Experimental of Water Mist to Put out Fire in the Electric Compartment of Utility Tunnel

Zhenpeng Bai, Xiaohan Zhao, Jin Zhang

Abstract—**This paper used full-scale experimental tests to study fine water mist system to extinguish fires in the electrical compartment of utility tunnel after cable fires. It used a 250 kW propane burner to ignite the cable. A high-pressure water mist system was implemented for cable fire extinguishing tests. The volume flow rate of fine water spray varied between 7 L/min and 10 L/min. The effect of different water mist volume flow rates on fire extinguishing in the electrical compartment of utility tunnel was investigated. In four cases, the ventilation speed of utility tunnels varied from 0 m/s to 1.2 m/s. The temperature above the ignition source and the lateral temperature distribution at different positions of the ignition source were measured. The effect of different longitudinal ventilation speeds on the fire extinguishing efficiency in the electrical compartment of utility tunnel were studied. The results showed that high-pressure water mist could reduce the internal temperature of the electrical compartment in utility tunnel to below 100 ℃ within 300 seconds. The high-pressure water mist system had good effects in reducing temperature and preventing re-ignition. Fine water mist system has an important practical significance in the electrical compartment of utility tunnel.**

Index Terms—**Water mist; Put out fire; Utility tunnel; Electric compartment**

I. INTRODUCTION

When the utility tunnel fire occurs, it is very dangerous [1][2]. In order to reduce the frequent excavation of urban roads, shorten the driving time, and keep the traffic smooth, the urban utility tunnel shows an increasing trend in all over the world. However, the fire causes great economic damage and casualties to the utility tunnel [3][4]. The fine water mist fire extinguishing system has two advantages of gas fire extinguishing system and water fire extinguishing system. It has the characteristics of environmental protection, high efficiency and non-pollution. It is gradually promoted in the urban fire control construction [5-7]. The water mist fire extinguishing system has the characteristics of high fire extinguishing efficiency, wide fire extinguishing range, thermal radiation and purification of the screen, no damage to equipment, and good electrical insulation for fire extinguishing. Compared with other fire extinguishing systems, water mist fire extinguishing systems have the advantages of less water consumption, long-distance transportation, small water supply pipe diameter required by the system, and small space occupation. As an alternative to halon extinguishing agents, fine water mist is environmentally friendly [8].

In recent years, previous studies have extensively studied the influence of the design parameters of tunnel, utility tunnel and large space water mist on the fire extinguishing effect of tunnel. Luo et. al. [9] explored the water mist fire extinguishing system in the tunnel model. Wang et al. [10] investigated low ambient pressure effect on the spray characteristics of sprayer at low pressure (<0.1MPa). Zhu et al. [11] conducted an indoor experiment of water mist suppressing transformer sump fire. Yu et al. [12] conducted a study on fine water mist fire extinguishing for industrial machinery casings. Pan [13] studied the prevention and control of methane combustion in enclosed underground spaces. It was recommended to use fine water mist. Zhu et al. [14] studied the attenuation of thermal radiation in large-scale fires by medium and low pressure fine water mist curtain. A new type of multi nozzle has been designed to produce a uniform and low water consumption water mist curtains. The author had conducted extensive research on fire and ventilation [15-19]. Prasad et al. [20] analyzed the influence of particle size, spray position and other parameters on water mist fire suppression. Research has found that in large enclosed spaces, fine water mist sprayed from the top has the shortest extinguishing time. Zhang et al. [21] proposed fine water mist fire to suppress combustion experimental tests by using rubber ignition as a flashover indicator. They found that as the pressure and flow rate of the fine water mist increased, the flashover and fire extinguishing effects improved. However, there is relatively little research on fine water mist in the electric compartment.

In summary, there is currently little research on the effects of nozzle flow rate and longitudinal ventilation that utility tunnel used fine water mist. There is currently no clear standard specification for the flow rate and longitudinal ventilation of fine water mist nozzles in the electrical compartment at home and abroad. Fine water mist in utility tunnel fire experimental tests was carried out. Fine water mist nozzle flow rate was considered as a major fire extinguishing

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factor. The temperature distribution of the electrical compartment was investigated when the fine water mist flow rates were 7 L/min, 8 L/min, 9 L/min, and 10 L/min. This paper investigated the effect of longitudinal ventilation speed on fine water mist fire extinguishing in the electrical compartment of utility tunnel with wind speed. This article provides guidance for the use of water mist in the electric compartment.

II. Method

A. Physical Model and Fire Scenario

The length, height, and width of the electrical compartment in utility tunnel were 25 m, 2.9 m, and 3.4 m, respectively. In this testing scenario, the right side (ignition side) of the ventilation speed inlet was a 7-layer cable. The cable width was 750 mm. The distance between adjacent cable layers was 350 mm. The bottom cable is 300 mm above the ground. The top cable was 500 mm away from the top. The cable types were the same. The cable diameter was 100 mm. This article used K-type thermocouples for temperature acquisition. The arrangement of thermocouples is shown in Fig. 1 and Fig. 2. The horizontal direction of the utility tunnel was X. And the vertical direction of the electrical compartment was Y. The width of the electrical compartment was in the Z direction. The ignition source was located on one side of the cable in the electrical compartment of the utility tunnel. One end of the cable compartment was the air inlet. The other end of the cable compartment was an exhaust vent.

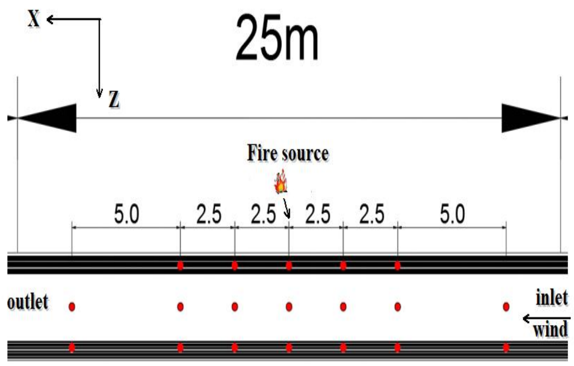

Fig. 1. Physical model of electric compartment

The nozzle was arranged in the middle of the utility tunnel, which was located below the ceiling of the electrical compartment. The nozzle spacing was 3 m. The installation angle and levelness of the nozzle were 45 degrees. It belonged to local applications of fine water mist. Under the experimental conditions of high-pressure water mist characteristics, the nozzle parameters and working pressure were 10 MPa. As shown in Table 1, it is parameters for the fine water mist nozzle. The ignition source was a propane burner. Heat release rate (HRR) was 250 KW. As shown in Table 2, it is the experimental conditions. The flow rate of fine water mist nozzles was different. The influence of volume flow rate of fine water mist nozzles on electric compartment fire was analyzed. This paper analyzed the effect of wind on fine water mist in electric compartment.

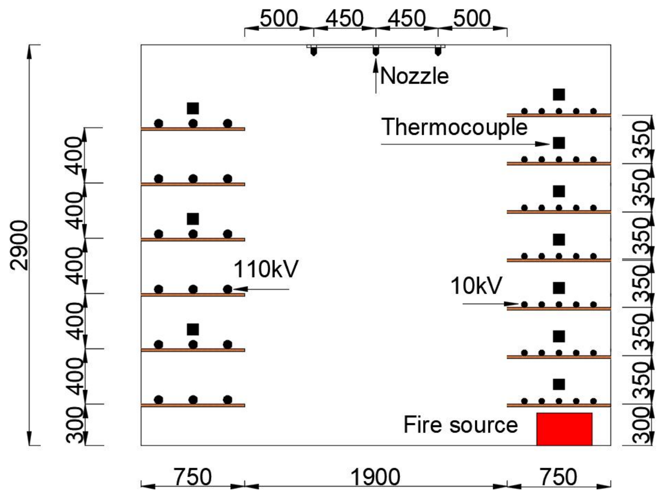

Fig. 2. Thermocouple layout sketch in electric compartment

TABLE 1 PARAMETERS OF SIMULATION PARAMETERS FOR SPRAY CHARACTERISTICS

Pressure (MPa)	Nozzle volume flow rate (L/min)	Atomizatio n cone angle (°)	Droplet size (μm)	Initial droplet velocity (m/s)
10	7/10	140	80	50

TABLE 2 EXPERIMENTAL CONDITIONS

Case	Nozzle flow rate (L/min)	Wind speed (m/s)	Fire source (kW)
1	7	0	250
2	8	0	250
3	9	0	250
4	10	0	250
5	7	0	250
6	7	0.4	250
7	7	0.8	250
8	7	1.2	250

The experimental process was performed as follows:

(1) The propane burner was ignited. It recorded the ignition time. Pre-ignition time lasted for 2 minutes. Then, it turned off the propane burner. Meanwhile, it manually opened the high pressure water mist area control valve group. The fine water mist system activated the corresponding area.

(2) The mist started to spray and extinguish the fire. And it recorded the start time of the mist spray.

(3) The temperature was recorded on the monitor screen. When the temperature remained constant, the staff confirmed that the fire had been extinguished and shut down the pump to release the pressure. The regional control manifold was closed.

(4) The temperature curve of the fire scene over time was recorded and saved.

(5) If the water mist system did not extinguish after 15 minutes of operation, the staff should manually extinguish the fire source with a fine water mist extinguisher.

(6) The ignition cable had been cleaned and replaced. The next set of tests was ready.

For cable tunnel and electrical compartment, the test results required that the average value of temperature measurement points within 5 s after the spray water mist system operates for 5 min shall not exceed 100 ℃.

III. Results And Discussions

A. *Effect of water mist flow rate*

Fine water mist flow rate is one of the important factors affecting fire extinguishing efficiency. This paper tested and analyzed the temperature of the electric compartment under different flow rates.

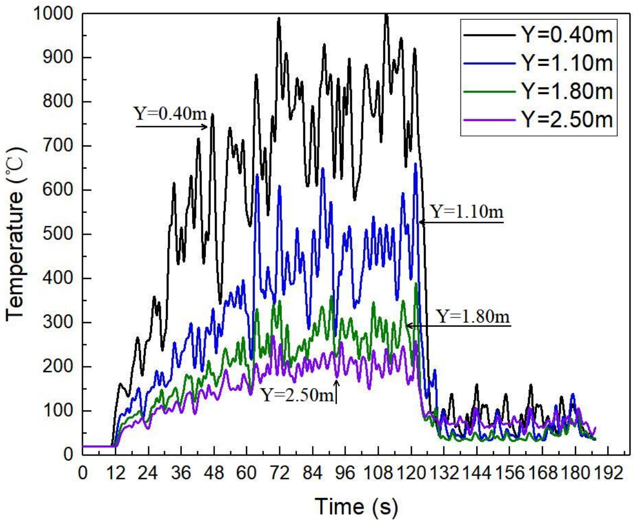

Fig. 3. Temperature above the fire source position when flow rate was 7 L/min

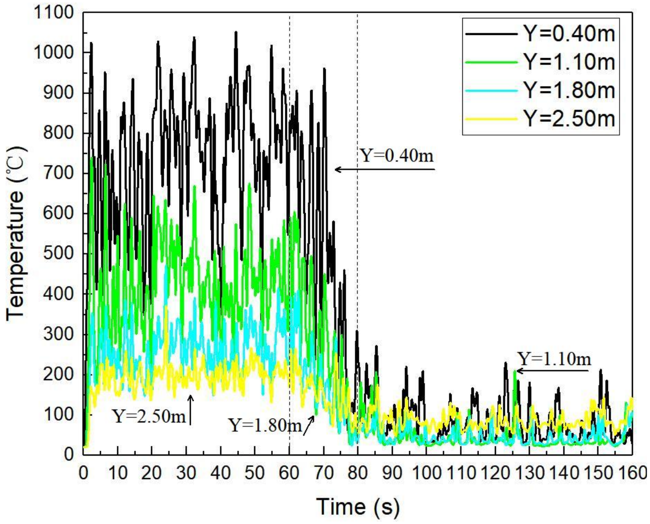

Fig. 4. Temperature above the fire source position when flow rate was 8 L/min

As shown in Figs. 3 ~ 6, when the flow rates were 7 L/min, 8 L/min, 9 L/min, and 10 L/min, the temperature of the thermocouples above the fire source position was affected. From the analysis of temperature fluctuations in Figs. 3-6, it can be seen that the temperatures in the bottom, middle, and upper spaces remained relatively stable since the beginning of water mist in 1960 s. After the water mist was turned on, the bottom and middle spaces temperature decreased by nearly 600 ℃ and 300 ℃ respectively in the first 20 s. During the period of 80 s to 140 s, the temperature of the bottom space thermocouples remained relatively high. When the flow rate was 8 L/min, the temperature range of the entire space was relatively concentrated and fluctuated within a small range. When the flow rate was 9 L/min, the temperature range of the entire space was relatively concentrated, and the temperature fluctuation was further weakened. When the flow rate was 10 L/min, the temperature fluctuation of the fine water mist was within 40 s, which was more intense than the previous groups. Due to temperature fluctuations, it was inaccurate to use certain temperature data to determine whether fine water mist was extinguishing the fire. However, within the first 20 s of the four flow modes, the overall temperature of the space dropped from the maximum temperature above 800 ℃ to around 200 ℃. That is to say, fine water mist has had a positive impact on controlling the spread of fire.

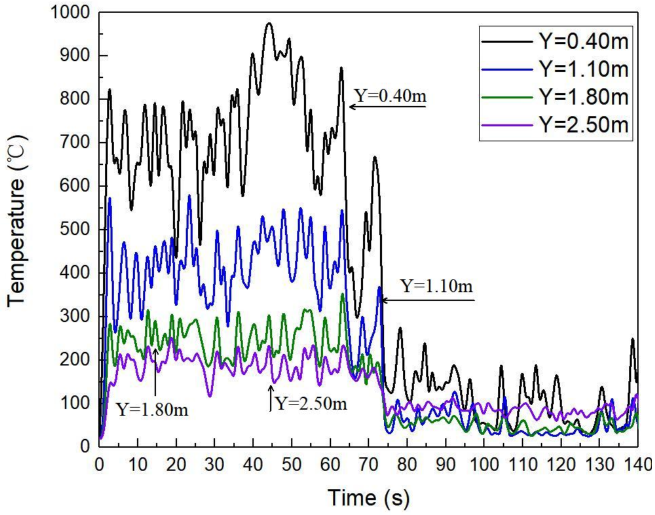

Fig. 5. Temperature above the fire source position when flow rate was 9 L/min

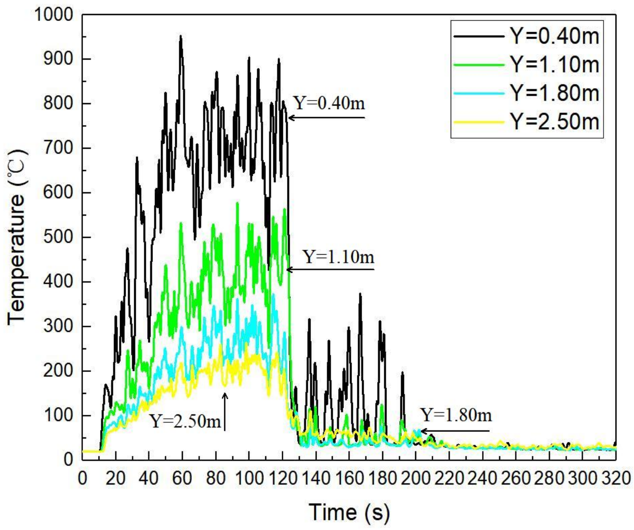

Fig. 6. Temperature above the fire source position when flow rate was 10 L/min

The flame retardant cable was ignited that it used a propane burner. After 120 s of pre-ignition, it activated water spray nozzle. The nozzle adopted a vertical nozzle form, with a water flow rate of 7 L/min. As shown in Fig.s 7-10, the temperature distribution of the electrical compartment in utility tunnel was given when the fine water mist flow rates were 7 L/min, 8 L/min, 9 L/min, and 10 L/min.

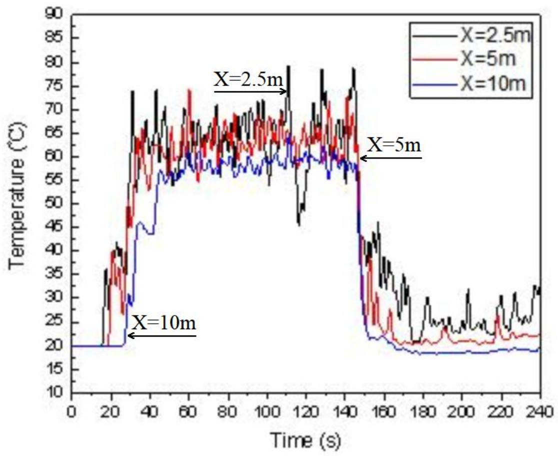

Fig. 7. Temperature at different locations from fire source when flow rate was 10 L/min

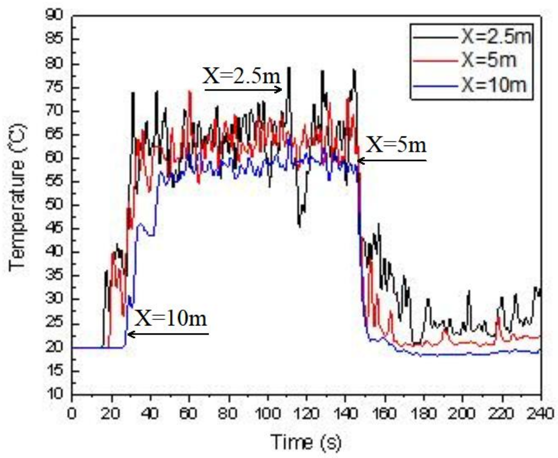

Fig. 8. Temperature at different locations from fire source when flow rate was 9 L/min

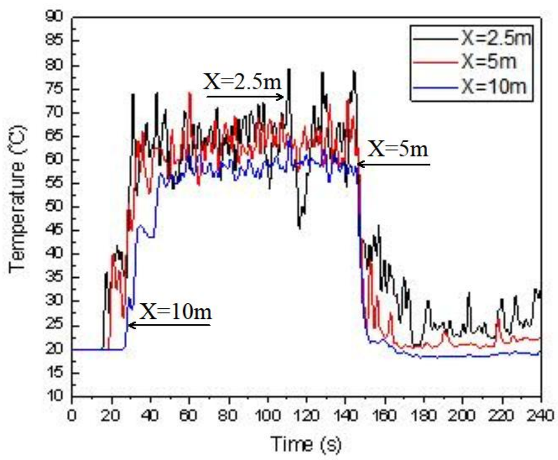

Fig. 9. Temperature at different locations from fire source when flow rate was 8 L/min

It can be noted that the farther away from the fire source, the lower the temperature in the electrical compartment. After the water mist nozzles were turned on, the temperature in the electrical compartment of the utility tunnel rapidly decreased after 20 s. At a distance of 2.5 m from the ignition source, the temperature dropped below 45 ℃. With the continuous spraying of fine water mist, after 240 s, the temperature around the fire source gradually dropped to around 20 ℃. At a distance of 5.0 m from the ignition source, the temperature dropped below 30 ℃. With the continuous spraying of fine water mist, after 240 s, the temperature around the fire source gradually dropped to around 20 ℃. At a distance of 10.0 m from the ignition source, the temperature dropped below 22 ℃. With the continuous spraying of fine water mist, after 240 s, the temperature around the fire source gradually dropped to around 20 ℃.

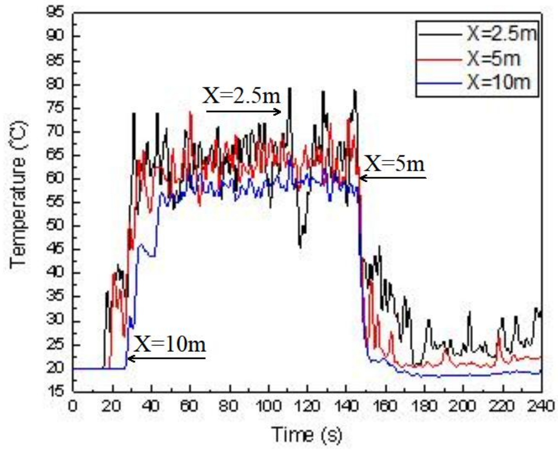

Fig. 10. Temperature at different locations from fire source when flow rate was 7 L/min

B. Effect of longitudinal ventilation

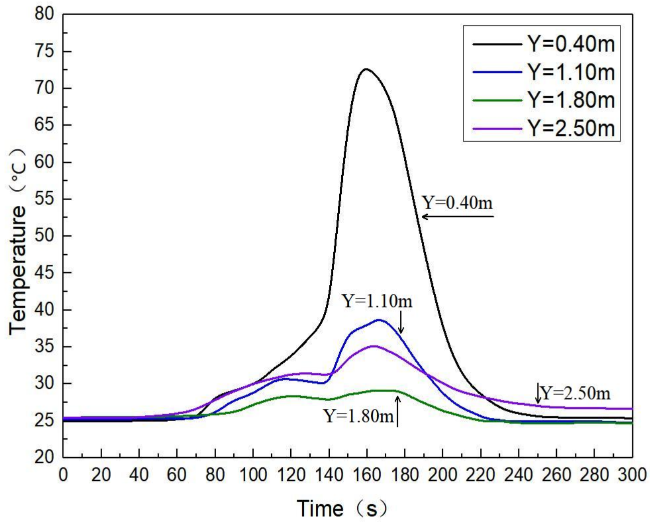

Fig. 11. Temperature above fire source position when ventilation velocity was 0 m/s

As shown in Figs. 11 ~ 14, it can be seen that the temperature data of the thermocouples were analyzed under longitudinal ventilation. Before the water mist started working, the electrical compartment ceiling temperature was higher than the temperature in the middle space. The temperature fluctuations at three locations were significant, which caused by the buoyancy of unstable smoke movement. Meanwhile, when the water mist was opened for 60 s and the temperature data was stable, the entire space temperature reached a stable state after 30 s. After water mist was sprayed, the water mist acted on the flame surface along the atomization cone angle and longitudinal ventilation direction. Fine water mist relied on the amount of mist to suppress the buoyancy rise of flames and smoke, as well as the heat exchange between fine water droplets and flames. The diffusion process of fine water droplets started from the nozzle and was released by tilting downwards. Fine water mist absorbed heat in areas with high temperatures near the fire source below and gradually spread throughout the entire space. The further away the nozzle was from the vertical direction, the stronger the spatial diffusion effect of fine water mist particles. Under longitudinal ventilation velocity conditions, fine water mist particles with lower momentum were more prone to horizontal displacement due to the influence of longitudinal ventilation velocity.

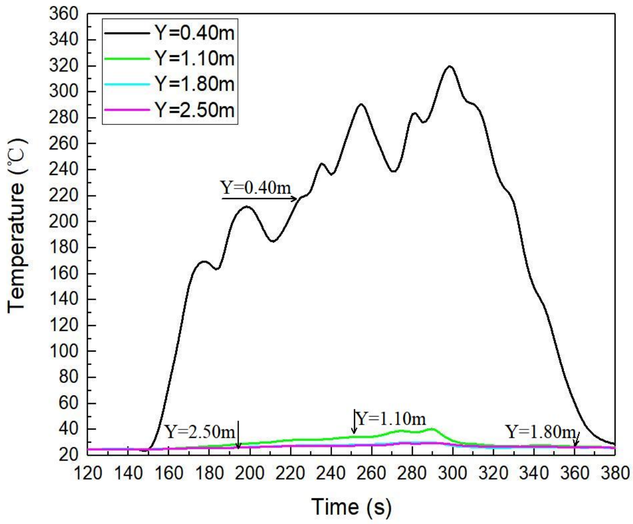

Fig. 12. Temperature above fire source position when ventilation velocity was 0.4 m/s

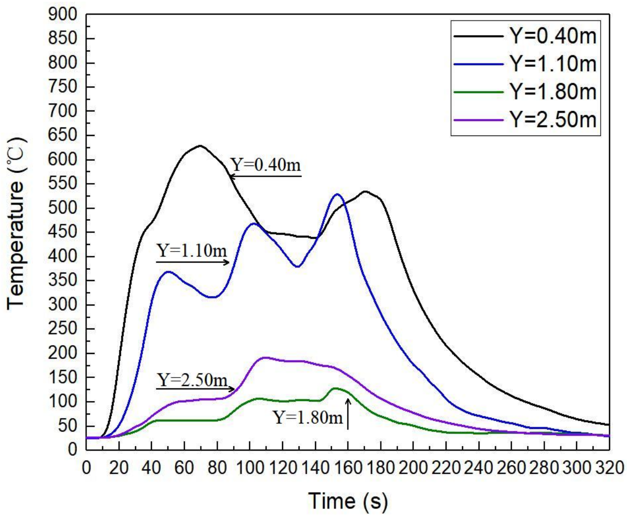

Fig. 13. Temperature above fire source position when ventilation velocity was 0.8 m/s

As shown in Fig. 13, when the ventilation velocity in the electrical compartment of the utility tunnel was 0.8 m/s, the temperature above the ignition source decreased after stable combustion. The electrical compartment ceiling temperature exceeded 70 ℃. The temperature data of the lower thermocouple showed that the maximum temperature did not exceed 40 ℃. And the ambient temperature remained constant in the middle position. After the water mist was turned on, the temperature of the bottom thermocouple droped to near the simulated ambient temperature within 10 s and remained stable. The temperature of the upper thermocouple droped to around 40 ℃ and remained stable for 80 s.

As shown in Fig. 14, when the ventilation velocity in the electrical compartment increased to 1.2 m/s, the temperature above the fire source further decreased. The electrical compartment ceiling temperature reached 40 ℃. The temperature data displayed by the bottom thermocouple did not exceed 30 ℃. When the temperature was maintained at the ambient temperature in the middle of the electrical compartment. Therefore, when the ventilation velocity reached 1.2 m/s and the HRR was 250 kW, the maximum temperature fluctuation range between fire source and ambient temperature was 20 ℃.

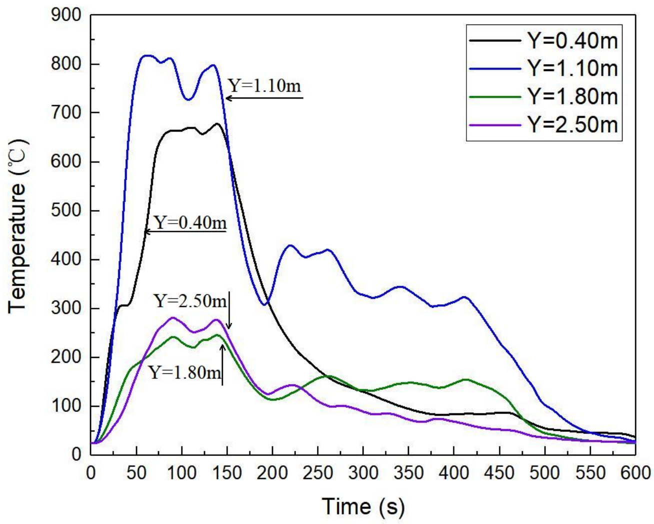

Fig. 14. Temperature above fire source position when ventilation velocity was 1.2 m/s

As shown in Figs. 15 ~ 18, the temperature changes in the upstream direction in the electrical compartment were represented at distances of -10.0 m, -5.0 m, and -2.5 m from the fire source location. The temperature changes in the downstream direction of the electrical compartment of the utility tunnel were displayed at distances of 10.0 m, 5.0 m, and 2.5 m from the fire source location. High-pressure water mist opened within 60 s until the temperature data stabilized. After the water mist in the electrical compartment lasted for 30 s, the overall temperature reached a stable state. Under the action of longitudinal ventilation, the extinguishing of electrical compartment fires by fine water mist had been severely affected.

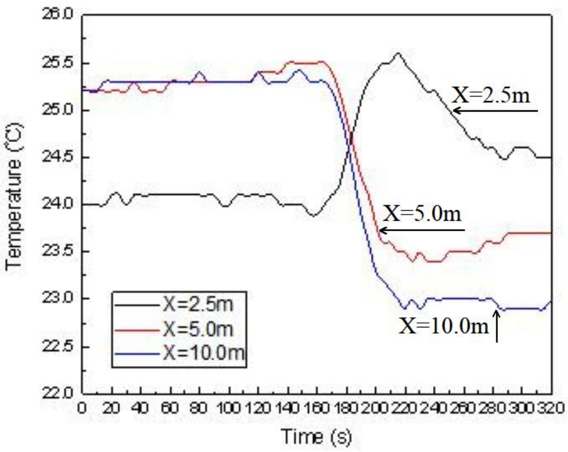

Fig. 15. Temperature at different locations from fire source when ventilation velocity was 0 m/s

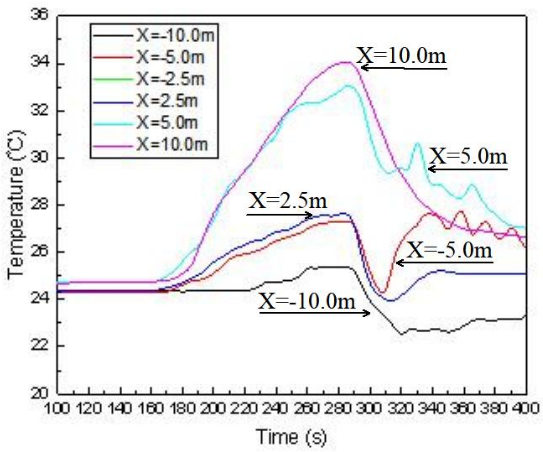

Fig. 16. Temperature at different locations from fire source when ventilation velocity was 0.4 m/s

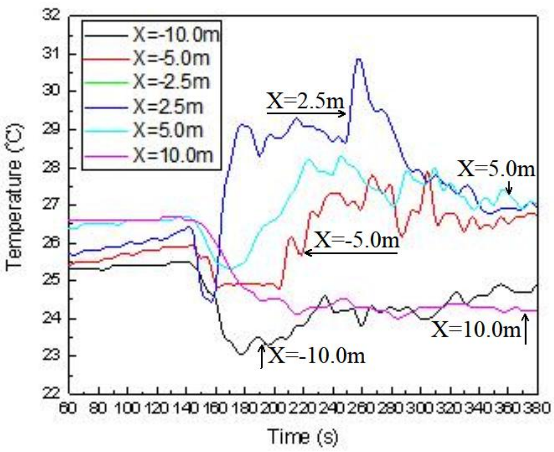

Fig. 17. Temperature at different locations from fire source when ventilation velocity was 0.8 m/s

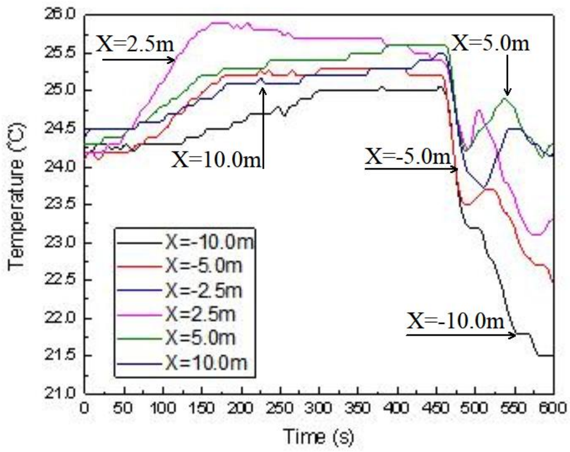

Fig. 18. Temperature at different locations from fire source when ventilation velocity was 1.2 m/s

The temperature of the electrical compartment continued to rise until the water mist was opened. The temperature curve was consistent at 2.5 m and 2.0 m from the ignition source. This is because when the distance from the ignition source was 2.5 m, the temperature was greatly affected by the ignition source. At 280 s, the temperature downstream of the ignition source reached its maximum. When the time was 400 s, the temperature from different positions of the fire source remained basically constant, and the temperature was below 28 ℃. Ventilation increased the temperature of electrical compartment downstream of the fire source. It reduced the temperature of electrical compartment upstream of the ignition source.

C. *Fire extinguishing time*

The comparison results were in Table 3 between the eight cases used in this paper. The nozzle flow rate had the effect on shortening the fire extinguishing time in the electrical compartment of the utility tunnel. When the water mist nozzle flow rate was 10 L/min, the time required for the electrical indoor temperature of the utility tunnel to drop to 100 ℃ was 60 s, and the time required to drop to 50 ℃ was 75 s.

TABLE 3 TEMPERATURE VARIATION OF EXPERIMENTAL CASES

Case	Nozzle flow rate (L/min)	Wind speed (m/s)	Temperature drops to 100℃ (s)	Temperature drops to 50℃ (s)
1	7	0	145	180
2	8	0	105	130
3	9	0	105	145
4	10	0	60	75
5	7	0	--	180
6	7	0.4	345	360
7	7	0.8	405	425
8	7	1.2	500	550

The ventilation experiment was conducted in the electrical compartment under a fine water mist nozzle with a flow rate of 7 L/min. As shown in Table 3, the time was gradually increased with the increase of ventilation velocity, leading to the temperature of the electrical compartment drop to 100 ℃. As time goes by, the temperature of the electrical compartment gradually decreased to 50 ℃. The reason is that with the ventilation speed increased, the larger longitudinal ventilation velocity blew away the fine water mist, which affected the original fire extinguishing effect. When the longitudinal ventilation speed was 0.4 m/s, the time required to reduce the temperature of the electrical compartment to 100 ℃ was 350s, and the time required to reduce the temperature to 50℃ was 360s. Therefore, it is recommended that the longitudinal ventilation velocity of the electrical compartment should not exceed 0.4 m/s.

IV. Conclusions

This article investigated the impact of fine water mist on fire accidents in electrical compartment through experiments. Fine water mist has a good fire extinguishing effect on electrical compartment fires. The main conclusions as follows:

(1) Within 20 seconds after the start of the water mist fire extinguishing system, the temperature of the entire internal space of the utility tunnel electrical compartment may drop from a maximum of 800 ℃ to 200 ℃. In other words, fine water mist played a positive role in controlling the spread of fires.

(2) If the longitudinal ventilation velocity is too high, it will reduce the fire in the electrical compartment. Therefore, the longitudinal ventilation velocity of the electrical compartment should not exceed 0.4 m/s when it used fine water mist.

(3) When a fire occurs in the electrical compartment, the flow rate of fine water mist is greater than 7 L/min. After the water mist system was turned on, the temperature inside the utility tunnel could drop below 100 ℃ within 300 s. These measures can protect the structural safety of electrical compartments in the utility tunnel.

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