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Performance Study of Mobile Fire Extinguishing Equipment using High Pressure Water Mist in Health Care Facilities

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Abstract

Personnel inside health care facilities are mostly at a disadvantage during evacuation, therefore in the event of a fire, evacuation would possess certain difficulties and result in serious consequences. Use of conventional fire hydrants for fire extinction could damage equipment because of the amount of water used. To avoid this, the amount of water used was a key consideration during this study besides fire extinction performance.This research used newly-developed mobile high pressure equipment and nozzle A with a K value of 3.7, and extinguished three standard wood cribs (7.5 MW), its performance being superior to that of the equipment used by the NRIFD (National Research Institute of Fire and Disaster).Using the equipmentat a pressure of 49.3kgf/cm^2 and discharge flow rate of 26 LPM, the time needed for extinction was 68 s, 76 s, and 60 s,without any recrudescence within 2 min afterwards. Calculations showed that this systemonly required 33 L of water for extinction, 27% less than the indoor hydrant, but was still effective, and it also showed no leakage of electricity under operation pressure and discharge flow rate. This research is a first to quantifiably analyze and compare the performance between mobile high pressure water mist equipment and indoor hydrants.

Keywords: Type 2 indoor hydrants; K value; Wood cribs; Fire extinguishing equipment; Discharge flow rate

Introduction

Health care facilities mostly consist of personnel that are at disadvantages during evacuation, if a fire were to occur and not be extinguished within a short amount of time, personnel evacuation would become a severe issue. Bish et al. [1] concluded that not only would the evacuation routes demand specific planning, the allocation of manpower and status of alternative care facilities would also require careful thought. During evacuation of patients in health care facilities, the decision of which patients should be prioritized is an issue which is controversial and lacks consensus [2]. In 2017, a fire occurred in a healthcare center in Taoyuan, Taiwan which killed 4 and injured 13.

One of the reasons for this tragedy was because of the overwhelming ratio of patients over medical staff, which inhibited effective management during an emergency situation [3]. Therefore, this research viewed fire extinc- tion as one of the methods towards solving this issue, however many difficulties were presented due to the num- ber of people and electronic equipment within these institutions. The use of inert gases for fire extinction could result in suffocation, while dry chemical extinction could damage electronic equipment and also affect surround- ing personnel and patients under surgery. The most commonly used water spray systems use large amounts of water to extinguish fires, however large amounts of water could potentially damage vital equipment. Because of this, many studies have been aimed towards increasing the operating pressure, atomizing the water column or creating water droplets to perform fire extinction tests and assess the viability of water spray or water mist.

Chang et al. [4] used spray nozzles under 3.43 bar and 360 LPM in a full scale tunnel test, successfully mit- igating the heat and radiation created by a 6 m2 pool fire, verifying the effects of water spray within tunnels.

To study the performance and limits of mobile water mist systems, Liu et al. [5] conducted full-scale fire tests using kitchen oil, n-heptane, and class A fire materials while using 0.7 – 4.4 GPM and 0.71 – 6.3 GPM sprin- kler nozzles during the tests. It was discovered that under the three fire tests mentioned above, water mist could effectively extinguish the fires. Studies by Gupta et al. [6] saw mist generated by a pair of twin-fluid atomizers installed in the center of the ceiling. 4 – 8 bar nitrogen and 104 - 136 LPM discharge flow rate discharged water at 0.18 – 0.22 LPM. It was discovered that extinction times were shortened when water mist pressures were stable. Li et al. [7] investigated suppression of n-heptane pool fires using water mist under different longitudinal ventilation velocities in a long and narrow space. Mechanism studies showed that the coupling effect of dilution, replacement of oxygen, and fuel surface cooling were the main mechanisms for extinction.

Qin et al. [8] indicated that water mist systems were affected by location, momentum, droplet size, confined space volume, building compartments, and fuel type, to name a few. To evaluate the performance of water mist systems while considering the factors mentioned above, the NRIFD [9] used direct dual spray nozzles and two phase flow nozzles on one set (2.5 MW), two sets (5 MW), and three sets (7.5 MW) of wood cribs. The discharge flow rate of the direct dual spray nozzle was 180 LPM, while the two-phase flow nozzle was 40 LPM. During the tests, the performance of water mist nozzles on one and two wood crib fires was positive, but the system was ineffective for three cribs.

Ho [10] proposed that for water spray systems, a large discharge flow rate and small droplet sizes result in quicker extinction of fires. Li [11] used a mobile water mist system set at a high working pressure to perform fire extinction. Adequate atomization resulted in no electricity leakage within 5 min of discharge between discharge pressures of 20 – 115 kgf/cm2 and at distances 4.5 m or farther, resulting in quick extinction. Studies by Darwin and Williams [12] concluded that water mist used on motors or switchboards would not pose electric shock hazards to personnel within 15 minutes if properly grounded. From the above, it can be acknowledged that water mist can be effective in extinguishing fires, but the working pressure and discharge flow rate must be considered in order to provide effective water mist.

Liu et al. [13] employed two different types of nozzles with a 9.4 L water mist fire extinguisher on n-heptane, diesel fuel, cooking oil, wood cribs, and class C fire materials during experiments, among which wood cribs were tested eight times. 50% of the fires were extinguished. Zhang et al. [14] proposed that when water mist with adequate volume flux is applied to the diffusion flame in a confined space, cooling plays a dominant role when suppressing a PVC fire. The higher the working pressure, the easier the suppression. Chang et al. [15] suggested that nozzles be fixed above and on the four sides of the acetone fire, ensuring that the mist has sufficient momen- tum to completely cover the surface of the pan.

Yang et al. [16] conducted a room fire extinguishing test using full scale experiments and numerical simulations. Temperature field results indicated that numerical data was in agreement with experimental results. Zhou et al. [17] used water mist fire extinguishers under different discharge pressures and extinguishing agents. When conducting the tests, it was suggested that extinction be performed from bottom to top, and that the first wood crib be extinguished before proceeding to the second one. To ensure proper extinction, every wood crib should be continuously sprayed for at least 10 s. Research by Jenft et al. [18] further confirmed that early application of water mist would allow fire growth to be controlled, but fire suppression would require a longer period of time.

From numerous fire extinction research regarding water spray and water mist, all have yielded favorable results, however there has not been any preceding quantitative study on the amount of water needed for fire extinction. At present, indoor hydrants in Taiwan have discharge flow rates of at least 60 LPM, therefore causing serious water damage during extinction. This research employed newly-developed mobile high pressure equipment with nozzle A, while increasing pressure and decreasing particle size to enhance thermal absorption, thus reducing the amount of water needed. This research focused on the relationship between working pressure, water usage, and fire extinction performance, while also considering water damage caused by conventional hydrants.

Experimental Setup

To study mobile high pressure equipment and indoor hydrants, this research selected the same fire source and used extinction times, temperatures, and changes in radiant heat as judgement criteria. The amounts of water used were calculated by substituting the discharge flow rates and extinction times into Eq. (1). Fire source type and size, locations of measurement points, and judgement basis used in the experiment are explained as below.

The fire sources were set up using three A-2 wood cribs, totaling 7.5 MW, with each wood crib consisting of 144 pieces of pine, as shown in Figure 1. Each piece of pine had dimensions of 90 cm x 3 cm x 3 cm, and oil pans were placed under each crib. 3 L of gasoline were poured into each pan, all of which burned for 3 min, allowing each of the wood cribs to reach heat release rates (HRR) of 2.5 MW.

Figure 1. View of three A-2 wood cribs (7.5 MW).

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The three wood cribs were placed in the center of the test site, and heat flux gauges were placed at horizontal distances of 3 and 5 m away from the fire sources; thermocouples were set above the wood cribs in a total of four locations, as pictured in Figure 2.

Figure 2. Cross-sectional view of wood cribs and thermocouples

Under normal circumstances, fire extinguishing equipment performance is associated with its discharge pres- sure, discharge flow rate, and nozzle type, as in Equation (1): $Q=K\sqrt{\Delta p}$(1)

Equation (1) is often used to describe the relationship between the three. Q: the discharge flow rate (LPM); the discharge pressure (kgf/ cm^2); K: the nominal orifice coefficient of the nozzle, the larger the value, the larger the water flow. This research measured the K values of type 2 indoor hydrants and mobile high pressure water sprays and then used them in fire extinction tests.

Type 2 indoor hydrants require a working discharge pressure of at least 2.5 kgf/cm^2, including a discharge flow rate of at least 60 LPM as shown in Table 1. Using Eq. (1), the K value was calculated to be 51.

Type 2 indoor hydrant	ΔP (kgf/cm^2)	$\Delta P^{1/2}$ ($(kgf/cm^2)^{1/2}$)	Q (LPM)
Test 1	2.5	1.58	80
Test 2	3.5	1.87	95
Test 3	4.1	2.02	103
Test 4	4.5	2.12	108
Test 5	4.6	2.14	110

Table 1 K value test for type 2 indoor hydrants.

For the newly-developed nozzle A with high pressure water mist equipment, as shown in Figure 3, bet- ter heat absorption could be achieved by increasing the working pressure while decreasing the particle size.

The K values of nozzle A could be studied by adjusting the discharge flow rates and pressures. Three different discharge pressures of 31.4, 25.0, and 19.5 kgf/cm^2, in accordance with discharge flow rates of 21.0, 18.5, and 16.5 LPM were tested, and then substituted into Eq. (1), obtaining a K value of 3.7 for nozzle A. These parameters were listed in Table 2.

An indoor hydrant with a discharge flow rate of 80 LPM and discharge pressure of 2.5 kgf/cm^2, and a high pressure column with a discharge flow rate of 26 LPM and discharge pressure of 49.3 kgf/ cm^2 were used in this study. The discharge distribution of both equipment is shown in Figure 4, while the working discharge pressures, discharge flow rates, and K values of the nozzles are listed in Table 3.

Figure 3. Nozzle A used in the high pressure water mist system.

High pressure water spray	ΔP (kgf/cm^2)	ΔP $^{1/2}$ (kgf/cm^2)$^{1/2}$	Q (LPM)
Test 1	31.4	1.58	21
Test 1	25	1.87	18.5
Test 1	19.5	2.02	16.5

Table 2: K value test for high pressure water mist nozzle.

Type of equipment	Discharge type	ΔP (kgf/cm^2)	Q (LPM)	K(LPM/(kgf/cm^2)$^{1/2)}$
High pressure water mist	Column	49.3	26	3.7
Type 2 indoor hydrant	Column	2.5	80	51

Table 3: Comparison of the two systems.

Figure 4. Discharge distribution of nozzle.

Results and Discussion

After the gasoline was ignited, fire quickly spread to the wood cribs, and fire extinction began approximately 3 min after ignition. Performance assessment for both equipment was conducted by temperature observation. Figure 5 shows the fire extinction process.

Figure 5 (a): Scenario before extinction.

Figure 5 (b): Scenario after extinction.

After 180 s of burning in the first test, high pressure water mist equipment was used for extinction. The tem- perature dropped rapidly, and after 40 s the flames around the source were extinguished; however, there were still flames inside the wood crib. These flames were referred to as ridge flames. To extinguish the ridge flames inside, water was continuously sprayed at the wood crib, attempting to further lower the temperature. After 68 s the temperature dropped below 100°C and stabilized, which could be determined as the time of extinction. The temperature changes are plotted in Figure 6.

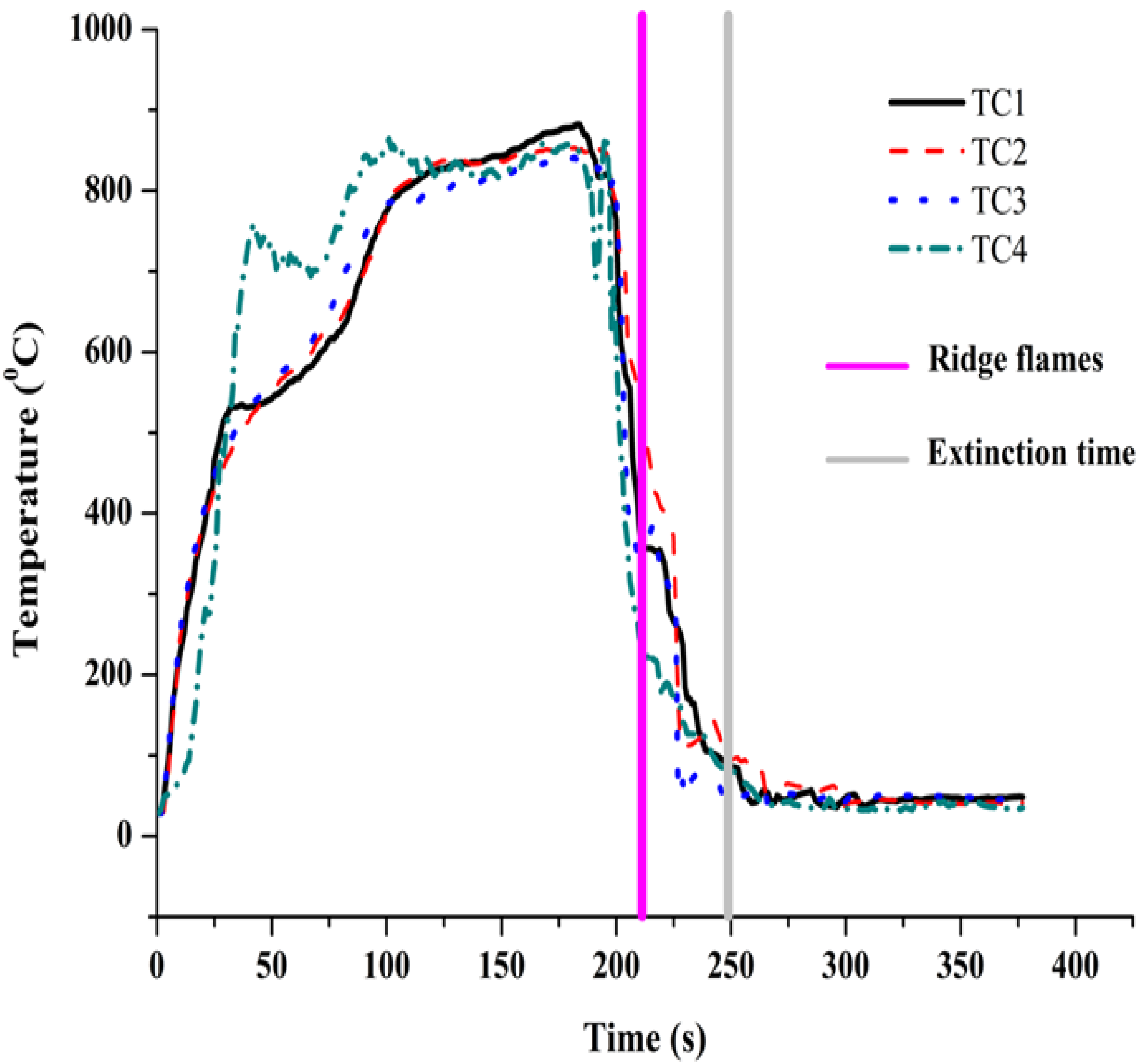

Figure 6. Temperature changes during high pressure water mist spray test.

When using the same system for a second test, the flames around the source were extinguished after 32 s, while the temperature dropped below 100°C after 76 s. A subsequent third test was performed, and the time of ridge flames observed and time of extinction were 23 and 60 s, respectively. Complete test data is listed in Table 4.

	Test 1 (s)	Test 2 (s)	Test 3 (s)
Ridge flames	40	32	23
Extinction	68	76	60

Table 4: Times of ridge flames and extinction using high pressure water mist.

Thermal radiation from the fire source could harm personnel during fire rescue, therefore, it was also monitored during the tests. Thermal radiation heat flux dropped immediately after using high pressure water mist. Results showed that this equipment not only protects emergency rescue personnel, but decreases the amount of environmental damage caused by thermal radiation. Thermal radiation heat flux changes are illustrated in Figure 7.

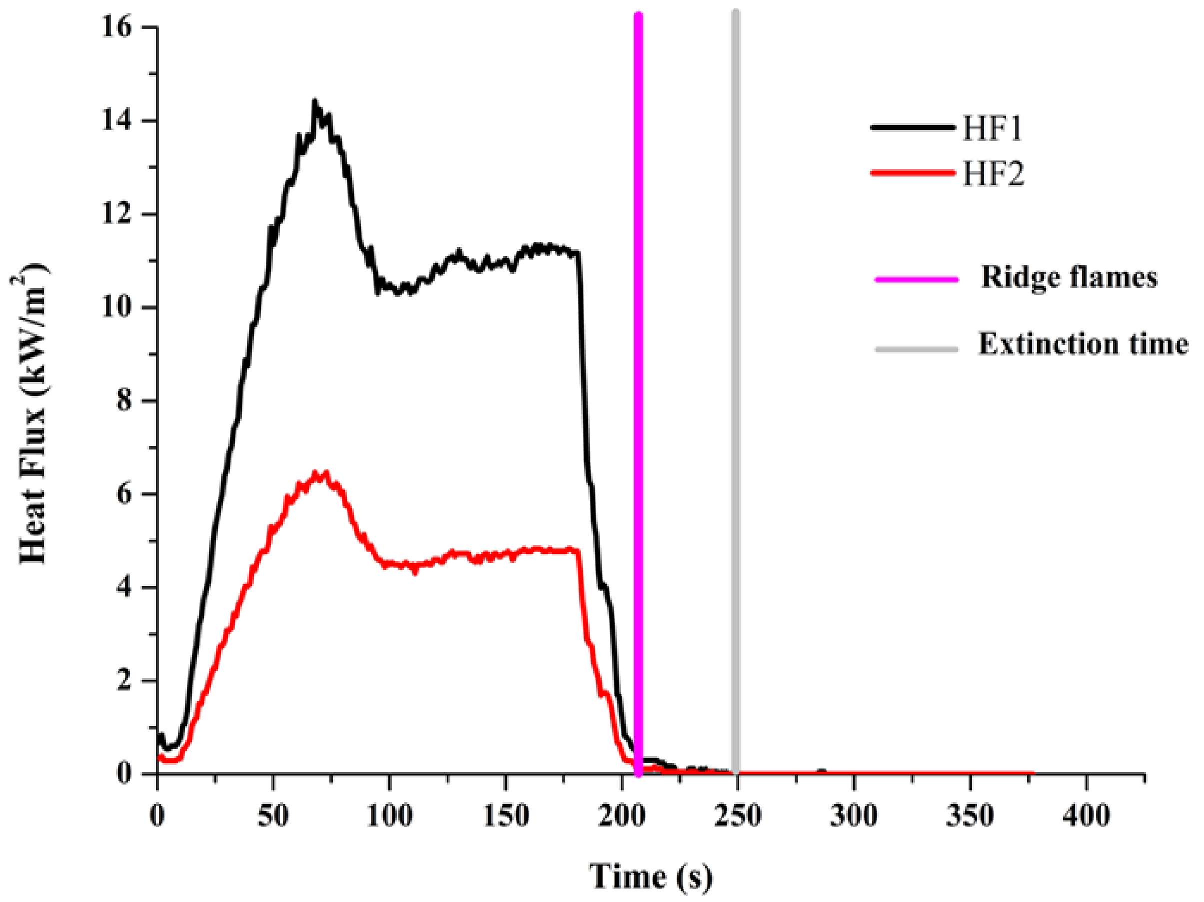

Figure 7. Thermal radiation during fire extinction when using high pressure water mist.

When switching to the type 2 indoor hydrant, which has a discharge flow rate of 80 LPM and working discharge pressure of 2.5 kgf/m², the time needed to extinguish the flames around the source was 18 s, while complete extinction required 41 s. The temperature profiles are plotted in Figure 8.

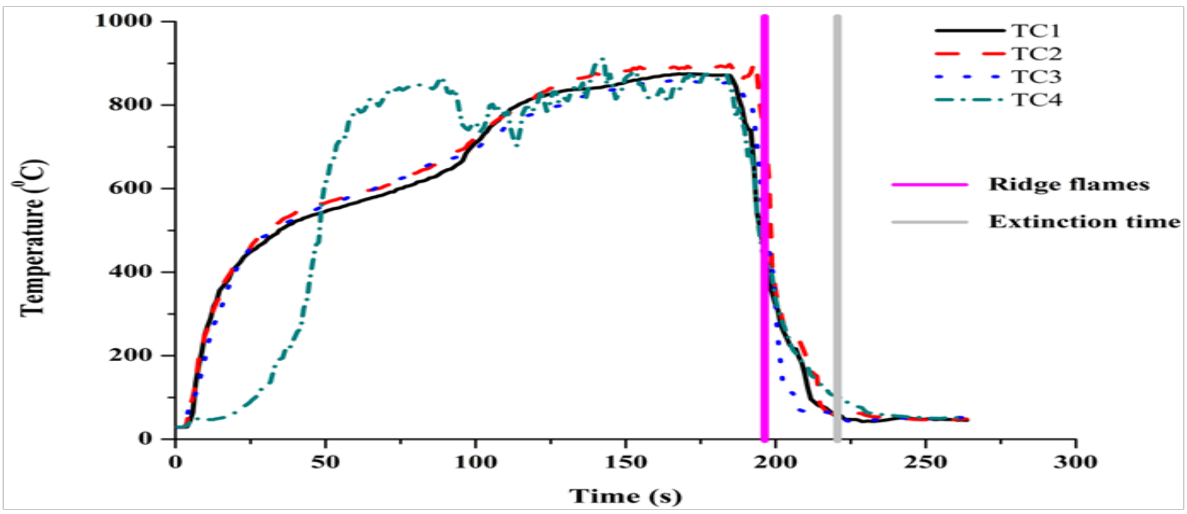

Figure 8: Temperature changes during type 2 indoor hydrant test.

The times needed for ridge flames to be observed with the type 2 indoor hydrant in the three tests were 18, 20, and 13s, while the times needed for the temperature to drop below 100°C were 41, 44, and 34s. The times described above are listed in Table 5. When the discharge pressure was set to 70.0 kgf/cm^2, the time of extinction was 46s, identical to the time needed at 49.3 kgf/cm2 discharge pressure, meaning that 49.3 – 70.0 kgf/cm^2 was the suitable discharge pressure range for fire extinction.

	Test 1 (s)	Test 2 (s)	Test 3 (s)
Ridge flames	18	20	13
Extinction	41	44	34

Table 5: Times of ridge flames and extinction using type 2 indoor hydrants.

Overall, both the high pressure water mist system and indoor hydrants have the ability to extinguish three sets of A-2 wood cribs (7.5 MW), but type 2 indoor hydrants have a discharge flow rate of 80 LPM, significantly larger than the 26 LPM of high pressure water mist. The discharge flow rate has a visible effect on extinction time, which further affects the amount of water used. The longest time needed for the type 2 indoor hydrants was 44 s, while it was 76 s for the high pressure water mist, which explained that larger amounts of water are faster in extinguishing fires. For type 2 indoor hydrants, the total amount of water used was approximately 59 L. In contrast, high pressure water mist required 32 more seconds for extinction, but only 33 L of water, 44% less than its counterpart.

If the shortest time of 34 s was chosen for type 2 indoor hydrants, the total amount of water used would be 45L, still exceeding the 33 L used by high pressure water mist, showing that high pressure water mist can save at least 27% of water. All test results are compared in Table 6.

Type of equipment	ΔP (kgf/cm^2)	ΔP (kgf/cm^2)	Time (s)	Amount used (L)	Excess amount of water (%)
High pressure water mist	49.3	26	76	33	------
Type 2	2.5	80	44 (Longest)	59	44
Type 2	2.5	80	34 (Shortest)	45	27

Table 6: Results of extinction tests.

Although type 2 indoor hydrants used less time to extinguish fires, they required significantly more water than mobile high pressure water mist. High pressure water mist equipment utilized high pressure and reduced the water droplet size, which increased the thermal absorption surface, thus improved fire extinguishing performance and minimized water damage. After calculating the amount of water needed by both equipment, it was evident that high pressure water mist used visibly less water than indoor hydrants. Occupancies with patients such as hospitals are very sensitive towards electrical safety issues, therefore the observation of less water usage for the water mist system was ideal, because less water corresponds to a lowered chance of electrical safety hazards.

In the past, the NRIFD used a direct dual spray nozzle with a discharge flow rate of 180 LPM and a twophase flow water mist spray nozzle with a discharge flow rate of 40 LPM on a wood crib. The times needed for extinction were 43 and 66.4 s, respectively. However, the water used by the two nozzles was 129 and 44.5 L, respectively, showing that the direct dual spray nozzle uses almost three times as much water as the water mist spray nozzle, inevitably causing more water damage. To understand the effectiveness of the 40 LPM water mist nozzle, a test was performed with two wood cribs placed side by side and another test with two cribs stacked vertically. Although extinction became more difficult, the fires were still extinguished in 120 and 147 s respectively for the two cases. Moreover, the 40 LPM water mist nozzle used significantly less water than the direct dual spray nozzle, regardless of which case, which is consistent with data obtained in this research.

If three wood cribs (7.5 MW) were used, the 40 LPM water mist nozzle was unable to extinguish the fires, which caused the thermal radiation to be too large for emergency rescue to enter the area. After comparing the water mist nozzle in Japan with the one used in this research, it was discovered that although the Japanese nozzle had a larger discharge flow rate, the nozzle used in this research had a higher working discharge pressure of 49.3 kgf/cm^2, which allowed better atomization and more effective mitigation of thermal radiation. This further highlighted that the high pressure water mist equipment used in this research exceeded the performance of the two-phase flow water mist nozzle. Complete experiment data is presented in Table 7.

Type of equipment	Number of wood cribs	Time of fire extinction(s)	Water needed for extinction (L)
Straight dual spray nozzle (180 LPM) (NRIFD, 2003)	1	66.4	129
Water mist nozzle (40 LPM) (NRIFD, 2003)	1	120	44.5
	2 (side by side)	147	80
	2 (stacked)	------	--
	3 (two stages)	66.4	98
High pressure water mist (26LPM) (This study)	3	120	33

Table 7: Data comparison of fire extinction tests by the NRIFD and this research

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Conclusion

This research is a first to quantifiably compare the efficiency between mobile high pressure water mist equipment and indoor hydrants. Results showed that mobile high pressure water mist equipment uses a higher working pres- sure while decreasing the amount of water needed for fire extinction by 27%. For electrical safety considerations, less usage of water is more ideal, especially for occupancies with patients such as hospitals, and the system used in this research yielded results which adequately fits this concept. This system yielded better performance than the equipment used by NRIFD in Japan, extinguishing three standard wood cribs, a 7.5 MW fire, instead of two, while also resolving the problem of water damage and forestalling secondary damage, both of which are major concerns in health care facilities. The equipment in this research is already commonly used in high-tech plants, and the convenient operability of the equipment makes it suitable for it to be utilized in not only health care fa- cilities but also a wider range of applications. It is hoped this technology can be used during the early stages of class A fires in health care facilities and other occupancies in the future.

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Conflict of Interest

The author has no conflict of interest

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