Study on Characteristics of Self-rotating Spray with Pre-mixed Compressed Air and Low-pressure Water for Extinguishing Class B fires

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Abstract. In view of the high-pressure water mist application problems, a method of self-rotating spray extinguishing class B fires was put forward with the pre-mixed compressed air and low-pressure water. The self-rotating spray fire extinguishing system of pre-mixed compressed air and low-pressure water and a high-pressure water mist fire extinguishing testing system were established, and the spray performance and fire suppression performance were tested respectively. The results showed that the self-rotating spray had finer and more evenly droplets, bigger effective spray radius, lower system pressure, more reduction in water quality requirements, less clogging nozzle than the high-pressure water mist under the basically same water consumption. The effective fire extinguishing distance of self-rotating spray fire was 2.5m and the effective fire extinguishing radius was 1.5m, which was better and would be more applicable for engineering applications than high-pressure spray fire extinguisher.

1. Introduction

Water mist extinguishing technology[1-2] is one of the main substitutes of halon extinguishing agent due to its environmental friendliness, high extinguishing rate, low water consumption and water economization characteristics. However, there are still many restrictive factors in the application of water mist fire extinguishing, such as high-pressure water mist had high requirements and high cost for the pipeline, nozzles, accessories and pumps’ work pressure, and nozzles will be clogged when water quality is not good[3]. The inert gas-water two-phase flow mist system is very complex and is not cost-efficient[4]. The pressure of water mist with bubble atomization is still high, which is the mix that pressure water with more water mixed with a small amount of compressed air, the internal structure is more complicated, and the extinguishing effect needs further study[5]. Therefore, a method of self-rotating spray fire suppression of pre-mixed compressed air and low-pressure water was put forward and relevant experimental research carried out in this paper.

2. Principle and composition

The self-rotating spray fire extinguishing system of compressed air and low-pressure water consists of air compressor, low-pressure water, gas-water mixer, the self-rotating atomizer, pipelines, valves, and etc. Simultaneously, the self-rotating atomizer[6] consists of a self-rotating shell, a rotary seal, a head air-water nozzle, a plurality of peripheral gas-water nozzles and a curved spray rod, and etc. As
shown in Figure 1, the compressed air from the air compressor and low-pressure water gets through the gas-water mixer, enters the self-rotating atomizer end face of the nozzle and the surrounding nozzles. Finally, the reaction force of gas and water is used to make the end nozzles and peripheral nozzles spin spray to extinguish the fire.

![Figure 1. Structure diagram of self-rotating atomizer](image)

The principle of self-rotating spray with pre-mixed compressed air and low-pressure water is as follows. When the compressed air and the low-pressure water were mixed through the air and water mixer, the first inertial collision and cutting separation of the air and water occurred. When the mixture passed through the guide core of air-water nozzle and reached the place not far from the nozzle, the pulsation and surface waves were generated, which was secondary atomization. In addition, the spray bar rotated automatically under the reaction force of the ejected gas-water mixture, the air-water mixture was further collided with the surrounding gas, which was third atomization. Therefore, the air-water mixture were acted on burning nuclear zone and gaseous combustion products, the heat absorption and cool, thermal attenuation, asphyxiation, emulsification and perturbation, and the extinguishing effect was better [7-9].

3. Experimental Methods and performance measure

3.1 Test system

In order to investigate the characteristics of self-rotating spray with pre-mixed compressed air and low-pressure water fire extinguishing, a pre-mixed compressed air and low-water self-rotating spray fire extinguishing system and a high-pressure water mist fire extinguishing test system were established.

The experiment was carried out in the restricted space of 4m long, 3m wide and 3m tall. The restricted space had ventilated doors and windows on the front and side, respectively. The wall with the door was equipped with ventilation equipment, which can eliminate the soot produced by combustion and promote the formation of convection in indoor air. In the experiment, the 0.2m oil plate was filled with 200mL of gasoline as a source of fire, and the bottom of the gasoline was filled with water to make the cushion.

![Figure 2. Self-rotating spray fire extinguishing test system](image)
nozzles and bending spray rods were used, the tap water pressure was 0.35 Mpa, the compressed air pressure was adjusted to 0.4~0.5 Mpa, and the gas consumption was adjusted to 20m³/h. The high-pressure water mist fire extinguishing test system was composed of the high-pressure water pump, the pipeline, the valve, the high-pressure nozzle. The high-pressure pump had rated pressure of 15Mpa, rated flow of 60L/min. The water pressure was regulated to 4Mpa, one high-pressure nozzle was used, which was solid cone nozzle and had nozzle diameter of 1.5mm, conditional atomization angle of 90°.

3.2. Performance measure

In the test of droplet performance, the particle size and distribution of the droplets were measured by Winner 318 spray laser particle size analyzer. The water pressure and air pressure were measured by the pressure gauge. The flow rate and pressure airflow were counted by the vortex flow meter. The effective radius and the effective range were measured by tape measure.

In the determination of fire extinguishing performance, the flame temperature was measured by thermocouple, which was arranged above the fire source, a total of 3 thermocouples. Thermocouple No. 1 was placed on the gasoline surface, thermocouple No.2 and No.3 were located in the distance of 20cm and 40cm from oil basin. The experimental data were obtained through the data acquisition module connected to the computer for data collection.

A camera was arranged at the window within the fire extinguishing experiment to make videos of the whole fire extinguishing process. After the test preparation, the door was opened, the data acquisition system was switched on and the oil plate was ignited. After 30s’ of pre-combustion, the spray system was opened to extinguish the fire. In order to ensure that the fire extinguishing experiment was not disturbed, the door was closed when spray extinguishing. When the flame was extinguished, continued 15s spray was also needed to prevent reignition. When the spray was over, the doors, windows and fans were opened for ventilation, and then the measurement data were saved. After the test, the oil plate of gasoline was reignited which could be a successful fire extinguishment if it was ignited again. Also, the fire extinguishing time was read by the video recorder. In order to prevent errors in the experiment, three experiments were carried out in each working condition.

4. Experimental Results and Discussion

4.1 Spray performance test results and analysis

According to the above test system and measure, the spray properties of self-rotating spray containing 5 gas-water nozzles and 1 high-pressure nozzle performance were measured respectively. Among them, the determination range of Sauter Mean Diameter (SMD) value of spray outlet was 1.0~2.0m. The effective radius measure was selected at 2.5m. The gas-water pre-mixed self-rotating spray gas consumption was 20m³/h, and the relevant test results are shown in Table 1.

| Types                        | Water consumption (L/min) | SMD(μm) | Effective radius (cm) | Effective range(cm) |
|------------------------------|--------------------------|---------|----------------------|---------------------|
| pre-mixed self-rotating spray| 8.0                      | 83~95   | 170                  | 250                 |
| High-pressure water mist     | 7.8                      | 120~140 | 85                   | 310                 |

It is not difficult to see that the water consumption of 5 gas-water nozzles of the pressurized water pre-mixed self-rotating spray and one high-pressure nozzle spray is basically same. The effective range of the pressurized water self-rotating spray is 2.5m, which is slightly shorter than that of the high pressure spray. The Sauter Mean Diameter (SMD) value of the self-rotating spray outlet 1.0~2.0m is 83~95μm. Compared with 120~140μm of high-pressure water mist, the droplet is finer and the atomization effect is better. The spray radius of the pressurized water self-rotating spray outlet 2.5m is 170cm, but the spray radius of the high pressure spray is 85cm. The former has larger effective range.
4.2. Test results and analysis of spray fire extinguishing performance at different distances

In the experiment, the fire source was arranged to carry out fire extinguishing experiments at different heights under the self-rotating spray of the pressurized gas-water.

The tests showed when the spray device was 1.5m away from the oil basin, the self-rotating spray droplet produced a strong impact on the oil surface, and quickly controlled the flame to extinguish it. The fire extinguishing time was only 8.86s. Because of the impact of the self-rotating spray, the oil basin had the phenomenon of external splash, which could increase the risk of fire spreading. When the fire extinguishing distance was 2.0m, the flame got quickly extinguished within 13.75s. When the spray device was 2.5m away from the oil basin, the fire extinguishing distance became 28.46s, more than twice the fire extinguishing distance of 2.0m, fire extinguishing efficiency was poor. When the fire extinguishing distance continued to increase up to 3.0m, fine water mist droplet momentum was smaller than the plume flow but still did not extinguish the fire source, it only played a certain inhibitory effect. The fire source at a certain temperature only continued combusting, until the gasoline burnt out and eventually ending fire. The results showed that self-rotating spray had the best effect with range of rotating spray outlet 2~2.5m.

4.3. Test results and analysis of effective range of spray fire extinguishment

In the self-rotating spray fire extinguishing test, the experimental fire source was kept unchanged. The vertical height of the spray device from the oil basin was determined to be 2.2m, and the flame temperature change of the gas source with different radial distance from the spray center was used as shown in Figure 3, and the fire extinguishing results are shown in Table 2. The test found that when the fire source was at 0.5m range of the spray center, the water mist could form a complete shroud of the fire source. At this time, spray droplets could effectively penetrate the fire to cool the flame and quickly extinguish the fire in 16.56s. However, when the radial distance from the spray center to the fire source was 0.5~1.2m, the effective control of gasoline fire could be realized quickly and the fire extinguishing efficiency was relatively good. Moreover, when the fire source had 1.2~1.5m radial distance from the spray center, the fire extinguishing time was significantly long, and the water consumption increase clearly which could extinguish the flame as well. In addition, when the radial distance of the fire source was 1.6m, the fire source basically reached the edge of the spray effective atomization range when the momentum of the droplet became smaller and the flow density distribution was smaller. Therefore, the fine water mist could only have a certain control effect on the fire source but could not achieve an effective fire extinguishment. When both the radial distance of the fire source was above 1.7m and the edge of atomization range was reached, the fine water mist had little effect on the combustion state of the fire source which did not achieve the purpose of fire control and fire extinguishment. This indicated that the effective fire extinguishing radius of the spray device was 1.5m when the installation height was 2.2m.

| Radial distance/m | 0    | 0.5  | 1.2  | 1.5  | 1.6  | 1.7  |
|-------------------|------|------|------|------|------|------|
| Fire extinguishing | 12.17| 16.56| 45.52| 53.69| 72.51| 93.43|
Figure 3. The change of flame temperature at different radial distances with self-rotating spray of pressurized gas water: (a) 0m, (b) 0.5m, (c) 1.2m, (d) 1.5m, (e) 1.6m and (f) 1.7m.

Fire extinguishing effect of high pressure spray was not as good as the self-rotating spray. When the high pressure water spray was arranged vertically above the fire source, the fire extinguishing time was 13.89s. Also, as at the time when the fire source was 0.7m from the spray center, the fire extinguishing time was at 65.33s. Furthermore, when the ignition distance from the spray center was 0.9m, it took more than 2 minutes to put off the fire. Also, Spraying on the flame combustion did not work indicates that the fire extinguishing radius at 0.7m was effective.

5. Conclusion

Through the experimental study, the following conclusions can be drawn.

1) When the water consumption was basically the same, the SMD value of the self-rotating spray outlet 1.0~2.0m is 83~95μm. The effective spray radius at 2.5m of spray outlet was 170cm. The effective range of the self-rotating spray was 2.5m. The mist drops were thinner and more uniform, the spray effect was better, the effective area was larger, and the effective range was slightly shorter compared to high pressure spray.

2) Under the test conditions, an effective fire extinguishing can be realized in the 2.5m range of the self-rotating spray outlet. The effective fire extinguishing radius of the spray device was 1.5m when the fire source height was 2.2m, and the effective fire extinguishing radius of the high pressure spray was 0.7m, which indicates that the self-rotating spray fire extinguishing effect was better than that of high pressure spray fire extinguishment. The test found that the participation of compressed air did not have a negative impact on the fire extinguishment.

3) Self-rotating spray fire extinguishing of pre-mixed compressed air and low-pressure water had better advantages. Compared with the high-pressure water mist, the working pressure of the system was much lower, the aperture of the pressurized gas nozzle was bigger with the same amount of water, the nozzles were not easy to be clogged, water quality requirements was more reduction, and it is easy to be applied in engineering. Compared with the inert gas water two-phase flow, this system was simple and the cost-efficient. The internal structure was simple and the water pressure was lower than that of the bubble atomization fine water mist.

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