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Flow Characteristics of Foamed Surfactant Solution in the Vertical Pipe for Decommissioning Nuclear Power Plant

Hyoin Lee [a], Eunsik Sung [a], Ji Hwan Jeong [a*]
[a] *School of Mechanical Engineering, Pusan National University, Busan, 46241, Korea*
[*]*Corresponding author: jihwan@pusan.ac.kr*

1. Introduction

Nuclear facilities typically begin to become contaminated with radiation during power generation. As the lifespan of nuclear power plants approaches, interest in the decommissioning of nuclear power plants is focused. During the operation of nuclear power plants, corrosive oxides are formed on the surface of system components. Physical and chemical methods are used to remove corrosive oxides. However, conventional decontamination methods generate a large amount of secondary waste. Therefore, recently, a method using foam has been considered to reduce secondary waste[1].

To remove contaminants, a small amount of liquid surfactant is mixed with a large amount of gas to generate foam. The bulky foam per unit mass is expected to significantly reduce the generation of secondary containments due to radioactivity in the decontamination process of nuclear power plants. However, there is a lack of physical understanding of the hydraulic behavior for applying foam flow in various pipe type. Foam flow is significantly influenced by several parameters such as foam shape, pressure, temperature, flow rate of supplied gas and liquid, foam quality, as so on[2-4]. Therefore, it is important to know the characteristics of the foam flow according to the operating conditions.

2. Methods and Results

2.1 Experimental setup

A schematic of the experimental setup for evaluating the rising foam flow in a vertical pipe is shown in Figure 1.

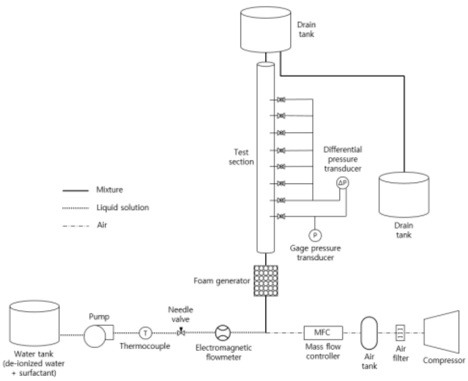

Figure 1. Schematic of the experimental set-up.

Table I. Properties of Elotant Milcoside 100 (EM-100).

Type	**Critical Micelle Concentration (wt%)**	**Surface tension (mN/m)**
Nonionic	0.110	27.97
Foamability (sec)	**Foam stability (%)**	**Ph (1wt% solution)**
86.0	96.0	10.5

The experimental setup consists of a test section assembly, an air supply line, and a liquid solution supply line. The diameter and length of the test section were 2.54 cm and 2 m, respectively. The air supply line included a compressor with combined air filter, an air tank, a regulator, and a mass flow controller (MFC). The liquid solution supply line included a 30 liter chemical tank, chemical pump, thermocouple, flow meter and needle valve to control liquid flow. The liquid surfactant solution and air were connected to a foam generator located at the bottom of the test section. For the experiment, Elotant Milcoside 100 (EM-100), a commercial surfactant, was used. Some of the properties of the surfactant used are presented in Table I.

Experiments were performed at atmospheric pressure and room temperature 25±1 ℃. To study the effect of surfactant concentration on vertical upward foam flow, the surfactant concentration was changed to 0.5 wt%, 1.0 wt%, and 2.0 wt%. The liquid flow rate was changed from 0.02 to 0.05 LPM and the gas flow rate was changed from 0.7 to 1.9 LPM. The ratio of gas phase in a foam flow was represented in terms of foam quality (α). The foam quality was defined as the ratio of volume flow rate of gas to the total volume flow rate as follows:

$$\alpha = Q_g / (Q_g+Q_l) \tag{1}$$

Experiments were performed on a foam quality range of 93% to 99%. If the bubble quality is less than 93%, foam flow was not maintained. Below this foam quality, the foam burst and the foam flow was not maintained. The liquid flowed downward along the test section wall and accumulated at the bottom of the test section. All measurements were made when the foam flow reached at a quasi-steady state. The quasi-steady state was confirmed based on visual observation of the flow behavior and negligible change of pressure readings. A high-speed digital video camera with a resolution of 640 x 480 and frequency of 1260 frames/sec was used to record the foam flow regime inside the test section.

2.2 Observation of foam flow in vertical pipe

The foam flow behavior of the vertical pipe can be classified into wet foam and dry foam according to the quality of the foam. Figure 2 shows the foam flow in a vertical pipe for various air flow rates at a liquid flow rate of 0.05 LPM and a surfactant concentration of 1.0 wt %. The Wet foam occurred at a relatively low foam quality (93.6% in present case). The bubble diameter inside the wet foam was relatively uniform. In the core of the wet foam flow and adjacent to pipe wall, some bubbles broke to form liquid film and flowed downwards. However, at a relatively high foam quality of 98.9%, dry foam with various bubble diameters were generated and even bubble slugs appeared.

The bubble diameter was determined by analyzing images captured with a high-speed video camera. The mean bubble diameter gradually increased with increasing foam quality. At 93.6% foam quality, the mean bubble diameter of the wet foam was in the range of 1.7-1.8 mm, while at 98.9% foam quality, the mean bubble diameter of the dry foam was in the range of 2.8-3.2 mm. The bubble velocity was dominated by the airflow and the velocity increased with higher foam quality.

The effect on the foam flow patterns was investigated by changing the surfactant concentration to 0.5wt%, 1.0wt%, and 2.0wt%. Figure 3 shows the flow patterns of wet and dry foams observed by varying the surfactant concentration. As shown in Figure 3, the flow patterns of wet and dry foams did not change at any surfactant concentration within the experimental range. Through this, it was observed that the flow pattern of the foam was more affected by the flow rate of the supplied liquid and gas rather than the surfactant concentration in the experimental range.

3. Conclusions

In this study, the characteristics of foam flow for a circular vertical tube were investigated through experiments. A foam flow pattern was determined according to the foam quality.

Relatively low quality, wet foams formed at high liquid flow rates and foams formed into uniform spherical structures. Dry foams with polyhedral bubbles have been produced with relatively high foam quality. The dry foam had a non-uniform bubble distribution and slug bubble were present. The surfactant concentration did not significantly affect the flow patterns of the foam flow.

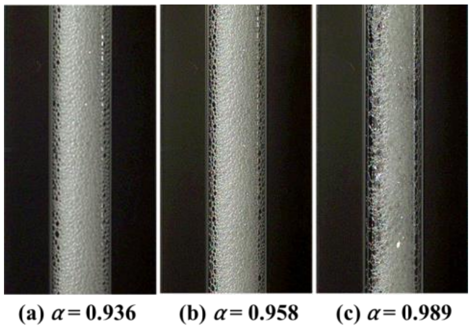

Figure 2. Foam flow with surfactant concentration of 1.0wt% (Q_l = 0.05 LPM)

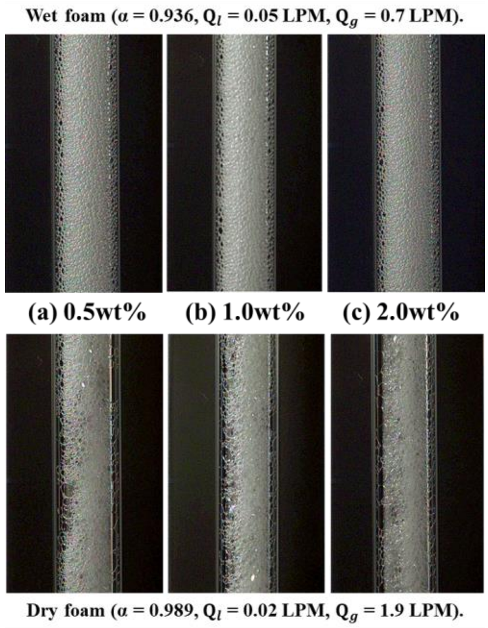

Figure 3. Flow patterns of wet and dry foams at various surfactant concentrations; (a) 0.5 wt%, (b) 1.0 wt%, (c) 2.0 wt%.

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