

# The Synthesis of an Aqueous Film Forming Foam Concentration and the Drainage Characteristic of the Foam

Xiujuan Wu, Changhai Li, Chuanwen Zhao, Youjie Sheng, Shouxiang Lu\*

State Key Laboratory of Fire Science, University of Science and Technology of China, Hefei 230027, China

**Abstract**—Aqueous film forming foam (AFFF) is a very effective agent for firefighting hydrocarbon fuel fires. A study was conducted to develop a small-scale test for quantifying the drainage behavior of a synthesized AFFF formulation in accordance with the requirements of MIL-24385-F. The rate of drainage was measured to increase sharply to top firstly and then to decrease significantly. Furthermore, the results revealed that there was a critical moment when the drainage of solution slowed down suddenly, and when the most part of solution had drained from the foam.

**Keywords**-*formulation; drain; firefighting foam; AFFF; foam mass*

## I. INTRODUCTION

Aqueous film forming foam (AFFF) is a very effective agent for firefighting liquid fuel fires[1]. Researches on AFFF focused primarily on testing the firefighting performance and chemical/physical properties of AFFF including extinguishment time, time to reignition or burnback time, drainage rate, evaporation rate and foam expansion ratio[2-8]. The drainage of solution from foam begins as soon as the foam is formed. Above all of these, drainage rate is an important parameter which is time-dependent and is widely used to quantify the foam stability[9]. The rate of drainage has been previously [2, 4, 6, 10-13] studied, and the rough drain rate of different foam formulations was obtained in these work, but none of these identifications was clearly enough. Furthermore, no quantitative explanation was found in these studies. As demonstrated through the study of Persson[4, 6, 11], different foam concentrates may result in different drainage rate. To characterize the drainage behavior of AFFF, a given AFFF concentrate was synthesized in this paper, and a modified small-scale test apparatus was developed to quantify the drainage characteristic the foam.

## II. EXPERIMENT

### A. Foam concentrate

Aqueous film forming foam solution which was used to generate foam was comprising of 3 percent or 6 percent of aqueous fluorochemical surfactant-containing concentrate by volume, and 97 percent and 94 percent water by volume, respectively[14-16]. The concentrate formulations exhibit excellent foaming characteristic, which enables the corresponding solution to produce a thick foam blanket that quickly extinguish the fire. The most important components

in the AFFF concentrate are fluorocarbon surfactants, hydrocarbon surfactants, foam stabilizing compound, thickening material, burn-resistant agent, antifreezing agent and dissolvent. The components selected to synthesize AFFF concentrate in this paper were shown in Table I.

TABLE I. THE COMPONENTS IN THE SYNTHESIZED AFFF CONCENTRATE FORMULATION

Category	Component	Quality percentage (%)
fluorocarbon surfactant	FC-001	5
hydrocarbon surfactant	SDS	4
foam stabilizing compound	Xanthan gum	0.2
thickening material		
burn-resistant agent.		
solvent	$C_8H_{18}O_3$	4
antifreezing agent	$(HOCH_2)_2$	20
cosolvent	$H_2NCONH_2$	5
others	Deionized water and others	61.8

### B. Foam solution's surface tension measurement

The AFFF solution was prepared by diluting the 3% of synthesized AFFF concentrate with the 97% of deionized water. The surface tension of the solution was measured by surface tension meter with maximum bubble pressure method. DHJF-4020 constant temperature mixing reaction bath was employed to keep the temperature of solution to be measured at 20°C.

### C. Foam generation

A repeatable compressed-air foam system was employed to generate the AFFF, as illustrated in Figure 1. The foam was produced by mixing compressed air with AFFF solution in the mixing chamber.

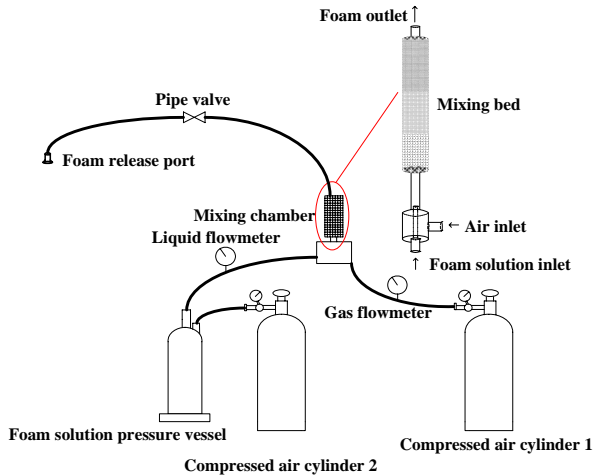


Figure 1. Schematic diagram of the compressed-air foam generator

#### D. Determination of foam characteristics

The foam expansion and 25% drainage time of consecutive batches of foam are the general parameters to be used to characterize the foam[9]. They could also be used to determine the reproducibility of the mechanically generated foam[2]. The definitions of both were proposed by NFPA 11[16]. According to this standard, expansion ratio is defined as the ratio of final foam volume to original foam solution volume. The 25% drainage time is defined as the time in minutes that it takes for 25 percent of the total solution contained in the foam in the sample containers to drain. The expansion ratio and 25% drainage time of foam were determined employing the method required in MIL-F-24385F[15].

The drainage rate of foam was determined using a small-scale test apparatus which was modified on the basis of Lattimer's test pan[2]. The cylindrical shaped test pan was 230mm in diameter and 150mm high. The mass of the foam in the test pan was continuously monitored employing Load Cell #1. The mass of the drained solution was continuously monitored employing Load Cell #2. There were two major modifications in the test apparatus. One modification was that the test pan was constructed of 3mm thick quartz glass instead of the stainless steel. The transparency of the quartz glass enabled the height of the foam visible in the test pan during the drainage process. The other modification was that the drained solution was bled from the test pan employing the theory of communicating vessel, instead of using the electronically actuated solenoid valve.

### III. RESULTS AND DISCUSSION

The physical property of AFFF solution synthesized in this research and the general characteristics of foam generated from the solution were shown in Table II. The values of these parameters confirmed to the requirements of MIL-F-24385F[15].

TABLE II. THE CHARACTERISTICS OF FOAM AND SOLUTION

Property	Value
Surface tension ( $\text{mN} \cdot \text{m}^{-1}$ )	16.09
Expansion ratio	13.5
25% drainage time (min)	5.24

The small-scale test used to quantify the drainage of AFFF was conducted at room temperature with no heating. The foam was continuously filled into the test pan for 74s to keep the initial height of the foam in the test pan at 100mm. The mass of foam in the test pan and the mass of drained solution were monitored and the results were shown in Figure 2.

As shown in Figure 2, the mass of foam in the test pan increased sharply in the first stage, then decreased after this stage. The mass of drained solution increased with time. On account of the physical process of foam in the test pan, the plot was divided into three stages in Fig.2. The rising stage of the foam mass (denoted as A) was the filling stage of foam. The stage from 74s to 291s (denoted as B) was the major drainage stage of AFFF. After time was 291s (denoted as C), the drainage of AFFF slowed down gradually. After the filling stage of foam, the mass balance of foam in the test pan and the drained solution was achieved.

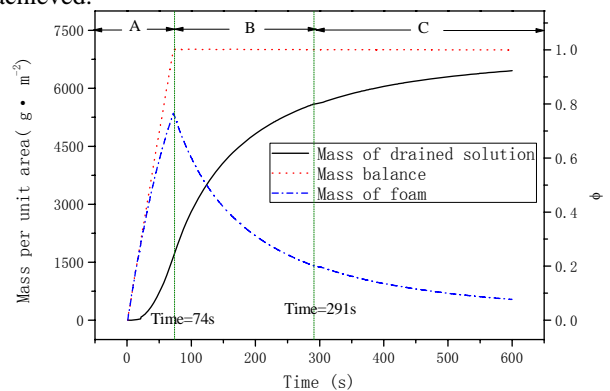


Figure 2. The mass of solution drained from AFFF with the initial height  $h=100$  mm

Note:  $\phi$  was defined as the ratio of the mass of drained solution to the total mass of AFFF.

Figure 3 illustrated the drain rate of foam in the test pan. As shown in Fig.3, the rate of drainage increased sharply to top, then it decreased significantly after the highest point. The decrement turned from notable drop to increasingly smooth drop. Then a sudden drop turned up in the plot. After that, the rate of drainage picked up to the value before the sudden drop, and then it dropped increasingly slowly. The plot was divided into three same stages with in Figure 2. In stage A before time was 74s, the rise of rate of drainage may be caused by the filling process of the foam. On the one hand, the drained solution out of foam increased with increase of foam in the test pan. On the other hand, the filling of foam had an impact onto the liquid surface,

resulting in more solution flowing out of the tube. After the filling stage, the liquid holdup in the the foam column was decreasing with solution draining out of the foam. On this basis, the drainage which is driven by gravity slowed down, as shown in stage B. It was worth noting that with decrease in rate of drainage, the pattern in which the drained solution flowed out of the tube turned from consecutive flow to discrete droplet at a critical moment when 80 percent of the solution had drained out of the foam. Therefore there was a sudden drop in the rate of drainage at the critical moment which was 291s. After that moment, the rate of drainage of foam picked up soon and then decreased smoothly, and its value was rather small due to the slow drainage.

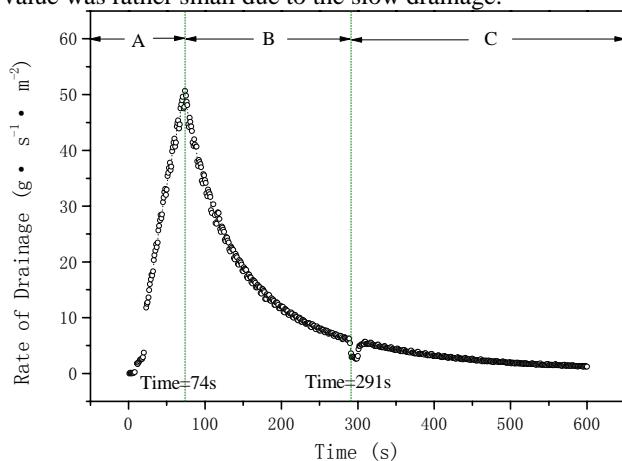


Figure 3. The rate of drainage of AFFF with the initial height  $h=100$  mm

#### IV. CONCLUSIONS

A study was conducted to develop a small-scale test for quantifying the drainage behavior of an AFFF formulation synthesized in accordance with the requirements of MIL-24385-F. The drain rate was measured to increase sharply to top then decrease significantly after the highest point. There was a critical moment when the drainage of solution slowed down suddenly, and when the most part of solution had drained from the foam.

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