Effect of Using Bubble Generator on Aeration Efficiency in Closed Fish Tank

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Received: January 8, 2024; Revised: January 17, 2024;
Accepted: January 30, 2024; Published Online: Febuary 25, 2024

Abstract

Usage of air diffuser or jet aerator was a typical technique that used for oxygenation process. However, the occurred bubbles were unstable, rapidly floated to the water surface and small amount of dissolved oxygen level. The objective of this study was to increase the efficiency of air bubble generator to produce the microbubble applying the venturi and pressure. Venturi-type microbubble generator at various pressure (1, 2, 3, 4, 5 and 6 kg/cm^2) and air diffuser were studied and compared. It was found that, the air bubbles from venturi-type microbubble generator without pressure and air diffuser were larger than 1 mm. Because of the unstable bubbles, the water only contained dissolved oxygen level at 3.72 mg/l. Whereas, the size of bubbles was decreased with increasing of the pressure level. Venturi-type microbubble generator with pressure at 6 kg/cm^2 generated the microbubble size 46.13 µm, the water contained dissolved oxygen level at 7.40 mg/l which had the highest rate of dissolved oxygen level. Moreover, venturi-type microbubble generator with pressure at 6 kg/cm^2 also had the highest in the oxygen transfer coefficient, oxygenation capacity, oxygen transfer rate and aerator efficiency which were 6.01 hr^{-1}, 33.20×10^{-4} mg O_2/hr, 3.70 mg O_2/kW/hr and 6.90%, respectively.

Keywords: Venturi-type, Bubble Generator with Pressure Tank, Microbubble Generator, Oxygenation

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Introduction

Currently, microbubble technology is being applied in many areas, such as adding air to wastewater treatment systems to preserve the environment, aquaculture, agriculture, food and beverage processing including scientific work for health and beauty. Since, micron level bubbles are small bubbles with a diameter of 50-200 μm which have a special property in a large amount of surface area contacted with air and does not coalesce into a large bubble and can easy to dissolve or penetrate into liquids. Also, it has low buoyancy that causes it to float slowly to the surface of water than normal air bubbles. (Liu et al., 2013). The method of creating micron-level bubbles (Agarwal et al., 2011), is divided into 4 methods, including the fluid movement, sound waves, electrochemical, and mechanical vibration method. All 4 methods can increase the amount of air bubbles in the system that depends on the purpose of the utilization and the bubble size control factors.

The micron air bubbles generator by using fluid movement is commonly used in the industrial sector due to little consume power and can be used in a variety of environments. Various forms of bubble generators have been developed (Onari et al., 1999; Terasaka et al., 2011; Nakatake et al., 2013) as shown in Figure 1 using fluid movement methods such as Spiral Liquid Flow Type and Pressurized Dissolution Type: Ejector (Ejector Type) and Venturi (Venturi Type).

The working principle of each type of bubble generator is different depends on the nature and structure of the foam generator. The fluid bubble generator rotates in a spiral pattern with high-speed fluid movement that cause centrifugal and shear forces to break down air bubbles into smaller sizes. For the pressure-dissolving bubble generator, when gas in saturated high-pressure water is released into normal pressure water will creates a larger amount of small bubbles. For the ejector and venturi air bubble generators using the principle of high velocity fluid flow through the area where the cross-sectional area changes that affects the pressure and generate the micron bubbles (Sadatomi et al., 2012). But the venturi bubble generator has a distinctive of uncomplicated structure feature, easy to install and no movement of internal parts also minimal uses of energy and easy to maintain (Parmar & Majumder, 2013). Which is suitable for applications such as use as an aeration device that can increase the concentration of dissolved oxygen in water to increase fish growth and agricultural production (Akhtar et. al., 2018; Bagatur, 2014; Dahrazma et al., 2019). It also has high efficiency in aeration (Li, 2006). The venturi bubble generator is a good choice for wastewater treatment systems (Mitra et al., 2016; Kaya et al., 2017). Discharging wastewater from community or industrial sources into natural water is an important problem that must be solved due to the wastewater contains impurities and low amount of oxygen in the water. Wastewater cause to buildup of gases and emit a disturbing odor and harmful for living creatures. Therefore, treating wastewater before releasing it into natural water sources is a process that will help to reduce contaminants and increase the better quality of water.

Currently, there are many methods of wastewater treatment, such as stabilization ponds, artificial pond, aeration pond, and adding biological substances. Each method has different complexity depend on various factors such as the nature and quality of wastewater, treatment costs, efficiency and control systems. The aerobic wastewater treatment system (Aan et al., 2015) is another method that is widely popular due to the low investment but high efficiency. This method used an aerator with a simple working process and maintenance (Nadayil et al., 2015) to increase the amount of oxygen in the water for microorganisms to decompose the organic matter. It takes less time compared to the naturally decompose. There are 4 types of aerators used in wastewater treatment systems: surface aerators, underwater aerator, turbine aerator and nozzle-type aerators. The nozzle aerator is higher efficient in transferring oxygen device than other type. (Panich et al., 2020) studied the effect of pressure on the formation of small air bubbles and the oxygen transfer coefficient using a venturi-style nozzle aerator combined with a pressure tank. It was found that increasing pressure, the rate of formation of small air bubbles and the oxygen transfer coefficient are increased. (Panich et al., 2021) studied the use of venturi with a pressure tank to produce micron-sized air bubbles by simulating the conditions of the water used in the experiment to have the amount of dissolved oxygen equal to zero. It was found that micron sized bubble increased higher and faster oxygen in the water than using porous material. In addition, there was a study of using a microbubble aerator to add oxygen for aquaculture such as tilapia, catfish and found that microbubble aeration can maintain a constant DO level in the water. As a result, aquatic animals are healthy and suitable for breeding due to a high survival rate (Heriyati et al., 2022; Subhan et al., 2022). It also helps in decomposing organic substances in the water and stimulates fish to grow faster when measured by length and weight (Budhijanto et al., 2016) Therefore, to be able to apply the research to fish tanks in closed systems, this research is aimed to comparative study on the use of a micron sized air bubble generator and porous material bubble generator. The objectives of this research activities as follow:

1) To study on the effect of using micron sized air bubble generators at various pressures that affects the size and quantity of micron-level air bubbles

2) To study on the efficiency of dissolving oxygen in water, dissolved oxygen coefficient, the oxygen filling capacity of the aerator efficiency value in oxygen transfer and the oxygen transfer rate of each experimental condition.

Materials and methods

1. Research tools

1.1 Details of the small air bubble generator set

The small air bubble generating set used for the experiment is divided into 3 types: i) a porous material air bubble release head (Air Diffuser) with a diameter of 11.6 mm connected to an air source; ii) a porous material air bubble release head that commonly used in fish farming (Air stone) connected to the air supply, and iii) micron sized air bubble generator. It uses the principle of Venturi (Venturi Tube) made from PVC material as a reducing pipe to create a pressure difference and allow air to flow into the bubble generator automatically. The micron sized air bubble generator is connected to a pressure tank that made from PVC material, pipe diameter 70 mm and 440 mm in length and the pipe size is reduced to a pipe diameter of 22 mm and connected to a globe valve to control the pressure inside the tank which will install a pressure gauge on the pressure tank as shown in Figure 1.

(a) Air bubble release head for porous material (Air Diffuser)

(b) Air bubble release head (Air stone)

(C) Micron sized air bubble kit

Figure 1. Air bubble generator kit.

1.2 Details of the experimental set

The experimental set for studying the effects of micron sized bubbles consists of 2 parts: i) a circulating water test chamber (Circulation Column) and ii) a set for generate micron sized bubbles (Microbubble Generator) characteristics of the test chamber. The flow channel is divided into 3 parts.

The first part is the part connected to the micron-sized bubble generator, width 30 cm, length 25 cm, and height of the baffle 80 cm. The water in the first part will overflow into parts 2 and 3, respectively. For parts 2 and 3, the flow channel is divided by installing a 20 cm height divider and leaving a gap on the cabinet floor in order to have space for water to flow from section 2 to section 3 without air bubbles flowing into the outlet channel and flows to the water tank. The set of micron-sized air bubbles consisting of equipment that creates air bubbles, including a water pump, (Pedrollo, model PQM90, 1 hp), which sucks water from the water tank and supply water into the experimental tank in Part 1 to create a turbulent flow of water in the system. Water flowing into the water pump passes through a flow measuring device (Water Flow Meter) which has a valve to control the water flow rate. And then flows into the micron sized bubble generating unit. Control the air flow with a flow measuring device (Air Flow Meter). The outside air will flow in and mix with water inside the unit, creating micron-sized air bubbles then flows through the water pump and enters into the pressure tank, which is equipped with a valve for controlling the pressure inside the tank. Water containing micron-sized air bubbles will flow out of the pressure tank into the experimental chamber.

The set for measuring the size of air bubbles for the bubble chamber is made from acrylic sheets glued together with clear glass sheets by leaving a gap of 1 mm between the plates and each end is connected to a rubber tube to allow water mixed with air bubbles from the experimental chamber to flow into the bubble retention chamber. Then close the valve to stop the movement of the air bubbles flowing through the test unit. In addition, the area at the top of the chamber traps air bubbles will be equipped with lights and a digital microscope (USB Digital Microscope 1600X) to be used to photograph air bubbles and save the images on a computer as shown in Figure 2

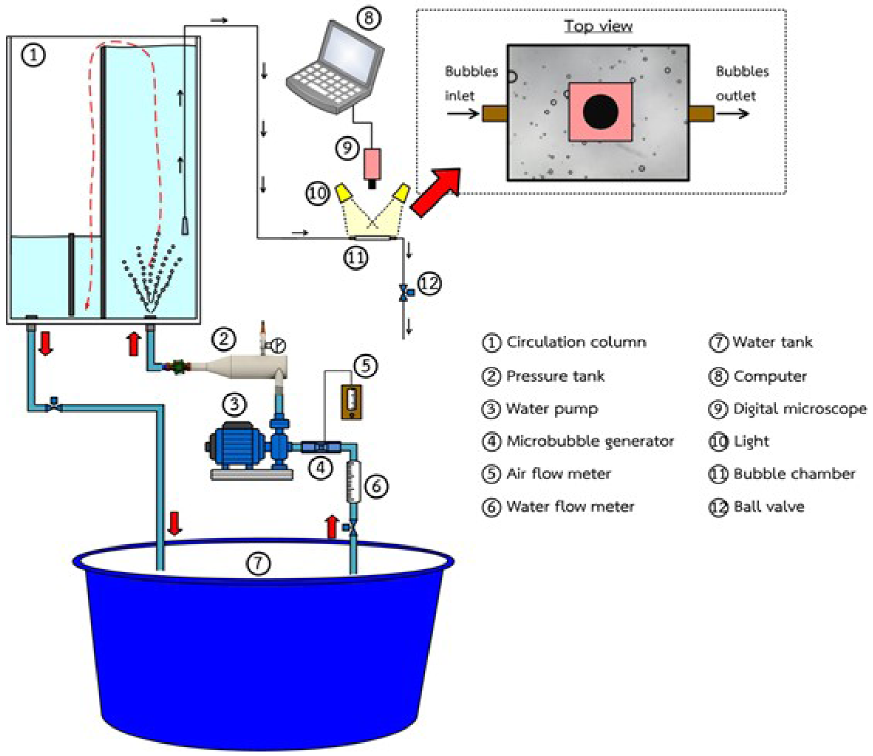

Figure 2. Experimental diagram for the formation of micron-sized air bubbles and air bubble size measurement set.

For a kit to measure the efficiency of adding oxygen to water for closed fish tanks. It is designed to be similar to a real closed fish farming system. A 1,000 liters tank will be used as a tank for studying the efficiency of adding oxygen to the water and connected together with 2, 150 liters tanks which were attached to water filter equipment for fish tanks. The tank for the water added oxygen efficiency measurement (1,000 liters tank) was contained 600 liters of water which was connected together with 2,150 liters tank of water filtration. The water was flown through both 150 liters tanks according to the actual fish farming model. In the water filter tank, the second tank will install a heater immersed in water. And in the tank to measure the efficiency of adding oxygen to the water, a set of copper pipes (Cooling Coils) will be installed, which is connected together with the water chiller to control the water temperature to be constant and use a dissolved oxygen and water temperature meter (DO Meter and Digital Thermometer brand (Lutron DO-5512SD, resolution 0.1 mg/l, accuracy ±0.4 mg/l) for measuring oxygen in the water. Then, the efficiency comparison between adding dissolved oxygen using a porous material air bubble head and a micron size air bubble generator has been evaluated as shown in Figure 3.

2. Data collection

2.1 Study on the size of air bubbles resulting from pressure tanks at various pressures

The formation of micron-sized air bubbles flowing through the unit to measure the size of air bubbles by allowing water mixed with air bubbles to flow into the experimental set. Then close the outlet that the water mixed with air bubbles does not move. The pictures of the air bubbles in the bubble sizing kit had been taken using a digital microscope (USB Digital Microscope 1600X) and release water to allow the captured air bubbles to flow out. Then, the outlet pipe was closed again and the pictures of the size of the bubbles had been taken 30 times in each experimental set. The photographs in each experimental set were then analyzed to determine the size of the bubbles by means of comparing the size to the number of pixels in 1 mm.

2.2 Study on the efficiency of adding dissolved oxygen to water

Study on a micron sized air bubble generator kit using the venturi with a pressure tank and a porous

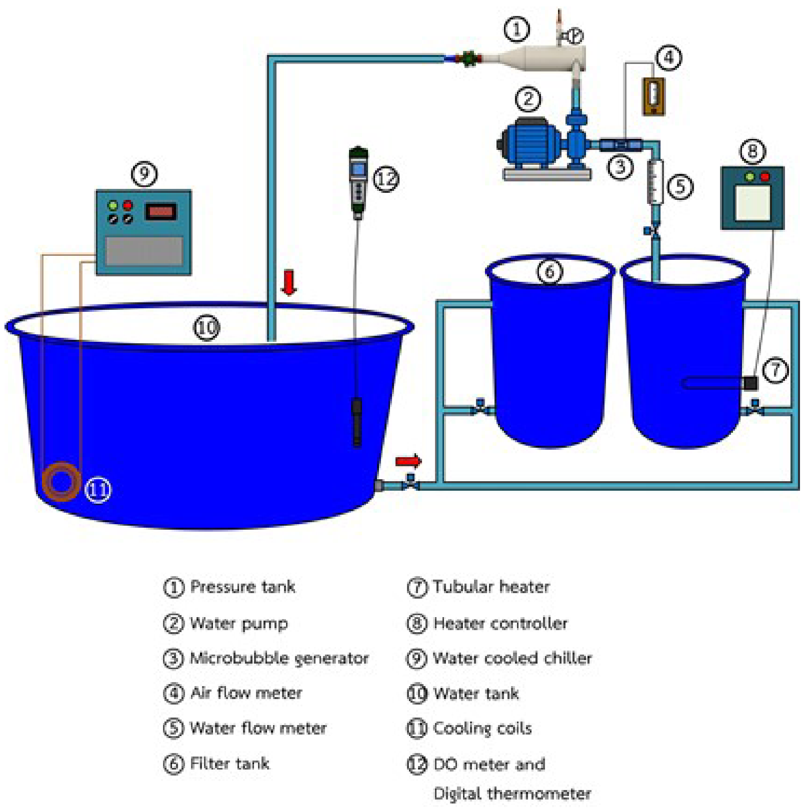

Figure 3. Experimental diagram to determine the efficiency of micron-sized aeration in a closed fish tank.

material type air bubble generator kit that adds air into the water by collecting data on the amount of oxygen in the water that changes all time. The experimental procedure began by adding 750 liters of tap water, controlling the water temperature at 28±1 °C, and reducing the amount of dissolved oxygen with sodium sulfite (Na_2SO_3) mixed with distilled water in a proportion of 1:10 and Cobalt (II) Chloride, $CoCl_2 .6H_2O$) mixed with distilled water in a proportion of 1:100. Then, both solutions were placed in water used for testing by adding 1.5 ml of sodium sulfite solution per 1 liter of water and 0.5 ml of cobalt chloride solution per 1 liter of water, stir the entire water solution and wait until the dissolved oxygen value is 0 mg/l, then turn on the experiment machine by starting from the porous material air bubble generator set that connected to an air pump (Magic, model 6600) which has an air flow rate of 1.5 l/min. Then dissolved oxygen is measured every 2 min until the amount of dissolved oxygen reaches to saturate. Then, change the water again to begin the next experimental procedure. Also, change a micron sized bubble generator kit by using the Venturi in conjunction with a pressure tank to controls the same initial conditions as the porous material bubble generator. Control the constant rate of water flow at 12 l/min with air flow rate of 0.3 l/min. Under this particular condition, the pressure in the pressure tank was adjusted from 0 – 6 kg/cm^2 by measuring the dissolved oxygen in every 2 min until the amount of oxygen in the water reached to saturate. The experimental conditions can be summarized as Table 1.

2.3 Theory of calculation

Aeration and water aeration are the significant parameters in increasing the efficiency of the biological aeration oxygen transfer rate. Therefore, the oxygen transfer coefficient (K_La) (Moutafchieva et al., 2013) must be used depending on the aeration system. The model of aeration equipment water characteristics and temperature for oxygen transfer coefficient can describe in equation (1).

$$\text{Slop} = K_La = 2.303 \left(\frac{\log(C_s - C_1) - \log(C_s - C_2)}{t_2 - t_1}\right) \quad (1)$$

Where K_La = oxygen transfer coefficient (hr^{-1})

C_s = dissolved oxygen concentration in saturated water (mg/l)

C_t = dissolved oxygen concentration at various times (mg/l)

t = time (min)

Oxygenation Capacity (OC) of the aerator by substituting the oxygen transfer coefficient. The ability to add oxygen depends on the characteristics of the aerator. In the case of using an aerator beneath the surface of the water, it can be calculated as in equation (2).

$$OC\left(\frac{mg\ O_2}{hr}\right) = \left[K_La_{(T)}1.024^{(20-T)}\right]\left[C_{S(T)}\frac{P + 73.53d - p}{760 - p}\right]V \quad (2)$$

Where OC = oxygen filling capacity of the aerator (mg O_2/hr)

$K_La_{(T)}$ = Oxygen transfer coefficient at the temperature during the experiment (hr^{-1})

T = water temperature at the time of experiment (°C)

Table 1. Conditions and variables used in the experiment.

Conditions	Variable used
Flow rate of water (l/min)	12
Air flow rate for micron size air bubble generator (l/min)	0.3
Air flow rate of porous material type (l/min)	1.5
Experimental water temperature (°C)	28±1
Gauge pressure air bubble generator kit	- Porous material air bubble generator set, pressure 0 kg/cm^2 - Small air bubble generator set with pressure tank 0 - 6 kg/cm^2

$C_{S(T)}$ = dissolved oxygen concentration in saturated water at the temperature during the experiment (mg/l)

P = Pressure value, any atmospheric pressure value (mmHg)

p = water vapor pressure (mmHg)

d = water depth value in the experimental set (m)

V = Volume of water in the experimental set (liter)

Represents the ability to add oxygen for the oxygen transfer rate (Oxygen Transfer Rate, R_O) as shown in equation (3) and calculate the efficiency of oxygen transfer of various aerators (E) from equations (4) and (5).

$$R_0 = \frac{OC}{P} \tag{3}$$

When R_O = oxygen transfer rate (mg O_2/kW/hr)

P = power supplied to the aerator (kW)

$$E = \frac{OC}{A} \times 100 \tag{4}$$

Where E = efficiency of oxygen transfer of the aerator (%)

A = amount of oxygen added to water at standard conditions (mg O_2/hr)

where $$A = Q_a \rho_{air} (0.23) \tag{5}$$

Q_a = Inlet air volume (m^3/s)

0.23 = weight of oxygen per unit of air

ρ_{air} = density of air at any temperature (at a temperature of 30 °C, ρ_{air} is equal to 1.164 x 10^{-6} g/m^3)

2.3 Data analysis methods

From an experiment on the efficiency of oxygen transfer of a micron sized air bubble generator for aerating water. Each condition was tested 3 times replication. The bubble size measurement was obtained from 30 photographs per experimental condition. The obtained data were analyzed statistically to report and discuss the experimental results.

Results and discussions

From the experiments on the formation of micron sized bubbles and the efficiency of adding dissolved oxygen to water. The results of the experiment explained the foam formation characteristics of various types of bubble generators and the conditions that affect the foam formation characteristics. Including the size of air bubbles obtained from various types of air bubble generator kits. Study on the amount of dissolved oxygen in water at various times until the dissolved oxygen value reaches a saturation value. Then, analyze the dissolved oxygen coefficient. The oxygen filling capacity of the aerator oxygen transfer efficiency and oxygen transfer rate of each experimental condition.

The results of the study found that the air bubble formation from each type of air bubble generating set was made of porous material (Air Diffuser) and bubble releasing head (Air Stone). The resulting air bubbles were large. Therefore, air bubbles quickly rise to the surface of the water. The air bubbles obtained from the kit generate micron-sized of air bubbles at a pressure of 0 - 1 kg/cm^2, the resulting air bubbles became smaller according to the pressure in the tank. In addition, the pressure in the pressure tank was found in the ranges of 2 - 4 kg/cm^2, due to smaller size of the air bubbles and increase in quantity with the pressure. This is because of the pressure inside the tank affects the accumulation of small air bubbles. However, there are still some bubbles that are large and quickly rise to the surface. In the case of increasing the pressure in the pressure tank to 5 kg/cm^2 and 6 kg/cm^2, there were many small air bubbles and accumulation of bubbles which have the appearance of a group of cloudy white air bubbles similarly to milk inside the experimental tank and the group of air bubbles slowly floats to the surface of the water as shown in Figure 3. And, when turning off the micron sized air bubble generator in 5 minutes, the air bubbles obtained from the tank pressure of 0-3 kg/cm^2 would completely disappear and float to the surface of the water. However, within a tank pressure of 4-6 kg/cm^2, the air bubbles still remain due to the pressure and generate a lot of micron sized bubbles with long time floating in the water as shown in Figure 4.

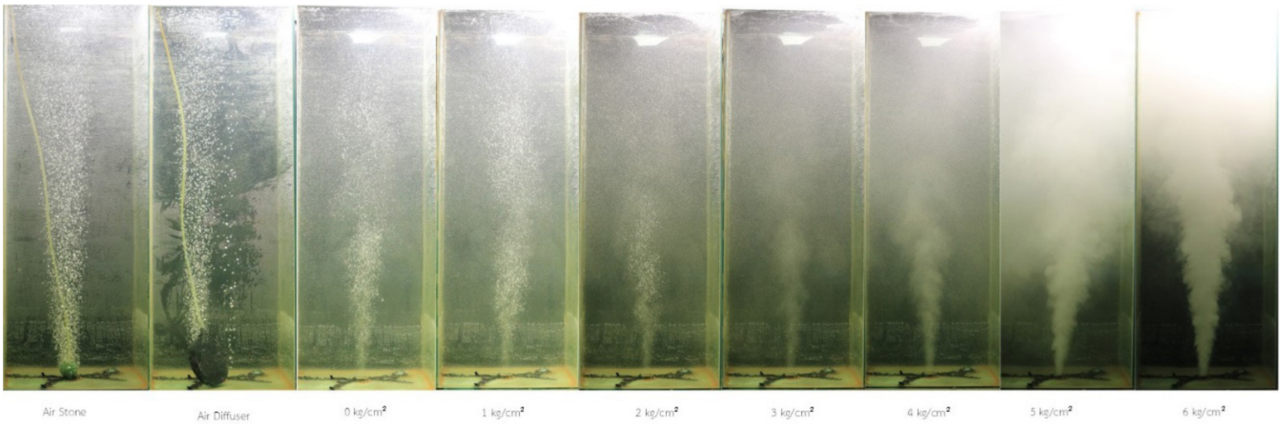

Figure 3. Characteristics of air bubble formation from various types of air bubble generator kits.

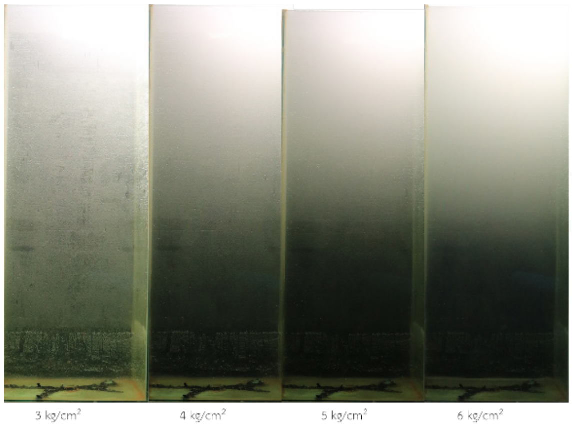

Figure 4. Remaining of air bubbles after turning off the micron-sized bubble generator for 5 minutes.

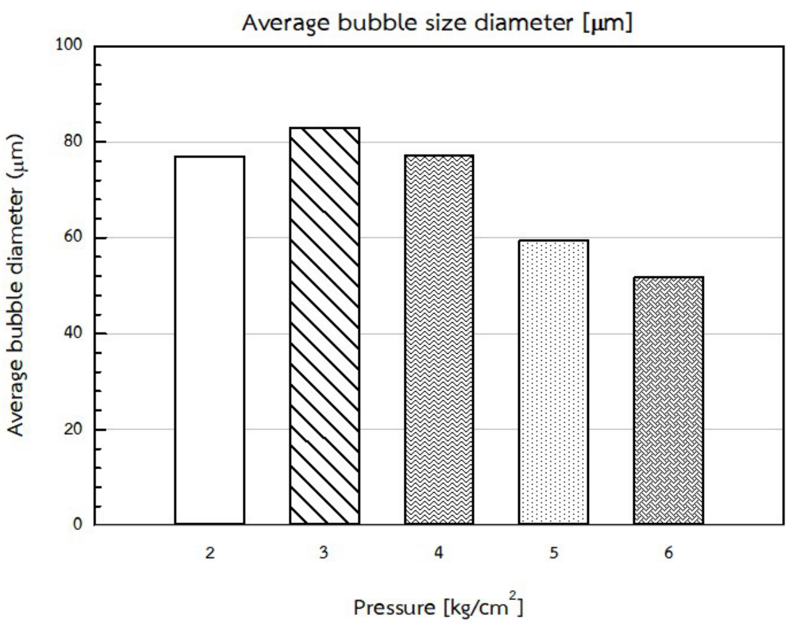

Figure 5. Effect of pressure level on the average bubble size diameter (µm).

From studying the size of air bubbles in the porous material air bubble generator set that generate the micron sized of air bubbles at pressures of 0 and 1 kg/cm^2, found that the air bubbles were larger than 1 mm. But, when the pressure in the pressure tank was increased from 2 - 6 kg/cm^2, the air bubbles were smaller at the micron level and increase in the amount of micron sized bubbles. In addition, at pressure in the range of 5 – 6 kg/cm^2, similarly size of air bubbles were generated. At a pressure of 6 kg/cm^2, the average of smallest micron bubble size was 51.71 μm as shown in Figure 5. For the size of air bubble, it was found that the kit most likely generated the micron-sized air bubbles in the range of 1 – 50 μm. From the experiment, it was revealed that the increasing of pressure in the tank, it caused increasing of micron-sized air bubbles to accumulate and float in the water for a longer time. Where a pressure of 6 kg/cm^2 has the greatest amount of small-sized air bubbles. However, the amount of micron-sized air bubbles was decreased when decreased the pressure, the results was represented in Figure 6.

Results of the study on dissolved oxygen, initially, the water was conditioned to have an oxygen content equal to 0 mg/l. From the experiment, found that the micron-sized bubble generator set at a pressure of 0 kg/cm^2 had the lowest dissolved oxygen value of 4.24 mg/l due to the bubbles formed in large-sized. This causes air bubbles to rise quickly to the surface of the water. In addition, the air flow rate into the machine was controlled to generate small micron-sized air bubbles. Therefore, causing the least amount of dissolved oxygen in the water. When, the generator kit generated micron-sized of air bubbles at a pressure of 1 kg/cm^2, the smaller sized air bubbles had been found compared to a pressure of 0 kg/cm^2, but still large and then float to the surface of the water. However, for the case of increase the dissolved oxygen to 5.35 mg/l, the air bubbles were smaller in size, but less than from the porous air bubble release head. Which the head releases in both types of air bubbles at similarly dissolved oxygen value of 6.26 mg/l, both bubble heads release air as the air pump with an air flow volume of 1.5 l/min, thus producing a higher dissolved oxygen value. In the case of generate micron-sized air bubbles at pressures ranging from 2 - 6 kg/cm^2, it directly affects the smaller air bubble size and the quantity of micron-sized air bubbles, respectively. The results showed that the rate of oxygen dissolution in water increased with the increase in pressure. At a pressure of 6 kg/cm^2, the amount of dissolved oxygen was 7.3 mg/l where the dissolved oxygen become saturated. From the slope of the graph of dissolved oxygen shown in the dotted line in Figure 7. that can be used to calculate the coefficient of oxygen transfer into the water.

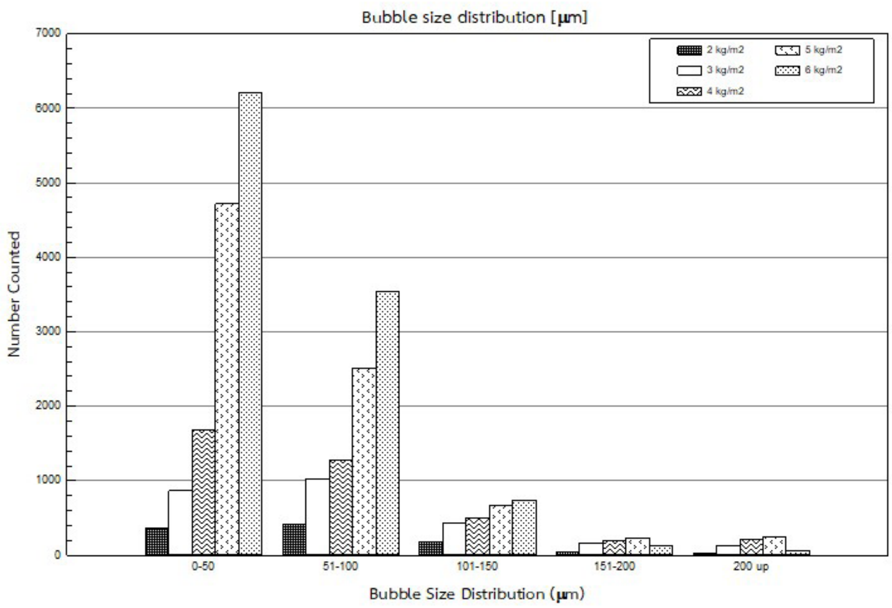

Figure 6. Effect of pressure level on the bubble size distribution (μm).

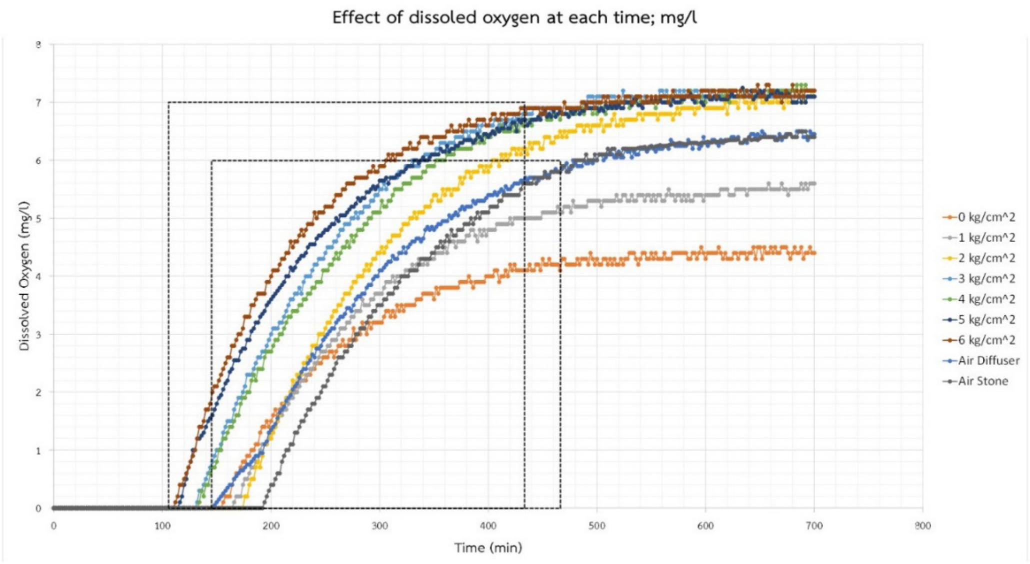

Figure 7. Effect of various types of air bubble generator kits on dissolved oxygen (mg/l) at various time.

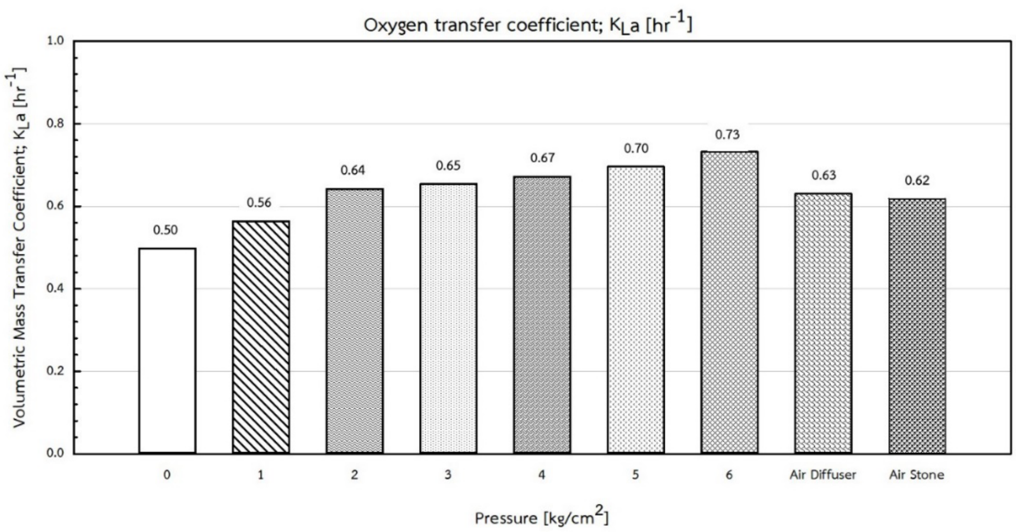

Figure 8. Effect of various types of air bubble generator kits on oxygen transfer coefficient (hr^{-1}) in water.

Results of dissolved oxygen represented increase of the curve in the dotted line as shown in Figure 7, the coefficient of oxygen transfer in water was found as shown in Equation (1) and found that the micron sized air bubble generator set at a pressure of 0 - 1 kg/cm^2 had the lowest oxygen transfer coefficient due to the large sized air bubbles quickly float to the surface of the water with minimal oxygen transfer into the water. When considering a porous material bubble generator kit and air bubble release head, there will be an increased in the oxygen transfer coefficient due to the amount of air passing through the two bubble nozzles with a higher air flow than the micron-sized air bubble generator unit at a pressure of 0 – 1 kg/cm^2. But, when increasing the pressure in the micron-sized air bubble generator unit at a pressure of 2 – 6 kg/cm^2, as a result, micron-sized air bubbles will increase according to the pressure of the micron-sized air bubble generator unit. Then, the oxygen transfer coefficient in the water increases according to the pressure of the micron-sized air bubble generator. At a pressure of 6 kg/cm^2, the highest oxygen transfer coefficient is 0.73 hr^{-1}, as shown in Figure 8. For the case of adding oxygen to water obtained from the oxygen transfer coefficient in water, substitute the values into equation (2), found that the micron sized air bubble generator set at a pressure of 2 - 6 kg/cm^2 had a better value for adding oxygen to the water. According to the pressure of 6 kg/cm^2, the highest water oxygenation capacity is 0.0032 mg O_2/hr as shown in Figure 9.

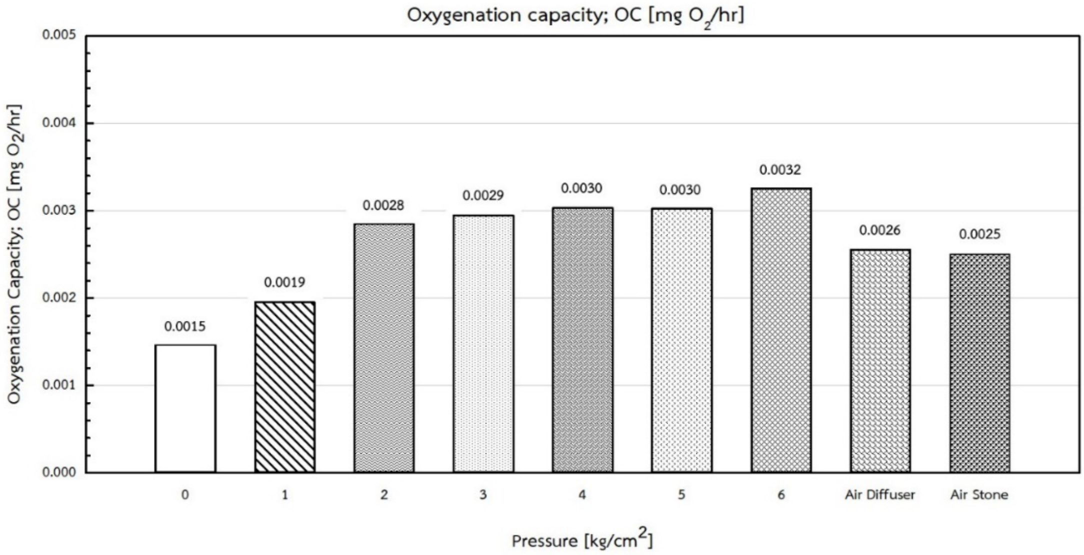

Figure 9. Effect of various types of air bubble generator kits on oxygenation capacity (mg O_2/hr) in water.

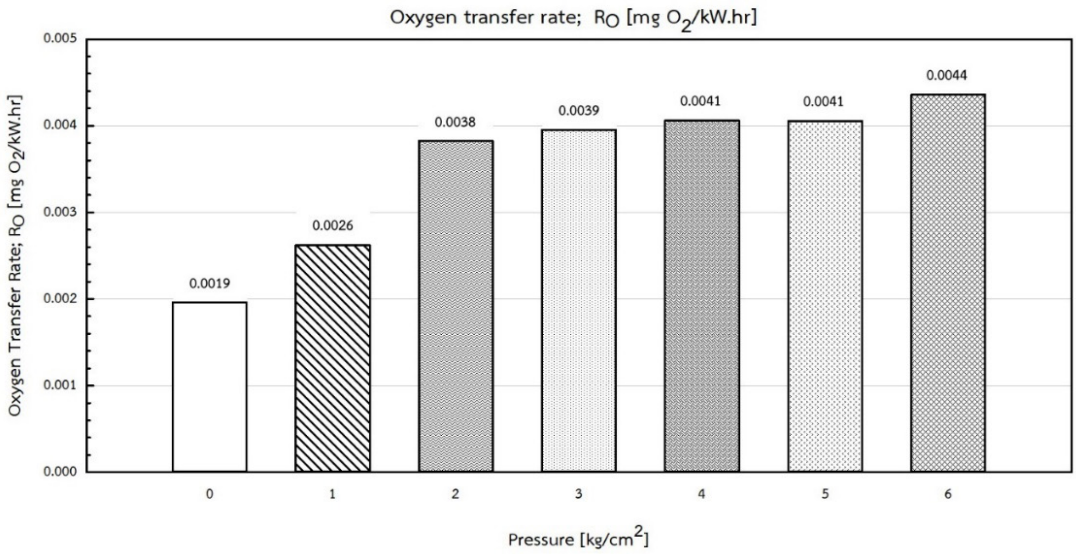

Figure 10. Effect of pressure level on oxygen transfer rate (mg O_2/kW.hr).

From studying the rate of oxygen transfer by substituting the value of adding oxygen to the water into equation (3), found that the micron-sized air bubble generator set at a pressure of 0 kg/cm^2 would have the lowest oxygen transfer rate of 0.0019 mg O_2/kW.hr and gradually increased. According to the micron sized air bubble generator set at a pressure of 6 kg/cm^2, the highest oxygen transfer rate of 0.0044 using porous materials has a better oxygen transfer rate. For the case of increase the pressure from 2 - 6 kg/cm^2, the ability to add oxygen to the water will improve accordingly. In this case, the pressure is at 6 kg/cm^2, 0.0044 mg O_2/kW.hr as shown in Figure 10. For the oxygen transfer efficiency of the aerator obtained by taking the value of the ability to add oxygen in the water, substitute the values into equations (4) and (5), found that the porous material type air bubble generator set, the oxygen transfer efficiency value is higher than the micron size air generator set at 0 – 1 kg/cm^2. But when increasing the pressure of the micron size air bubble generator set in the range of 2 – 6 kg/cm^2, the efficiency of oxygen transfer in water will increase as the pressure increases. At a pressure of 6 kg/cm^2, the efficiency of oxygen transfer in water is the best at 67.3%, as shown in Figure 11.

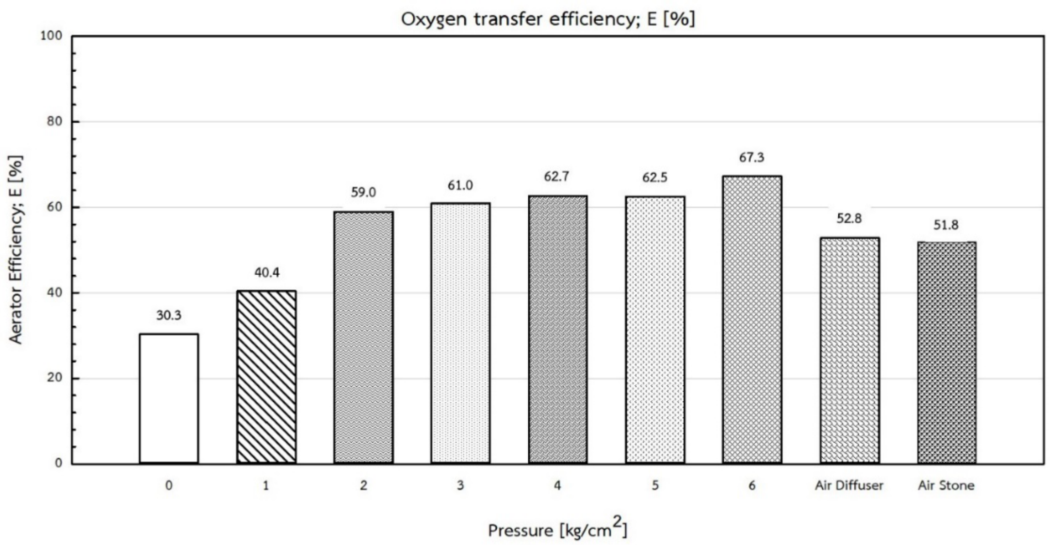

Figure 11. Effect of various types of air bubble generator kits on oxygen transfer efficiency of the aerator.

The formation of air bubbles from each type of air bubble generator kit found that the porous material type air bubble generator set generate a large sized air bubble. Therefore, air bubbles quickly rise to the surface of the water. And there are some bubbles that break before rising to the surface of the water. The air bubbles obtained from the kit generate micron-sized air bubbles. As a result, the air bubbles become smaller and the amount of air bubbles increases as the pressure increases inside the pressure tank. Therefore, the appearance of the bubbles formed affects the dissolution of oxygen in water corresponds to the oxygen transfer coefficient. Oxygen transfer capacity and rate represent the efficiency of oxygen transfer of each type of aerator. Thus, increasing the pressure in the tank, as a result, have significantly increased the values.

Conclusions

From a study of micron sized air bubble generator kits on the efficiency of adding oxygen to water for closed fish tanks. The results of the experiment can be summarized as follows.

1. The characteristics of air bubbles are different depends on the model of the bubble generator set. For the porous material type, bubble generator set can form air bubbles that are larger than 1 mm, causing the air bubbles to have a little surface area and quickly float to the surface of water. The set of micron-sized air bubbles generator was found that when the pressure increased, the air bubbles became smaller and a lot of quantity. At a pressure of 6 kg/cm^2, the greatest amount of small air bubbles was formed and the average bubble size was 51.71 µm.

2. Effect of dissolved oxygen in water while turning on the air bubble generator. It was found that the porous material air bubble generator set and bubble nozzle had a higher dissolved oxygen content than the micron sized air bubble generator set at a pressure of 0 – 1 kg/cm^2. But the resulting air bubbles are still large, causing the dissolved oxygen saturation value to be less than the micron sized air generator set at a pressure of 2 - 6 kg/cm^2, with a pressure of 6 kg/cm^2 having the highest amount of dissolved oxygen, which is 7.3 mg/l at the point where dissolved oxygen become saturated with the same rate of dissolved oxygen.

3. Micron sized air bubbles generator set at the pressure of 6 kg/cm^2, the oxygen transfer coefficient, the oxygen filling capacity and oxygen transfer rate in water were the highest at 0.73 hr^{-1}, 0.0032 mg O_2/hr, and 0.0044 mg O_2/kW.hr, respectively. In addition, the oxygen transfer efficiency of the aerator was the highest value is 67.3%.

Recommendations

From the test results, it was found that there should be further testing as follows.

1. Experiment with raising real fish in a closed system as well as study on the quality of water ob-

tained from actual fish farming.

2. Apply micron sized air bubble generators for other uses.

3. Comparative economic studies regarding costs value in building and energy used.

Acknowledgments

Greater indebted for Faculty of Engineering, Princess of Naradhiwas University that supports the budget for publishing and disseminating works and thank for the Thailand Science Research and Innovation (TSRI) for supporting the budget for this research.

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