

Research Article

Use a Controlled Vibration to Mixing and Separation of a Gas Bubbles and a Liquid Under Reduced and Microgravity Conditions

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Abstract

The study of mixing and separation of the gas bubbles and the liquid under reduced gravity conditions may be used in the conceptual design of a spacebased materials processing and a gas-liquid management system. This study may be conducted on a larger samples in microgravity than on Earth because the acoustic or electromagnetic forces used to manipulate of mixing and separation of the gas bubbles and the liquid are not overwhelmed by gravity. Ultimately this research may result in improvements to production methods and materials on Earth. The main purpose of the present research to establish the vibration effect on the mixing and separation of gas bubbles and liquids under reduced gravity conditions. It has been developed a new mathematical techniques to model the behavior of the gas bubbles in the liquid under vibration. These techniques have been used to predict a controlled behavior of the gas bubbles by the controlled vibration under reduced and microgravity conditions. The developed model permitted to establish that the vibration can be used for control of the gas bubbles moving in vertical direction (from top to bottom and, on the contrary, from bottom to top), and determine conditions of the gas bubbles floating, drowning and oscillations (at the equilibrium level) in the liquid under reduced and microgravity conditions. The theoretical conclusions and numerical calculations of the developed model have been proofed on the conducted parabolic aircraft's tests. The tests have proofed the theoretical conclusion that vibration can be used to control of the gas bubbles moving in vertical direction (from top to bottom and, on the contrary, from bottom to top) in the liquid (gas bubbles and liquid separation) under reduced and microgravity conditions. On the other hand, experimental observations made in the tests have proofed theoretical conclusions and numerical calculations that the gas bubbles can be injected (gas bubbles and liquid mixing) into the different liquids under controlled vibration in reduced and microgravity conditions. The microgravity's isotropic phenomenon uniformly distributes the gas bubbles in the different liquids and influenced vibration does not give the bubbles possibility to collect in the liquid's center. The proposed process can be used by the same manner to mixing and separation of solid particles, a dense drops and different liquids under reduced gravity conditions. Therefore, the developed process can be used also to emulsions, suspensions, composite materials processing and gas-liquid management under reduced and microgravity conditions.

Keywords: Gas bubbles and drops control by vibration; Decreased and microgravity; Gas bubble separation in a liquid in microgravity; Gas filled materials; Composite materials processing in microgravity

Introduction

The study of mixing and separation of a gas bubbles and a liquid under reduced gravity conditions may be used in the conceptual design of a space-based materials processing and gas-liquid management system. This study may be conducted on a larger samples in microgravity than on Earth because the acoustic or electromagnetic forces used to manipulate of mixing and separation of the gas bubbles and the liquid are not overwhelmed by gravity. In the present research to mixing and separation of the gas bubbles and the liquid under reduced gravity conditions was used the controlled vibration.

Objectives

The main goal of the present research is to investigate the possibility of mixing and separation of the gas bubbles and liquid (melted material) by using controlled vibration under reduced gravity conditions.

To decision of this goal were determined specific objectives are listed below:

- to establish that the vibration can be used to control of the gas bubbles moving in vertical direction (from top to bottom and, on the contrary, from bottom to top) in the liquid under reduced and microgravity conditions (separation);
- to investigate the sides vibration influence on the small moving of the gas bubbles in horizontal direction from the liquid center to the right or left sides of the vessel contained these bubbles and liquid separation);

 to establish that the vibration can be used for the controlled gas bubbles injection into the center of the melted material under reduced and microgravity conditions (mixing).

Organization of paper

Section 2 describes the theoretical study of the gas bubbles behavior in the liquid under controlled vibration in reduced and microgravity conditions. Section 3 discusses the results of experimental study of the gas bubbles behavior in the liquid under controlled vibration in reduced and microgravity conditions.

Theoretical Study of the Gas Bubbles Behavior in the Liquid under Controlled Vibration in Reduced and Microgravity Conditions

The developed mathematical techniques to model the behavior of the gas bubbles in the liquid under vibration [1-5] have been used to predict a possibility of the controlled gas bubbles moving in reduced

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and microgravity conditions. The model is based on a hypothesis that the vibration influence on the system of the gas bubbles and the liquid generates the interference of two waves: one wave directed from the liquid bottom to the liquid free surface and other, reflected wave, directed from the liquid free surface to the liquid bottom. The interference divides the all-liquid column on the low dense (equilibrium levels) and the high dense places. The gas bubbles are collected at the equilibrium levels, since at these places the liquid density is minimum. As a result, it has been concluded the equation of the gas bubbles moving in the liquid, the equation of the gas bubbles floating, drowning and oscillations at the equilibrium level under vibration in the Earth and reduced gravity conditions (**n** - gravity decreasing and the surface tension force action consideration):

$$\alpha(\alpha N-2) + 12\sigma/\rho\lambda^2 \alpha^2 < 0 \text{ (floating)} \tag{1}$$

$$\alpha(\alpha N-2) + 12\sigma/\rho\lambda^2 \alpha > 0 \ (drowing) \tag{2}$$

$$\alpha(\alpha N-2) + 12\sigma/\rho\lambda^2 \alpha^2 = 0 \text{ (Oscillations)}$$
(3)

Here α is determined by

$$\alpha = \frac{3Nngh}{\alpha^2(\lambda^2 - \omega^2)}$$

and *h* - equilibrium level, ω - vibration frequency, N - vibroaccelaraty, λ - frequency of gas bubbles small oscillations at equilibrium level, *a* - common gas bubbles radius, σ - surface tension, ρ - liquid density, *g* - Earth gravity.

The equilibrium level depends on the vibration frequency (ω) and vibroaccelarity (*N*) as it is shown in 4:

$$h = \frac{P}{ng\rho l \left[\frac{N^2 \lambda^2}{2\nu (1 - 6\sigma / \rho \lambda^2 \alpha^3)(\lambda^2 - \omega^2)} - 1\right]}$$
(4)

where P - on the liquid surface air pressure and v - polytropic constant.

As equation 4 shows, when the vibroaccelaraty is a constant and the vibration frequency is increased, the equilibrium level is decreased (equilibrium level directed from the liquid free surface to the liquid bottom), and, on the contrary, when the vibration frequency is decreased, the equilibrium level is increased. It means, that collected at the equilibrium level gas bubbles can be controlled by the vibration frequency change: when the vibration frequency is increased, the collected gas bubbles "float" and when the vibration frequency is decreased, collected gas bubbles "drown". In reduced and microgravity conditions, when the gravity (n) is decreased or equals zero, and the surface tension force action is considered, as it is seen from equation 4, the equilibrium levels will be higher than in the Earth conditions case. On the Stills 1, 2, 3 and 4 is demonstrated a simulation program, based on equation 4, which shows the control of the gas bubbles group volume **0.7 cubic cm.** (*a*=**0.6 cm.**) by the vibration frequency change under *n* decrease from 1 to 0.03. The program illustrates that under *n* decrease from 1 to 0.03 the gas bubbles group is falling to the liquid bottom at the constant frequency and vibroaccelaraty (Stills 1 and 2) and the controlled gas bubbles group lifting under the frequency increase at the constant *n* equals **0.03** (Stills 3 and 4). Therefore, the developed model has permitted to establish that the vibration can be used to control of the gas bubbles moving in vertical direction (from top to bottom and, on the contrary, from bottom to top) in the liquid under reduced and microgravity conditions.

Experimental Study of the Gas Bubbles Behavior in the Liquid under Controlled Vibration in Reduced and Microgravity Conditions

The theoretical conclusions and numerical calculations of the developed model have been proofed during a parabolic aircraft's tests [6,7].

Apparatus and method to the gas bubbles moving in vertical and horizontal direction in the liquid under reduced and microgravity conditions (separation)

The experimental study of the gas bubbles behavior in the liquid under controlled vibration in reduced and microgravity conditions was conducted on the apparatus illustrated in Chart 1. The apparatus consisted of the vessel, fixed on the vibrostand. Before the experiment, the vessel was completed the gasfilled liquid. When reduced gravity was started, the vibrostand was switching on. In reduced gravity, the bubbles were collected and removed to the upper or to the under part of the vessel by using the increase or the decrease of controlled vibration frequency.

Experiment Tests Results

The tests have shown that the formed gas bubbles group was falling to the bottom under *n* decrease from 1 to 0.03 at the constant frequency and vibroaccelaraty (Figure 1). The experiments have proofed the controlled this gas bubbles group lifting from liquid bottom to the free liquid surface under frequency increase at the constant n equals 0.03 (Figure 2). These results completely coincide with the theoretical conclusions and numerical calculations conducted in Section 2. Both conducted theoretical calculations and parabolic aircraft's tests permitted to indicate the small moving of the gas bubbles in horizontal direction from the liquid center to the right or left sides of the vessel contained the bubbles and liquid under these sides vibration. This factor can be used to prevent the gas bubbles collection in a liquid's center under a liquid-melted material solidification in reduced and microgravity conditions. This process can be used by the same manner to separation of a solid particles, dense drops and different liquids under reduced and microgravity conditions. Therefore, the developed process may be used in the conceptual design of a spacebased gas-solid particles-dense drops- liquid management system in microgravity.

Apparatus and method to the controlled gas bubbles injection into the center of the melted material by using controlled vibration under reduced and microgravity conditions (mixing)

The experiment is conducted on the apparatus illustrated in Chart 2. The apparatus consisted of the vessel with two electrodes at the bottom,



Figure 1: The gas bubbles group 0.7 cubic cm. is falling under *n* decrease from 1 to 0.03.

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Figure 2: The gas bubbles group 0.7 cubic cm. lifting under frequency increase at *n* equals 0.03.

fixed on the vibrostand, and the heater to the material melting in the vessel. Before the experiment, the vessel was heated and completed by water - **20%** and the low temperature melted paraffin - **80%**. When reduced gravity was started, the vibrostand and electrodes were switching on simultaneously. In reduced gravity, formed at the bottom of the vessel electrolysis hydrogen and oxygen bubbles were collected and injected into the center of the melted material by using increase of the controlled vibration frequency. When the gas bubbles reached the center of the melted material, the controlled vibration frequency was changed to **40 Hz**. At this moment, the microgravity's isotropic phenomenon uniform distributed the small gas bubbles in the melted material and influenced vibration did not give the bubbles possibility to collect in a liquid's center under melted material's solidification.

Experiment Test Results

In accordance to equation **4**, the experimental observations made in the parabolic aircraft's tests [6,7] have permitted to establish that the vibration can be used for controlled electrolysis hydrogen and oxygen bubbles injection from the water into the melted material (mixing) under reduced and microgravity conditions (Figures 3 and 4).

Also as in the previous experiment, it was indicated the small moving of the gas bubbles in horizontal direction from the liquid center to the right or left sides of a vessel contained the bubbles and the liquid under these sides vibration. This factor prevented the gas bubbles collection in a liquid's center under a melted material solidification in reduced and microgravity conditions. The developed process can be used by the same manner to the solid particles, dense drops injection into the melted material (mixing) by using the controlled vibration to emulsions, aerosols, composite (or crystal) materials processing under reduced and microgravity conditions.





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Stills 3 and 4: Still demonstrating a simulation program.



Figure 3: The gas bubbles group injection from water into the melted by vibration under reduced gravity conditions.

Conclusions

Both conducted theoretical modeling and parabolic aircraft's tests permitted to establish:

- the gas bubbles moving in vertical direction (from top to bottom and, on the contrary, from bottom to top) in the liquid under reduced and microgravity conditions;
- the small moving of the gas bubbles in the horizontal direction from the liquid center to the right or left sides of the vessel contained these bubbles and liquid ;
- the controlled gas bubbles injection into the center of the melted material under reduced and microgravity conditions.



Figure 4: Gasfilled Materials in Microgravity.

These results have permitted to realize in the parabolic aircraft's tests the main goal of the present research.

The separation and the mixing of the gas bubbles and liquids (melted materials) by using the controlled vibration under reduced gravity conditions

The developed process can be used by the same manner to separation and mixing of a solid particles, dense drops and different

liquids under reduced gravity conditions. Therefore, the process can be used also in the conceptual design of a spacebased gas-solid particlesdense drops-liquid management systems and to emulsions, aerosols, composite (or crystal) materials processing under reduced and microgravity conditions.

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