Design and application of water gun for pre-cleaning exposure footwear and helmet

Jianjun Xia*, Hongyang Wang, Zhiming Bao and Lishuai Jing

Fire Extinguishing Agent Research Division, Tianjin Fire Research Institute of MEM, Tianjin, 300381, China

*Corresponding author's e-mail: Xujianjun@tfri.com.cn

Abstract. The hard equipment of exposure footwear and helmet should be cleaned thoroughly to keep firefighter's healthy. To balance the relationship between effective removing of contamination and equipment's well preserved, new water gun with suitable air pressure was studied. Firstly, the water gun containing flow stabilizer part, venturi part and jet-flow part was designed for pre-cleaning step. Secondly, the contaminating and cleaning experiments were carried out by introducing new water gun. Thirdly, the result data was analyzed using histogram graph and the conclusions were obtained. This new water gun for pre-cleaning could remove contamination like mud effectively avoiding any damage. Further study should focus on removing the hard equipment's oil stain in the washing step.

1. Introduction

Firefighter or fireman was a person with protective equipment to fight fire or save lives. There were generally three types of equipment according to Allocation standard for personal protective equipment of firefighters including body protective equipment, respiratory protective equipment and portability protective equipment. These equipment would be contaminated with smoke particles, polluted water and some gases after fire rescue [1]. The liposoluble particles like PAHs and PBDEs, the watersoluble particles like mud and inorganic compound, the biological particles like bacterial and viral would threat firefighter's healthy [2].

Figure 1: Contaminated exposure footwear and contaminated helmet in fire scene

To remove the soft equipment's contamination, there were five steps including pre-cleaning, washing, rinsing, drying and after treating [3, 4]. To remove the hard equipment's contamination, there were four steps including pre-cleaning, washing, rinsing and drying. The pre-cleaning tool for soft equipment was water gun with 0.07 MPa to clean up the fire protective clothing's obvious blot. But this water gun's water pressure couldn't clean up the contamination on exposure footwear's boot surface or helmet's shell. So the water gun for soft equipment shouldn't be used for hard equipment.
directly. There was also water gun for car washing with about 7 MPa. But this water gun's pressure might be too high to keep the attachments' preserved. Even the pressure could be regulated, the cover area was still not suitable for exposure footwear and helmet. Therefore, the new water gun with suitable pressure and cover area for hard equipment should be designed [5]. This paper would take the data analysis method after actual experiment using new water gun. Then this new water gun would be studied systematically.

2. Design of new water gun with suitable pressure and cover area

2.1. New water gun's three parts' structure

![Figure 2: The cutaway, front and back view of new water gun](image)

Firstly, the new water gun's diameter with 20 mm was determined according to the normal water pipe's size with about 25 mm. Then this water gun could connected with the normal water pipe. Secondly, the new water gun's length was determined by the exposure footwear with 250 mm height and helmet with 440 mm height and 300 mm length. The cover area could be calculated. Then this new water gun was suitable for hard equipment. Thirdly, the venturi structure was designed considering air fluid or detergent liquid's mixed-effect through the negative pressure area near the middle of the pipe hole.

2.2. The venturi effect and fluid field

There were three parts containing flow stabilizer part, venturi part and jet-flow part. The first flow stabilizer part's length was 15 mm. There was a cross in the middle of this tube part with four leaf with thickness 2 mm. This cross could keep the water flow's stability. The second venturi part had 20 mm inlet pipe, 15 mm shrunken pipe and 25 mm enlarged outlet pipe. Based on the principle of conservation of mechanical energy, the velocity of a fluid passing through a constricted area would increase and the static pressure would decrease. Then the air fluid or detergent liquid could be inhaled by venturi negative pressure through the hole near 15 mm shrunken pipe's middle location.

![Figure 3: The venturi part's fluid field and new water gun with a complete appearance.](image)

The third jet-flow part could form bigger spraying cover area based on the fluid field. This mixing effect would be high enough to generate water flow. This new water gun's pressure might be between 0.1 MPa and 5 MPa. And the cover area from the outlet pipe was suitable for hard equipment. Compared with other venturi structure, this new water gun had a complete appearance [6]. The new water gun was manufactured using stainless steel and rubber with high-pressure resistance [7].

3. Contaminating and cleaning experiment

3.1. Contaminating experiment

Before cleaning the exposure footwear or helmet, the contaminating experiment should be carried out. Firstly, the exposure footwear and helmet should be smoked by reduced scale oil pan's fire and smoke.
Secondly, the exposure footwear and helmet should be contaminated with plastic cup and wood firewood's smoke [8]. Thirdly, the exposure foot's boot surface and helmet's outer shell should be immersed in mud suspension liquid or painted by mud suspension drop. Finally, the exposure footwear or helmet would be contaminated with oil particles, plastic particles, wood particles and mud suspension after drying.

![Figure 4: The helmet and exposure footwear before and after contaminating experiment](image)

### 3.2. Contaminating experiment

To clean the hard equipment, there were four steps including pre-cleaning, washing, rinsing and drying. The experimental parameters including tool or machine, time, detergent, temperature were as shown in in Table. Some dish-washing or relative machine had all the functions of washing, rinsing and drying. While some dish-washing or relative machine might only have the function of washing and rinsing. Then the drying process would be finished using other hot air dryer or cold air dryer.

| Step     | Pre-cleaning | Washing       | Rinseing            | Drying             |
|----------|--------------|---------------|---------------------|--------------------|
| Tool     | Water gun    | Dish-washing  | Dish-washing        | Dish-washing or relative machine |
| Time     | 10 mins      | 40min         | 10min               | 30min              |
| Detergent| Normal or none| Low foam detergent | -                  | -                  |
| Temperature | 25° C  | 30-80° C       | 30-80° C            | 30-50° C           |

![Figure 5: The inner structure of dish-washing machine (1: water inlet; 2 grid tray; 3 lower water spray jet; 4 water outlet; 5 rotating motor; 6 upper water spray jet; 7 samples)](image)

To detergent, the low foam type reagent could form effect detergent using a small amount of water. The detergent dosage was about 50 g with anionic surfactant, non ionic surfactant, emulsifier, auxiliary, coconut oil soap base and optimized double active ion. With the help of hot water or hot mist from water spray jet, the cleaning effect would be enforced. Then fire particles would react with the water or mist to form a mount of foams [9, 10]. These foams or liquid with detergent could be washed away in the rinsing step easily [11].
4. Data analysis

4.1. Exposure footwear's cleaning experiments
To verify the pre-cleaning's effect on contaminated exposure footwear, three comparison experiments with or without different water guns in pre-cleaning step were carried out.

- The No.1 experiment process for cleaning exposure footwear contained the washing step using dish-washing machine, rinsing step using dish-washing machine and dying step using dish-washing machine.
- The No.2 experiment process for cleaning exposure footwear contained the pre-cleaning using water gun for car washing, washing step using dish-washing machine, rinsing step using dish-washing machine and dying step using dish-washing machine.
- The No.3 experiment process for cleaning exposure footwear contained the pre-cleaning using new water gun, washing step using dish-washing machine, rinsing step using dish-washing machine and dying step using dish-washing machine.

Then the weight percentage of added contaminate material including oil particles, plastic particles, wood particles and mud was calculated together. The lower data meant better removing effect. All the exposure footwear after cleaning experiments remained well-preserved without any damage.

![Figure 6: Exposure footwear's cleaning comparison result](image)

To exposure footwear, the pre-cleaning using water gun was quite necessary to remove contaminating particles effectively. There was little different cleaning effect between using water gun for car washing with high pressure and using this new water gun for hard equipment with suitable pressure. So this new water gun could be used to pre-clean the contaminated exposure footwear.

![Figure 7: The footwear before No.3 pre-cleaning experiment using new water gun, after No.3 pre-cleaning experiment using new water gun and after No.3 washing and rinsing experiment using dish-washing machine](image)

4.2. Helmet's cleaning experiments with new water gun and without new water gun
To verify the pre-cleaning's effect on contaminated helmets, three comparison experiments with or without different water guns in pre-cleaning step were carried out as below.

- The No.4 experiment process for cleaning helmet contained the washing step using dish-washing machine, rinsing step using dish-washing machine and dying step using dish-washing machine.
The No.5 experiment process for cleaning helmet contained the pre-cleaning using water gun for car washing, washing step using dish-washing machine, rinsing step using dish-washing machine and drying step using dish-washing machine.

The No.6 experiment process for cleaning helmet contained the pre-cleaning using new water gun, washing step using dish-washing machine, rinsing step using dish-washing machine and drying step using dish-washing machine.

Both the helmets in No.4 and No.6 remained well-preserved without any damage. But the helmet's mask rotation axis was broken because of high pressure from water gun for car washing.

To helmets, the pre-cleaning using water gun was not quite necessary to remove contaminating particles. There was a little different cleaning effect between with pre-cleaning and without pre-cleaning. Compared with water gun for car washing, new water gun caused little damage on helmet's mask or any other attachments.

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5. Conclusion and further study
Based on the experiment and data analysis results, conclusions could be obtained. Firstly, the new water gun could remove the hard equipment's contamination like residual mud effectively. The reason could be that associated force between mud and hard equipment's surface was small compared with oil particles. Secondly, the pre-cleaning was quite necessary to exposure footwear compared with helmet. The reason would be that the associated force between mud and helmet’s PA66 material was smaller than the exposure footwear’s rubber material. Thirdly, the pre-cleaning using new water gun could keep the helmet's well preserved without any damage. With the help of new water gun, the helmet and exposure footwear's contamination like mud could be removed thoroughly without any damage. Then other contamination would be removed effectively using dish-washing or relative machine. This work would contribute to provide a healthy environment to fighter or fireman.
Figure 10: The oil stain on the helmet shell (2) could only be removed by external force like finger (1). Furthermore, the corresponding studies should be carried out to remove the contamination more thoroughly. For example, a lot of oil stain remained on the exposure footwear's surface or helmet's shell after the whole cleaning steps. The additive of detergent should be improved or modified as well as the cleaning process.

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