Optimization of Paddle Wheel Aeration, a preliminary study of Integrated Smart Aquaculture System

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Abstract. The paddlewheel aerator is one of the supporting facilities in the intensive aquaculture pond system. Assuming all the land uses an intensive cultivation system, more than two million paddlewheels worth more than 10 trillion will be needed by 2024. Currently, all paddlewheels are produced abroad or imported. This is very unfortunate considering the vast market potential. This paper discussed a preliminary study of developing paddlewheel aeration for shrimp ponds using an integrated intelligent aquaculture system to support intensification. Two paddlewheel aerators with modifications in the gearbox have been successfully installed. Based on the observation and user’s testimony, the newly installed paddlewheel was quite good, the sound of the motor was smooth, then the flow range was longer, the coverage area was more expansive than the existing waterwheel. This research would be a foundation for intelligent paddlewheel aeration design that can be developed domestically to support local industry in Indonesia.

1. Introduction
The aquaculture industry has been a dominant sector in aquatic food production and continues a thriving industry that supports the nation’s economy. The aquaculture industry in Indonesia is an up-and-coming sector. According to data from previous research [1], in terms of gross yearly aquaculture production globally, Indonesia ranks number four as the most productive country. Indonesia takes advantage of as an archipelago country located along the equator with a tropical climate. A recent survey [2] places Indonesia as the third-longest coastline with 95,181 km. The most significant aquaculture product exported is shrimp, fish, and seaweed.

It has been observed that aquaculture in Indonesia contributes more than 40% to its fish supply compared to only about 10% back in 1960 and is projected to outpace capture fisheries production by 2026 under business as usual scenarios [3]. About 8% of total shrimp world production equals almost half a million tons produced in 2004. A previous study [4] reported that more than half a million hectares’ area in Indonesia was occupied by aquaculture in 1999, 60% of which was brackish water ponds, 28% of which was integrated rice and fish farming, and the rest was freshwater ponds.

Aquafarming production systems are diversified, varying from intensive to extensive models. Extensive aquaculture includes breeding until harvesting fisheries products, where human interference is mainly focused on reproducing the stocks. Low yields in this system will be produced, lower than 50 kg per hectare per year. On the other hand, Intensive aquaculture produces a very high yield, according to previous research [5]. As a result, high energy demand would also require.

Expenses in keeping the water quality level are one of the significant issues in intensive aquafarming. There is a large number of published studies like [6], [7] explained that the dissolved
oxygen (DO) concentration in water ponds is the most crucial parameter in order to make sure the physical condition and survivability of stock under culture. Aquatic animals like fish and shrimp breed in ponds are entirely different from related species living in seas or rivers. The need for a high DO in the ponds is the main thing, particularly in intensive aquaculture systems. The proper aeration system is engineered to boost the oxygen content to avoid DO deficiency and increase production.

According to [8], several aeration systems are available in most cases. A pure oxygen contact system boost DO concentration by discharging oxygen bubbles into the water. Bubbler and splasher systems use motors and pumps with power grids or diesel engines in rural areas to raise the oxygen transfer rate between air and water. Traditionally, it has been argued that paddlewheel and propeller aspirator pump aerator types are the most commonly used aerators applied due to the high-efficiency oxygen transfer rate between air and water [9]. Moreover, paddlewheel aerator type could make the pond easier to clean since the food leftovers and excrement could be directed to a particular area in the pond.

In previous studies, paddlewheel aerators usually run day and night continuously, even if the DO level within the pond is already saturated [6]. The consequences of this practice would be off-gassing DO, wasting energy, and high electricity costs. Several types of research have been conducted to control appropriate DO levels and lessen power consumption. Several authors have demonstrated the improvement of energy consumption when paddlewheel aerators are set in intermittent mode [10]. Several lines of evidence suggested automation control [11], while numerous studies have attempted to applied effective intelligent control to reduce energy consumption [12], [13].

According to the Ministry of Marine Affairs and Fisheries, Indonesia’s national shrimp production in 2024 is targeted at 1.3 million tons with a production value of more than 90 trillion with a land area requirement of 120 thousand hectares. The need for facilities and infrastructure to support intensive cultivation systems is 2.8 million units of paddlewheel aerators. The price of 2 impellers paddlewheel aerators is around 5 million, so the total need for the paddlewheel aerators is more than 10 trillion rupiahs. Currently, all of the paddlewheel aerators components are imported from China and Taiwan. Many political leaders have seen the undesirable phenomenon, and policymakers urge Indonesia to promote a localization strategy to reduce the dependency on imported products [14]. Previous research findings suggested that Indonesia achieves 100% local content by producing all necessary parts from upstream to downstream [15].

Research ideas that lead to the independence of paddle wheel production will impact many things, including increasing the competitiveness of domestic products, increasing job opportunities, driving the regional economy, increasing regional original income, and improving people’s welfare. This paper discussed a preliminary study of developing paddlewheel aeration for shrimp ponds using an integrated intelligent aquaculture system to support intensification. The research would be a foundation for intelligent paddlewheel aeration design that can be developed domestically to support local industry in Indonesia.

2. Materials and Methods
The paddlewheel aerators were manufactured by a local factory in Gresik, East Java, collaborating with one of the well-known state-owned enterprises engaged in the manufacturing industry. According to the factory owners, not all of the components were made by the factory. In this preliminary research, the gearbox ratio was modified to be 1: 13.5, compared to the existing 1: 14. Tests are carried out at the production site (in-situ) both at the factory site and at the pool site using calibrated equipment. The test implementation refers to the technical instructions of the SNI certification scheme of waterwheel products SNI 8679-1:2018, Paddlewheel facilities in fish farming – Part 1: Paddlewheel 1 phase [16]. The scope of the certification scheme is valid for reference for the implementation of product SNI Certification for paddlewheel for 1 phase, namely a series of 2 or 4 impellers or wheels which is assembled with a gearbox and driven by an electric motor 1 phase.
The test is located in Pasuruan, using a pond owned by the Ministry of Marine Affairs and Fisheries. The initial testing was performed before installation in the pond could be seen in figure 1 below. The testing showed an encouraging result based on the overall stability, shaft rotation, revolution speed, and sound upon being turned on for several hours. The pond size was 32.5 m x 70 m (Area ≈ 2275 m²) and depth about 0.9 – 1.1 m. The pond was used for fish cultivation. There was an aerator that had been installed previously. The condition of the pond water was slightly muddy and brownish. Two new paddle wheels were installed, so there were three paddle wheels within one pond in total with the existing paddle wheel—detail of the installed paddle wheels depicted in Figure 2.

3. Results and Discussions
The electricity supply for the existing and new paddlewheel can be seen in table 1. All of the paddlewheel aerators operate at the same frequency and almost the same voltage measured. Prior installed in the pond, both new paddle wheels were measured to determine the unloaded power and current. The existing paddle wheel was already installed, so the unloaded power and current were unknown. The difference between new paddle wheels is not much, since basically, both paddle wheels are identical. A different result could be as an effect of the possibility of measurement errors during data sampling.
### Table 1. Electricity Supply

| No | Parameter       | Unit | Paddlewheel 1 | Paddlewheel 2 | Existing paddle wheel |
|----|-----------------|------|---------------|---------------|-----------------------|
| 1  | Power (Unloaded)| W    | 621.51 W      | 559.03 W      | -                     |
|    |                 | HP   | 0.83 HP       | 0.75 HP       | -                     |
| 2  | Voltage         | Volt | 395           | 396           | 390                   |
| 3  | Current         | Ampere | 1.07           | 0.96           | -                     |
|    | - unloaded      |      | 1.72           | 1.69           | 1.48                  |
| 4  | Frequency       | Hz   | 50            | 50            | 50                    |

Paddlewheel motor characteristics are illustrated in Table 2. All three paddlewheels operate at the same frequency and similar rotation speed. Loaded power for new paddlewheel motors is relatively higher than the existing paddle wheel. At the same time, the difference in voltage among the paddlewheel motors is insignificant. Unloaded current in new paddlewheel motors is measured before installment in the pond. Hence unloaded current for the existing paddle wheel was unidentified. In general, the loaded current for new paddlewheel motors is slightly higher than the existing paddle wheel motor. Gear ratio modification in the new paddlewheel could be the reason for the variety.

### Table 2. Motor Characteristic

| No | Parameter       | Unit | Paddlewheel 1 | Paddlewheel 2 | Existing paddle wheel |
|----|-----------------|------|---------------|---------------|-----------------------|
| 1  | Power (loaded)  | W    | 952.59 W      | 848.04 W      | 831.57                |
|    |                 | HP   | 1.27          | 1.13          | 1.12                  |
| 2  | Voltage         | Volt | 395           | 395           | 390                   |
| 3  | Current         | Ampere | 0.90           | 0.84           | -                     |
|    | - unloaded      |      | 1.64           | 1.46           | 1.45                  |
|    | (loaded)        |      |               |               |                       |
| 4  | Frequency       | Hz   | 50            | 50            | 50                    |
| 5  | Rotation Speed  | Rpm  | 108.9          | 109.4          | 104                   |
| 6  | Gear Ratio      |      | 1 : 13.5      | 1 : 13.5      | 1 : 14                |

Figure 3 presents water quality around paddle wheels. The existing paddle wheel showed the lowest dissolved oxygen and oxygen saturation compared to the new paddle wheels.

![Figure 3. Water Quality](image-url)
Paddlewheel performance is given in table 3. All new paddle wheels performed better than the new paddlewheel floats the area covered and the depth of reach by the newly installed paddle wheel are also higher, increasing oxygen and water transfer, the food leftovers and excrement collection would be more accessible to perform. Dissolve oxygen is also promoted by the splash height, the distance the water could achieve in a vertical direction.

| No | Parameter                        | Unit | Paddlewheel 1 | Paddlewheel 2 | Existing paddle wheel |
|----|----------------------------------|------|---------------|---------------|-----------------------|
| 1  | Float height from water level    | cm   | 12            | 11            | 5                     |
| 2  | Area Coverage                   | m²   | 52.2          | 51.52         | 43.2                  |
| 3  | Flow range                       | m    | 9             | 9.2           | 9                     |
| 4  | Depth of reach                   | cm   | 90-100        | 90-100        | 72                    |
| 5  | Water Flow                       | - 1 m mm/s | 0.92     | 0.81          | 1.09                  |
|    |                                  | - 10 m mm/s | 0.21     | 0.29          | 0.15                  |
| 6  | Splash height                    | m    | 1.1           | 1.1           | 0.72                  |

Average paddle wheel parameter summary compared to existing paddle wheel presented in table 4. The presence of oxygen in the pond water is proportional to the splash height difference. The dissolved oxygen level is essential to the water quality and thus affects yield production. Pond waste removal is also positively affected by the depth of reach under the paddlewheel and the area coverage and flow range.

| Parameter            | Average |
|----------------------|---------|
| Dissolve Oxygen      | +19%    |
| Oxygen Saturation    | +4%     |
| Flow Range           | +1%     |
| Splash height        | +18%    |

4. Conclusion
Two paddlewheel aerators have been successfully installed at a pond owned by the Ministry of Marine Affairs and Fisheries in the Pasuruan facility. Based on the observation and user’s testimony, the newly installed paddlewheel was quite good, the sound of the motor was smooth, then the flow range was longer, the coverage area was more expansive than the existing waterwheel. Initial testing based on the SNI 8679-1:2018 has been completed, measurements show that the DO and Oxygen saturation of the new waterwheel is better than the existing paddlewheel. The Splash height in the new paddlewheel is also higher than the existing one. Currently, the paddlewheel aerators are still operating at the pond to test the durability of the paddlewheel.

Going forward, more researches integrating intelligent aquaculture system is need to be performed. The application of intelligent technology to ensure the pond water quality with surveillance and monitoring system will improve production. It is recommended to assess the design and materials variations to achieve paddle wheel optimum parameters. Further investigation and experiment focusing on the part of the paddlewheel are necessary. Paddlewheel parts like motor, float, frame, gearbox, wheel and coupling would be fruitful for further studies. Contribution in the aquaculture sector will support Indonesia’s industrial competitiveness and increase the value-added of the manufacturing sector.
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5. References
[1] Nhuong T, Rodriguez P, Chan C, Phillips M, Mohan C, Henriksson P, Koeshendrajana S Suri, S, Hall S 2017 Indonesian aquaculture futures: An analysis of fish supply and demand in Indonesia to 2030 and role of aquaculture using the AsiaFish model Marine Policy. 79: 25–32
[2] World Resources Institute 2012 Coastal and Marine Ecosystems - Marine Jurisdictions: Coastline length
[3] Leung P, Carole R 2006 Shrimp Culture: Economics, Market, and Trade Wiley-Blackwell
[4] Kooiman J 2005 Fish for Life: Interactive Governance for Fisheries Amsterdam University Press
[5] Fast A 1992 Penaeid Growout Systems: An Overview Marine Shrimp Culture Amsterdam Elsevier 345-353
[6] Boyd C 1998 Pond water aeration systems Aquacultural Engineering 18 1 9-40,
[7] Moore J, and Boyd C 1992 Design of small paddlewheel aerators Aquacultural Engineering 11 1 55-69
[8] Boyd C, Torrans E, and Tucker C 2018 Dissolved oxygen and aeration in ictalurid catfish aquaculture Journal of the World Aquaculture Society 49 1 7-70
[9] Boyd C, Darryl E, Chamberlain G Global Aquaculture 2006 Aerated pond management in Operating Procedures for Shrimp Farming: Global Shrimp OP Survey Results and Recommendations, 1st ed. St. Louis, MO, USA: Global Aquaculture Alliance 68-75
[10] Zhu D, Cheng X, Sample D, and Yazdi M 2020 Effect of intermittent aeration mode on nitrogen concentration in the water column and sediment pore water of aquaculture ponds Journal of Environmental Sciences 90 331-342
[11] Hoagland R, Rouse D, Teichert-Coddington, and Boyd C 2001 Evaluation of automated aeration control in shrimp ponds Journal of Applied Aquaculture 11 3 45-55
[12] Cruz F, Mahmudov K, Marouchos A, and Bilton A 2019 A Feasibility Study on the Benefits of Feedback Aerator Control in Precision Aquaculture Applications for the Developing World American Society of Mechanical Engineers, p. V02BT03A004
[13] Deng H, Peng L, Zhang J, Tang C, Fang H, and Liu H 2019 An intelligent aerator algorithm inspired by deep learning Mathematical biosciences and engineering 16 4 2990-3002
[14] Amiti, M., and Konings J 2007 Trade Liberalization, Intermediate Inputs, and Productivity: Evidence from Indonesia American Economic Review 97 5 1611-38
[15] Aswicahyono H, Basri, M, and Hill H 2000 How Not to Industrialise Indonesia’s Automotive Industry Bulletin of Indonesian Economic Studies 36 1 209-241
[16] SNI 8679-1:2018 Petunjuk teknis skema sertifikasi SNI produk kincir air, Sarana kincir pada budidaya ikan – Bagian 1: Kincir 1 phase