Experimental Study on Polymeric materials Suppressing Fires Using Low Pressure Water Mist System

Abd El-Salam.A, Sadek.H, Abu-Elyazeed.O
Mechanical Power Department, F.E.Mataria. Helwan University Cairo, Egypt

Abstract

Water mist technologies have the potential either to replace and overcome problems where traditional technologies have not been as effective as desired. Thus the present work aims to describe the suitability of a low pressure water mist system in suppression class (B) (PMMA) fire. The present experimental work examine and evaluate the performance of the proposed system design configurations against the conventional sprinkler system. The evaluation is performed by analyzing both visual, temperature behavior, fire extinction time and water flow rate. The experimental program includes several tests which are conducted with four different types of nozzles include the conventional one. The results of the present work showed that low pressure water mist system have notables shorter time of flame knock-down, ghost flame, suppression and extinction is with noticeable low water flux density than the conventional system.

KEYWORDS: Water mist; PMMA Fire suppression; Fire extinguish; Conventional sprinkler system; Low pressure water mist system.

1. Introduction

Polymeric materials are widely used as consumer products, building materials, and many others. One of the drawback of using these materials it can be ignited easily, producing toxic gases such as carbon monoxide, carbon dioxide, un-burnt fuel gases and hydrogen chlorine; leading to loss of human lives and property. It's worth to mention that the performance of conventional fire suppression systems which used against Class B and Class C is not efficient because its poor cooling ability, obscuration when used in confined places, the residual mess, environmentally un acceptable and toxicological effect for example, halocarbon streaming agents, CO_2 and toxicological effect . Moreover, There are several problems are related to the usage of conventional sprinkler such as high water flow rate, damage of sensitive equipment or occupancies, inability to control flammable liquid fires due to splashing and spillage of the fuel, [2].

It's important to study how the fire hazard of these polymeric materials to develop fire retardants and modify the fire behavior of these materials [1]. Therefore extensive efforts have been made over the last few years to find alternative means of active fire protection to overcome the above problems. Recent studies, [1, 3, 4], concluded that the water mist technique is considered favorable in extinguishment of multiple fire types such class A, B, and K. Moreover water mist is non-toxic, no asphyxiation problems, low system cost, limited or no water damage environmentally friendly, provides effective space cooling, short clean up time and faster post fire recovery, [6]. Accordingly, water mist technology has gained an acceptance in a wide range of fire suppression applications as an alternative to conventional system. Water mist system deploys rapid generation and release of dense cloud of fine water droplets, generally less than 1000 micron in diameter in the fire space. In addition to these droplets because of their small size behave almost like 'total flooding' agent.

In theory, small droplets are more efficient in fire suppression than large droplets, because of their larger total surface area available for evaporation and heat extraction. They are more effective in radiation attenuation [2, 4]. However, large droplets can penetrate the fire plume easily to provide direct impingement, and to wet and cool the combustibles. Nevertheless, small droplets have longer residence times, allowing them to be carried by air currents to remote or obstructed parts of an enclosure. They can exhibit more gaseous-like behavior and superior mixing characteristics. However, it is very difficult for small droplets to penetrate into the fire plume and to reach the fuel surface due to the drag and the hydrodynamic effect of the fire plume. Fine droplets with low momentum are easily carried away from the fire by air currents. In addition, more energy is required to produce fine droplets and transfer them to the fire.

It worth to mention that the research conducted to date has not altered the above problems as well as the accuracy of such extinguishing mechanisms. Hence, it is important to experimentally evaluate the performance of a new designed water mist nozzles that overcome the above problems. The present study also aims to give better understanding of the extinguishing mechanisms of water mist systems under different fire scenarios for PMMA fires.

2. Experimental set up and procedures

The test rig components of the present system are shown in Figure (1), and consist of: storeroom wooden box consist of single door storeroom wooden box (3 x 3 x 2.4) m, is used with a vent added to provide air leakage into the box. The store room consists of sandwich panel with (20 cm) thickness and covered by ceramic layer from inside. Transparent glass with dimensions (2x1.2 m) with (thickness of 40 mm) is fixed in one side of storeroom for experiment visualization and video recorder. The room was outfitted by two nozzle arrangement installed with nominally spacing distance of 2 m. The store room equipped by Smoke fan which is used to evacuate the room from smoke every time when experiment is beginning.

Detection system consists of: Fire alarm control panel connected to fire pump contactor, sensing system which consists of smoke sensor (SIMPLEX), fire alarm (SIMPLEX), and siren with flasher (SIMPLEX). The detection system is programmed to response and activates the fire suppression system as follows: When the fire starts, the smoke begins to rise; the smoke detector detects the smoke and sends a signal to fire alarm control panel, the fire control panel starts to send an operating signal to fire pump contactor, when the fire pump contactor responses an electric signal from fire alarm control panel, it will activate the fire pump to start working, When the fire pump starts to work, it provides the water with certain flow and pressure for the nozzle/or sprinklers is pumped there are two directional gate valves used to direct the water to the two nozzles array.

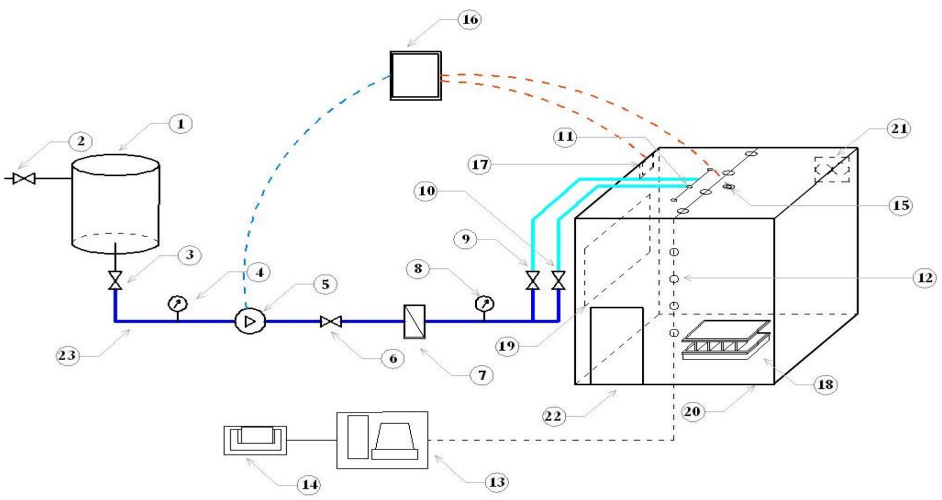
Water supply system consists of two water tanks with total capacity of 3 m3, electric pump, pipes including its accessories and nozzles. The capacity of water tank was determined to cover 10 minutes continues flow in case of using conventional sprinkler type which consumes highest water consumption comparing with other water mist nozzle. Electric pump is used to pressurized water to the nozzle. The capacity of water pump is 40 GPM, while the total head of pump (7 bars) was decided according to the maximum working pressure needed for water mist nozzle sprinklers. The piping is used in this experiment from the black seamless steel type according to NFPA 13 with diameter 1/2 inch.

Measuring System consist of the following parameters, temperature, pressure, time, and water flow rate. The temperature is measured using type K thermocouple with diameter of 1.5mm. The locations of thermocouples are installed in bracket on the center of the ceiling in the horizontal position, thermocouples are connected to data acquisition system were used for continuous recording of temperature. The pressure is measured using pressure gauge. While the time is measured using stopwatch. The water flow rate is measured by Flow meter (3) type (GEC-LLIOT-CROYDON). A Charge Coupled Device (CCD) video camera is installed to record the suppression phenomena for post-processing the images of the flame structure in a 'frame-by-frame' analysis. Results can be used to determine the fire suppression time. Thermocouples and pressure gage and flow meter were carefully calibrated before the experiments.

The present experimental program was designed to evaluate and assess the proposed system and to compare its performance with that of conventional system. Class B fire scenario which represented by PMMA sample can be used to evaluate the capabilities of the mist system against conventional sprinkler. A PMMA sample of size 500 mm by 500 mm and 10 mm thick was placed horizontally on the sample holder at a height of 20 cm above the floor.

The experiments are performed at ambient temperature around 20°C. The storeroom door is fully closed to set up the natural ventilation scenario determined based on the temperatures measured directly above the fire by smoke sensors and on visual observations. Since the PMMA sample was not easy to ignite without an external heat source, about 250 ml of ethanol was used to start a fire. Free burning was allowed for 150 s before discharging the water mist to ensure that the fire was due to burning PMMA, not ethanol.

The fire scenario depends on the position of the PMMA sample which is in the middle of store room and using two sprinklers/ nozzles, Figure 1 The fire scenario is repeated 4 times according to the types of nozzles which are conventional, TYCO, HS10, HS20 types respectively. Each experiment is repeated twice for repeatability



1- Water tank (1.5m^3).	**9- Gate valve for single nozzle array pipe.**	**17- Siren with flasher.**
2- Gate valve for makeup water.	**10- Gate valve for double nozzle array pipe.**	**18- Wood crib inside heptanes tray.**
3- Gate valve for suction line of pump.	**11- Nozzles.**	**19- Transparent glass.**
4- Gate valve for suction line of pump.	**12- Thermocouples.**	**20- Store room.**
5- Pump.	**13- Computer.**	**21- Smoke fan with opening window.**
6- Gate valve at delivery line of pump.	**14- Printer.**	**22- Opening door.**
7- Flow meter.	**15- Smoke sensor.**	**23- Black seamless pipes.**
8- Press-gauge at delivery line of pump.	**16- Fire alarm control panel.**	

Figure 1 The Test Rig Components

3. Results and discussion

The main fire suppression mechanisms using water mists have been identified as [2]: Heat extraction (flame cooling and fuel surface cooling), oxygen displacement and radiation attenuation.

According to the visual observation during all experiments the phenomenon of above mechanism will be explained as follows:

An instant flare up was observed at start of fire and continue for about 3 to 4 Seconds and Yellowish flame was observed. Figure (2. a, b and c).

When the yellowish flame color turns to orange or yellow reddish flame and this means that the fire was continued by burning PMMA sample not ethanol, time 150 sec, Figure (2. d).

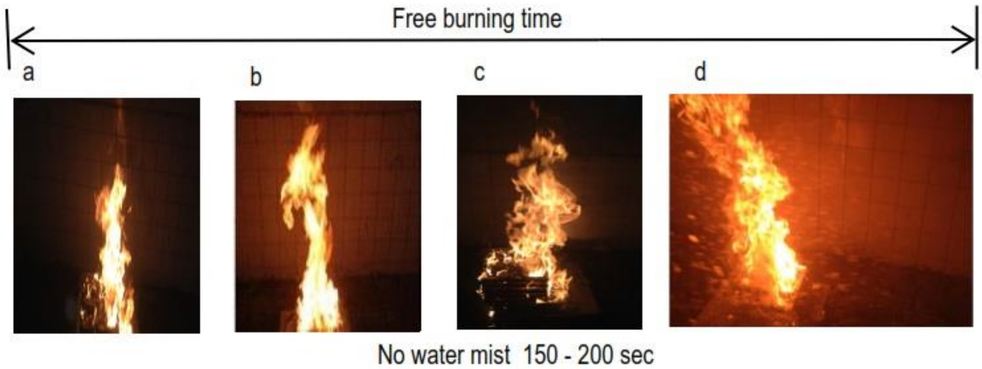


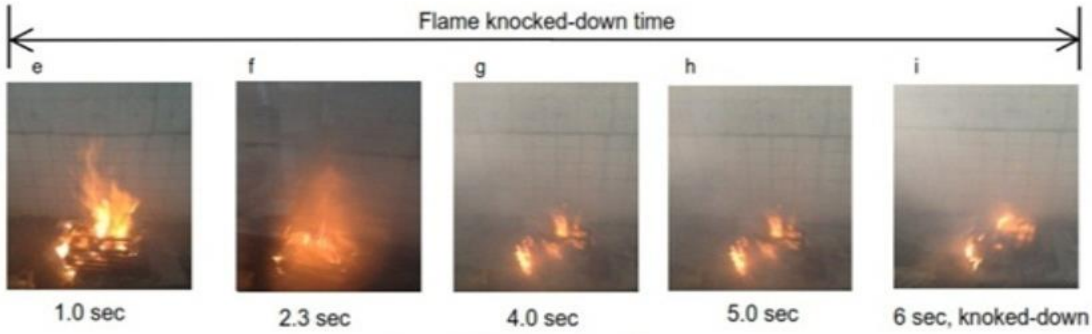
Figure 2 Free Burning period for PMMA fires Before water mist discharged fixed for all fire tests.

After that Free burning period was allowed for 150 to 200 seconds and after orange or yellow reddish flame has been observed the water supply system started to suppress the fire. At this period it was observed that:

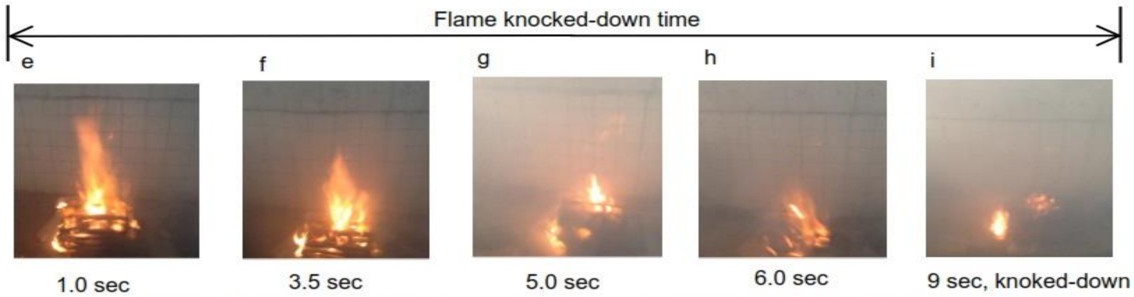
After 6 to 9 seconds, the flame size was reduced and then knocked down to the sample surface. This short period measured when applying water mist is taken as the ‘flame knocked-down time', and its different for each nozzle. This period can be shown in Figure (3. e, f and g). The flame was knocked down to the sample surface and more droplets would reach the sample surface because of the weak buoyancy effects of the fire and plume.

After that the flame size and the luminosity radiation decreased and small orange flames was observed . Figure (3. h and i)

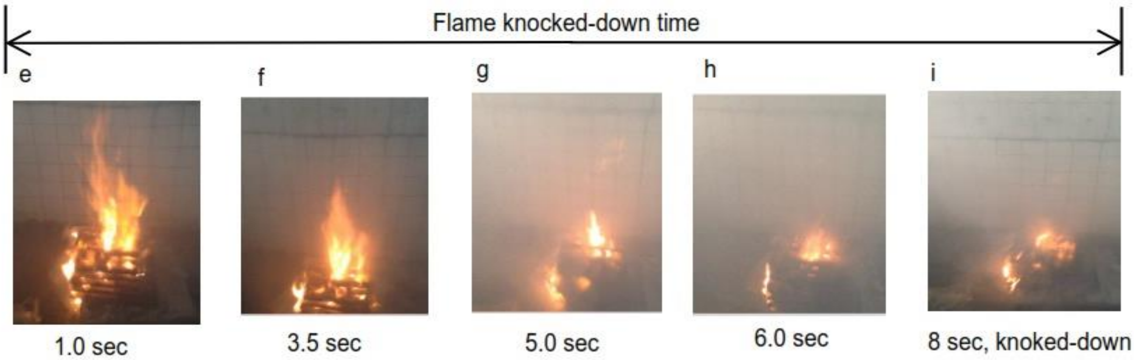
A small ghost flames (the flame changes positions from one place to another) were observed at the edge of the sample. The flame appeared to be extinguished but re-ignited again at the sample surface.



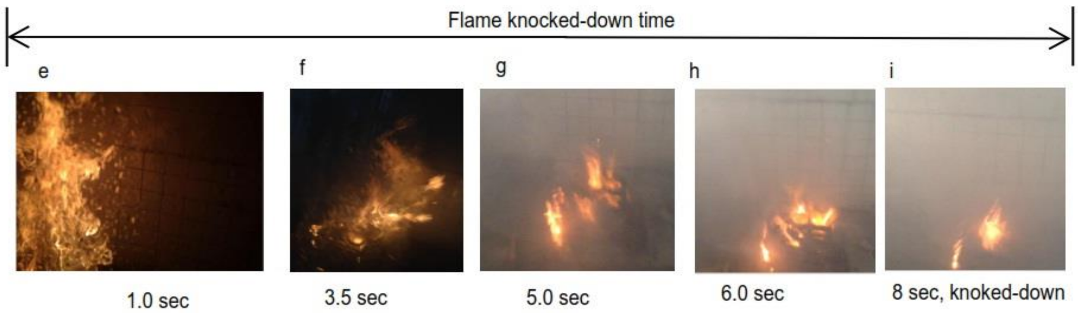
Flame Knocked-down time after water mist discharged using water mist Nozzle (HS20 model)



Flame Knocked-down time after water mist discharged using water mist Nozzle (HS10 model)



Flame Knocked-down time after water mist discharged using water mist Nozzle (Tyco AM27 model)



Flame Knocked-down time after conventional system discharged using Conventional sprinkler (Viking model)

Fig.3 Flame Knocked-down time after water mist discharged

This period can be shown in Figure (4.J and K).
Flame cooling are observed to be diminishes the flame and high amount of smoke is observe. It's worth to mention that the water supply system is working till the most of smoke is diminishes.

8 to 15 seconds later after flame Knocked-down a white smoke was observed, a containing water vapor and volatiles from the fuel surface was observed during the whole period of discharging the water mist. Figure (3. L – m - n).

Surface cooling would play a dominant role. So, we kept the water mist discharged after the fire has been extinguish for 400 seconds to avoid the re-ignition of the sample. Figure (4. o)

The results will be presented in the manner of temperature and time, the time is measured from the start of fire until the end of cooling process.

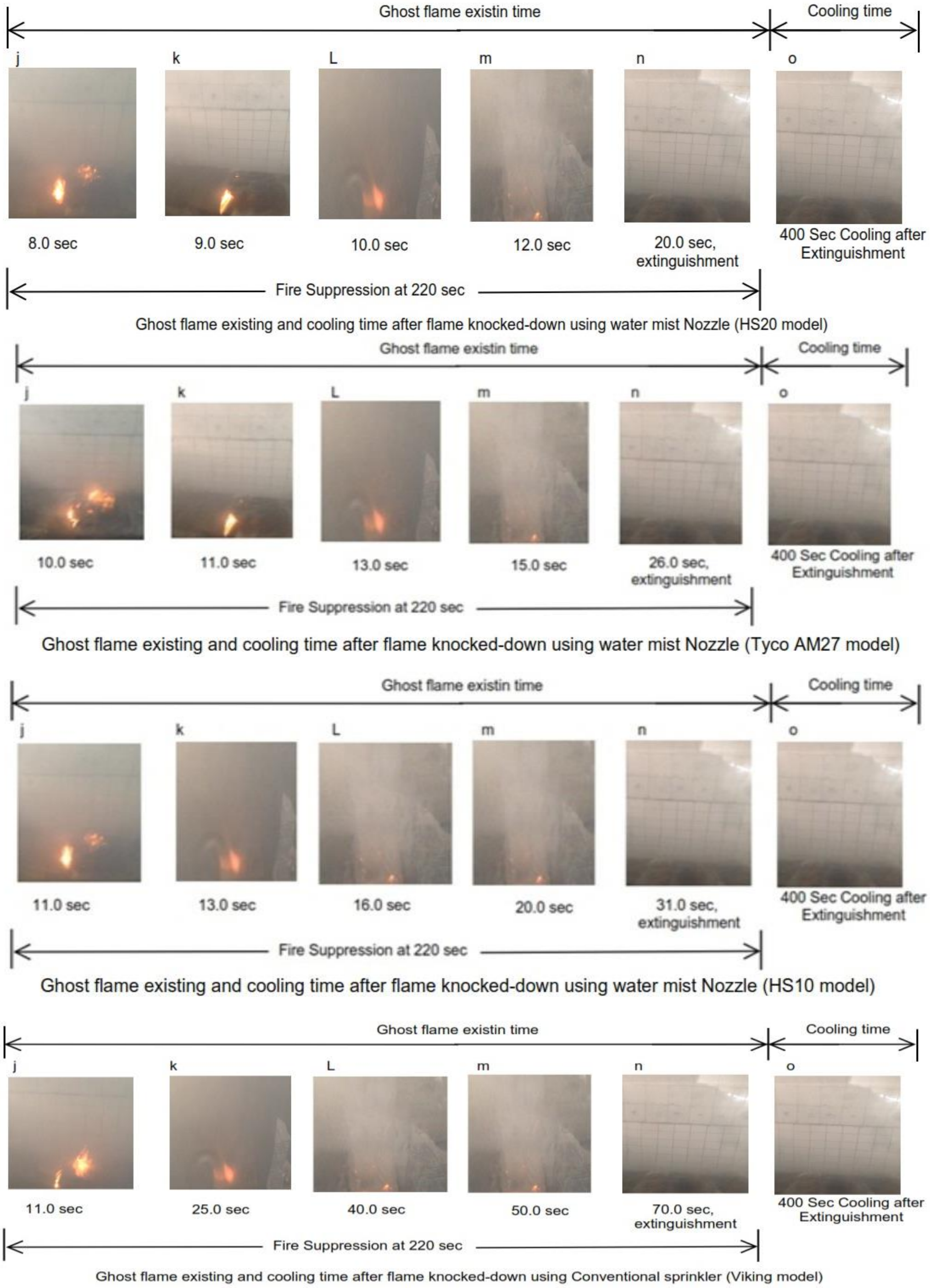


Fig.4 Ghost flame existing and cooling time after flame knocked-down

The measurements of all experiments showed the same trends, see Figure (5) This figure show the general trend of temperatures profiles which are classified into three main distinctive zones as :

Zone “A” The initiation of fire.
Zone “B” Fire suppression phase.
Zone “C” Cooling.

The behavior of those zones can be explained as follows:

The initiation of fire (zone 'A') is characterized by step increase of the temperature level from room temperature (F) to the level M, which mainly due to the hot exhaust gases which are produced from the combustion of material or fuel. It worth to mention that the fire extinguish system begins to activate when the signal from smoke detector reaches the control system or release the set point of temperature level. Free burning without discharging water mist, this phase starts to raise the temperature of free burning period to ensure that the fire will occurs due to PMMA not ethanol. This phase characterized by increasing the temperature levels from point M to the maximum temperature level.

Fire suppression phase which indicted to zone (B), the increasing rate of water is working to decrease oxygen as well as decrease the atmospheric temperature. This phase is nominated as fire suppression dominating region. A complete suppression region is characterized by a step decrease in temperature level from maximum temperature to temperature level (S), this attributed to large temperature difference between droplets and chamber gases, heat absorption and rapid evaporation, it results in creating the rapid cooling regime. In addition, the vapor could decreases of the oxygen ration in the flame region.

Cooling zone which indicated by zone "C", this phase starts from point (S) till point (L) it is characterized by slow decrease in temperature levels from (S) to (L) which is due to the decrease in temperature difference between droplets and chamber gases and the evaporation rate which is slow down, it leads to the gradual cooling regime as consequential of the fire suppression meanwhile the combustion temperature is decreased also till the fire suppression is completed.

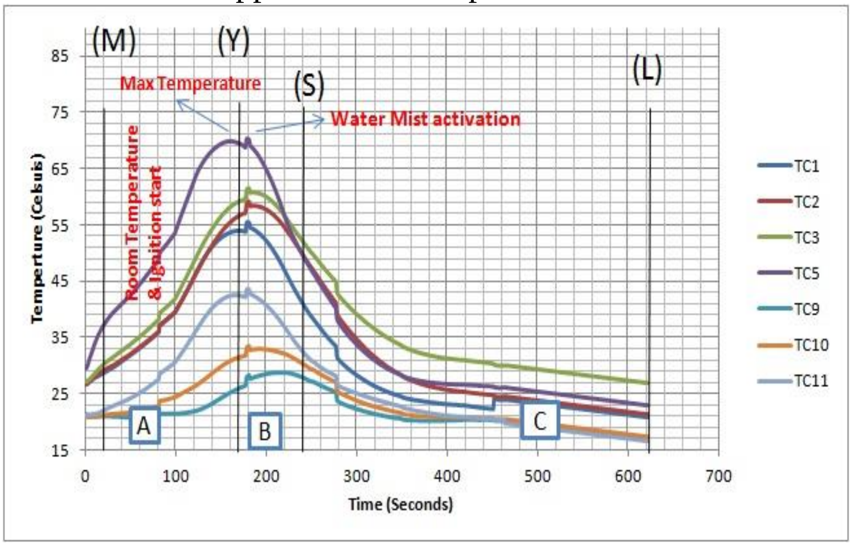


Figure 5 General trend of time and temperature profile

The results and discussion of the effect of nozzle type on the performance of fire suppression is based on the following parameters:

Total fire suppression time (initiation to the end of fire), Maximum temperature, Total water flow rate and Maximum pumping pressure.

Figure (6) shows results of fire test using low pressure water mist nozzle (HS20 Model) with the initiation of fire zone which is indicated by zone "A", starting from room temperature. The combustion time is about 150 seconds. When the temperature raised from 25º to 75º C. then the fire suppression zone "B" is noted and finished during 150 to 250 seconds with temperature range 35º to 55º C. Then the final cooling is started after 250 seconds which no heat re-ignition phenomenon will appeared and kept for 350 seconds. The discussed trend is related to the type of combustion which represent class (B) fire and the heat released from the PMMA needs an amount of water to absorb the heat released from combustion,.

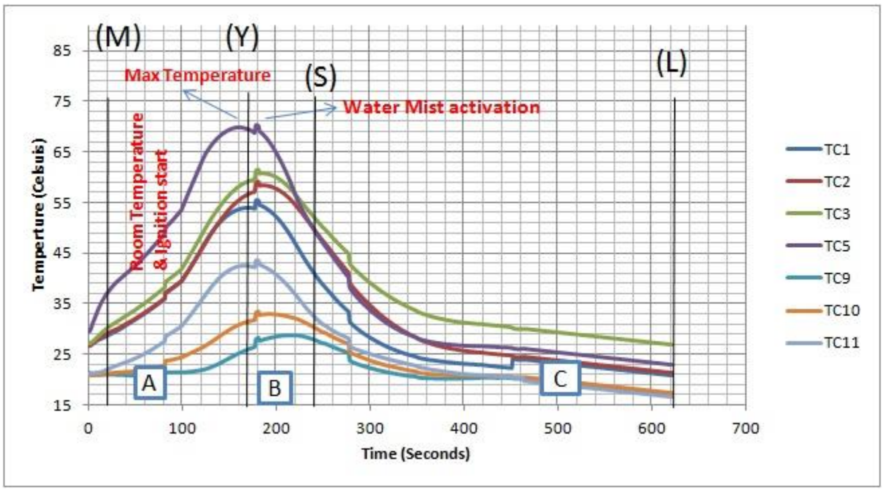


Figure 6 Fire test with LPWM nozzle (HS20 Model)

On the other hand Figure (7) shows results of fire test using low pressure water mist nozzle (HS10 model) with the initiation of fire zone which is indicated by zone "A", starting from room temperature. The combustion time is about 150 seconds. When the temperature raised from 25º to 75º C. then the fire suppression zone "B" is noted and finished during 150 to 250 seconds with temperature range 35º to 55º C. Then the final cooling is started after 250 seconds which no heat re-ignition phenomenon will appeared and kept for 350 seconds. The discussed trend is related to the type of combustion which represent class (B) fire and the heat released from the PMMA needs an amount of water to absorb the heat released from combustion.

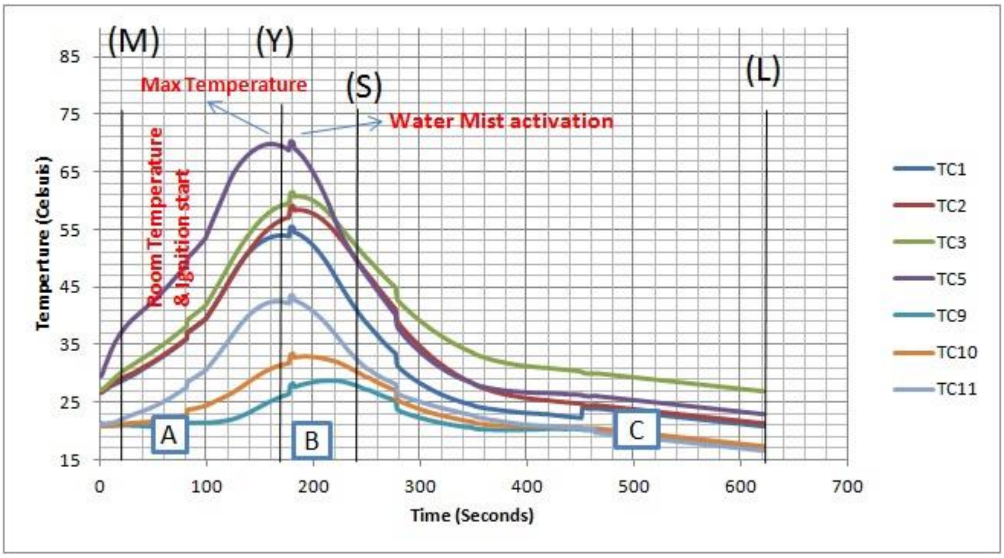


Figure 7. Fire test with LPWM nozzle (HS10 Nozzle)

Figure (8) shows results of fire test using low pressure water mist nozzle (Tyco AM27 model) with the initiation of fire zone which is indicated by zone "A", starting from room temperature. The combustion time is about 150 seconds. When the temperature raised from 25º to 75º C. then the fire suppression zone "B" is noted and finished during 150 to 250 seconds with temperature range 35º to 55º C. Then the final cooling is started after 250 seconds which no heat re-ignition phenomenon will appeared and kept for 350 seconds. The discussed trend is related to the type of combustion which represent class (B) fire and the heat released from the PMMA needs an amount of water to absorb the heat released from combustion.

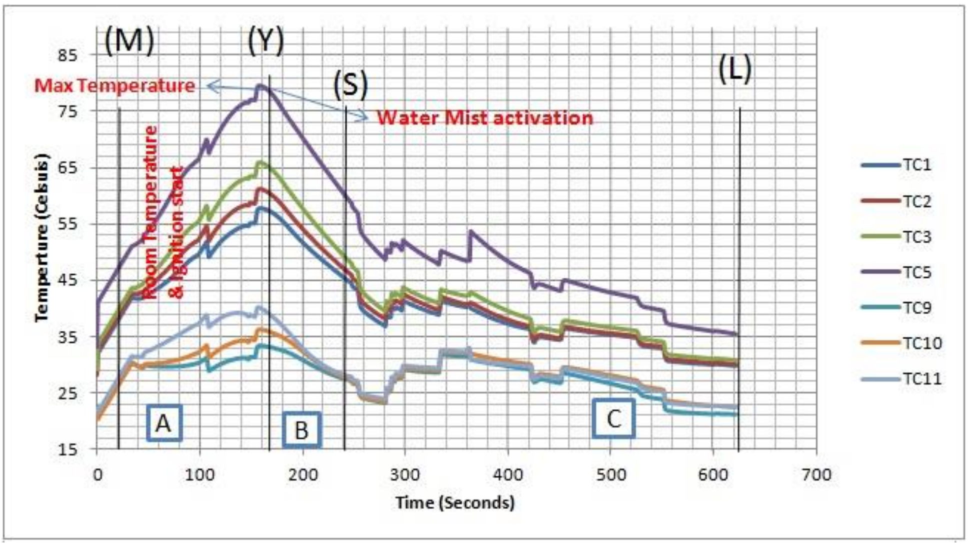


Figure 8 Fire Test With LPWM Nozzle (Tyco AM27)

Figure (9) shows scenario (1) of conventional sprinkler (Viking) with the initiation of fire zone which is indicated by zone "A", starting from room temperature. The combustion time is about 7 seconds. The combustion time is about 150 seconds.

When the temperature raised from 25º to 75º C. then the fire suppression zone "B" is noted and finished during 150 to 250 seconds with temperature range 35º to 55º C. Then the final cooling is started after 250 seconds which no heat re-ignition phenomenon will appeared and kept for 350 seconds. The discussed trend is related to the type of combustion which represent class (B) fire and the heat released from the PMMA needs an amount of water to absorb the heat released from combustion.

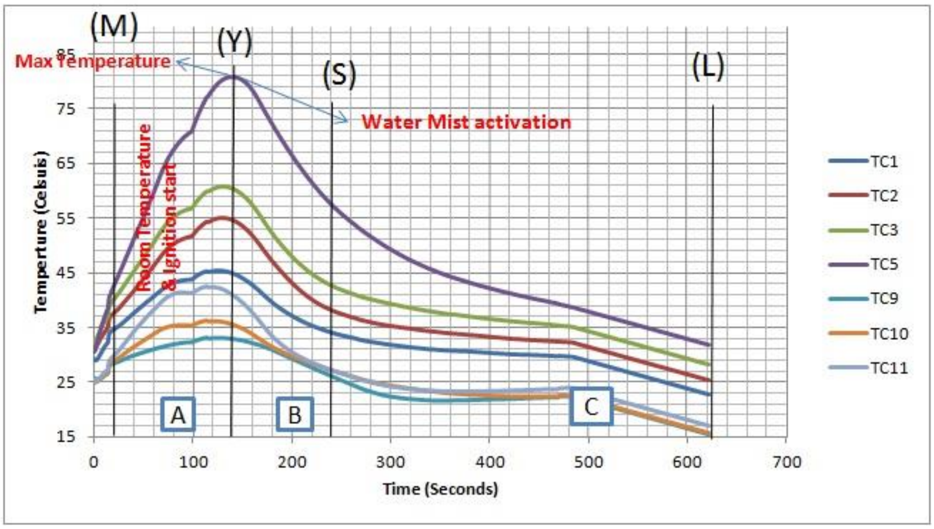


Figure 9 Fire Test with Conventional Nozzle (Viking)

In Figure (10), comparisons of the average results take for all cases are plotted where; the comparison of performance between those cases is studied with the time – temperature profiles. The maximum temperature shown in figure (10) is the average value from 7 readings of 7 thermocouples. In table (1) shows that the flow rate of (HS20) nozzle is the lowest one but the conventional sprinkler registered the highest one. The working pressure of conventional is the lowest one but the working pressure of (HS20) nozzle is the highest one. From the above analysis it could be concluded that (HS20) results has the highest performance of suppression comparing with all nozzles at this type of scenario.

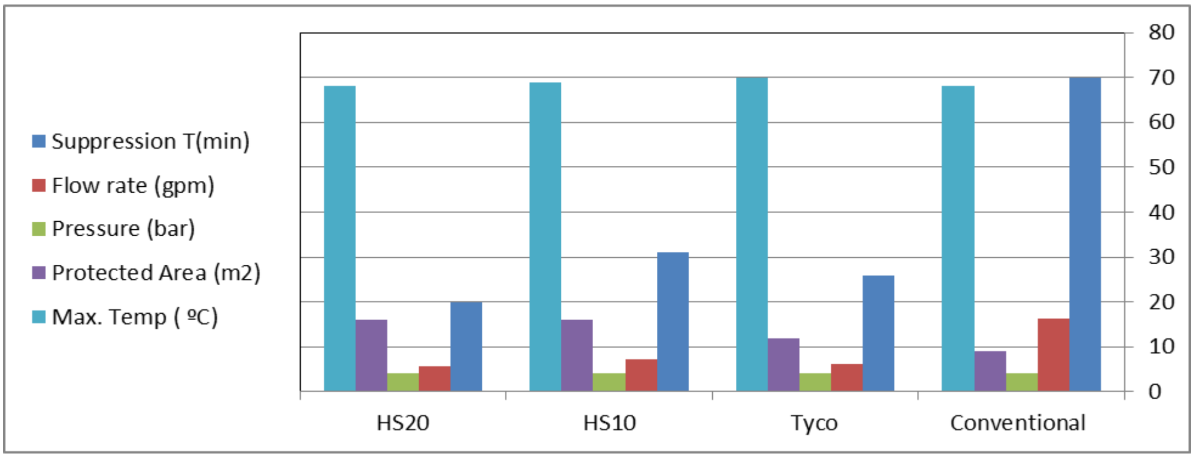


Figure 10 Comparison between fire test results.

Table 1. Comparison between fire test results.

	Conventional	Tyco	HS10	HS20
Suppression T(min)	70.0	26.0	31.0	20.0
Flow rate (gpm)	16.28	6.16	7.29	5.72
Pressure (bar)	4	4	4	4
Protected Area (m2)	9	12	16	16
Max. Temp (ºC)	68	70	69	68

The main fire suppression mechanisms using water mists have been identified [1] as: Heat extraction (flame cooling and fuel surface cooling). Oxygen displacement. Radiation attenuation.

In this set of experiments, flame cooling and flame temperature are observed to be significant when the water mist has just been discharged. This conclusion is based on the residence time argument. When water is injected into the fire, not all the sprays that are formed are directly involved in fire suppression. They are partitioned into a number of fractions as follows [2]:

Droplets that are blown away before reaching the fire. Droplets that penetrate the fire plume, or otherwise reach the burning surfaces under the fire plume, to inhibit pyrolysis by cooling, and the resultant steam that dilutes the available oxygen

Droplets that impact on the walls, floor of the room and cool them, if they are hot, or otherwise run-off to waste. Droplets that vaporize to steam while traversing the compartment and contribute to the cooling of the fire plume, hot gases, compartment and other surfaces. Droplets that pre-wet adjacent combustibles to prevent fire spread [2]. The flame height was about 1.2 m, based on the visual observations. The flame was knocked down to the sample surface ; more droplets would reach the sample surface because of the weak buoyancy effects of the fire.

After flame Knocked-down a white smoke was observed, a containing water vapor and volatiles from the fuel surface was observed during the whole period of discharging the water mist.

Surface cooling would play a dominant role. So, we kept the water mist discharged after the fire has been extinguished for 400 seconds to avoid the re-ignition of the sample.

In this experiment, the flow rate of the water mist was from 4 to 6 gpm The PMMA fire can be extinguished by such a water mist.

4. Conclusions

The effects of water mists on small-scale PMMA fires were studied experimentally. From the preliminary tests, the following conclusions can be drawn:

- Small-scale PMMA (class B) fires can be suppressed effectively using this low-pressure water mist system.

- The Flame knocked-down time tfk (s) is almost the same for all nozzles except for HS20 Nozzle has lowest Ghost flame existing time tgf (s). It's worth to mention that the less The Flame knocked-down time tfk (s), is considered critical for controlling the flame size and the fire suppression.
- The WMFSS have shorter Total extinguishment time tfe (s) than conventional sprinkler.

The above are just preliminary observations, but the results are useful for modeling the water mist system, still further investigation are required in the following subject:

- Full scale experiments for large PMMA fires should be conducted.
- The effect of controlling water flux on the production rate of smoke, carbon dioxide and carbon monoxide would be reduced.
- Water mist particle dynamics behavior during the fire extinguishment processes should be measured.
- The fire extinguishment behavior should be measured using laser technique, PIV system.
- The performance of high pressure water mist system for PMMA fires should be measured.
- The effect of changing the operating pressures for water mist system should be conducted.

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