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Effect of Water Mist Fire Suppression System on Electrical Cable Fires

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Abstract. Firefighting systems for electrical cables are crucial for safety and functionality during emergencies. They ensure the continuity of critical safety systems, minimize fire spread, and reduce the risk of smoke and toxic gas exposure. Therefore, the objective of the current work is to experimentally investigate the performance and effectiveness of a water mist firefighting system for protecting electrical cables, contributing to the design and development of water mist nozzles. Three types of cables, namely navigation cable, power cable, and electrical cable, were used to investigate the fire protection performance of two different fire nozzles: the Viking nozzle and the ES nozzle. The experiments were conducted in the Firefighting Laboratory of the Mechanical Power Department, Faculty of Engineering (El-Mataria), Helwan University, using a low-pressure water mist system to extinguish cable fires. The experimental comparison between the water mist nozzles was based on visual observation, temperature, fire extinction time, working pressure and water flow rate. The results of this experiment showed that low pressure water mist system is very effective for small-scale cable fires. Moreover, the Viking nozzle achieved superior performance by reducing the fire suppression period by around 76%, 55% and 25% for power cables, electrical cables, and navigation cables, respectively, and shortening the cooling period by about 82 - 83% compared with the ES nozzle.

Keywords: Low pressure water mist, fire nozzle, electrical cables, water droplet.

1 Introduction

Nowadays, we are looking for a clean energy to protect the environment so in our field “firefighting” also we need to improve the techniques that we are using to keep our plant clean so water mist system one of the most clean, cheap, available and effective systems in firefighting field, additionally, as urban cable scale continues to expand and service time increases, the risk of cable tunnel fire accidents also increases because the tunnels are long and narrow, which means that fire spreads quickly and the temperature of the terminated cable reaches 1200 K. Water mist systems are fire suppression systems that using extremely tiny water droplets, this tiny water droplet size improves evaporation, lowers the necessary application rate, and lowers oxygen levels. The technologies of water mist fire suppression systems are hotspot in fire protection field, recently the mist system has been developed to control and

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extinguish the fire rapidly with little amount of water and without making any harm to the environment [1 - 3].
Zhang et al. [4] studied the effect of low-pressure water mist by applying two different operating pressure (0.4 MPa and 0.7 MPa) on the small-scale of solid fuel polyvinyl chloride (PVC) fires in a confined space experimentally. The water mist has been generated by single pressure nozzle with deoplet size 90 microns to suppress a fire of a PVC sample. the resulte porve that, using a high operation pressure, the suppression will be easier, and the faster PVC fire suppressed by using enough water flux of the water mist and the less amount of toxic gases produced. Moreover, water mist has a good effect on the black smoke produced from PVC fire through absorbing soot and some dissolvable gases , which would decree the damage of smoke which would effect on the properties and occupants in the buildings. Zhu and Wang [5] submit a numerical study to determine the effects of ambient air pressure on water mist characteristics by using CFD under different ambient pressures from (0.2 to 3 atm.), and locate the measuring point at 0.5 m and 1 m below the nozzle. The results shown that variation in droplet velocity along the spray centerline at these same distances under varying ambient pressures and the data reveal that droplet velocity decreases rapidly at lower ambient pressures. While, highwe ambient pressures cause a greater concentration of droplets near the nozzle, while droplet velocities at locations farther from the nozzle are notably lower because of the drag Force effect. Tianshui et al. [6] investigate numerically the performance of results of water mist suppression system in the opening machinery space by using the large eddy simulation (LES) method to analyze the turbulent flame. The results showed that vertical spray flame is easily extinguished by direct coverage of the flame envelope by using water mist system, while horizontal spray flame is difficult to extinguish, but water mist can suppress spray fires efficiently. Jack R. Mawhinnev [7] use the experimental technique to know the effect of using water mist fire suppression system and fire detection in cable trays arrays and electronic rooms, the dimensions of the cable trays test room were (6 × 9 × 6 m) (W × L × H), two trial designs for the water mist system were employed. The idea was to use a total-flooding technique to produce a thick cloud of mist in the upper half of a 3 m × 6 m part of the space. different flow rates, nozzle types, and nozzle spacing were employed. Study came to the conclusion the water mist fire suppression system can be used to extinguish the electronic equipment and electrical fires in a manner that to limit water damage. Angel et al. [8] studied experimentally and numerically electrical fires for spacecraft application under normal gravity inside a container using direct and indirect water mist injection with different droplet size and flow rates. With pressure ranges from 100 to 1000 psi, droplet size distributions with a sauter mean diameter (SMD) of 40 to 27 µm are obtained. Water mist rapidly extinguishes a fire that is directly influenced by the droplets, substantially longer spraying times and bigger volumes of water are required to suppress fires burning because a large number of droplets hit the walls of container and the obstacle. As the droplet size distribution is decreased, extinction times and water volumes decrease. The average extinguishment time for the direct was 10 secondss and for the indirect injection was 95 secondss. Quan et al. [9] used numerical technique to study the performance of a high pressure water mist system in a utility tunnel model with dimensions (20 × 2.7 × 3.5 m). The area designated for the fire source is (0.25 × 0.25 m) and 0.7 MW is the intended fire source heat release rate. The utility tunnel has eight shelf on each side, with cable trays on both sides, each cable tray is 20 m long, 0.8 m broad, and spaced 0.2 m apart. The water mist nozzles are positioned 2.5 meters apart on the ceiling in the center of the utility tunnel. Along the utility tunnel's longitudinal path, nine nozzles are positioned. The resultes shown that, fire extinguishing time period are about 500 s with water mist system and 800 s without water mist

system. Jukka and Amit [10] investigate experimentally the performance of high-pressure water mist system for industrial cable tunnels fires by using a large scale fire test, power and control cables were positioned on trays along one wall of a mock cable tunnel to serve as the fire load for cable tunnels. Approximately 800 to 900 ºC are the highest temperatures recorded during the experiments, the places to reach these temperatures are around the gas burner's placement. When the water mist system is turned on, the temperature decrease sharply, which indicating that the fire will be put out quickly and successfully prevented the fire from spreading. Boyan et al. [11] investigate experimentally the performance of fire extinguishing using low pressure water mist (LPWM) in a utility tunnel, and a number of fire extinguishing tests were carried out in order to confirm the system's efficiency in putting out cable fires in urban utility tunnels and to determine the critical elements influencing its effectiveness.The test findings show that LPWM may quickly and efficiently put out cable fires in utility tunnels, in addaition the tunnel's internal temperature decreased from 650 to 40 °C in about 50 secondss. Moreover, when using different nozzles k-factor, increase the nozzle K-factor , the time of fire extinguishing decreases. Zhenpeng et al. [12] employed full-scale experimental testing to investigate the effectiveness of a high water mist system to put out flames in electrical utility tunnel, by varying water mist volume flow rates. The electrical utility tunnel measuring 25 × 2.9 × 3.4 m, a seven-layer arrangement of identical cables (100 mm diameter, 750 mm wide) was installed. Temperature measurements were obtained using K-type thermocouples, the ignition source, a propane burner, was placed on one side of the cable arrangement. The nozzle operated under high-pressure conditions (10 MPa) and was used to deliver fine water mist for local fire suppression. After the operation of water mist, the temperature drops from a maximum of 800 °C to 200 °C within 20 seconds. Also, the temperature inside the utility tunnel might fall below 100 °C in 300 seconds after the water mist system was activated and the flow rate was greater than 7 l/min. These precautions can safeguard the structural integrity of the utility tunnel's electrical compartments [13]. Abd El-Salam et al. [14] investigated experimentally how a low pressure water mist system is appropriate for suppression class (B) fires. The performance of the suggested system is examined and assessed in comparison to the traditional sprinkler system. The tested sample's location in the center of the store room and the use of two sprinklers/nozzles determine the fire scenario, in accordance with the types of nozzles conventional, TYCO, HS10, and HS20 the fire scenario is repeated four times. We can conclude that, the low pressure water mist system is an excellent way to control and extinguish a small-scale fire of (class B) flames. Futrthermore, all nozzles have about the same flame knock-down time, with the exception of the HS20 nozzle, which has the shortest ghost flame duration. It's important to note that reducing the flame knockdown time is thought to be essential for managing flame size and suppressing fire. Compared to traditional sprinklers, the water mist fire suppression system has a shorter complete extinguishment time [15]. Farrell et al. [16] examined the latest developments in water-mist suppression, emphasizing various application areas ranging from electrical equipment rooms to tunnels where mist provides quick extinguishment with minimal water impact. For fires in enclosed spaces, Moinuddin et al. [17] utilized a combination of experiments and CFD to demonstrate that the right droplet size and nozzle arrangement can decrease extinguishment time and lower peak temperatures. In experiments related to cable-tunnel scenarios, Zhu et al. [18] discovered that fine water mist combined with mechanical ventilation is more effective for regulating ceiling temperatures and managing smoke than using mist alone. Regarding transport compartments, Zhu et al. [19] indicated that enhancing the spray pattern and nozzle configuration in cargo holds significantly improves suppression effectiveness. Kan and Feng [20] showed that water mist can effectively manage heat in road-tunnel fires (both single- and double-source), reinforcing design decisions about nozzle spacing and activation methods in long, ventilated structures similar to utility tunnels.

1.1 Work Novelty

Experimentally assessing the effectiveness of two distinct low-pressure water mist nozzles (Viking and ES) on several kinds of electrical wires (power, electrical, and navigation) in controlled fire scenarios is what makes this study novel. This paper offers a comparative evaluation across many nozzle designs and cable types, providing insights into suppression efficiency, cooling effectiveness, and water consumption, in contrast to the majority of earlier research that concentrated on a single nozzle type or cable category. The findings help the development of safer, more effective, and more affordable fire suppression systems and selection for electrical cable fire protection.

2. Methodology

2.1 Test Rig Description

As shown in Fig. 1 and Fig. 2, the test rig contains the firefighting room with dimension (3 m width × 3 m length × 2.4 m height), has one wooden door, the wall is designed as a sandwich panel (thickness 0.2 m) then covered by ceramic layer. One side of the room is made of transparent glass to help us to record videos and take pictures for the experiment to get more accurate analysis. Two different brands for water mist nozzles were used (Viking nozzle and ES nozzle) (see, Fig. 3) to obtain different flow rate and working pressure to compare the effectiveness of each nozzle on the electrical cable fire specially (Power Cable, Electrical Cable and Navigation Cable) to know in this case and under this condition which design will be more effective.

2.2 Instrumentation and Measurements

In the current study, Table 1 lists the specification details for all equipment's and tools that used in the experimental work. flow meter to measure the required flow rate for each nozzle, and pressure gauge to measure the working pressure for each nozzle. In addition, Anemometer devise to measure the air velocity in the room before starting the experiment each time. Also, thermocouple which connected to data acquisition to record the temperature difference with time and to measure the room temperature before starting the experiment each time.

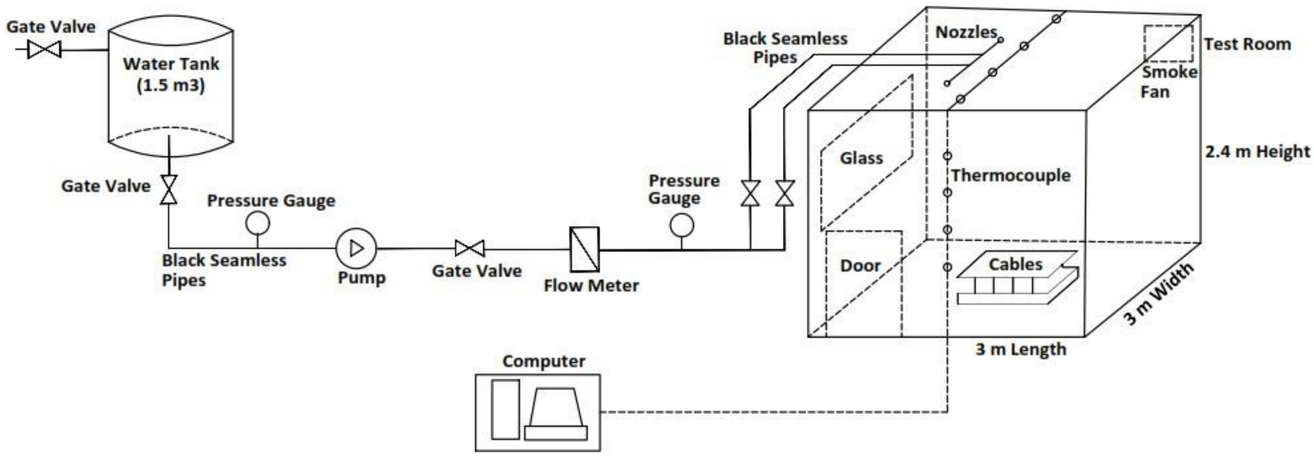


Fig. 1 Test rig schematic diagram

Fig. 2 Experimental test rig components

(a) Viking Nozzle

(b) ES Nozzle

Fig. 3 Water mist nozzles using in the experiment

Table 1 List of the Equipment and tools in the experiment

Sr.	Equipment / Tools	Description / Capacity
1	Electrical Water Pump	9.08 m^3/hr (40 GPM) @ 7 bar
2	Water Tank	2 unit each (1.5 m^3)
3	Flow Meter	Range from (0 to 3000) l/h GEC-Elliott , accuracy ±1.5%
4	Pressure Gauge	Range from (0 to 12) Bar BOCH, Accuracy 3/2/3%
5	Pipes	Seamless Black Steel, Sch.40
6	Water Mist Nozzles	Viking Nozzle and ES Nozzle
7	Anemometer	Range from (0 to 30) m/s, accuracy ±(5%+1 digit) UNI-T UT363/UT363BT
8	Thermocouple	Omega J-Type, model TJ8-CAXL-IM30U-6000, accuracy ±0.75% of reading
9	Power Cable	1 phase (16 mm)
10	Electrical Cable	2 phase (2 x 6 mm^2)
11	Navigation Cable	3 phase (3 x10 mm^2)

2.3 Experimental Procedures

Firstly, the current experimental work has a constant parameter and variable parameters were considered in all experimental steps as following. There are six constant parameters in the experimental work,

1. Room temperature.
2. Air velocity in the test room.
3. Number of nozzles.
4. Direction of nozzles.

5. Flame type.
6. Ignition time.

Moreover, there are two variable parameters in the current work,

1. Nozzles design which meaning a variable flow rate.
2. Cables type (power cable, electrical cable, and navigation cable).

The experimental work was started when 20 cm length cable ignited at the center point of the cable by a methane pilot flame for about 40 seconds continuously, then manually operated the low-pressure water mist system which consist of two water tanks with capacity 3 m^3 and pump with rated capacity 9.08 m^3/hr (40 gpm) and 7 bar head.

During the experiment, the room temperature was measured before starting the fire which recorded about 30°C, and the maximum temperature for the cables was recorded and the increasing and decreasing rates of temperature before and after the fire.

After the water mist system working, the temperature measurements inside the room were measuring by using a thermocouple (J Type) which was placed at distance 10 mm from the cable rear surface at the center of cable. The same fire scenario is repeated six times, three times for each cables using two nozzle types.

3. Results and discussion

In this section, the experimental results for six cases will be discussed. Where, the Firefighting process is divided to three main periods (zones),

1. Zone A (Initiation period), in this zone the temperature increases from room temperature to the maximum temperature of gases which rising from the cable combustion.
2. Zone B (Fire suppression period), which start from the maximum temperature to the rapid decreasing point.
3. Zone C (Cooling period), in this step the temperature decreases slowly because of the temperature difference between droplets and gases, in addition the evaporation rate, which is slow down, leads to the gradual cooling until the suppression of fire is completed.

3.1 Fire Scenario I - Power Cable 16 mm

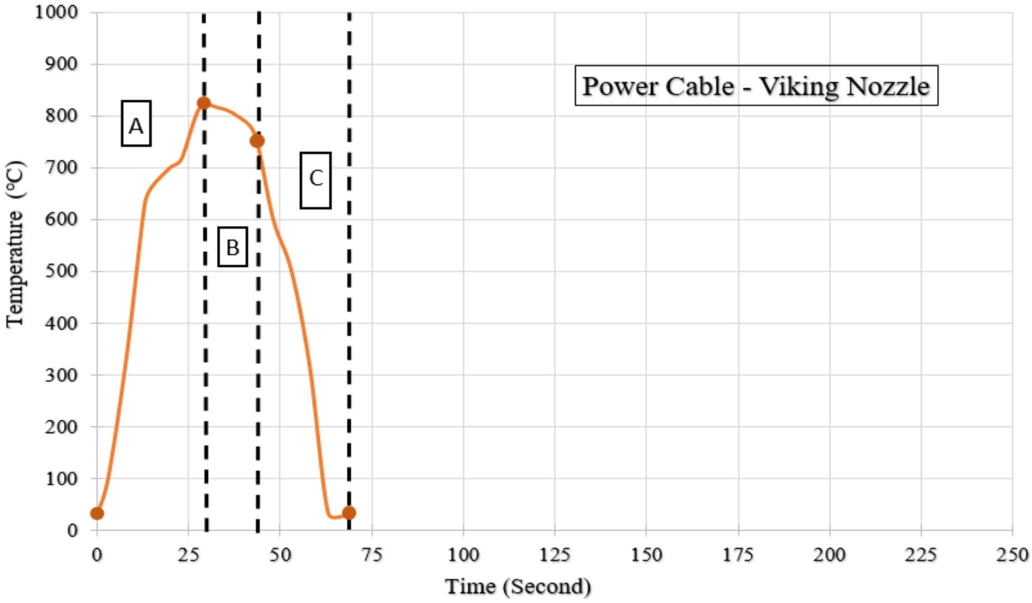
As shown in Fig. (4a), the fire suppression results using Viking nozzle type were presented. The initiation period (Zone A) starting from room temperature 30º C to 815º C and takes about 30 seconds, while the fire suppression period (Zone B) takes 14 seconds with temperature range from 815º C to 763º C, then the cooling period (Zone C) is started which takes 26 seconds and the temperature decreases from 763º C to 30º C.

While Fig. (4b) shows fire suppression results using ES nozzle type. Zone (A) starts from room temperature 30º C to 815º C where the same material of power cable was combusted and takes about

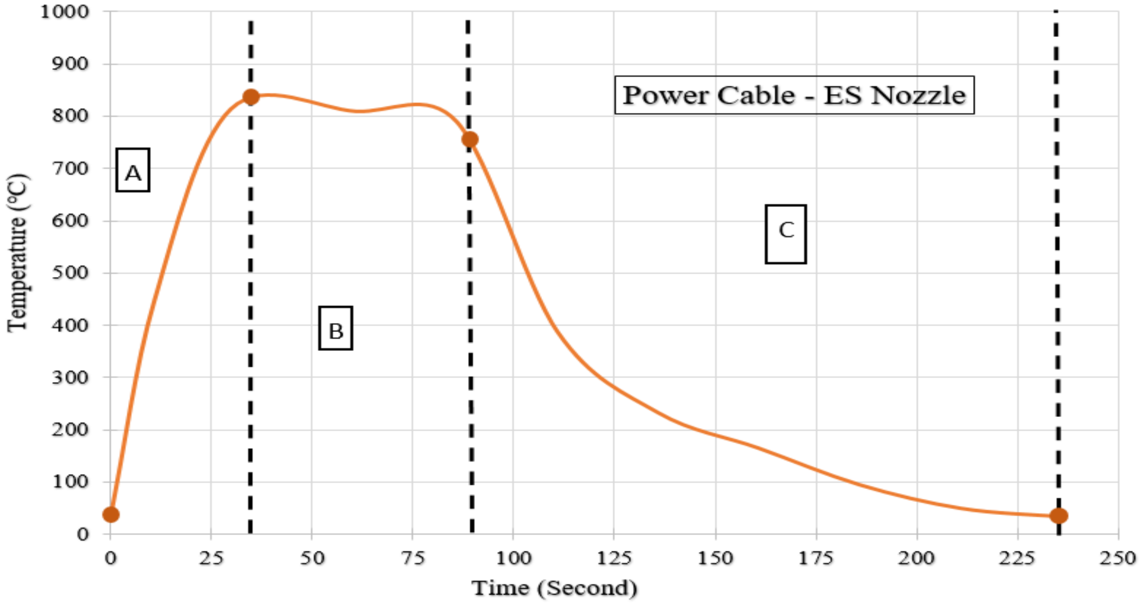
30 seconds, zone (B) takes about 59 seconds with temperature decreases from 815º C to 760º C, then the zone (C) was started which takes 145 seconds and the temperature decreases from 760º C to 35º C.

It is clear from the previous results that the performance of Viking nozzle is better than ES sprinkler nozzle, and the reason for this is maybe due to the droplet size and the Viking nozzle atomization which was better than ES nozzle, which speeds up the absorption of the heat from flame and diluting the Oxygen that will lead to faster control of the fire source. [1]

Furthermore, the results from all fire scenarios were listed in Table 2 including the temperature ranges (start – end) and the time.



(a) Viking Nozzle



(b) ES Nozzle

Fig. (4) Fire protection performance using two different water mist nozzles in case fires of power cables

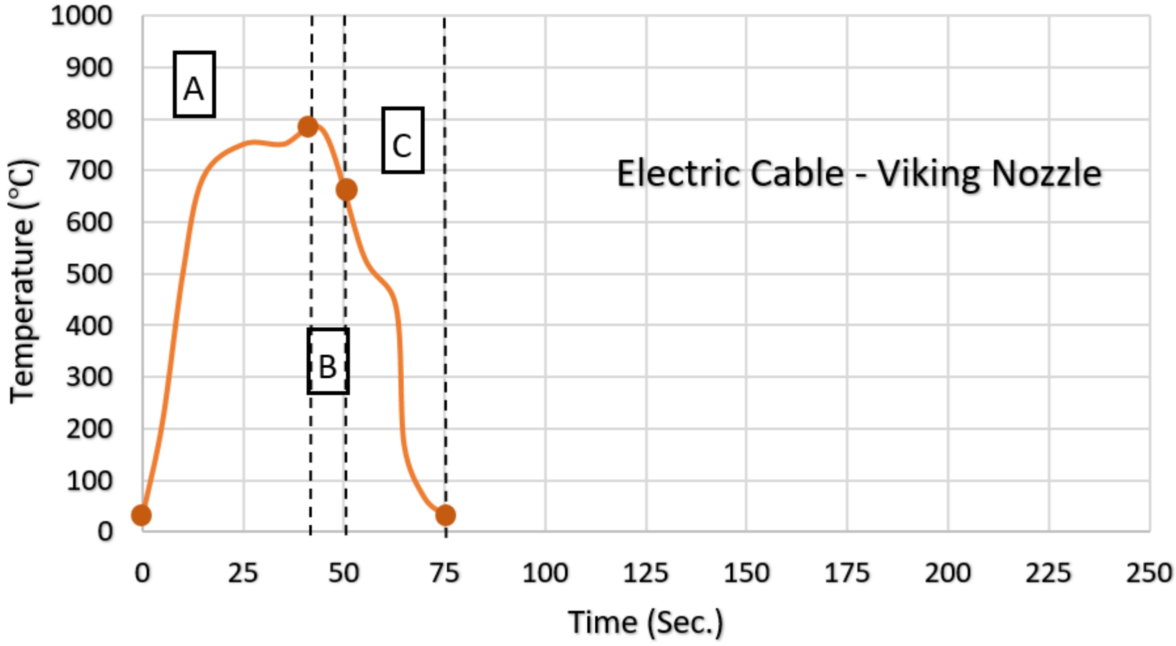
3.2 Fire Scenario II - Electrical Cable

As shown in Fig. (5a) the fire suppression results using Viking nozzle type were presented. The initiation period (Zone A) starting from room temperature 30º C to 775º C and takes about 40 seconds, while the fire suppression period (Zone B) takes 10 seconds with temperature range from 775º C to 650º C, then the cooling period (Zone C) is started which takes 25 seconds and the temperature decreases from 650º C to 33º C.

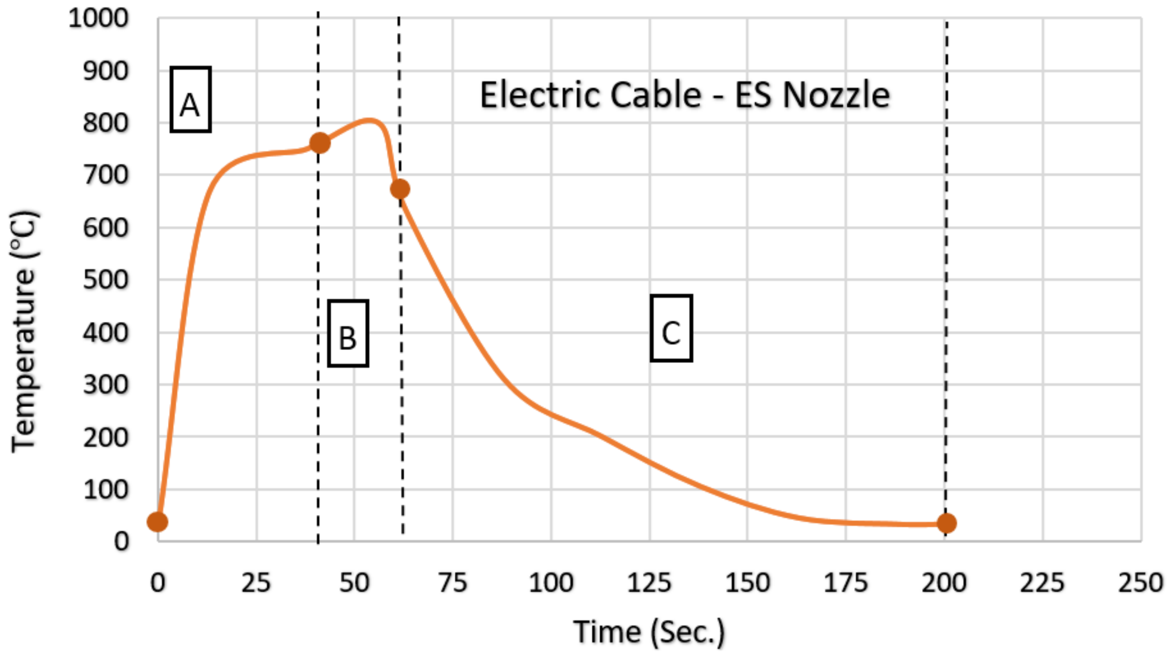
While Fig. (5b) shows fire suppression results using ES nozzle type. Zone (A) starts from room temperature 30º C to 775º C where the same material of electrical cable was combusted and takes about 40 seconds, zone (B) takes about 22 seconds with temperature decreases from 775º C to 670º C, then the zone (C) was started which takes 137 seconds and the temperature decreases from 670º C to 33º C.

Table 2 Fire protection performance using two different water mist nozzles in case fires of various cables

Zone	Viking Nozzle			ES Nozzle		
	Temp. (˚C) (Start – End)		**Time (Sec.)**	**Temp. (˚C) (Start – End)**		**Time (Sec.)**
Fires of power cables						
(A) - Initiation Period	30	815	30	30	815	30
(B) - Fighting Period	815	763	14	815	760	59
(C) - Cooling Period	763	30	25	760	35	145
Fires of electrical cables						
(A) - Initiation Period	30	775	40	30	775	40
(B) - Fighting Period	775	650	10	775	670	22
(C) - Cooling Period	650	33	25	670	33	137
Fires of navigation cables						
(A) - Initiation Period	33	820	30	33	820	30
(B) - Fighting Period	820	690	15	820	700	20
(C) - Cooling Period	690	33	25	700	33	150



(a) Viking Nozzle



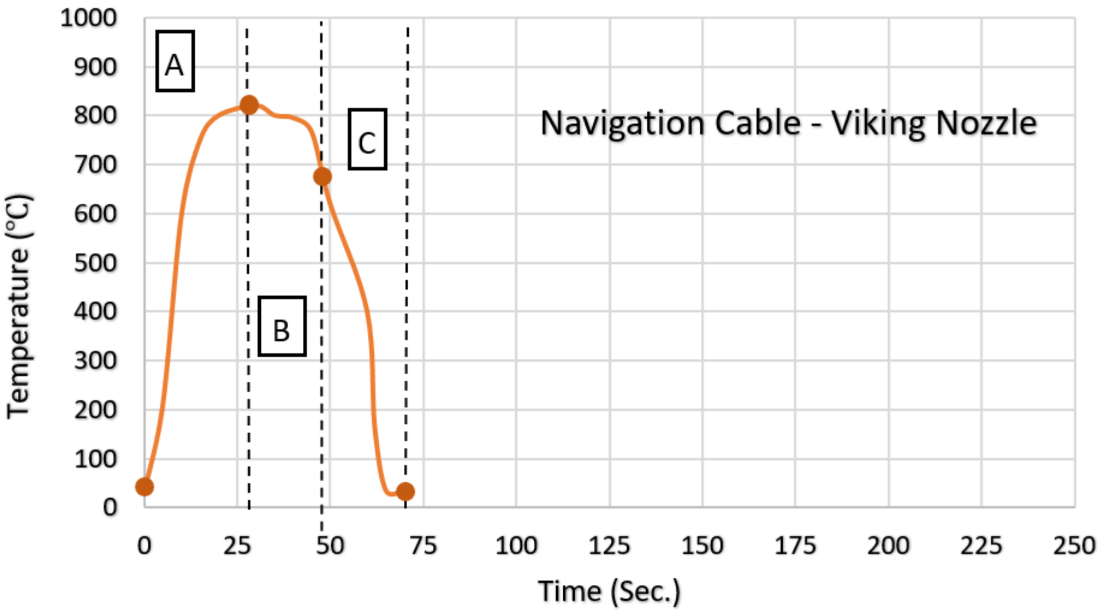
(b) ES Nozzle

Fig. (5) Fire protection performance using two different water mist nozzles in case fires of electrical cables

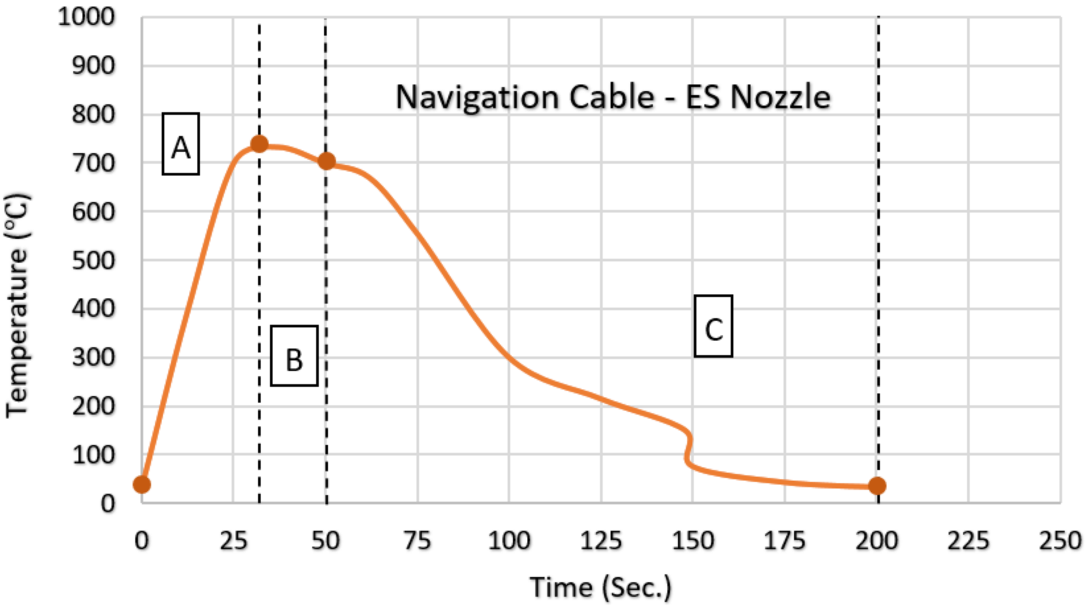
3.3 Fire Scenario III - Navigation Cable

As shown in Fig. (6a) the fire suppression results using Viking nozzle type were presented. The initiation period (Zone A) starting from room temperature 33 ºC to 820 ºC and takes about 30 seconds, while the fire suppression period (Zone B) takes 15 seconds with temperature range from 820 ºC to 690 ºC, then the cooling period (Zone C) is started which takes 25 seconds and the temperature decreases from 690 ºC to 33 ºC.

While Fig. (6b) shows fire suppression results using ES nozzle type. Zone (A) starts from room temperature 33 ºC to 820 ºC where the same material of navigation cable was combusted and takes about 30 seconds, zone (B) takes about 20 seconds with temperature decreases from 820 ºC to 700 ºC, then the zone (C) was started which takes 150 seconds and the temperature decreases from 700 ºC to 33 ºC.



(a) Viking Nozzle



(b) ES Nozzle

Fig. (6) Fire protection performance using two different water mist nozzles in case fires of navigation cables

As presented from Fig. (4) to Fig. (6) and as listed data in Table 2, the summary and observations as following.

1- Initiation Period (Zone A):

- Both nozzle types have similar initiation periods, with Viking and ES nozzles taking 30-40 seconds to reach their peak temperatures in each fire scenario.

2- Suppression Period (Zone B):

- Viking nozzle consistently performs faster during suppression, with durations ranging from 10 to 15 seconds.
- ES nozzle, on the other hand, takes much longer to suppress the fire, with suppression times ranging from 20 to 59 seconds.

3- Cooling Period (Zone C):

- Viking nozzle also cools the environment faster, with cooling durations of 25 to 26 seconds.
- ES nozzle has a significantly longer cooling period, taking between 137 and 150 seconds to bring the temperature down to near room temperature.

3.4 Present study limitations

The main limitation based on the content can be summed up as follows.

- Results may not accurately reflect large-scale or real-world cable tunnel fires because the study was limited to small-scale experiments and was carried out in a laboratory-scale test room (3 m × 3 m × 2.4 m).
- Limited nozzle types, this limits the ability to draw generalizations about other nozzle designs because only two nozzles (Viking and ES) were evaluated.
- Cable types and sizes, only three cable types with particular sizes were tested (power, electrical, and navigation cables). Insulation may respond differently in fire depending on its diameter, composition, or placement.
- Short test durations: The analysis ignored long-term re-ignition concerns and post-fire cable integrity in favor of concentrating on initiation, suppression, and cooling over brief time periods (tens to hundreds of seconds).

4. Conclusions

Absolutely, firefighting systems for electrical cables are essential for safeguarding both lives and property, especially in critical infrastructure. Electrical cables often run through places with dense equipment, machinery, and sometimes hazardous materials, so any fire can rapidly escalate if not controlled promptly. Thus, the main goal of the current work is to experimentally investigate the efficacy and performance of the low presure water mist firefighting system in order to protected the electrical cables using different nozzles. Through the Experiment that was previously presented and through the analysis of the results that were reached in the six scenarios according to the experimental work we got the following conclusion.

- The low-pressure water mist (LPWM) system is highly effective for small-scale electrical cable fires.

- The LPWM system extinguishes flames quickly and reduces room temperature rapidly.

- Viking nozzle is much faster in both fire suppression with durations ranging from 10 to 15 seconds for all fire sceneries and with cooling durations of 25 to 26 seconds, which might make it more effective in quickly extinguishing fires and preventing re-ignition.
- ES nozzle takes longer in the suppression phase with suppression times ranging from 20 to 59 seconds, but it has a slower and more gradual cooling period taking between 137 and 150 seconds, which might offer advantages in preventing thermal shock or damage to surrounding areas.
- Among the tested nozzles, the Viking nozzle demonstrated the best performance in terms of extinguishing time and cooling efficiency, using the least amount of water, that may because of the droplet size and the Viking nozzle atomization which was better than ES nozzle, which speeds up the absorption of the heat from flame and diluting the Oxygen that will cause a faster control of the fire. Therefore, it is recommended for combating electrical cable fires.

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