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An efficient methodology for evaluating the nozzle performance of water-based automatic fire extinguishers

Younggeun Kim and Kyungok Kwon†

Department of Fire Safety Engineering, College of Engineering, Jeonju University, 45, Baengma-gil, Jeonju 560-759, Korea
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Abstract−The performance of automatic fire extinguishers (AFE) was tested using a novel nozzle distribution test in relation to a point of visual approach. The visual nozzle distribution data was obtained from the mapping of the amount of the collected fire extinguishing agent to each position and the gradient was given in accordance with the visually collected amount. The results showed that the effective discharge time was determined by the nozzle structure and its size. The visual nozzle distribution test (VNDT) provided relevant information regarding the performance efficiency of AFE, including the nozzle coverage area, the effective amount of the fire extinguishing agent and the distribution uniformity of fire extinguishing agents, and calculations for the proper amount of a fire extinguishing agent to extinguish a fire. Consequently, the results indicate the VNDT is an excellent method for analyzing the performance efficiency of AFE.

Key words: Fire Extinguisher, Nozzle, Nozzle Distribution, Performance Test

INTRODUCTION

Over the last several years, there has been a great deal of interest in the performance evaluation of fire extinguishers with diverse performance tests. In particular, cooking appliance extinguishers have been extensively studied because of their importance in kitchen fire protection [1,2]. Furthermore, to date, numerous skyscrapers have been built through the development of high-rise building-construction techniques and the risk of their kitchen fire is also increasing. The kitchen fire being recognized as a major factor because kitchens have many cooking appliances, such as microwave ovens and stoves which store combustible materials such as cooking oil, butter, and other materials. In the case of apartments, it is recommended to install an AFE above the stove in accordance with the terms of the national fire safety code. Because of the character of kitchen fires, most fires start from an oil fire, where the water-based fire extinguishing agent is widely used. The AFE consists of a nozzle, controller, fire extinguishing container, sensors, including gas sensors, temperature sensors and flame sensors. Particularly, the nozzle is the most important piece to determine the performance efficiency of AFE.

Recently, the nozzle distribution test has been highlighted as the proper method to analyze the performance efficiency of fire extinguishing products [3,4]. However, the nozzle distribution test has been performed for sprinkler systems and mist systems and has rarely been used in relation to the AFE [5-9]. The conventional nozzle distribution test was restrictedly conducted to determine the range of distribution. To overcome these disadvantages, it is still challenging to provide a reliable and general method for measuring the performance of fire extinguishers using a quantitative analysis.

This paper reports an effective method to analyze the performance efficiency of AFE through a novel nozzle distribution test combined with a visual approach (VNDT). The VNDT calculates the coverage area, the distribution uniformity of fire extinguishing agents, the proper amount of fire extinguishing agents and other factors. The fundamental analyses, such as pressure variation, discharge time and average pressure, were demonstrated in accordance to the various nozzle sizes and structures. Various nozzles were tested in the VNDT to determine the performance efficiency of AFE.

EXPERIMENTAL SECTION

1. The Measurement of the Internal Pressure and the Amount of Agent Residual for AFE

The AFE was pressurized at 900 kPa and its total weight was measured on the electronic scale. The volume of the cylinder was 1,000 ml and the amount of the fire extinguishing agent was 800 grams. Three different diameter nozzles were used (1.5 mm, 2 mm, and 2.5 mm), along with a nozzle invaded vane inside. The AFE was operated automatically and the pressure and weight were recorded every 0.5 seconds.

2. The Main Ingredients and Physical Properties of the Fire Extinguishing Agent

A fire extinguishing agent, having a 1.1 specific gravity, a pH of 8, a −22 °C freezing point and a 20 dyne/cm surface tension, was prepared by mixing a combination in weight of 70% water and 30% potassium carbonate (K_2CO_3).

3. The Nozzle Distribution Test and Coverage Area

A divider, with an 80 mm×80 mm×100 mm dimension, was arranged into a lattice shape according to its designated coverage area [10]. The nozzle was located at the center of the arranged collecting vessels with a designated height, and distance from the divider to the nozzle. The nozzle distribution test apparatus was pressurized at 340 kPa for one minute. After the fire extinguishing agent was collected, the sample was weighed.

†To whom correspondence should be addressed.
E-mail: kokwon@jj.ac.kr

4. The Fire Extinguishing Performance Test

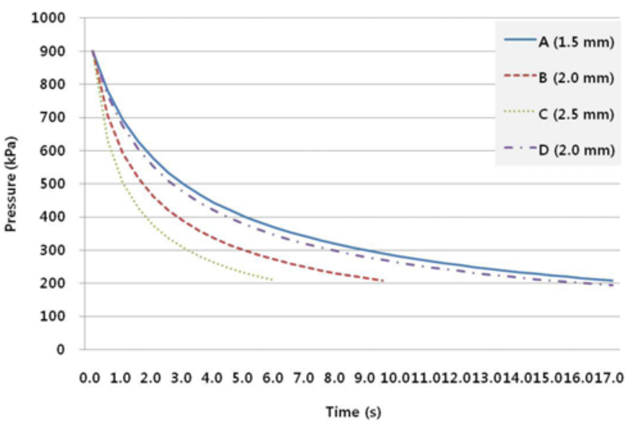
The AFE was installed in a designated position, while heating 800 ml of soybean oil on the stove in a steel frying pan with a diameter of 300 mm. The pan was heated until the oil ignited naturally (the ignition point ranged from 360 °C to 370 °C). After discharging, the oil should not be reignited for two minutes [10].

RESULTS AND DISCUSSION

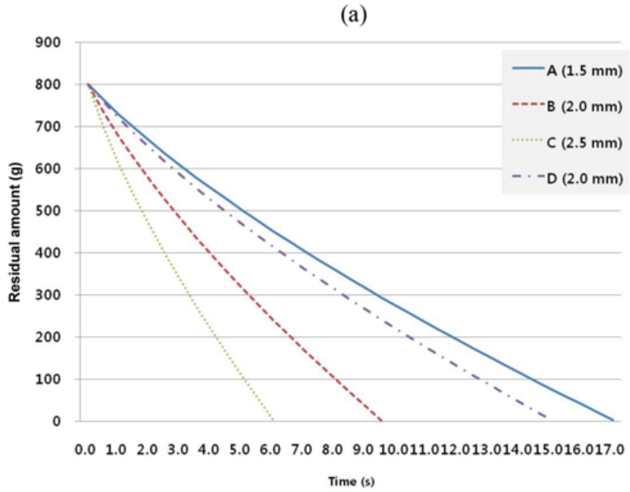
To analyze the performance efficiency of AFE, various tests were conducted. Fig. 1(a) shows the pressure decrease and the effective discharge time of AFE, depending on the nozzle size variation and its morphology. The AFE was pressurized at 900 kPa, and possesses a volume of 1,000 ml, which are the general specifications for protecting the kitchen stove from a pan fire. An 800 ml water-based liquid type of fire extinguishing agent was used. The internal pressure of AFE was measured from the start of discharging agent to the gas point when the discharge changed from an extinguishing agent to the combination of the gas and the fire extinguishing agent [11].

The nozzle diameter was changed from 1.5 mm to 2.5 mm at 0.5 mm increments. The effective discharge time, one of the most important factors to determine the performance of the fire extinguisher, was calculated from the gas point at around 200 kPa. Each effective discharge time was altered according to the variation of nozzle sizes. As can be noticed, the 1.0 mm nozzle diameter difference (1.5 mm and 2.5 mm) produced more than two times the amount for its discharge times (6 s and 17 s). This information explains that the nozzle size affected much regarding the effective discharge time. Graph D describes the pressure decrease and the effective discharge time of the fire extinguisher invaded vane inside the nozzle. Comparing graph B with graph D, the nozzle size was identical, yet had a different morphology, resulting in a pressure variation and a different effective discharge time. The reason for the difference is that the vane produces friction and turbulence inside the nozzle. As the inner structure of the nozzle becomes more complicated, the pressure decrease becomes smaller and the discharge time requires a longer period of time.

Fig. 2 illustrates the general nozzle structure of AFE. The nozzle determines the basic performance, such as the discharge time, internal pressure and the amount of the residual of the fire extinguisher agent. The vane plays an important role for establishing a wider coverage area and a uniform distribution in relation to various types of spray shapes. The nozzle coverage area of the fire extinguisher was adjusted by the shape of the vane and its location inside the nozzle.



(a)



(b)

Fig. 1. (a) The pressure decrease of AFE and (b) the amount of residual of a extinguishing agent depending on the nozzle size variation and its morphology.

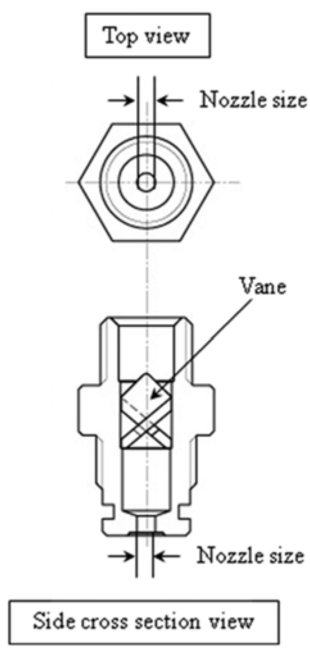


Fig. 2. The top and side cross section view of a general nozzle structure of an AFE invaded vane.

Table 1. The average pressure and effective discharge time for nozzle variation

Graph	A	B	C	D
Nozzle diameter (mm)	1.5	2.0	2.5	2.0
Vane installation	×	×	×	○
Effective discharge time (s)	17.0	9.5	6.0	15.0
Average pressure (kPa)	354.0	345.4	335.2	352.6

The nozzle manufacture condition, such as the roughness control and the distance from the vane to the end of the nozzle, greatly influenced the distribution uniformity.

Table 1 illustrates the average pressures and effective discharge times calculated from Fig. 1. The average pressure decreased from 354.0 to 334.5 kPa as the nozzle diameter was increased from 1.5 mm to 2.5 mm at 0.5 mm increments. The effective discharge time also decreased rapidly as the nozzle diameter was increased. In case of the vane installed nozzle, having a 2 mm diameter, the average pressure value was higher than the 2 mm diameter vaneless nozzle.

Fig. 1(b) displays the change of the amount of the residual of the fire extinguishing agent according to the discharge time. It also displays different curves as a result of the variation of nozzle sizes and the internal morphology of the nozzle. The rectilinear-shaped graphs show that the amount of the discharged fire extinguishing agent was uniform during the effective discharge time. Considering Fig. 1(a) and 1(b), the gas point was the time when the residual amount of fire extinguishing agent was at zero and the internal pressure was 200 kPa.

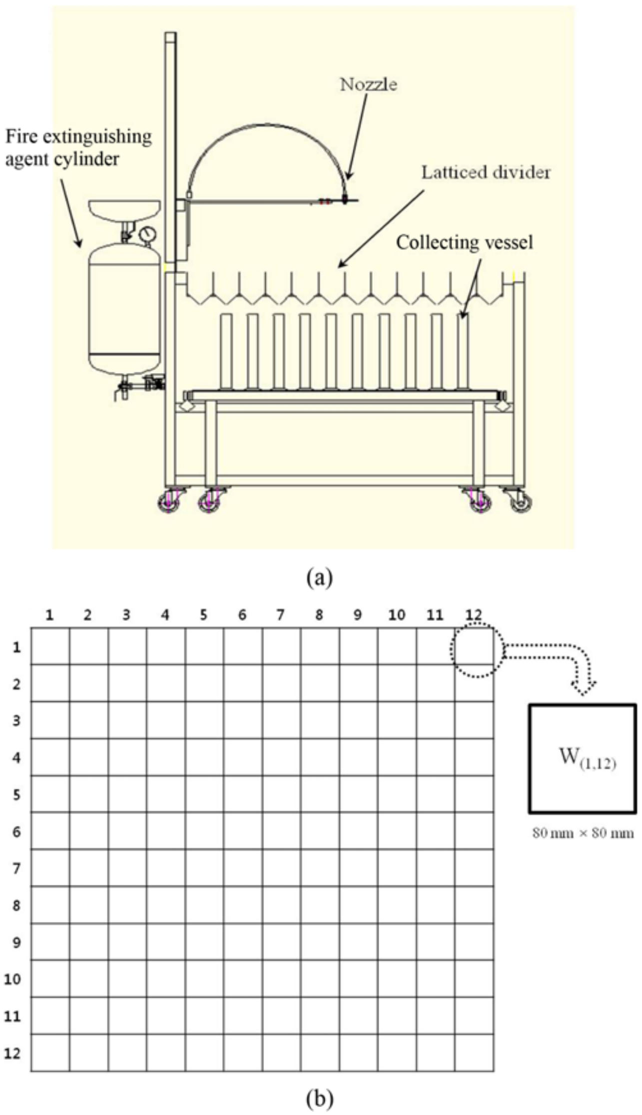


Fig. 3. (a) The apparatus for a VNDT, (b) The dimensions of latticed divider.

Judging from Fig. 1 and Table 1, the internal pressure and effective discharge time were influenced by the nozzle size. The internal morphology of the nozzle also had a decisive effect on the performance of the fire extinguisher as we compare graph B and graph D. Through the experimental analysis for the 2 mm diameter vane nozzle in Fig. 1, the widespread nozzle type of an AFE has the average internal pressure of 352.6 kPa and a uniform discharge amount per time. To analyze the performance efficiency of AFE, numerous VNDT were conducted. The apparatus for a VNDT is shown in Fig. 3(a). The apparatus is composed of a nozzle, latticed divider, a collecting vessel and a fire extinguishing agent cylinder. The latticed divider consists of 144 (12×12) tetragonal frames with each frame possessing a dimension of 80 mm×80 mm (Fig. 3(b)). The total test area was about 0.9 m^2 and the designated protected-area of the nozzle used in this experiment was the same. The nozzle was set in a designated location, discharging the fire extinguishing agent for one minute. The discharged fire extinguishing agent was accumulated in each collecting vessel and weighed.

The average weight of the discharged fire extinguishing agent [$W_{(Average)}$] in the vessel was calculated as follows:

$$W_{(Average)} = \frac{W_{(1,1)} + W_{(1,2)} + \ldots + W_{(n,n-1)} + W_{(n,n)}}{n \times n}$$

Where $W_{(n,n)}$ was the weight of the collected fire extinguishing agent in the collecting vessel. n was the number of collecting vessels of each length and width. The collected fire extinguishing agent, which was outside of the designated protected-area, was not weighed.

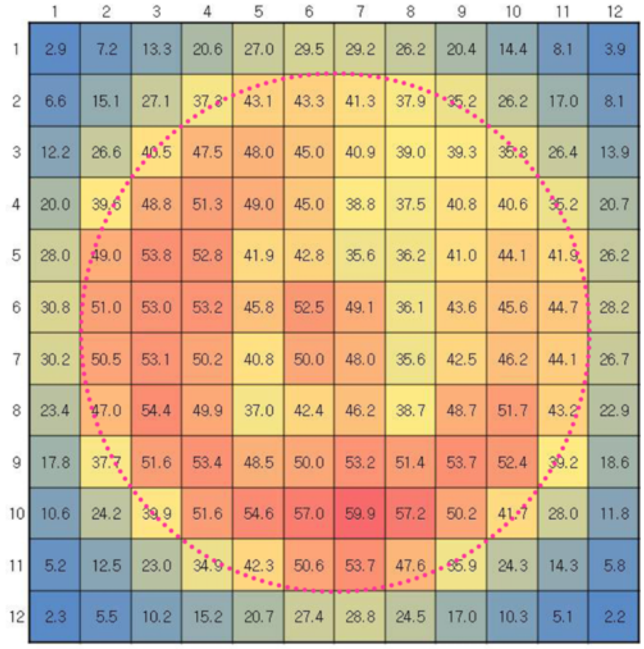
The amount of the fire extinguishing agent required for protecting the area [$W_{(Required)}$] is calculated as follows:

$$W_{(Required)} = N \times W_{(Average)}$$

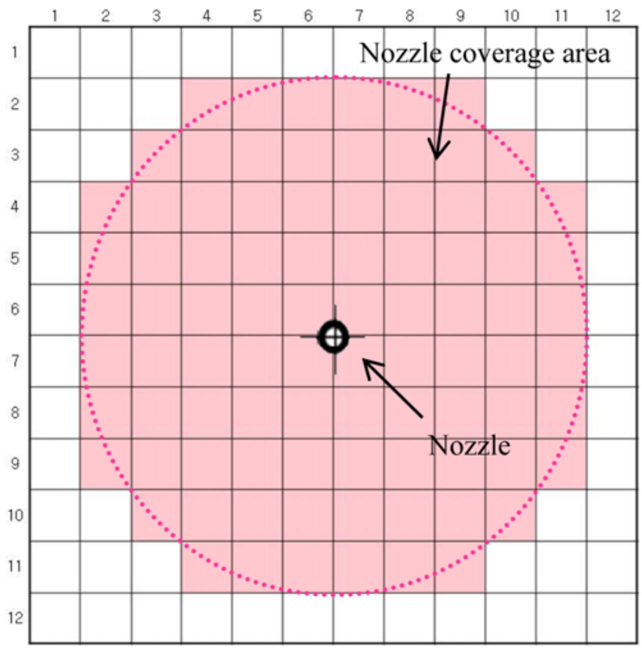
Where N is the number of collecting vessels in the protected area.

Calculating the amount of the fire extinguishing agent is a significant factor in designing a fire extinguishing system. The number of nozzles and fire extinguishing agent containers, the location of the nozzle, and other factors are basically calculated from the $W_{(Average)}$. The uniform distribution of the fire extinguishing agent is the main point to determine the performance efficiency of an AFE. The uniformity is derived from the deviation of the fire extinguishing agent collected within each collecting vessel, while the maximum deviation [$W_{(n,n)} - W_{(Average)}$] shall be under ±50% of $W_{(Average)}$ [12].

Fig. 4(a) was designed through the mapping of the amount of the collected fire extinguishing agent to each position and the gradient was given according to the visually collected amount in order to understand its distribution. The blue colored area indicates the deficiency of the fire extinguishing agent while the red-colored area means its sufficient quantity. Based on the data displayed in Fig. 4(a), information regarding the fire extinguisher performance, including the nozzle coverage area, the distribution of the fire extinguishing agent and the discharge rate on the nozzle coverage area, was able to be calculated. The VNDT apparatus pressurized at 340 kPa was operated for one minute at a height of 0.6 m. The VNDT produced twice the progress regarding the same nozzle and conditions to confirm the reliability of the test. The differences between first test and second test covered less than 10% of the nozzle coverage area, while the distribution morphology was identical. The nozzle



(a)



(b)

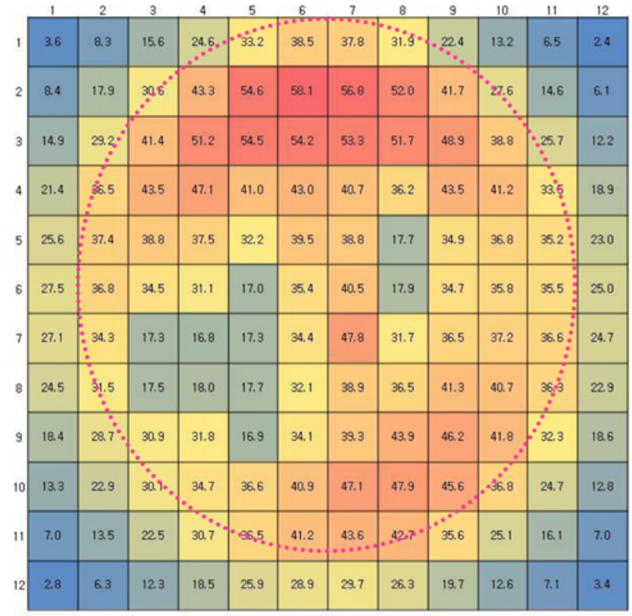
Fig. 4. (a) The fire extinguishing agent distribution data and (b) calculation of the nozzle coverage area using a VNDT.

distribution data was reliable along with the supply information about the nozzle performance, including the nozzle coverage area, the distribution uniformity, and other pertinent information. Fig. 4(b) was the nozzle coverage area obtained from the VNDT.

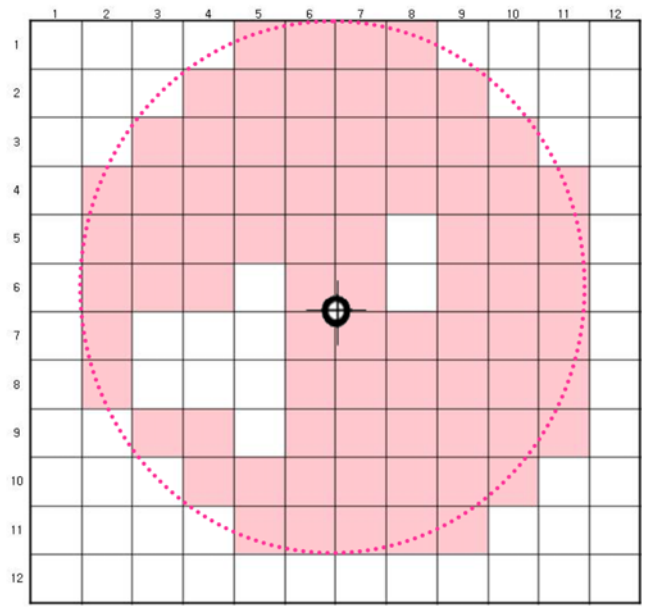
The nozzle coverage area (A_N) was calculated from the following equation:

$$A_N = N \times A_L$$

Where N is the number of collecting vessels in the protected area (88 EA), A_L is the area of each latticed divider (80 mm×80 mm).



(a)



(b)

Fig. 5. (a) The VNDT for eccentric nozzles and (b) the morphology of a nozzle coverage area.

The nozzle coverage area of this nozzle was 0.56 m^2. The weight of the fire extinguishing agent collected in each vessel was from 33.2 g to 59.9 g, and the average weight of the discharged fire extinguishing agent [$W_{(Average)}$] was 45.4 g. The range of deviation was from −27% to +32% and the maximum deviation was 32%. These results indicate that the nozzle has uniform distribution.

Fig. 5(a) displays the nozzle distribution data for eccentric nozzles and the morphology of the nozzle coverage area. The phenomena generated on emergence of an irregular distribution, including an eccentric distribution, and a distorted doughnut shape distribution (Fig. 5(b)). The eccentric distribution was provoked by the processed and assembled inferior such as a biased vane position, rough

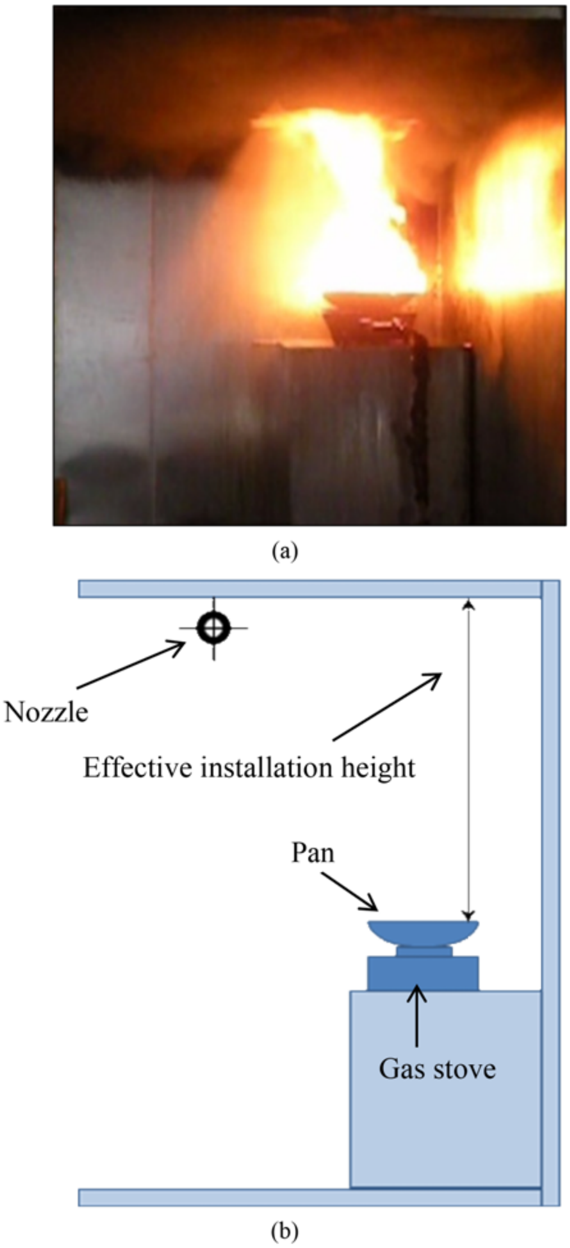


Fig. 6. (a) The picture and (b) the diagram of a fire extinguishing test for an AFE [10].

surface and an alien substance, etc. The doughnut shape distribution was induced by the inner structure similar to a simplex-type swirl structure. The weight of the fire extinguishing agent collected in each vessel varied from 16.8 g to 58.1 g, and the average weight of the discharged fire extinguishing agent [$W_{(Average)}$] was 37.6 g. The range of deviation was from −55% to +55% and the maximum deviation was 55%. The data explains that the nozzle had an irregular distribution. The AFE having irregular distribution nozzle was not able to suppress the fire properly, due to the location of the fire source.

The fire extinguishing test for an eccentric nozzle is shown in Fig. 6, including a photograph and a diagram. The nozzle was installed at an effective installation height (H) and in the protected area. The 800 ml soybean oil was heated in a steel frying pan with a diameter of 300 mm until igniting naturally on the stove. The oil ignited after 30 minutes, and the AFE discharged within three minutes after ignition.

In the case of the pan located as A in Fig. 5(b), after the ignition and the putting out the pan fire, there was no reignition. In location B in Fig. 5(b), however, there was a reignition due to a lack of fire extinguishing agent. These experiments explained the nozzle structure, and the processed and assembled appearances were very important factors for the performance efficiency of AFE.

CONCLUSION

The VNDT was conducted to analyze the performance efficiency of AFE. The correlation between the internal pressure and the amount of the residual of the fire extinguishing agent according to time was evaluated by using various sizes and structures of a nozzle. The VNDT proceeded at an average internal pressure of a fire extinguisher. The visual nozzle distribution data was designed from the mapping of the collected fire extinguishing agent in each vessel. The average weight of the discharged fire extinguishing agent in the unit vessel was calculated from the nozzle distribution data. The degree of uniform distribution was determined by the difference between the average weight of the discharged fire extinguishing agent and the collected weight in the each collecting vessel. The required fire extinguishing agent to cover the protected area was also calculated from the average weight. The effective discharge time and average internal pressure decrease as the nozzle size increases. The nozzle distribution data explains the manufacturing condition and the morphology of its nozzle, while the ineffective nozzle generates an eccentric distribution. The results have shown that the VNDT serves as the most powerful method to determine the performance efficiency of AFE.

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