Theoretical Investigation on Particle Brownian Motion on Micro-air-bubble Characteristic in H₂O Solvent

Irana Eka Putri¹ and Grace Gita Redhyka

Technical Implementation Unit of Instrumentation Development, Indonesia Institute of Sciences, Bandung, 40135, Indonesia

E-mail: iran003@lipi.go.id

Abstract. Micro-air-bubble has a high potential contribution in waste water, farming, and fishery treatment. In this research, submicron scale of micro-air-bubble was observed to determine its stability in H₂O solvent. By increasing its stability, it can be used for several applications, such as bio-preservative for medical and food transport. The micro-air-bubble was assumed in spherical shape that in incompressible gas boundary condition. So, the random motion of particle (Brownian motion) can be solved by using Stokes-Einstein approximation. But, Hadamard and Rybczynski equation is promoted to solve for larger bubble (micro scale). While, the effect of physical properties (e.g. diffusion coefficient, density, and flow rate) have taken important role in its characteristics in water. According to the theoretical investigation that have been done, decreasing of bubble velocity indicates that the bubble dissolves away or shrinking to the surface. To obtain longevity bubble in pure water medium, it is recomended to apply some surfactant molecules (e.g. NaCl) in micro-air-bubble medium.

1. Introduction

Several researches have addressed benefits of micro-air-bubble in some area, such as in fishery, waste treatment, agricultural industry, and mining [1-3]. Oh et. al. had been proven that micro-gas bubble can be found in gasoline fuel to improve engine efficiency and emission performance [4]. In other hand, it can also be found in solid-liquid phase, such as Pt-nanoelectrode, graphite and polymer surface [5-7]. Physically, micro-air-bubble has diameter size about 4 to 15 μm at constant periodic rate [8,9]. It is segmented into three phases, e.g., gas, aqueous liquid, and shell phase. Actually, measured size of micro-air-bubble is equal to hydrodynamic size of particle (main particle and Debye length constant).

According to fluid dynamics properties, micro-air-bubble has a small rising speed in high viscosity. Similarly, according to Stokes’s law, a smaller bubble also has a smaller rising speed and so tends the bubble stay longer in some specific fluid [10]. Its longevity can be increase over a few months by the addition of surfactant molecules (salt, hydrocarbons, or hydrochloride acid) that decrease the pressure difference and lower the surface tension between inner bubble and surroundings in fluid medium [11-13]. High interaction of van der Waals bonding and longevity in several solvent are specific characteristics of micro-air-bubble that has been observed [14,15]. A smaller micro-air-bubble than 5 μm in diameters does not rise and its physical stability does not dissolve away [16].

Micro-air-bubble may maintain in constant small size at low and medium gas flow rates, but increases dramatically at high gas flow rates. The bubble is much smaller in salt water medium and its radius less than 0.01 cm because the varying drag forces may be applied. So, the bubble density may also take an effect of its behavior [17]. According to Hadamard and Rybczynski equation, first
solution of a slowly moving sphere micro-air-bubble through an ambient fluid is determined by the different viscosity and density of inside and outside bubble [18].

In this letter we consider micro-air-bubble in perfect spherical shape assumption is taken to analyze its characteristics in pure water medium. So, the effects of some parameters (bubble density, water flow rate, and capillarity dimensional) are included to determine its characteristics.

2. Theoretical and experimental model

2.1. Single-bubble Formation
The single Nano-gas-bubble has the chemical balance reaction according to yield hydrogen gas that described in the following equation,

\[ 2H^+(aq) + 2e^- \leftrightarrow H_2(g) \]  

According to the reaction, the generation of micro-air-bubble is done through electrolysis process, which is combining process of hydrogen ions (H\(^+\)) with electrons (e\(^-\)) through in H\(_2\)O interface.

\[ O_3(g) + H_2O(l) \leftrightarrow OH_{(aq)} + OH^2_{(aq)} \]  

Single bubble growth occurs when the bubble passes the maximum pressure and it grows quickly, then separates from its capillarity and the new bubble is formed. When the capillarity is immersed into \( h \) (depth of liquid medium), so the hydrostatic pressure for bubble maximum pressure (\( P_{\text{max}} \)) can be determine by using the following equation.

\[ P_{\text{max}} = 2\gamma / r + \Delta \rho gh \]  

The effect of surface tension (\( \gamma \)) and internal hydrostatic pressure of liquid (\( \Delta \rho gh \)) are included to determine the hydrostatic pressure of bubble. Hydrostatic pressure regulation allows for the quantitative control of growth, shrinkage, or the obtained bubble size stability [19]. Another characteristics like bubble size and rise velocity distribution are depended on its value.

2.2. Velocity and Displacement of Bubble

The bubble motion near a surface is greatly influenced by Brownian motion between the bubble and the surface, as well as Van der Waals force. When a particle or bubble moves in certain medium, it is not attached to a surface, its movement can be determined by using electrostatic and Van der Waals force [20,21]. The Brownian motion theory is about the random motion of very small particle that immerse in a fluid medium. Rise of temperature surrounds the particle can affect the Brownian motion.

In modern theoretical of Brownian motion based on kinetic theory that has been developed by George G Stokes can determine the spherical small particle size by using the particle motion (velocity) that can be affected by viscosity and density of fluid medium. A relation between \( D \) and atomic properties of matter are found and can be expressed by using Stokes’s law equation. For larger bubble (\( > 200 \mu m \)) is appropriate to use Hadamard and Rybczynski equation (see equation (4)) by including the effect of viscosity (\( \eta \)) and density (\( \rho \)) of fluid medium and bubble [22,23].

\[ v_b = \frac{2}{3} \frac{d^2 g (\rho_b - \rho_f)}{\eta_f} \left[ \frac{\eta_f + \eta_b}{2\eta_f + 3\eta_b} \right] \]  

Where \( d, g, \rho_b, \rho_f, \eta_b \) and \( \eta_f \) are bubble diameter (\( \mu m \)), gravity acceleration (m/s\(^2\)), bubble density, fluid medium density, viscosity of bubble, and viscosity of fluid medium, respectively. The velocity of bubble movement is calculated by depending on the rise velocity when viscosity of fluid is taken place and surface tension effects are significant in the system.

3. Result and discussion

In this part, the effect of capillarity on bubble quantities was studied in theoretical predictions. The results are shown in figure 1. It indicates that a wider capillarity can increase the bubble quantities rapidly. A bubble generated system is built by using single capillarity (pipe) with length \( l \) and diameter
outlet $d_p$ are about 29.3 mm and 1 to 8 mm, respectively. According to [5], bubble diameter $d$ under 5 μm did not rise to the surface and it could maintain floating in water medium. So, variations of bubble diameter (1 to 4 μm) were determined. The bubble quantities $q$ that can be generated from single capillarity are about,

$$q(d_p) = \frac{2}{3} Q^2 \rho_g d^3 \left[1 - \frac{1}{24 \pi d_p^2 d} \right]$$

(5)

Where $Q$ is the flow rate of water (ml/s) and $\rho_g$ is the density of bubble (0.00143 gram/cm$^3$). The nucleation of a new bubble can determine the bubble’s lifetime [24].

Figure 1. The effect of pipe (capillarity) diameter $d_p$ on bubble quantities $q$ with single-bubble diameter $d$ difference.

Figure 2 expresses the theoretical prediction of the bubble growth rate $R$ (figure 2a) and the bubble velocity (figure 2b) from $t_0$ to $t_n$ according its Brownian movement. At the initial time, the bubble moves rapidly, it indicates that the bubble does not dissolve. In the opposite, the bubble dissolves away when it moves in slow velocity. The decreasing of bubble velocity shows that its movement reaches saturated point, it means the bubble is dissolved in water or shrinking. The terminal velocity was particularly sensitive to the presence of contaminant molecules [25].
4. Conclusions

The theoretical study of bubble movement in pure water medium has been formulated by using some parameters. The bubble quantities are increase above 5000 bubbles per second when bubble particle is about 1 μm. While, its size grows rapidly above 5 μm in around 90 seconds, then the velocity is decrease slowly.
5. References

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