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Bubble Coalescence on Photobioreactor Bubble Columns by Using Horizontal Baffle for Microalgae

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Abstract: Photobioreactors are used to increase microalgae productivity. As an improvement of the photobioreactor, the horizontal baffle is used to increase mixing capabilities. The phenomenon that occured using a horizontal baffle was bubble coalescence. A phenomenon of joining some bubble that affects mass transfer capabilities. This study aimed to reveal the effect of the horizontal baffle on the bubble size distribution and bubble behavior but only quantitatively. Bubbles distribution data was taken using a high-speed camera on three different vertical position processed by using ImageJ. Based on the result of the study, bubble coalescence occurred because of velocity difference, and the bubble was trapped, which led the bubble to coalescence. The higher position of the data retrieval shows that the more bubble with larger diameter because of the coalescence that occurs in the H/0.25, H/0.5, and below h/0.75. The bubble size 200-400 μm seems to be constant because of its not carried away by the wake of the larger bubble.

Keywords: Photobioreactor, Horizontal Baffle, Bubble Coalescence, Microalgae

1. Introduction and background

Indonesia has an extensive energy resource from fossil fuels. However, at the same time, a crisis will occur when resources run out caused by increasing energy consumption. In addition, Indonesia also has a high potential for renewable energy. Therefore, Indonesia is developing and expanding the production capacity and absorption of renewable energy to support energy independence and security programs. Aside from Indonesia, Japan is also focusing on developing renewable energy. Developing a self-sufficient energy system to produce and supply energy to support its economic development remains a strategic concern for Japan[1)]. Achieving energy security has become a vital challenge for Japan over time. Energy diversification, renewable energy, and energy saving technologies are significant priorities for energy security[2)]. Renewable energy sources must be explored to sustain overall advancements and minimize energy dependency on others [3,4)]. Microalgae biomass can be potentially used as biofuel feedstock with an effective photobioreactor and growth media[4,5,6,7)]. Microalgae are micro-organisms that grow 100 times faster and can double biomass in less than a day than land plants[8)]. As biofuel feedstock, microalgae have benefits in terms of decreased land use and do not compete directly with food as with crop-based fuels[9,10)].

A photobioreactor is a system for producing microorganism which needs photosynthetic for their productivity. Photobioreactor technology is can increase microalgae productivity[9,11,2,13)]. There are some principal factors in Photobioreactor design such as light, mixing, mass transfer, temperature, and pH [9,14,15,16,17)]. Good mixing and better mass transfer are presented in rectangular photobioreactor [10,18)]. The addition of static mixers or baffles aims to increase the capability of mixing. Structural optimization with horizontal baffle might enhance mass transfer and gas residence time, so thus influencing algal productivity and economically [19,20)]. According to Hafidho, in 2020, photobioreactors with horizontal baffles showed better simulation results in terms of microalgae growth than photobioreactors without baffles in greater gas flow rates in the form of mixing performance[21)].

In this study, using a triple segmental baffle from an adaptation of the working baffle in the heat exchanger was expected to increase mixing capabilities and microalgae productivity. The phenomenon that occured by using the horizontal baffle in hydrodynamics of the multiphase system was bubble coalescence. By understanding the coalescence of bubbles, the behavior and response of the system could be understood [18,22,23]. Bubble coalescence is generally divided into three steps. There are bubble collision, drainage of liquid film, and film rupture. Bubble distribution should be estimated to predict the gas-liquid contact area that affects the mass transfer. The bubbles generated in the system undergo bouncing and coalescence due to contact with each other as they rise and collision. Because of the coalescence of the same diameter bubble, bubble surface area decreases 20% approximately, having a negative impact on the mass transfer[24]. The indication of the bubble coalescence can be understood by investigating the increase of the Sauter mean diameter and the evolution of the bubble distribution [21,25,26,27]. This study aimed to reveal the effect of the horizontal baffle on the bubble size distribution and bubble behavior but only in a quantitative manner.

2. Method and experimental setup

The rectangular photobioreactor with a horizontal baffle was used in this study. The total volume of the photobioreactor is 22 L, with the height, length, and width being 400 mm x 400 mm x 150 mm. The Photobioreactor is filled with 20 L, giving the top clearance 30 mm. The distance between baffle in the vertical direction is 30 mm. Acrylic was used as the material in a photobioreactor to enable the light to enter for photosynthesis and observation. Aeration used a 0.5 μm diameter sparger (SHENZEN HENGKO TECHNOLOGY) through the air filter (ADVANTEC ®) that placed the bottom of the bubble growing region, which was controlled by the flowmeter (Viebrock) at the bottom. These experiments used tap water instead of pure algae containing water or water because it was efficient. For the minimum 1.5 mm bubble size, the impurities in fresh tap water can be negligible on the dynamic bubble size [28].

The experiments were performed using two techniques, and there are video imaging to observe bubble. In the present study, the airflow rate was set at 1 LPM. A high-speed video camera, Phantom Mito M310, was used to capture the bubble phenomena. All measurements were taken at 3200 FPS with the resolution 1280 × 800 at the same distance in every experiment. The camera was combined with the NIKON Lens with a focal length and aperture of 85 and 2.5 mm to get a wide measurement plane and has a narrow depth of field [29]. The technique that used in video imaging was shadowgraph or backlighted imaging. A light diffuser was used to get a homogenous illumination plane from the 50W halogen lamp as the light source. The calibration of the camera found that 1 mm in-camera represents 10 μm. The image was taken in 3 different vertical distances H/0.25, H/0.5, and H/0.75.

The image split to every frame was using "MATLAB" then using "ImageJ," an open-source software application in java to process the image and analyze the bubble size measurement. The image was set into greyscale color, and then the bandpass filtering feature was used to remove the blurred image. After removing the blurred image, the image was converted into binary format to make it contrast and to reduce noise that will interfere with the accuracy [30]. To get the accurate size of the single bubble, the ratio of circularity was set 0.6-1.0 to separate the single bubble from the overlapping bubble. The bubble size measurement use Sauter mean diameter equation that represents the average bubble size [25,31].

$$d_{BS} = \frac{\Sigma n_i d_i^3}{\Sigma n_i d_i^2} \qquad (1)$$

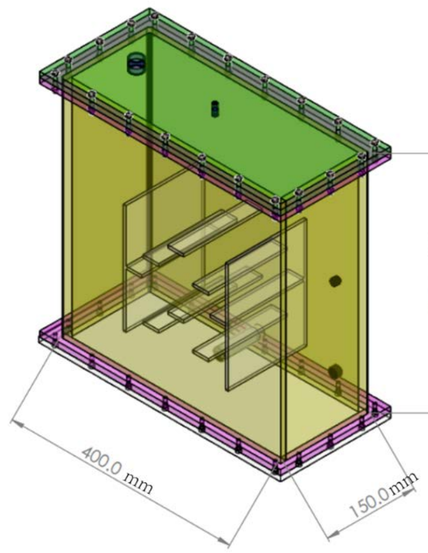

Fig. 1: Photobioreactor

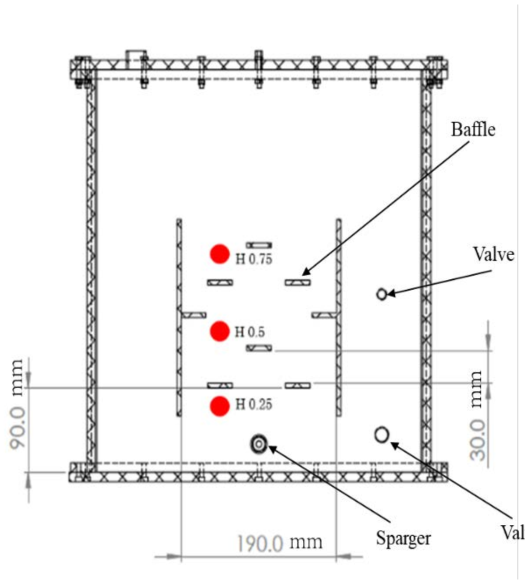

Fig. 2: Measurement Points

3. Results and Discussion

The results describe the behavior of the main object. The image that has been processed shows bubble size distribution in every position. To obtain reliable data, over 2000 bubble diameters were measured. To understand the bubble density difference, the amount of bubbles has been plotted with the size of the bubble. While investigating the image from H/0.5, It was found that the bubbles were coalescent while rising. After the coalescence, the rise velocity decreased approximately 20%, although the buoyancy force increased as the bubble growed [26]. As seen in figure 3, the bubble experience several mechanisms for bubble coalescence there are approach step, touch step, and fusion step. Figure 3 shows, because of the different rise velocities, buoyancy-driven coalescence. According to Sanada, in 2009, the bubble B bouncing with its rear bubble caused a decrease in the rising rate. Still, an increase in the horizontal speed after a collision led to bubble coalescence to bubble A [24]. This incidence was expected due to the bubble being generated with the sparger that has a little distance in the orifice and the shape of the sparger that leads to joining each bubble.

As shown in Fig 4, we investigate the downside of the baffle. We observe that the bubble was a collision with the baffle. The collision of the bubble makes the bubble trap because of the drag coefficient. While the bubble rises, velocity decrease, the approach velocity of the bubble increase [24]. The increasing of the local gas hold up, and the coalescence probability was produced because the bubble was trapped, this led the bubble to be coalesced.

As seen in Fig 4, five bubbles coalesce, beginning with the tiny ones and then growing large. Those phenomena not only occur in the H/0.25 but also H/0.75, so in the lead to produce a larger bubble, the first contact of the bubble was leading the coalescence as the starting point in bubble coalescence time.

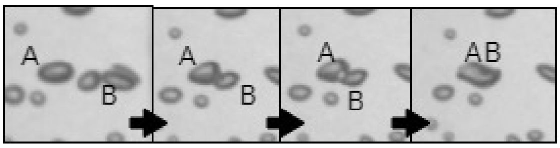

Fig 3: Bubble Coalescence in H/0.5 after baffle

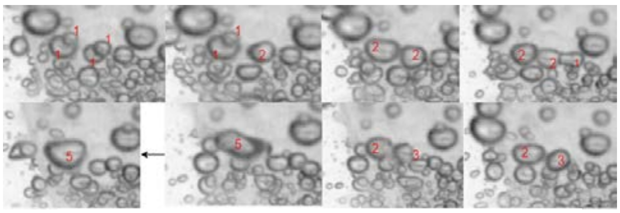

Fig 4: Bubble Coalescence in H/0.25 below baffle

The result from the bubble distribution in three-position was obtained, as shown in Fig. 5. The more the number of bubbles, the smaller the bubbles produced by the double loop fluid oscillator. The smaller the bubble size, the greater the concentration of carbon dioxide contained in the air. A high concentration of carbon dioxide is a desirable condition for the photosynthetic process of microalgae.

Based on the data, the distribution of the bubbles was homogenous in the H/0.25 with the higher value of 100-300 μm of the bubble size. After the first baffle, the effect of the coalescence phenomena occured, the bubble size 100-300 μm was dropped while the bubble size 600-1000 μm increase as an effect of the bubble coalescence below the baffle. The phenomenon was continued in the free-rising zone and at the second baffle. The result showed that the bubble distribution in H/0.75 was different due to its wonders. The size of the bubble seems to increase, that shown in the graphic. The Effect of the coalesces is proven by finding the value of Sauter mean diameter in Table 1. That increase is parallel with Fig 5. However, some of the coalescence bubbles grew about > 20 mm, as shown in Fig. 6. Those phenomena effect of trapped bubble in some baffle. Because of the coalescence of the bubble, the capabilities of the mass transfer seem to decrease.

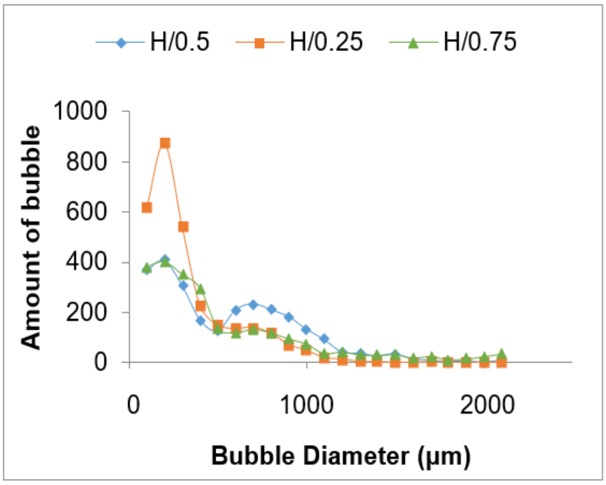

Fig 5: Bubble Distribution Graphic

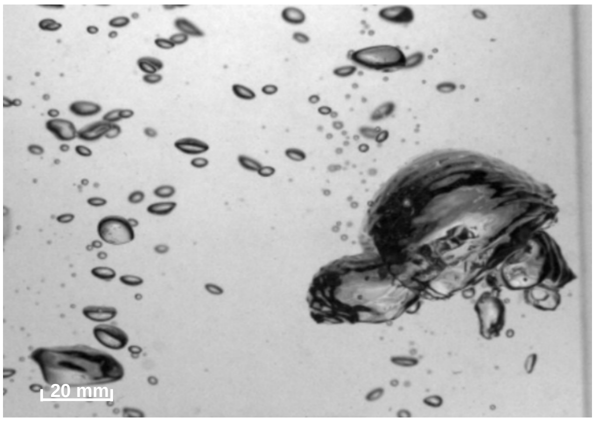

Fig 6: Bubble size >20mm

Table 1 Sauter mean diameter

Position	Sauter Mean Diameter (μm)
H/0.25	675
H/0.5	1001
H/0.75	1125

4. Conclusions

In this study, bubble distribution and bubble coalescence phenomena as an effect using horizontal baffle were evaluated. The higher the data retrieval location, the more bubble with a bigger diameter due to the coalescence that occurs in the H/0.25, H/0.5, and below H/0.75. The bubble size of 200-400 μm appears to remain constant since it is not carried away by the wake of the larger bubble. The bubble coalescence below the baffle because of its trapped effect of the drag coefficient and tend to coalesce as an effect increasing the local gas hold up. Otherwise, the mixing capabilities of the photobioreactor were increased due to its baffle and the bubble flow.

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Nomenclature

d_i	Bubbles diameter (mm)
d_{BS}	Sauter mean diameter (mm)

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