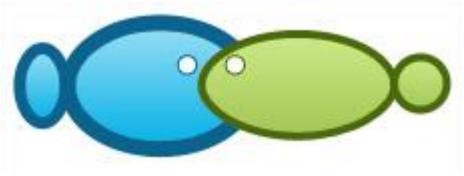

Microbubble aerator test and harvest target prediction based on oxygen consumption of red tilapia (*Oreochromis* sp.)

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Abstract. This study compared the performance of microbubble aeration to conventional aeration system (blower) in increasing Dissolved Oxygen (DO) content, measure the standard oxygen transfer rate (SOTR), Standard Aeration Efficiency (SAE), and assessed the oxygen consumption of red tilapia to estimate the harvest target. The results showed that in the rate of air discharge of 3 L min^{-1}, the microbubble aerator produced higher DO content (6.58±0.03 mg L^{-1}) than conventional aerator (5.59±0.24 mg L^{-1}). The increase of DO content in microbubble aeration was amounted to 2.13 mg L^{-1}, while the DO content in conventional aeration increased 1.14 mg L^{-1} from the control treatment. The SOTR value from the microbubble aeration was 0.0019 kg O2 h^{-1} with the SAE value of 0.022 kg O2 KW^{-1} h^{-1}. The values were higher than the conventional blower aeration treatment with SOTR value of 0.0007 kg O2 h^{-1} and SAE value of 0.0067 kg O2 KW^{-1} h^{-1}. This study also assessed the DO value of recirculating aquaculture system (RAS) where the DO value produced by microbubble aeration was 7.44±0.14 mg L^{-1}, which was significantly higher ($p<0.05$) than the conventional aeration (6.51±0.26 mg L^{-1}) and the control treatment (5.35±0.06 mg L^{-1}). The measurement of the oxygen consumption rate of fed tilapia was higher than the unfed treatment. The value of oxygen consumption rate of fish in fed treatment and the measured DO value was used to estimate the number of fish harvested in certain body weight. This study concluded that microbubble aerator produced higher DO value, increased the rate of oxygen transfer, and saved more energy compared to conventional blower aeration. The harvest target of fish cultured with microbubble aeration was 17 % higher in comparison with blower aeration.

Key Words: dissolved oxygen, fish oxygen consumption, harvest target, microbubble aeration

Introduction. Aeration system for aquaculture has been developed to support the cultivation of fish and invertebrate biomass. In semi-intensive aquaculture systems, aeration system is periodically used when the dissolved oxygen (DO) content in culture media depleted. However, in intensive aquaculture systems, aeration is always utilized for the culture media (Boyd 1998). The constant utilization of aeration is typically used due to the high presence of waste materials in the media. The chemical process to breakdown the waste materials absorb the oxygen content in the cultivation media. The process thus increased the DO demand not only for the biological needs of cultivated fish. Boyd (2017) stated that good management of water quality will lower the negative impact of aquaculture waste materials to the cultured organism.

The assessment of aeration tools for its efficiency is needed to be performed, considering aeration is one of the most intensive costs in Asian aquaculture, and amounted from 45% to 75% of total energy cost in aquaculture (Rosso et al 2008), while in the more developed countries, they only amounted to 1% of total utilized electricity (Zimmerman et al 2011). In China, the electricity that was utilized by mechanical (conventional) aeration in aquaculture ponds made up 30% of total electricity consumption in the agricultural sector in 2017. According to Kumar et al (2013), the cost needed for mechanical aeration was 15% of total production cost in the intensive aquaculture system, calculated alongside larva and feed cost. Hence, the choice of the aeration system is crucial for maximizing profits in intensive aquaculture systems.

The utilization of varied types of aerators has been conducted in fish aquaculture systems, and the assessment of the oxygen transfer efficiency of different types of aerators has been tested (Boyd & Ahmad 1987; Boyd 1998; Andinet et al 2016). However, most of the tests of different types of aerators usually produced coarse bubbles that quickly rise and burst on the water surface, thus decreasing their efficiency in gas transfer (Heo & Kim 2004; Endo et al 2008; Oh et al 2013).

As aquaculture technology advances, the microbubble aeration system was invented. The microbubble aeration system has several different characteristics than the conventional millimeter-sized bubble (Li 2006). The advantages of microbubble aeration compared to conventional aeration are its ability to produce micro-sized bubbles, which increased oxygen solubility (Sadatomi et al 2012; Endo et al 2008; Deendarlianto et al 2015), better-dispersed gas, have larger surface area contact with water, have slower bubble rise speed (Takahashi 2003; Liu et al 2013; Parmar et al 2013), and have lower energy consumption (Parmar et al 2013). Microbubble aeration can also degrade waste with higher efficiency (Rehman et al 2015; Wu et al 2019). Previous studies reported that micro-sized bubbles increased growth in fish aquaculture (Matsuo et al 2001; Onari et al 2002; Nobui et al 2002; Wiratni et al 2017).

Microbubble aeration test was previously conducted by Andinet et al (2016), in which he assessed the effect of the operational parameter of microbubble generation in producing DO in water with the focus of oxygen mass transfer (K_La). This study focused more on assessing the performance of microbubble aerators in comparison to conventional aeration in producing DO, gas transfer, and standard efficiency value by equalizing air discharge rate in both instruments. The DO value produced by the aerator and fish consumption rate was set as the basis for calculating carrying capacity, which is the capacity of an ecosystem or aquaculture in maintaining a healthy environment for maximum production of an organism (Legović et al 2008). Willoughby (1968) stated that carrying capacity was restricted by oxygen consumption and available oxygen as limiting factors in determining the pond capacity. Following that premise, the present study predicted the harvest target density with oxygen solubility approach, which was produced by the microbubble aerator in recirculating aquaculture system (RAS), and the calculation of oxygen consumption rate in the cultivated tilapia fish. The dissolved oxygen variable is considered crucial in determining the stocking density (Nabhitabhata et al 2002). The optimization of tilapia production depended on the carefully determined stocking density (Glasser & Oswald 2001). The higher value of carrying capacity with larger fish can be obtained by decreasing stocking density. The determination of stocking density in every step of both hatchery and fish growing is crucial in increasing the success of aquaculture processes (Boyd 1990).

Material and Method

Location and study period. This research was carried out at the Aquaculture Laboratory, Department of Fisheries, Faculty of Agriculture, University of Gadjah Mada (UGM), Yogyakarta (7°46'1.5' S, 110° 22' 54' E) Indonesia, during December 2019.

Aerator equipment test. In this study, the performance of microbubble aerator in aquaculture systems was tested and compared to conventional aerators (blowers) and included non-aerated media as the control treatment. The equipment used was microbubble aerator type with orifice and porous pipe/multi-fluid mixed aerators with pump specifications as follows: Yamano WP-106 brand, with a power of 85 W, a maximum discharge of 4 m3.h-1, maximum head of 4 m. The conventional aerator CE used was Resun LP 100, with 140 L min-1 output and 100 W power. Other tools used are gas flow meter, wind hose, and Water Quality Checker (WQC-YSI MM). The input and output apertures of the microbubble aerator were 19 mm in diameter, while the diameter of the microbubble aerator was 46 mm. Two different sizes of pipes were used in this study. Pipes with 1-inch diameter were used as pump output while 1-inch diameter pipes were used for pump input. To regulate the flow rate of air entering the aerator, a

rotameter-type gas flowmeter was used. A set of recirculation system units with a water discharge of 1.8 L min^{-1} was used for water recirculation.

The performance conventional aerator, microbubble aerator, and non-aerated pond were tested in terms of their dissolved oxygen (DO) production. The samples measured were 800 L of water from each treatment. The waters in each treatment were left still for 24 hours without additional treatments that decrease the DO level. The initial DO value used in this study was 4.39±0.02 mg L^{-1}, following the previous study by Andinet et al (2016) that used an initial DO of ±4 mg L^{-1}. DO measurement test for each treatment was carried out for 3 times. In the microbubble aerator test, natural air was introduced into the water through a microbubble aerator with an adjusted gas flow rate of 3 L.min^{-1}. DO level measurement was performed every 30 minutes until the DO level on the microbubble aerator reaches 85% saturation at the 210^{th} minute. The time of DO measurement for the conventional blower aerator treatment was adjusted to the measurement time for the microbubble aerator treatment. Temperature measurements were taken along with DO measurement because the temperature affects the solubility of the gas.

This research was carried out in indoor conditions, and the ambient temperature was relatively uniform at 27.99±0.13^oC. The parameters measured at this stage are dissolved oxygen (DO) test, oxygen deficit (OD), K_La_T, K_La_{20}, and SOTR (Boyd 1998). The calculation of SOTR was based on the method by Boyd (1998), in which the measured DO level is converted to the measured DO value in the temperature equivalent to the standard temperature of 20^oC and 1 atm pressure. The DO concentration was also measured on the media with 140 individuals of test fish (equivalent to 10 kg) in aeration and non-aeration treatments until the DO value in the non-aeration treatment reached zero.

To test the DO resistance of the aeration device, in the 210^{th} minute both the microbubble aerator and the blower were turned off and the oxygen level was measured. The decrease of DO value was measured up to the point where the DO level in the microbubble aerator treatment was like the initial DO level at the start of the experiment. The aerator was also tested in a RAS with a water flow rate of 0.03 L.sec^{-1} without the addition of fish.

Standard oxygen transfer rate (SOTR) calculation. DO concentrations at saturation (Cs) for certain water temperatures and barometric pressures can be calculated as follows:

$$Cs = C_{tab} \text{ X } BP/760$$

where: Cs: DO concentration on saturation (mg L^{-1}); Ctab: DO concentration at existing temperature & standard barometric pressure (mg L^{-1}) (Cole 1983); BP: barometric pressure (mmHg).

DO pressure in water can be estimated as:

$$PO_2 = Cm /Cs \text{ X } 0.2095 \text{ X } 760$$

Oxygen deficit (OD) values are calculated as follows:

$$OD = Cs - Cm$$

where:
PO_2: DO pressure in water (mmHg)
Cm: DO concentration measured in water (mg L^{-1})
OD: oxygen deficit (mg L^{-1})

The oxygen transfer test in a stable state was carried out according to Boyd's calculations (1998). Oxygen deficit (OD) values from minute 0 to minute 15 were transformed into Ln deficit OD (Y) plotted versus aeration time (X); two points of

saturation values were chosen to obtain oxygen deficit at two different times during aeration to estimate the slope of the reaeration line and determine the oxygen transfer coefficient (KLa), to make the reaeration line linear, then the regression analysis line was drawn. The result was converted to the standard 20°C state using the following equation:

$$K_La_{20} = K_La_T : 1.024^{T-20}$$

Furthermore, for the calculation of SOTR using the following formula:

$$SOTR = (K_La_{20})(Cs_{20})(V)(10^{-3})$$

where:
SOTR: standard oxygen transfer rate (kg oxygen h^{-1})
KLa20: oxygen transfer coefficient at 20°C h^{-1}
Cs_{20}: DO concentration on saturation (mg L^{-1}) and 20°C
V: tank volume (m^3)
10^{-3}: kg g^{-1}

$$SAE = STOR / power (kg\ O_2\ KW^{-1}h^{-1})$$

SOTR is the amount of oxygen that the aerator will transfer to water per hour under standard conditions (clean water at 20°C temperature). The SOTR value was divided by the power applied to get the standard aeration efficiency (SAE).

Measurement of oxygen consumption rate. Oxygen consumption was measured both in fed and unfed fish treatment. Metabolic measurements were carried out on conditions after the organism is fasted (postabsorptive), at neutral environmental conditions, and the organisms were in resting state (low-motility state) (Wuenschel et al 2005). Fish were fasted to ensure that all fish were in the same nutritional condition, and temperature measurements were also taken when measuring fish oxygen consumption. The measurement of oxygen consumption was also carried out on fish after being fed for 3 days, to confirm the increase of oxygen consumption rate.

The fish used in this study was red tilapia (*Oreochromis* sp.), nilasa strain, a nationally accredited superior strain (MMAF-RI 2012). Fish were of various sizes, ranging from 15 to 289 g. The fish were kept in a fiber container. In conjunction with oxygen consumption measurement, fish were placed in containers whose size can limit the fish to small movements. Measurements were made using one fish per container. Fish measuring 15-100 g were placed in a 3 L container, fish measuring 100-200 g in a 6.5 L container, and fish with a weight of more than 200 g were placed in a 10 L container. DO levels were measured using Water Quality Checker (WQC), carried out within one hour and calculated with the following formula (Salas-Leiton 2008):

$$OCR = (DO*V)/(B*T)$$

where:
OCR: oxygen consumption rate
DO: dissolved oxygen concentration (mg L^{-1})
V: tank volume (L)
B: single biomass (kg)
T: time (h)

The results of the fish oxygen consumption measurement were then used to calculate fish carrying capacity (CC) of various sizes.

Calculation of carrying capacity (CC) and harvest target. The information on fish oxygen consumption levels allowed for direct calculation of CC, with the following formula (Ross & Ross 1983):

$$CC = 0.06\ X\ \frac{(Ci-Cm)}{OCR}$$

where:
CC : carrying capacity (kg L^{-1})
Ci : measured DO
Cm: DO minimum of 5 mg L^{-1} (Boyd 1998)
OCR : oxygen consumption (mg O_2 $g^{-1}h^{-1}$)

The calculated carrying capacity level was then used to determine the stocking density for harvest target (SDHT) based on the size of the fish using the following equation:

$$SDHT = CC / weight\ (g)$$

Statistical analysis. All data obtained from this study were analyzed with a one-way variant analysis (ANOVA) using SPSS version 25. Duncan's Multiple Range Test was used to compare significant differences between treatments. K_La_T, K_La_{20}, SOTR, and SAE values on microbubble aerators and blowers in the t-test. The treatment effects were considered with a significance level of $p<0.05$.

Results

Aerator test. The results of the aerator test are shown in Figure 1. The microbubble aerator produced DO at saturation levels reaching 85% by an average of average 6.58±0.03 mg L^{-1} with a DO increase of 2.13 mg L^{-1} from the control, higher than the blower aerator whose DO value was 5.59±0.24 mg L^{-1} with an increase of 1.14 mg L^{-1} ($p<0.05$).

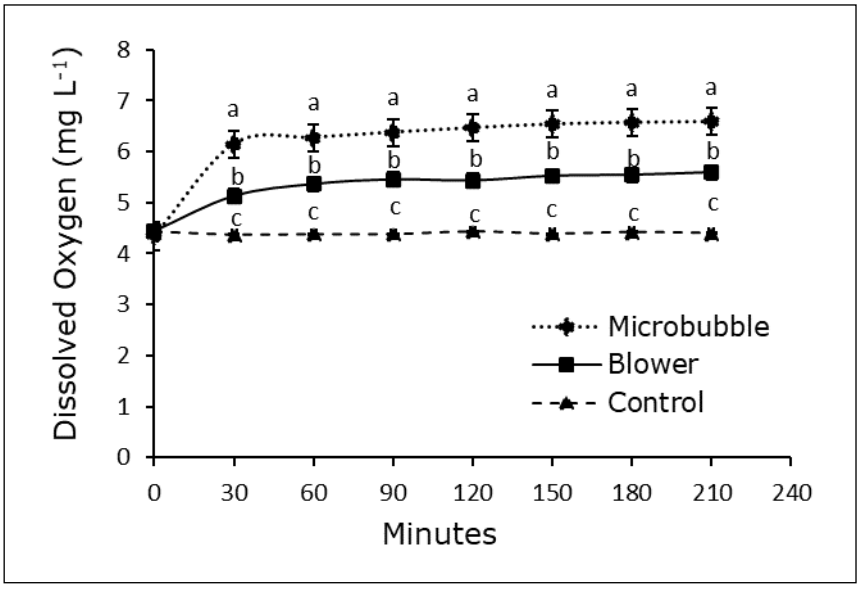

Figure 1. DO levels produced for 210 minutes in the aeration and non-aeration treatments (Different letters on the treatments show significant differences at 5% level).

Oxygen deficit (OD) values in the aeration treatment are presented in Table 1. The values were then transformed into ln for calculating SOTR and SAE in the microbubble aerator and conventional blower aeration treatment (Figure 2).

Table 1

Oxygen Deficits (OD) values

Minute	*Microbubble*	*Blower*	*No aeration*
	OD	*OD*	*OD*
0	4.34±0.06	4.31±0.03	4.28±0.02
30	1.62±0.10[a]	2.42±0.15[b]	3.56±0.10[c]
60	1.50±0.15[a]	2.41±0.31[b]	3.52±0.07[c]
90	1.39±0.09[a]	2.32±0.29[b]	3.44±0.01[c]
120	1.31±0.03[a]	2.34±0.39[b]	3.51±0.05[c]
150	1.24±0.08[a]	2.26±0.35[b]	3.51±0.07[c]
180	1.20±0.06[a]	2.23±0.29[b]	3.51±0.07[c]
210	1.19±0.03[a]	2.18±0.25[b]	3.51±0.07[c]

Note: Different letters on the same line show significant differences at 5% level.

Microbubble aeration has an oxygen deficit value of 1.19±0.03 mg L^{-1}, significantly different from the blower treatment which value of 2.18±0.25 mg L^{-1} ($p<0.05$) and control treatment value of 3.51±0.07 mg L^{-1} (Table 1). DO concentrations that were measured up to the 210th minute were still below total saturation, and only reached 85% saturation.

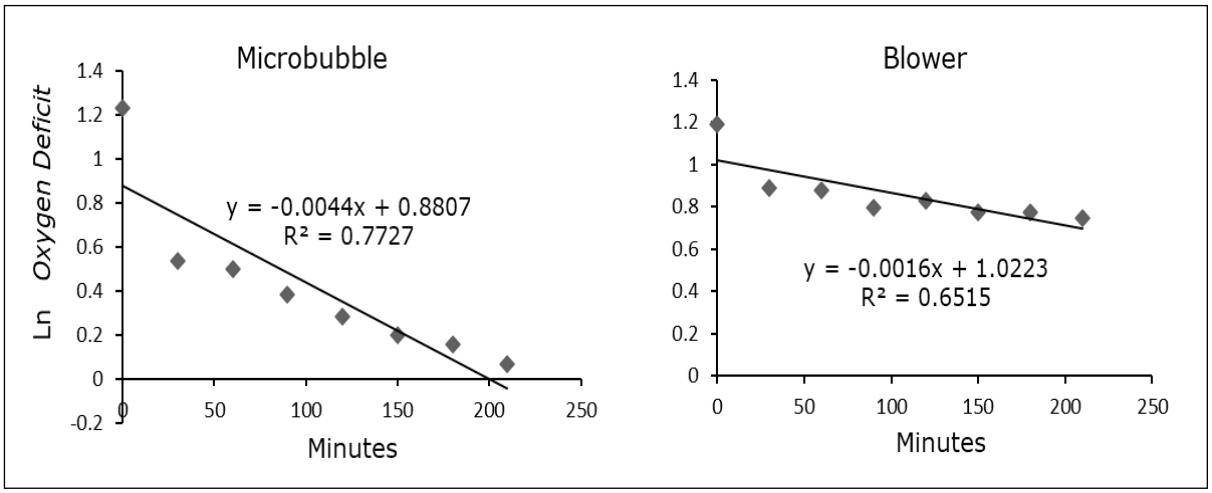

Figure 2. The relationship between time and Ln Oxygen Deficits in the microbubble aerators and blowers with point method.

From the line graph in Figure 2, the calculation was then performed to obtain the value of K_La_T, K_La_{20}, SOTR, and SAE for microbubble aerators and blowers. The results are presented in Table 2.

Table 2

The value of K_La_T (h^{-1}), K_La_{20} (h^{-1}), SOTR (kg O_2 h^{-1}), and SAE (kg O_2 KW^{-1} h^{-1}) on aerator performance microbubble and blower

Parameter	*Treatment (mean±SE)*		*Statistic*		
	Microbubble	*Blower*			
K_La_T (h^{-1})	0.247±0.0129[a]	0.090±0.0153[b]	t-test : 7.882;	P<0.05;	df: 4
K_La_{20} (h^{-1})	0.210±0.0057[a]	0.0733±0.0120[b]	t-test : 10.250;	P<0.05;	df: 4
SOTR (kg O_2 h^{-1})	0.0019±0.0001[a]	0.0007±0.0001[b]	t-test : 9.621;	P<0.05;	df: 4
SAE (kg O_2 $KW^{-1}h^{-1}$)	0.0220±0.001[a]	0.0067±0.0009[b]	t-test : 11.500;	P<0.05;	df: 4

Note: Different letters on the same line show significant differences at 5% level.

The gas transfer coefficient (K_La_T) in microbubble aeration (0.247±0.0129 h^{-1}) is greater than the coefficient value in blower aeration (0.090±0.0153 h^{-1}), which consequently affects the high SOTR value in microbubble aerator. The SOTR value of microbubble aerator was 0.0019±0.0001 kg O_2 h^{-1} with the default aeration efficiency (SAE) value of 0.022±0.001 kg O_2 KW^{-1} h^{-1} is greater than the SOTR value of blower aerator, in which the only produces 0.0007 ± 0.0001 kg O_2 h^{-1} with SAE value of 0.0067 ± 0.0009 kg O_2 KW^{-1} h^{-1} (Table 2). This shows that microbubble aerators were able to transfer oxygen at a higher rate and more energy-efficient than blower aerators.

DO resistance test. In this test, the persistence of dissolved oxygen in the water was assessed. The test was performed in the aeration treatments, and by turning off the aeration. The results are presented in Figure 3:

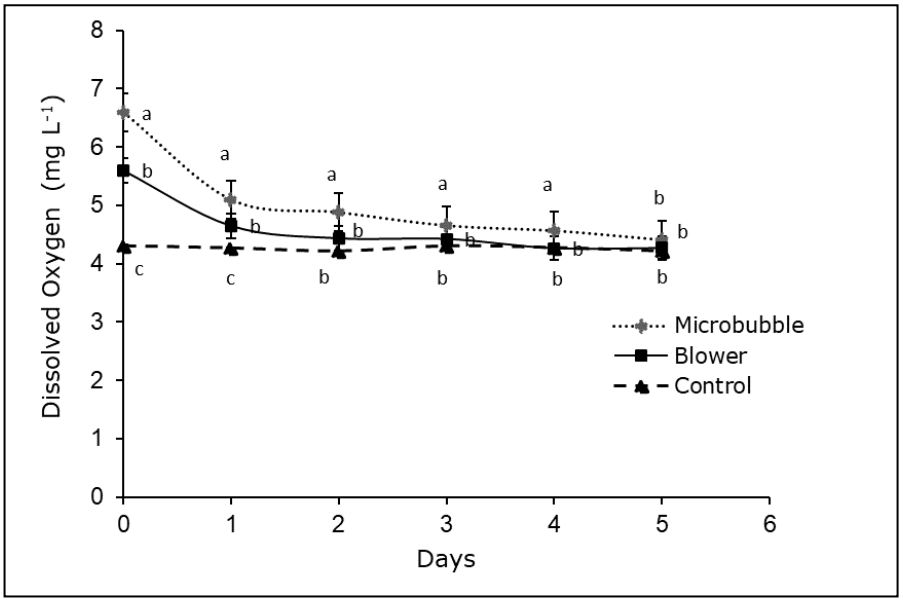

Figure 3. The DO reduction rate per day in the water after the aeration turned off (Different letters on the treatments show significant differences at 5% test level).

The DO reduction rate until the value is equal to the control DO after the microbubble aeration is turned off (Figure 3) is 0.47 mg L^{-1} day^{-1}, while the DO reduction rate in water previously aerated with a blower shows a greater value of 0.65 mg L^{-1} day^{-1} ($p<0.05$). The DO level in the microbubble aeration persisted after the aerator was turned off, and it returned to the initial value on the 5th day (4.41±0.03 mg L^{-1}). The DO level in blower treatment returned to the initial value on the 2nd day. This could indicate that the size of the gas bubbles produced by the microbubble aeration can last for an extended time in the media.

Aerator test using fish. Following the previous test, an aerator test was performed to see the persistence of DO concentration in water with the presence of fish. The assessment was performed in both treatments of unfed fish and fed fish. The results are presented in Figure 4:

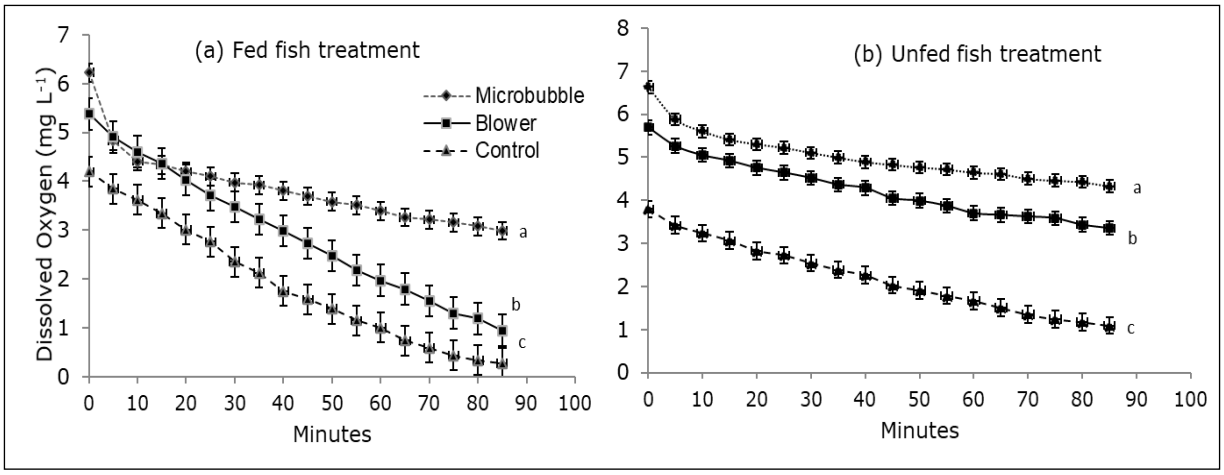

Figure 4. The dissolved oxygen reduction rate (mg L^{-1}) in aquaculture water with fed fish (a) and unfed fish (b) on aerator performance.

In the treatment using fed fish, the DO value in the microbubble aeration was 2.98 mg L^{-1} at the 85th minute, and the DO concentration was higher compared to the blower aerator aeration (0.95 mg L^{-1}) and control (0.27 mg L^{-1}) (Figure 4). The DO values of microbubble aerator treatment using unfed fish reached the same value as the initial pre-aerated value at the 85th minute (4.33±0.15 mg L^{-1}), whereas the media with blower treatment at the 35th minute (4.37±0.20 mg L^{-1}), and in the control treatment at the 85th minute the DO value was 0.95 mg L^{-1}.

Table 3

The amount of oxygen (mg L^{-1}) used by unfed and fed fish

Minute	*A. T : 27.97±0.18°C*		*B. T : 28.2±0.41°C*		*C. T : 27.89±0.12°C*	
	unfed	*fed*	*unfed*	*fed*	*unfed*	*fed*
5	0.75±0.09^{a}	0.55±0.31	0.43±0.10^{b}	0.48±0.32^{c}	0.38±0.07^{b}	0.35±0.15
10	1.03±0.17^{a}	0.56±0.17	0.65±0.01^{b}	0.77±0.28	0.56±0.17^{b}	0.77±0.28
15	1.22±0.17^{a}	0.73±0.17	0.77±0.09^{b}	1.02±0.08	0.73±0.17^{b}	0.86±0.21
20	1.32±0.13	0.97±0.27	0.94±0.16	1.35±0.31	0.97±0.27	1.19±0.31
25	1.41±0.09^{a}	1.07±0.19^{a}	1.05±0.02^{b}	1.66±0.20^{b}	1.07±0.19^{b}	1.44±0.31^{ab}
30	1.52±0.20^{a}	1.25±0.14^{a}	1.17±0.08^{b}	1.90±0.21^{b}	1.25±0.14^{ab}	1.84±0.17^{b}
35	1.63±0.13	1.41±0.22^{a}	1.33±0.12	2.16±0.20^{b}	1.41±0.22	2.07±0.25^{b}
40	1.74±0.19	1.54±0.19^{a}	1.41±0.12	2.40±0.22^{b}	1.54±0.19	2.44±0.27^{b}
45	1.80±0.16	1.77±0.18^{a}	1.64±0.05	2.65±0.31^{b}	1.77±0.18	2.62±0.18^{b}
50	1.86±0.14	1.89±0.14^{a}	1.70±0.01	2.90±0.27^{b}	1.89±0.15	2.81±0.12^{b}
55	1.91±0.16	2.01±0.16^{a}	1.82±0.08	3.20±0.38^{b}	2.01±0.16	3.05±0.16^{b}
60	1.98±0.14	1.98±0.14^{a}	1.99±0.05	3.41±0.05^{b}	2.13±0.19	3.13±0.19^{b}
65	2.02±0.16^{a}	2.29±0.07^{a}	2.03±0.04^{a}	3.59±0.56^{b}	2.29±0.07^{b}	3.61±0.08^{b}
70	2.12±0.08^{a}	2.45±0.08^{a}	2.01±0.03^{a}	3.82±0.03^{b}	2.45±0.05^{b}	3.60±0.05^{b}
75	2.17±0.07^{a}	2.56±0.07^{a}	2.11±0.02^{a}	4.08±0.08^{b}	2.56±0.07^{b}	3.76±0.01^{b}
80	2.20±0.09^{a}	2.62±0.09^{a}	2.26±0.16^{a}	4.19±0.39^{b}	2.62±0.06^{b}	3.86±0.05^{b}
85	2.30±0.15^{a}	2.71±0.13^{a}	2.34±0.17^{a}	4.43±0.45^{b}	2.71±0.13^{b}	3.92±0.04^{b}

Note: Different letters on the same line show significant differences at 5% level.

Table 3 showed that the oxygen consumption level between the microbubble aeration and blower aeration treatment were relatively similar in the unfed fish treatment group, which amounted to 2.3 mg L^{-1} ($p>0.05$). The control treatment had higher oxygen consumption level compared to the aeration treatments (2.71 mg L^{-1}). In contrast, the oxygen consumption level of the microbubble aeration treatment was lower in the fed fish group (2.71±0.13 mg L^{-1}) compared to the blower aeration treatment (4.43±0.45 mg L^{-1}) and the control treatment (3.92±0.04 mg L^{-1}) ($p<0.05$).

DO in RAS with aeration. To determine the size of harvest target and the number of fish in the RAS, DO measurements were carried out on the microbubble aeration up to 96% saturation. The increase of DO values from the initial starting condition, the aeration, and circulation treatment is shown in Figure 5.

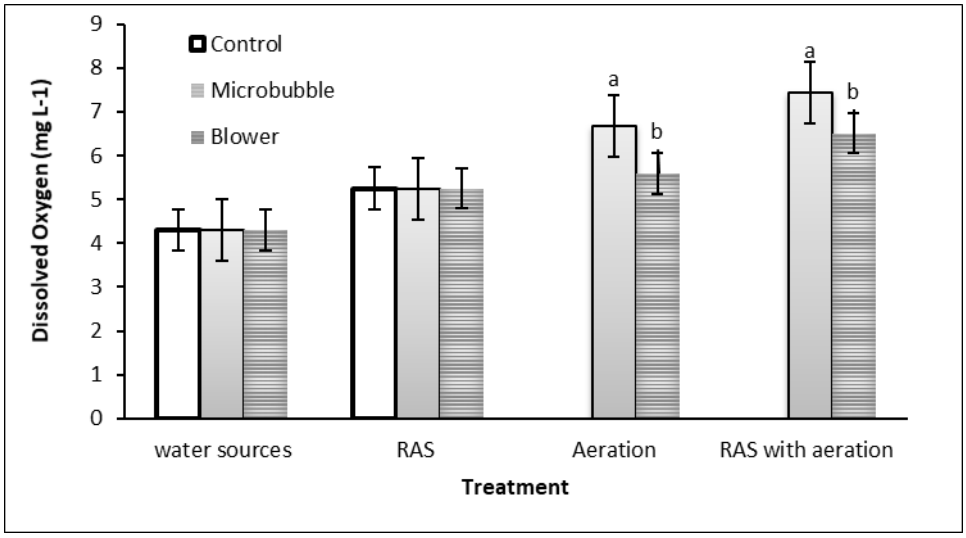

Figure 5. DO value (mg L^{-1}) on water source, on RAS system (no aeration), on aerated water (no RAS), and on the use of aeration in RAS system (Different letters in each treatment, showed a significant difference at 5% level).

The DO value of microbubble aeration on RAS was 7.44±0.14 mg L^{-1}, which gained 2.09 mg L^{-1} increase compared to the control treatment. The DO levels were higher compared to the blower treatment, which had an average DO value of 6.51±0.26 mg L^{-1}, an increase of 1.16 mg L^{-1} compared to the control treatment. The DO level produced by the RAS was increased by 0.99 mg L^{-1} compared to the no RAS phase. The DO measurement from the aeration treatment in the recirculating media was carried out to determine the carrying capacity and the fish target size for harvest based on its oxygen consumption rate.

Fish oxygen consumption test. In this phase of the study, the oxygen consumption rate of different sizes of fish were calculated. The results are shown in Figure 6 below.

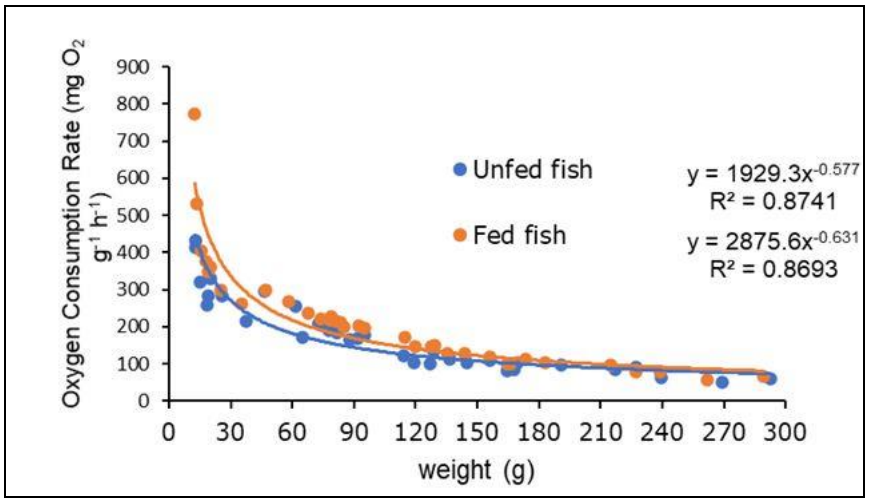

Figure 6. Oxygen consumption rate (OCR) of various sized fish (15-289 g) in unfed and fed treatments.

The fish oxygen consumption rate was measured using several size classifications (15-289 g) both in the fed and unfed treatment. The result described the relationship between the rate of oxygen consumption and the tilapia's body weight (Figure 6). The rate of oxygen consumption in small/younger fish is higher than that of the larger fish. This shows that oxygen consumption per unit of mass decreases along with the increase of fish size.

Stocking density on harvest target. The DO data obtained from the aeration devices and the regression equation of the oxygen consumption rate were then used to calculate the carrying capacity value in recirculation media. The carrying capacity values obtained were then used to determine the stocking density based on the recommended maximum fish weight for harvest (Figure 7).

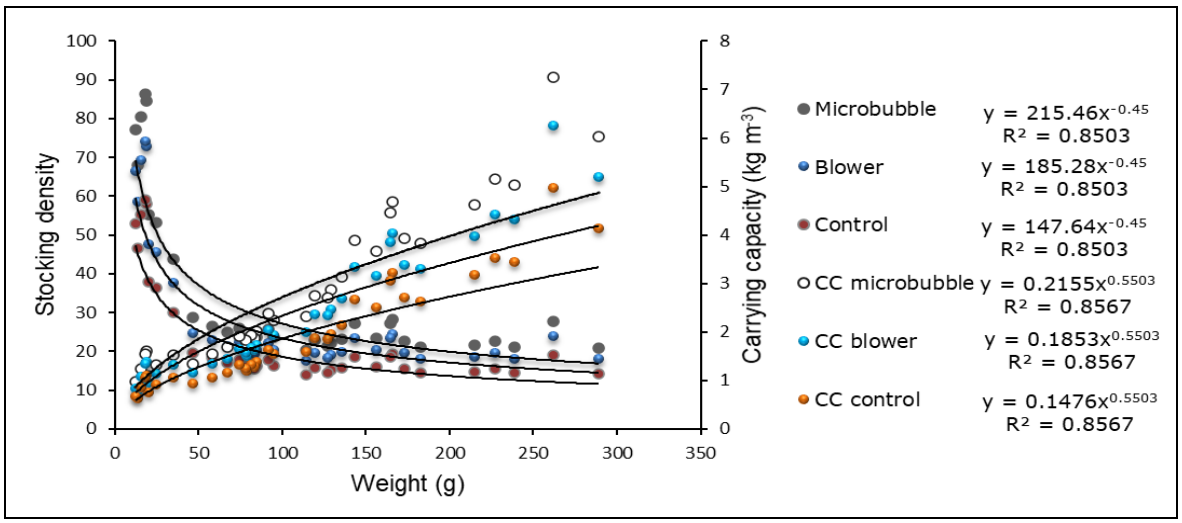

Figure 7. Relationship between red tilapia weight (g fish^{-1}), stocking density and carrying capacity (kg m^{-3}) on microbubble aeration, blower, and control treatments.

After the fish oxygen consumption rate was calculated, it would be easier to predict the carrying capacity of tilapia in a tank. Based on the carrying capacity formula of tilapia (Ross & Ross 1983), the exponential equation was obtained $Y=0.2155X^{0.5503}$ which described the relationship between fish weight (g) and carrying capacity (kg m^{-3}) in microbubble aeration treatment, and $Y=0.1853X^{0.5508}$ in blower aeration. This equation can be used as a reference in determining the carrying capacity of fish based on individual fish size, fish oxygen consumption and DO produce by the aeration used. Based on the calculation of these equations, the microbubble aerator was able to increase the target harvest 17 % higher than the blower aerator.

Discussion. The purpose of this study is to compare the performance of microbubble aerators and conventional aerators by measuring the rate of oxygen transfer and energy efficiency using calculation methods based on Boyd (1998). DO value produced by the aerator was then used as the basis for predicting the target harvest size by the fish oxygen consumption.

In the aerator test, the DO increase (Figure 1) produced by the microbubble aerator was 2.13 mg L^{-1}. The value is like the result from a previous study conducted by Deendarlianto et al (2015), in which the DO value produced by microbubble aerator was higher than 2 mg L^{-1} in constant pH and temperature values. The DO value produced by the conventional blower aerator was 1.14 mg L^{-1}, lower than the aeration produced by microbubble aeration ($p<0.05$), because the conventional blower aerator produced coarse bubbles which rapidly rise and burst on the water surface (Heo & Kim 2004; Endo et al 2008; Oh et al 2013), while microbubble aeration produced smaller-sized bubbles (Parmar et al 2013; Tsuge 2015) which float and burst inside the water column, thus

contributed to increasing the DO level in the waters. DO measurement was also conducted after the aerators were turned off. The results (Figure 3) showed that the water DO level from microbubble aeration decreased to the starting DO value before aeration (4.41±0.03 mg L^{-1}) on the 5th day of observation. In the conventional aeration treatment, the decrease reached the starting DO value on the second day. The DO value results showed that the gas bubbles produced by microbubble aeration have a higher retention period in the culture media (Takahashi 2003), and the bubbles also rise slowly and have a larger interface area (Liu et al 2013).

Supriyono et al (2016) stated that microbubble aeration could facilitate increased air diffusion into water. It is proven by the value of oxygen deficit that was assessed in this study. Oxygen deficit is the driving force that caused oxygen to be transferred into or out from the water body. If the oxygen deficit value is low, it inferred a higher driving force that transfers oxygen into the water. In the study, microbubble aeration showed the lowest value of oxygen deficit (1.19±0.03 mg L^{-1}) at the 210th minute of treatment. This could mean that the capacity of the water body to contain oxygen is reaching its limit. The value was higher ($p<0.05$) in conventional aerator treatment 2.18±0.25 mg L^{-1} and in the control treatment 3.51±0.07 mg L^{-1} (Table 1). It could be inferred that the microbubble aerator has more driving force than the conventional blower aerator, even though the level of air input was the same in both instruments. According to Serizawa et al (2003), microbubbles have different physicochemical properties and fluid dynamics compared to coarse/macro bubbles produced by conventional aerators. In microbubble, there were larger specific area and higher gas pressure inside the bubble, which yielded higher gas dispersal potential (Bredwell & Worden 1998).

The high driving force of microbubble aeration resulted in a higher gas transfer coefficient (K_La_T) 0.2267±0.0186 h^{-1} by the instrument. The value is significantly higher compared to the K_La_T value of conventional aerator (0.090±0.0153 h^{-1}), in which the STOR value of microbubble aeration was also higher than the blower aeration. The SOTR value of microbubble aerator was 0.0017±0.0001 kg O_2 h^{-1} with Standard Aeration Efficiency (SAE) of 0.0200±0.0015 kg O_2 KW^{-1} h^{-1}, which were higher than the SOTR value of the conventional blower aerator which amounted to 0.0007±0.0001 kg O_2 h^{-1} with SAE value of 0.0067±0.0009 kg O_2 $KW^{-1}.h^{-1}$ as presented in Table 2. The values showed that the microbubble aerator could transfer a higher amount of oxygen at a lower energy cost compared to conventional aerators. The results corresponded with previous findings by Navisa et al (2014), which stated that bubbles with smaller diameters with longer retention in the water body would produce higher gas transfer rates and yield higher dissolved gas concentration. In the present study, the test to measure SOTR and SAE for defining the effectivity of the aeration process was only conducted in calm water conditions, in accordance with Boyd (1998) who stated that all aerator tests were conducted in calm water condition.

The aerator test was performed using both unfed and fed fish, to observe the resistance of oxygen concentration in the media after being utilized by fish for its metabolism processes. The results showed that microbubble aeration in the unfed fish treatment (Figure 4) reached the same DO level with pre-aerated DO value which was 4.33±0.5 mg L^{-1}, at the 85th minute. The DO level reached an initial pre-aerated value in conventional aeration at the 35th minute, amounted to 4.37±0.20 mg L^{-1}. This indicates (Table 3) that even though the fish constantly consumed 2.30±0.15 mg L^{-1} amount of oxygen for 85 minutes in the microbubble aeration treatment, and 2.34±0.17 mg L^{-1} in conventional aerator treatment ($p>0.05$), the microbubble aeration could supply more oxygen than conventional aerators. As for the control treatment, at 85th minute the DO value only amounted to 1.09±0.15 mg L^{-1}, with higher oxygen uptake of 2.71±0.13 mg L^{-1} caused by the tilapia fish constantly consuming oxygen but there was no input of oxygen in the water, thus decreasing the total DO in the media. The results were consistent with the results of the study conducted by Søderberg (2017), which found that the level of oxygen consumption in fish is affected by the DO levels in its environment.

The aerator test with fed fish treatment (Table 3; Figure 4), from the first minute to the 20th minute, showed no significant difference in the oxygen consumption level of the fish ($p>0.05$). The increase of oxygen consumption in fed fish treatment was higher

than the unfed fish treatment. At the end of the observation period, the DO level in the control treatment was 0.17 mg L^{-1} and the amount of oxygen consumed was 3.92 mg L^{-1} (Table 3). These values were not significantly different from the DO value in conventional blower aeration group (0.96±0.52 mg L^{-1}; $p>0.05$), but it was significantly different compared to microbubble aeration group with DO value of 2.98±0.45 mg L-1 and oxygen consumption value of 2.71 mg L^{-1} ($p<0.05$). The amount DO of microbubble aeration left at the end of the observation period was considered the minimum amount of DO levels for tilapia culture, according to Ross et al (2013). Furthermore, Ross and Ross (1983) stated that the critical DO value in *Oreochromis niloticus* culture is 2.92 mg L^{-1} at the temperature of 28°C. The results obtained in this study inferred that the fed fish consumed oxygen more rapidly for their biological needs such as respiration and metabolism, both in the conventional blower aeration media and non-aerated media. The rapid consumption of oxygen could be caused by no additional oxygen supply in the control treatment, while conventional aeration could only supply a limited amount of oxygen. The lack of adequate oxygen supply in the media made the fish increase their biological effort to obtain oxygen from the water. This was consistent with the previous study by Izzati (2008) which concluded that low oxygen concentration would increase the respiration rate of fish and decrease their respiration efficiency.

The sizes of some of the cultured fish, both in the fed and unfed treatment group, were measured to assess the oxygen consumption level of the fish. It was then used to predict the carrying capacity of the culture media. Measurements of oxygen consumption were performed after the fish were fasted (post-absorptive state), in neutral environment condition, and the fish was in low motility state (Wuenschel et al 2005). The results of the relationship between oxygen consumption of tilapia fish with its body weight (Figure 6) showed that the oxygen consumption level of the younger and smaller fish was higher than the bigger-sized fish. This could be linked to the higher metabolism rate of younger fish compared to the bigger fish; hence its biological system demands a higher amount of oxygen for respiration and cell growth (Boyd 1990). This also corresponded with previous studies conducted on various species of fish, including tilapia, which concluded that the oxygen consumption per unit of mass decreases along with the increase of fish body size (Beamish & Mookherjii 1964; Morgan & Iwama 1991; Kisa & Hughes 1993).

The DO testing conducted in the recirculating system without aeration (Figure 5) showed that the DO was increased by 0.99 mg L^{-1}. The increased DO levels could be due to the water supply connected filter and underwent aeration process, thus increasing dissolved oxygen concentration before the water was aerated by the aeration instrument. The recirculating water also increased DO supply by mixing the oxygen saturated water surface with the water column containing lower DO concentration. Such a process decreased the amount of oxygen loss from the water body caused by diffusion (Boyd 1998). However, it was also mentioned that mechanical aeration was still the best method for increasing DO concentration in culture pond. The DO levels in the RAS with microbubble aeration increased with 2.09 mg L^{-1} from the control treatment and was higher than conventional blower aeration. The DO levels with blower aeration increased 1.16 mg L^{-1} from control. This means that the DO increase by the aeration from both recirculating (RAS) and non-recirculating (non-RAS) media were equal, ranging between 2.09-2.13 mg L^{-1} in microbubble aeration treatment, and 1.14-1.16 mg L^{-1} in blower aeration treatment.

In this study, the prediction of the harvest target was assessed based on oxygen consumption from different sizes of fish. The calculation was based on DO levels produced by aeration treatment from the RAS media. This was considered due to aeration instrument alone was not adequate to provide sufficient oxygen levels needed for tilapia consumption which were cultured inside the culture vessel. Fish oxygen consumption in an intensive aquaculture system is one of the most crucial parameters to determine the optimal water flow rate and the required oxygenation rate for sustainable fish biomass at a certain temperature (Randall 1982). According to the calculation based on the equation in Figure 7, microbubble aerators could increase the harvest target with 17% compared to conventional blower aerators. Harvest target could be the primary factor in stocking density that determines the amount of production of profit from fish

culture, due to it directly affects fish survival, growth, behavior, health, water quality, and feed (Oké & Goosen 2019). The miscalculation of stocking density based on oxygen consumption could potentially become the source of stress for culture fish (Abou et al 2016; Ellis et al 2002), and negatively impacted specific growth rate and final weight (Abou et al 2016; Ullah et al 2018), and fish survival rate (Das et al 2016; Rowland et al 2006).

Conclusions. Microbubble aeration could increase DO levels with an average of 2.14 mg L^{-1} in 85% oxygen saturation, higher compared to the DO levels produced by conventional aerator with an average of 1.13 mg L^{-1}. Based on the SOTR and SAE values, microbubble aerator is considered more efficient and utilizes less energy compared to blower aerators. Harvest target in RAS with microbubble aeration was 17% higher compared to conventional aeration, based on oxygen consumption, and DO level produced. Our finding should be made as a reference and comparison for a larger scale recirculating system for tilapia aquaculture.

Acknowledgements. The authors would like to thank the financial support provided by Gadjah Mada University Final Project Recognition no. 2607/UN1/DITLIT/DIT-LIT/PT/2020 and the facilities provided by Gadjah Mada University.

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Received: 18 July 2020. Accepted: 18 September 2020. Published online: 27 October 2021.
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How to cite this article:
Heriyati E., Rustadi, Isnansetyo A., Triyatmo B., Istiqomah I., 2021 Microbubble aerator test and harvest target prediction based on oxygen consumption of red tilapia (*Oreochromis* sp.). AACL Bioflux 14(5):3006-3022.