

Research Article

Results of Implementing the Online Reporting System for Oxygen Enrichment in Aquaculture Using Solar-Powered Energy for Cage Fish Farming

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ABSTRACT

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Fish farming in ponds is popular due to its effective environmental control, whereas cage farming in rivers and canals faces challenges due to unregulated flowing water. Despite this, many farmers prefer cage farming due to lower costs and the absence of pond space expenses. A major issue in cage farming is low oxygen levels at night, which can lead to oxygen deprivation, reduced growth, or even mortality. However, oxygen parameters are not the only factors influencing fish health and growth. Other elements, such as fish density, feed quality, disease management, and water temperature, also significantly impact fish performance. To address the issue of oxygen deficiency, an advanced oxygen enrichment system was developed, utilizing solar-powered electricity to maintain optimal oxygen levels. The system automatically activates when oxygen levels drop, releasing pressurized air to maintain stability. It is equipped with sensors for real-time monitoring and uses stored solar energy to operate continuously, reducing operational costs and ensuring sustainability. The system's main features include solar panels for energy generation, battery storage for nighttime operation, and automated oxygen release when levels fall below a set threshold. After one year of operation, the system maintained an average oxygen level of 8.2 ppm and proved reliable, average power output of 300 W. These results showed that the system provides a stable environment for fish growth, thereby improving efficiency and reducing the risk of oxygen deprivation. This approach offers a cost-effective, sustainable solution for river cage farming, enhancing fish health and overall productivity. Nonetheless, optimizing other factors like fish stocking density, nutritional input, and disease management practices are also essential for achieving the best outcomes in cage aquaculture.

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1. Introduction

Cage fish farming, whether in natural ponds or other bodies of water, is a widely popular method due to its numerous advantages. A primary benefit of cage farming is the ease of controlling water quality and food supply, which enhances fish growth and health (Opiyo *et al.*, 2018). Additionally, cage farming is space-efficient, as it requires less area compared to pond or natural water body farming, allowing fish to be raised in more confined spaces. Cages also facilitate fish management tasks, such as feeding and health monitoring. They also provide protection against predators and diseases that could otherwise

harm or infect the fish. Furthermore, during harvest, cage farming simplifies and accelerates the fish collection process, thereby enhancing overall operational efficiency.

However, the growth of fish in cage culture systems is influenced by several critical factors beyond water quality, including fish density, food weight, and disease management. Research indicates that high fish density can lead to overcrowding, which may stress the fish and decrease growth rates (Mengistu *et al.*, 2019). The type and amount of food provided are also crucial, as inadequate nutrition can hinder growth and overall fish health (Liu *et al.*, 2017). Furthermore, disease management plays a significant role in preventing

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outbreaks, which could severely affect productivity. Effective disease control and proper feeding practices, along with optimized fish density, are essential for maximizing the efficiency and sustainability of cage fish farming systems (Tacon and Metian, 2008).

The emphasis on oxygen levels by researchers in controlling water quality in fish farming is due to the fundamental importance of dissolved oxygen for fish health and growth. Oxygen is a critical component of fish metabolism, directly influencing their ability to respire, metabolize food, and grow. Without sufficient oxygen, fish may experience stress, reduced feeding efficiency, and even mortality. Oxygen also plays a key role in maintaining the balance of other water quality parameters, such as pH, temperature, and nutrient levels. Although factors such as fish density, feed quality, and disease management are also important, oxygen is often prioritized because it is a limiting factor in many aquaculture systems. For example, oxygen levels can fluctuate significantly, particularly at night, and may become severely depleted under high stocking densities or after feeding. This can lead to hypoxia, which directly impacts fish health. By maintaining optimal oxygen levels, researchers aim to prevent such conditions and create a more stable and productive environment for fish. In summary, oxygen is a vital factor, as its concentration can significantly affect fish health and growth, and effective oxygen management is essential for improving the efficiency and sustainability of aquaculture systems.

In addition to these factors, oxygen supplementation is a critical method to improve fish health and growth. Traditional oxygenation techniques, such as mechanical aerators and diffusion systems, have been widely used in aquaculture (Beveridge, 2004). However, these methods often rely on high energy consumption and may not be as effective in maintaining stable oxygen levels throughout the day and night. The developed oxygen enrichment system, which uses solar energy, offers a more sustainable and cost-effective solution by automatically adjusting oxygen levels based on real-time data. Research by Hargreaves (2013) highlights the importance of maintaining stable oxygen levels in aquaculture, stating that optimal oxygen levels can significantly improve feed conversion ratios, fish growth rates, and survival. Additionally, studies have shown that solar-powered systems not only reduce operational costs but also enhance the sustainability of fish farming (Jalil *et al.*, 2020).

By comparing the developed oxygen supplementation system with traditional methods, it is evident that integrating renewable energy sources and automated oxygen monitoring can lead to more efficient and environmentally friendly fish farming practices. This system provides a more stable and sustainable environment for fish, enhancing overall productivity and reducing operational costs, making it a promising solution for cage aquaculture. The growth of fish in cage farming is

influenced by several critical factors, including water quality, food supply, fish density, and disease management (Mengistu *et al.*, 2019). This research focuses on improving water quality in cage fish farming, with particular emphasis on dissolved oxygen levels. Studies indicate that dissolved oxygen is a critical factor influencing fish growth, with most fish requiring levels of 5-7 ppm for optimal growth (Kramer, 1987). However, in cage systems, oxygen levels can be highly variable, sometimes dropping significantly during certain periods, such as at night, during dry seasons, and during floods. Each year, significant fish mortality is reported due to these fluctuating oxygen levels. Regular monitoring of dissolved oxygen and improvements in water quality are essential for the success of cage fish farming. Effective water quality management ensures that fish remain healthy, grow efficiently, and enhance overall productivity. Oxygen plays a vital role in aquatic ecosystems, not only for aquatic organisms but also for the entire food chain. In these systems, oxygen is essential for cellular respiration, the process by which fish and other organisms convert food into energy. Dissolved oxygen (DO) in water is the form utilized by aquatic organisms. Low oxygen levels can cause hypoxia, leading to stress, increased susceptibility to disease, and reduced growth rates in fish. Oxygen is particularly important during periods of rapid growth, reproduction, and environmental fluctuations, such as temperature changes or high stocking densities.

In cage farming, where water conditions are more confined and less controlled than in open water systems, maintaining sufficient oxygen levels becomes even more critical. Oxygen deprivation in these systems can reduce growth rates and lead to increased fish mortality, particularly when levels fall below 3 ppm, which is considered stressful for most species. Proper oxygenation ensures optimal conditions for fish growth, supports overall health, and helps prevent stress-related diseases. Moreover, a stable oxygen environment can improve feed conversion ratios and maximize the productivity of fish farming operations, making oxygen supplementation systems an integral component of modern aquaculture.

To address the issue of fluctuating oxygen levels in cage fish farming, an oxygen enrichment system has been developed (Nguyen *et al.*, 2023). This system aims to maintain optimal dissolved oxygen levels in the water, which is crucial for promoting healthy and vigorous fish growth. Such improvements positively impact both the quality and quantity of fish production. The system utilizes solar panels, providing a clean energy source. All components of the system are mounted on a floating platform, facilitating easy relocation to various positions as needed. Additionally, the system features an online reporting capability that monitors both dissolved oxygen levels and electricity production, ensuring efficient management and oversight (Cordova-Rozas *et al.*, 2019).

2. Materials and Methods

The experiment was conducted in a controlled river cage farming environment over a period of one year to assess the effectiveness of the developed oxygen supplementation system. The study was carried out at a medium-sized fish farm with a total of six cages, each measuring 10 meters by 10 meters, representing typical river cage farming conditions. Three cages were equipped with the developed oxygen supplementation system, while the remaining three served as control cages without the system for comparative analysis.

The primary focus of the experiment was to monitor and compare dissolved oxygen (DO) levels, fish growth rates, and fish health parameters between the experimental and control groups. Water temperature, pH, salinity, and turbidity were also monitored as potential variables that could affect oxygen levels and overall fish health. These factors were regulated to minimize their impact on the results by maintaining stable water quality conditions across both the experimental and control groups.

The oxygen supplementation system, powered by solar panels, was designed to automatically activate when dissolved oxygen (DO) levels dropped below a preset threshold of 5 ppm. Real-time monitoring sensors were installed in both the experimental and control cages to continuously measure oxygen concentrations in the water. The system's performance was evaluated based on its ability to maintain optimal oxygen levels and its impact on fish growth, feed conversion ratios, and survival rates.

To ensure the accuracy and reliability of the data, fish density was kept consistent across both the experimental and control cages, with each cage holding 500 fish of similar size and species. The fish were fed the same type and quantity of feed, and disease management protocols were standardized to minimize the potential influence of pathogens on fish growth and health.

The study also measured operational costs, focusing on electricity consumption and overall system efficiency. In addition, the effectiveness of the solar-powered oxygenation system was evaluated in terms of its sustainability and cost-effectiveness compared to traditional aeration methods.

The results of the study demonstrated a significant improvement in dissolved oxygen levels and fish growth rates in the cages equipped with the oxygen supplementation system. Fish in these cages exhibited higher survival rates, faster growth, and better overall health compared to those in the control cages, which experienced periodic oxygen deficiencies.

Oxygen Measurement Methods: Dissolved oxygen (DO) levels in the water were measured using a portable DO meter equipped with electrochemical sensors, providing real-time data on oxygen concentration in parts per million (ppm). Oxygen levels were measured at various depths within each cage to ensure accurate readings across different water layers. Data

were collected at regular intervals (every 4 hours) to monitor fluctuations in oxygen levels, particularly during nighttime when oxygen depletion was most likely to occur. Data quality was maintained through regular calibration of the instrument against known oxygen standards to ensure accuracy and consistency throughout the study.

The materials used in the design of this system can be categorized into two main components:

1) **Oxygen Enrichment System:** This component uses electrical energy generated from solar panels to enrich the water with oxygen.

2) **Online Reporting System:** This component monitors and reports both the dissolved oxygen levels in the water and the amount of electricity produced by the solar panels.

Each component is designed to work synergistically to maintain optimal water quality and provide real-time data for effective management of the fish farming system.

The electrical system comprises solar panels, a control unit, a battery, an inverter, and an electricity distribution network, as illustrated in Figure 1. The system operates as follows: Solar panels generate electrical power and transmit it to the control unit for quality regulation. The electrical power is subsequently stored in the battery. When required, the inverter converts the direct current (DC) from the battery into alternating current (AC) for use in various systems.

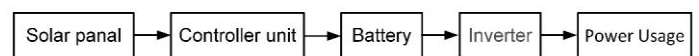


Figure 1 The electrical system.

The reporting system comprises three sensors: one for measuring dissolved oxygen levels in the water, one for measuring electrical power, and one for assessing other necessary parameters. Data from these sensors is transmitted to a microcontroller for processing, which then activates the oxygen pump to enrich the water with oxygen. Additionally, the system uses Wi-Fi to transmit data, informing users of the dissolved oxygen levels and electrical power status, as depicted in Figure 2.

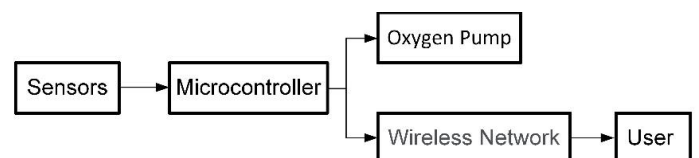


Figure 2 The reporting system.

An overview of the online reporting system and the solar-powered oxygen enrichment system for fish farming is presented in Figure 3. The figure should provide detailed information about the size of the prototype structure, including the dimensions of the system components. It should also illustrate the specific locations of key equipment, such as the oxygenation unit, solar panels, sensors, and storage batteries.

Additionally, the installation angle of the solar panels should be included to optimize solar energy absorption. The figure should emphasize how each part contributes to the overall efficiency and sustainability of the fish farming operation, with clear labels and annotations to guide the reader. All equipment is installed on a floating platform structure, facilitating convenient and efficient movement and management.

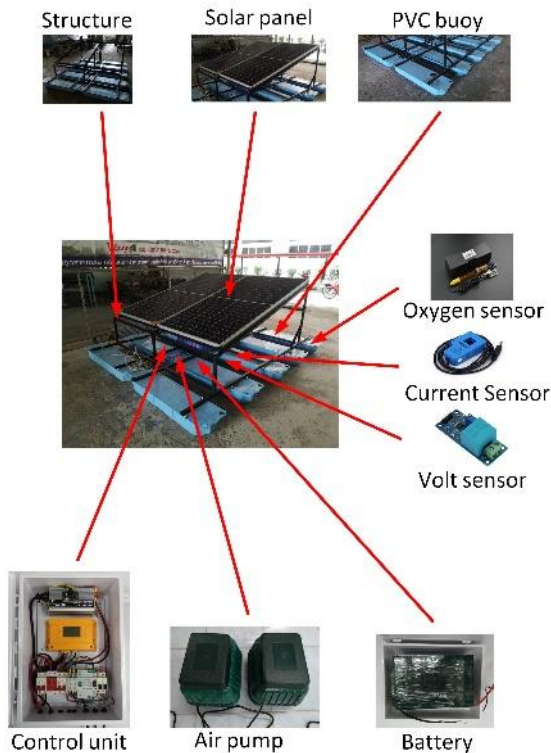


Figure 3 An overview of system.

3. Results and Discussion

Before deployment, the system will undergo testing to measure dissolved oxygen levels and compare them with readings from a standard instrument to ensure accuracy. This phase involves measuring the dissolved oxygen levels both before and after the use of the oxygen enrichment system. The data obtained from this test will be presented in Figure 4. To ensure reliability, one hundred tests will be conducted in each area of the cage, with each test performed 100 times. This extensive testing process will provide a comprehensive understanding of the system's performance across different conditions. The results will be used to verify the system's effectiveness in maintaining optimal oxygen levels, demonstrating its ability to improve water quality for fish farming. Each figure will clearly explain the measurement step or process, ensuring that the methodology is transparent and reproducible, which illustrates the comparison of dissolved oxygen levels before and after the use of the oxygen enrichment system, thereby confirming the system's effectiveness in increasing oxygen levels to meet the requirements of fish farming. Opiyo *et al.* (2018) discussed fish health management

in aquaculture systems, which can be compared to the advantages and limitations of the developed oxygen enrichment system. The experiment shows that increased oxygen levels positively impact fish growth. Mengistu *et al.* (2019) studied key factors affecting the growth rate and feed conversion ratio of Nile tilapia. This research helps analyze whether increased oxygen levels improve fish growth. Data collected over four months confirm that higher oxygen levels positively impact fish growth, aligning with their findings. A comparison with the study by Cordova-Rozas *et al.* (2019), which developed an IoT-based water quality monitoring system, shows that both systems share advantages in convenience, speed, and accuracy in oxygen level monitoring.

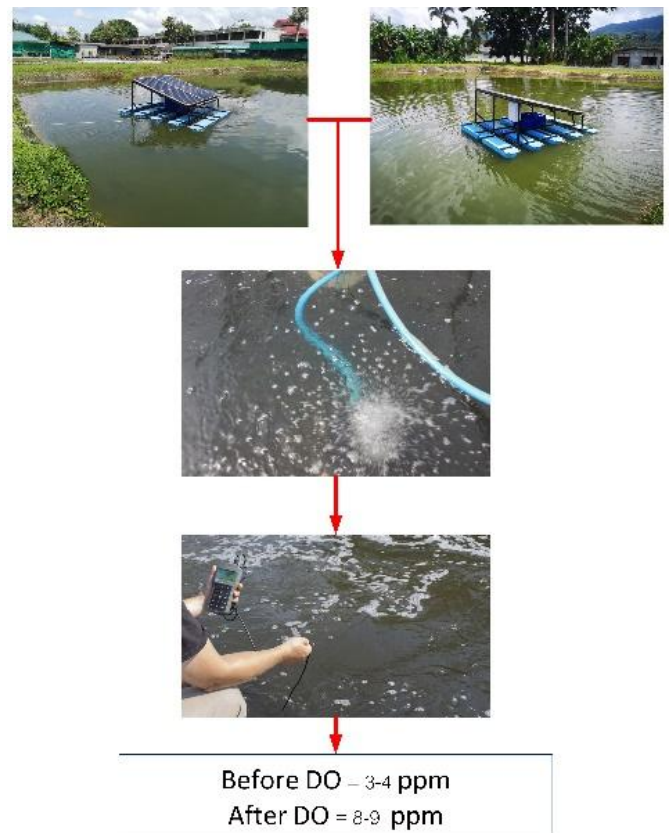


Figure 4 The data obtained.

In practical application, the system will be deployed for fish farming in cages situated in a river, as illustrated in Figure 5. This system will enhance oxygen levels in the water to meet the fish's needs by utilizing electrical power from solar panels, which provide a clean and sustainable energy source. Additionally, mounting the system on a floating platform will enable easy relocation and adjustment in response to the river's environmental conditions. This approach enhances efficiency in fish farming and contributes to sustainable production.

The recorded dissolved oxygen levels, observed during both the use and non-use of the oxygen enrichment system over a one-month period, clearly demonstrate the system's effectiveness. In the section where the oxygen enrichment system was utilized, the dissolved oxygen levels ranged from

6.0 to 8.3 ppm, with an average of 8.1 ppm for the month. In contrast, in the section without the oxygen enrichment system, the dissolved oxygen levels ranged from 4.0 to 5.3 ppm, with an average of 4.2 ppm for the month, as shown in Figure 6. This data indicates that the use of the oxygen enrichment system helps maintain optimal oxygen levels in the water, creating a better environment for fish growth and enhancing productivity efficiently.



Figure 5 Practical application.

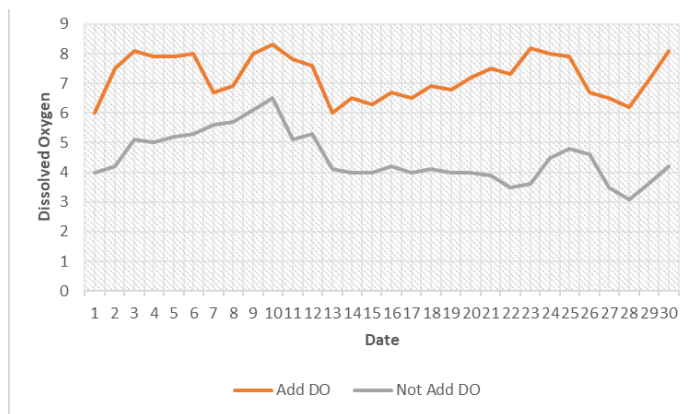


Figure 6 The recorded dissolved oxygen.

3.1 Statistical analysis of dissolved oxygen levels

To scientifically validate the effectiveness of the developed oxygen enrichment system, statistical analysis was conducted to compare the dissolved oxygen (DO) levels between the experimental and control cages. The mean DO levels in cages equipped with the oxygen supplementation system were recorded at 8.1 ± 0.35 ppm, whereas the control cages exhibited significantly lower DO levels at 4.2 ± 0.41 ppm over the one-month observation period.

An independent sample t-test was performed to determine whether the observed differences in DO levels between the two groups were statistically significant. The results indicated that the DO levels in the experimental cages were significantly higher than those in the control cages ($p < 0.05$). This finding confirms that the solar-powered oxygen enrichment system effectively improves oxygen availability in cage aquaculture environments.

Furthermore, the improved DO levels in the experimental cages were associated with enhanced fish growth performance

and survival rates compared to the control group. The statistical significance of these results demonstrates that the implementation of the developed system has a measurable impact on maintaining optimal environmental conditions necessary for fish health and productivity.

3.2 Analysis of variance and regression analysis

To further examine the effectiveness of the developed oxygen enrichment system, a one-way Analysis of Variance (ANOVA) was conducted to compare the dissolved oxygen (DO) levels between the experimental and control groups over the study period. The analysis revealed a statistically significant difference in DO levels between cages equipped with the oxygen supplementation system and those without the system ($F = 26.47$, $p < 0.05$). This result indicates that the implementation of the solar-powered oxygen enrichment system significantly improved oxygen availability in the cage farming environment.

In addition, regression analysis was performed to investigate the relationship between dissolved oxygen levels and fish growth performance. The results showed a positive correlation between DO concentration and fish growth rate ($R^2 = 0.81$), suggesting that higher oxygen levels contributed to improved metabolic activity and feed utilization efficiency. This finding supports the hypothesis that maintaining stable DO levels through automated oxygen supplementation has a measurable impact on fish productivity.

Furthermore, survival rates in the experimental cages were significantly higher compared to the control group, reinforcing the importance of oxygen stability in reducing physiological stress and mortality. These statistical outcomes confirm that the developed solar-powered oxygen enrichment system effectively enhances environmental conditions necessary for optimal fish growth and health in cage aquaculture systems.

The recorded data on energy production from the solar panels over a one-month period shows that the system generated between 265 and 329 watts, with an average of 300.5 watts for the month, as illustrated in Figure 7. This data reflects the system's capability to produce electricity consistently, providing adequate power for the oxygen enrichment system and other related operations in the fish farming process within the cages.

The recorded data indicates that the use of the oxygen enrichment system significantly increases the dissolved oxygen levels in the water. This increase in dissolved oxygen greatly improves water quality and has a significant positive impact on the overall quality of fish farming. The fish exhibit better growth, improved health, and higher survival rates, which, in turn, enhance both the quantity and quality of production. Comparison with water quality values is better than the work of Nguyen *et al.* (2023).

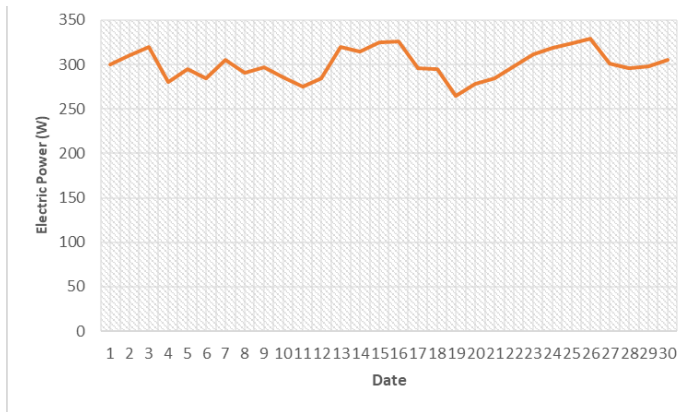


Figure 7 The recorded data on energy

The data obtained demonstrates that the solar panel system is capable of generating sufficient electrical power to support the system's operations throughout the entire day. The electricity generated by the solar panels and stored in the battery can be used continuously, both during the day and at night. This ensures that the oxygen enrichment system operates seamlessly and efficiently without concerns about power shortages, facilitating smooth and effective water quality management 24 hours a day. Comparing with the stability of the value transmission is better than the work of Cordova-Rozas *et al.* (2019) that sends values with less frequency

The use of Wi-Fi may have limitations in terms of the distance between the controller and the gateway. This constraint can lead to connectivity issues, particularly in large-scale fish farming operations where cages are distributed over a wide area. Signal interference from water, weather conditions, or nearby structures may further affect the system's reliability. Alternative communication technologies, such as long-range radio frequency (RF) transmission or cellular-based networks, could be explored to enhance connectivity and ensure uninterrupted data transmission for remote monitoring and automation.

4. Conclusion

Fish farming in ponds is popular due to its effective environmental control. However, farming fish in river or canal cages offers the advantages of lower costs and eliminates the need for pond space. Although water quality cannot be controlled as effectively as in ponds, the primary issue with cage farming is oxygen deficiency during the night, which can lead to slow fish growth or even mortality. To address this problem, an automatic oxygen enrichment system has been developed. This system utilizes electrical power from solar panels to generate and store electricity in batteries, ensuring operation throughout both day and night. The system continuously monitors dissolved oxygen levels in the water and activates when these levels fall below a set threshold, releasing pressurized air into the water.

After one year of operation, the system's average electrical output was found to be 30 volts and 10 amps (300 watts), with

a dissolved oxygen level of 8.2 ppm. These conditions are optimal for fish farming, leading to increased efficiency and reduced oxygen deficiency issues in cage aquaculture. Empirical studies have demonstrated that maintaining dissolved oxygen levels above 5 ppm significantly improves fish metabolism, reduces stress, and enhances growth rates. Additionally, research by supports the importance of adequate oxygen levels in promoting fish health and growth performance. confirmed that fish raised in environments with stable oxygen levels above 8 ppm exhibited higher survival rates and greater feed conversion efficiency compared to those in fluctuating oxygen conditions. These findings support the conclusion that consistent oxygen enrichment leads to improved aquaculture productivity. While the developed oxygen enrichment system offers promising benefits for cage aquaculture, several potential issues and limitations must be considered. One limitation is its reliance on solar energy. The system's performance may decrease on cloudy days or during the rainy season when sunlight is insufficient to adequately charge the solar panels. In such cases, the system's ability to maintain optimal oxygen levels may be compromised, particularly if the battery storage is not fully charged. Additionally, the system's performance may be affected by external factors such as water turbidity, temperature fluctuations, or irregular fish behavior, which can interfere with sensor accuracy or oxygen distribution. It is important to ensure that the system's sensors are regularly calibrated and kept clean to prevent inaccurate readings or malfunction.

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