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Fluorinated and fluorine-free firefighting foams spread on heptane surface

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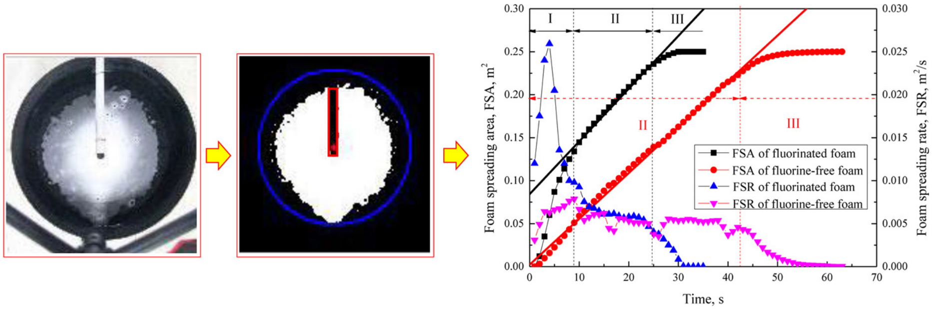
GRAPHICAL ABSTRACT



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ABSTRACT

The application of fluorinated firefighting foam has been restricted due to its serious environmental hazard. Thus, new fluorine-free firefighting foam formulations must be urgently developed. In this work, fluorinated and fluorine-free firefighting foams are synthesized. The spreading of the two foams on the surface of liquid fuel is achieved by using a circle stainless steel tray. Variation in the instantaneous spreading area of the foams versus time is analyzed. In addition, the effect of foam flow rate and expansion ratio (ER) on foam spreading is studied. Results indicate that an aqueous film on the heptane surface is observed during fluorinated foam spreading but not during fluorine-free foam spreading. At the same foam flow rate and ER, fluorinated foam shows faster spreading than fluorine-free foam. The foam spreading rate (FSR) increases with the increasing foam flow rate and decreases with the increasing ER. The high surface tension and great viscosity of fluorine-free foam solution are significant factors resulting in its slow spreading. Therefore, fluorine-free foam can spread on the heptane surface as fast as fluorinated foam by increasing the foam flow rate and lowering the ER.

1. Introduction

Foam is a large conglomerate of gas bubbles that are separated from each other by thin liquid lamellae. Foam properties, such as foaming ability, foam stability, foam drainage, and foam coarsening, have been previously investigated [1–5]. Foams are currently applied in chemical, textile, firefighting, washing, food industries, flotation, water treatment, pharmaceutical, and enhancement of oil recovery [6–10]. Aqueous film-forming foam (AFFF) is a firefighting foam that has been widely used to fight liquid fuel fire for both military and civilian uses with high efficiency. Its high effectiveness in fire suppression is provided by the rapid spreading of foam and the formation of an aqueous film layer on the surface of liquid fuel upon AFFF application.

The properties of conventional AFFFs have been studied to understand their contribution to fire extinguishment; these properties include their film-forming property [11], rheological properties [12], drainage [13,14], and fire extinguishing and burn-back performance [15–17]. Foam spreading is another important property of firefighting foams.

Abbreviations: AFFF, aqueous film-forming foam; ER, expansion ratio; FSA, foam spreading area; FSR, foam spreading rate; FST, foam spreading time

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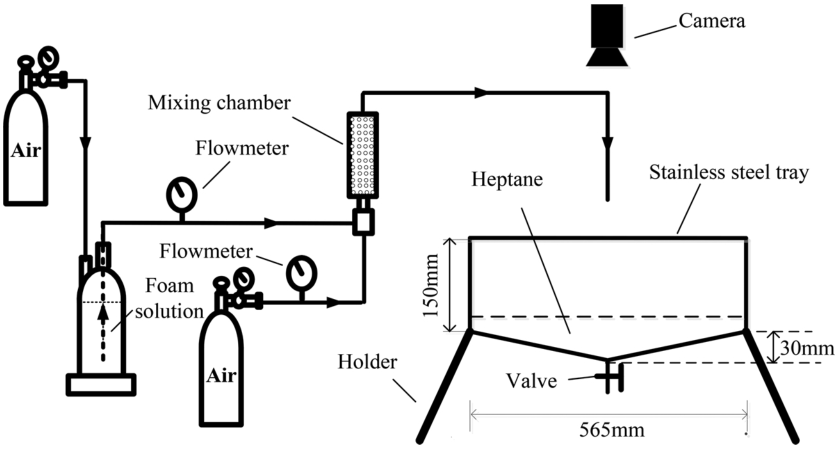

Fig. 1. Schematic diagram of foam generation and foam spreading property test setup.

Predicting foam spreading would serve as a basis for the design of foam suppression equipment and the improvement of firefighting tactics. This process would also provide information about the relative importance of different foam properties for a successful suppression. However, foam spreading property has received relatively minimal attention due to the lack of standard test methods. Although two simple models of predicting foam spreading were established, their prediction did not agree completely with experimental results [18,19]. Work on the spreading properties of firefighting foams should be further conducted to enhance our understanding.

The application of conventional AFFF has been severely restricted [20–22] due to the serious environmental hazard caused by fluorocarbon surfactants, the key component in conventional AFFF. New fluorine-free firefighting foam formulations are being developed. To date, commercially available formulation has not been applied. Several studies on foam properties of fluorinated and fluorine-free firefighting foams have been conducted [4,5,11,23]. However, these studies only focused on dynamic surface and interfacial tension, sealability properties, foam degradation and bubble coarsening of fluorinated and fluorine-free firefighting foams. The difference in foam spreading behavior between fluorinated and fluorine-free foams remains uncertain.

In this study, fluorinated and fluorine-free firefighting foams are prepared. First, the properties of the aqueous solutions of the two foams are analyzed. Then, the spreading behavior of the two foams on the surface of liquid fuel is observed and compared by using a circle stainless steel tray filled with 5 liters of heptane. Variation in the instantaneous spreading area of the foams on heptane surface versus time is obtained based on MATLAB image processing technology. In addition, the spreading experiments of the foams with different flow rates and ERs are also performed to understand the effect of foam flow rate and ER on foam spreading property.

2. Experimental section

2.1. Materials

Two kinds of firefighting foams, namely, fluorinated and fluorine-free foams were used in this study. The fluorinated firefighting foam concentrate consists of 0.4% fluorocarbon surfactant, 30% hydrocarbon surfactant, 1% silicone surfactant, 20% ethylene glycol, 5% diethylene glycol monobutyl ether, 0.3% xanthan gum, and 3% carbamide and water. The fluorine-free firefighting foam concentrate consists of 32% hydrocarbon surfactant, 3.3% silicone surfactant, 15% ethylene glycol, 5% diethylene glycol monobutyl ether, 1% lauryl alcohol, 1% isobutanol, 0.3% xanthan gum, and 3% carbamide and water. Foam solutions were prepared by mixing foam concentrates with fresh water according to the volume ratio of 3:97.

The fire extinguishing and burn-back performances of the fluorinated and fluorine-free foams have been previously evaluated based on the methods provided by the Chinese standard GB15308-2006. The detailed information about GB15308-2006 can be found in the reference [24]. The fire extinguishing and burn-back performance of the two foams were compared with those of a commercial AFFF formulation purchased from Yangzhou Jiangya Fire Equipment Co., Ltd. The fire extinguishing times of fluorinated foam, fluorine-free foam, and commercial AFFF are 37, 44, and 52s, respectively, whereas their burn-back times are 753, 801, and 785s, respectively. The fluorinated and fluorine-free foams used in this study were confirmed as highly efficient firefighting foams that can be use used to fight liquid fuel fire.

2.2. Apparatus

Many methods for generating foam have been developed. The common methods of generating firefighting foams are compressed-air foam (CAF) and aspirated foam. Laundess et al. [25] showed that CAF exhibits a more uniform distribution of bubbles than aspirated foam and is more suitable for study on foams in laboratory even though aspirated foam is frequently used at the place of incident. Thus, a foam generation system of CAF was established and used in this study. Notably, the specific value of foam spreading may be not exactly similar to that obtained when other foaming methods are used. However, the conclusion obtained from this study would not be changed by using other foaming methods.

Fig. 1 shows the apparatus for generating foam and recording foam spreading. Foams are generated by mixing the foam solution with compressed air. The foam ER and flow rate can be changed by controlling the ratio of foam solution flow and air flow. The spread of foam over the heptane surface is recorded by a camera. The variation in foam spreading area (FSA) versus time is obtained by using MATLAB image processing.

3. Results and discussion

3.1. Comparison of spread behavior of fluorinated and fluorine-free foams

3.1.1. Foam spread on heptane surface

Fig. 2(A) shows the spreading of fluorinated firefighting foam on the surface of heptane. The process can be roughly divided into three stages. At stage I, the foam spread rapidly as an approximate circle on the heptane surface. A clear aqueous film layer was formed on the heptane surface and was then rapidly covered by a thin foam layer. At stage II, the freshly generated foam from the system began to pile up on the thin foam layer, and the extension of foam layer edge apparently slowed down. The fresh foams were mainly used to increase the