EVALUATION OF A COMBINED SYSTEM OF HIGH PRESSURE WATER MIST AND AEROSOL FIRE SUPPRESSION SYSTEM

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1 INTRODUCTION

A new hybrid system combining High Pressure Water Mist (HPWM) and aerosol fire suppression systems was examined to investigate the effectiveness of the hybrid system in providing fire protection with view to high risk spaces, e.g. machinery rooms.

The HPWM system produces ultra-fine droplets of water upon activation. The ultra-fine water mist droplets are effective in cooling flames and hot gases. Through the course of the cooling, the fine water mists tend to evaporate quickly, which causes displacing oxygen and in turn suppresses the fire.

The aerosol total flooding fire suppression system is a newly developed advanced system, which is significantly simple for installation and maintenance. In the event of a fire, the activated aerosol system produces ultra-fine aerosol. Fire suppression is achieved through interference between the ultra-fine aerosol particles and the flame's free radicals – terminating propagation of the fire, and providing quick fire extinguishment. In previous tests, conducted at in the NRC fire lab [1, 2], the aerosol system demonstrated rapid fire extinguishments when the discharged aerosol was well mixed in the test room.

If both the HPWM and aerosol systems were used, the fine water droplets and aerosol would be mixed in the enclosure. No previous study has been undertaken to identify how these two systems would interact with each other. A question raised is "Whether HPWM water droplets wash off aerosol particles". If the answer to this question is yes, the next question will be "To what extent the scrubbing would affect the fire suppression performance of the aerosol system". On the other hand, if there is no direct interaction between the water droplets and aerosol, the new hybrid system would then provide the benefits of both the HPWM and aerosol systems. The water mist provides quick control of the fire as well as rapid cooling of the protected space. While the aerosol provides quick fire extinguishment.

In this paper, the fire suppression performance of the hybrid system was evaluated in general conformance with the IMO 1270, Guidelines for the approval of fixed aerosol fire extinguishing systems equivalent to fixed gas fire extinguishing systems [3]. The main objective of the study is to investigate how both the HPWM and aerosol systems interact with each other; and whether the hybrid system enhances or diminishes the fire suppression performance of each system. Various activation sequences of the HPWM and aerosol systems were explored to compare the fire suppression performance of the new hybrid system in realistic settings to determine the best fire protection measures.

2 TEST FACILITY AND PROCEDURES

Fire tests were conducted in a 500 m^3 compartment. The compartment was equipped with both a high pressure HPWM system and an aerosol fire suppression system. Water mist nozzles and aerosol generators were installed on the ceiling. Temperatures, pressures and gas concentrations were monitored to observe fire behaviour. The fire scenarios presented in this paper included heptane and diesel fires; wood and plastic crib fires.

2.1 Test Room

The 500 m^3 test compartment with dimensions of 10 m (W) by 10 m (L), with a ceiling height of 5 m, was assembled with metal panels in the VTT fire lab, Finland. A 3-dimensional perspective view of the room is shown in Figure 1.

The test compartment had an access door with a minimum area of 4 m^2. The test room was provided with a closable ventilation hatch at the ceiling with an area of 6 m^2. The walls and ceiling of the test room were built with metal panels, and the gaps between the metal panel assemblies were sealed with fire retardant sealants. A door blower test was conducted following ASTME E1827 [4] to identify the level of leakage from the room, and the test results showed that the room was nominally leak-tight when the doors and hatches were closed.

The test compartment also had two weight-loaded pressure relief vents. Figure 1 shows the locations and dimensions of the over-pressure relief vent and the under-pressure relief vent.

An engine mock-up with dimensions of 1 m (W) x 3 m (L) x 3 m (H) was constructed of sheet steel. The mock-up was centrally located in the room. A deck plate with dimensions of 4 m (W) x 6 m (L) x 0.75 m (H) was built, surrounding the engine mock-up, to simulate bilge plates in the machinery spaces.

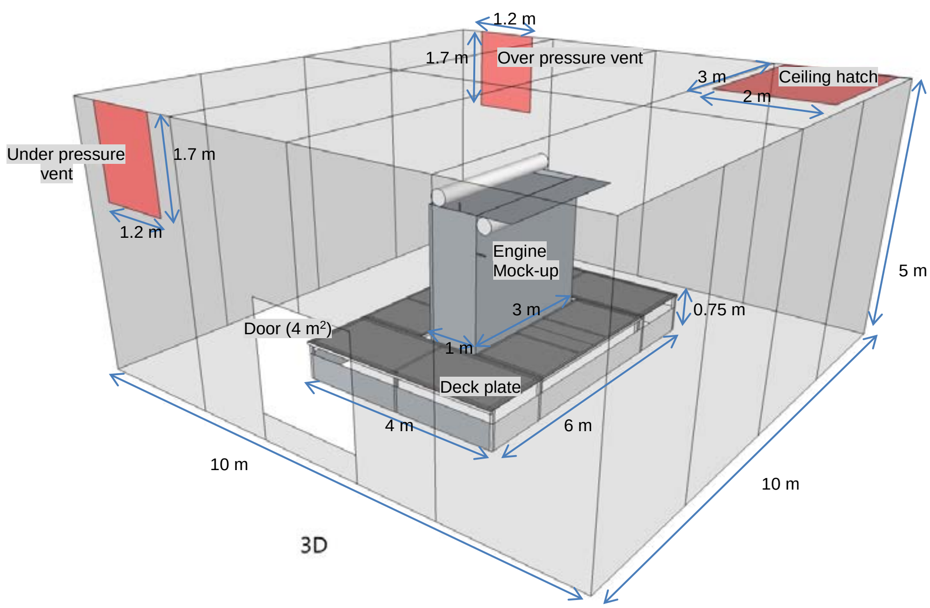

Figure 1. 3-dimensional perspective view of the test room.

2.2 High pressure water mist system

A high pressure water mist (HPWM) system using spray heads, consisting of discrete micro nozzles, was installed on the ceiling of the test compartment. The K factor of the nozzles was 1.9 l/min/bar$^{0.5}$, and the system operating pressure was 70 bar (1015 psi).

There were five mist nozzles installed on the ceiling at a 5 m spacing, as shown in Figure 2. Plain water was used as a suppression medium. The total water flow rate measured at the main water pipe line was about 60 l/min with the operating pressure of 70 bar. These nozzles produced a cone spray pattern down to a distance of about 0.6 m from the nozzles. While at further distances, the spray widened and the fine mists quickly filled up the whole test room. Droplet size information provided by the manufacture is Dv90 140 - 150 µm, Dv50 70 µm and Dv10 20 µm at 1 m distance from the spray head at 80 bar.

2.3 Aerosol system

On the ceiling of the test room, as shown in Figure 2, brackets were installed for 16 aerosol generators. The aerosol density designed for the tests was 80 g/m^3, which met the target concentrations suggested by the manufacture in the range of 52 g/m^3 to 80 g/m^3 in the test compartment.

2.4 Fire Scenarios

Various types of fires were tested in the full-scale tests. A diesel pan fire (C), spray fire (E), plastic crib fires (H-ABS, H-PMMA, H-PP) and wood crib fires (F-6). The 360 seconds (6-minute) pre-burn wood crib and three plastic cribs with different polymer materials were placed on the floor with ignition burners. The heptane spray fire was installed on the side of the mock-up under the shield plate. The 2 m^2 diesel pan (C) was placed on the metal deck. Figure 2 shows the test set-up and instrumentations. Details of each fire set-up can be found in the IMO 1270, Guidelines for the approval of fixed aerosol fire extinguishing systems equivalent to fixed gas fire extinguishing systems [3]. Table 1 lists the fire scenarios and conditions used in each test.

Table 1. List of test scenarios.

Test #	**Aerosol**	**HPWM**	**Note**
Hybrid System			
H3	80 g/m^3	70 bar (1015 psi), 60 l/min	aerosol system activated first
H4	80 g/m^3	70 bar (1015 psi), 60 l/min	HPWM system activated first
H5	80 g/m^3	70 bar (1015 psi), 60 l/min	both systems activated at the same time

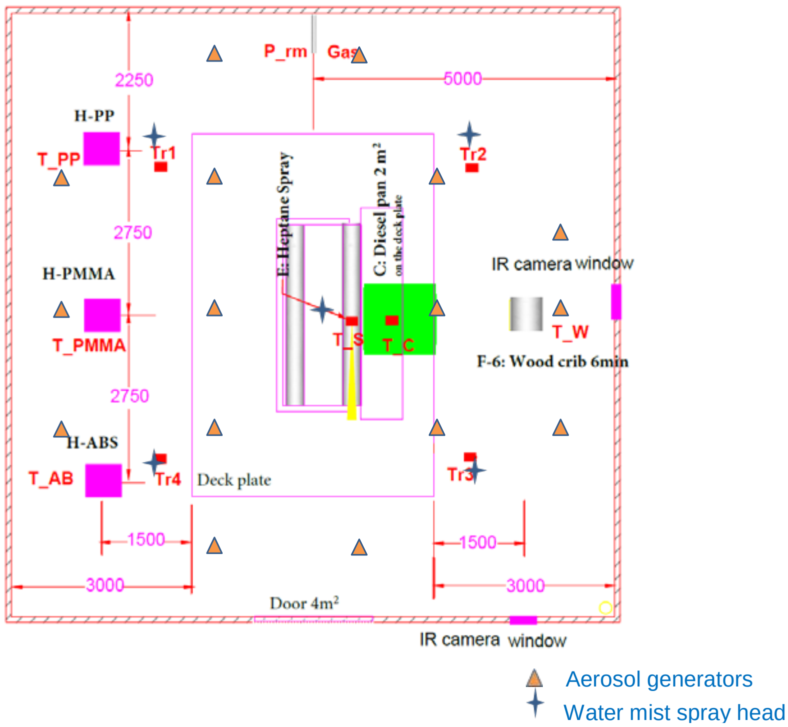

Figure 2. Fire scenario #3 (the IMO test 3) fire set-up and instrumentations.

2.5 Instrumentation and Gas Measurements

Figure 2 shows the instrumentation of the test room.

- Thermocouples

  Room Temperatures: Four thermocouple trees (Tr1, Tr2, Tr3 and Tr4) were set up in the room (shown in Figure 2) to monitor the temperature during the tests. Each tree was 5 m high, and Tr1 and Tr2 measured temperatures at a 0.3 m interval. Tr3 and Tr4 measured temperatures at approximately 0.5 m intervals.

  Pan Fire Temperatures: Two thermocouples were installed above each pan fire to monitor the flame temperature. T_C1 and T_C2 were installed to measure the temperature of the diesel pan fire (C).

  Spray Fire Temperature: Two thermocouples, T_S1 and T_S2, were installed in front of the spray fire (E).

  Crib Fire Temperatures: Two thermocouples, T_W1 and T_W2, were installed in the wood crib fire (F-6); T_W1 above the ignition pan and T_W2 in the wood crib. Two thermocouples were installed in each plastic crib; T_PP1 (above the ignition pan), T_PP2 (between the PP sheets), T_PMMA1 (above the ignition pan), T_PMMA2 (between the PMMA sheets), T_AB1 (above the ignition pan), and T_AB2 (between the ABS sheets).

- Pressure taps: One pressure tap was installed on the rear wall to monitor the pressure changes in the room (P_rm) during the tests (Figure 2). The pressure tap was located at mid-height of the room.
- Gas analyzers: A sampling probe was placed on the rear wall of the compartment at mid-height (Figure 2) and was connected to the gas analyzers to measure CO, CO_2 and O_2.
- Video cameras: Video cameras were set up in the test compartment to obtain visual records of the water mist, aerosol discharge and fire behaviour during the tests. Also, two infrared cameras were used to monitor the fire behaviour after the activation of the water mist and aerosol system. Two IR windows were installed in the test room (see Figure 2).
- Water flow meter and water pressure gauge: An ultrasonic transit-time flow meter was installed on the main water pipe to measure water flow rate. Pressure gauges were also installed near the outlet of the high pressure water pressure pump and on the ceiling pipe line close to one of the spray nozzles.
- Fuel pressure gauge: For the spray fire (E), fuel nozzle pressures were measured using a low-range pressure transducer. The pressure transducer was installed on the fuel line at about 5.5 m away from the spray nozzle.
- pH meter: After fire testing, a hand-held pH meter was used to measure the pH level of the water used for each fire test to identify any aerosol scrubbing by the water mists. .
- Moisture meter: A pin-type moisture meter was used to measure moisture contents of the wood cribs prior to the fire tests..

3 TEST RESULTS

3.1 Hybrid system tests

Tests H3, H4, and H5 were conducted following the IMO test protocol #3, in which the 2 m^2 diesel pan fire (C), heptane spray fire (E), plastic crib fires (H-ABS, H-PMMA, H-PP) and wood crib fire (F-6) were used. For the wood crib fire, one crib was tested considering only 360 seconds (6-minute) free burn.

In these hybrid system tests, aerosol generators were installed on the ceiling and tested along with the HPWM system. For the HPWM system, the operating pump pressure of the HPWM system was about 70 bar, and the measured water flow rate was about 60 l/min. The aerosol concentration used in this test was 80 g/m^3.

The wood crib (F-6) was first ignited (see Figure 2 for the location). The three plastic cribs were then ignited at 150 seconds later. Subsequently, the diesel pan fire was ignited at 4 minutes (240 seconds). At approximately 360 seconds (6 minutes), the heptane spray fire was ignited. The door and the ceiling hatches were closed shortly after, and then the hybrid system, using both the aerosol and HPWM system, was activated. The same test procedure was repeated in Tests H3, H4, and H5, with varying activation sequences of the HPWM and aerosol systems.

In Test H3, after allowing the required free burn time for each fire, the door and the ceiling hatch were closed. Then, the aerosol system was activated first, followed by the HPWM system activated after 35 seconds of delay.

Test H4 was conducted following the same procedure used in Test H3, but the HPWM system was discharged first. After a delay of 30 seconds from the HPWM system activation, the aerosol system was then activated.

In Test H5, both the aerosol and the HPWM systems were activated concurrently after allowing the required free burn time for each fire scenario.

After a required hold time (i.e. the minimum amount of time for which the door should be kept closed) , the door was opened, and the pH level was measured for water sampled from the test room. The wood crib, plastic cribs and aerosol generators were weighed before and after each test.

3.1.1 Test H3

The peak room pressure at the discharge of the aerosol system was about 150 Pa. After the activation of the HPWM system, the room pressure dropped suddenly to -120 Pa. As shown in Figure 3, the sudden pressure drop in the room was caused in part by the sudden cooling in the room by the HPWM system, which filled up the entire room with fine water mists within 20-30 seconds.

As shown in Figure 4, the heptane spray fire was started at 15 seconds prior to the activation of the aerosol system, and the spray was kept on for about 170 seconds. The temperature measured in front of the fuel nozzle (T_S2) started to decrease at the end of the aerosol discharge (37 seconds from the start of activation). The temperature data shows that the heptane spray fire was extinguished in about 90 seconds from the aerosol activation and in 30 seconds from the water mist activation.

Figure 4 also shows the temperatures measured above the diesel pan fire (T_C2). At the end of the aerosol discharge, the temperature of the diesel pan fire started to decrease, and the temperature decreased further with the HPWM system activated. The diesel fire was extinguished at about 500 seconds, 120 seconds after the activation of the aerosols system and in 90 seconds after the activation of the HPWM system.

The plastic crib fires (H-AB, H-PP, H-PMMA) were ignited at 150 seconds and allowed to free burning for 210 seconds. Within 30 seconds after the activation, the temperatures from all three plastic cribs promptly decreased even before the HPWM system was activated. The three plastics crib fires were extinguished within 90 seconds from the aerosol activation, as shown in Figure 5.

The 360-seconds (6-minute) wood crib fire was affected by the aerosol system immediately after the end of discharge (see T_W2 in Figure 6). With the HPWM system activated, the temperature of the wood crib fire decreased further, and the fire was extinguished at about 600 seconds, 240 seconds from the activation of aerosol system and 180 seconds from the activation of HPWM system.

During the hold time of 15 minutes, no fire was re-ignited, including the heptane spray fire, which was restarted at 15 seconds prior to reopening the door. After opening the door, each fire was checked, and no flame remained for each fire set-up. There was still diesel fuel remaining in the fuel pan (C), which confirmed that the fire was extinguished by the hybrid suppression systems.

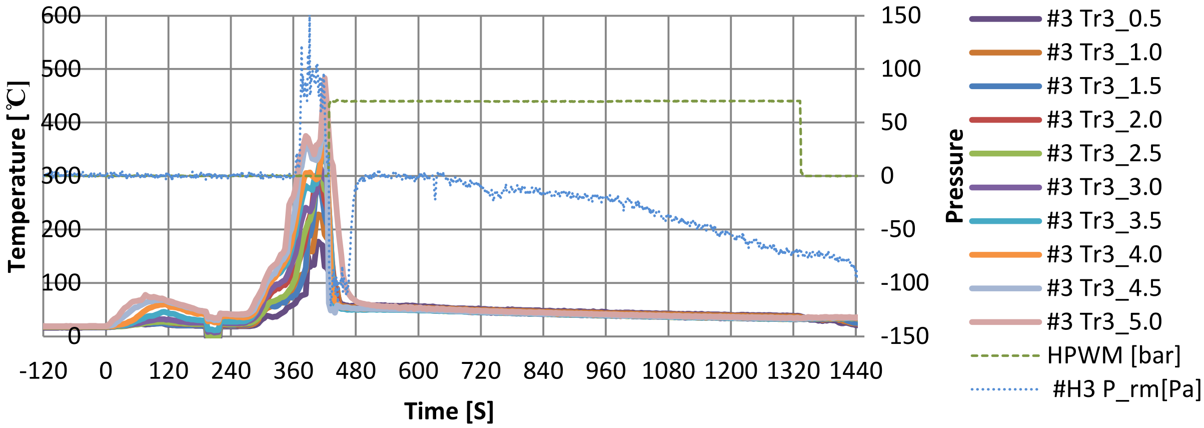

Figure 3. Room Temperature (Test H3).

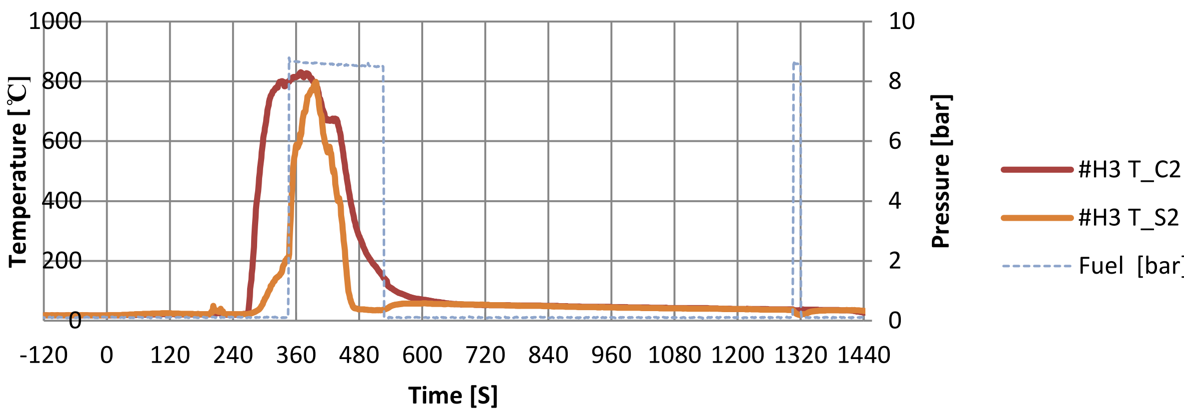

Figure 4. Heptane spray and diesel pan fire temperatures (Test H3).

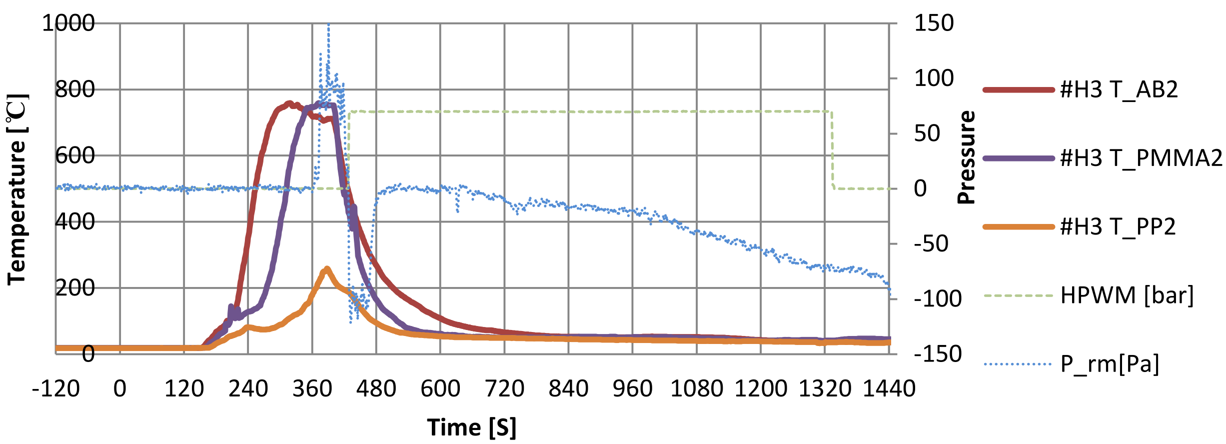

Figure 5. Plastic crib fire temperature (Test H3).

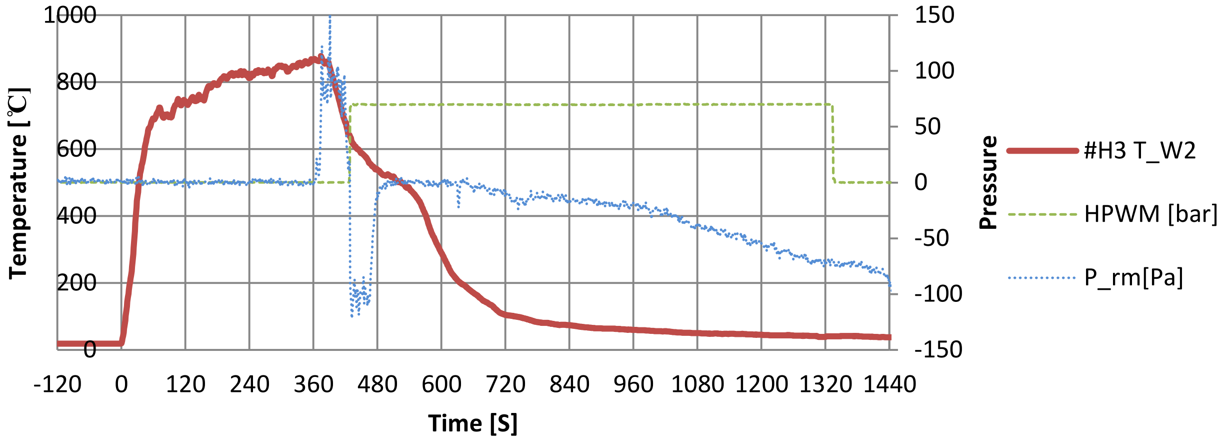

Figure 6. Wood crib fire temperature (Test H3).

3.1.2 Test H4

As shown in Figure 7, the room temperature decreased suddenly with the activation of the HPWM system that was activated at 360 seconds after closing the door and ceiling hatch. In 30 seconds, the aerosol system was then activated, and the peak room pressure at the discharge was about 120 Pa.

The heptane spray fire was started after the activation of the HPWM system. At the start of the heptane spray fire, the temperature measured in front of the fuel nozzle (T_S2) immediately increased, but the increase was not stopped by the HPWM. However, as shown in Figure 8, the activation of the aerosol system caused the temperature to decrease. The temperature (T_S2) decreased to 200°C, and the fire was extinguished at 450 seconds, which is 60 seconds after the aerosol activation and 90 seconds after the activation of the HPWM system.

Figure 8 also shows the temperatures measured above the diesel pan fire (T_C1 and T_C2). The diesel pan fire was allowed a 120 seconds free burn. The temperature decreased to 200°C in about 120 seconds from the activation of the hybrid system. The diesel fire was extinguished at about 480 seconds that is after 100 seconds from the activation of the aerosols system and 120 seconds after the activation of the HPWM system.

The plastic crib fires (H-AB, H-PP, H-PMMA) were ignited at 150 seconds and allowed free burning for 210 seconds. Within 30 seconds from the activation, the temperature from the ABS crib fire decreased but the temperatures of PMMA and PP started to decrease after the aerosol system discharged. The three plastics crib fires were extinguished at 450 seconds, 90 seconds from the activation of the HPWM system and 60 seconds from the activation of the aerosol system.

Figure 10 shows the temperature from the 360-seocnds (6-minute) wood crib fire, which started to decrease in 40 seconds after the activation of the HPWM system and in 10-20 seconds from the activation of the aerosol system (see T_W2 in Figure 10). The wood crib fire was extinguished at about 480 seconds, which is 120 seconds faster than in Test H3.

During the hold time of 15 minutes, no fire was re-ignited including the heptane spray fire.

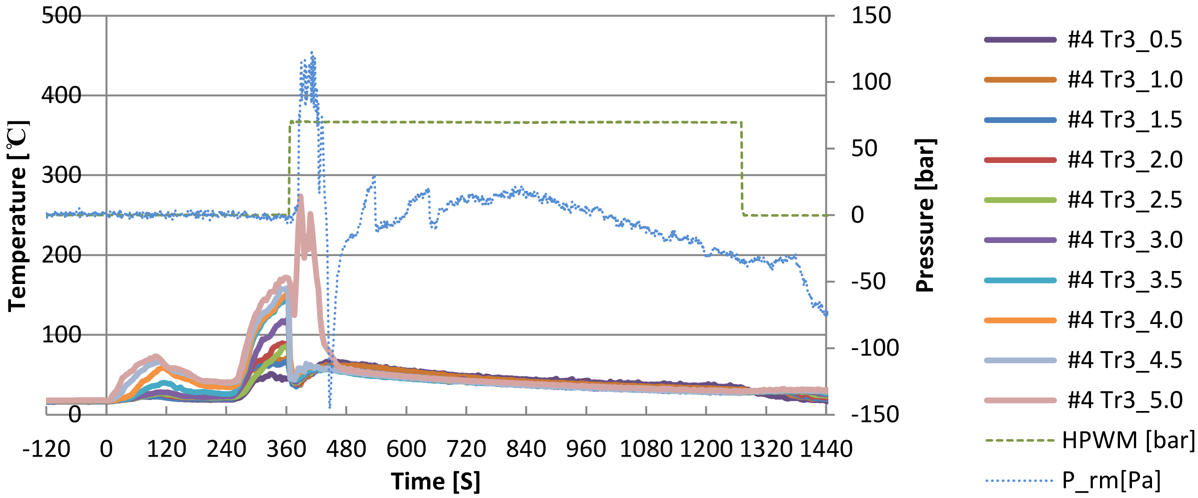

Figure 7. Room temperature and pressure (Test H4).

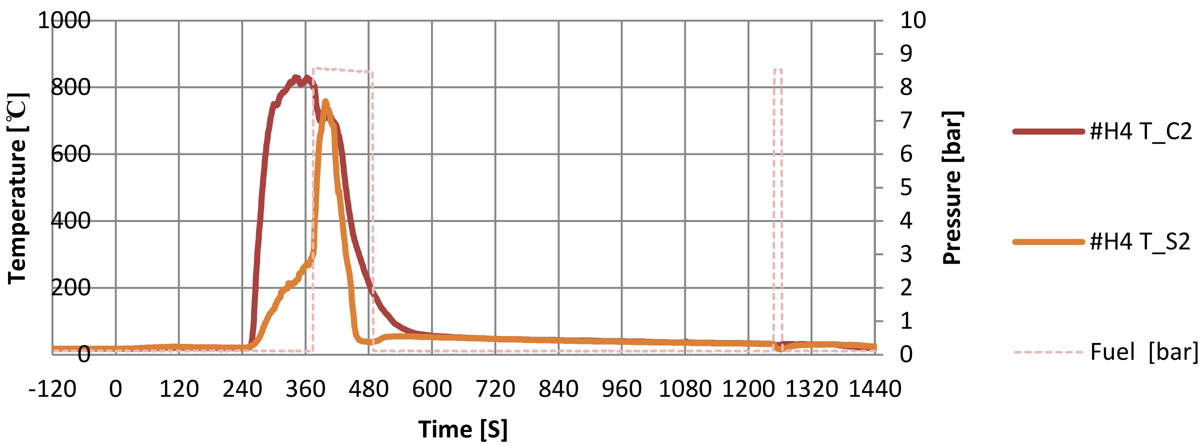

Figure 8. Heptane spray and Diesel pan fire temperature (Test H4).

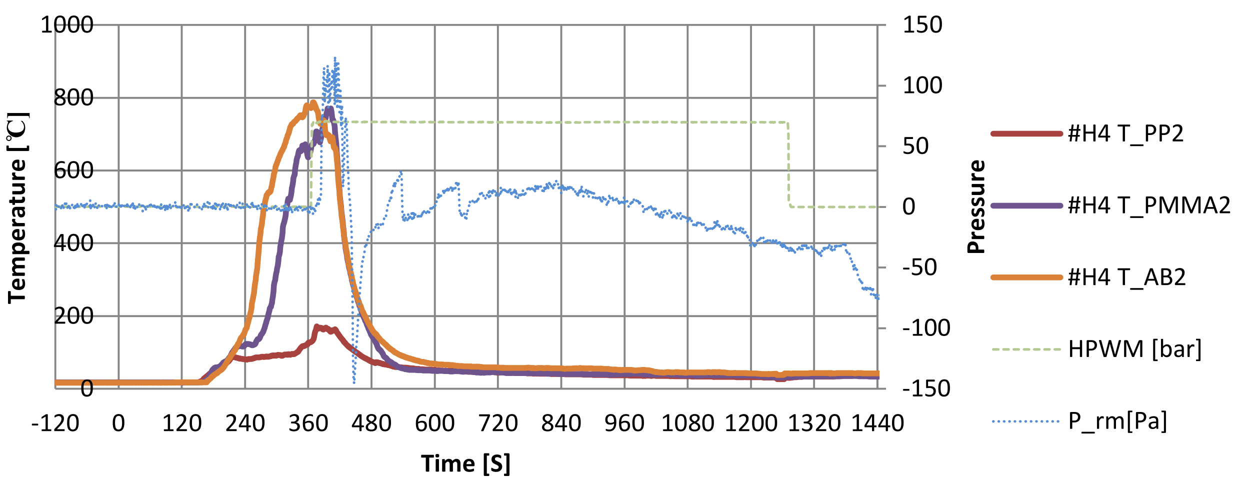

Figure 9. Plastic crib fire temperature (Test H4).

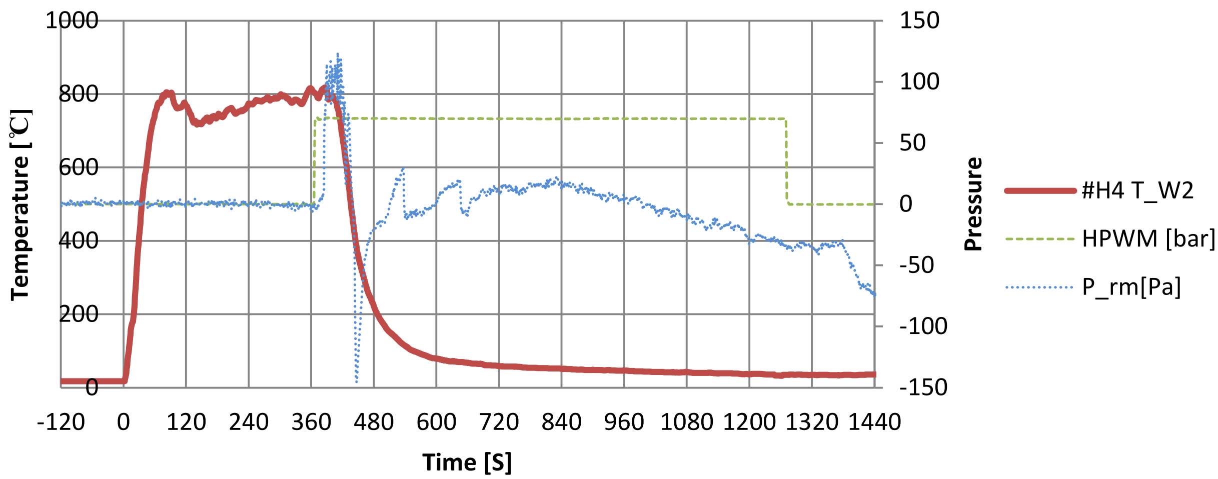

Figure 10. Wood crib fire temperature (Test H4).

3.1.3 Test H5

The wood crib fire (F-6), plastic crib, heptane spray fire and diesel fire were also prepared in Test H5 following the IMO test #3 protocol.

At 360 seconds, both systems were activated manually, and as the room pressure measurements were similar to Test H4. The HPWM system filled up the entire room with fine mists within 20-30 seconds, which resulted in a uniform room temperature of about 50°C.

The diesel fire was also suppressed very quickly at about 460 seconds, 100 seconds after the activation of both systems. This result is very similar to that from Test H3 and H4, but the extinguishment was slightly faster in Test H5 than in the others.

The temperature measured for heptane spray fire immediately decreased within 20 seconds from the start of activation. The temperature data shows that the heptane spray fire was extinguished by the hybrid system, and the extinguishment time was 420 seconds, which was within 60 seconds from the activation of the systems. The extinguishment of the spray fire in Test H5 was also slightly faster than in the other tests.

Similarly in Test H3 and H4, the plastic crib fires (H-AB, H-PP, H-PMMA) were ignited at 150 seconds.

The temperature from the 360-seconds (6-minute) wood crib fire also decreased from 700°C to 550°C after 120 seconds from the activation, as shown in Figure 11, and the fire was extinguished at about 570 seconds, that is within 210 seconds from the activation of both systems. The extinguishment of the wood crib fire was much faster in Test H4, where the HPWM system was first activated.

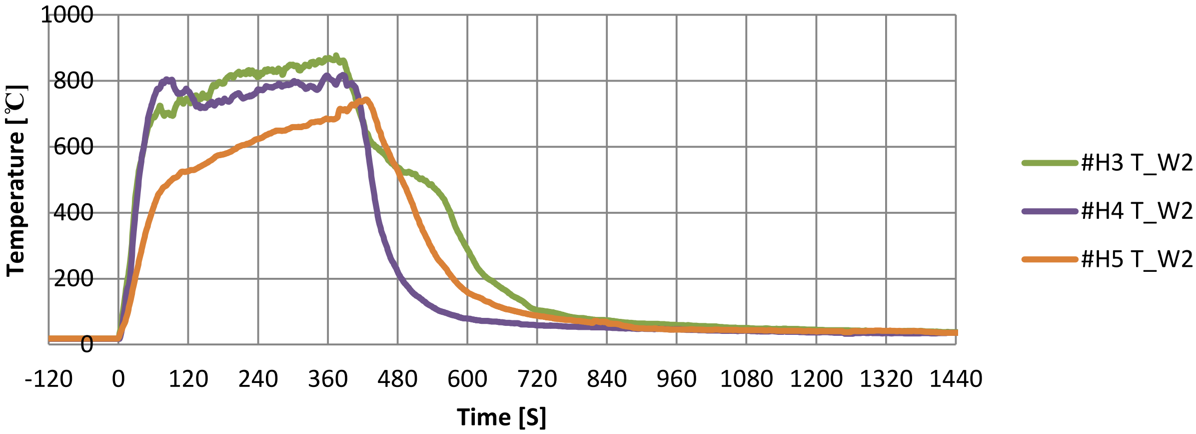

Figure 11. Wood crib fire temperature (Test H3-H5).

4 DISCUSSION AND CONCLUSIONS

Fire suppression tests in accordance to IMO 1270 were carried out to investigate the performance of the hybrid system using both the HPWM and aerosol fire suppression systems. The new hybrid system provided the benefits of both the high pressure water mist and aerosol systems.

Aerosol scrubbing effect by the HPWM

To check if there is any significant aerosol scrubbing effect by the fine water mists, pH level was measured for the water sampled from the test room after each fire test. The aerosol system generates Potassium nitrate (KNO3), which was moderately soluble in water and the aqueous solution is pH **7** [5]. The pH level of water from the main line was about 10. After each test, the sampled water from the test room showed a pH level in the range of 9.5-10 for all tests. This indicated that there was no significant scrubbing by the water mist. For this reason, both the fine water droplets and aerosol mixed in the test enclosure were effective in controlling and suppressing the fires.

Activation sequences in the Hybrid system

The suppression times of the wood crib fire (F) varied with different activation sequences of the HPWM and aerosol system. The earliest fire extinguishment resulted from Test H4, in which the HPWM system was activated first, followed by the aerosol system activated with a delay of 30 seconds. For the other fire scenarios (C, H, F and E), the hybrid system appeared to be slightly less effective when the aerosol system was activated earlier than or concurrently with the HPWM system.

As discussed, the aerosol system could potentially provide rapid fire extinguishment of all the fire types tested in this study, when complemented with the HPWM system. Furthermore, this study showed that the hybrid system is feasible and effective. However, the use of two systems with different design requirements necessities that certain parameters be properly considered in the design of the hybrid system (e.g. air tightness of the enclosure and the peak pressure relief of the enclosure). Therefore, further study is warranted with the focus on realistic settings of an actual machinery room.

ACKNOWLEDGEMENT

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REFERENCES

1. Ko, Y.J. and Kim, A.K. 2016. Evaluation of aerosol fire suppression system, Client Report A1-005917-01.1, National Research Council Canada.
2. Ko, Y.J. and Kim, A.K. 2016. Evaluation of low pressure water mist fire suppression system, Client Report A1-007157-01.1, National Research Council Canada.
3. International Maritime Organization. 2008. IMO Circ. 1270 Guidelines for the approval of Fixed aerosol fire extinguishing systems equivalent to fixed gas fire extinguishing systems, as referred to in SOLAS 74 for machinery spaces.
4. ASTME E1827. “Standard Test Methods for Determining Airtightness of Buildings Using an Orifice Blower Door”.
5. https://pubchem.ncbi.nlm.nih.gov/compound/potassium_nitrate#section=Decomposition