The Effect of Bubbling Generation Methods on the Performance of Microbubble Generator Pressurized Type

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Abstract

Microbubble generator (MBG) is one of the solution in the wastewater treatment using the latest technology and environmental friendly purposes. Besides it is simpler in construction, it also has the ability to purify the water better than the other technologies. But until now there is no MBG that can generate an optimum micro-sizes bubble effectively. A further study has been conducted to analyze the optimum design of MBG. MBG with porous pipe and orifice, MBG with porous pipe and orifice and microbubble generator with spherical body and drilled holes were investigated in this experiment. The micro-bubble generator is placed at a depth of H = 40 cm from the surface of water in the aquarium (75 cm x 50 cm x 40 cm). Three different pressure transducers were placed around the microbubble generator body to analyze the inlet water pressure P_L, the air suction pressure, P_G, and the pressure at the outlet of microbubble generator. The output signals from the above sensors were sent to a personal computer via an A/D converter to determine the respective time-averaged values. Water was supplied from centrifugal pump from Q_L= 2 m^3/hour until Q_L= .5 m^3/hour, with air suction rate Q_G was form 0.1 l/min until 0.8 l/min. The water flow rate ,Q_G, and the air suction rate, Q_L, were measured by calibrated flowmeter and controlled by gate valve .The bubble diameter was measured by capture the bubble pictures using digital camera CANON EOS 550 D with additional 100m macro lens, and analyzed by image processing technique using MATLAB. The hydraulic power, the bubble generation efficiency and dissolved oxygen number were defined as parameters of the performances of microbubble generator. The study revealed that the bubble intensity increases with the increase of water supply rate, and found that MBG with porous pipe and orifice is the optimum designs in producing microbubble, although it required more power. From these experiments, we succeeded in producing microbubble sizes ranging between 50 to 200 µm.

Keywords: microbubble generator, microbubble generator performances, microbubble, image processing, hydraulic power, bubble generation efficiency.

Introduction

Microbubble is a bubble which have diameter less than 200 µm (Sadatomi,2005), the application of microbubble have widely been used in many application area, such as in fishery, medical, PIV, water purification, and others. Overall, the suitable microbubbles sizes are different in the various fields of application (Tsuge and Li, 2006).
Microbubble generator (MBG) is a tool that can generate microbubble. The research on MBG has been doing since a long time ago. Microbubbles are often generated by different ways that can be divided into three types in terms of their mechanism (Pan li 2006). There are pressurized type, Cavitation type and rotational type.
The pressurization type of micro-bubble generating system is based on the Henry's Law, In the pressurization type, high pressurized water is saturated with gas and then injected into normal environment with atmospheric pressure through a nozzle. Microbubbles are formed during the sudden pressure drop. In the cavitation type bubble is formed due to the phase change in the water which caused by a sudden change in pressure which falls below the liquid's vapor pressure at the local ambient temperature. Venturi tube is one example (Takemura, 2003; Fujiwara et al., 2003).
A typical design of the rotating flow type micro-bubble generator is done by Tatsumi (2008). Microbubble generation is initiated by pumping water from the tangential direction into it. The fluid flows in a rotating motion along the inner wall to form a vortex. The center of the vortex is a low pressure area because of centrifugal force, which makes air drawn into it. When the fluid takes air out of generator with very high rotating velocity, the air can be sheared into micro-bubbles.

Iriawan (2013) have conducted a research to optimize the performance of MBG with spherical body, which have been developed by Sadatomi (2005) and succeeded to produce microbubble by 50 µm in diameter.
Sadatomi et al. (2009) was developed a multi fluids mixer as MBG that have the similar principle with spherical body type developed before. The difference is by using orifice and the porous material, porous pipe, to compose the negative pressure in vacumn side of MBG, so that the air will be sucked automatically. Multi fluids mixer could generated micro-bubble by supplying liquid and sucking gas. It also generated mist by supplying gas and sucking liquids. And found that the bubble generator efficiency number will increase by adding the number of air suction holes.
In this research¸ Three different designs of micro-bubble generator are used. These three different designs are spherical body with drilled hole¸ orifice with porous pipe¸ and spherical body with porous pipe microbubble generator. There won’t be any significant difference in ability to dissolve oxygen in the water because three of them can produce micro-bubble. For the value of pressure drop¸ there will be a little bit different among the three designs. It’s because there is a different ratio between orifice diameter and pipe diameter. The different value in pressure drop will affect air suction. So¸ the hydraulic power and the bubble generation efficiency are important to observe in deciding the most optimum design among the three MBG in generating microbubble.

Nomenclature

Q_L = water flow rate (m^3/hour)

Q_G. = Gas Flow Rate (l/min)

L_w = Hydraulic power

P_a = Initial Pressure (kPa)

P_b = Vacuum Pressure (kPa)

dp = Differential pressure (kPa)

μ = liquid viscosity (Pa.s)

ρ = liquid density (kg/m^3)

η_B = bubble generation efficiency.

H = Depth of water (m)

Subscript

G = gas phase

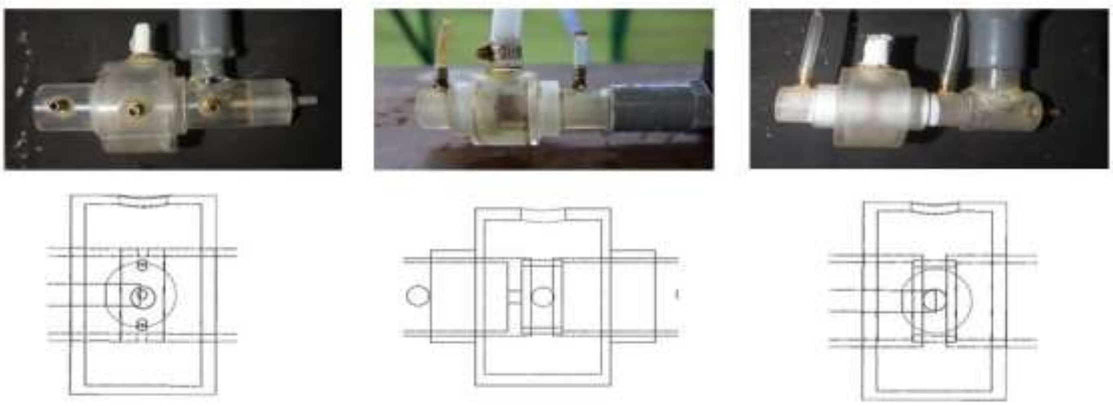
L = liquid phase

Experimental Apparatus and methods

Three different design of MBG have been tested to investigate the performance of microbubble generator, there are MBG with spherical body and drilled hole, MBG with spherical body and porous pipe, and MBG with orifice and porous pipe.

Table 1. The specification of the tested MBG

No	*Name*	*Core*	*Pipe Diameter*	*Hole*	*Core Diameter*
1.	PO-1	Orifice	18 mm	Porous pipe	10 mm
2.	PB-1	Spherical body	18 mm	Porous pipe	14 mm
3.	DB-1	Spherical body	18 mm	12 drilled holed (d = 0.7 mm)	14 mm



a) b) c)

Figure 1. the Tested MBG, a) DB-1, b) PO-1, c) PB-1.

Three different MBG were put in the depth of water in aquarium (size 75 cm x 50 cm x 40 cm) at H = 0.4

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m, the water flows from water pump and measured by calibrated water flowmeter into the microbubble generator, within the MBG there are three pressure transducer sensor alongside the body to measure the Inlet Pressure, the vacuum pressure and the outlet pressure, the output signal from those sensors were sent directly to a personal computer via A/D Converter with sampling time 627 sample/s, to determine the respective time-averaged values. The sucked air in the MBG was measured by air flowmeter.

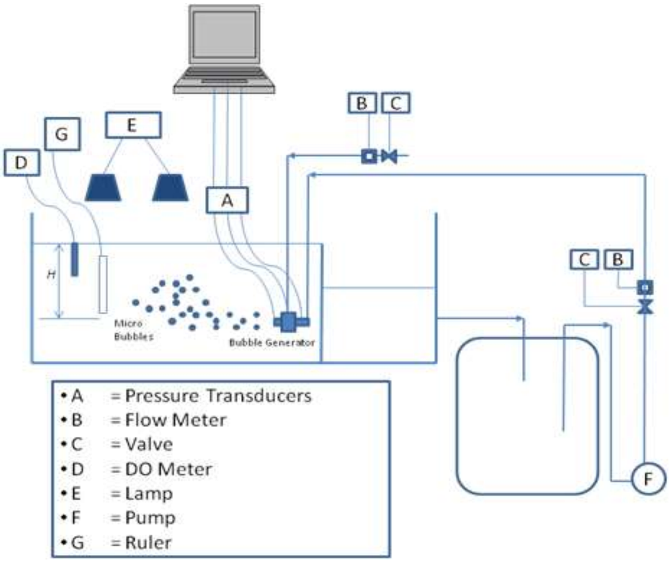


Figure 2. Eperimental set up.

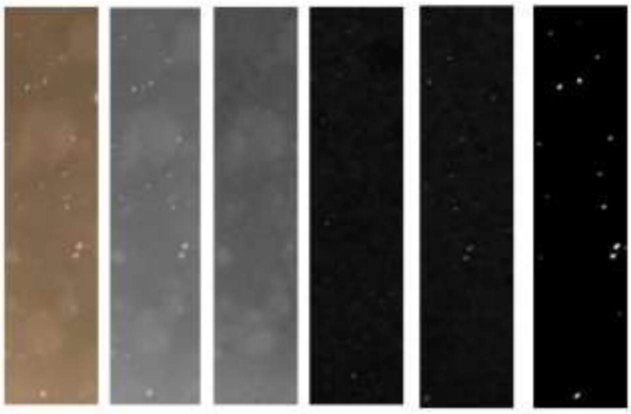
The bubble diameter was measured by capture the bubbles pictures using digital camera CANON EOS 550 D with additional 100m macro lens, and analyzed by image processing technique using Matlab. The process of the image processing will describe below.

To examine the quality of the water, we used DO meter (Lutron DO 5510) to analyze the amount of dissolved oxygen in the water and monitoring the water temperature

Result and discussion.

Bubble Size measurement

Bubble size measurement was done by processing some captured images of bubbles using image processing toolbox in MATLAB R2010a. The camera settings for capturing the bubbles are shutter speed 1/4000¸ and ISO 3200. Tripod is used to stabilize camera. Perforated black paper is patched to primary water tank's wall. It is used to keep the photos that will collect¸ are from the same place. The bubble that is measured from the photo is the bubble that captured by camera near the ruler.



a) b) c) d) e) f)

Figure 3. Sequential process in image processing a). Original Image. b) Grayscale image. c) Background image d) Substracted image. e) Filtered image. f) Binary image.

The outcome of every step of the procedure is shown in the images of Fig. 3, and briefly described below,

Image conversion.

the original image which in RGB format was changed into grayscale for the first step of the process. The output image has 256 range grays level from 0 (black) until 256 (white). After that, the image was subtracted with the background image (formatted in grayscale), the background image could be created by two ways, the first one is created by capturing the image when there are no bubble generated from microbubble, the other ways is created by using the function in Image processing toolbox on Matlab.

Image filtering.

Next step is filtering image to reduce noise in order the image can be calculated easily. Gaussian filtering as linear filtering is used.

Binary image conversion.

Conversion of a greyscale image to binary mode consists in a reduction to two of the number of grey levels of the original image: one corresponding to black (0) and another corresponding to white (1) (Mayor, 2007). In conversing the filtered image of microbubble, some difficulties found in conversion image to binary, because of the lightning from the halogen lamp was not distributed uniformly along the images. So, in order to converse the filtered images into binary version, the level of grey which belong to white and black was chosen manually by using "if else" algorithm.

Post processing images.

The bubble sizes distribution was measured by using function in Matlab to measure the object diameter. Bubble size is measuring by comparing the scale between ruler and pixel photo. From the information of the picture detail, the pixel value of 1mm ruler is 257 x 573. It means that the length of 1 pixel image is 3.89μm. Bubble diameter is measured by converting it from pixel scale to mm or μm scale.

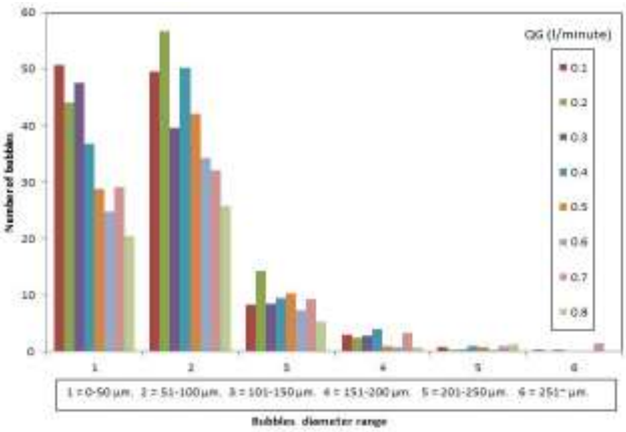


Figure 4.Bubble size distribution under various Q_G.

Figure 4. shows the total bubble sizes distribution in different air supply rates and it only shows bubbles in sizes 30μm-250μm. The increase of air supply rates decrease the amount of bubbles in micro-sizes. The more the air that sucks into microbubble generator the lesser the bubbles in microsizes is produced. These microbubbles were produced when the air flow rate at 0.1-0.7 l/min, but the highest number of microbubble was achieved when the air flow rate at 0.2 l/min.

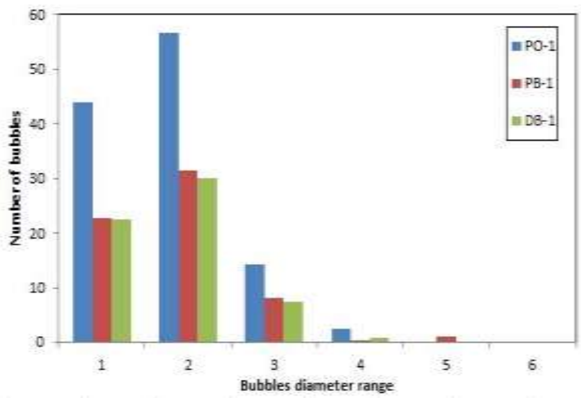


Figure 5. Bubble size distribution from three different MBG at the same Q_G and Q_L condition.

Figure 5. Show that PO-1 generates more bubble in micro sizes than the other. It also shows that bubble with 51μm - 100μm in diameter have the most amount of bubble that is generated.

Pressure Distribution.

The pressure alongside the body inside MBG was measured to analyze the performance of each MBG, The primary variables that we observed to evaluating the performance of microbubble generator were the Pressure. Because the examined MBG are microbubble generator cavitation type which using the amount of pressure drop to generate microbubble (Iriawan, 2013).

Iriawan (2013) was investigated the performance of the MBG with spherical body within the generator and found that, the more increasing the initial pressure or the pressure drop inside the body, the more microbubble generated.The experiments were done based on the value of Q_L from 1.6 m^3/hour to 3 m^3/hour , and Q_G range remains the same ie from 0.1 l / min to 0.8 l / min.

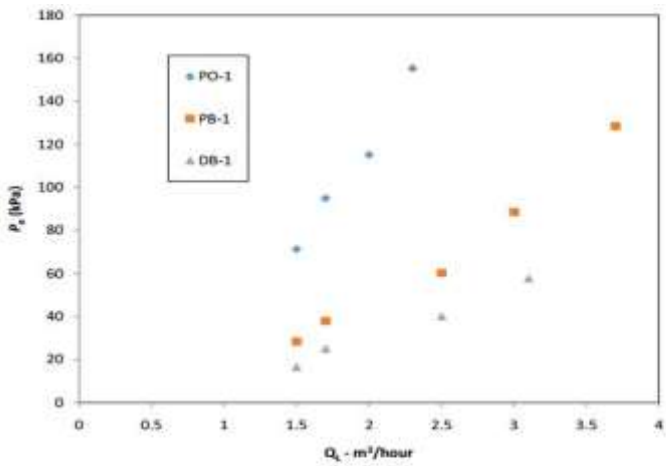


Figure 6. P_a againts Q_L

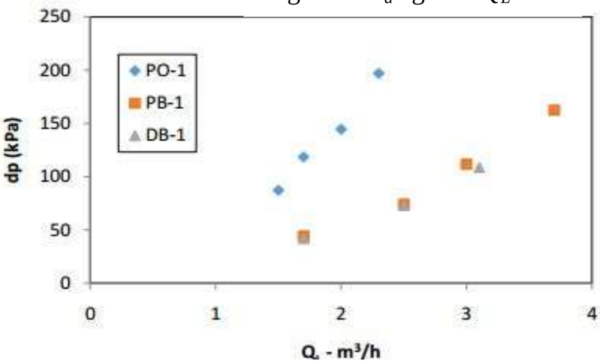


Figure 7. *dp* againts Q_L

Figure 6 and Figure 7 depict the relation between the initial pressure (P_a), the differential pressure (*dp*) and the water low rate (Q_L) respectively. From the figure, PO-01 is higher than the initial pressure at PB-1 and DB-1.It's happened due to the ratio between orifice and pipe diameter. The orifice ratio in PO-01 is smaller than the orifice ratio in other design. Small ratio of the orifice produced higher pressure drop. From the Figure 6 and Figure 7, the number of P_a and *dp* increasing with the increase of Q_L respectively.

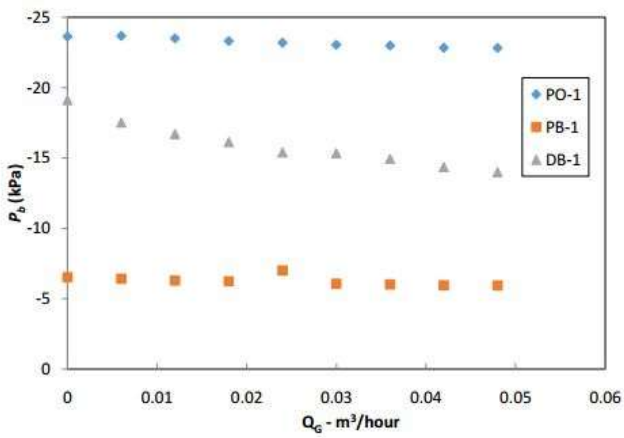


Figure 8. P_b against Q_G

The vacuum pressure (P_b) decreases with the increase of air supply (Q_G) as showed at Figure 8. The vacuum pressure at PO-1 is higher than other designs. The value of water supply is 2m^3/hour. The value of vacuum pressure at DB-1 is higher than PB-1.The perforated area is affecting the ability of MBG to sucks air. The perforated area at porous pipe (PB-1) is larger than drilled pipe (DB-1). The air supply increases with the increase of perforated area in pipe. This is why the number of microbubble decreased when Q_G is increase.

Hydraulic power and Bubble Generator Efficiency.

Hydraulic power (L_w) and bubble generation efficiency (η_B) used as the performance of micro-bubble generator which is formulated by

$$L_w = (p_1 + \rho_L v^2_{L1}/2)\, Q_L,$$

$$\eta_B = \rho_L\, g\, H\, Q_G / L_w.$$

Hydraulic power (L_W) is defined as the power needed by microbubble generator to function. The lower the hydraulic power needed is better, while bubble generation efficiency (η_B) is the energy received by the air from the water per unit time to produce microbubble.

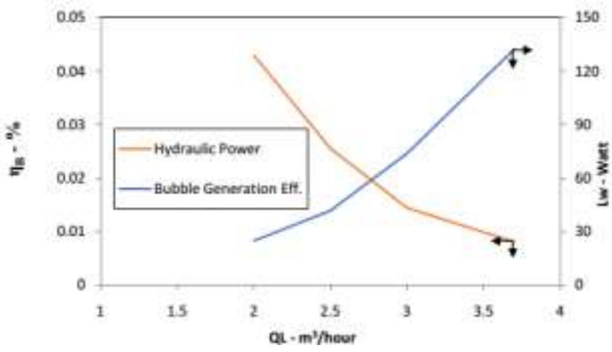


Figure 9. Hidraulic power and bubble generation eficiency againts water flowrate.

Figure 9. compares the hydraulic power and the bubble generation efficiency against water supply rate. L_w increases with the increase of Q_L, on the other hand, η_B decrease with the increase of Q_L. The low efficiency means that most of the water energy is not used to suck air, but is used to break the air into a great number of microbubble

Dissolved oxygen

Dissolved oxygen (DO) is one of the quality water's parameter. The higher the value of dissolved oxygen showed¸ the better the water quality produced. DO meter is used to collecting the DO data. The data collect for every 10 minutes. The author compares the ability of micro-bubble generator to dissolve oxygen in the water by varying the air supply for every micro bubble generator design in the same water supply. In collecting DO data¸ The water temperatures needs to observed to. Temperatures affect the ability of water to dissolved oxygen. Types of DO meter that used is using probe. DO meter that is using probe, will showed the valid value of dissolved oxygen if only the runoff water in primary water tank is less than 0.3m/s. So those MBG have to turn off 15 seconds before DO data is collected.

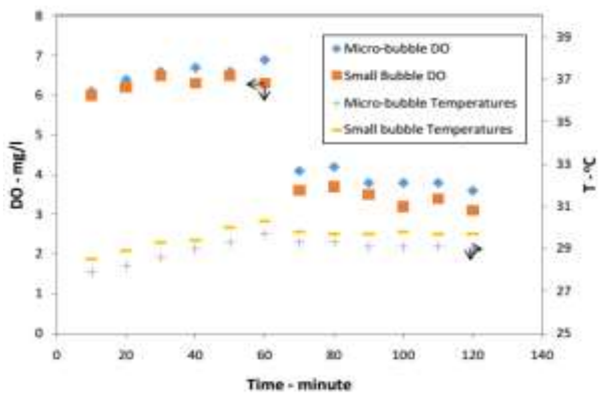


Figure 10. Dissolved oxygen againts time in different size of bubble.

Figure 10. shows the ability of the bubble to dissolved oxygen to the water. With the same Q_L = 3.7 m3/hour¸ air supply for MBG is Q_G = 0.3 l/min for micro-bubble and Q_G = 0.8 l/min for small bubble. PB-1 is used to collect This DO data. The first 60 minutes¸ micro-bubble generator is in turn ON mode. The last 60 minutes¸ MBG is in turn OFF mode. From figure 4.23, in turn ON mode¸ the value of dissolved oxygen by micro-bubble is a little bit higher than small bubble. And for turn OFF mode¸ the value of dissolved oxygen by micro-bubble is also higher than small bubble. This happened because microbubble has low rising velocity characteristic so microbubble dissolved oxygen longer than small bubble.

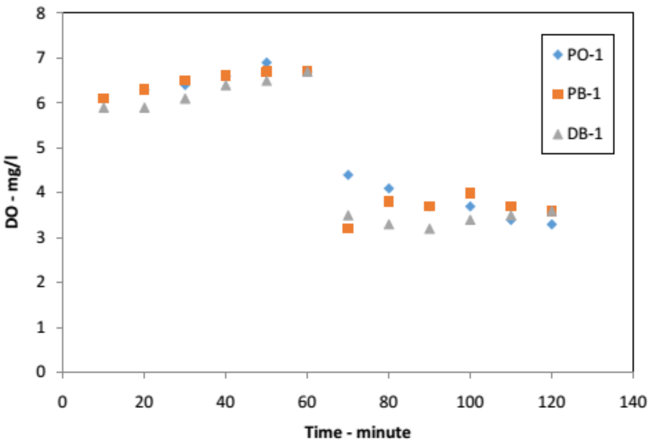


Figure 11. Disolved oxygen againts time in various MBG.

Figure 11. shows the ability of the bubble to dissolved oxygen to the water. With the same Q_L = 2 m3/hour, air supply for microbubble is Q_G= 0.2l/min for each MBG. The first 60 minutes, MBG is in turn ON mode. The last 60 minutes¸ micro-bubble generator is in turn OFF mode. From figure 11, both in turn ON mode¸ and turn OFF mode there are a little bit different value of DO between those 3 designs of MBG because all of MBG produce bubbles in micro-sizes.

Conclusions.

From the experimental result, it can be concluded that, All of micro-bubble generator designs can generate bubble in micro sizes, but The optimum design of micro-bubble generator in producing micro-bubble between those three designs is PO-1. Although it's required more power¸ but the result is equal. Micro-bubble can hold the dissolve oxygen longer than small bubble after the micro-bubble generator turned off.

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References

Asutosh Agarwal,Wun Jern Ng, Yu Liu,2011,'Principle and application of microbubble and nanobubble technology for water treatment',Chemosphere,Vol.84,pp.1175-1180.

Chun liu, T.Hiroshi, Jin Zhang,Lei Zhang, Jiangliang Yang,Xia huang,Nobuhiko Kubota,2013,'succesfull application of Shirasu Porous Glass (SPG) membrane system for microbubble aeration in biofilm reactor treating synthetic waste water', Separation and Purification Technology, Vol 103,pp.53-59.

Goto, Y., A. Serizawa, T. Eguchi, H. Tanaka and M. Izumi, 2006, *Japanese J. Multiphase Flow,* **20,** 39

Ishikawa, M., Irabu, K., Teruya, I., Nitta, M., 2008, *PIV Measurement of a Contraction Flow Using Micro-Bubble Tracer,* Proc. Of JSMF Annual Meeting 2008, Aizu, Japan, pp. 288-289 (In Japanese).

Iriawan. A.G.W., Deendarlianto, Wiratni, Alva Edi Tantowi, and Adhika W, 2013 Experimental Study on Optimization the Suction Volume Air and the Axial Position of the Spherical Body on the Microbubble Generator in a Flowing Water Tube, International Conference of Multiphase Flow (ICMF) 2013, Jeju, South Korea.

Kawahara, A., Sadatomi, M., Matsuyama, F., Matsuura, H., M. Tominaga and M. Noguchi,2009, *Prediction of Micro-Bubble Dissolution Characteristics in Water and Seawater,* Department of Mechanical System Engineering, Kumamato University, Japan

Lecoffre, Y., Domene.,Marcoz, J., 1985,*Micro-bubble Injector*,US Patent, US4556523.

Li¸ P., 2006¸'Development of advanced water treatment technology using microbubbles'¸ Keio University

McCormick, M. E. And R. Bhattacharyya, 1973, *Naval Eng.*, **85**, 11

Ohnari, H, *Application of microbubble technology to fishery*, 2003, Chemical Engineering, **67,** 130-14 (In Japanese)

Ohnari, H., T. Saga, K. Watanabe, K. Maeda and K. Matsuo, 1999, *High Functional Characteristics of Micro-bubbles and Water Purification*, Resources Processing, **46,** 238-244

Ohnari, H., *Water Purification of Ocean Environment* *and Revival of Fisheries Cultivation Using Micro Bubble Technology,* 2002,The 21st Symposium on Multiphase Flow, Nagoya, Japan, July

Rajeev Parmar, Subrata Kuma Majumder,2013, ‘Microbubble generation and microbubble-aided transport intensification- A state-of-the-art report’, Chemical Engineering and Process: Process Intensification, Vol 64,pp.79-97.

Sadatomi¸ M.¸ Kawahara¸ A.¸ Matsuura¸ H.¸ Shikatani¸ S.¸ 2008¸ ‘Micro-bubble generation and bubble dissolution in water by a multi-fluid mixer with orifice and porous tube’¸ Kumamoto University, Japan

Sadatomi¸ M.¸Kawahara¸ A.,Kano¸ A.¸ Ohtomo¸ A., 2005,*Performance of new micro-bubble generator with a spherical body in a flowing water tube*¸ Experimental thermal and fluid science, Vol.29¸ pp. 615 - 623.

abei, K., Haruyama, S., Yamaguchi, S., Shirai, H., Takakusagi, F., 2007, *Study of Micro Bubble Generation by a Swirl Jet*, Dept. Of Mechanical Engineering, Gunma University, **71,** 173-178

Takahashi, T., *Water Treatment Technology and Facility in The Future,* Kagaku Soti*,* **1**, 71-80 (2004) (In Japanese)

Terasaka¸ K.¸ Hibarayashi¸ A.¸ Nishino¸ T.¸ Fujioka¸ S.¸ Kobayashi¸ D.¸ 2011¸ ‘Development of micro-bubble aerator for waste water treatment using activated sludge’¸ Chemical Engineering Science¸ Vol. 66¸ pp. 3172 – 3179.

Yoen, Roe-Hoan., Adel, G.T., Luttrell G.H., 1991, *Process and Apparatus For Separating Fine Particle by Microbubble Flotation Togeteher With A process and apparatus for generation of Microbubbles*, US Patent, US498158.