# PORTABLE WATER MIST FIRE EXTINGUISHERS AS AN ALTERNATIVE FOR HALON 1211

Zhigang Liu, Andrew K. Kim, and Don Carpenter
National Research Council of Canada

Ping-Li Yen
Fountain Fire Protection, Inc.

## INTRODUCTION

Fixed water mist fire suppression systems as an alternative for total-flooding halons have already demonstrated their capabilities in providing protection in machinery spaces, gas turbine enclosures, and other applications [1, 2]. However, studies of portable water mist extinguishers are limited. There is one type of commercial portable water mist extinguisher for use on fires associated with wood and paper (Class A) and electrical equipment (Class C) [3]. The capability and limitation of portable water mist fire extinguishers as an alternative for Halon 1211 against flammable liquid fires have not yet been studied. Previous research [4] showed that it was very difficult for water mist to extinguish flammable liquid fires with flash points below normal ambient temperatures, such as n-heptane ($C_7H_{16}$, **FP** = -4 °C), because fuel temperature cannot be cooled enough to reduce the vapour/air mixture above the surface of the fuel to below its lean flammability limit. In addition, it is also very challenging for water mist to extinguish cooking oil fires, because the hot cooking oil has a strong propensity for reignition due to its high burning temperature (approximately 400 "C) and low auto-ignition temperature (approximately 330 °C) with respect to its burning temperature [5]. Currently, there is no commercially available water mist extinguisher for use on flammable liquid fires.

The National Research Council of Canada, with Fountain Fire Protection, Inc., has carried out a series of full-scale fire tests to investigate the capability and limitation of portable water mist extinguishers as an alternative for Halon 1211 in suppressing various types of fires. The types of fires used in the tests included cooking oils, n-heptanes, diesel fuels, and wood cribs. The impact of key water mist characteristics, such as flow rate, spray angle and droplet size, discharge pressures, nozzle discharge angles, as well as the types of nozzles on fire suppression, was studied. Based on this study, a prototype water mist fire extinguisher for multi-purpose fire protection was developed for use on fires associated with cooking oils, woods, papers, flammable fuels, and electrical equipment.

## PROTOTYPE PORTABLE WATER MIST FIRE EXTINGUISHER

The prototype portable water mist fire extinguisher developed in this project consists of a commercially available cylinder, a hose assembly, a nozzle holder, and a nozzle. The cylinder has a maximum capacity of 9.4 L of water. To develop the prototype extinguisher for flammable liquid fuel fires, the spray performances, such as spray angles, spray coverage areas and flow rates, etc., of seven types of commercially available mist nozzles were evaluated under various operating conditions. Based on the evaluation, *two* of these nozzles were selected as suitable for further full-scale fire tests. The flow rate of Nozzle #1 was varied from 0.7 to 4.4 gpm and its spray angle was 60 deg. The flow rate of Nozzle #2 was varied from 0.71 to 6.30 gpm. Its spray angle was 120 deg under 100 psi discharge pressure and reduced with increase in discharge pressure.

## TEST RESULTS AND DISCUSSION

The capability and limitation of water mist fire extinguishers against various types of fires were studied with *two* types of nozzles, using different discharge pressures, flow rates, spray angles, and the nozzle distance from the fire. Four types of fires were used in the tests: pool fires of vegetable cooking oil, n-heptane, diesel fuel, and wood crib fires. Full-scale fire tests were conducted following NFPA 10 "Standard for Portable Fire Extinguisher" *[6]* and **ULC** "Standard for the Rating and Fire Testing of Fire Extinguishers and Class D Extinguishing Media" [7].

## COOKING OIL FIRES

A commercial propane-fired deep fat fryer (Pitco Frialator, Model 18) was used in the tests. The fryer had a frying area of 0.457 m x 0.457 m, and a 0.153 m drip board. The depth of the fryer was 0.457 m. During the tests, the fryer contained 42 L of vegetable cooking oil (0.228 m depth in the fryer). The cooking oil (a mix of canola and soybean oils) in the fryer was heated continuously at a rate of 9 °C/min and it auto-ignited at a temperature of 368 °C. After auto-ignition, the fire was left to bum freely with the heating source remaining on for 1 min, which further increased the oil temperature to 396 °C. Water mist discharge started after a 60 s free burning period. The extinguisher nozzle was not extended over the front edge of the fryer during discharge. The heating source to the fryer remained on during discharge.

Two thermocouples were located 25 mm and 50 mm, respectively, below the fuel surface, and two thermocouples were located 50 mm and 100 mm, respectively, above the fuel surface. For each test, fire and cooking oil temperatures, fire extinguishing time, and operating parameters of the portable extinguisher (e.g., discharge pressure, flow rate and discharge period) were measured.

Seven full-scale tests involving cooking oil fires were conducted. During Tests K-1 and K-2, the nozzle was placed 0.22 m away from the edge of the fryer and 0.47 m above the oil surface. As observed in the tests, discharged water mist could not reach oil fires behind the integral drip board, because the nozzle was located too far from the fryer. The water mist fire extinguisher using both Nozzles #1 (discharge pressure of 155 psi) and #2 (discharge pressure of 170 psi) could not extinguish the fires. It was noted that, in order to extinguish cooking oil fires, the water spray must be able to reach the entire fuel surface and to extinguish the cooking oil tire by cooling its fire plume and the bulk of the hot oil as well as displacing oxygen available for combustion.

During Tests K-3 and K-4, the nozzle was placed at the edge of the fryer and the water mist discharge was able to reach the entire oil surface. In Test K-3, using Nozzle #2 with 175 psi discharge pressure, the fire was extinguished at 3 s after the start of water mist discharge. No fire ball and no splashed buming oil were observed in the test. A large amount of steam was produced after the fire was extinguished. The cooking oil was cooled to below 315 °C after 30 s of water mist discharge. The oil and fire temperatures measured in the test are shown in Figure 1. In Test K-4, the discharge pressure was reduced to 125 psi and the extinguishing time was increased to 19 s, because the water mist spray in Test K-4 had a lower flow rate and less discharge momentum; consequently, the spray was not able to penetrate the fire plume fully, compared to the high discharge pressure in Test K-3.

In Test K-5, after 1 min of free burning, the operator activated a full water mist discharge (175 psi) 3 m away from the fryer and then gradually approached the fryer until the nozzle was almost at the edge of the fryer. The fire was extinguished at 8 s after the start of water mist discharge. The fire size was enlarged during water mist discharge, but no fire ball was observed in the test.

In Test K-6, the nozzle was changed from Nozzle #2 to #1 and the other test conditions were the same as in Test K-3. After 1 min of free buming, the operator activated full water mist discharge (I 75 psi) with the nozzle location near the edge of the fryer. The oil fire was extinguished at 8 s after the start of discharge. The extinguishing time was longer than that of Test K-3 using Nozzle #2, because at the same discharge pressure, Nozzle #1 had a lower water flow rate and smaller spray angle than Nozzle #2.

In Test K-7 using Nozzle #1, the discharge pressure was reduced to 150 psi while keeping other test conditions the same as in Test K-6. The fire was extinguished at 10 s after the *start* of discharge. The extinguishing time was longer than that in Test K-6 because of lower water flow rate and discharge momentum.

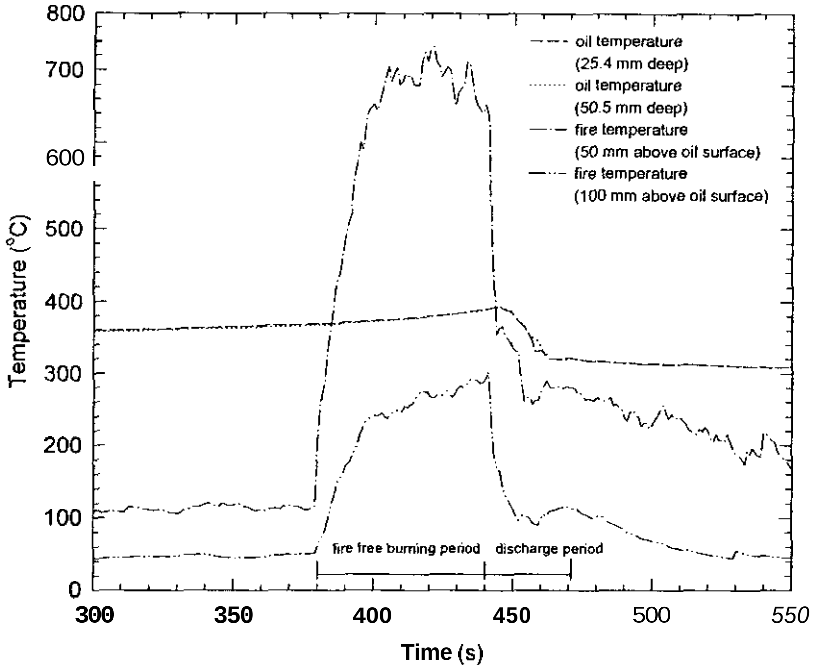


Figure I. Variation of oil and fire temperatures with time in a cooking oil fire test.

## FLAMMABLE LIQUID FIRES

A total of 6 full-scale fire tests were conducted to evaluate the effectiveness of the portable water fire extinguisher in extinguishing flammable liquid fuel fires. A 0.47 x 0.47 x 0.3 m high steel pan was used in the tests. The test fuel consisted of not less than a 0.05 m deep layer of liquid fuel. The surface of the liquid fuel layer was located 0.15 m below the top edge of the pan. This fire scenario was the same **as** that used for extinguishment of **Class** 2-B rating fire [7]. Nozzles #1 and #2, used in the cooking oil fire tests, were used in these tests.

Two thermocouples were located 20 and 50 mm below the fuel surface, and two thermocouples were located 30 and 40 m above the fuel surface. For each test, the impact of the discharge pressure, flow rate, and the discharge period on the effectiveness of the portable water mist extinguisher to extinguish flammable liquid fuel fires were investigated. Fire and liquid fuel temperatures, fire extinguishing times, and operating parameters of the portable extinguisher (e.g., discharge pressure, flow rate, and discharge period) were measured. After ignition, the fuel was allowed to bum for 60 **s** before the fire was attacked with the extinguisher. The attack was made from one side only and the operator was not allowed to extend any part of his body past the edge of the test pan while fighting the fire.

During Tests B-1 and B-2, water sprays discharged from Nozzle #1 with discharge pressures of 175 and 225 psi, respectively, were able to cover most of the liquid fuel surface but could not effectively cover much beyond the steel pan. The fires in both Tests B-I and B-2 were quickly controlled by the water mist, but they could not be extinguished after 1 min ofthe water mist discharge.

Nozzle #2 was used in Test B-3. During the test, the operator stood 1.1 m away from the pan with the nozzle located near the edge of the pan, and activated the discharge. The large water spray generated by Nozzle #2 with discharge pressure **of** 175 psi was able to cover the entire liquid fuel surface **as** well as the steel pan. Fine water droplets not only effectively cooled the fire plume **and** the pan, but **also** blocked fresh **air** entraining into the fire plume and reduced the oxygen available for the combustion. As a result, the n-heptane fire was extinguished at 4 **s** after the start of discharge while the fuel temperature was kept unchangeable during suppression. The oil and fire temperatures measured in Test B-3 are shown (Figure 2). Test B-3 also showed that, at the initial moment of fire suppression by water mist, a large momentary fire flare-up was observed. The initial water mist discharge increased turbulence and stirring around the fire and brought a stream of air into the fire plume, resulting in increase in fire size and heat release rate.

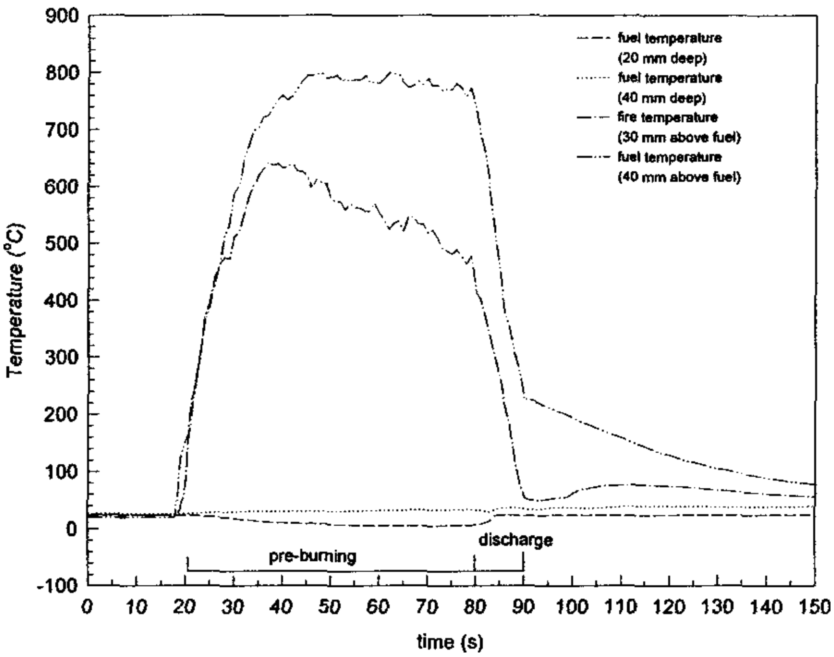


Figure 2. Variations of fuel and fire temperatures with time in a heptane fire test.

Test **B-3** was repeated in Test **B-4.** The n-heptane fire was extinguished at **3 s** after the start of discharge in Test **B-4,** and a large momentary fire flare-up was also observed during initial water mist suppression. The total discharge duration was **5** s, and no auto-reignition was observed. The total water quantity used in the test was 1.21 litres.

During Test **B-5,** the operator activated the water mist discharge from **3** m away from the pan and then gradually approached the pan and stopped 1.1 m away from the pan, which placed the water mist spray nozzle near the edge of the pan. The n-heptane fire was extinguished at **8 s** after the start of discharge and the initial fire flare-up in Test **B-5** was worse than those observed in Tests **B-3** and **B-4,** because the fresh air entraining into the fire plume, caused by the discharge of the water mist, was increased with nozzle distance from the fire. In Test **B-5,** the total discharge duration was **13** s, and no auto-reignition was observed. The total water quantity used in the test was **2.75** litres.

During Test **B-6,** n-heptane fuel was replaced with diesel fuel while other test conditions were kept the same as in Tests **B-3** and **B-4.** The diesel fuel fire was extinguished at 2 s after discharge, and a small momentary fire flare-up was observed during suppression. The total discharge duration was **5 s,** and no auto-reiguition was observed. The total water quantity used in the test was 1.21 litres. Compared to the n-heptane fires, it was much easier for the water mist to extinguish diesel fires, because water mist was able to cool the diesel fuel to below its flash point (FP = **60 °C**).

## WOOD CRIB FIRES

Wood cribs were used for Class **A** fire tests. The wood cribs consisted of cube-shaped stacks formed from nominal **0.038** x **0.038** x **0.635** m long spruce wood members, built upon **0.064** x **0.064** m angle iron supported on concrete blocks at a height of **0.39** m above the floor. The number of wood members was 112, and the arrangement of the crib was **16** layers of 7. **A** pan with 2 L of n-heptane was placed centrally beneath the crib and acted as an ignition source. This fire scenario is equivalent to the fire extinguisher test protocol for Class **2-A** rating. In each test, the total mass of the crib was determined prior to the test and the ignition fuel (n-heptane) was added to the pan. The n-heptane in the pan was then ignited and the crib allowed to burn until its mass was reduced to 55% of its original mass. The same type of nozzle (Nozzles #1 and #2) used in the previous tests were also used in the wood crib fire tests. Water mist discharge pressure in these tests was kept at 175 psi. Water mist was applied to the crib on its three sides, top and bottom, using a continuous discharge. After the crib fire was extinguished, the crib was left for 15 min and checked for possible reignition. During water mist application, no discharge was directed at the back of the crib.

Eight full-scale tests were conducted. During the fire tests, the impact of discharge pressure, flow rate, and discharge period on the effectiveness of the portable water mist fire extinguishers to extinguish wood crib fires was investigated. When water mist was discharged, no fire flare-up was observed, and the crib fire was quickly controlled. However, extinguishing performance of the water mist fire extinguisher for the crib fire was heavily dependent on the way in which the water mist was applied. For Tests A-I to A-5 using both Nozzles #1 and #2, the water mist was applied randomly covering the top and the sides of the crib, at times, chasing flames. This random application wasted a lot of water spray by being lost in the upward fire plume before reaching the fuel surface. The flame located in the center and back of the crib was especially difficult to extinguish. Among Tests A-I to A-5, only the crib fire in Test A-3 using Nozzle #1 was extinguished; fires in other tests using both Nozzles #1 and #2 could not be extinguished.

For Tests A-6 to A-8, the water mist spray was applied systematically, starting from underneath the crib and then side by side. The fire on the top of the crib was attacked last. Water mist spray was maintained for a minimum of 10 s on each side of the crib, making sure the fire on that side was extinguished before moving on to the other side. As a result, the extinguishers using both Nozzles #1 and #2 successfully extinguished the crib fires, and no reignition was observed. The extinguishing time using Nozzle #I was 1 min 45 s while Nozzle #2 extinguished fires at 51 s after the start of discharge, because at the same discharge pressure, Nozzle #2 had higher water flow rate than Nozzle #1.

## CONCLUSION

The portable water mist fire extinguisher developed in this project was suitable for use on cooking oil fire (Class K), wood crib fire (Class 2-A), and flammable liquid fire (Class 2-B). Compared to other extinguishers, the water mist fire extinguisher is suitable for providing fire protection for a wide range of applications. However, in order to extinguish fires, the operator must stand relatively close to the fire and momentary flare-ups may occur while suppressing some types of flammable liquid fires.

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