Design and automation of a solar-powered floating-type aeration system (SPFTAS) for fish ponds

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Abstract. Aeration helps improve water quality and make it favorable to fish. SPFTAS was designed based on the environment and characteristics of freshwater ponds. SPFTAS consist of floating platform, power source, sensors, signaling and aeration system. It functions to disperse and increase dissolved oxygen (DO). It possessed capability to monitor real time condition of water, store data and send it through short messaging service (SMS). The SPFTAS oxygen transfer rate was 0.07 kg of oxygen using four diffusers and the standard aeration efficiency of 0.2710 kg oxygen/hp-hr. The standard oxygen transfer efficiency was 0.36 at 18 kg of oxygen transferred. SPFTAS increased DO level to 1.32 ppm and rated highly effective during the test. The DO level using 1, 2, 3 and 4 diffusers at different depths, distances and time results were significantly different. The DO level using different diffusers at time intervals was highest at 7.16 ppm in three hours operation. The total cost of automated SPFTAS was ₱170,385.75. The cost analysis of using the machine indicated a breakeven point of 1,440 hours per year. The annual operation expected save ₱32,737.39 and expected recover the investment in 5.33 years. Finally, machine was found beneficial to increase DO concentration in fishponds.

1. Introduction
Fisheries are one of the major industries in the agriculture sector. It is composed of three aquaculture sectors, namely: commercial fisheries, municipal fisheries, and aquaculture. Based on the recent national accounting estimates, fisheries sector contributes 19.6% of the total Gross Value Added (GVA) in agriculture and 1.8% of the total GDP. The Philippines is ranked 7th among the top fish producing countries in the world in 2012. However, since 2010 its economic contribution has been declining [1].

Nowadays, aquaculture sectors are moving towards highly intensive farming to significantly increase the production and contest the growing demand as projected years to come, but the chances of risk increased due to management failures. In addition, the intensive production does not have enough facilities and equipment to maintain since the acquisition and installation costs are highly expensive in developing countries like the Philippines.

The use of an aeration system in pond increases the dissolved oxygen (DO) levels; it creates water movement, it enhances fish productivity, makes pond healthier and prevents unwanted vegetation growth. A diffused aeration system works by pushing the air from bottom to top of the pond water, releasing it into thousands of tiny bubbles that rise to the surface and disrupt the thermocline. This water movement provides a more uniform DO and temperature throughout the entire body of water.
The study was conducted to design and automate a SPFTAS to improve DO in the fishpond. Specifically, the study aimed to design a solar powered aeration floating type system, evaluate the performance in improving the dissolved oxygen level and to perform cost analysis.

2. Methodology

The automated SPFTAS was designed based on the environmental condition and the actual characteristics of fresh water fishpond. It was also based on the design requirements of the automation and acquired aeration system. The evaluation of the system with respect to its capacity and performance was determined in terms of the rate oxygen transfer, aeration efficiency, sensitivity of sensors and signals, cost of aeration, and the ability of the system to maintain good water quality favourable for fish environment.

2.1. Design and fabrication

The floating platform of automated SPFTAS was composed of three major components; the main hull is made of fiberglass and it can be dismantled into three (3) modular parts. Each of the modules part can be detached when the structure was not in use or has been transported.

The automated controls of the SPFTAS used a process controller and a sensor system. The controller process all the data collected from the sensors into useful information. The information was saved and transmitted by the GSM module to a cellular phone. It also used a LCD monitor display to show the current status of the machine and the current readings of the sensors. Device also used four different colors LED lights and horn for the signalling system. Lights were programmed to indicate the status of the operation. This will help the monitoring of operation during night-time. The horn provides sound in case the lights are not visible, especially during daytime operations when the aerator is turn-on and off.

2.2. Data gathered

The following data gathered and obtained during the final test of the SPFTAS: performance of the aerator, aeration effectiveness in pond with intensive stocking rate, DO level, sensitivity of sensors and cost analysis.

2.2.1. Aeration performance. The performance evaluation of aerator was measured in standard oxygen transfer rate (SOTR) or standard aeration efficiency (SAE) and standard oxygen transfer efficiency (SOTE) [2]. The SOTR is the amount of oxygen added to the water in one hour under standard conditions expressed as kilograms of O₂/hr and can calculated using equation (1) below [2].

\[
SOTR = (KL a20) \times CS,20 \times V
\]

where:
- \(SOTR\) - standard oxygen transfer rate
- \(KL_{a20}\) - volumetric mass transfer coefficient at standard condition for measuring probe \(i\), temperature 20°C and 1 atm, second-1
- \(CS,20\) - DO saturation concentration at standard condition measuring probe \(i\), temperature 20°C and 1 atm, mg/L
- \(V\) - volume of water, m³

The SOTE refers to the fraction of oxygen in an input airflow dissolved under the standard condition. It is expressed as SOTR over mass flow of oxygen in air stream and can be obtain using the equation (2) below [3].

\[
SOTE = \frac{SOTR}{W_{O2}}
\]

where:
- \(SOTE\) - standard oxygen transfer efficiency
- \(SOTR\) - standard oxygen transfer rate
- \(W_{O2}\) - mass flow of oxygen in air stream
The SAE is the standard oxygen transfer rate divided by the horsepower (hp) of the unit, expressed as kg of \( \text{O}_2 / \text{hp-hr} \) transferred to the water [3] and calculated using the equation (3) below.

\[
SAE = \frac{\text{SOTR}}{\text{Power Input}} \tag{3}
\]

where: 
- SAE - standard aeration efficiency
- SOTR - standard oxygen transfer rate
- Power Input - aeration power, watts

The aerator DO transfer capacity. The rate of oxygen transferred by the aerator is the aerator capacity \((A_C)\), which is defined as the rate of oxygen transferred in one hour operation divided by DO requirement per liter. It is expressed in cubic-meter per hour and calculated using the equation (4) below.

\[
A_C = \frac{SOTE}{O_R} \tag{4}
\]

where: 
- \( A_C \) - aerator capacity
- SOTE - standard oxygen transfer efficiency
- \( O_R \) - oxygen requirement, mg/l

### 2.2.2. Dissolved oxygen level

The dissolved oxygen levels of concentration in water using four diffusers at different distances from the device in a given time intervals and water depth were measured in the test pond. The level of DO after the time of operation was measured to determine the increase of DO level and effectivity of SPFTAS in increasing the level of DO at different time duration. Performance parameters for the evaluation SPFTAS effectivity were the following:

- Highly effective (HE): when the dissolved oxygen level increase 1 ppm from initial DO level in 10 minutes operation within 2.0 m radius of influence
- Moderately effective (ME): when the dissolved oxygen level increase 1 ppm from initial DO level in 15 minutes operation within 2.0 m radius of influence
- Less effective (LE): when the dissolved oxygen level increase 1 ppm from initial DO level in 20 minutes operation within 2.0 m radius of influence

### 2.2.3. Sensitivity of SPFTAS process controller

The sensitivity of process controller and signaling system were evaluated based on the timeliness it triggered the aerator to start when the DO level decreased below 3.0 ppm and the time it stopped when the DO level increased above 5.0 ppm. The range of time durations for sensitivity ratings were as follow:

- Highly Sensitive (HS): when the system responds within 5 seconds
- Moderately Sensitive (MS): when the system responds within 5-10 seconds
- Less Sensitive (LS): when the system respond within 10-30 seconds

### 2.3. Cost analysis

#### 2.3.1. Cost of aeration

The cost of aeration was determined by obtaining the total cost and hours of operation per growing cycle using equation (5). The fixed cost included only the depreciation cost. The variable cost of the device included the labor cost, repair, and maintenance incurred in the operation.

\[
C_A = \frac{F_c + V_c}{T_o} \tag{5}
\]
where: $C_A$ - Cost of aeration, ₱/hr  
$F_C$ - Fixed cost, ₱  
$V_C$ - Variable cost, ₱  
$T_O$ - hours of operation per year, hr /yr

2.3.2. Cost of operation. The cost of operation in terms of variable cost and fixed cost was analyzed to present the break-even point analysis. The break-even point was computed based on the optimum aeration capacity at an estimated hours of operation, cost of investing in building SPFTAS and cost of aeration per hour of operation using equation (6).

$$BEP = \frac{F_C}{C_A - V_C}$$  \hspace{1cm} (6)

where: $BEP$ - Breakeven Point, hr/yr  
$C_A$ - Cost of aeration, ₱/hr  
$F_C$ - Fixed cost, ₱  
$V_C$ - Variable cost, ₱/hr

2.4. Data analysis
The regression analysis was used to describe the effects of different number of diffusers in relation to the dissolved oxygen level in a given time intervals, different depths and different distances. The characteristics of DO using four diffusers were analysed using univariate analysis.

3. Results and discussion
The automated SPFTAS shown in figure 1 was fabricated based on the design requirements of the aeration system, solar power system, buoyancy control system (floating platform), process control and sensor system, and signaling system.

The SPFTAS used inverter battery to improved power efficiency. This provide a small amount of current consistently for longer durations of time. The power source of aeration and automation system were all permanently connected to the power inverter during testing operations. And to the conserved energy, the aerator only operated when the sensor detected the DO level lower than 3 ppm and will automatically turn-off when the DO level reach 5.0 ppm.

![Figure 1. Perspective view of automated SPFTAS.](image-url)
The SPFTAS has significant advancement compared to existing aerators. The design has capability to perform automation process turning-on/off of aerator. It can operate without supervision, it detects DO level in the pond, record and save the data gathered in secure digital (SD) memory card. The device also send the data gathered to cellular phone through short messaging system (SMS). It is also equipped with alarm horn and lights that indicates status of system for nighttime monitoring.

The SPFTAS used conventional source of energy yet efficient in aerating bottom and upper surface of the water. Compared to conventional aerators that used high power motors that demand huge amount of energy, yet they are inefficient as they aerate only the upper surface.

3.1. Aeration performance and efficiency
The test results obtained 0.07 kg of oxygen per hour using four (4) diffusers. The SAE obtained was 0.2710 kg of oxygen per hp-hr. The SOTE attained during the test was 0.36 or equivalent to 18 kg of oxygen mass transferred by aerator into the water. The aeration capacity of machine was 14.0 \( m^3/hr \). This is the volume of water that would be supplied by DO (0 to 5 ppm).

The SPFTAS has capability to improve the DO level in the water compared with other aerators since it uses four diffusers installed at the pond bottom. These diffusers allow the fine bubbles to suspend in the water for more oxygen exchange. The results of test of two aerators revealed an average increase of 2.05 ppm in 1 hour operation was higher than 1.0 hp paddle wheel with an average increase of 1.72 ppm. This result also indicated that SPFTAS is comparable to the performance of conventional aerators available in the market.

3.2. Dissolved oxygen (DO) levels
The evaluation was tested in the pond with a stocking rate of 15 pcs/m\(^3\). The water depth at the time of evaluation was 1.2 m. Evaluation was conducted in 10, 15 and 20 min aeration test. The results revealed that the dissolved oxygen level increased by 1.32 ppm. Since it exceeds 1.0 ppm after 10 min aeration threshold. The test was rated highly effective.

3.3. Performance of SPFTAS in dispersing DO
The performance of SPFTAS in dispersing DO was evaluated in three parameters: A varying depths from the surface (20 cm), middle (40 cm) and bottom (60 cm); distances at 2 m, 4 m and 6 m from the center; different time intervals of 1 hour, 2 hours and 3 hours.

3.3.1. DO at depths and number of diffusers. The results on 1, 2 and 3 diffusers shows that the DO were highest at the surface. This revealed that the DO levels were highly significant from each depths at different number of diffusers. The results on 4 diffusers shows that the DO at the surface was still the highest. This revealed that the DO levels at different depths were significantly different among each other. The figure 2 shows the DO levels at different depths using 1, 2, 3 and 4 diffusers.

![Figure 2. DO levels at varying depths.](image-url)
3.3.2. **DO at distances and number of diffusers.** The results of using 1, 2 and 3 diffusers revealed that the DO at the center was still the highest among other distances. The results also showed that the DO levels using the 1, 2 and 3 diffusers at different distances were significantly different from each other. The results on 4 diffusers showed that the DO at the center was higher than the DO at other distances. This revealed that the DO levels at varying depths were not significantly different from each other using four diffusers. The figure 3 shows the DO levels at different distances.

![Figure 3. DO levels at different distances](image)

3.3.3. **DO at time intervals and number of diffusers.** The results showed that the DO after 3 hours of operation was highest among the levels at other time durations. This revealed that the DO levels at different time intervals were significantly different. The results on 2, 3 and 4 diffusers showed that the DO level after 3 hours of operation were constantly the highest among the levels at other time duration. The results also revealed that the DO at different time intervals were highly significant from each other using 2, 3 and 4 diffusers. The figure 4 shows the DO levels at time intervals (1, 2, and 3 hrs.) using 2, 3 and 4 diffusers.

![Figure 4. DO levels (ppm) at different time intervals](image)

3.4. **SPFTAS automation system**

3.4.1. **Process controller, sensor and signalling system.** The results of sensitivity analysis showed that most of all the components involved in the automation process, data logging and transmission, signaling and turning-on of aerator were highly sensitive. Most of the components responded within 5 seconds after initiation of command and functions. The aerator and the yellow light exhibited less sensitive when the DO level was at 5 ppm. This can be attributed to the weak mobile network signal in the area which
caused the delay in the sending and this made the aerators respond late. The data transmission was found moderately sensitive. It was observed that only 15 out of the expected 22 messages sent were received through text messages (SMS) resulted to 68% reliability.

3.5. Cost analysis

The overall cost of automated SPFTAS amounted to ₱170,385.75. This included the cost of procured materials, delivery cost and tax, and miscellaneous expenses. The cost of operating the machine was based on the actual field observation. If the SPFTAS will operate 4 hours per day for a four-month growing period at three growing seasons per year, the cost of using the machine was calculated to be ₱22.73 per hr.

The financial analysis found the total fixed cost amounted to ₱31,237.39 per year, while the variable cost amounted to ₱1,500.00. The computed total operating expenses amounted to ₱32,737.39 per year. The analysis using the fixed cost and variable cost resulted to a breakeven point operation of 1,440 hours per year.

The SPFTAS cost of operation is still cheaper than ₱28.80 per hour of paddle wheel with fixed cost of ₱30,000.00 and variable cost of ₱11,520.00 at ₱8.0 per kWh in 1440 hours per year operation.

4. Conclusions

Based from the results of this study the following conclusions were made:

1. The performance of aeration system in maintaining dissolved oxygen level in intensive production system in 20 min operation was highly effective in 2 m range and 1 m water depth.
2. The levels of DO dispersed at different depths and distances, and orientations exceeded the 5 ppm maintaining DO level requirement in fish pond using four diffusers. The DO levels of highest mean reached 6.95 ppm. Therefore, the performance of SPFTAS was enough to improve the water quality in fish pond.
3. The overall performance of SPFTAS was significant at 1, 2, 3, and 4 diffusers, depths, distances and time. While in different orientations there were no significant differences. This results of analysis attested the positive impact of aeration system in terms of uniformed distribution of DO. Based on the results it concluded that the greater the number of diffusers installed, the higher is the DO level at any depth, time and distance.
4. The results of the study on automation indicated that automated SPFTAS was verified as important device in real time monitoring, improving and maintaining water quality as well as in immediate response to the water environment. Therefore, automation is very much important to address the pressing problems in fish ponds.
5. The completed SPFTAS cost ₱170,385.75. The cost of using the machine amounted ₱22.73 per hour and the breakeven point operation was 1,440 hours per year.

References

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[3] Lawson T and Merry G 1993 Procedures for evaluating low-power surface aerators under field conditions Techniques for Modern Aquaculture ed J Wang (Michigan: American Society of Agricultural Engineers) p 511