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**Paper:**

# Development of Firefighting Equipment for Efficient Firefighting Strategy (Development of New Nozzle)

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**We have developed a new type of hose nozzle, which uses either water or compressed air foam (CAF), as a more efficient fire-fighting strategy. In this paper, a description of the measured spray range and foam expansion of both the prototype nozzle and conventional nozzles is given. The results show that the spray range of the prototype nozzle is equal or superior to that of conventional nozzles. The foam expansion capability of the prototype nozzle is far superior to that of existing nozzles. From these results, it was confirmed that the new type of hose nozzle suggested in this paper will be an effective addition to existing firefighting equipment, resulting in a more efficient firefighting strategy.**

**Keywords:** firefighting equipment, firefighting nozzle

## 1. Introduction

One of the urgent problems in recent years has been the need to make firefighting more efficient and to reduce the burden on firefighters, by the development and improvement of efficient methods of extinguishing fires with only a small amount of water and firefighting equipment. One of the ways to solve this problem is to introduce a new, efficient, firefighting strategy which uses a smaller-diameter nozzle, which allows the nozzle head to be opened or closed to increase or reduce the water volume, a hose with a diameter of 40 mm, which is smaller than that of generally-used hoses and compressed air foam (CAF). It was reported that this strategy could achieve a reduction in the amount of water required for fire extinguishing, improvement in firefighter mobility, and suppression of the reaction force from the discharged water [1, 2]. However, the introduction of this firefighting strategy created new problems on a nozzle and a hose, as these were often used under condition that had not been encountered before.

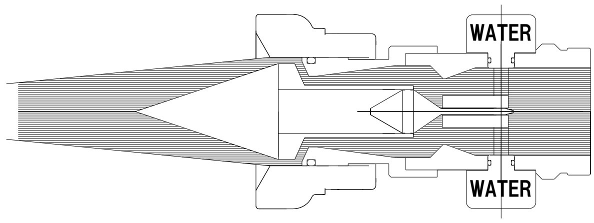
With respect to a hose, the authors developed a new hose which solves the problems related to conventional hose. A rated diameter of new hose is 40 mm and it has a smaller pressure loss and is harder to bend (i.e., has less kinks). They then verified the pressure loss, external damage resistance, kink resistance, cost efficiency of the hose by comparing it with conventional hoses [3].

On the other hand, with respect to a nozzle, the pointed problems which were created by the introduction of the efficient firefighting strategy were summarized as follows:

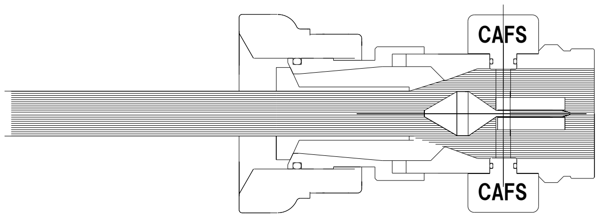
- Firefighters need to use either a small-diameter nozzle, which allows the nozzle head to be opened or closed to increase or reduce the water volume, or a large-diameter nozzle, which is used for large fires. The time needed for a firefighter to choose and replace the nozzles can disrupt prompt firefighting actions.
- For effective firefighting, the CAF discharged from the nozzle needs to attach to and penetrate a target, and then remain on the target for a long period of time. However, during discharge from a conventional small-diameter nozzle, whose head can be opened or closed, most of the CAF bubbles break at the nozzle outlet.

For efficient firefighting, it is therefore desirable to develop a nozzle that can discharge an appropriate amount of various extinguishing agents (i.e., water or CAF), in an appropriate form (e.g., stream or mist), and in an appropriate condition. In general, effective discharge of CAF is realized when the CAF bubbles passing through the hose do not break at the nozzle outlet, but are instead discharged intact. One method of accomplishing this unbroken discharge is using a large-diameter straight nozzle. In this study, we developed a new nozzle to solve the above problem. The developed nozzle combines a straight nozzle for discharging either CAF or a large amount of water, with a variable-bore nozzle for spraying water. The discharge range of the nozzle, the foam expansion ratio of the discharged CAF, CAF adhesion to a wall, foam shape, and foam dropping speed were experimentally measured for both the newly developed nozzle and a variety of conventional nozzles. The results of the comparison and a discussion of their characteristics are reported in this paper.

**Fig. 1.** Prototype of new nozzle.




(a)




(b)

**Fig. 2.** (a) Flow path of the new nozzle (Variable-bore nozzle). (b) Flow path of the new nozzle (Straight nozzle).

## 2. Experimental Equipment and Methods

### 2.1. Experimental Equipment

The new nozzle developed in this study is shown in **Fig. 1**. It has a straight nozzle in the center of a variable-bore nozzle, which allows for four different bore sizes. **Figs. 2(a)** and **(b)** shows the flow paths for the variable-bore nozzle and the straight nozzle, respectively. The shaded area of the figure indicates the flow path. The flow path inside the nozzle can be chosen by using the flow-path switching knob on the nozzle. Five levels of flow rate are available, with a maximum flow rate of 580 L/min, which allows a large amount of water to be discharged for fires of large wooden buildings. If the straight nozzle and the variable-bore nozzle are used simultaneously, a maximum flow rate of 800 L/min is possible. Since the hose connection structure was improved to reduce the reaction force from discharging water, to improve operability, and to reduce the burden on firefighters, a single firefighter can hold the nozzle, even when employing the maximum flow rate. In this paper, the discharge range, the foam expansion ratio of discharged CAF, CAF adhesion to a wall, foam shape, and foam dropping speed of both the new nozzle and conventional nozzles (QuadraFog nozzle, CAFS FORCE nozzle, and straight 21 mm nozzle) are detailed.

The characteristics of the abovementioned conventional nozzles are now briefly explained. The QuadraFog nozzle is a small, lightweight nozzle with a variable bore, and has been widely used by various fire departments for discharging either water or CAF. The CAFS FORCE nozzle is dedicated specifically to discharging CAF in the most appropriate manner, and is not suitable for use with water. The straight 21 mm nozzle is the most basic and most widely used hose nozzle that has been used for firefighting. Hereinafter, the QuadraFog nozzle, the CAFS FORCE nozzle, and the straight 21 mm nozzle are called nozzles 1, 2, and 3, respectively. When the variable-bore nozzle of the new nozzle is used to discharge water, it is referred to as "new nozzle (variable)," and when the straight nozzle of the new nozzle is used, it is called "new nozzle (straight)."

### 2.2. Measurement Methods of Nozzle Discharge Range and CAF Expansion Ratio

The discharge range and foam expansion ratio of discharged CAF for the new nozzle and the three conventional nozzles were measured using the following method. To simulate actual firefighting activities, a large-diameter (65 mm) hose was connected to a carriage on which a compressed air foam system (CAFS) was mounted. Forty mm diameter hoses, each with one type of nozzle attached, were connected to the large-diameter hose via a bifurcated branch pipe. The pump pressure of the CAFS was set to 0.7 MPa. The experiments were conducted indoors to avoid the influence of wind. The nozzles' elevation angle was set to 38°. Containers were placed at 1 m intervals in a straight line in the direction of the CAF discharging from the nozzle outlet. We first discharged the CAF in another direction until the discharge became stable. Then we directed the nozzle toward the containers and discharged the CAF for 1 min. We used two kinds of foam. One had an air-to-water ratio of 18 to 1 under atmospheric pressure (called dry foam), and the other had a ratio of 7 to 1 (called wet foam). The weight $M_i$ [g] and volume $V_i$ [m$^3$] of the CAF collected in each container was measured ($i = 1, \ldots, n$, where $n$ is the number of containers used in each round of the experiment). The discharge ranges for four nozzles were estimated from the weight $M_i$ of foam in each container. The foam expansion ratio $F_m$ of the discharged CAF was calculated from the following formula :

$$F_m = \frac{\rho}{n} \sum_{i=1}^{n} \frac{V_i}{M_i} \quad \ldots\ldots\ldots\ldots \quad (1)$$

where $\rho$ is the specific weight of water [g/m$^3$].

### 2.3. Measurement Methods for CAF Adhesion to Wall, Foam Shape, and Foam Dropping Speed

The CAF's adhesion to a wall (or other target) was studied by the following method. The CAF was discharged from the new nozzle (straight), the new nozzle (variable),

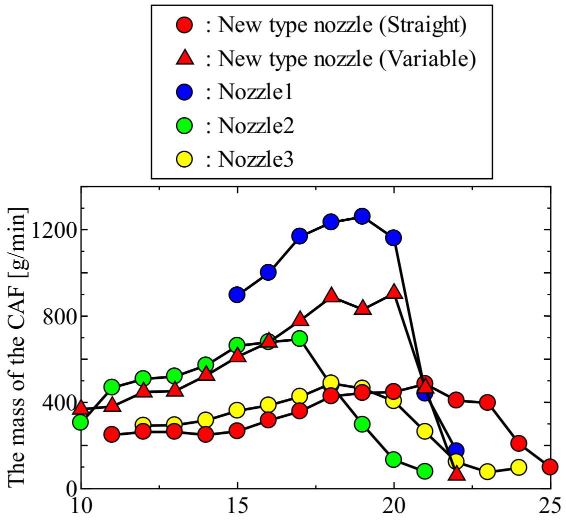



**Fig. 3.** Weight of DRY CAF at each point.

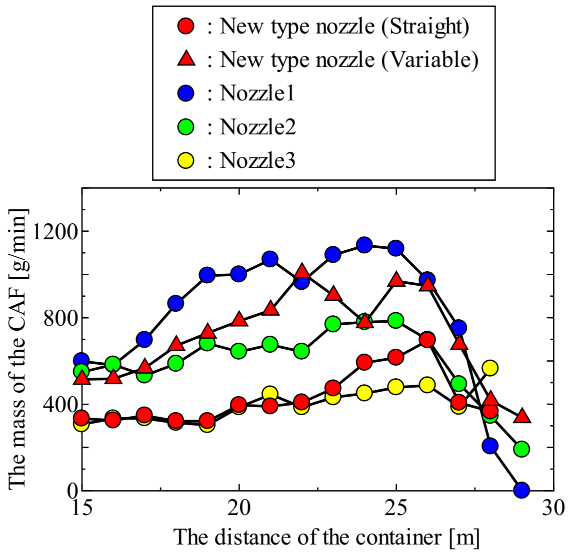



**Fig. 4.** Weight of WET CAF at each point.

nozzle 1, and nozzle 3 toward a polywood panel, and the behavior of the CAF on the wall was observed. Two kinds of CAF, dry foam and wet foam, were used, and the same fire-extinguishing agent was used for each round of experiments. The distance between the nozzle and the wall was 6.0 m and photographs of the wall were taken every minute for a period of 3 min after discharge.

The foam shape and flow were checked using the following method. CAF was discharged from the new nozzle (straight) and nozzle 1 onto a glass pane and observed with a microscope from the back of the glass. The foam shape was checked with the recorded images every minute for a period of 3 min after discharge, and motion picture analysis was used to calculate the average dropping speed of the CAF along the glass surface. The measurements were conducted for both the dry foam and the wet foam.

**Table 1.** Expansion ratio of dry CAF.

| Nozzle | Expansion ratio |
|---|---|
| New nozzle (straight) | 4.8 |
| New nozzle (variable, with a maximum flow rate) | 3.2 |
| Nozzle 1 (maximum flow rate) | 2.6 |
| Nozzle 2 | 12.2 |
| Nozzle 3 | 5.5 |

**Table 2.** Expansion ratio of wet CAF.

| Nozzle | Expansion ratio |
|---|---|
| New nozzle (straight) | 4.2 |
| New nozzle (variable, with a maximum flow rate) | 2.4 |
| Nozzle 1 (maximum flow rate) | 2.2 |
| Nozzle 2 | 7.4 |
| Nozzle 3 | 4.2 |

## 3. Experimental Results and Discussions

### 3.1. Nozzle Discharge Range and CAF Expansion Ratio

**Figures 3** and **4** show the weight of the dry foam and wet foam in each container. In the figures, ● shows the discharge from the new nozzle (straight), ▲ shows the discharge from the new nozzle (variable, with a maximum flow rate of 490 L/min), and ●, ●, and ● show the discharge from nozzle 1 (at a maximum flow rate of 475 L/min), nozzle 2, and nozzle 3, respectively. The experiments were conducted indoors to avoid the influence of wind. However, since it was rather difficult to maintain a constant discharge direction, the amount of CAF remaining in the containers varied from experiment to experiment. Therefore, we did not focus on the absolute value of the amount of CAF but on the relative value as a function of distance. Note that the scale of the horizontal axis is different in **Figs. 3** and **4**. **Tables 1** and **2** show the average foam expansion ratios of the dry foam and the wet foam.

The results for the dry foam, which are shown in **Fig. 3** and **Table 1**, is discussed first. From the figure one can see that the discharge range of the new nozzle (straight) is larger than that of nozzles 2 or 3 and that the discharge range of the new nozzle (variable, with a maximum flow rate) is almost the same as that of nozzle 1. Therefore, the superiority of the new nozzle with regard to the discharge range is confirmed. From **Table 1**, one can see that the foam expansion ratio for nozzle 2, dedicated to CAF discharge, is considerably large. However, the foam expansion ratio of CAF discharged from the new nozzle (straight) is almost the same as that for nozzle 3, and hence is large enough for practical use. Therefore, the straight nozzle is effective for discharging CAF from the viewpoint of the foam expansion ratio. With the conventional nozzle 1 or new nozzle (variable, with a maximum flow rate), the foam bubbles break at the outlet of the noz-

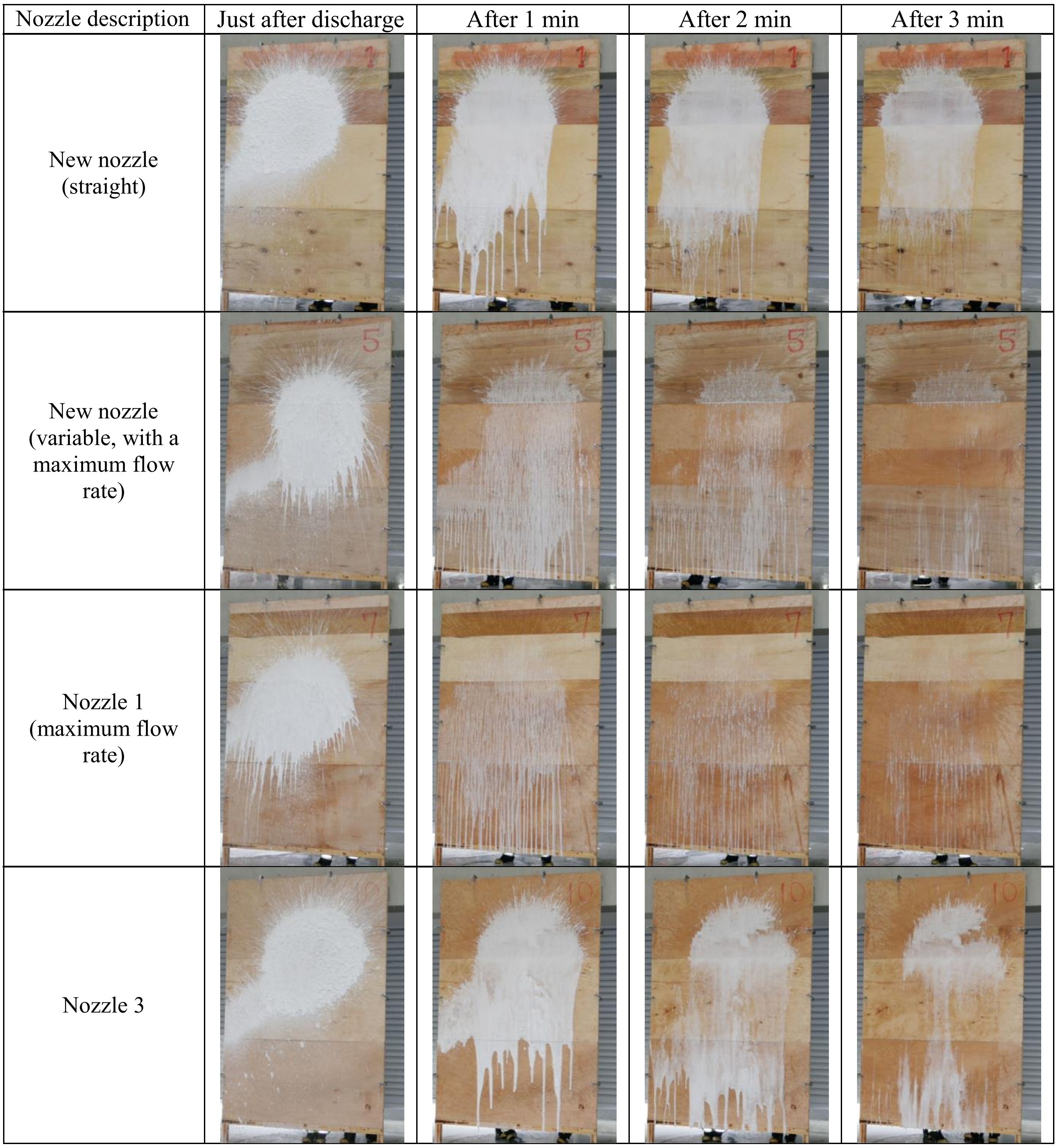


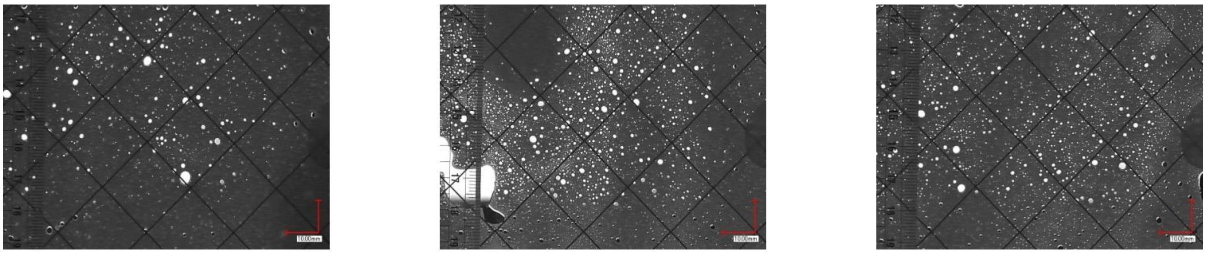

**Fig. 5.** Photographs of dry CAF sprayed on a composite panel.

zle and the foam expansion ratio is low. Therefore, CAF from these nozzles does not work fully. **Fig. 4** and **Table 2**, which show the results for the wet foam, indicate that the discharge range and foam expansion ratio exhibit the same tendencies as those of the dry foam. The discharge range of the new nozzle (variable) and (straight) is almost equal to or larger than that of the conventional nozzle. The foam expansion ratio of the wet foam is less than that of the dry foam for every nozzle, but the foam expansion ratio tendency observed between the nozzles is the same as that of the dry foam.

The above results show that the discharge range of the new nozzle is almost identical to or larger than that of the conventional nozzles for both the dry foam and the wet foam. The foam expansion ratio is largest for nozzle 2. However, since nozzle 2 is not suitable for discharging water, and the foam expansion ratio of the new nozzle is large enough for practical use, the new nozzle is considered effective for efficiently discharging both water and foam.

### 3.2. Adhesion to Wall, Foam Shape, and Dropping Speed of CAF

**Figure 5** shows photographs of the wall onto which the dry foam was discharged. As seen in this figure, a sufficient amount of CAF remained on the wall, even 3 min after discharge, when the new nozzle (straight) was used.



(a) 1 min (b) 2 min (c) 3 min

**Fig. 6.** Shape of dry foam discharged from new nozzle (straight), after (a) 1 min, (b) 2 min, (c) 3 min.

(a) 1 min (b) 2 min (c) 3 min

**Fig. 7.** Shape of dry foam discharged from nozzle 1 (at maximum flow rate), after (a) 1 min, (b) 2 min, (c) 3 min.

When the new nozzle (variable) was used, the foam bubbles broke at the outlet of the nozzle and the CAF disappeared in about 2 min. Similarly, with nozzle 1 (at maximum flow rate), the CAF disappeared completely within 2 min of being discharged. On the other hand, with nozzle 3, the CAF remained on the wall even 3 min after discharge. The same results as those for the dry foam were obtained for the wet foam. The results for the wet foam are omitted here because of space limitations. These indicate that the adhesion property of CAF discharged from the new nozzle was at the same level as that from conventional nozzle 3, and was sufficiently effective.

**Figures 6** and **7** show photographs of the CAF taken with a microscope every minute for a period of 3 min after discharge. The two crossed red lines in the lower right of the photographs indicate a 10 mm length in each direction. **Figs. 6** and **7** show the dry foam from the new nozzle (straight) and conventional nozzle 1, respectively. Comparison of the CAF from these two nozzles indicates that larger bubbles were formed in the foam discharged from the new nozzle. This could be because the foam from the new nozzle adhered to the glass surface without breaking, whereas the foam bubbles from nozzle 1 broke at the outlet of the nozzle. In addition, while the foam from the new nozzle remained on the glass surface for 3 min, most of the foam from nozzle 1 dropped within 2 min, leaving almost nothing behind.

**Table 3** shows the average dropping speed of the CAF discharged from the nozzles, as calculated from the photographs in **Figs. 6** and **7**. As seen in the table, the average dropping speed of the foam from the new nozzle was less than that from nozzle 1. This quantitatively indicates the excellent wall adhesion property of CAF discharged from the new nozzle.

**Table 3.** Average dropping speed of foam from nozzles.

| Nozzle description | Average dropping speed |
|---|---|
| New nozzle (straight) | 1.68 |
| Nozzle 1 (maximum flow rate of 475 L/min) | 3.14 |

## 4. Conclusions

We developed a new nozzle for efficient firefighting, and compared its characteristics with those of conventional nozzles. The results are summarized below:

(1) A new nozzle was developed to discharge water in various forms, such as straight, stream, spray (full cone), and protection spray.

(2) The new nozzle can discharge water at rates up to 580 L/min, so it can be used to fight large fires in wooden buildings. If the straight nozzle and the variable-bore nozzle of the new nozzle are used simultaneously, a flow rate of 800 L/min can be realized.

(3) Through measurements, it was found that the discharge ranges of the new nozzle (straight) and new nozzle (variable, with a maximum flow rate) were almost equal to, or larger than, that of the conventional nozzles for both the dry foam and the wet foam.

(4) The foam expansion ratio of nozzle 2, dedicated to discharging CAF, was considerably large. However, the foam expansion ratio of CAF discharged from the new nozzle (straight) was almost the same as that from nozzle 3, and hence is large enough for practical use. Therefore, the straight nozzle is effective for

discharging CAF, from the viewpoint of the foam expansion ratio. With conventional nozzle 1 or the new nozzle (variable), the foam bubbles broke at the outlet of the nozzle and the foam expansion ratio was low.

(5) When CAF was discharged from the new nozzle (straight), a sufficient amount of CAF adhered to the wall, even 3 min after discharge. With the new nozzle (variable), the foam bubbles broke at the outlet of the nozzle and the CAF disappeared in 2 min. With conventional nozzle 1, the CAF disappeared entirely within 2 min after discharge.

(6) From the comparison between CAF discharge from the new nozzle (straight) and from conventional nozzle 1, it was found that the foam from the new nozzle clearly contained larger bubbles. The foam discharged from the new nozzle remained in large bubble form on the glass discharge surface, even after 3 min, but most of the foam from nozzle 1 dropped within 2 min. Thus, it was found that the foam shape varied depending on the nozzles. It was also observed that the foam discharged from the new nozzle kept its form on the wall, making a layer of CAF. Therefore, the new nozzle effectively extinguished the fire of the target object, and prevented it from spreading.

**Acknowledgements**

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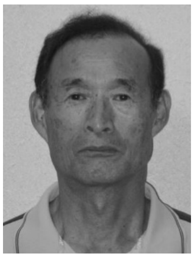

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