FIRE AND MATERIALS
Fire Mater. 2008; **32**:383–397
DOI: 10.1002/fam.967

Evaluating the performance of a portable water–mist fire extinguishing system with additives

Wen-Yao Chang[1], Ping-Kun Fu[1], Chiun-Hsun Chen[1] and Yi-Liang Shu[2,*,†]

[1] *Department of Mechanical Engineering, National Chiao Tung University, HsinChu, Taiwan*
[2] *Department of Safety Health and Environmental Engineering, Central Taiwan University of Science and Technology, Taichung, Taiwan*

SUMMARY

This study investigates how high-pressure water–mist system discharge methodologies influence the fire extinction performance for pan pool fires and the corresponding mechanisms of restraining fire. The fire source is a pool-fire burner. Fine water spray is injected using a portable device. The additive in the water–mist is neither toxic nor corrosive. All the tests are regarded as fuel controlled. The fire test parameters are fuel type, nozzle discharge angle, and additive solution volume. The fuels used are heptane, gasoline, and diesel. Nozzle discharge angles are 30, 45, and 60° with respect to the ground. Additive solution volumes are 0% (pure water), 3, 6, and 10%. Test results indicate that the nozzle discharge angle and additive solution volume in a water–mist fire extinction system play a significant role. Fire extinguishing efficiency is influenced by mist effects and the additive. Furthermore, the water–mist system can reduce radiation and can provide good protection for operators using portable fire extinguishing equipment. Copyright © 2008 John Wiley & Sons, Ltd.

Received 7 March 2007; Revised 8 August 2007; Accepted 10 February 2008

KEY WORDS: water–mist; fire protection; portable; additive

1. INTRODUCTION

Fixed fire extinguishing systems have demonstrated their capability in providing the fire protection in a wide range of applications. However, their performance is generally limited by spray nozzle distribution and allocation. Portable fire extinguishers whose spray nozzles are designed as movable and can be aimed at a fire are generally utilized for the early stage of fire control. For portability,

---

[*] Correspondence to: Yi-Liang Shu, Department of Safety Health and Environmental Engineering, Central Taiwan University of Science and Technology, Taichung, Taiwan.
[†] E-mail: ylshu@ctust.edu.tw

Contract/grant sponsor: National Science Council of the Republic of China, Taiwan; contract/grant number: NSC 94-2622-E-166-004-CC3
Contract/grant sponsor: Ministry of Education, Republic of China, Taiwan

the weight of such extinguishers should not be too heavy to carry and, consequently, extinguisher content should be limited. Thus, portable fire extinguishers can be only operated for a short time and are unfavorable controls for the larger fire. However, water damage is unacceptable, particularly in contexts where collateral damage by water is undesirable, such as in high-tech facilities, on aircraft, and in shipboard engine rooms, and in museums. Consequently, identifying a fire control system that can be operated for a long time and with reduced amounts of water to reduce water damage is necessary.

According to NFPA 750 [1], water–mist is defined as sprays in which 99% of spray droplets, for flow-weighted cumulative distribution, have diameters $<1000\,\mu\text{m}$ as the minimum design operating pressure of water–mist nozzle. The extinguishing performance of the water–mist system depends on the water–mist characteristics (e.g. droplet size, spray angle, spray pattern, water flow rate, and momentum) and discharge methodologies (e.g. nozzle discharge angle, timing, and compartment configuration). A large number of many studies of pool fires have investigated the use of water–mist as the fire extinguisher. Mawhinney [2] used a twin-fluid nozzle to produce a fine spray to extinguish liquid pool fires. It was Mawhinney who found that spraying downward directly at the flame is the most effective means of extinguishing a fire. Obstructions in the spray path lower the spray's momentum and the amount of water suspended in the air as mist, resulting in reduced capacity to extinguish a fire.

Richard *et al.* [3] conducted an experimental study of the effects of water–mist on a small heptane pool fire. The obtained map of temperature and extinction coefficient due to soot and water droplets provided new information about the flame structure. Richard *et al.* showed that extinguishing a fire with water–mist is done by rapid and total clearance of water, rather than by a reduction in burning rate. Moreover, Richard *et al.* [4] conducted a phenomenological study investigating the effect of water vapor addition through the base of a small heptane pool fire. Heptane suspended on a pool of water burned as a pool flame and the water underneath the heptane was heated to boiling. Water vapors were applied to the diffusion flame, where chemical reactions and air entrainment took place. Such an addition of water vapors influences the physical phenomena (inhibits soot formation) and chemical reactions (CO is transformed into CO_2). The effects of water vapor addition are further confirmed by injecting an inert gas instead of water vapor into a fire. However, fire temperature is significantly decreased as the resulting heat released is insufficient for counteracting the cooling effect of water vapor.

Few studies have investigated the capability and limitations of portable water–mist fire extinguishers. Liu *et al.* [5, 6] performed a series of full-scale fire tests using portable water–mist extinguishers to suppress various fire types, including those of cooking oils, *n*-heptanes, diesel fuels, and wooden cribs. Diesel fire, compared with a heptane fire with the same size fuel pan, is much easier to extinguish, as diesel fuel has a higher flash point ($\text{FP}=60^\circ\text{C}$) and a lower heat release rate.

To further enhance the fire-extinguishment performance of water–mist, many additives have been developed in recent years. Zhou *et al.* [7] conducted a phenomenological study of the effect of multi-composition (MC) additive on water–mist fire-extinguishing efficiency based on ethanol, diesel, and wood fires. Zhou *et al.* found that adding a small quantity of MC additive into water–mist significantly improves the performance of water–mist systems in suppressing fires. However, when too much of MC additives are utilized, fire-extinguishing efficiency declines.

The operational units of a water–mist system (Figure 1) are similar to those used in sprinkler systems. As a water–mist system is operated at a higher pressure than sprinkler systems, pipes, pumps, and valves in high-pressure systems must be able to contain the high pressure, sometimes

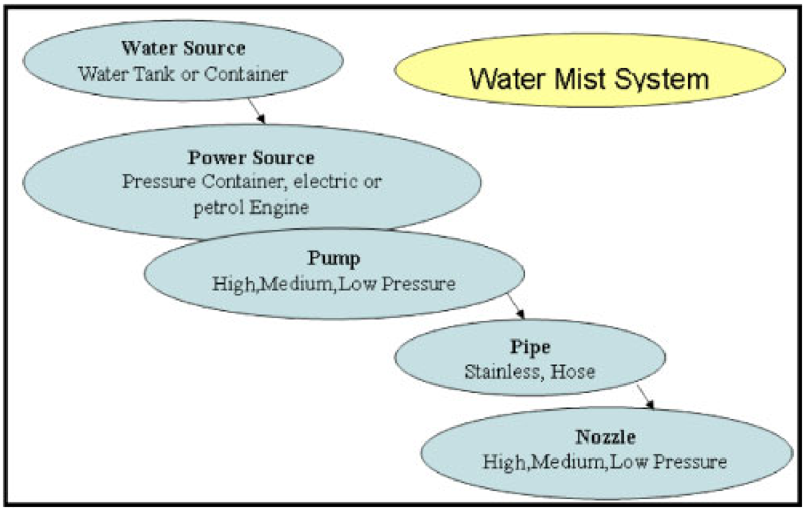

Figure 1. The operational units of water–mist system.

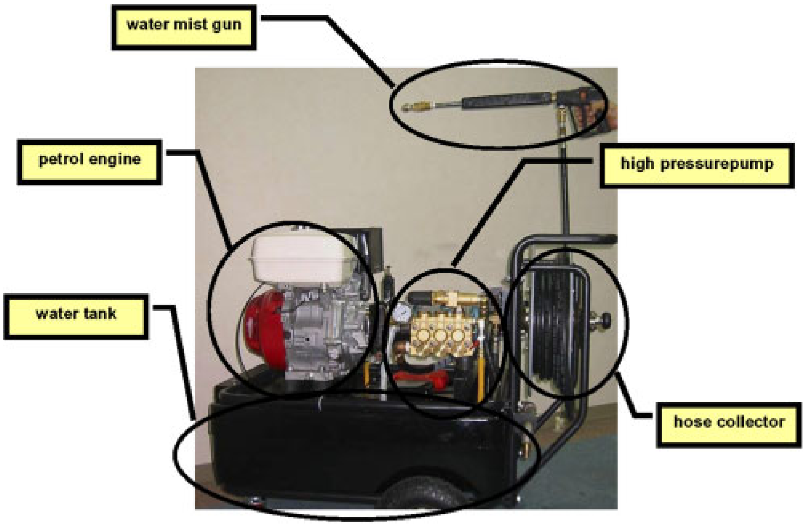

Figure 2. A portable system driven by petrol engine.

to 150 bar (2175.54 psi). According to Figure 2, a fixed water–mist system can be transformed into a portable or moveable system when the water supply system, power source, and pump are redesigned.

For operating pressure, a water–mist system can be divided into three types: high-, medium-, and low-pressure systems. A high-pressure system has an operational pressure of $\geqslant$34.5 bar (500 psi).

Low-pressure system has operational pressure of <12.1 bar (175 psi). The medium-pressure system has an operation pressure of 12.1–34.5 bar (175–500 psi). A high-pressure portable water–mist system is used in this study.

Many water–mist additives have been developed to increase fire-extinguishing performance. Applying additives to a portable water–mist system should reduce the amount of water used and time required for fire suppression. Such additions can improve the efficiency and practicality of portable water–mist systems. However, some additives have serious application shortcomings—some inorganic metal additives corrode equipment and some organic additives are toxic to humans—and cannot significantly improve the fire-extinguishing efficiency of water–mist systems. However, few studies have investigated portable water–mist extinguishers with additives.

This study conducted qualitative and quantitative fire tests in a test field. Qualitative fire tests utilized Class A and Class B, motorcycle, and car fires. For quantitative study of a portable system, several fire scenarios and discharging methodologies were designed to evaluate fire suppression performance of portable water–mist systems with additives to identify the key fire protection parameters. The effects of high-pressure water–mist system discharge methodologies on performance and the corresponding mechanisms of restraining fire are evaluated. The fire source is a pool-fire burner. Fine water spray is injected from a portable device in an open environment. The additive is neither toxic nor corrosive. Different nozzle discharge angles, fuels, and concentrations of water–mist additives are selected as the primary experimental parameters. The aim of this study is to investigate the effects of directions of water–mist injected and resulting fire-extinguishment performance. Moreover, a phenomenological study investigates the effects of the additive on water–mist and different fuels.

2. EXPERIMENTAL APPARATUS

To control experimental conditions, most fire tests were held in field test facility, about 25 m long, 9 m wide, and 7 m high. All the tests were considered as open-air tests, that is, air was supplied naturally. The test facility consists of a test compartment, portable water–mist systems, and instruments for data collection.

2.1. Experimental layout

Figure 3 presents the schematic configuration of the experimental apparatuses. The fuel pan was placed in the center of the test field and the mist nozzle was fixed on the test frame. In fact, it was secured on an iron test frame. The discharge angle and the distance between the nozzle and the pan were measured before the tests. The K factor of the nozzle was $1.42\,\mathrm{L/min/bar}^{1/2}$. The volume mean diameter of the droplet is about $100\,\mu\mathrm{m}$ at 100 bar, which was measured by an image-processing technique. The spray angle is 60°. There are 21 jet holes in the nozzle, 3 in the inner ring and remaining 18 in the outer ring. The mist discharge nozzle angle was adjusted from 0 to 90° relative to the ground for various test scenarios. The mist nozzle was connected to an electric high-pressure pump via a soft hose. The pressure release was adjusted using the pump pressure valve. Pressure was measured using the pressure gauge attached behind the nozzle. Fire temperature was measured with a thermocouple tree in the pan center. The radiometer was utilized to observe the radiant attenuation effect of the mist. All measured data were transferred to a disk storage system using a PC-controlled data acquisition system.

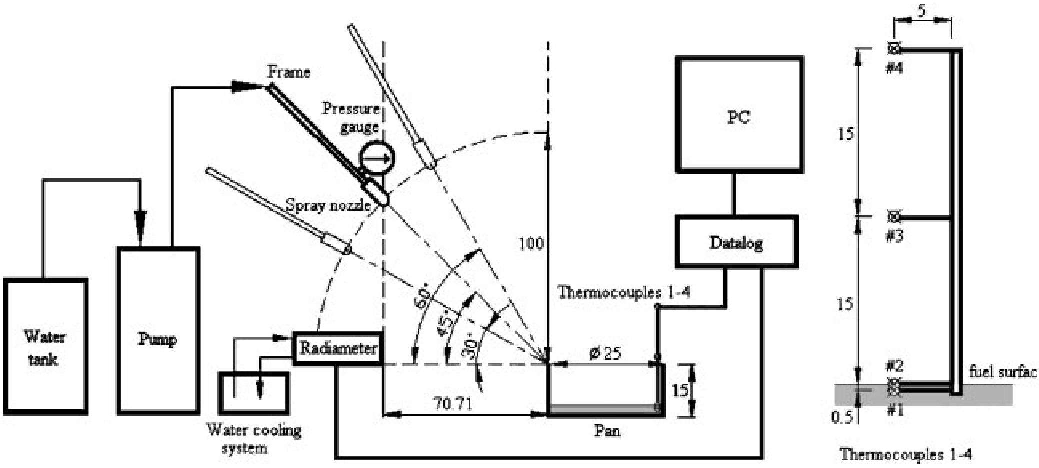

Figure 3. Experiment layout of flammable liquid pan fire.

2.2. *Fire source*

In the qualitative fire tests, according to the Chinese National Standard 1387 test protocol in Taiwan, the area of the pan is $1 \times 1\,\text{m}^2$ with 0.2 m height. In the quantitative fire tests, the pan is 25 cm in diameter with a height of 15 cm to simulate a small pool fire.

The small pool fire generated using heptane, gasoline, or diesel as the fuel was contained in a circular stainless pan. The pan was mounted onto a steel stand 15 cm above the ground to minimize the effects of surrounding ground surfaces on fire behavior.

2.3. *Data collecting sensors*

These thermocouples were located 0.5 cm (#1) under the fuel surface and 15 cm (#3) and 30 cm (#4) above the fuel surface. Thermocouple #2 was located at the fuel–air interface. A radiometer was used to measure the heat flux from fuels.

2.4. *Test parameters for flammable liquid pan fires*

Fire tests parameters were fuel type, nozzle discharge angle, and additive solution volume. The fuels used were heptane, gasoline, and diesel. Nozzle discharge angles were 30, 45, and 60° relative to the ground. The volume concentrations of the additive were 0% (pure water), 3, 6, and 10%. For each fuel, the fire tests applied three nozzle discharge angles and four additive solution volumes. Each fire test was repeated at least twice for data consistency.

Table I presents the water (mist) volume flow rate at different additive rates over 1 min. The volume flow rates are approximately the same, indicating that the water volume flow rate is minimally influenced by the additive rate.

2.5. *Water–mist additive property*

The water–mist additive utilized was a 97% fire-retardant chemical, 1.8% surfactant, 0.6% mint, and 0.6% camphor, and was non-toxic. The components of the fire-retardant chemical are citric

Table I. The volume flow rates of mist in different additive solution volumes (L/min).

Additive solution volume (%)	0	3	6	10
Volume flow rate	8.8	9.0	9.0	8.8

acid ($HOC(COOH)(CH_2COOH)_2$), borax ($Na_2B_4O_7 \cdot 10H_2O$), and salt (NaCl). The additive forms a thin layer of foamy film on the fuel surface when sprayed from the nozzle. This foamy film blocks oxygen access to the fire and fuel vapors, and mitigates radiation feedback from the fire to the burning fuel surface; therefore, re-burning the fuel is difficult.

3. RESULTS AND DISCUSSION

Generally, a water-based fire protection system should not be used for Class B fires as most of the oil will splash over the water. Therefore, cooling the fuel surface with water evaporation is difficult and may generate a 'running liquid fire.' However, in water–mist systems, there is insufficient water for oil to float on, as water is only $\frac{1}{10}$ of that used in conventional sprinkler systems. Furthermore, with a large surface-to-volume ratio, water–mist can greatly enhance both evaporation rates and suspension time when cooling the oil surface. Water–mist system can suppress Class B fires effectively with proper design and operation.

3.1. *Qualitative fire tests*

3.1.1. Class A fire tests—wood slabs. Class A fire test was conducted according to the CNS1387 [8] test protocol. The test object (Figure 4) comprises wood slabs ($0.9 \times 0.9 \times 0.9$ m) on a rack and a pan with 1.5 l gasoline located under the rack. During the test, the gasoline is ignited first. The portable water–mist system then starts 3 min later. Figure 5 presents a series of photographs of the fire test. The fire was extinguished in 10 s. During the test, portable water–mist was very effective for extinguishing wood slab fire. The dark smoke generated by the fire changed to a light-colored smoke after the mist was released. The reason why the smoke changed color may be that the water–mist cooled the fire temperature and decreased the combustion rate, thereby reducing the smoke production rate. Another reason is that the mist has a large interaction surface with smoke and may have stifled the smoke.

3.1.2. Class B fire tests—gasoline pan fire. A gasoline pan fire was used as the Class B fire test scenario. The pan 1×1 m square and 0.2 m high was filled with 5 l of gasoline. After 60 s of pre-burning, the portable water–mist was released. Figure 6 presents a series of pictures of fire test. The fire was extinguished in 10 s. In the test series, operator skill had a significant effect on extinguish time. The mist had to cover the pan for good performance, and the mist angle is also important when extinguishing fires.

3.1.3. Motorcycle fire tests. Motorcycles were used as the fire source. Gasoline was sprinkled on three motorcycles and then ignited. After 30 s of pre-burning, the portable water–mist was released. As plastics are the primary motorcycle components, smoke production was high. Just as in the Class A fire test, after the water–mist was released, the smoke changed to a light color, and

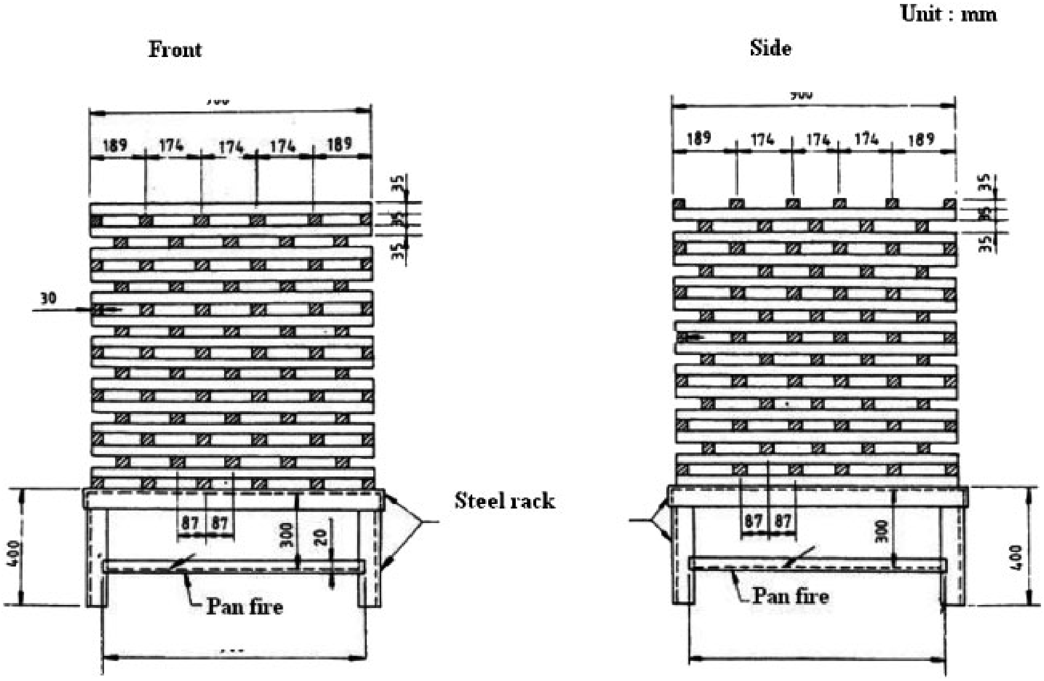

Figure 4. Wooden slabs of CNS1387.

Figure 5. Pictures of Class A fire test.

it is safe for an operator. The motorcycle fire was extinguished in approximately 20 s. However, operator skill has a significant effect on the time required to extinguish the fire. Figure 7 presents a series of photographs of the fire test.

3.1.4. Car fire tests. A car was utilized as the fire source. The gasoline was sprinkled into the sedan and then ignited. After 30 s of pre-burning, the portable water–mist was released. As plastics are the primary components of sedan, the smoke production rate remained high. Just as in the

Figure 6. Pictures of Class B (pan fire) fire test.

Figure 7. Pictures of motorcycles fire test.

Figure 8. Pictures of car fire test (1).

motorcycle fire test, after the water–mist was released, the smoke color became light. The car fire was extinguished in approximately 30 s. Operator skill critically affected the time required to extinguish the fire. Figures 8 and 9 present a series of photographs of the test fire.

3.2. Quantitative fire tests

3.2.1. Pure water tests with different fuel types. In this section, pure water was utilized as the fire suppression agent and experimental results were adopted as baseline data for comparisons. Table II lists the time required to extinguish different fires generated using different fuels under three nozzle discharge angles. Figure 10 presents these experimental results plotted on a graph.

The time curves were divided into two types: a monotonic decreasing curve for diesel and convex curves for gasoline and heptane. The narrow combustion limits and high FP of diesel generate a curve that differs from those for gasoline and heptane. To diesel, the extinction time declined

Figure 9. Pictures of car fire test (2).

Table II. Nozzle discharge angle and corresponding extinction time (s) without additive.

	Fuel type		
Discharge angle (degree)	Diesel	Gasoline	Heptane
Pure water without additive			
60	8	89	82
45	54	154	106
30	59	106	79

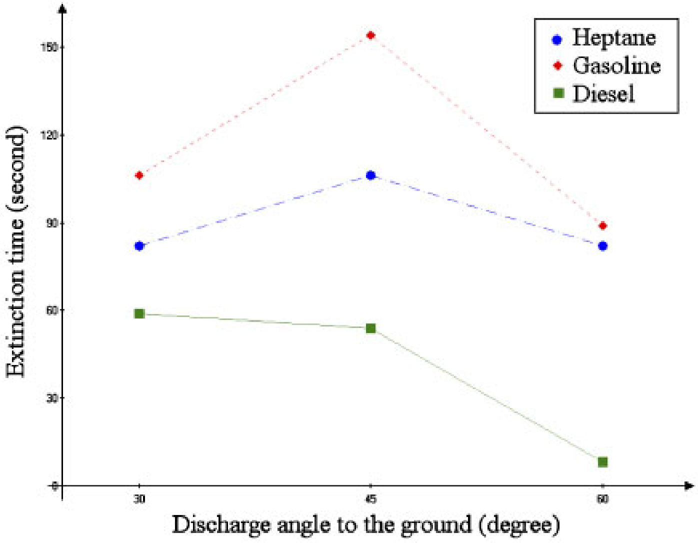

Figure 10. The relationship between nozzle discharge angles and extinction time in different fuel types without additive.

as nozzle discharge angle increased, which shows the adverse behaviors during the experiments for gasoline and heptane. The adverse effects occurred at a nozzle discharge angle of 45°. The extinction time declined regardless of whether the nozzle discharge angle increased or decreased. With a nozzle discharge angles of $>45°$, the water–mist covered the pan fire fully, such that flame cooling and oxygen displacement played key roles in extinguishing the pool fires. Conversely, at nozzle discharge angles of $<45°$, the mist jet rebounded from the pan wall and formed a thin mist layer parallel to the fuel surface, thereby blocking and diluting fuel vapors. Thus, it makes fire extinction easier in the low nozzle discharge angle tests than that at 45°. Thus, fire extinction is easier when nozzles are at lower angle than when nozzles are at 45°.

Figure 11 presents the temperature variation history of diesel fire with a nozzle discharge angle of 30°. The temperature measured at 15 cm above the fuel surface (i.e. thermocouple #3) in the flame center was the highest and reached temperatures as high as 600°C. After the water–mist was released at 152th s, the flame size decreased rapidly and pushed back to the pan sidewall, which was located close to the nozzle. The fluctuation of temperature at 0.5 cm below the fuel surface was not distinct, but temperatures measured by thermocouples #2, #3, and #4 rapidly decreased as the water–mist reached the flame.

Figure 12 shows the radiation heat flux history of diesel fire with a nozzle discharge angle of 30°. The heat flux of the fires rapidly reached roughly zero after the water–mist was released, indicating that the water–mist system has a good ability to decrease radiation and provides effective protection for operators using portable extinguishing equipment.

3.2.2. Water–mist with additives on diesel pan fires. As diesel is hard to ignite due to its narrow combustion range and high FP ($>52°C$), an extra 50 ml of gasoline was used as the accelerator. To ensure gasoline burnout and reach quasi-steady diesel burning, 120 s of pre-burning was used before activating the water–mist system. Table III lists the extinction times for different additive

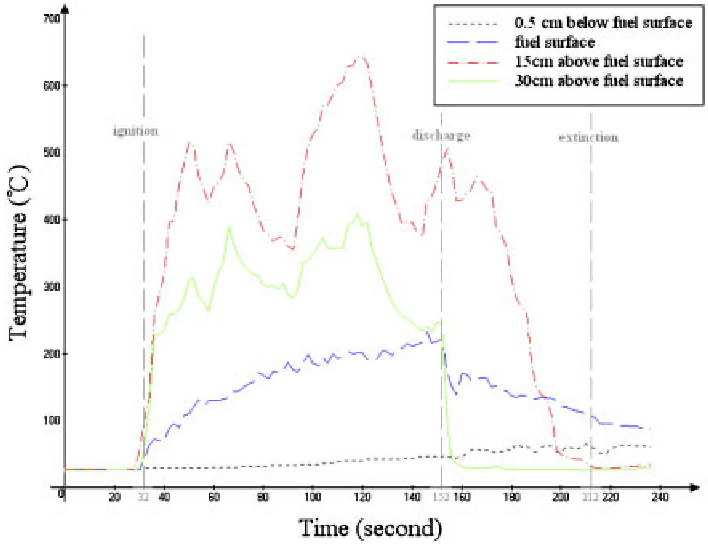

Figure 11. The temperature history of diesel fire with pure water at the nozzle discharge angle of 30°.

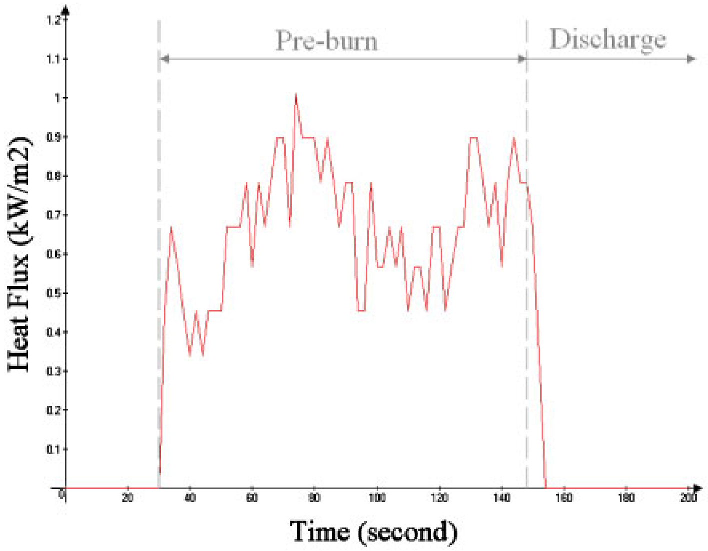

Figure 12. The heat flux history of diesel fire with pure water at the nozzle discharge angle of 30°.

Table III. Additive solution volume and corresponding extinction time (s) of diesel fires.

	Additive (%)			
Discharge angle (degree)	0	3	6	10
Diesel				
60	8	3	5	8
45	54	9	19	10
30	59	3	25	38

solution volumes at three nozzle discharge angles. For fire suppression using pure water, the best fire extinction performance occurred when the nozzle discharge angle was 60° as the mist fully covered the pan fire. Fire-extinguishing efficiency improved when water–mist with additive was used. The extinction times for the three nozzle discharge angles were all significantly reduced compared with those using pure water (Figure 13). Notably, when the nozzle discharge angle was at 30° and extra additive was added, the time required to extinguish the fire increased, showing that at the 30° nozzle discharge angle, the vaporizing effects of the water–mist played a more significant role in fire suppression than that of the additive. However, the fire extinction time remained still less than that using pure water.

3.2.3. Water–mist with additives on heptane pan fires. In the heptane tests, flames were turbulent and little smoke was produced. When water was first discharged, flame height was reduced and the flame size grew larger than the initial flame as fresh air was entrained into the fire plume with the water–mist. The flame then expanded rapidly and stretched out concurrently with the continuous discharge. Extinguishing heptane pan fires in these tests was difficult. The extinction times for

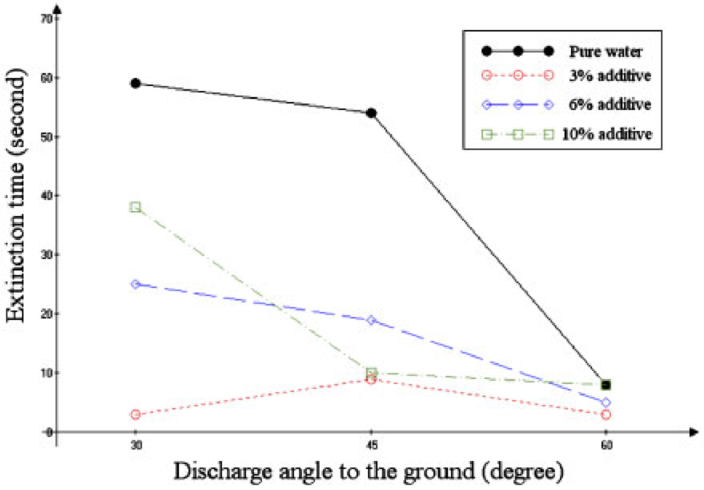

Figure 13. Extinguishing time for diesel fire with different nozzle discharge angles and additive solution volumes.

Table IV. Additive solution volume and corresponding extinction time (s) of heptane fires.

	Additive (%)			
Discharge angle (degree)	0	3	6	10
Heptane				
60	82	18	28	18
45	106	58	36	37
30	79	17	77	79

different additive solution volumes at three nozzle discharge angles were listed in Table IV, and Figure 14 presents the two curves for extinction time relationships—one was convex for pure water and that with 3% additive, whereas the other was a monotonic decreasing curve for 6 and 10% additives.

When using water–mist and 3% additive for fire suppression, the fire extinction time when the nozzle discharge angle was 30° was less than that when the angle was 45°. During the low-angle nozzle discharge tests, the entrained flow rebounded from the pan wall and blocked fuel vapors. When 3% additive was used, the fire extinction time was substantially reduced compared with that for pure water. However, fire suppression performance with a low additive solution volume is similar to that for pure water. For the cases of 6 and 10% additives, the size of the discharge angle was inversely correlated with the time taken to extinguish the fire, because at the low nozzle discharge angle decreased amounts of mist reached the fuel pan.

At a nozzle discharge angle of 30°, the best fire suppression performance was with the 3% additive solution. As additive solution volumes increase, fire extinction time increases, because the vaporizing effect of water–mist plays a more significant role than the additive in fire suppression at a 30° nozzle discharge angle. When the nozzle discharge angle increased to 60°, a different

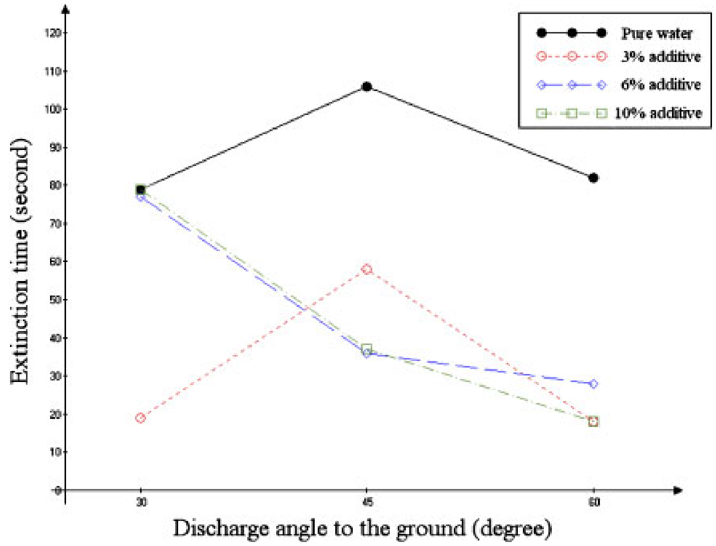

Figure 14. Extinguishing time for heptanel fire with different nozzle discharge angles and additive solution volumes.

trend emerged. First, fire extinction time increased with additive solution volume, which was <6%. An additive solution volume of 6% took the longest time to extinguish the fire. Subsequently, the fire extinction time declined as the additive solution volume increased, as the fire extinction efficiency was influenced by water–mist effects and those of the additive. Therefore, an optimal zone between water–mist and additive effects must exist for fire suppression.

3.2.4. Water–mist with additives on gasoline pan fires. In gasoline fire tests, flame turbulence was extremely intense producing considerable amounts of smoke. The fire extinction behavior of gasoline was similar to that of heptane. Table V lists the extinction times for different additive solution volumes at three nozzle discharge angles; Figure 15 presents plots of these times. Additionally, two curves as a function of time existed, one was a convex curve for pure water and for 3% additive, and the other was a monotonic decreasing curve for 6 and 10% additive solution volumes. The fire suppression performance with 3% additive was similar to that with pure water. However, when an increased amount of additive was used, fire extinction times were clearly decreased compared with that using pure water. The additive utilized in these tests for fire suppression performed better when applied to gasoline fires than heptane fires. At a nozzle discharge angle of 30°, fire extinction time clearly increased as three additive solution volumes (3, 6, and 10%) increased, indicating that the vaporizing effects of water–mist are more important than the additive effects at a low nozzle discharge angle.

4. CONCLUSION

Based on this series of qualitative fire tests, the portable water–mist system is effective in extinguishing Class A fires, Class B fires, and motorcycle and car fires and particularly effective with

Table V. Additive solution volume and corresponding extinction time (s) of gasoline pan fires.

	Additive (%)			
Discharge angle (degree)	0	3	6	10
Gasoline				
60	89	9	15	9
45	154	26	15	14
30	106	9	34	54

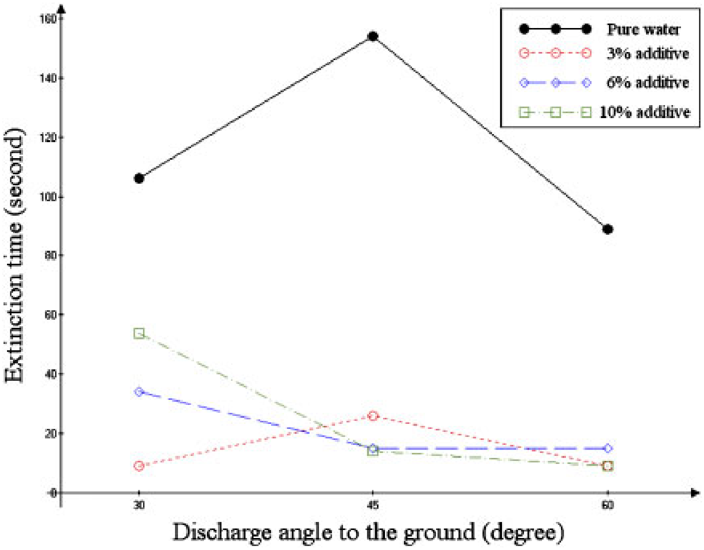

Figure 15. Extinguishing time for gasoline fire with different nozzle discharge angles and additive solution volumes.

additive on Class B fires. For long operation time, good fire control performance, good smoke control, and increased safety performance, a portable water–mist system is more reliable than a conventional portable fire extinguisher. A portable water–mist system comprises a new and good choice for early fire control.

In quantitative fire tests, the effects of high-pressure water–mist system discharge methodologies on fire extinction performance for pan pool fires and the corresponding mechanisms of restraining fires were investigated. The fire test parameters were fuel type, nozzle discharge angle, and additive solution volume. Test results indicate that the water–mist system has good ability to attenuate radiation, reduce temperature, and offer good protection for operators using portable fire extinction equipment.

Test results for fire suppression using pure water demonstrate that with a high nozzle discharge angle of >45°, flame cooling and oxygen displacement play key roles. Conversely, for a low nozzle discharge angle of <45°, blocking and dilution of fuel vapors were the dominant factors.

Heptane and gasoline fires have similar fire extinction behaviors in that fire suppression performance with 3% additive solution volume is similar to that with pure water. Additionally, for tests with 6 and 10% additives, the lower the nozzle discharge angle, the more the extinguishing time spends as there is less mist being able to reach the fuel pan. Furthermore, the additive used in these tests for fire suppression performed better with gasoline fires than with heptane fires. The fire extinction efficiency is influenced by water–mist and additive effects. Therefore, an optimal zone between the water–mist and additive effects must exist for fire suppression.

ACKNOWLEDGEMENTS

The authors would like to thank the National Science Council of the Republic of China, Taiwan (Contract No. NSC 94-2622-E-166-004-CC3), and the Ministry of Education, Republic of China, Taiwan, for financially supporting this research.

REFERENCES

1. NFPA 750. *Standard for the Installation of Water Mist Fire Protection Systems* (2003 edn). National Fire Protection Association, Quincy, MA, 2003.
2. Mawhinney JR, Dlugogorski BJ, Kim AK. A closer look at the fire extinguishing properties of water mist. *Fire Safety Science—Proceedings of Fourth International Symposium*, Ottawa, 1994; 47–60.
3. Richard J, Garo JP, Souil JM, Vantelon JP. On the flame structure at the base of a pool fire interacting with a water mist. *Experimental Thermal and Fluid Science* 2003; **27**:439–448.
4. Richard J, Garo JP, Souil JM, Vantelon JP, Knorre VG. Chemical and physical effects of water vapor addition on diffusion flames. *Fire Safety Journal* 2003; **38**:569–587.
5. Liu Z, Kim AK, Carpenter D. Portable water mist fire extinguisher as an alternative for halon 1211. *Halon Options Technical Working Conference*, Albuquerque, U.S.A., 24–26 April 2001; 435–439.
6. Liu Z, Kim AK, Carpenter D. A portable water mist fire extinguisher for multi-purpose applications. *Workshop on Fire Suppression Technologies*, Mobile, AL, 24–27 February 2003; 1–3.
7. Xiaomeng Z, Guangxuan L, Bo C. Improvement of water mist's fire-extinguishing efficiency with MC additive. *Fire Safety Journal* 2006; **41**:39–45.
8. CNS 1387. *Fire Extinguishers* (2004 edn). Chinese National Standards, Taiwan.

DOI: 10.1002/fam