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Dynamic Modeling Analysis of *Paddle Aerator* Performance on *Litopenaeus vanamei* Ponds

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Abstract

Paddle aerator is an important tool in intensive shrimp farming. The purpose of this study is to determine the performance and electrical power consumption of paddle aerators based on the results of dynamic modelling analysis. This study uses causal ex-pose facto design concept with data analysis using dynamic modelling system. The results showed the salinity levels of pond 1 20-27 gr/L and pond 2 31-33 gr/L, pH pond 1 7.9-9.0 and pond 2 8.1-8.3, DO concentration pond 1 4.43-6.93 mg/L and pond 2 4.72-5.99 mg/L, temperature pond 1 27.15-31.400C with a brightness of 43 cm and pond 2 ranging from 27.50-29.850C with a brightness of 49 cm. From the calculation of the level of oxygen production paddle aerator power 1 HP produces oxygen average 2.12 mgO2 / hour (1.68-2.89 mgO2 / hour) with gas pressure 10.31-16.00 mmHg and paddle aerator power 2 HP produces oxygen average 3.20 mgO2 / hour (2.82-3.65 mgO2 / hour) with gas pressure 10.05-14.56 mmHg. From the accumulated results, the electrical load power required for pond 1 is about 6.83-10.38 kW and pond 2 is about 6.59-7.71 kW. The performance of 1 HP paddle aerator is more effective than 2 HP paddle aerator 4 pieces. The results of dynamic model analysis estimated the level of dissolved oxygen production by paddle aerators during one cultivation cycle ranged from 1-2.70 mgO2/hours and 1-2.75 mgO2/hours with a rotational speed of 0-30 rpm/s and power requirements of 8-10 kW. The conclusion from the results of this study is that the use of 1 HP paddle aerators in large quantities is proven to be more effective and based on the results of dynamic modelling system analysis, it is shown that the performance of DO production by paddle aerators will stagnate at week ten of the cultivation period, with increasing electrical power requirements.

Keywords *dissolved oxygen, shrimp, intensive, diffusion, electricity.*

INTRODUCTION

Vaname shrimp (*L. vannmaei*) is a type of organism that has a high level of sensitivity to changes in aquatic environmental conditions (AftabUddin et al, 2020). Physiologically, vaname shrimp will easily experience stress when there are extreme fluctuations in water quality parameters. One parameter that has a direct physiological impact on shrimp metabolism is oxygen dissolved (Araneda et al, 2020). Dissolved oxygen will fluctuate diurnally following the dynamics of temperature and salinity solubility in waters (Wafi et al, 2021). Shrimp will stress and die when water conditions are hypoxic (Ariadi et al, 2019). Hypoxic conditions can mean that the concentration of dissolved oxygen in the pond water ecosystem is very low (<4 mg/L) (Ariadi et al, 2021).

One way to avoid hypoxic water conditions is to add *paddle aerators* according to the carrying capacity of shrimp biomass. *Paddle aerator* is one of the aquaculture engineering tools used in intensive pattern vaname shrimp (*L. vannamei*) farming activities (Dalla Santa and Vinatea, 2007). The main function of *paddle aerator* is as an engineering tool to increase the intensity of dissolved oxygen production through the process of air diffusion (Moulick et al, 2002). The mechanism of dissolved oxygen production through the use of *paddle aerators* is the touch of *paddle aerator* water splash results to the air pressure in the atmosphere (Ariadi et al, 2020). If the air pressure in the atmosphere is higher than the water pressure in the water column, oxygen will diffuse directly from the air to the water column (Delgado et al, 2003; Ariadi et al, 2020).

Another function of *paddle aerators* in ponds is to create currents and make water conditions homogeneous (Ariadi, 2019). The current from the *paddle aerator* blast will form a water current that serves to collect dirt into the pond's central drain (Moulick et al, 2002). In addition, the vertical movement of the current from the *paddle aerator* will create a mixture that causes the water conditions to become homogeneous (Hasan et al, 2020). Therefore, the installation position of *paddle aerators* in intensive shrimp ponds is arranged in such a way as to be optimally useful.

The use of *paddle aerators* in ponds is determined based on the estimated biomass of shrimp reared (Aljufri et al, 2021). 1 HP *paddle aerator* is estimated to cover the waste load of 500 kg of shrimp in the pond (Ariadi et al, 2021). The level of use of *paddle aerators* also affects the amount of electricity consumption and operational costs of aquaculture (Choi et al, 2021). Based on the results of research by Wafi and Ariadi, (2022) showed that the lower the level of dissolved oxygen production produced by *paddle aerators*, the higher the electricity load required. This means that there is a correlation between the amount of shrimp biomass, the level of oxygen production by *paddle aerators*, and the amount of electrical power consumption by *paddle aerator*.

The correlation between the amount of shrimp biomass, the level of oxygen production by the *paddle aerator*, and the amount of electrical power consumption will largely determine the performance level of the *paddle aerator*. The performance of *paddle aerators* is very important to support the production cycle of intensive vaname shrimp farming (Dayioglu, 2022). Therefore, the objective of the study was to determine the performance and electrical power consumption of the *paddle aerator* based on the results of dynamic modelling analysis. The analysis of the performance and electrical power consumption of *paddle aerators* was carried out by comparing the performance levels of *paddle aerators* of 2 different types of power (1 HP and 2 HP) in intensive vaname shrimp farming activities.

The objective of the study was to determine the performance and electrical power consumption of the *paddle aerator* based on the results of dynamic modelling analysis.

The performance level of the *paddle aerator* is positively correlated with the level of oxygen production in intensive vaname shrimp farming activities in a correlative manner.

This research is expected to provide scientific information related to efforts to utilize *paddle aerators* as aquaculture engineering tools. In addition, the results of this study are expected to provide scientific information to aquaculturist regarding the effectiveness of the number of *paddle aerators* used during the operational shrimp farming.

The conceptual model can be clearly presented in the following Figure 1.

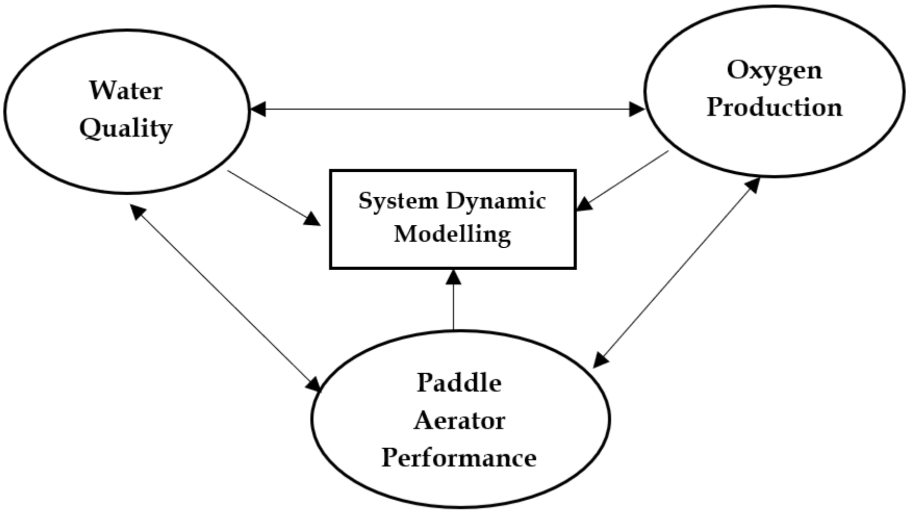

Figure 1. Conceptual model of research

LITERATURE REVIEW

*Paddle aerator*s are widely used in aquaculture and sewage treatment systems to increase dissolved oxygen levels in water. Dissolved oxygen is essential for aquatic life, as it supports the respiration of organisms such as fish and microorganisms. *Paddle aerators* operate by rotating paddles in a pond or tank, which moves the water and creates turbulence. This process increases contact between water and air, allowing oxygen from the atmosphere to be dissolved into the water. According to research by García et al, (2015), the efficiency of oxygen transfer by *paddle aerators* is influenced by rotational speed, paddle design, and water depth.

Several factors affect oxygen production by *paddle aerators* including rotational speed, *paddle aerator* design, and water depth. The rotational speed of *paddle aerators* suggests that higher rotational revolutions can increase oxygen transfer rates but can also lead to increased turbulence that can potentially damage the aquatic environment (Bai et al, 2018). The design and size of the *paddle aerator* also affects the level of aeration efficiency as larger *paddle aerator* paddles tend to produce more turbulence, thereby increasing dissolved oxygen levels (Chen et al, 2019). The level of dissolved oxygen production by the *paddle aerator* is also affected by the depth of the pond. *Paddle aerator* performance is more effective at pond depths that tend to be shallower (Lee et al, 2020).

The performance of *paddle aerators* has been proven to be effective in various applications. In aquaculture, the use of *paddle aerators* increases fish growth and reduces stress levels in fish (Nunes et al, 2021). In sewage treatment systems, it was found that *paddle aerators* are able to accelerate the biodegradation process by increasing dissolved oxygen which supports the activity of decomposing microorganisms (Saha et al, 2022).

METHOD

The research was conducted in intensive ponds in Ulujami Village, Pemalang Regency from 25 June to 25 July 2023 or 30 days of intensive vaname shrimp culture. Shrimp ponds at the research site were HDPE plastic ponds with a stocking density level of

100 shrimp/m^2. The research concept used is causal ex-pose facto design or data collection based on natural conditions in the field without any treatment engineering. Two research ponds were observed. The first pond observed was a 2,500 m^2 HDPE pond with the use of *paddle aerator* capacity of 1 HP as many as 8 pieces. The second pond observed was a 2,500 m^2 HDPE pond with the use of 4 *paddle aerators* of 2 HP capacity. Stocking density (100 shrimp/m^2) and technical treatment of cultivation in both ponds were the same. Data collection was conducted daily during the first 30 days of shrimp culture.

The research variables observed were water quality parameters (pH, dissolved oxygen, salinity, temperature, and brightness), oxygen production rate, water pressure, and *paddle aerator* electricity demand. To calculate the rate of dissolved oxygen production by *paddle aerator* is calculated based on the following formula (Boyd, 1998):

$$OTR = SOTR \times \frac{Cs-Cp}{9.09} \times 1{,}024^{T-20} \times \alpha$$

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

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

$$\alpha = K_L\alpha \text{ air kolam} \div K_L\alpha \text{ air murni}$$

Where: OTR = oxygen transfer rate (mgO$_2$/hour); 1.024T-20= temperature correction factor; SOTR= standard oxygen transfer rate (mgO$_2$/hour) ; Cs = value of salinity in the pond (ppt); Cp= concentration of saturated oxygen in the pond (mgO$_2$/L); Csat = pond saturation percent value (%O$_2$); KLα = gas transfer coefficient (mgO$_2$/hour); α = balance coefficient (mgO$_2$/hour); V=volume of water (m^3); KLα pool temperature gas transfer coefficient (7.24 mgO$_2$/hour).

The water pressure rate in pond waters is calculated using the formula introduced by Boyd, (1998), such as:

$$Po_2 = \frac{Cm}{Cs} \times 0.2095 \times 760$$

Where: Po$_2$ = oxygen pressure in water; cm = dissolved oxygen level; Cs = oxygen saturation value; 0.2095 = air pressure constant; 760 = normal air pressure.

The estimation of the level of electrical power requirements for the use of *paddle aerators* in intensive ponds can be calculated based on the following formula (Roy et al, 2015):

$$P_T(kW) = TOD\ (kgO_2/h)\ /\ AE\ (kgO2/kWh)$$

Where: PT (kW) = Total electrical energy needed by the *paddle aerator*; TOD (kgO$_2$/h) = Total oxygen demand in the pond; AE (kgO$_2$/kWh) = Efficiency level of using *paddle aerators* in ponds.

Furthermore, the research data were grouped based on indicators of the desired test parameters. The research data were analysed descriptively using graphs and tables. In addition, the research data was further analysed through the dynamic modelling analysis method with the help of Stella ver 9.14 software.

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RESULT AND DISCUSSION

Water Quality Parameters

pH and Salinity

The pH concentration and salinity levels of pond water can be seen in Figure 2. Based on the display of Figure 2, it is shown that the salinity levels in pond 2 tend to be higher and more stable (31-33 gr/L) than pond 1 (20-27 gr/L). The pH concentration in pond 2 is also relatively more stable (8.1-8.3) compared to pond 1 (7.9-9.0). Salinity and pH levels in pond 1 tend to fluctuate more. Fluctuations in pH and salinity levels are due to the intrusion of seawater and rainwater (Ahmed et al, 2023).

Fluctuating salinity levels affect the dynamics of pH in pond water. Salinity levels in pond waters are influenced by the solubility of mineral ions (Ariadi, 2020). The solubility of mineral ions will accumulatively affect the salinity levels of waters (Whangchai et al, 2004; Torun et al, 2022). The dynamics of fluctuations in pH values in shrimp ponds are generally influenced by alkalinity levels and temperature (Whangchai et al, 2004).

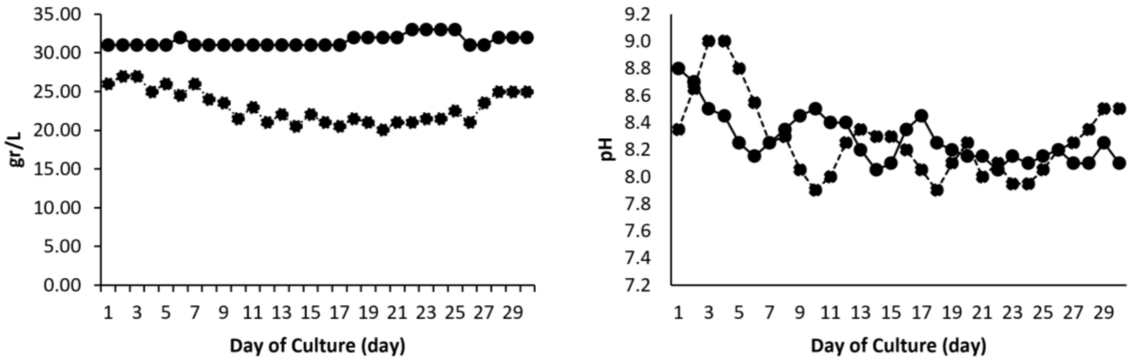

Figure 2. The levels of pH and salinity of research pond waters

Dissolved Oxygen and Temperature

Data on dissolved oxygen concentration and water temperature distribution can be seen in Figure 2. Figure 2 illustrates that dissolved oxygen and temperature in pond 2 tend to be more stable than pond 1. The concentration of dissolved oxygen and temperature in pond 1 (4.43-6.93 mg/L) is higher than pond 2 (4.72-5.99 mg/L). The high dissolved oxygen concentration correlated with the temperature distribution in pond 1 (27.15^{0}C-31.40^{0}C) which was higher than pond 2 (27.50^{0}C-29.85^{0}C) (Figure 2). This means that the higher the temperature, the higher the oxygen solubility. The increase in oxygen concentration and higher temperature is due to the different pond sizes (Ariadi et al, 2021).

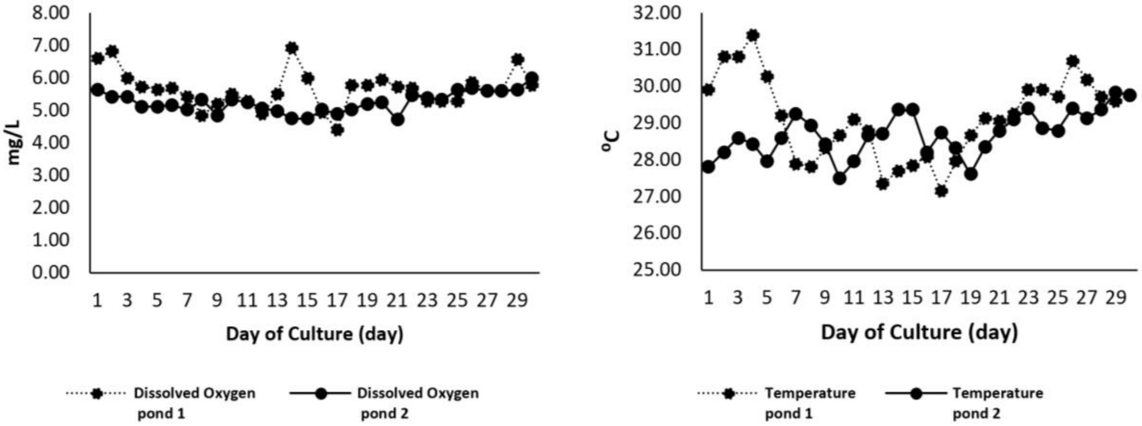

Figure 3. Dissolved oxygen concentration and temperature of research pond waters

The temperature distribution trend is much more dynamic than the dissolved oxygen concentration flux (Figure 3.). The fluctuating temperature distribution is caused by the shading process of the turbidity level of the water in the pond (Yang et al, 2018). Implicitly the level of oxygen solubility in intensive shrimp pond waters is strongly influenced by fluctuations in water temperature (Ariadi et al, 2019). Pond 1 has a smaller pond area that allows periodic temperature shocks. Temperature fluctuations are not only caused by shading but also by plankton succession (Case et al, 2008; Koyama et al, 2020).

Water Brightness

The level of brightness of pond waters can be observed in Figure 4. Based on the data in Figure 4. can be described that between pond 1 and pond 2 have similar flukes water brightness values. The brightness of pond water is described to be increasingly concentrated as the age of shrimp farming increases (Ariadi et al, 2021). The more concentrated water brightness is caused by the accumulation of shrimp feces, feed residues, and dissolved particles (Li et al, 2021; Ahmed et al, 2023).

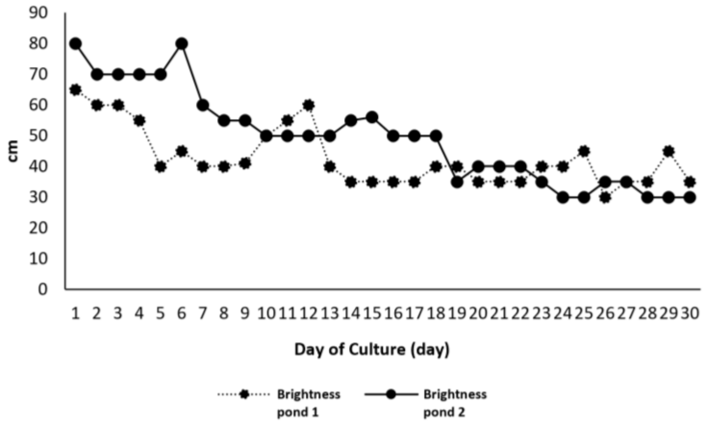

Figure 4. Fluctuations in brightness values in research pond waters

The level of brightness of the pond waters will prevent the penetration of sunlight to reach the bottom of the pond. Extreme fluctuations in temperature levels also affect the

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immune system of shrimp reared (Luo et al, 2023). Shrimp is an organism that is very sensitive to changes in its ecosystem (Ariadi et al, 2021). The increasingly dense brightness level also indicates the dominance of plankton in the pond ecosystem (Soeprapto et al, 2023).

Oxygen Transfer Rate by *Paddle Aerator*

Oxygen production rates by *paddle aerators* can be seen in Figure 5. Oxygen production rates by *paddle aerators* tended to be unstable during the 30-day observation period. Pond 1 (*paddle aerator* 1 HP) produced an average *paddle aerator* oxygen production of 2.12 mgO_2/hour (1.68-2.89 mgO_2/hour) or smaller than pond 2 (*paddle aerator* 2 HP) of 3.20 mgO_2/hour (2.82-3.65 mgO_2/hour). The high rate of oxygen production by the *paddle aerator* did not correlate with the concentration of oxygen solubility in the pond. The 1 HP *paddle aerator* had a mean DO of 5.63 mg/L or higher than the 2 HP *paddle aerator* with a mean of 5.25 mg/L.

The difference between the level of dissolved oxygen production by *paddle aerators* and DO concentrations in ponds is due to the treatment, fluctuations in water parameters, and different conditions in the pond ecosystem (McGraw et al, 2001; Xiao et al, 2017). *Paddle aerator* dissolved oxygen production rates and DO concentrations in pond 2 tended to be more stable due to the use of larger *paddle aerator* types. The use of engine power and the positioning of the *paddle aerator* will influence the level of oxygen production and distribution in the pond (Delgado et al, 2003; Boyd and McNevin, 2020). The *paddle aerator* performance is also influenced by salinity levels and pond water levels (Ariadi et al, 2020).

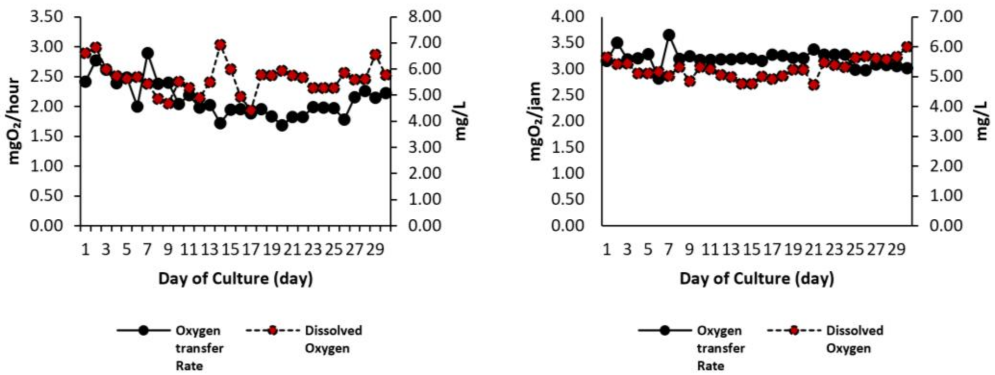

Figure 5. Oxygen transfer rate at 1 HP (left) and 2 HP (right) paddle aerators

The main factors affecting the performance level of *paddle aerators* are rotational speed, energy input, and energy distribution flow (Brown and Tucker, 2014). In addition, pond size also affects the level of oxygen solubility in shrimp pond ecosystems (Hopkins et al, 1991; Wafi and Ariadi, 2022). In this study, pond 1 is smaller in size so that it can produce higher DO concentrations. Pond 2 uses a larger type of *paddle aerator* so that it can produce higher dissolved oxygen. Implicitly, *paddle aerators* not only play a role for oxygen supply but also have an effect in producing stable pond water currents (Tanveer et al, 2018).

Oxygen Pressure in Water

The mean oxygen pressure level of the 1 HP *paddle aerator* (13.09 mmHg) was higher than the 2 HP *paddle aerator* (12.22 mmHg). High pressure was negatively correlated to the level of oxygen transfer by the *paddle aerators* in the ponds (Figure 6.). In pond 1 (*paddle aerator* 1 HP) a pressure of 10.31-16.00 mmHg was able to produce oxygen solubility rates between 1.68-2.89 mgO_2/hour. Pond 2 (*paddle aerator* 2 HP) with a pressure of 10.05-14.56 mmHg is able to produce oxygen solubility range of 2.82-3.65 mgO_2/hours.

High gas pressure in the water will make oxygen diffused into the atmosphere slowly and vice versa (Ariadi, 2019). High gas pressure in pond 1 due to the small size of the pond and the greater number of *paddle aerators* allows for even stirring. Proper positioning of the *paddle aerator* will result in more efficient tectonic pressure and kinetic energy from the current (Robinson and Zhou, 2008). The oxygen diffusion process takes place intensely from high pressure to low pressure until saturation conditions in the atmosphere and water column (Castillo et al, 2015).

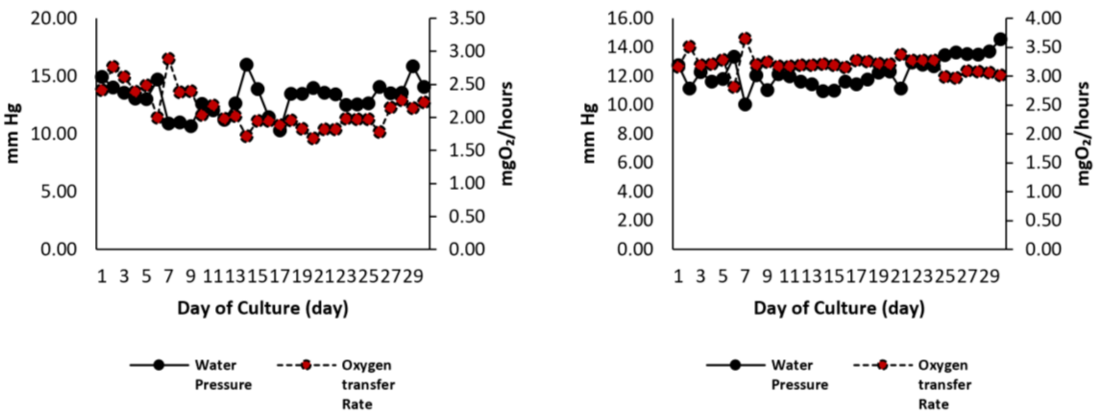

Figure 6. Water pressure at paddle aerator 1 HP (left) and 2 HP (right)

Paddle Aerator Electrical Consumption

The estimated level of electrical load used for *paddle aerator* operations during the study period is presented in Figure 7. The level of electrical load usage on pond 1 (*paddle aerator* 1 HP) tends to fluctuate steadily while on pond 2 (*paddle aerator* 2 HP) is oscillatory. Electrical load requirements for *paddle aerator* 1 HP ranged from 6.83-10.38 kW and *paddle aerator* 2 HP ranged from 6.59-7.71 kW (Figure 7.). The average oxygen production rate by the 2 HP *paddle aerator* was 2.12 mgO_2/hour or less than the 1 HP *paddle aerator* 3.20 mgO_2/hour. This means that the use of 1 HP *paddle aerator* is much more electricity efficient and effective in producing oxygen per time. The technical design of the *paddle aerator* will affect the level of transfer performance and energy use (Tien et al, 2019).

The technical structure and abiotic factor conditions affect the oxygen production rate by the *paddle aerator* (Itano et al, 2019). The higher the oxygen production rate, the smaller the amount of electrical load required by the *paddle aerator* (Wafi and Ariadi, 2021). The more intense the *paddle aerator* wheel moves, the higher the electricity consumption per unit time. The rotational speed of the *paddle aerator* wheel depends on the input and energy flow rate of the engine (Brown et al, 2016). The rotational speed and the level of

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water splashing from the *paddle aerator* wheel will affect the effectiveness of dissolved oxygen diffusion (Ariadi et al, 2020).

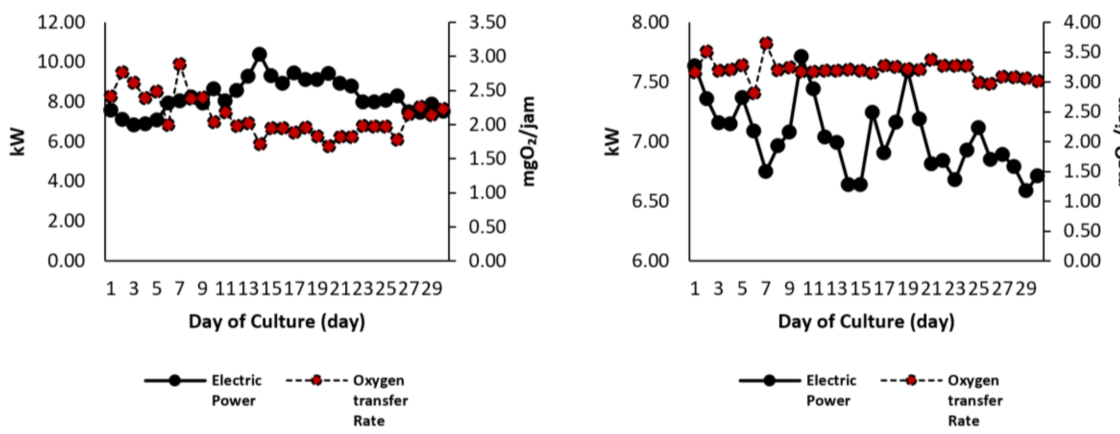

Figure 7. Electrical load for 1 HP (left) and 2 HP (right) paddle aerators

The electrical load will fluctuate dynamically throughout the intense operation of the *paddle aerator*. The technical operational cycle of the *paddle aerator* will determine the stability of the power input and energy flow into the engine (Brown et al, 2016). The nature of the engine and the pond water depth will determine the level of energy output produced by the *paddle aerator* wheels (Brown and Tucker, 2014). Simulatively the energy output generated by the *paddle aerator* will also impact the distribution of current flow in the water column (Peterson et al, 2001).

Causal Loop* Model of Oxygen Production by *Paddle Aerator

The results of the dynamic modelling analysis using the *causal loop* are described in Figure 8. The causal loop figure in Figure 8. shows a description of the correlation between the level of dissolved oxygen production by the *paddle aerator* and the level of electrical power requirements for the *paddle aerator* operation. The technical working system of *paddle aerators* is influenced by energy input, flow rate, wind speed and electrical load (Brown and Tucker, 2014; Brown et al, 2016).

Based on the theoretical review of Brown and Tucker, (2014) and Brown et al, (2016), it is outlined in the form of a causal loop correlation. The causal loop model is then validated to ensure that the model can be analysed. To analyse the model, we can choose the indicators to be tested as needed.

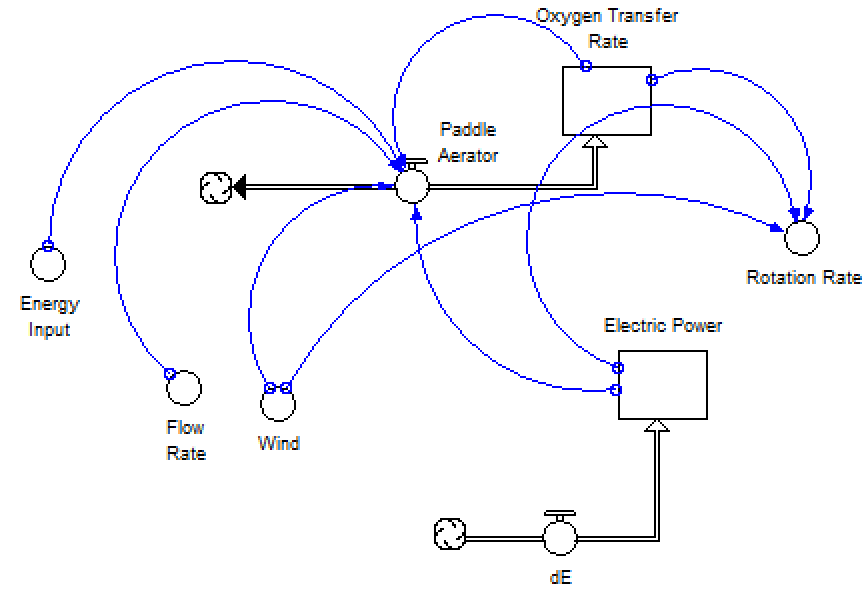

Figure 8. Causal loop model for dynamic modelling analysis

Estimation of Dissolved Oxygen Production

The performance of the *paddle aerator* in the intensive pattern of udan aquaculture is described in Figure 9. Descriptively, it is illustrated that the performance of the *paddle aerator* is oscillative during the 20-week estimation period. The level of oxygen production is simulatively described as increasing from week one to ten and then stagnating. Oxygen production rates by the 1 HP *paddle aerator* based on dynamic modelling analysis ranged from 1-2.75 mgO_2/hour with a rotational speed of 0-30 rpm/s (Figure 9A.). The oxygen production rate by the 2 HP *paddle aerator* was estimated to be around 1-2.70 mgO_2/hour with a rotation speed of 0-30 rpm/s (Figure 9B.). This means that there is no significant difference in oxygen production between the two *paddle aerators*. Based on the analysis of the dynamic modelling system, it can be assumed that the maximum oxygen production level of the *paddle aerator* is 2.70-2.75 mgO_2/hour with a wheel rotation speed of 30 rpm/s.

There is a correlation between the number of wheel rotations and the amount of dissolved oxygen production by the *paddle aerator* (Boyd and McNevin, 2020). The higher the rotation intensity, the more the amount of oxygen solubility in the waters will increase (Ariadi et al, 2021). The rotation of the pinwheel on the *paddle aerator* will affect the amount and intensity of the water splash produced each rotation (Brown and Tucker, 2014). The amount of spark intensity will affect the friction force between the water body and the atmosphere so that the diffusion process occurs (Ariadi et al, 2020).

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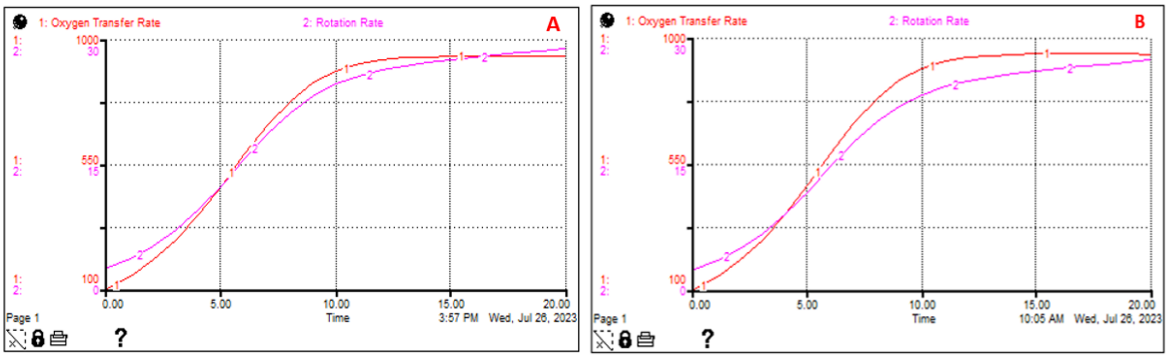

Figure 9. Estimation model of oxygen transfer rate by paddle aerator A.) 1 HP dam B.) 2 HP

Estimation of *Paddle Aerator* Electrical Power

The estimated electrical power load for the operation of *paddle aerators* during the shrimp culture period is estimated in Figure 10. 1 HP *paddle aerator* with a rotation rate of 0-30 rpm/s requires 8-10 kW of electrical power (Figure 10A.), while a 2 HP *paddle aerator* with a rotation rate of 0-30 rpm/s also requires the same electrical power load (Figure 10B.). The estimated rate of oxygen production by the *paddle aerator* that increases and then stagnates will affect the accumulative electrical energy demand. The existence of technical factors and the performance period of *paddle aerators* will have an impact on electrical energy requirements which tend to increase (Kazemzadeh et al, 2020).

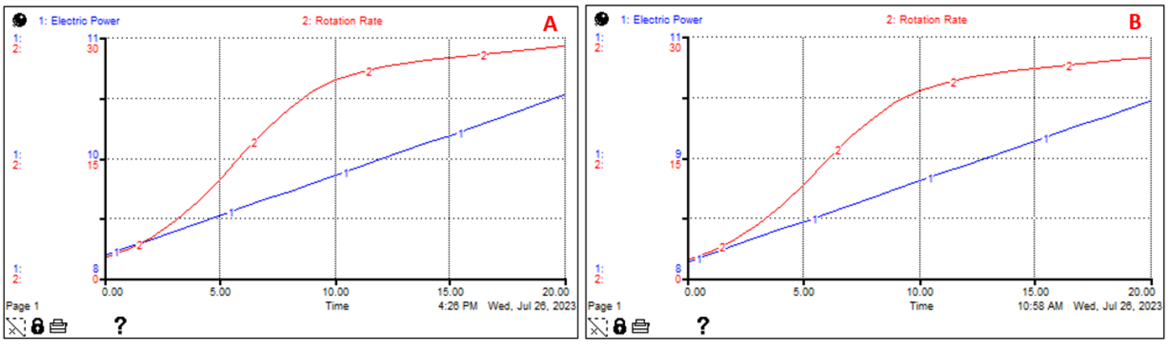

Figure 10. Electric power estimation model by paddle aerator A.) 1 HP and B.) 2 HP

The rotation rate of the *paddle aerator* will affect the daily water circulation process in the pond (Peterson et al, 2001). Consistent water circulation serves to reduce suspended particles in the water column (de Morais et al, 2020). The intense aeration process through *paddle aerators* is a limiting factor for oxygen production in pond waters (Iber and Kasan, 2021). The effective use of *paddle aerators* and the level of electricity consumption will affect the amount of operational costs of aquaculture production (Moore and Boyd, 1992).

Overall, the use of a 1 HP *paddle aerator* can provide a higher level of dissolved oxygen production than a 2 HP *paddle aerator*. The higher dissolved oxygen production is due to the lower amount of gas pressure in the water (Boyd, 1998). Dissolved oxygen production levels are negatively correlated with oxygen solubility concentrations which tend to be lower. Differences in oxygen solubility fluctuations and concentrations are caused by differences in air pressure and pond area at the farm site (Samocha, 2019). Differences in dissolved oxygen production levels and *paddle aerator* capacity correlate with the electrical power used in the pond (Wafi and Ariadi, 2022). The level of electrical power consumption of *paddle aerators* will fluctuate diurnally following the ecological conditions of the water and the performance of the *paddle aerator* itself (Kitazawa and Zhang, 2016).

CLOSING

Conclusion

The conclusion from the results of this study is that the use of 1 HP *paddle aerator* with a large number proved to be more effective than the 2 HP *paddle aerator* with a smaller number. Furthermore, based on the results of simulative dynamic modelling system analysis, it is shown that the performance of dissolved oxygen production by *paddle aerators* will increase and stagnate in the tenth week of cultivation, these conditions have a correlative effect on electricity demand which is increasing every week.

Sugession And Recommendation

In the future, it is necessary to conduct research on the technical engineering of the effectiveness of the use of *paddle aerators* in intensive shrimp farming activities integrated with the use of IoT technology. In addition, it is also necessary to conduct modelling research on the effectiveness of the use of *paddle aerators* in aquaculture activities carried out integratively.

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