STUDY OF ALTERNATIVE AERATION SYSTEM APPLIED IN AQUACULTURE PONDS

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Abstract. Aeration is the important factor in aquacultural system due to the vital condition for all organisms living and having an aerobic respiration in water. Generally, the mechanical surface aerators are widely used in Thailand due to their advantage for increasing DO and having the horizontal mixing of the culture pond with large-surface area. However, the low oxygen transfer efficiency (OTE) and energy performance should be considered as the main drawback of this aerator type. Regarding to this issue, the alternative aeration systems should be studied and applied. The objective of this research is to study the aeration mechanism obtained with the diffused-air aeration combined with Liquid-Film-Forming Apparatus (LFFA). The effect of gas flow rates, types and patterns of aerator installation were investigated in aquaculture pond with 10 m*10 m*1.5 m in dimension. The analytical parameters were the volumetric mass transfer coefficient (k_La), the oxygen transfer efficiency (OTE), and the oxygen transfer rate (OTR). From the results, the "4-D" with partitions was proposed as the suitable pattern for the LFFA installation. The advantage could be obtained from highly energy performance with 1.20 g/W-h of OTR. Then, the operation conditions can be applied as a design guideline for this alternative aeration system in aquaculture pond.

Keywords: *Alternative aeration system; Diffused-air aeration; Liquid-Film-Forming Apparatus; Aquaculture pond; Volumetric mass transfer coefficient; Oxygen transfer efficiency.*

1 Introduction

In aeration process, oxygen is generally introduced by either diffused or mechanical aerators. Contacting between the gas phase and the liquid phase is the important factor for oxygen transfer, due to interface area is used as an oxygen transfer pathway. The introduced oxygen will be transferred into the liquid phase as dissolved oxygen (DO) via interfacial film between gas phase and liquid phase, after that turbulence or mixing will be needed due to distribute DO concentration uniformly [1]. The oxygen is the important factor in aerobic biological process and aquaculture system due to the vital condition for all organisms living and having an aerobic respiration in water. Therefore, the DO value is one of the parameters applied for monitoring and controlling the aeration system.

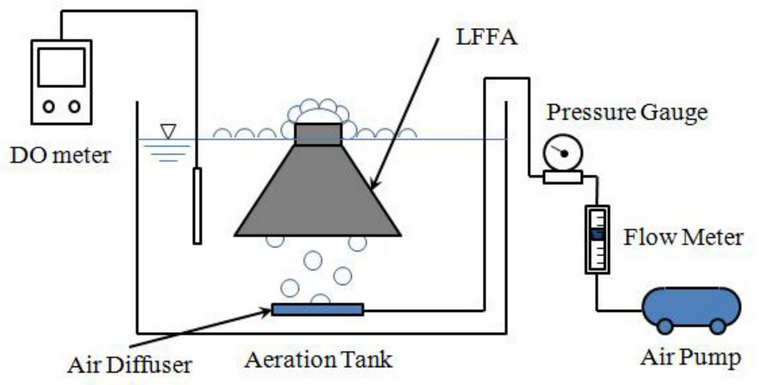
The volumetric mass transfer coefficient (k_La) is widely used to evaluate aeration performance, by observing the variation of DO values with time, after that the oxygen transfer efficiency and the oxygen transfer rate (OTR), which can describe oxygen transfer rate per power consumption or energy performance. Normally, the k_La coefficient can be experimentally obtained as a combined parameter, which consists of liquid-side mass transfer coefficient (k_L) and interfacial area (a). The k_L coefficient relates with the properties of the water, which relate to the oxygen transfer mechanism through the interface film between the gas phase and the liquid phase [2]. Therefore, the k_L coefficient can be described as an oxygen transfer velocity through the contacting film. The a-area relates with the bubbles characteristics in term of the ratio of interface area per overall volume, which includes the gas phase volume and the liquid phase volume [3]. Therefore, the a-area can be described as an oxygen transfer pathway.

Generally, the mechanical surface aerators are widely used in Thailand due to their advantage for increasing DO and having the horizontal mixing of the culture pond with large-surface area. However, the low oxygen transfer efficiency (OTE) and energy performance should be considered as the main drawback of this aerator type. Then the liquid film foaming apparatus (LFFA) is proposed as equipment for improving oxygen transfer performance. The objective of the LFFA is to create a large amount of interfacial area, which is a thin film of the liquid phase, in form of bubble foam at the water surface. The oxygen can transfer both inner and outer interface of the bubble foam, then the oxygen performance can be improved. From the previous research, the LFFA can improve the aeration system with 37 % of the k_La [4].

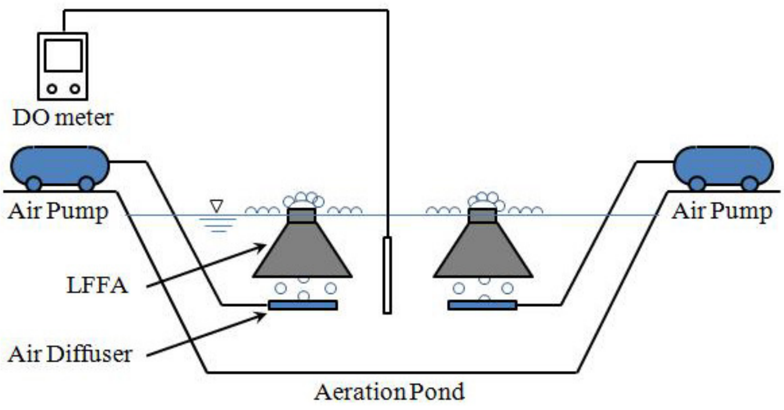
To complete the research, the aeration system design and the suitable operation condition should be studied and applied. The objective of this research is to study the aeration mechanism obtained with the diffused-air aeration combined with the LFFA. The effect of gas flow rates, types and patterns of aerator installation were investigated in aquaculture pond with 10 m*10 m*1.5 m in dimension. The k_La, OTE, and OTR are compared with the mechanical surface aerator. The preliminary design criteria and operating condition are expected to be concluded and proposed for applying the alternative aeration system in aquaculture pond.

2 Materials and Methods

2.1 Experimental set up



1-a Experimental set up in laboratory aeration tank



1-b Experimental set up in aquaculture pond

Figure 1 Schematic diagrams of the Experimental set up

The experiment set up was shown in Figure 1. The experiment consisted of 2 scales:

1. Laboratory scale was conducted in 330 liters of an aeration tank (0.96 m in width, 1.24 m in length, and 0.40 m in depth)

2. Actual scale was conducted in 90,000 liters of an aquaculture pond (10 m in width, 10 m in length, and 1.5 m in depth).

The Compressed air-pumps and Fine air-diffusers, which can generate 3-4 mm in diameter of bubbles, were used in this research. The introduced air was contributed by a rubber hose that connected the air-pump and the diffuser, one by one. In the laboratory experiment, the air flow rate (Q_G) and pressure (P) were monitored by a gas flow meter, and a pressure gauge, respectively. The YSI Model DO meters were used for monitoring the dissolved oxygen (DO) while starting the aeration. The DO measurements were corrected with the different operating conditions; temperature, pressure, and salinity by considering the correcting function of the DO-meter. The aeration in the laboratory experiments were conducted in clean water and the actual-scale experiments were conducted in the local water, which it was 11% of salinity. The k_La coefficients were measured by the American Society of Civil Engineers method (ASCE), by using sodium sulfite (Na_2SO_3) for de-oxygenation. For the operating conditions were shown in the table 1.

Table 1 The operation conditions of the experiment

Conditions	Laboratory Aeration Tank	Aquaculture Pond
Air flow rate per diffuser (L/min)	24	100
Water volume (L)	330	90,000
LFFA + Diffuser sets	1 - 4	1 - 4
Submerged depth of diffuser (m)	0.40	0.50
Submerged depth of DO measurement (m)		
- Surface	-	0.10
- Middle	0.20	0.75
- Bottom	-	1.50
Temperature (°C)	5 - 33	30 - 35
Pressure (atm)	1.00	1.00

2.2 Materials

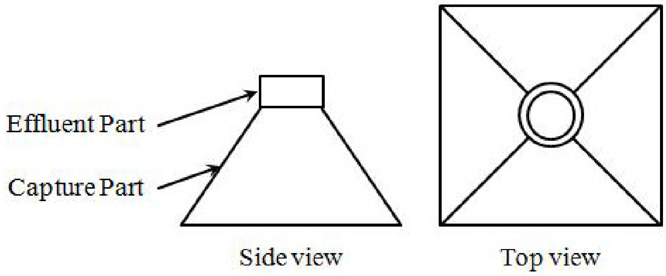


Figure 2 Schematic diagram of the LFFA

The schematic drawing of the LFFA was shown in Figure 2. The LFFA had a simple structure that consist of capture part and effluent part, which it made from plastics. The introduced air was collected within the capture part and released through the effluent part in form of liquid foam, due to increase the interfacial area. Generally, the LFFA can be installed in an existing conventional aeration system. For this research, the LFFA were installed with a fine air-diffuser. Then, they were applied into 2 types; Standing type, and Floating type, as shown in Figure 3.

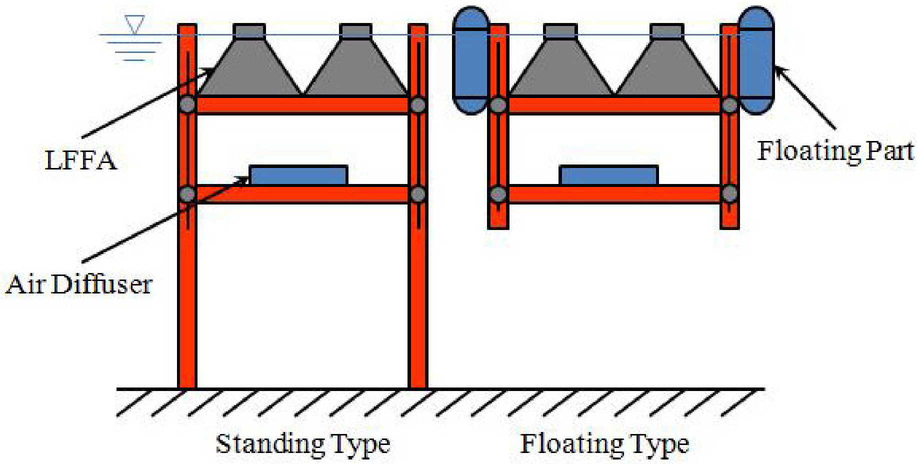


Figure 3 Application of the LFFA

In this study, the suitable installation of the LFFA could be investigated by 4 patterns, and then proposed the optimum number of LFFA by minimizing from 4 sets into 1 set, as shown in Figure 4 and Figure 5.

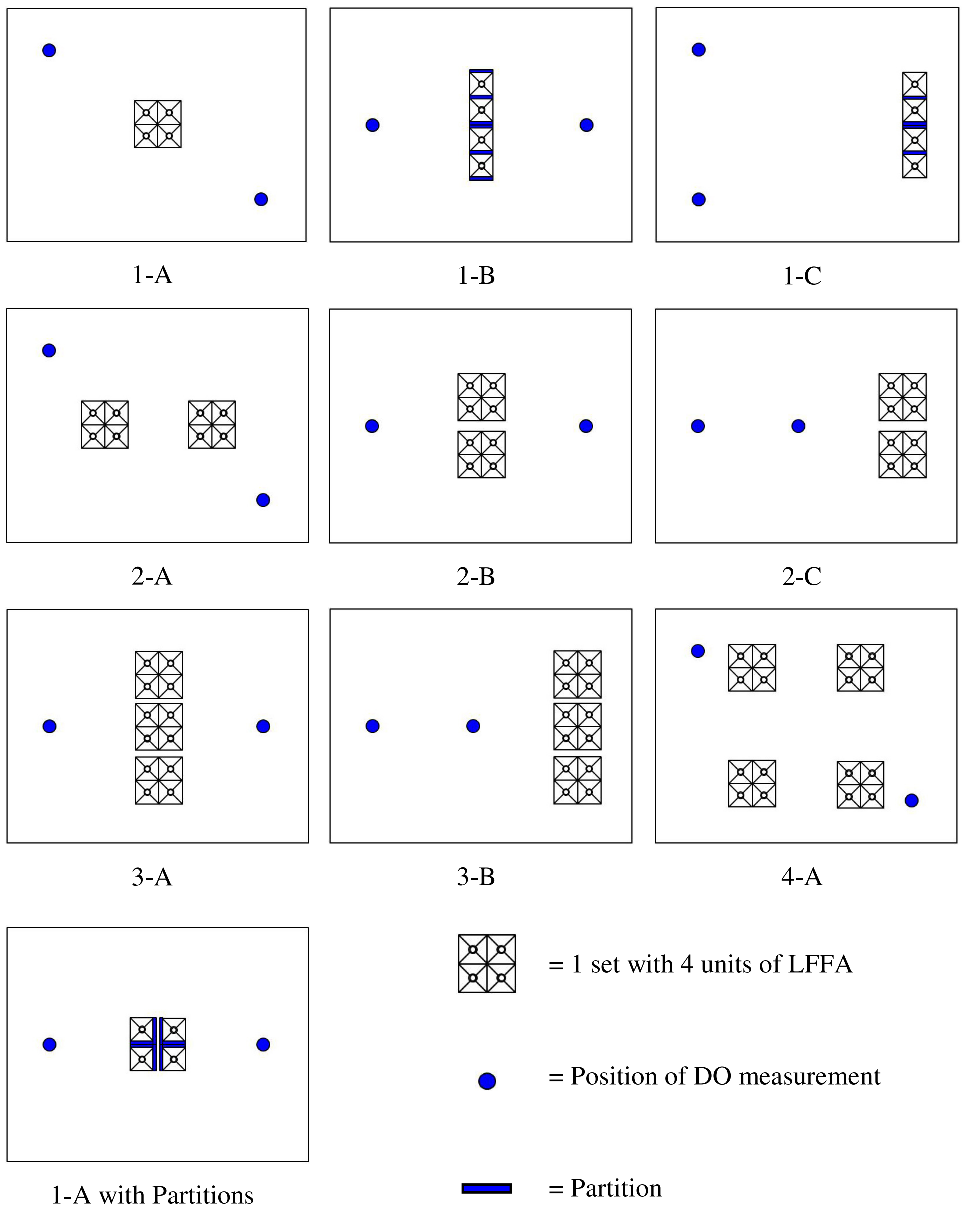


Figure 4 Top view of the LFFA installation in the laboratory aeration tank

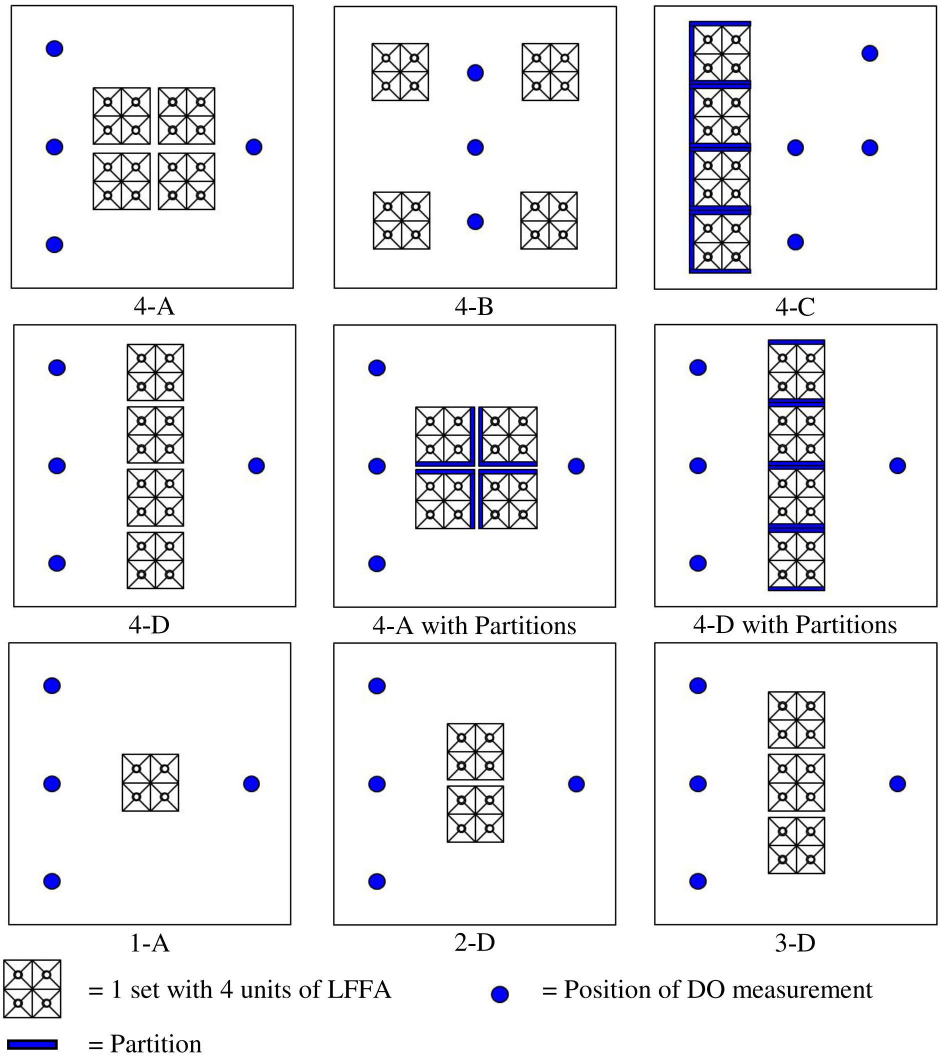


Figure 5 Top view of the LFFA installation in the aquaculture pond

2.3 Analytical parameters

The volumetric mass transfer coefficient (k_La) was the main parameter for evaluating oxygen transfer performance, which could be measured by the American Society of Civil Engineers method (ASCE), and using sodium sulfite (Na_2SO_3) for de-oxygenation, the calculation could use these equations [5].

$$\frac{C_S - C_t}{C_S - C_0} = e^{-(k_L a) \times t} \tag{1}$$

$$\ln(C_S - C_t) = \ln(C_S - C_0) - k_L a \times t \tag{2}$$

Where C_S (mg/L) was saturated DO, C_t (mg/L) was DO concentration with time, and t (s) was aeration period. After the k_La could be estimated, it could be converted into the k_La at 20°C due to the temperature effect, by this equation.

$$k_L a_T = k_L a_{20°C} \times 1.024^{T-20} \tag{3}$$

Where 1.024 was a constant of air-diffusers and mechanical aerators, and T (°C) was an operating temperature. After the $k_La_{20°C}$ were obtained, then the oxygen transfer efficiency (OTE) could be estimated, and the energy performance could be estimated in term of oxygen transfer rate (OTR) by using these equations [6]

$$OTE = \frac{Oxygen_{Transferred}}{Oxygen_{Introduced}} = \frac{k_L a \times C_S \times V}{\rho_G \times Q_G \times W_{O2}} \tag{4}$$

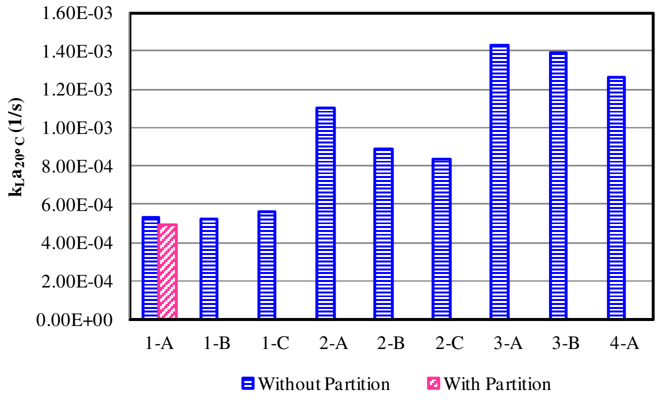
$$OTR = \frac{k_L a \times C_S \times V}{P} \tag{5}$$

Where V (m^3) was water volume, ρ_G (kg/m^3), Q_G (m^3/s), and W_{O2} were air density, air flow rate, and fraction of oxygen in the atmosphere (0.23), respectively. And P (W) was essential power for aeration. According to the k_La were converted into the $k_La_{20°C}$, the obtained OTE and OTR could be assumed as a standard oxygen transfer efficiency (SOTE) and standard oxygen transfer rate (SOTR), respectively.

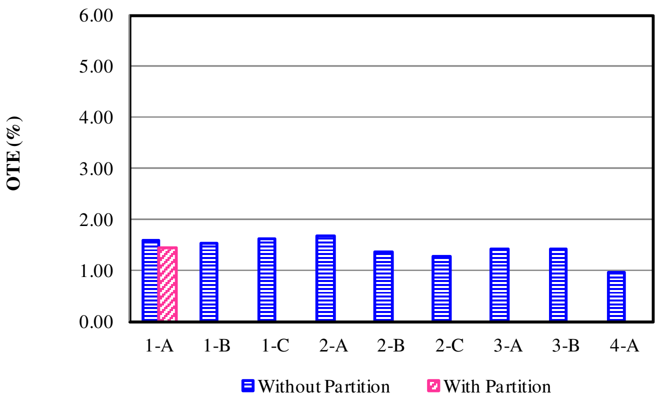
3 Results and Discussion

3.1 Results from laboratory aeration tank

Firstly, the installation patterns that followed to the Figure 4 were compared in the laboratory aeration tank for investigating the suitable installation. The $k_La_{20°C}$ and OTE were used for evaluating the installation patterns in terms of oxygen transfer performance, as shown in Figure 6.



6-a The volumetric mass transfer coefficient at 20°C ($k_La_{20°C}$)



6-b The oxygen transfer efficiency at 20°C (OTE)

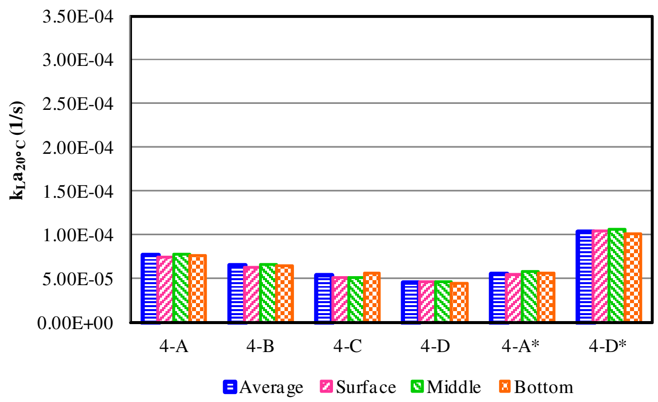
Figure 6 Oxygen transfer performance of LFFA in the laboratory aeration tank

The Figure 6 showed the best installation pattern was “3-A” with 1.43 x 10^{-3} 1/s of $k_La_{20°C}$, and 1.44 % of OTE. In this pattern, 3 sets of the LFFA were installed at the center of the tank, as shown in the Figure 4. According to water circulation around the LFFA, the oxygen could be transferred into the water throughout the overall volume, and then the $k_La_{20°C}$ was improved.

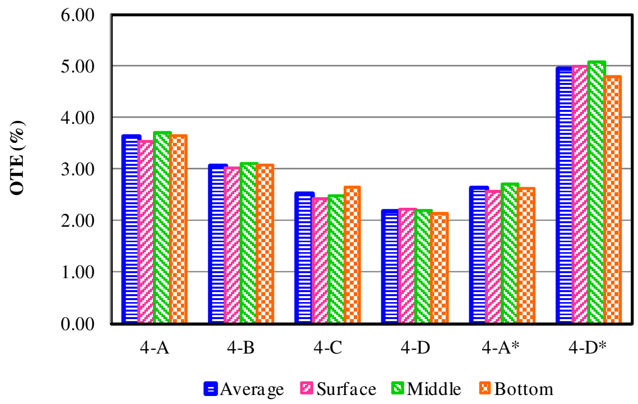
Regarding to [7], the partitions were equipped, in this work, in order to control the water flow direction and to improve the oxygen distribution. But, the partitions seemed to be unnecessary for the pattern “1-A” in this experiment: the OTE value was seemed to be slightly dropped. Moreover, it can be noted that the k_La and OTE were increased with the number of LFFA, and then they were decreased after 3 sets of the LFFA. So, the optimum number of the LFFA could be investigated by this tendency.

3.2 Results from aquaculture pond

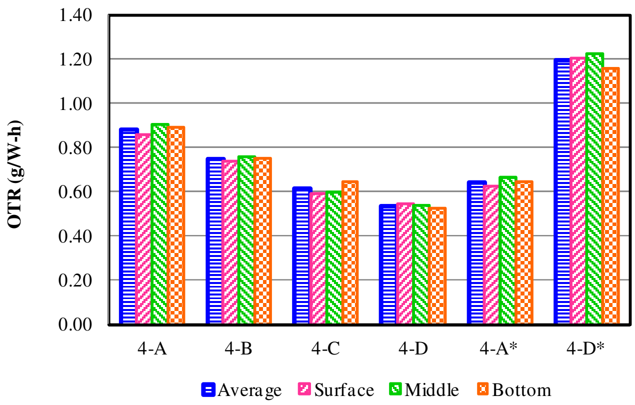
After the suitable installation pattern could be obtained in the laboratory aeration tank, then it was confirmed and applied in the aquaculture pond. The $k_La_{20°C}$, OTE, and OTR were used for evaluating, as shown in Figure 7.



7-a The volumetric mass transfer coefficient at 20°C ($k_La_{20°C}$)



7-b The oxygen transfer efficiency at 20°C (OTE)



7-c The oxygen transfer rate at 20°C (OTR)

Figure 7 Oxygen transfer performance of LFFA in the aquaculture pond

The Figure 7 showed the best installation pattern was "4-D*", which it was the same pattern as "3-A" in the laboratory experiment, and the partitions were added. The "4-D*" could achieve with 1.04 x 10^{-4} 1/s of $k_La_{20°C}$, 4.96 % of OTE, and 1.20 g/W-h. In this experiment, the "4-D*" could be improved 0.31 % of the OTE by adding the partitions, more than without them in the "4-D*".

3.3 Comparison of Standing and Floating types

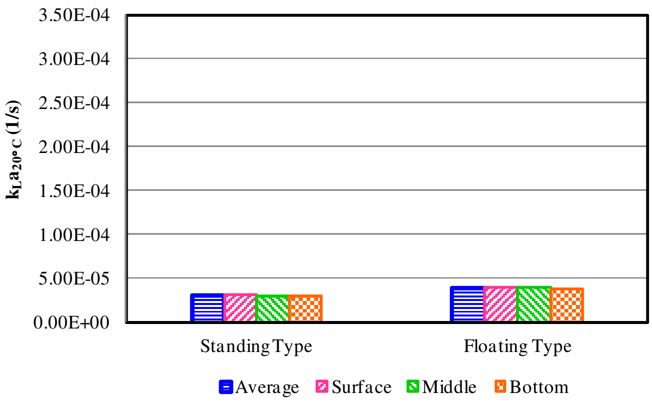
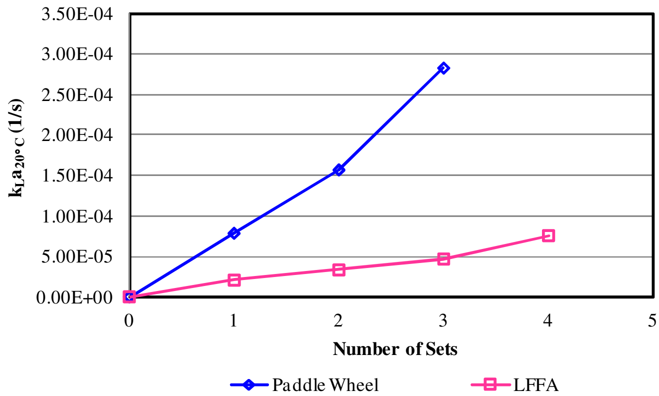


Figure 8 Comparison of the LFFA type

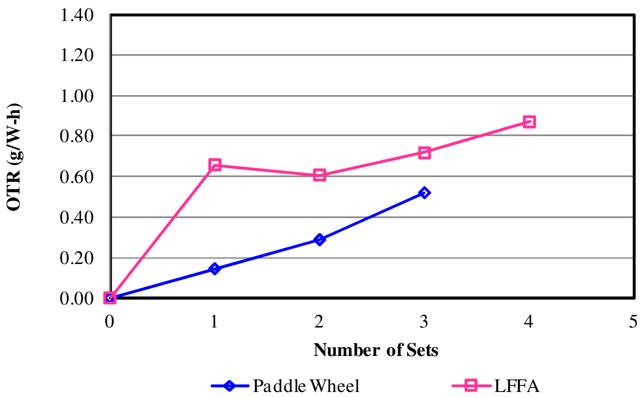
According to the suitable installation pattern, The LFFA could be applied as a floating unit due to convenient of installation and operation. Then the oxygen transfer performance was compared between the original type (Standing type) and the Floating type. The Figure 8 compared the $k_La_{20°C}$ of the LFFA between standing type and floating type. It was found that both of them were the same tendency with 3.09 x10^{-5} - 4.01 x 10^{-5} 1/s of the $k_La_{20°C}$. Moreover, the OTE and OTR were 2.41 - 2.62 %, and 0.59 - 0.64 g/W-h, respectively. Therefore, the LFFA could be applied as a floating unit with the same efficiency.

3.4 Comparison of LFFA and mechanical surface aerator

After that the LFFA were installed by the recommended patterns: 4-D, 4-D*, 3-D, 2-D, and 1-A, then they were compared to the existing aerator (mechanical surface aerator) in the aquaculture pond. Then, the suitable number of LFFA was investigated by varying the number with the recommended pattern, while the numbers of paddles were varied for the mechanical surface aerator. The $k_La_{20°C}$ and OTR were used for comparing and evaluating the oxygen transfer performance with the number, as shown in the Figure 9.



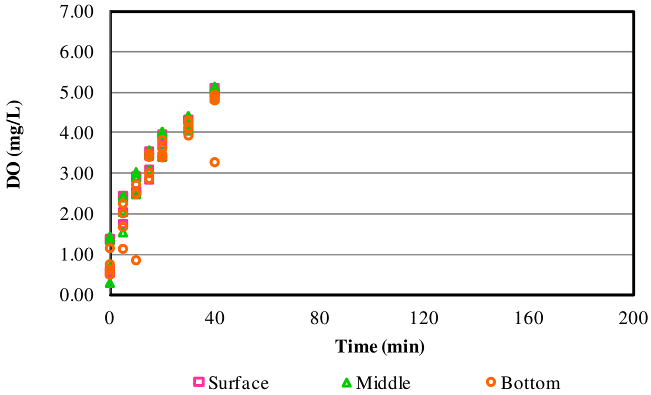
9-a The volumetric mass transfer coefficient at 20°C ($k_La_{20°C}$)



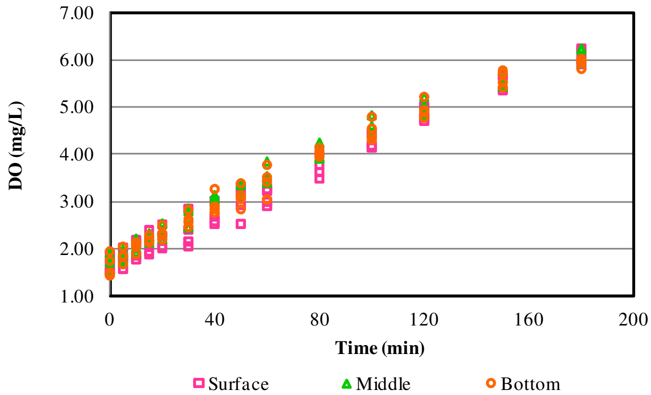
9-b The oxygen transfer rate at 20°C (OTR)

Figure 9 Comparison of the oxygen transfer performance

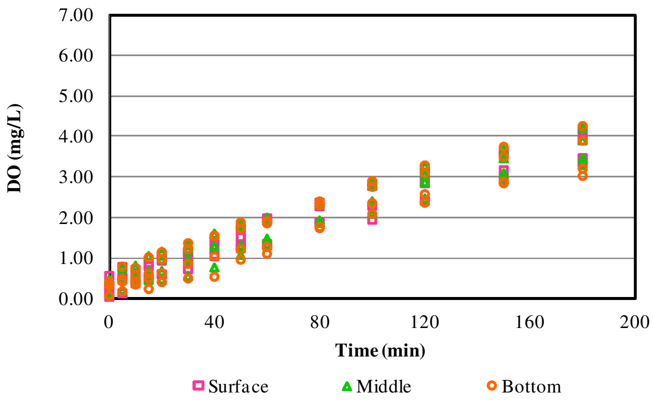
The Figure 9 showed the $k_La_{20°C}$ of the mechanical aerator was higher than the LFFA 2 or 3 times, but the LFFA had the OTR higher than the surface aerator. Moreover, the increasing of DO with time was concerned as an oxygen transfer distribution due to investigate the suitable number of the LFFA, as shown in Figure 10.



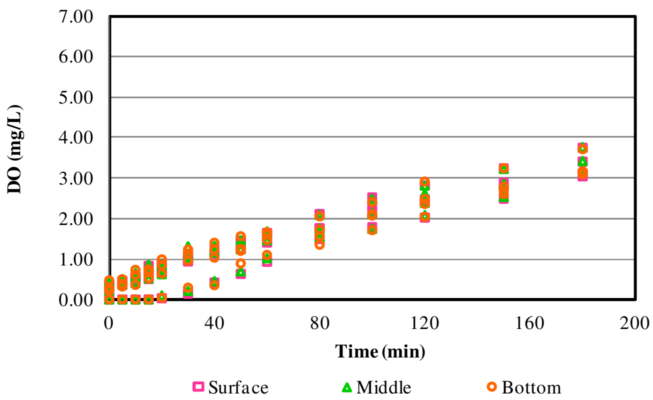
10-a Mechanical surface aerator with 3 paddle wheels



10-b The “4-D*” pattern with 4 sets of LFFA



10-c The "3-D" pattern with 3 sets of LFFA



10-d The "2-A" pattern with 2 sets of LFFA

Figure 10 The DO profile within the aeration period

The Figure 10 compared the DO profile with time of the surface aerator and the LFFA. The DO of the surface aerator became uniform or completely mixing within a short period of aeration, while the LFFA took the longer time. The DO of the LFFA was started with a scattered concentration between the water surface and the bottom of the pond, and then they became more uniform with time. The increasing of the number of LFFA improved the DO distribution through the uniform of DO profile. So, the "4-D*" pattern with 4 sets of the LFFA was confirmed as the suitable installation for 10 m x 10 m of this aquaculture pond.

4 Conclusions

From the results, the LFFA has an accessibility to be an alternative aerator for aquaculture pond, due to highly OTR as the main advantage. The "4-D*" (with partitions) is preferred as the suitable installation pattern for this experiment, with 1.04 x 10^{-4} 1/s of $k_La_{20°C}$, 4.96 % of OTE, 1.20 g/W-h of OTR, and good in DO distribution or mixing. In this case, the partition can improve both terms of the oxygen transfer performance and the energy performance ($k_La_{20°C}$, OTE, and OTR) around 0.31 %. In order to convenient installation, the LFFA can be applied as a floating type with the same oxygen transfer efficiency. Moreover, the recommended operation condition can be proposed as the Table 2.

Table 2 The recommended operation condition for the LFFA

Parameters		Unit	Condition
Air flow rate	per surface area	m/s	1.67E-05
	per unit of LFFA	m^3/s-unit	1.04E-04
	per set of LFFA	m^3/s-set	4.17E-04
Number of LFFA	per surface area	unit/m^2	0.16
		set/m^2	0.04
Submerged depth		m	0.5
Installation pattern		-	4-D with Partition

5 Acknowledgements

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