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Oxygen Transfer Rate Efficiency of Paddle Wheel Aerators in Intensive Shrimp Ponds

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Abstract. The purpose of this study was to determine the oxygen transfer rate efficiency of paddle wheel aerators in intensive shrimp farming. This study was conducted with the causal *ex-pose facto* concept by comparing the performance of paddle wheel aerator. The results showed that water quality in Pond 1 (1 HP) and Pond 2 (2 HP) only brightness which do not comply with water quality standards. The oxygen transfer rate paddle wheel aerator was 1 HP of 3.20 (2.82-3.65) mgO_2/hours and for 2 HP of 2.12 (1.68-2.89) mgO_2/hours. The dissolved oxygen in Pond 1 (1 HP) was 5.25 mg/L and Pond 2 (2 HP) was 5.63 mg/L. The shrimp growth rate in pond 1 is 1.95 (0.01-4.0 gr/day) and pond 2 is 1.25 (0.01-2.55 gr/day). Dissolved oxygen in pond 1 (1 HP) ranged from 4.15-7.26 mg/L and pond 2 (2 HP) ranged from 4.03-8.31 mg/L. Dynamic modeling results show a description the energy input to paddle wheel aerator will gradually decrease from 2 kW to 0.25 kW. The results of this study concluded that the use of a 1 HP paddle wheel aerator has a better oxygen transfer rate and shrimp pond performance than using a 2 HP paddle wheel aerator.

1. Introduction

Shrimp farming is a potential agribusiness activity that is worth developing in coastal areas. Shrimp farming activities are widely developed in Indonesia because of its tropical climate [14]. Shrimp farming activities in Indonesia are developed with traditional, semi-intensive, and intensive farming patterns [3]. One of the characteristics of intensive shrimp culture systems is the use of high stocking densities and long culture cycles [21].

The consequence of this high stocking density is a very excessive level of aquaculture waste load [12]. Aquaculture waste in intensive shrimp farming activities comes from feces, feed residues, and other aquaculture treatment activities [1]. The accumulation of all these activities will cause waste and pollution in the shrimp pond ecosystem. One option to reduce the waste load is the use of paddle wheel aerators. Paddlewheel aerators function to produce oxygen which is beneficial for the decomposition process [26].

Paddlewheel aerators in intensive ponds also function to generate water currents and homogenize pond water quality [15]. The use of paddle wheel aerators is adjusted to the

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carrying capacity of the shrimp biomass. 1 HP paddle wheel aerator is estimated to be able to cover the waste load of 500 kg of shrimp biomass [5-6]. The performance of paddle wheel aerators in shrimp farming activities is also determined by energy input, engine capacity, and other technical factors [17].

Paddlewheel aerators have an important role as oxygen supply for shrimp and decomposition processes [4, 37]. The role of paddle wheel aerators is vital at night or when there is no photosynthetic activity because it is the only source of oxygen input in the pond ecosystem [23, 32]. The level of performance of paddle wheel aerators will have an impact on the productivity of shrimp farming. Shrimp will easily stress and die if the pond water conditions are hypoxic [39]. The level of oxygen solubility in intensive pattern shrimp ponds is required to always be >4 mg/L [41].

Based on the literacy study above, the purpose of this research is to determine the level of efficiency of the oxygen transfer rate in paddle wheel aerators used in intensive-pattern shrimp farming activities. from the results of this study, it is expected that an analysis of the estimated oxygen transfer rate produced by paddle wheel aerators of various types will appear.

2. Materials and Methods

This research was conducted in an intensive shrimp pond in Ulujami Village, Pemalang Regency from 25 June to 25 July 2023. The research ponds used for the study were HDPE plastic ponds totaling 2 ponds with the use of 8 HP paddle wheel aerators. The first pond used 8 paddle wheel aerators of 1 HP and the second pond used 4 paddle wheel aerators of 2 HP. The stocking density used was the same as 100 fry/m^2. The research concept in causal ex-pose facto research with random sampling.

The research variables tested in this research are water quality parameters (pH, dissolved oxygen, salinity, temperature, and brightness) and shrimp weight which are measured every day for 30 days of the study period. To calculate the level of oxygen transfer rate calculated based on the formula [8] :

$$OTR = SOTR \ x \ \frac{Cs-Cp}{9.09} x \ 1{,}024^{T-20} \ x \ \alpha \qquad (1)$$

$$SOTR = (K_L\alpha) \ x \ (Csat) \ x \ (V) \ x \ (10^{-3}) \qquad (2)$$

$$K_L\alpha = K_L\alpha_T \div 1{,}024^{T-20} \qquad (3)$$

$$\alpha = K_L\alpha \ pond \ waters \div K_L\alpha \ water \ origin \qquad (4)$$

Note: OTR = oxygen transfer rate (mgO$_2$/hour); $1{,}024^{T-20}$= temperature factor; $SOTR$= standard oxygen transfer rate (mgO$_2$/hour) ; C_s= water salinity (gr/L); C_p= oxygen saturated in pond (mgO$_2$/L); C_{sat} = pond saturation percent (%O$_2$); $K_L\alpha$ = gas transfer coefficient (mgO$_2$/hour); α = balance coefficient (mgO$_2$/hour); V = water volume (m^3); $K_L\alpha$ = pond temperature gas transfer coefficient (7,24 mgO$_2$/hour).

The results of field measurements were then grouped based on the parameters observed. Furthermore, the research data were analyzed descriptively using dynamic modeling system analysis with the help of Stella software ver 9.02.

3. Results and Discussion

3.1 Water Quality

Water quality parameters in the research ponds are described in Table 1. Overall, the condition of water quality parameters in the location of the research ponds is still by the threshold of water quality standards for aquaculture activities. Parameters that are not by the quality standard threshold are the brightness with a value of 30-80 cm (pond 1) and 30-65 cm (pond 2). The ideal brightness indicator for shrimp farming activities is 25-35 cm [1]. The dynamics of weather and waste in the pond ecosystem make the brightness of pond waters vary [11].

Table 1. Water quality perameter in silvofishery ponds

Parameters	Pond 1	Pond 2	Standart*
pH	(7.9-8.8) 8.3 ± 0.19	(7.7-9.1) 8.3 ± 0.30	7.5-8.5
Salinity (‰)	(31-33) 32 ± 0.73	(20-27) 23 ± 2.16	15-35
Dissolved Oxygen (mg/L)	(4.15-7.26) 5.15 ± 0.32	(4.03-8.31) 5.65 ± 0.56	>4
Temperature (^{0}C)	(26.8-31.0) 28.71 ± 0.61	(26.5-33.1) 29.15 ± 1.12	28-31
Brightness (cm)	(30-80) 49 ± 15.31	(30-65) 42.7 ± 9.44	25-35

Sources : [1]

Water quality parameter values in Pond 1 and Pond 2 tended to be stable and consistent (Table 1.). Weather factors and farm management play an important role in the stability of pond water quality parameters [25]. The stability of water quality parameters is interrelated and influences each other [38]. The dynamics of water quality parameters will have a significant influence on other parameters on an ongoing basis [20]. Turbidity and solubility of organic matter will trigger diurnal fluctuations in water quality parameters in shrimp ponds [22].

3.2 Oxygen Transfer Rate

The oxygen transfer rate or oxygen transfer rate by the paddle wheel aerator on the research pond can be seen in Figure 1. The oxygen transfer rate paddle wheel aerator 1 HP is higher than the paddle wheel aerator 2 HP. Oxygen transfer rate paddle wheel aerator 1 HP 3.20 (2.82-3.65) mgO2/hours, for paddle wheel aerator 2 HP 2.12 (1.68-2.89) mgO2/hours. The difference in pond size and paddle wheel aerator installation distance will affect the oxygen transfer produced [19]. The average dissolved oxygen concentration in pond 1 (1 HP) was 5.25 mg/L and pond 2 (2 HP) was 5.63 mg/L (Figure 1.).

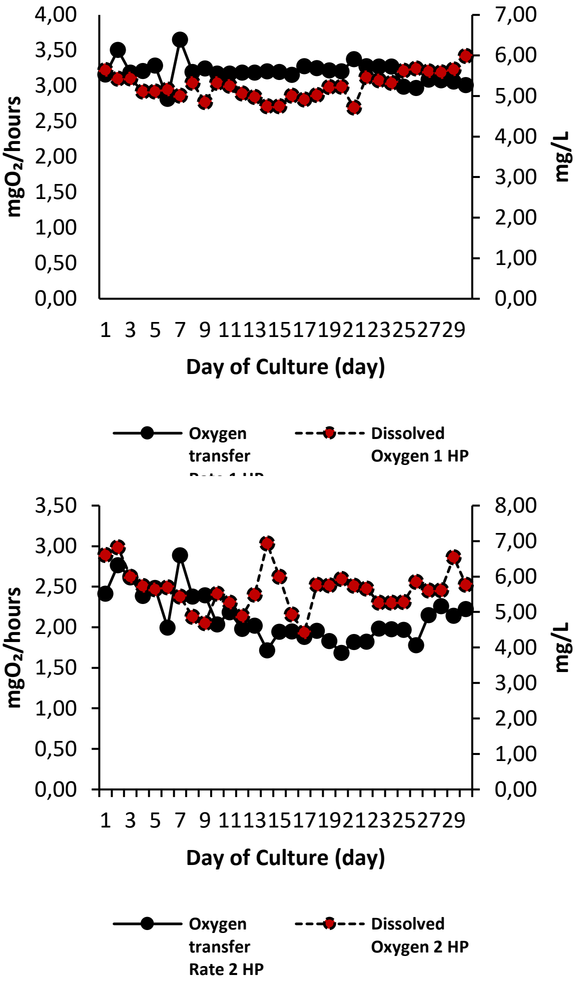


Fig. 1. The level of oxygen transfer rate on the paddle wheel aerator is 1 HP and 2 HP

The existence of contradictory results between the value of oxygen transfer rate and the level of oxygen solubility in ponds is caused by the area and effect of water turbulence. There is a correlation between the level of turbulence and variations in paddle aerator installation models and designs [37]. Paddle aerators will provide continuous horizontal and vertical currents in the water column to produce oxygen bubbles [27]. The current and bubble intensity of the paddle aerator's fluttering process will determine the oxygen diffusion rate in the pond [34].

The oxygen transfer rate of the 1 HP paddle wheel aerator is relatively more stable, while the 2 HP paddle wheel aerator tends to fluctuate (Figure 1.). Technical design and environmental factors such as salinity and temperature will affect the level of oxygen transfer rate fluctuations [2, 4]. The level of oxygen transfer efficiency in paddle aerators is determined by the level of salinity and the rotation of the pinwheel [35-36]. In addition, the force of gravity and the standard value of the pinwheel rotation geometry also affects the perform of the paddle wheel aerator [37].

3.3 Shrimp Growth

The growth rate of shrimp in the research ponds is described in Figure 2. The growth rate increased in absolute terms from 1-30 days of age. The growth rate of vaname shrimp (*L. vannamei*) tends to be faster at 30 days of culture [13]. The growth rate of shrimp in Pond 1 was 1.95 (0.01-4.0 gr/day) and in pond 2 1.25 (0.01-2.55 gr/day). The shrimp growth rate is physiologically closely related to the level of oxygen consumption [28]. Oxygen transfer rates by paddle wheel aerators were not significantly correlated (Figure 2).

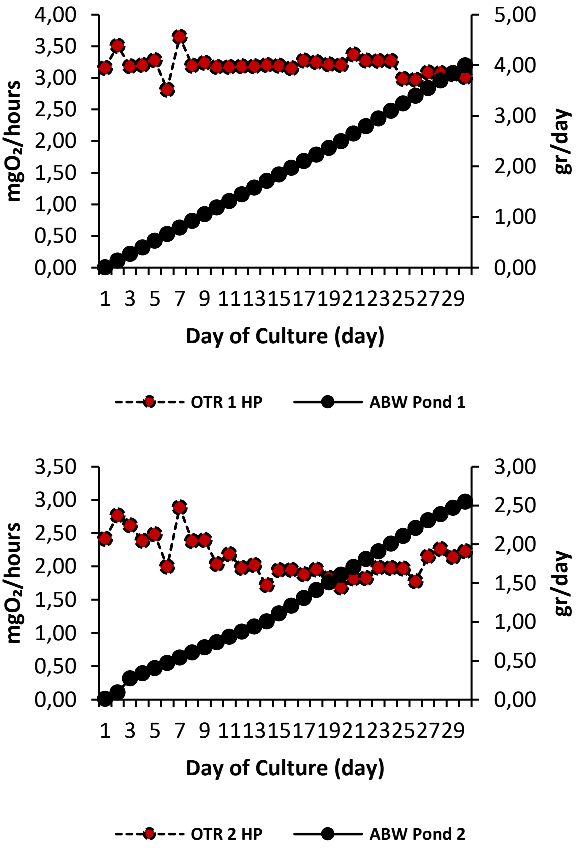


Fig. 2. Shrimp growth rate in 1 HP and 2 HP paddle wheel aerator treatment

The shrimp growth rate is correlated with the level of oxygen consumption in the waters [2]. The aggregative growth rate of shrimp means that shrimp have a level of energy utilization for metabolism [24]. Aggregate growth will affect the amount of feed needed by shrimp [7]. Implicitly the rate of biomass growth will affect the level of nutritional needs of shrimp [29].

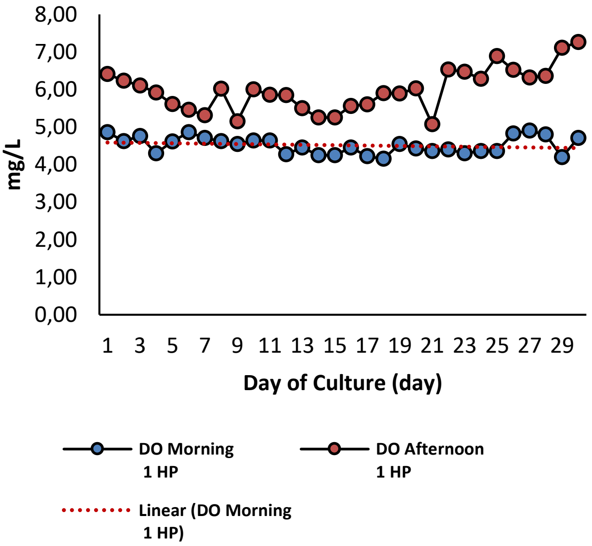
3.4 Oxygen Solubility Level

The concentration of dissolved oxygen in the research ponds during the observation period can be described in Figure 3. The concentration of dissolved oxygen in pond 1 (1 HP) ranged from 4.15-7.26 mg/L and pond 2 (2 HP) ranged from 4.03-8.31 mg/L. This means that the average concentration of dissolved oxygen in Pond 2 is higher than in Pond 1 at 5.65 mg/L versus 5.25 mg/L. However, the range of morning and afternoon oxygen fluctuations in Pond

2 was also higher (0.33-3.80 mg/L) than in Pond 1 (0.60-2.91 mg/L). The high fluctuation of dissolved oxygen is due to the higher range of oxygen solubility concentration in Pond 2. Dissolved oxygen levels in the waters will fluctuate dynamically due to photosynthesis and water circulation [31].

The different ranges of dissolved oxygen fluctuations indicate respiration and biochemical processes in the pond ecosystem. Aquatic organisms will adapt physiologically if there are fluctuations in the level of oxygen solubility in ponds [42]. Oxygen substance in the form of gas is also possible to cause derivative reactions in aquatic ecosystems [9]. The high intensity of oxygen solubility will affect the oxidation rate and nitrification cycle in the waters [18].

The level of oxygen solubility in pond waters is caused by the process of photosynthesis, oxygen diffusion, water changes, and the use of paddle aerators. Photosynthesis has a significant effect on increasing algal abundance and oxygen solubility in waters [40]. Intense oxygen solubility in intensive ponds is influenced by the agitation force of using paddle aerators [5]. So the presence of oxygen in intensive shrimp ponds will continue to fluctuate throughout the day [30].



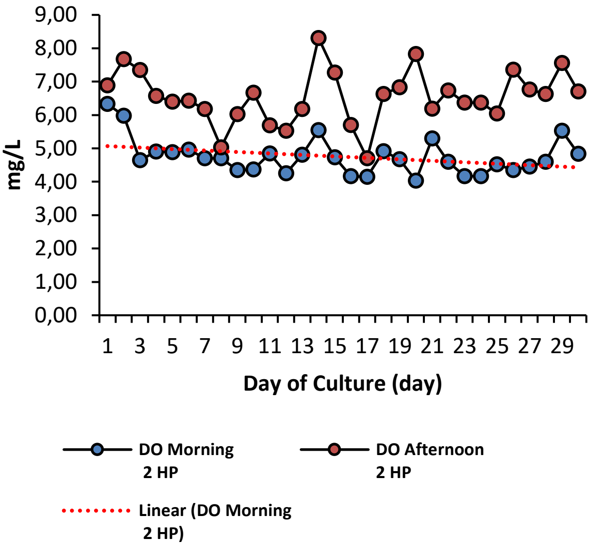


Fig. 3. Oxygen solubility level in ponds 1 (1 HP) and 2 (2 HP)

3.5 Oxygen Transfer Rate Estimation Model

The results of dynamic modeling estimation of oxygen transfer rate by paddle wheel aerator during one cycle of shrimp farming can be seen in Figure 4. In the causal loop model, it is described that the performance of the paddle wheel aerator is influenced by energy input and water salinity levels, so it will produce an oxygen transfer rate and oxygen solubility in the water (Figure 4A.). Then, the results of the dynamic modeling analysis can be seen in Figure 4B. Based on the results of the dynamic modeling analysis, it is shown that the oxygen transfer rate in the pond will continue to increase to a limit of 3 mgO2/hour, but the energy input to the paddle wheel aerator will continue to decrease from a capacity of 2 kW to 0.25 kW (Figure 4B.). This means that the performance of the paddle wheel aerator will continue to decrease as the age of the shrimp farm increases.

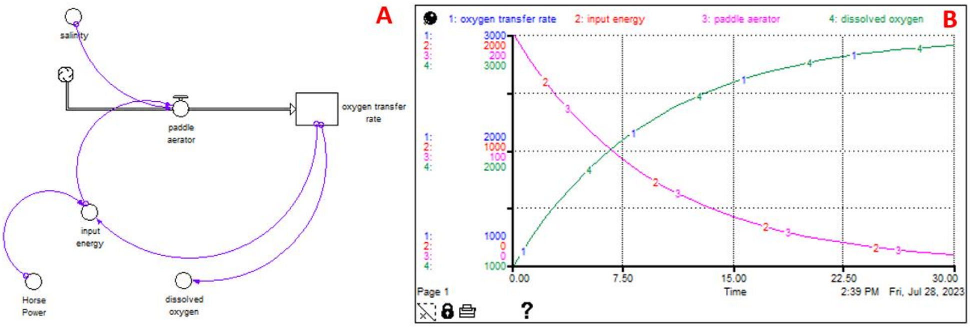


Fig. 4. Results of dynamic modeling analysis; A.) Causal loop model, B.) oxygen transfer rate paddle wheel aerator in ponds

The performance of the paddle wheel aerator will decrease due to the technical age of the engine used [36]. Decreased engine energy input will affect the rotation of the wheel [16]. If the pinwheel on the paddle wheel aerator has decreased rotation, the agitation force and the amount of water splashing will decrease [23]. This reduction in the intensity of water splashing and agitation force causes oxygen diffusion to be inhibited. But overall, a decrease in energy input on the paddle wheel aerator does not affect the absolute level of oxygen solubility in ponds. Oxygen solubility in ponds is influenced by many other factors such as water turnover, photosynthesis, and air diffusion [4].

Overall, water quality in pond 1 with the use of a 1 HP paddle wheel aerator has a better oxygen transfer rate. The good oxygen transfer rate in Pond 1 correlated with the water quality profile and shrimp growth rate. High oxygen conditions (*normoxia*) will increase the growth rate and shrimp metabolism becomes more active [10]. The higher dissolved oxygen solubility in pond 2 was due to the more intense agitation of the paddle wheel aerator. The process of agitation of water currents and air diffusion are the main factors affecting oxygen solubility in ponds [43].

Based on the dynamic modelling estimation, it is predicted that the energy input to the paddle wheel aerator will continue to decrease. The energy input will affect the rotation rate of the paddle wheel aerator which makes the oxygen diffusion process stagnant [33]. However, the overall decrease in energy input does not significantly affect the oxygen solubility rate. The decrease in energy input in paddle wheel aerators is very likely due to the long shrimp culture cycle [8].

4 Conclusion

The results of this study conclude that the use of a paddle wheel aerator of 1 HP has an efficient level of oxygen transfer rate as well as the impact on growth performance and water quality better than using a paddle wheel aerator capacity of 2 HP.

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