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Towards Controlling of Surfactant Foam Production in Space

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Abstract

The foam production in space has been studied. The foam was generated by mixing surfactant-sugar solution with air in a porous media. The produced foam on the ground moved linearly, but it moved spirally under the microgravity. To explain the results, the foam production along the gravity was examined in a wide range of experimental conditions. In the foam motion state diagram dependent on air pump and liquid pump flow rates, the area of the spiral motion located at the higher air flow rate side and the area of the linear motion located at the lower air flow rate side. In higher surfactant concentrations the area of the spiral motion expanded by increasing the viscosity of the solution. On the other hand, in lower surfactant concentrations the area of the spiral motion shrank by increasing the viscosity of the solution.

Keyword(s): Foam motion, Linear motion, Spiral motion, Gravity, Viscosity
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1. Introduction

Foam is made of a continuous liquid phase that surrounds and traps the gaseous phase[1)]. Foam is of major importance in daily life, in industry, in fire-fighting and in chemical engineering. In chemical engineering, presence of some amount of surfactant or some impurities which may act as a surfactant in crude oil, can cause unwanted foaming in oil-gas separation[2)]. The overall low toxicity and effectiveness of the foam suppressants makes them valuable tools for bushfire fighting[3)]. Investigation of shampoo and toothpaste foams revealed that the various measurements are useful in characterizing foams. Some measurements such as the viscosity differential are characteristic for individual foams, whilst others like foam volume, do not in themselves characterize the foam[4)]. As of yet no research has been done on the foam motion stability. This research interest attracts much attention from view point of non-equilibrium issues. In this work motion of foam produced from a nozzle has been investigated to determine the relationship between gravitational effect and experimental controlling factors in foam production.

2. Material and Method

2.1 Preparing Solution

The solution was prepared using dish washing liquid (P & G, Joy) which contained 33% of anionic surfactant sodium lauryl sulfate purified white sugar (Mitsuiseito, Johakuto) and distilled water (Yamato, WG201). Different amounts (0.5 g and 3g) of the dish washing liquid and different amounts (1g, 3g, 5g, and 10g) of the sugar was dissolved into 30 mL of water to prepare the solution. After this, in this text “dish washing liquid” is expressed as “surfactant”. The sugar was added to rise the viscosity of the solution and to stabilize the foam.

2.2 Experimental Setup and Procedure

The foam generating apparatus was designed in our laboratory (**Fig. 1(a)**). To produce foam, a hand-made nozzle was used and the nozzle was made of a porous plastic rod with 30 mm length and 5 mm diameter (Suisaku, Plaston) in a plastic tube with 45 mm length and 9 mm inner diameter. The nozzle had two inlets and one outlet. The solution was pumped to the nozzle from the side inlet by a micro-tube pump (EYELA, PM3) and at the same time air was pumped to the nozzle from the other inlet by an air pump (Nichido, S200). The generated foam exited the nozzle from the outlet. Foam generation was recorded by a video camera (JVC, Everio GZ-E265-N), under a 1 W red LED (OptoSupply, OSR5XME1CE). The experiment was always performed in the dark. To ensure the accuracy of the foam generation, the experiment was repeated three times in three successive days under the same conditions. Foam production was observed and recorded under different air pump and liquid pump flow rates. To determine the air pump and liquid pump flow rates, the air pump was calibrated using two flow meters (KOFLOC, 140502-301 and 131211-303) and the liquid pump was calibrated by mass measurement of pumped liquid with an electronic balance. The 30 sec data taking was

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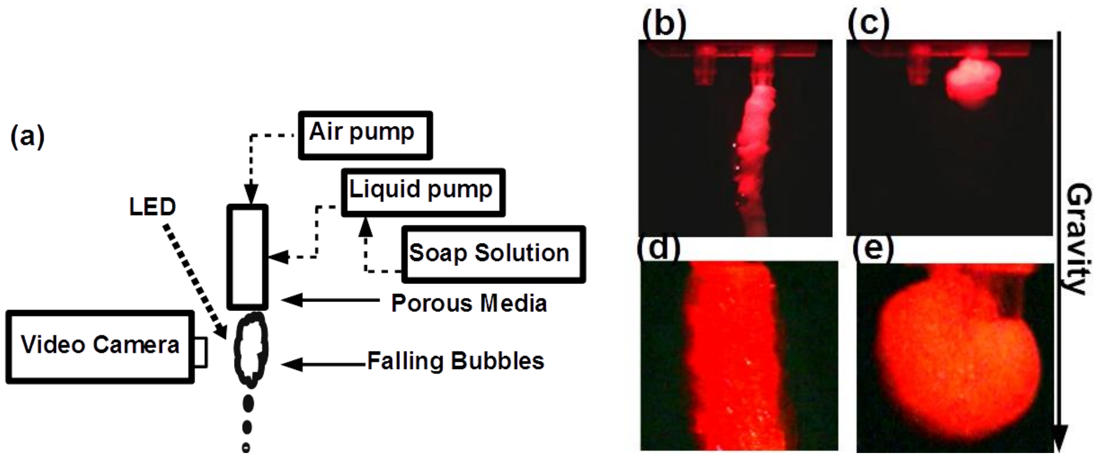

Fig. 1 (a) the foam generating apparatus. The foam was generated by mixing air and soap (surfactant) solution in porous media and was recorded by a video camera under red LED illumination. (b), the linear motion of the produced foam at the airplane under 1 G, (c) the spiral motion of the produced foam under 0 G, at the airplane, (d) the linear motion of the produced foam at the lab under 1 G, (e) the spiral motion of the produced foam at the lab under 1 G.

done for each experiment and the data taking started 6 sec after the foam production`s starting in order to avoid the initial state instabilities.

3. Results and Discussion

3.1 Foam Production under Microgravity

Foam generation under the parabolic flight microgravity was done under the following experimental conditions: the foam production solution contained 3 g of sugar and 3 g of surfactant in 30 mL of water, the air pump flow rate was 0.5 L/min and the liquid pump flow rate was set at 1.37 mL/min. **Fig. 1(b)** shows a typical foam motion in the airplane under 1 G and **Fig. 1(c)** shows a typical foam motion in the airplane under the microgravity. To explain the results, foam production along the gravity was examined in a wide range of experimental conditions in the laboratory.

3.2 Foam Motion Patterns in the Laboratory

Several kinds of foam motions were observed depending on the experimental conditions. The motion patterns were identified by a simple visual inspection. The linear and spiral motions were proposed as fundamental motions. **Figs. 1(d)** and **(e)** show typical snapshots for the linear and spiral motions. The foam production solution contained 1 g of sugar and 1 g of surfactant in 30 mL of water. for **Figs 1 (d)** and 1 **(e)**. The air pump flow rate was 0.8 L/min and the liquid pump flow rate was 0.001 L/min for **Fig 1(d)**, and 2 L/min and 0.00028 L/min for **Fig 1(e)**.

Giving suitable experimental conditions of flow rates and chemical compositions results in linear and spiral motions even on the ground The experimentally observed motions were classified into the six groups based on the proposed fundamental motions:

(1) The foam motion appeared in a linear manner. This motion was named linear motion, L_1 (**Fig. 2 (a)**).
(2) The foam motion appeared twisting, rising up and expanding its width. This is named spiral motion, S (**Fig.2 (b)**).
(3) The produced foam's width changed but it didn't rise up and didn't twist. This linear motion with changing width was named L_2 (**Fig. 2(c)**)..
(4) Sometimes during the 30 second recording of the foam production, the foam moved linearly for certain time then, it moved spirally for certain time. This kind of foam motion was considered a bi-stable motion and was named L_1/S (**Fig. 2 (d)**).
(5) The foam showed S to L_2 motion. This motion was named S/L_2 motion (**Fig. 2(e)**).
(6) The foam exhibited L_2 to L_1 motion. This motion was named L_2/L_1 (**Fig. 2(f)**).

3.3 Higher Surfactant Concentrations

For foam production in laboratory we used solutions containing 1 g of the surfactant in 30 mL of water but the amount of added sugar differed for each used solution. Foam motion was observed under the liquid pump flow rates of 0.00028 L/min, 0.0004 L/min, 0.0006 L/min, 0.0008 L/min and 0.001 L/min and the air pump flow rates of 0.8 L/min, 0.95 L/min, 1.2 L/min, 1.5 L/min and 2 L/min..

First, 1 g of sugar was added to the tested solution giving the solution a viscosity of 1.082 centipoises[5]. This condition is

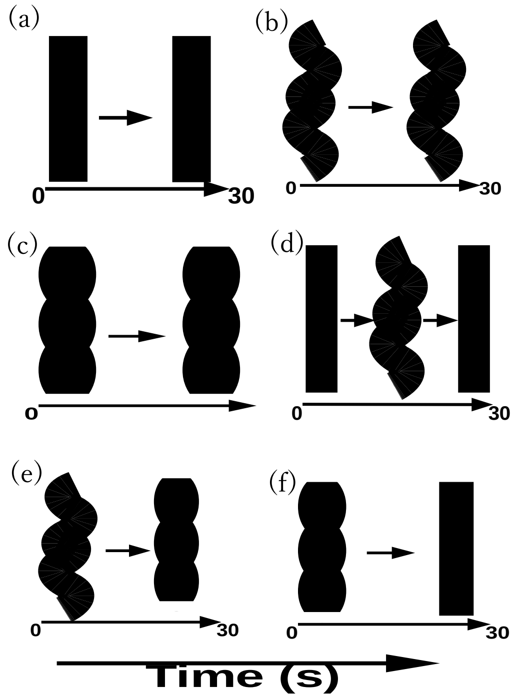

Fig. 2 Foam motion classes: (a) linear, (b) spiral, (c) linear motion with changing width, (d) bi stable or L_1/S motion, (e) S/L_2 motion, L_2/L_1 motion.

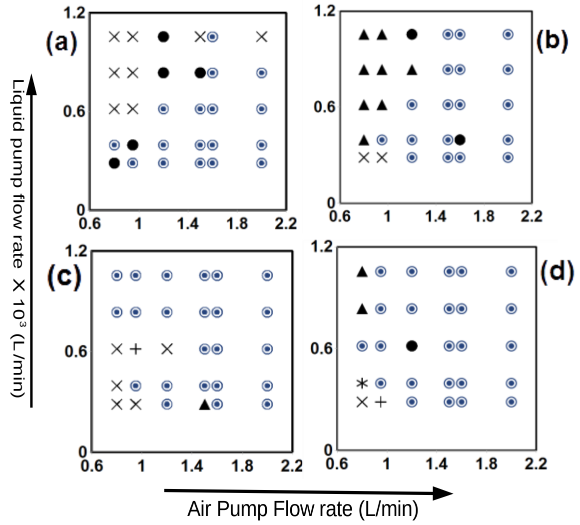

Fig. 3 The foam production state diagrams dependent on liquid and air pump flow rates: surfactant concentration = 1 g/30 mL; Sugar concentration = (a) 1 g /30 mL, (b) 3 g/ 30 mL, (c) 5 g / 30 mL, (d) 10 g/ 30 mL. The triangles show L_1 motion, the targets show the S motion, the circles show B motion, the crosses show the L_2 motion, the stars are for L_1/L_2 motion and the plus sign is for L_2/S motion.

considered the standard condition. In order to know dependence of foam motion on the flow rates, the foam motion state diagram dependent on liquid and air pump flow rates was employed. In the state diagrams, we focused on the area of the spiral motion. In **Fig. 3(a)** the area of the spiral motion of foam expands by increasing the air pump flow rate. However, by increasing the liquid pump flow rate, the foam shows linear motion at lower air pump flow rates. The spiral motion area is located mainly at the right side of the diagram and the linear motion area is located at the left side of the diagram. Second, the amount of sugar in the tested solution was increased to 3 g, giving the solution a viscosity of 1.333 cp[5]. In **Fig. 3(b)** by increasing the air pump flow rate the foam shows spiral motion. However, when the liquid pump flow rate is increased, the foam shows linear motion at lower air pump flow rate. The area of the spiral motion is located at the right side of the diagram. Third, the amount of sugar in the tested solution was increased to 5 g, giving the tested solution a viscosity of 1.16 cp[5]. In **Fig. 3(c)** the area of the spiral motion is located at the right side and the area of the linear motion is located at the left side. By increasing the air pump flow rate the foam shows spiral motion. In lower and medium liquid pump flow rates the foam shows L_2 motion at lower air pump flow rate. Compared to **Fig. 3(a)** and **Fig. 3(b)**, in **Fig. 3 (c)** the area of the spiral motion expanded more and the area of the linear motion shrank. Finally, the amount of sugar in the tested solution was increased to 10 g giving the solution a viscosity of 3.246 cp[5]. In **Fig. 3(d)** by increasing the air pump flow rates the spiral motion area of the foam increases.

The foam shows L_2 motion in the lower and medium liquid pump flow rates, in this diagram the area of the spiral motion increased and it occupied almost all over the diagram and the area of the linear motion almost disappeared.

3.4 Lower Surfactant Concentrations

For foam production in laboratory, the used solutions contained 0.5 g of surfactant in 30 mL of water, but the amount of added sugar differed for each used solutions.

First, 1 g of sugar was added to the tested solution giving the solution a viscosity of 1.082 cp[5]. In **Fig. 4(a)** by increasing the air pump flow rate the spiral motion area of foam increases. However, with any liquid pump flow rate at lower air pump flow rate the foam shows linear motion. Second, the amount of sugar was increased to 3 g giving the solution a viscosity of 1.333 cp[5]. In **Fig. 4(b)** by increasing the air pump flow rate foam shows spiral motion but the area of the spiral motion gets smaller compared to **Fig. 4(a)**. Also the area of the L_2 motion gets wider in this diagram. Third, the amount of sugar in the tested solution was increased to 5 g giving the tested solution a viscosity of 1.16 cp[5]. In **Fig. 4(c)** by increasing the air pump flow rate the spiral motion area of the foam increases and with

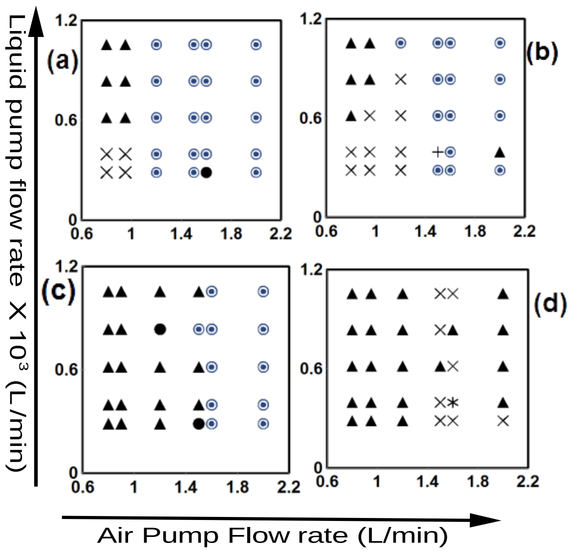

Fig. 4 The foam production state diagrams dependent on liquid and air pump flow rates: surfactant concentration = 0.5 g/30 mL; Sugar concentration = (a) 1 g /30 mL, (b) 3 g/ 30 mL, (c) 5 g / 30 mL, (d) 10 g/ 30 mL. The triangles show L_1 motion, the target symbols show the S motion, the circles show B motion, the crosses show L_2 motion, the stars are for L_1/L_2 motion and the plus sign is for L_2/S motion.

any liquid pump flow rate at lower and medium air pump flow rates the linear motion area of the foam increases. If this diagram is compared to the two previous diagrams (**Figs. 4(a)** and **(b)**), it's clear that by increasing the amount of sugar the spiral motion area in this diagram contracts and the linear motion area gets wider. Fourth, the amount of sugar in the tested solution was increased to 10 g giving the solution a viscosity of 3.246 cp[5]. In **Fig. 4(d)** there are only L_1 and L_2 motions and the area of the spiral motion has completely disappeared.

3.5 Foam Motion Stabilizing Factors

Foam production behavior is a non-equilibrium phenomenon and stably appears given by two kinds of factors competing each other: (A) stabilizing factors for linear motion and (B) stabilizing factors for spiral motion. There is a competition between the two mentioned factors. We tried to classify the experimental controlling factors into the two kinds of stabilizing factors. The linear motion stabilizing factors are gravity, sugar concentration with lower surfactant concentration and liquid pump flow rate. The spiral motion stabilizing factors are sugar concentration with higher surfactant concentration and air flow rate.

4. Conclusion

Two significant points can be drawn from this work.

(1) Some trends appeared in relationship between foam production behaviors and experimental controlling factors.

(2) The relationship between gravitational effect and experimental controlling factors to generate foam was discussed.

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