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The Investigation of the Effect of Reduced and Microgravity Conditions on Single Bubble (Drop) Behavior Fixed on a Solid Surface in a Liquid

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Abstract

The study of the gas bubble (drop) behavior under reduced gravity and microgravity conditions may be used in the conceptual design of aircraft's and space based gas-liquid management system. It is very important to consider the changed gravity and microgravity conditions influence on the gas bubble (drop) behavior fixed on the solid surface, as this influence can be more strongly than other external forces action. The main purpose of the present research to investigate the effect of reduced and microgravity conditions on single bubble (drop) behavior, fixed on the solid surface in the liquid. It has been developed a new mathematical techniques to model the behavior of the gas bubbles (drops), fixed on the solid surface in the liquid under reduced and microgravity conditions. These techniques have been used to modelling of the gas bubbles (drops) profiles behavior and to calculation of their common surface energy change under decreased, increased and microgravity conditions. The model has been used also to estimate conditions of bubbles (drops) tear from and fixation on the solid surface in these conditions. The numerical calculations of the developed model permitted to establish that under decreased gravity the gas bubble (drop) is 'raised' on the solid surface in the liquid and its common surface energy is free. The gas bubbles with volumes (as example) from 1.9-2.2 cm^3 are tore from solid surface and their free energy is transformed to the kinetic energy of bubble jumping from top to the liquid bottom. The gas bubbles with volumes from 2.3-2.8 cm^3 were fixed on the solid surface and their free energy was expensed on the gas bubbles oscillations at the solid surface. Under increased gravity conditions the gas bubble (drop) is 'laid' on the solid surface in the liquid and the common surface energy is not a free and it is expensed on the bubbles (drops) oscillations at the solid surface.

The theoretical conclusions and numerical calculations of the developed model have been proved on the conducted parabolic aircraft's tests. The tests have proved that the developed model can correctly simulate the gas bubbles and drops profiles behavior, their common surface energy change and estimate conditions of their tear from and fixation on the solid surface in reduced and microgravity conditions. The computer techniques of the model can simulate the bubbles and drops behavior under different external forces influences in microgravity conditions (g=0) when they are considered. Besides, using of the developed model permits to control of the gas bubbles and drops behavior in microgravity by controlled changing of surface tension and cohesive angle (apolar reactives action).

Introduction

Bashforth F and Adams J [1] for the purpose of checking the mathematical theory of capillarity published the precise tables, which became the basis of many absolute methods of determining the profiles of the drops of liquids (gas bubbles) and based on them the calculation of surface tension. Padday J [2], using computer calculations, has supplemented these tables. These published tables are applicable only for narrow diapason of drops and gas bubbles and do not have universal nature. In [3] was presented the computer model, which permits to determine the profiles of any drops of liquids (gas bubbles), to calculate their common surface energy and the resultant force, which retains them on the solid surface. The developed model is still novel at the present time, since it does not have any analogues in the modern scientific literature.

The study of the gas bubble (drop) behavior under reduced gravity and microgravity conditions may be used in the conceptual design of an aircraft's and space based gas-liquid management system. It is very important to consider the changed gravity and microgravity conditions influence on the gas bubble (drop) behavior, fixed on the solid surface, as this influence can be more strongly than other external forces action. In this research is presented the investigation of gas bubbles (drops) with positive Bond Number behavior, fixed on the solid surface in a liquid under decreased, increased gravity, microgravity ('self-gravity') conditions.

Objectives

The main goal of the present research is to investigate of the effect of reduced and microgravity conditions on single bubble (drop) behavior, fixed on a solid surface in a liquid.

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

- to establish the gas bubble (drop) profiles change under decreased, increased gravity and microgravity conditions;

- to investigate the gas bubble (drop) common surface energy change under decreased, increased gravity and microgravity conditions;

- to estimate conditions of bubbles (drops) tear from and fixation on the solid surface under decreased, increased gravity and microgravity conditions

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Organization of Paper

Section 2 describes the theoretical study of the gas bubbles (drops) behavior, fixed on a solid surface in a liquid under reduced, increased and microgravity conditions. Section 3 discusses the results of experimental study of the gas bubbles (drops) behavior, fixed on a solid surface in the liquid under reduced, increased and microgravity conditions.

Theoretical Study of the Gas Bubbles (Drops) Behavior Fixed on a Solid Surface in a Liquid under Reduced, Increased and Microgravity Conditions

The developed mathematical model of gas bubble (drop) with positive Bond Numbers behavior, fixed on the solid surface in a liquid under decreased, increased gravity, microgravity ("self gravity") conditions [3] is based on the Laplace condition which is written for common drop (bubble) profile coordinates as:

(1) $1/\rho 1+Sin\ F/X=2+\beta Z$

and boundary's equation:

(2) $2\pi a\sigma Sin\ F+\rho gVol=\pi\sigma a^2\ (1/\rho 1 + Sin\ F/X)$

where ρ -density equals ρ *(liquid)* for gas bubble case and ρ *(drop liquid)*-ρ *(liquid)* for drop case; $\beta=\rho gb^2/\sigma$-Bond Number; $\rho 1$, F, X and Z-common main radius and coordinates of bubble's (drop's) profile; Vol-bubble's (drop's) volume; g-Earth gravity, b-multiply coefficient; π=3. 1416, σ-surface tension and a-bubble's (drop's) contact radius.

The main principles of the model are:

1. The liquid is considered as uncompressed liquid and, thus, the density liquid is a constant. In accordance to the law of mass preservation, in this case, a volume of gas bubble (drop) is a constant.

2. The behavior of gas bubble (drop), fixed on the solid surface in the liquid is considered under surface tension and gravity force action only, other external forces are not present;

3. The cohesive angle F of gas bubble (drop), fixed on the solid state under decreased, increased gravity conditions is a constant (F is determined only by molecules force interaction).

In the model, the changed gravity conditions influence on the gas bubble (drop) profile is determined by the following manner: under change of gravity (g) the Bond Number (β) is changed and, in accordance to this change, it is calculated one of the common coordinates of bubble's (drop's) profile (X or Z), and other coordinate is recalculated under constant bubble's (drop's) volume condition (law of mass preservation): the bubble's (drop's) volume value before and after gravity changing is the same. The bubble's (drop's) profiles and their common surfaces, numerical calculated under decreased, increased and equal zero gravity, permit to prognosticate a common surface energy change of the gas bubbles (drops) and to estimate conditions of bubbles (drops) tear from and fixation on the solid surface in these cases. The bubbles (drops) profiles were calculated by Adams method. The conditions of bubbles (drops) tear from and fixation on the solid surface and common surface energy change were determined by equation (2) and (3):

(3) $dE=\sigma[dS1+dS2\ (Cos\ F)]$

Here, dE-common surface energy change; $dS1$, $dS2$ - bubble's (drop's) side surface square change and bubble's (drop's) contact square change, calculated in accordance to bubble's (drop's) profiles, F-cohesive angle.

Numerical analysis

The n umerical m odelling o f g as b ubble (drop) w ith p ositive Bond Number behavior, fixed on the solid surface in a liquid under decreased, increased gravity, microgravity ('self-gravity') conditions was conducted for example to gas bubbles with volumes of gas bubbles from 1.9-2.8 cm^3. The parameters of gas bubble and liquid were: ρ (water)=1g/cm^3, σ=70 din/cm, cohesive angle F=1.49 radians. Gravity (g) was changed from 980 cm/sec^2 to 9.8 cm/sec^2 (from 1-0.01 g) and from 980 cm/sec^2 to 1760 cm/sec^2 (from 1-1.8 g)

Numerical calculations of the mathematical model have shown that:

1. Under decreased gravity the gas bubble (drop) is 'raised' on the solid state in the liquid and its common surface energy is free. This free energy grows from 260 Erg for 1.9 cm^3 bubbles to 300 Erg for 2.8 cm^3 bubbles. The gas bubbles with volumes from 1.9 to 2.2 cm^3 are tore from solid surface and their free energy is transformed into the kinetic energy of gas bubble jumping from top to the liquid bottom. In the Figure 1 and 2 demonstrated about a simulation program, based on the numerical calculations of the developed model, which shows the gas bubble with volume of 2.05 cm^3 behavior under decreased gravity from 1 g (Still 1) consecutively to 0.8 g (Still 2). 0.2 g (Still 3) and its tear from solid surface and moving down to the liquid bottom under decrease gravity from 0.2 g to g=0 (Still 4) These results will be the same for water's drop with volume 2.05 cm^3 behavior under decreased gravity from 1 g (Figure 3, Still 1) consecutively to 0.8 g (Figure 3, Still 2). 0.2 g (Figure 4, Still 3) and its tear from solid surface and moving up to the top under decrease gravity from 0.2 g to g=0 (Figure 4, Still 4). These results will be the same for water's drop with volume 2.05 cm^3 behavior under decreased gravity from 1 g (Figure 3, Still 1) consecutively to 0.8 g (Figure 3, Still 2) 0.2 g (Figure 4, Still 3) and its tear from solid surface and moving up to the top under decrease gravity from 0.2 g to g=0 (Figure 4, Still 4). The gas bubbles with volumes from 2.3 to 2.8 cm^3 were fixed on the solid surface and their free energy was expensed on the gas bubbles oscillations at the solid surface.

2. Under increased gravity the gas bubble (drop) is 'lain' on the solid surface in the liquid and the common surface energy is not a free and is expensed on the drops (bubbles) oscillations at the solid surface. In the Figure 5, (Stills 5) the gas bubble and water's drop volume of 2.05 cm^3 behavior under increased gravity up to 1.8 g.

3. The developed model can simulate the bubbles and drops behavior under different external forces influences in microgravity conditions (g=0) when they are considered. Besides, using of the developed model permits to control of the gas bubbles and drops behavior in microgravity by controlled changing of surface tension and cohesive angle (apolar reactives action [4]).

Experimental Study of the Gas Bubbles (Drops) Behavior Fixed on a Solid Surface in the Liquid Under Reduced, Increased and Microgravity Conditions

The theoretical conclusions and numerical calculations of the developed model gas bubble (drop) with positive 'Bond Number' behavior on the solid surface in a liquid under decreased (increased) gravity; microgravity ('self-gravity') conditions have been proved during a parabolic aircraft's tests [5]. The experiments were conducted to gas bubbles with volumes of gas bubbles from 1.9-2.8 cm^3 with

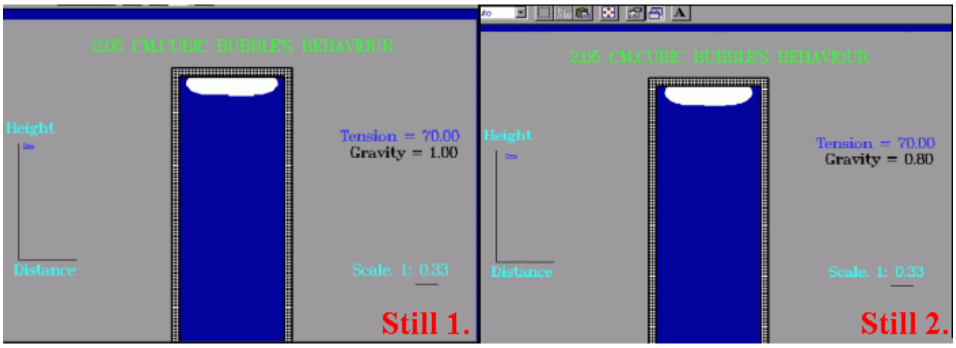

Figure 1: Gas bubble with volume of 2.05 cm³ behavior under decreased gravity from 1 g (Still 1) consecutively to 0.8 g (Still 2).

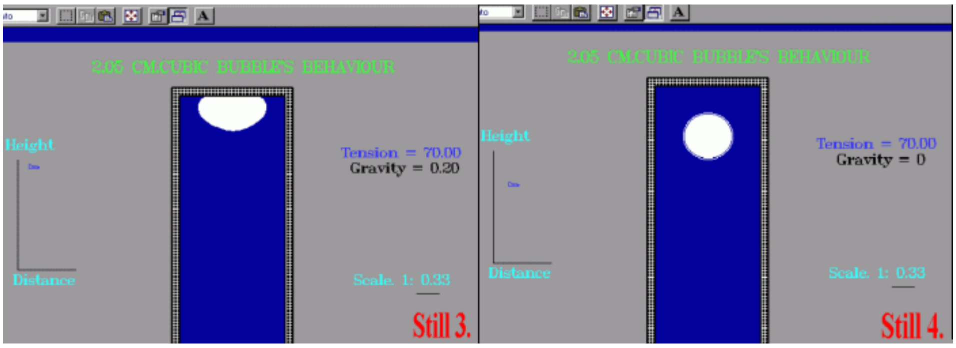

Figure 2: Gas bubble with volume of 2.05 cm³ behavior under decreased gravity from 0.2 g (Still 3) and its tear from solid surface and moving down to the liquid bottom under decrease gravity from 0.2 g to g=0 (Still 4).

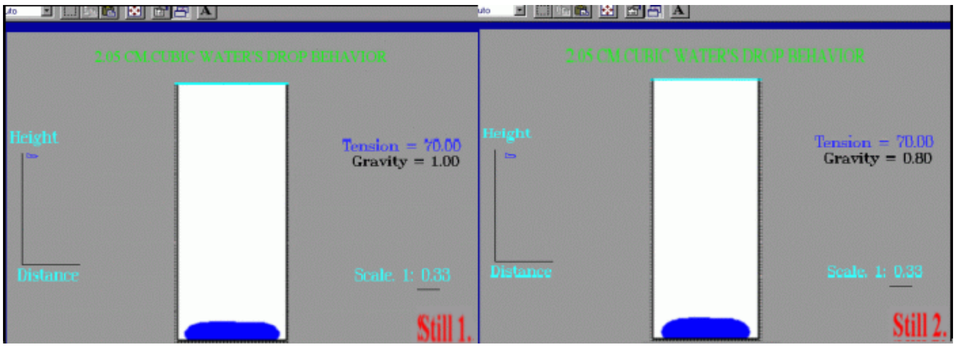

Figure 3: Water's drop with volume 2.05 cm³ behavior under decreased gravity from 1 g (Still 1) consecutively to 0.8 g (Still 2).

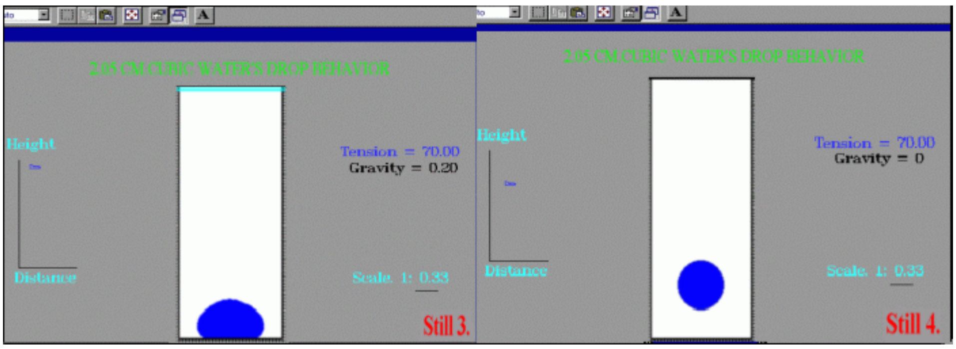

Figure 4: Water's drop with volume 2.05 cm³ behavior under decreased gravity from 0.2 g (Still 3) and its tear from solid bottom and moving up to the liquid surface under decrease gravity from 0.2 g to g=0 (Still 4).

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parameters of gas bubble and liquid: ρ (water)=1g/cm^3, σ=70 din/cm, cohesive angle *F*=1.49 radians. Gravity (*g*) was changed from 980 cm/sec^2 to 9.8 cm/sec^2 (from 1 to 0.01g) and from 980 cm/sec^2 to 1760 cm/sec^2 (1-1.8 g).

The tests have shown that under decreased gravity the gas bubble (drop) is 'raised' on the solid state in the liquid and its common surface energy is free. The gas bubbles with volumes from 1.9-2.2 cm^3 are tore from solid surface and their free energy is transformed into the kinetic energy of gas bubble jumping from top to the liquid bottom. On the Figures 6 and 7 are shown the gas bubbles with volume of 2.05 cm^3 (1) and 2.8 cm^3 (2) behavior under decrease gravity from 1 g-0.2 g (Figure 6), and tear 2.05 cm^3 gas bubble from solid surface and moving down to the liquid bottom under decrease gravity from 0.2 g to g=0 (1, Figure 7). The gas bubbles with volumes from 2.3 to 2.8 cm^3 were fixed on the solid surface. On the (2), Figure 7 is shown the 2.8 cm^3 gas bubble fixation on the solid surface under decrease gravity from 0.2 g to g=0. The tests have shown that under increased gravity the gas bubble (drop) is 'laid' on the solid surface in the liquid and the common surface energy is not a free and is expensed on the drops (bubbles) oscillations at the solid surface. These results completely coincide with the theoretical conclusions and numerical calculations conducted in Section 2.

Conclusions

The mathematical model of gas bubble (drop) behavior, fixed on the solid surface in a liquid under decreased, increased gravity, microgravity ('self-gravity') conditions, proved on a conducted parabolic aircraft's tests, permits to model the gas bubble's and drop's profiles, to prognosticate their common surface energy change and to estimate conditions of their tear from and fixation on the solid surface in these cases. The computer techniques of the model can be used to simulating of gas bubbles and drops behavior under different external forces influences in microgravity (g=0) conditions when *g* is changed on the volume external forces acceleration. Besides, using of the developed model permits to control of the gas bubbles and drops behavior in microgravity by controlled changing of surface tension and cohesive angle (apolar reagents action [4]).

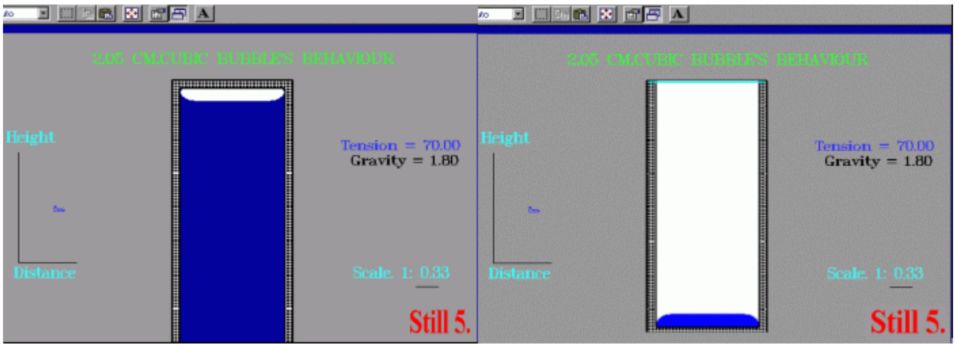

Figure 5: Gas bubble and water's drop volume of 2.05 cm³ behavior under increased gravity up to 1.8 g.

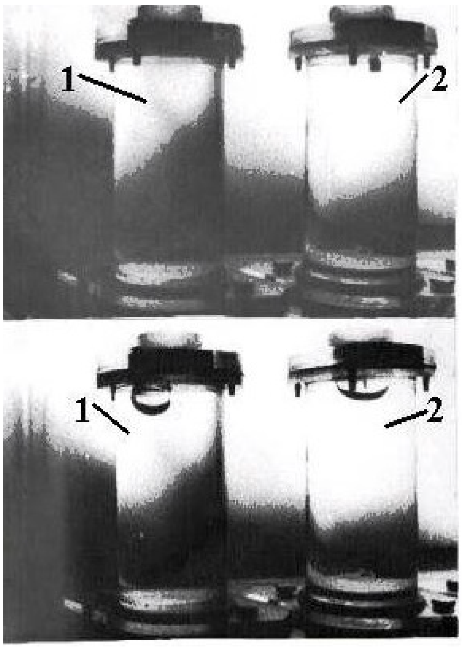

Figure 6: Gas bubbles with volume of 2.05 cm³ (1) and 2.8 cm³ (2) behavior under decrease gravity from 1 g to 0.2 g.

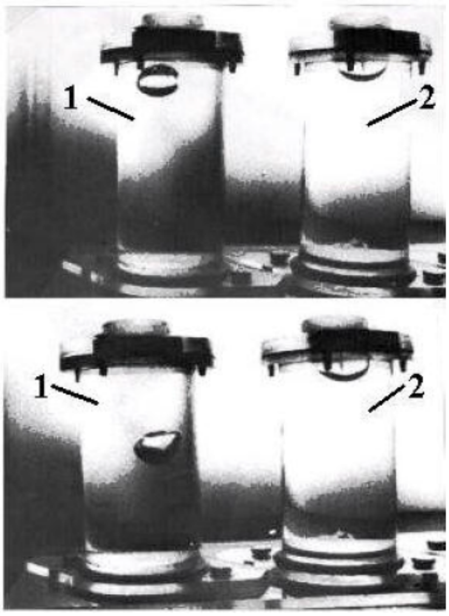

Figure7: Tear 2.05 cm³ gas bubble from solid surface and moving down to the liquid bottom under decrease gravity from 0.2 g to g=0 (1). 2 .8 cm³ gas bubble fixation on the solid surface under decrease gravity from 0.2 g to g=0 (2).

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