Study on the impact of airport fire foam performance and fire extinguishing effectiveness

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***Abstract*—The paper analyzed the effects of gas flow rate, liquid flow rate and gas-liquid mixture ratio on foam expansion by using the self-made gas-liquid two-phase foam nozzle. It is found that the fitting relationships between the expansion of AFFF and gas-liquid ratio varying from 2.5 to 22.5 are established as $E=A_1+A_2*\ln(x)$. Aviation kerosene fire extinguishing experiments were also conducted to study the relationship between expansion of AFFF and the extinguishing time. An array of 12 K-Type Nickel Cadmium thermocouples is placed above the pan to measure the flame temperature. The expansion varies from 5.0 to 17.0 by adjusting the gas-liquid ratio. The measured parameters include the gas-liquid ratio, expansion of AFFF, flame temperature, extinguishing time, and et al. The results show that the effect of the different expansion on extinguishing time is significant, and extinguishing time is shorter with higher foaming expansion.**

Keywords—gas-liquid mixture ratio, foam expansion, extinguishing time, flame temperature

I. Introduction

Nowadays, air is used for foaming in a foam nozzle. The foam solution will accelerate after passing a small hole and then, a negative pressure zone occurs. Air flows through open holes in the pipe wall and mixes with foam aqueous solution. The mixture impacts on the bolts near the exit for foaming. But in practice, the expansion decreases sharply when the flow of the foam nozzle is relatively small which has an adverse influence on fire fighting. A solution to this problem is split-flow which will lead to the increase of experimental equipment and the wasting of AFFF. Besides, the flow and the gas-liquid ratio are unable to accurately calibrate.

There were some previous tests carried out in the literature which preliminarily showed the characteristic of gas-liquid two-phase flow. Otake[1] in his study found that there are plug flow, annular flow, bubble flow and squirt flow in a pipe and they can transform into the other. He also found that bubble flow start to transform into squirt flow when the gas-liquid ratio is between 1 and 2. Dutta and Raghavan[2] put forward that bubble flow transform into squirt flow by gas-liquid two-phase flow when gas-liquid ratio is 0.65. Dirix and van der Wiele[3] found that two fluid states exist in the nozzle as liquid or gas flow changes and bubble flow will transform into squirt flow when gas-liquid ratio is 1.3. Cramers[4] suggested that operating condition and internal structure of nozzle have a great impact on the flow pattern.

Gamble and McCabe H[5] improved a method and approach to install foam proportional mixer. Arvidson and Horeck [6-7]designed a method of installation by analyzing the change rule of water flow and improved a system that foam liquid can be transported to fire engines automatically. Hosfield R L [8] designed a system that foam mixing ratio can be controlled in various ways.

In this paper, the influence of different gas-liquid ratio number of foaming generator on expansion is discussed by taking the gas-liquid two-phase foam nozzle as the research object and the law of change is detected. The effects of variable expansion of AFFF on the fire-fighting performance is also studied.

II. Apparaus And Methods

A. Foam generation system

The foam generation system consists of high pressure nitrogen gas bottles, data collection system, liquid storage tanks, foam nozzles, gas flow meters, liquid flow meters, control valves and other components. The foam generation system is shown in Fig1. The high-pressure gas in the high-pressure nitrogen bottle is divided into two ways, one way gas enters the liquid storage tank, so that the foam base liquid in the tank is discharged from the upper end outlet from the middle pipeline, and the liquid flows through the liquid flow meter to transmit the data to the data acquisition system in real time; The gas enters the foam gun from the air inlet through the gas flow meter and the control valve, and the flow rate of the gas and the liquid is controlled by a flow meter that regulates the gas and the liquid, and is mixed at the foam nozzle to generate the foam.

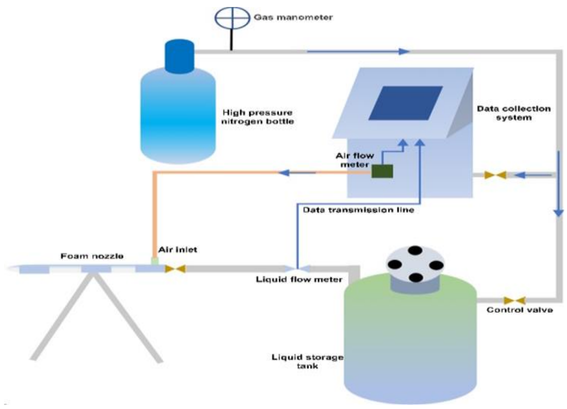

Fig1-2. Foam generation system based on the principle of gas-liquid two-phase reaction

B. The method of testing foam performance

When the foam generating system prepares the stable foam, the foam is received using the foam receiving tank can as shown in Fig. 3, and placed on the prepared electronic scale, and the expansion ratio is measured. $E=V_{foam}/V_{solution}=(m_{foam}/\rho_{foam})/(m_{solution}/\rho_{solution})=(M-m)/V$. At the same time, the computer records the time when the 25% mass of water droplets flows out from the foam, which is the 25% drainage time.

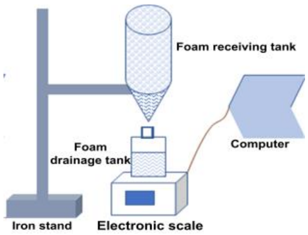

Fig.3. The device for testing the performance of foam

C. The method of tested temperature

The thick of water layer was 40mm added to the square oil pan with a side length of 900mm to ensure that the oil level was horizontal. The thick of aviation kerosene was 20mm. At the same time, 12 thermocouples were placed on the top of the oil pan to measure the change in flame temperature when the foam was sprayed. The arrangement is shown in Fig.4. The distance between the thermocouple and the edge of the oil pan was 300mm, 300mm from the oil surface, and the distance between the thermocouples is 250mm.

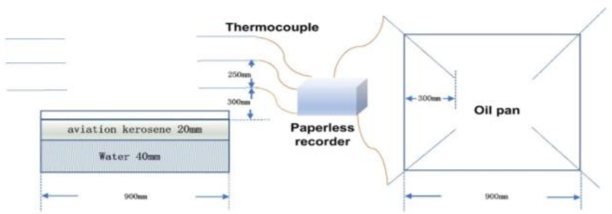

Fig.4. The schematic layout of pan

D. Changed the number of foaming net

The AFFF is mixed with water at a ratio of 6:100 and stainless steel wire is used as frothing material and the working pressure of fluid reservoir is 0.7MPa. The gas-liquid ratio is adjusted over the range of 2.5 to 22.5 by changing air inflow. Nine different ratios are selected to test and each test is repeated several times until the results of three experiments are similar. The average of the three results is considered as the measurement result. Gas flow is set as 29L/min and the gas-liquid ratio is adjusted ranging as 1.3L/min, 2.9L/min, 4.8L/min, 5.6L/min, 7.0L/min and 11.4L/min by adjusting the liquid flow. Due to the existence of error in the experimental devices, there are differences between the theoretical and the actual parameters.

The experiments with foaming net are carried out with the same AFFF and the working pressure is 0.7MPa. The liquid ratio and gas ratio are set as 2.9L/min and 29.0L/min respectively. And the number of foaming generator is adjusted from 1 to 7. The distance between two generators is 1cm and the mesh number is 80 and the aperture is 180μm. Seven different foaming generators are selected to test and each test is repeated several times until the results of three experiments are similar. The average of the three results is considered as the measurement result. The schematic drawing is shown in Fig.5.

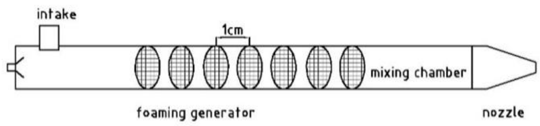

Fig.5 .The schematic layout of foaming net

III. Results and Discussion

A. The effect of liquid flow rate on expansion

Experiments are carried out with the mental foaming generators and the mesh number is 80. And the number of mental foaming generators has four grades, respectively 1,2,3 and 4. Liquid flow is set as 2.9L/min. The gas-liquid ratio is adjusted ranging from 2.5 to 22.5 by adjusting the gas flow. 9 different gas-liquid ratios are selected for the experiments and each experiment of a predefined ratio is repeated several times. The expansions with different gas-liquid ratio are observed and recorded until the results of three groups of experiments are close. The average values of the three groups are taken as the test results which are shown in Fig.6.

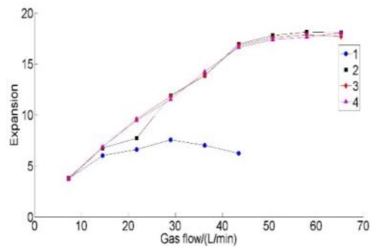

Fig.6 .The expansions for different gas flows under various foaming generators

The figure shows that when the number of foaming generator is 1, the expansion increases first and then decreases with the increase of gas flow in the range of 7.25~43.50L/min. Actually, before the expansion reaches maximum value that is 7.57 where the gas flow is 29.00L/min, the rate of change gets smaller with gas flow. And when the gas flow exceeds 29.00L/min, the expansion starts to fall off slowly.

A cursory view of Fig. 5 would indicate that the same change tendency of expansion with gas flow when the number of foaming generator is 2,3 and 4, and therefore the experimental results just from 2 foaming generators are analyzed. Fig.5 shows that expansion increases with gas flow over the range of 7.25~43.50L/min in proportion basically and after the gas flow rate exceeds 43.50L/min, the change rate of the expansion begins to slow down, and tends to a constant value of about 18. Since gas pressure increases with gas flow for AFFF in the same liquid flow when gas flow is less than 43.50L/min. Thus, the higher sliding speed of gas-liquid two-phase contributes to a more obvious liquid jet column and a faster liquid flow. As a result, the kinetic energy and the impact of AFFF on the foaming generator both increase, so the liquid is more easily dispersed into small droplets which is conducive to increase the contact area between gas and liquid. The foaming process is accelerated with the improvement of gas-liquid two-phase mass transfer, so the expansion gets larger significantly. When gas flow exceeds 43.50L/min, the foaming process is completed basically. With the increase of gas flow, foaming will not happen again, so the expansion begins to stabilize.

B. The effect of air flow rate on expansion

Experiments are carried out with the mental foaming generators and the mesh number is 80. And the number of mental foaming generators is 4. Gas flow are set as 29.00L/min. The gas-liquid ratio is adjusted ranging from 2.5 to 22.5 by adjusting the fluid flow. 6 different gas-liquid ratios are selected for the experiments and each experiment of a predefined ratio is repeated several times. The expansions with different gas-liquid ratio are observed and recorded until the results of three groups of experiments are close. The average values of the three groups are taken as the test results which are shown in Table 1 and the variations of the expansion as a function of gas flow are shown in Fig.7.

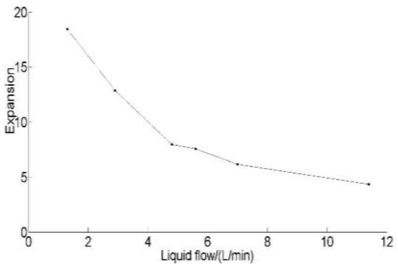

Fig.7 .The expansion for different liquid flows

As indicated in Fig.7, expansion increases as the fluid flow decreases. That's because the kinetic energy and the flow rate increase when fluid flow increases for gas in the same flow. Thus, the contact time between gas and liquid is shortened and the atomization effect of foam gets worse in the same resistance.

Meanwhile, the mass transfer between gas and liquid becomes worse with the increase of the contact area between gas and liquid. The expansion decreases dramatically with fluid flow over the range of 1.3L/min to 5.6L/min since gas-liquid ratio significantly decreases when fluid flow increases for the gas in the same flow. The content of gas is not enough to meet the demand of foaming which causes the residue of the liquid. When fluid flow exceeds 5.6L/min, the descending speed of expansion becomes slower and gas-flow ratio declines slowly as the fluid flow increases so the reduction of foaming ratio gets slow.

C. The fitting relationship between expansion and gas-liquid mixture ratio

The changes of expansion of actual measurement are shown in Fig.8 to Fig.11 as a function of gas-liquid ratio. As shown in the figures, the first scatter plot is markedly different from the others, so a logarithmic function relation is built. On the basis of the figures other than the first one, the fitting can be expressed as: $E=A_1+A_2*\ln(x)+\varepsilon$.

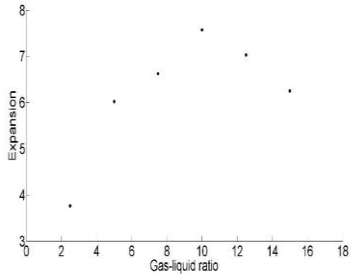

Fig.8 .The scatter plot of expansion when the layer of foaming net is 1 and the credibility is 95%

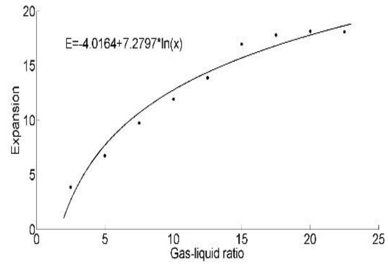

Fig.9 .Fitting for expansion when the layer of foaming net is 2 and the credibility is 95%

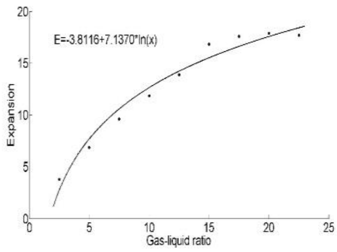

Fig.10. Fitting for expansion when the layer of foaming net is 3 and the credibility is 95%

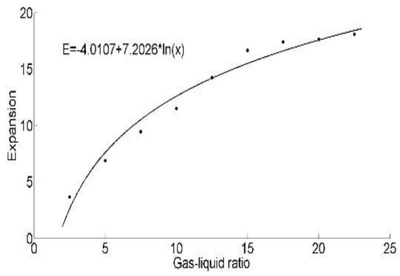

Fig.11. Fitting for expansion when the layer of foaming net is 4 and the credibility is 95%

The relation between expansion and gas-liquid ratio is figured out after the model is transformed into linear relationship. As shown in the figures, the expansion and the gas-liquid ratio have a logarithmic function relation which can be expressed as $E=A_1+A_2*\ln(x)$.

In some cases, data anomalies will occur due to abnormal equipment, human errors and some accidental factors. A residual analysis is essential for excluding abnormal data. And the residuals are in confidence belt with 95% confidence level which indicates that no abnormal data exist.

D. The effect of expansion on fire extinguishing time

A 0.8m^2 pool fire is extinguished by AFFF when its expansion is 5 and the change of temperature is shown in Fig.11 as a function of time. The temperature falls more quickly than that in a blank test and the fire extinguishing time varies greatly.

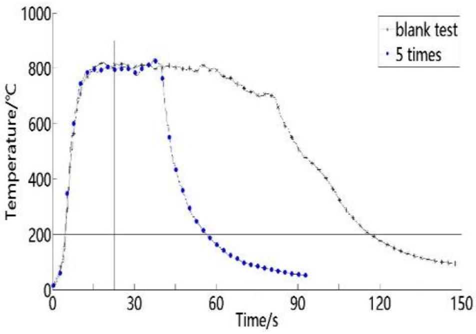

Fig.12. The comparison of the temperature

This shows that the pool fires under various conditions die out due to AFFF rather than the depletion of the fuel. The fuel surface is isolated from the air by the AFFF which plays a role of suffocation. And the heat radiation from the flame is greatly blocked so it helps to extinguish the fire. Only after we prove that the AFFF used in this experiment is effective for fire fighting, the discussion followed is meaningful.

Fire extinguishing time which characterizes the fire-fighting effect of AFFF refers to the time from the start of the foam injection to the time that pool fire is completely extinguished. A short fire extinguishing time indicates a good fire extinguishing performance of AFFF. The influence of different expansion on fire extinguishing time is studied through carrying out the experiments to measure the fire-fighting time of AFFF.

A stopwatch is used to record the fire-fighting time and the time of extinguishing a 0.8m^2 pool fire is shown in Fig12. Taking into account that there are human errors when using stopwatch to record time, we attempt to find a method to determine if the poor fire dies out.

It is found experimentally that the air temperature on the surface of the oil pan is still high when the pool fire is completely extinguished because a certain amount of time is needed for the dissipation of heat and the temperature is about 200℃. If this temperature is considered as the symbol of extinguishing a fire, the time of extinguishing a 0.8m^2 pool fire is shown in Fig12. The errors of the two curves in the figure are quite small so for the convenience of data analysis, the temperature of 200 is taken as the method to determine whether the poor fire is extinguished or not through which the fire-fighting time can be calculated.

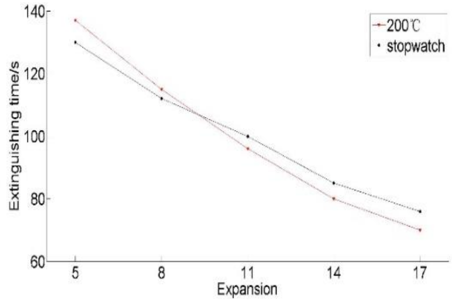

Fig.13. The comparison of the extinguishing time

The changes of temperature as a function of time under different conditions are shown in Fig.13 and Fig.14 and the fire extinguishing time of the corresponding expansion is shown in Fig15. As indicated in Fig15, the fire extinguishing time gets shorter as expansion increases. The foam on the surface of become thicker with the increase of expansion when liquid flow is a fixed value and the foam separate the oil from the air so the heat radiation from the flame is greatly blocked.

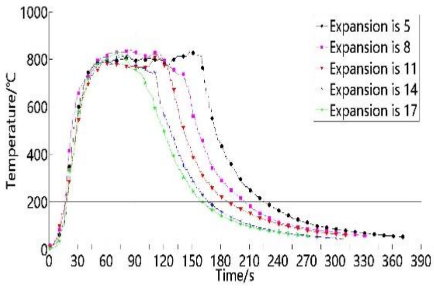

Fig.14. The temperature when the pan is 0.8m^2

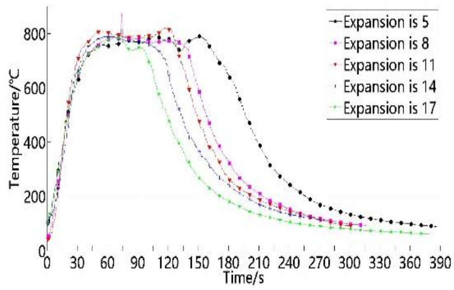

Fig.15. The temperature when the pan is 1.3m^2

IV. CONCLUSION

- The foaming performance of AFFF will be affected by the external conditions, including gas-liquid ratio and number of mesh, except its own nature. The expansion of any qualified foam is adjustable by controlling the gas-liquid ratio and the range is very wide.
- The air input has a significantly influence on expansion in foaming process. The expansion increases firstly and then tends to be stable as gas-liquid ratio increases. It is found that within limits, the expansion and the gas-liquid ratio have a logarithmic function relation which can be expressed as $E=A_1+A_2*\ln(x)$.
- The expansion ratio of AFFF is positively correlated with the number of mesh.

- The efficiency of fire extinguishing can be improved by increasing the expansion of the AFFF and the fire-fighting time will be shorter as expansion increases.

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