The Effectiveness of Microbubble Technology in The Quality Improvement of Raw Water Sample

F Ali¹, K N Azmi² and M R Firdaus²

¹ Department of Civil Engineering, Universitas Indonesia, Depok, 16424, Indonesia
² Indonesia Water Institute, Tanjung Barat, South Jakarta, 12530, Indonesia
*Corresponding author: firdausali@ymail.com

Abstract. An experimental study to observe the performance of microbubble generator (MBG) and microbubble-generating nozzle on water is carried out under laboratory conditions. The MBG is used to treat wastewater from water bodies which was impacted by domestic and industrial wastewater. The study uses MBG with a spherical body and a drilled hole, along with a dispersing nozzle placed at the bottom of microbubble reactor tank. The MBG used is considered to be more applicable for water bodies rather than other types. Two types of pressure gauges are installed around the MBG and the nozzle in order to examine and configure the inlet water pressure and the inlet gas pressure based on the best microbubble size produced from a prior experiment. Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Dissolved Oxygen (DO), Total Suspended Solids (TSS), and Turbidity has been analyzed in the beginning and every 10 minutes of a 60 minute detention time to examine the effectiveness of MBG. The results of study shows the MBG have a high rate of removal percentage in a 60-minute retention time with 60 to 90% for TSS, up to 90% for Turbidity, 74 to 96% for BOD, and 41 to 59% for COD.

1. Introduction
There are an abundant number of water resources used to acquire raw water that is then treated accordingly, to a degree of quality that is fit for human consumption. Water resources are natural source of water from the earth ranging from surface water (freshwater lakes, wetlands, rivers, etc.) to glaciers and groundwater. In Indonesia itself, rivers and lakes cover about 60% of the water source used for water supply [1]. To ensure the safety and quality of the raw water that are going to be treated, water bodies in Indonesia is regulated by Government Regulation No. 82/2001 on Management of Water Quality and Water Pollution Control in Indonesia. The regulation holds the quality standard of surface water based on the water bodies classification for physical, inorganic chemistry, organic chemistry and microbiology parameters.

Based on the report made by Directorate General of Environmental Pollution and Damage Control Ministry of Environment and Forestry, in 2015, almost 68% of the majority of river in 33 provinces of Indonesia is classified as heavily polluted. The evaluation is based on the classification and quality standard parameters in Government Regulation No. 82/2001 [2].

Rivers and lakes being the most important water resource are used for residential, commercial and industrial use. Residential water use includes drinking, cleaning, personal hygiene, sanitation, lawn care and car washing. Whereas commercial and industrial sectors consume water for processing products and cooling [3]. Utilizing appropriate water treatment technologies is one of the challenges that is continuously encountered in ensuring the quality standard of water that will be used for residential,
commercial and industrial sectors. Specifically, by considering the cost of chemical used, land use, effluent quality, and the time needed to treat the water itself. Microbubble generator is a “Dissolved Air Flotation” type unit treatment, as an alternative to sedimentation unit with the application of microbubbles with a diameter range of 10 - 40 μm, it governs a physical-chemical method of pollutant separation of effluent and has advantages such as fast operations, less space required, flexibility in installation and economic cost [4]. One of the advantages of utilizing microbubble technology for water treatment is its ability to broaden the contact surface between water and air, hence large spaces and complex technology is not needed. This study focuses on analyzing the revamped and improved microbubble generator and its post-treatment effluent quality of parameters such as DO; TSS; & Turbidity for every 10 minutes in a 60-minute treatment detention time, as well as BOD & COD before and after 60 minutes of the treatment retention time.

2. Literature Review

2.1. Water Quality Guidelines
In ensuring safety and health in utilizing water from water resources, water quality guidelines are pivotal as a suited quality standard. Globally, World Health Organization (WHO) and US Environmental Protection Agency (EPA) are the two organizations that issues water quality guidelines that are used internationally. The Guidelines for Drinking-water Quality (GDWQ) are an international reference point for the establishment of national or regional regulations and standards for water safety and are addressed to water and health regulators, policy-makers and their advisors and assist them in the development of national standards [5]. The GDWQ covers water quality standard for various microbial, chemical, radiological and physical contaminants parameters. It is periodically updated, with its last updated version the 4th Edition on 2017. US EPA also issues water quality guidelines “Water Quality Standards Handbook”. EPA states that there are a difference between the term “Water Quality Standards” and “Water Quality Criteria”. Water quality standards are regulations that include designated uses and water quality criteria to protect those uses. Whereas, water quality criteria is apart of the water quality standards, in which are generally listed at some threshold concentration that, if exceeded, would cause harm to aquatic life, wildlife or human health [6].

Other countries uses those guidelines and handbooks from WHO and EPA as a foundation for their national regulations. In Indonesia, the national regulation that are used for water quality standards for surface water or water bodies is Government Regulation No. 82/2001 on Management of Water Quality and Water Pollution Control in Indonesia. The regulation covers the water quality standards for water body and it is classified into four classes based on the designated uses of the water body itself. The water quality standard parameter differs based on the classes, where physical, inorganic & organic chemical, microbiology, and radioactivity parameters are covered in this regulation. Rivers and surface water are classified into the 2nd class which are for water resources that won’t be utilize as drinking water, whereas surface waters that will be utilize for drinking water consumption purposes are classified into the 1st class. This type of classification is widely used in many countries that falls into the UN regional commissions of Europe (ECE) and Asid and the Pacific (ESCAP). A number of these countries require, as a policy goal, the attainment of water quality classes I or II (which characterise out of a system of four or five quality classes, excellent or good water quality) over a period of time [7].

2.2. Characteristics of Water Resources
Water resources, specifically surface water, originates mostly from rainfall and is a mixture of surface run-off and ground water. The quality of surface water is governed by its content of living organisms and by the amounts of mineral and organic matter which it may have picked up in the course of its formation. Based on the national regulation, Government Regulation No. 82/2001, characteristics of a healthy surface water (river, lakes, etc.) are surface water with a BOD, COD, and TSS value of 2-3 mg/L, 10-25 mg/L, and 50 mg/L. A normal surface water also has a minimum DO value of 4-6 mg/L. BOD (Biochemical Oxygen Demand) and COD (Chemical Oxygen Demand) are the main parameters analyzed to indicate the degree of pollution in the river [8].
The status of rivers in Indonesia is really poor and keep degrading from year to year. Out of the 90 rivers in Indonesia, only 10% of it is deemed lightly polluted, whereas the rest falls into the categories of polluted or heavily polluted based on the water quality criteria of Government Regulation No. 82/2001 Class II classification [9]. Around 64 of a total 470 watersheds in Indonesia are in critical condition. Out of those 64 critical watersheds are 12 areas in Sumatera, 26 areas in Java, 10 areas in Kalimantan, 10 areas in Sulawesi, 4 areas in Bali, NTB, and NTT, 4 areas in Maluku and 2 areas in Papua [10]. Most of the river in Java Island has already fallen to Class III and IV, which is only suitable for fresh fish preservation, livestock, irrigation and/or other usages requiring similar quality [11].

2.3. Bubble System Technology for Water Treatment

Knowing that raw water acquired from rivers are mostly contaminated and polluted at some degree, the need for an efficient water treatment technology is at an upmost high. Water treatment technology has been utilizing air bubbles as a means of treating raw water or polluted water for a number of years. The two method types that has been using air bubbles, specifically the contact process of water and air are aeration and flotation. Aeration supplies oxygen needed for biological treatment and also treating in physically and is utilized to get rid of odor, taste as well as iron and manganese. The main function of aeration process otherwise is getting rid of iron & manganese, organic matter, as well as increase oxygen level [12]. Mechanism of aeration process in degrading contaminant is by injecting air to wastewater it will supply oxygen needed by microorganisms in degradation of organic matter in wastewater (hence, decreasing BOD), increasing dissolved oxygen in water. Aeration uses diffuser that differs in types according to the bubble sized required for the treatment from. The bubble sizes used for aeration is divided into two groups, fine bubbles (0 – 3 mm) and coarse bubbles (3 – 50 mm) [14]. Flotation, on the other hand, is the most effective method in solid/liquid separation by injecting air by dispersing it and releasing it. Dissolved-air flotation (DAF), creates air bubbles in smaller sizes than dispersed-air flotation and usually has a size of 0.1 mm or less than a diameter [13]. Microbubble technology works by combining aeration and flotation methodology.

Microbubble or fine bubbles are defined as small bubble ranging in sizes 10 to 50 micrometers [14] and has characteristics in which it will float slowly (retention time in minutes) and has more mass transfer capability than macro bubbles [15]. In the last 10 years, a lot of attention has been put upon the utilization of microbubble technology in water treatments because of its ability in generating reactive free radicals [16]. Microbubbles can increase aerobic and anaerobic microorganism activity in a bioreactor membrane under the water surface, also supplies oxygen in the aerobic biodegradation process[17-18]. Microbubble works by carrying fine particles floating it from the lower part of the tank afloat and supplies oxygen needed for oxidation process needed to degrade organic contaminant. Hence, Microbubble technology can be used to treat a number of physical -chemical parameter such as TSS, BOD, COD as well as increasing DO values from it oxidation process. Generally, there are two types of microbubble generators (MBGs), the water-air circulation type and the “pressure decompression” type. In the water-air circulation type, gas is injected to the water vortex and the produced air bubbles will transform into microbubbles by breaking the vortex, whereas the “pressure decompression” produces saturated liquid that is created from an amount of gas that is dissolved in water in high pressure. Figure 1 shows types of microbubble spargers mentioned before.
3. Methodology

3.1. Materials & Apparatus

The microbubble generator used in this study is made up of three water columns. With the main column/first column as the Microbubble column (Injection tank) with a 25 cm x 25 cm x 90 cm dimension with 4 valves attached to it in the front part of the tank in a 15 cm space between each valve, with the lowest valve in a 30 cm elevation from the bottom of the water column. The sparger used in this study here is a Pressurized dissolution sparger (vortex type) that is connected with an air compressor and water pump that is kept at an air flow rate of 0.1 liter/minute and discharge of 9 liter/minute. The sparger used in the study has a microbubble generation of 50 μm to 100 μm. The second and third thank serves as a connector tank and recirculation tank, with a 25 cm x 25 cm x 20 cm dimension. The schematic illustration is shown in figure 2.
3.2. Experimental Setups

Figure 3 shows the schematic of the microbubble generator as well as the process flow. First, the main tank/water column is filled with the water sample, in which water sample from Cikeas River (Java, Indonesia) is used, which the river itself falls into the 2nd class water bodies category based on Government Regulation No. 82/2001. The second and third tank is also filled and then the air compressor and water pump will be turned on. Microbubble will generate from the sparger and water will keep recirculating from the second tank to the third tank and back to the water pump to be pumped as a microbubble. Overtime, the water sample in the main tank that is exposed to the microbubble will be treated by it and a layer sludge will form on the surface of the water in the main tank.

The experiment is done three times, each experiment is conducted with the addition of coagulant (at optimum dose and with coagulation of 100 rpm using hand-manual mixing) and without a coagulant. PAC in an optimum dose is used for the experiment with coagulant, the optimum dose is acquired after performing a jar test for each sample prior the treatment process. A sample is taken prior from starting the experiment and then for every 10 minutes in the 60 minutes microbubble treatment retention time, as well as DO is checked using a DO meter. The sample is taken from the third valve with a distance of 45 cm from the bottom of the main tank. The sample taken every 10 minutes is then checked in the Laboratory for parameters BOD, COD, TSS, Turbidity for Non-Coagulant experiments and only TSS and Turbidity were checked for the Coagulant experiments. BOD and COD parameters, for coagulant experiments are not checked because time constraint and cost-wise considered, which the experiment would take longer time and will be more expensive.

![Figure 3. MBG tank illustration highlighting 3rd valve.](image)

4. Discussions

4.1. The Microbubble Generator Installation

The Microbubble generator (MBG) installation used in this study has gone through modifications and consideration to achieve the optimum performance for water treatment. As mentioned before there are many types of sparger that can be used in producing microbubbles. A previous experiment has been conducted using the microbubble generator apparatus and different types of sparger to determine the optimum sparger type for the MBG installation. The pressurized dissolution sparger, also known as Vortex type, was chosen and used for this study based on the previous experiment [19]. The microbubble generation from the pressurized dissolution sparger shows a stable discharge of 50 to 100 μm sized
microbubbles. The MBG tank height, is modified to a 90 cm height, because most of the previous studies on MBG has a minimum tank height of 90 cm. So that microbubble performance could be more efficient because of the duration of the microbubble until it dispersed is prolonged, compared to a normal sized bubble. Valves are also installed in various height for a more accessible sample taking, this could also be studied in detailed for future studies regarding the retrieval zone of the sample of treated water by microbubble.

4.2. Microbubble role in Contaminant Removal
Microbubble in water treatment, works as a physical-chemical treatment. Factors such as oxygen supply, adhesion factor, and highly reactive free radicals generated plays greatly in the water treatment performance. Each microbubble carries an amount of oxygen, because of its micro size and generated in a massive amount, it supplies oxygen to the water in the water column and thus increasing the Dissolved Oxygen (DO) value of the water itself. This process works as an aeration process treating the water physically and chemically, supplying oxygen needed for microorganisms to decompose and break down organic contaminants in the water. This can directly impact the BOD and COD level of the water, as shown in table 1. Adhesion factor of the microbubbles is the adsorption tendency of the contaminant towards the microbubble surface. The contaminant sticks itself towards the microbubble surface, while it floats to the water surface carrying the attached contaminant. This is shown by a sludge layer forming on the water surface shown in figure 4 (for experiments with coagulant). Free radicals are generated and formed through the collapse of the microbubbles in the absence of dynamic stimulus, the highly reactive free radicals and turbulence associated with the collapsing microbubbles provides great potential for water disinfection [14].

![Figure 4. Sludge build-up in MBG water column: (a) top-view and (b) side-view.](image)

4.3. The relationship between Retention Time and Removal Efficiency
The purpose behind using Microbubble Generator (MBG) as a physical-chemical water treatment is for a more space-saving treatment unit with a shorter retention time than the normal aeration tank. This can be shown by figure 5 and table 1 which shows the result of the experiment done. Figure 5 shows the relationship between the removal percentage against the retention time for experimental sets with coagulant and without coagulant. For parameters such as Turbidity and Total Suspended Solids (TSS), the addition of coagulant impacts greatly in the removal percentage, making the decrease in contaminant concentration is much more constant. A layer of sludge is produced on the surface of the water for the first 10 to 20 minutes (figure 4), these shows that particles that makes up turbidity and TSS are floated to the water surface and can be removed by scraper. By comparing the results of the experiments with coagulant and without coagulant, the graph in figure 5, shows that by the addition of coagulant combined with the MBG is proven to result to a better performance in water treatment. Based on table 1, Turbidity and TSS has a better removal percentage for treatment with coagulant. Referencing from the experiment
conducted by Han et al. [20] concerning the application of a coagulant to microbubble water treatment, the maximum efficiency adhesion could be achieved when the floc and microbubble sizes are within the same size range (40–100 micrometers); thus, the appropriate floc-micron particle size should be within the 10–100 micrometer range. Furthermore, collisions between microbubbles and particles are bound to happen, and they are caused by a group of microbubbles that stick together and carry the floc to the water surface, creating aerated flocs [21].

Figures 5. Removal percentage of contaminant (a) turbidity and (b) TSS over retention time.

The initial DO value of the water sample is 3 to 4 mg/Liter but after the MBG is turned on the DO value reaches a stable value of 7 to 8 mg/Liter throughout the 60-minute retention time. BOD and COD concentration is measured before the MBG is turned on and after 60 minutes of retention time without the addition of coagulant, this is because of the cost and time it would take. The result shown in table 1, BOD has a removal percentage of 74 to 97 %, whereas COD has a removal percentage of 42 to 59 % after a retention time of 60 minutes. The final BOD concentration passes the water quality standard for Class I (2 mg/L) of Government Regulation No. 82/2001, but the final COD concentration doesn’t pass the water quality standard for Class I (10 mg/L), with a range COD value of 11 to 21 mg/L. Although the COD value doesn’t fit the quality standard, it still achieves a high removal percentage for an adequate time of 60 minutes. Parameters such as turbidity and TSS passes the water quality standards with the help of coagulant addition. BOD, COD and TSS has an optimum retention time of 50 to 60 minutes, while turbidity has an optimum retention time of 20 to 30 minutes.

The results of the experiment show conformity with the theory that MBG could be used for raw water treatment, especially surface water (rivers), with the addition of coagulants. Microbubble generator technology is an extension of DAF technology, improving greatly the performance of the traditional DAF because of its microbubble properties. The removal process physically (decrease in Turbidity and TSS) happens when floc floats with microbubbles, while the chemical process happens when a coagulant is added and a reaction between the microbubbles and floc particles forces them to stick to each other and floats to the water surface. Biological process could occur because of the microorganisms getting supplies of oxygen from the microbubble, so it can exist to treat organic contaminants in the water (decrease in BOD & COD). In further researches, the impact of coagulant in the BOD and COD removal percentage need to be looked upon.
Table 1. Microbubble Generator Experiment Results.

| Parameter          | Standard Valuea | Initial Concentration | Outlet Concentration | Performance | Non-Coagulant (NC) | Coagulant (C) |
|--------------------|-----------------|-----------------------|----------------------|-------------|-------------------|---------------|
|                    |                 |                       |                      | 50          | 20                | 30            |
|                    |                 | 83-100 NTU            | 35-44 NTU            | Set 1       | 61-104 NTU        | 11-15 NTU     |
|                    |                 | (NC)                  | (NC)                 | Set 2       |                     |               |
|                    |                 | 61-104 NTU (C)        | 11-15 NTU (C)        | Set 3       | 59                 | 56            |
|                    |                 |                       |                      | Removal Percentage (%) | 63          | 38            |
|                    |                 |                       |                      |             | 94                 | 90            |
|                    |                 |                       |                      |             |                    |               |
| Turbidity          | 75-100 mg/L     | 13-71 mg/L            | Optimum Time (Min)   | 50          | 60                | 60            |
| Total Suspended    | 50 mg/L         | 9-51 mg/L             | Removal Percentage (%) | 66          | -2.9               | 83            |
| Solid (TSS)        | 8.68-9.47 mg/L  | 0.32-0.95 mg/L        | (NC)                 | 97          | 75                 | 89            |
| BOD                | 2 mg/L          | 0.32-0.95 mg/L        |                        |             |                    |               |
|                    | 21-36 mg/L      | 11-21 mg/L            | Optimum Time (Min)   | 60          | 60                 | 60            |
| COD                | 10 mg/L         | 11-21 mg/L            | Removal Percentage (%) | 59          | 42                 | 43            |
|                    | 21-36 mg/L      | (NC)                  |                        |             |                    |               |

The microbubble generator can be simply utilize as a substitute unit to sedimentation unit (flotation aspect) in water treatment plants (WTP) and aeration tank (Aeration aspect) in wastewater treatment plants (WWTP). For water treatment plants, the microbubble generator works as a flotation unit as the bubble floats the flocs towards the surface creating a sludge consistency that could easily be removed by a scrapper unit. Whereas, in wastewater treatment it substitutes the aeration tank unit as well as the clarifier unit after it. In WTP, it is possible to solely use the microbubble generator as the main unit treatment with the addition of several other supporting unit such as plasma ozone for desinfection. Supposedly, the microbubble generator has been used commonly for water treatment purposes by a few countries. The utilization of microbubble technology has actually been used in asian countries such as Japan, South Korea and the People’s Republic of China. In Japan itself, a number of local manufacturers produced MBG technology for water treatment such as Aura Tech Co., Ltd, Shigen Kaihatsu Co., Ltd, and Nanoplanet Co., Ltd. [22]. Even in, South Korea itself a small city has a water treatment plant using MBG as it main aeration unit. Looking at the results of this study shows that MBG has a big potential to be used in water treatments for water resources in Indonesia. The challenge itself is in manufacturing the technology (sparger, tank, apparatus, etc), because there are little to none local manufacturers for MBG technology, Indonesia has to buy parts or technology from countries that have implemented the use of MBG in water treatment. If the technology are planned to be widely used for cities in Indonesia then, buying parts and technology from other countries may be vastly expensive hence the need of more local manufacturers of MBG parts and unit. Other than that, the power needed to operate the microbubble generator would be in great amounts so although utilizing the microbubble generator would save on matters such as space and chemicals (coagulant) needed, it will cost more on the power generator.
5. Conclusions
The study shows that Microbubble generator (MBG) with the addition of coagulant is effective to treat raw water from water resources such as rivers. Comparing the use of the microbubble generator to conventional water treatment, the MBG have a higher rate of removal percentage in a 60-minute retention time of 60 to 90 % for TSS, up to 90 % for Turbidity, 74 to 96% for BOD, and 41 to 59% for COD. Almost all of the contaminant parameters passed the water quality standards of Government Regulation No. 82/2001 after a 60-minute treatment with MBG with an exception optimum retention time of 20 to 30 for turbidity. The utilization of microbubble generator would be more efficient in water treatment plants with the addition of supporting units. Furthermore, after the MBG treatment process the water still needs to go through disinfection process such as plasma ozone unit before it is supplied. Matters such as the absence of local manufacturers for the unit parts and power needed plays greatly in the cost aspect of it. Further research is needed to be conducted for comparison in aspects of economical and efficiency against conventional water treatment.

6. References

[1] Hendrayanto 2004 Watershed and Water Resources Management in Indonesia: An Overview of Forest Degradation and Present Situation of Water Resources Supply and Efficient Utilization for Human Survival Bioproduction Tsuchub Asian Seminar on Agriculture (TASAE)/UNESCO-APEID (Japan)
[2] Ministry of Environment and Forestry 2016 End of Year Notes KLHK 2016: Healthy Living Environment for People (Jakarta: Ministry of Environment and Forestry) pp 10
[3] Steffan R 2010 Uses of Natural Water Resources Retrieved on July 14, 2020 from https://homeguides.sfgate.com/uses-natural-water-resources-79287.html
[4] Tsai, J. C., Kumar, M., Chen, S. Y., and Lin, J. G. 2007. Nano-bubble flotation technology with coagulation process for the cost-effective treatment of chemical mechanical polishing wastewater. Separation and Purification Technology, 58(1), 61-67.
[5] World Health Organization 2018 A Global Overview of National Regulations and Standards for Drinking-Water Quality (Geneva: World Health Organization) pp 1 - 2
[6] US EPA 2017 Relationships between Water Quality Criteria and Water Quality Standards Retrieved on July 14, 2020 from https://www.epa.gov/standards-water-body-health/relationship-between-water-quality-criteria-and-water-quality-standards
[7] Enderlein U S, Enderlein R E and Williams W P 1995 Chapter 2 - Water Quality Requirements. Retrieved on July 15, 2020 from https://www.who.int/water_sanitation_health/resourcesquality/wpccchap2.pdf
[8] Lee A H and Nikraz H 2015 BOD: COD ratio as an indicator for river pollution. International Proceedings of Chemical, Biological and Environmental Engineering 88(15) 89-94
[9] BPS-Statistics Indonesia 2018 Environment Statistics of Indonesia 2018 (Jakarta: BPS-Statistics Indonesia) pp 107 - 110
[10] Center of Environmental Technology Agency for the Assessment and Application of Technology 2007 Condition of water resource in Indonesia and its environmental technology, JAI. 3 111-119
[11] Asian Development Bank 2016 Indonesia: Country Water Assessment (Manila: Asian Development Bank) pp 22
[12] Droste R L and Gehr R L 2018 Theory and practice of water and wastewater treatment (John Wiley & Sons)
[13] Packham R F and Richards W N 1972 Water Clarification by Flotation-1 The Water Research Association (Medmenham, Marlow, Buckingham:England)
[14] Agarwal A, Ng W J and Liu Y 2011 Principle and applications of microbubble and nanobubble technology for water treatment. Chemosphere 84(9) 1175-1180
[15] Temesgen T, Bui T T, Han M, Kim T I and Park H 2017 Micro and nanobubble technologies as a new horizon for water-treatment techniques: A review. Advances in colloid and interface science 246 40-51
[16] Masuda N, Maruyama A, Eguchi T, Hirakawa T and Murakami Y 2015 Influence of microbubbles on free radical generation by ultrasound in aqueous solution: dependence of ultrasound frequency, *The Journal of Physical Chemistry B* **119**(40) 12887-12893
[17] Yamasaki K, Sakata K and Chuhjoh K 2010 *U.S. Patent No. 7,662,288.* (Washington, DC: U.S. Patent and Trademark Office)
[18] Khuntia S, Majumder S K and Ghosh P 2012 Microbubble-aided water and wastewater purification: a review, *Reviews in Chemical Engineering* **28**(4-6) 191-221
[19] Suwartha N, Syamzida D, Priadi C R, Moersidik S S and Ali F 2020 Effect of size variation on microbubble mass transfer coefficient in flotation and aeration processes, *Heliyon* **6**(4) e03748
[20] Han M, Kim W and Dockko S 2001 Collision efficiency factor of bubble and particle (abp) in DAF: Theory and experimental verification, *Water science and technology* **43**(8) 139-144
[21] Oliveira C and Rubio J 2012 A short overview of the formation of aerated flocs and their applications in solid/liquid separation by flotation, *Minerals Engineering* **39** 124-132
[22] Terasaka K, Hirabayashi A, Nishino T, Fujioka S and Kobayashi D 2011 Development of microbubble aerator for waste water treatment using aerobic activated sludge, *Chemical engineering science* **66**(14) 3172-3179

**Acknowledgments**
The authors acknowledge the Directorate Research and Community Engagement Universitas Indonesia (DRPM UI) for the funding given under QQ research grants number NKB 0317/UN2.R3.1/HKP.05.00/2019. We would also express our gratitude to Nyoman Suwartha, University of Indonesia Environmental Engineering lecturer for guidance and provision during the experiment and research, and Indonesia Water Institute's team for the insight regarding the reactor’s design development.