system achieves better results than it dose with a steady discharge of mist. The full-scale cycled discharge tests carried by Kim et al. [15] showed that the use of continuous water mist discharge can not extinguish the shielded round-pan fire under forced ventilation condition, whereas the use of the cycled water mist discharge can extinguish the same fire at 168 s. It was also observed that the minimum oxygen concentration measured in the cycling discharge test is 16% and the maximum CO2 concentration measured was 3.3%. For the shielded heptane spray fire under forced ventilation conditions, both the continuous and cycling water mist discharge can extinguish the fires from 227 to 510 seconds and the water requirement from 4.3 liters/$m^2$ to 15.6 liters/$m^2$. With the cycling water mist discharge, the gas temperature near the ceiling is higher than that of continuous discharge case. When the water mist discharge stops, the suppressed fire is quickly recovered and the thickness of the hot gas near the ceiling increases. As the water mist discharge activates again, more water vapors are produced in the compartment, enhancing the fire suppression effectiveness.

Erdem et al. [16,17] carried out the fire tests in an 80 $m^3$ enclosure by applying the fine water spray system, employing 5lpm (nominal) dual fluid nozzles operated by air and water. Six nozzles were installed on the ceiling and eight were mounted on the sidewalls parallel to the turbine axis. Water is sprayed in a cyclical fashion: 20 seconds on, 20 seconds off, and then 20 seconds on. The fine water spray system extinguished the fires and successfully fulfilled the requirements of the FMRC fire performance test protocol.

## 1.3 Scope of Present Study

The full-scale test scenarios in this thesis are based on the test standard of machinery space by FMRC fire performance test protocol [18]. It assumes that the damper does not work well when the fire is detected. There are three fire protection means in the study, which are non-protection, conventional sprinklers and high-pressure water mist fire suppression system, respectively. The tests of high-pressure water mist system contain two designs, which one is using 6 high-pressure nozzles and the other one is using 4 high-pressure nozzles. Its purpose is to evaluate which design has a better fire suppression effectiveness. The main purpose for these series experimental tests are to compare the fire extinguishing performance of high-pressure with that of conventional sprinklers by the corresponding measured temperature and CO concentration distributions, and the smoke opacity change on the test space. It also intends to know if the obstructions of fire source make any influence on the fire extinguishing performance of water mist system.

This part of experiments is to study the fire extinguishing performance of water mist on the shielded/unshielded pool fires.