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THERMAL EFFECT ON BUBBLE RISE - AN EXPERIMENTAL STUDY

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Abstract

This paper presents the findings of an experimental study on the effect of temperature gradient on bubble rise velocity in water. At the bottom of the chamber holding water, a bubble (equivalent diameter, req 1 mm) is created and rises through it. At a height of 60 cm from the chamber's bottom, a high-speed camera (1000 fps, Kodak, Model 1000 HRC) is mounted with a 90 mm Macro lens. It is connected to a computer. For image capture and processing, the commercial tools Sigma Scan Pro 5.0 and Adobe Photoshop are used. The chamber can be heated with infrared light, resulting in a constant temperature gradient of 1.1^{0}C/cm between 30 and 40 cm above the needle in the water. Bubble rise characteristics, such as bubble size and rise velocity, are determined both in the presence and absence of a temperature gradient. The current study clearly demonstrates that this gradient causes an additional increase in terminal rise velocity.

Keywords: Bubble, Temperature Gradient, Rise Velocity, Water

I. Introduction

In many industrial operations, air bubbles rising in water can be seen. Bubble columns, loop reactors, agitated stirred reactors, flotation, and fermentation reactors are all examples of chemical engineering [I-II],[V-VIII],[X],[XIII], XVI-XVII]. Detail knowledge of bubble sizes and shapes, rise velocities, internal circulation, swarm behavior, bubble-produced turbulence, and other factors are required for the design of efficient two-phase reactors. As a result, knowing the characteristics of bubbles will aid in comprehending the many hydrodynamic events that occur in the industrial bubble column.

Bubble Shape: Surface tension minimizes surface area for a given volume, hence a bubble at rest usually takes on a spherical shape. As illustrated in Fig 1 [IX], bubbles in a free rise in infinite media by gravity are classified into three groups depending on their shape:

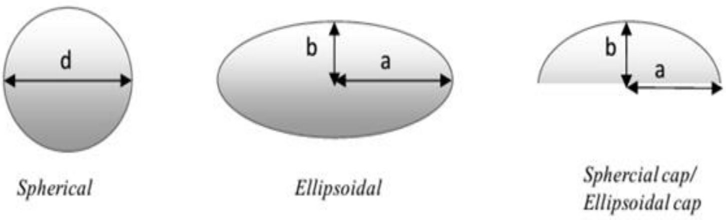

Fig 1. Types of bubbles based on their shape

The rise velocity, form, and motion behaviour of a rising bubble are all factors to consider. All three characteristics are linked to the system's physical properties, particularly the liquid phase's viscosity, flow, and interfacial bubbles in particular.

As a result, knowing the characteristics of bubbles will aid in comprehending the many hydrodynamic events that occur in the industrial bubble column. Grace et al. [XI], [XII] constructed a graphical association [Fig 2] in terms of the Eötvös number, Eö; Morton number, M; and Reynolds number, Re, for bubbles rising freely in infinite media. This map is useful for estimating the forms of rising bubbles in Newtonian liquids based on visual observations, but it cannot provide flawless forecasts. As a result, an experiment on the rise of bubbles in a stagnant fluid could be a good place to start.

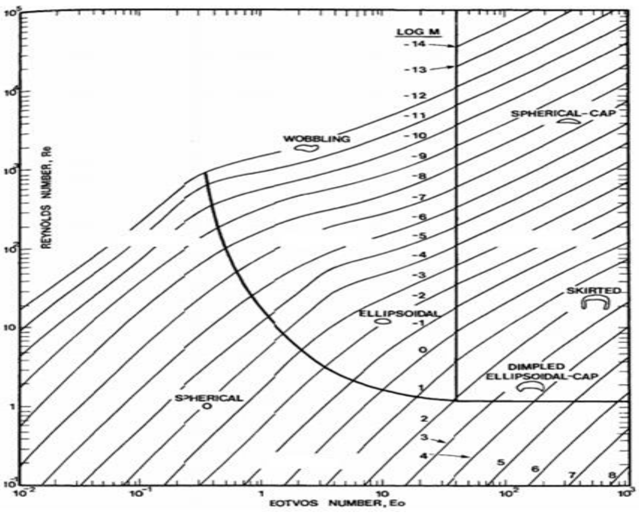

Fig 2. Bubble shape regimes

Experimental experiments were carried out in stagnant water in a vertical rectangular chamber in the current study. At the bottom of the chamber, bubbles are produced. Their size and rise velocity are analyzed using video-image analysis in temperature gradient as well as in the absence of it in water.

II. Experimental Setup

The experimental setup is shown in Fig.3. Experiments are conducted in an open-top polycarbonate chamber with dimensions of 34 cm 28 cm 200 cm (length, width, and height) [III], [IV], [XV] which is large enough to eliminate the impacts of the walls. The chamber is filled with water. Bubbles are generated sequentially from the compressed air mains through an aperture at the bottom of the column's center. Flow meters control the size of the bubbles and their frequency of formation. At a height of 60 cm from the chamber's bottom, a high-speed camera (1000 fps, Kodak, Model 1000 HRC) is mounted with a 90 mm Macro lens. It is linked with a PC. For image capture and processing, the commercial tools SigmaScan Pro 5.0 and Adobe Photoshop are used. Infrared light can be used to heat the water in the chamber to get a constant temperature gradient (1.1^{0}C/cm) between 30 and 40 cm above the needle in the water. Using video-image analysis, we investigate the form and rise velocity of bubbles rising through stagnant water in the presence of a temperature gradient as well as in the lack of one.

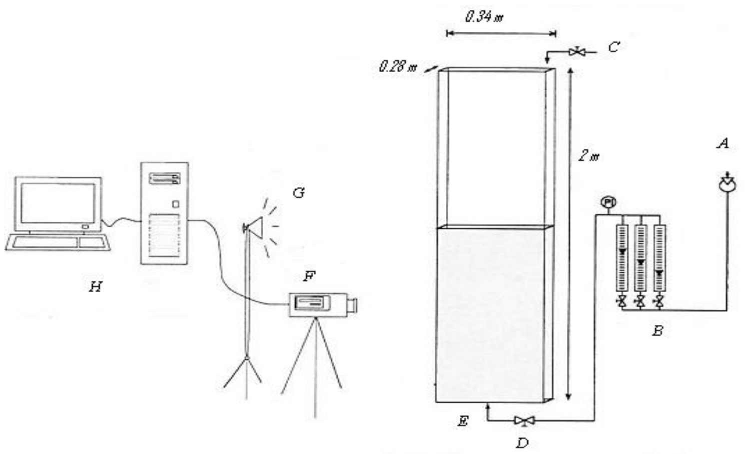

Fig 3. Experimental Apparatus

A: Compressed air, B: Rotameters, C: Water supply, D: Valve, E: Orifice injection, F: Video camera, G: Halogen lamp, H: Image processing PC

III. Results and Discussion

Bubble Shape and Diameter

The bubble shape is determined by analyzing the still images acquired by the camera on a PC using the commercial software Sigma Scan Pro 5.0 and Adobe Photoshop (height and width).

As illustrated in Fig 4 [XIV], the bubble equivalent diameter deq is determined as follows:

$$d_{eq} = (d_h \times d_w)^{1/3}$$

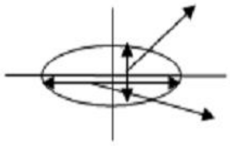

Fig 4. Major and minor axes of bubble

The equivalent diameters of the bubbles are measured and found to be very close to 1 mm.

Bubble Velocity

The concept of a rising bubble's final velocity is hazy to some extent since the forces acting on it (Archimedian force, drag, lift, and virtual mass forces) never balance out. As a result, the bubble motion is always not steady. However, if the bubble motion is examined in an infinite fluid media, we can speak about a specific average "rising velocity" after a certain period, whose change in time can be ignored. The averaging is done here over a significantly shorter time frame than the time since the bubble motion began. As a result, we refer to a time-averaged ("smoothed") bubble rise velocity as terminal velocity.

The bubble's velocity is calculated using video footage of the bubble. When the bubble is released, the video camera moves up with it, recording images as the bubble climbs via several markers spaced 15 cm apart from the bottom to a height of 1.8 meters. Velocity is measured for a 15 cm distance and is averaged for the entire 0.75-meter travel from 1.05 to 1.80 m along the scale.

Effects of Temperature Gradients

The effect of the temperature gradient on the terminal increase velocity be visualized by comparing the data in the absence of a temperature gradient. The horizontal solid line in Figure 5 indicates the rise velocity of a bubble in water held at a uniform temperature of 28°C. The horizontal dotted line indicates the temperature. The dotted curve represents the rise velocity of a bubble in a temperature gradient of 1.1˚C/cm. The region of 28˚C is reached at about 37.3 cm above the capillary. The terminal rising velocity has already been reached in this location. After reaching a point 32 cm above the release point, where the temperature is only about 22.2˚C, the gradient's velocity increases just marginally. As a result, all-temperature gradient measurements were taken for a bubble that had already attained its 'final' velocity of 5cm lower, indicating that the final state of bubble shape, route, and wake had already been achieved.

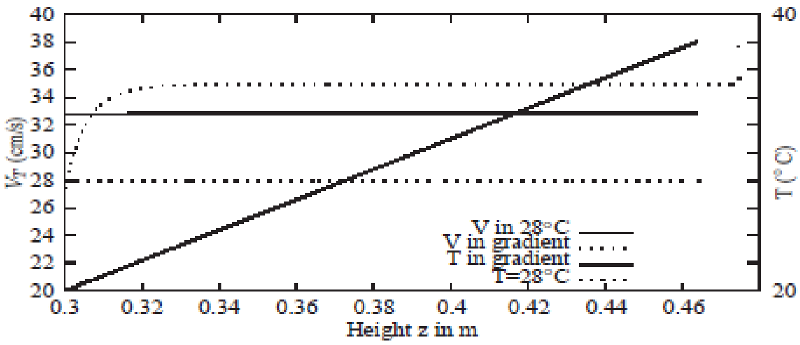

Fig 5. The influence of a temperature gradient on a bubble's rise velocity (req = 1.0 mm), accounts for Levich drag and temperature-dependent water viscosity. The bubble in a temperature gradient has a larger velocity at 28°C than in a uniform temperature of 28°C, as can be seen.

IV. Conclusion

We present a video-image analysis of the shape and rise velocity of bubbles in stagnant water in the presence and absence of a temperature gradient in this experimental study. The images were captured and processed using a high-speed camera (1000 fps, Kodak, Model 1000 HRC) and a 90 mm Macro lens, as well as commercial software Sigma Scan Pro 5.0 and Adobe Photoshop. At the bottom of the water-holding chamber, bubbles are produced. Bubble rise properties, such as bubble form and rise velocity, are determined using this setup. The current study clearly demonstrates that this gradient causes an additional increase in terminal rise velocity.

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