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Designing and fabrication of different types of aerators in commercial aquaculture

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Abstract
Dissolved oxygen content is the most critical factor in intensive fish culture and it significantly affects the production of fish. Application of huge amount of fertilizers and fish feeds in heavily stocked fish ponds upsets the dynamics of dissolved oxygen. This becomes more pronounced in the early morning hours and on cloudy days resulting in severe depletion of dissolved oxygen of pond water. In addition to the problem of dissolved oxygen, toxic intermediates formed in the transformation of organic matter also inhibit growth of fish. These two factors which limit the production of fish in intensive culture, can be effectively controlled by the use of artificial aeration. Pond aeration systems were developed to sustain large quantities of fish and biomass materials. Aerator test results can assist in aerator design, aid aqua culturists in selecting aerators and provide a basis for estimating the amount of aeration required in specific situations. In the present study, four different types of aerators were designed and fabricated such as three tier perforated tray aerator, cascading wooden plank aerator, rotating wheel aerator and vertical perforated cylindrical aerator.

Keywords: Dissolved oxygen, fabricated aerators, efficiency, oxygen transfer co-efficient, standard oxygen transfer co-efficient

1. Introduction

Aquatic animals and organisms in water require oxygen for respiration and other biological activities. One can expect that a decrease in the rate of the oxygen production by phytoplankton may have catastrophic consequences for life on earth, possibly resulting in mass extinction of organisms. Besides having capabilities to produce oxygen, planktonic community also depends on the oxygen availability and its confounding factors. Phytoplankton produces oxygen due to photosynthesis during the day, but consumes it through respiration during the night. Oxygen consumption by plankton is a function of DO levels that depends on temperature. The DO of water increases with increasing atmospheric pressure while it decreases as the temperature and salinity increases. In warm water with increasing temperature, oxygen depletion may arise because of a simple physical property of water. The warmer the water, the less dissolved oxygen it can hold. Most of the warm water species can survive long period at dissolved oxygen concentration of 2 to 3 mg/l [1] but cold water species require a minimum of 4 to 5 mg/l. A minimum criteria of 6 mg/l is recommended for all juvenile fish and crustaceans. Aquaculture ponds require artificial aeration when stock biomass exceeds the natural re-aeration and delivered by wind, photosynthesis and water exchange [2]. In production ponds dissolved oxygen concentration may decrease by 5-10 mg/l at night and in un-aerated ponds dissolved oxygen concentration at sunrise may be less than 2 mg/l [3]. Such low dissolved oxygen concentration can cause stress or mortality in culture organisms. Therefore, identification of potential threats to the oxygen content and availability for planktonic community in the water is literally an issue of vital importance. Oxygen depletion refers to low levels of DO and may result in fish mortality. When organisms die from oxygen depletion, there can be serious financial consequences for commercial aquaculture operations [4]. Recent studies suggested that the use of heavy aeration to provide the greatest possible production is less profitable than moderate aeration to improve water quality and enhance the feed conversion efficiency. Further, the development of automatic devices to start and stop aerators in response to daily changes in dissolved oxygen concentration are improving, but they are expensive and nor completely reliable. Aeration cost is the third largest cost in intensive aquaculture system after post larvae and feed cost representing about 15% of total production [5]. The cost of the mechanical aerators is more and it requires more operational and maintenance cost. So by keeping the above points in view the present study was carried out for designing, fabricating, testing the efficiency of low cost fabricated aerators.

2. Materials and Methods

The present research was conducted at the Research and Instructional Fish Farm of the College of Fisheries, Mangaluru. Three uniform square shaped cement ponds of the size (5 × 5 × 1 m) were selected for conducting the experiment. Four aerator designs namely i) Three tier perforated tray aerator ii) Vertical perforated cylindrical aerator iii) Rotating wheel aerator and iv) Cascading wooden plank aerator were planned, designed and fabricated. Each aerator designs were fabricated in triplicate.

2.1 Design and working mechanism of aerators

a. Three tier perforated tray aerator

Using the GI (Galvanized Iron) perforated sheets, three tier perforated tray aerator designs with a dimension of 85 × 85 × 5 cm were fabricated**.** The water falling from the shower, has been made to fall on the top of perforated tray and it passes through pore of each perforated tray before falling into the pond water. When it passes through the pores of these trays, it splits into minute particles and observe the oxygen content present in the atmosphere before reaches the pond water.

Fig 1: Perforated tray aerator design

Fig 2: Three tired perforated tray aerator

b. Cascading wooden plank aerator

Cascading wooden plank aerator design was made with wooden plank of size 95 × 85 × 2 cm. The rectangular shaped wooden pieces of size 85 × 2 × 7 cm were inclined in such a manner to create a cascading effect of flow of water. The water is allowed to fall on the upper portion of the aerator and flows towards down side. During this process water tumble in the form of thin sheet and splits into minute particles. These minute particles absorb the oxygen present in the atmosphere before falling into the pond water.

Fig 3: Cascading wooden plank

Fig 4: Cascading wooden plank aerator

c. Rotating wheel aerator

Rotating wheel aerator design was made with wooden planks of size 40 × 30 × 2 cm. Four wooden planks were fitted to GI (Galvanized Iron) pipe of diameter 1.25 cm and length of 80 cm. The two ends of the GI (Galvanized Iron) pipe was fitted with bearings for easy rotation of wooden planks. Water from the shower falls on the rotating wheel, which makes the wheel to rotate due to the force generated by the water. Due to this process wheels gets rotated and the water splits into small particles which interacts with air present in the atmosphere before reaches the pond water and gets aerated.

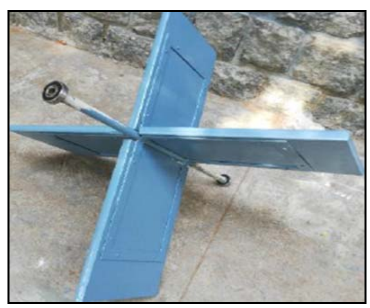

Fig 5: Rotating wheel aerator

Fig 6: Rotating wheel aerator with stand

(d) Vertical perforated cylindrical aerator

Vertical perforated cylindrical aerator is made from a perforated Galvanized Iron (GI) sheet for a height of 38 cm and 11 cm diameter. Bottom of the aerator model is connected to the water supply pipe with the help of elbow and the other end of the aerator is closed with a sheet. The water supplied from the pipe, which passes through the bottom of the aerator and flows out through the pores of the aerator. During this process the water splits into minute particles and interacts with air presents in the atmosphere and gets aerated.

Fig 7: Vertical perforated cylindrical aerator design

Fig 8: Vertical perforated cylindrical aerator

2.2 Aerator performance tests

The oxygen-transfer tests were conducted in a 25 m² pond with an average depth of 0.5 m. Before each test, the pond was deoxygenated with 7.88 mg/l of sodium sulfite to remove 1.0 mg/l of oxygen. The cobalt chloride as a concentration of 0.25 mg/l was used as a catalyst. The chemicals were dissolved in water, splashed over the pond surface, and mixed throughout the pond volume with manually. Three sampling stations, one surface, one mid depth, and one near bottom, were taken. DO concentrations were measured at each station at 10-min intervals with a polarographic DO meter. The natural logarithm of the difference between the DO concentration at saturation and the measured DO concentration was plotted against the time of aeration. The slope of the regression line between 10% and 90% of DO saturation is the oxygen transfer coefficient.

2.3 Data analysis

The data obtained from this research work were analysed statistically using Microsoft Excel, 2016. The linear regression was used to determine the slope of the K_La value of aerators Microsoft Corporation, WA.

3. Experimental results

The performance of fabricated aerators have been tested by measuring the increasing dissolved oxygen level in the experimental cement ponds after dropping the dissolved oxygen to below 0.5 mg/l. At the beginning of the experiment, the dissolved oxygen level increased sharply and then slowly until it reached the final value. The increase of DO content in the pond water shows the similar trend from all the aerators.

3.a. Without using aerator (Control)

Experiments were carried out in triplicate as W_1, W_2 and W_3. The pond water was initially deoxygenated and DO content measured were 0.43 mg/l, 0.43 mg/l and 0.50 mg/l in the above ponds respectively. In the three ponds, DO was measured after three hours and finally it reached the values of 4.20 mg/l, 4.15 mg/l and 4.16 mg/l in the above ponds respectively.

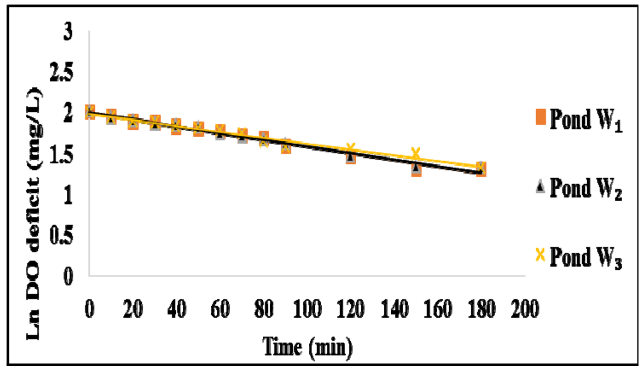

Fig 1: Comparison of Ln DO deficit and time

The overall oxygen-transfer coefficient (K_L a_T) values obtained were 0.258 h^{-1}, 0.24 $h^{-1}$and 0.21 h^{-1} respectively. Standard Oxygen Transfer Rate (SOTR) in above ponds was 0.024 kg O_2/h, 0.023 kg O_2/h and 0.020 kg O_2/h individually.

3.b. Vertical perforated cylindrical aerator

After deoxygenated the ponds water initially, the DO measured were 0.33 mg/l, 0.10 mg/l and 0.18 mg/l in ponds V_1, V_2 and V_3 respectively. After reoxygenated the pond water using above aerators for a duration of three hours the DO reached 8.07 mg/l, 7.76 mg/l and 7.9 mg/l respectively in the above ponds.

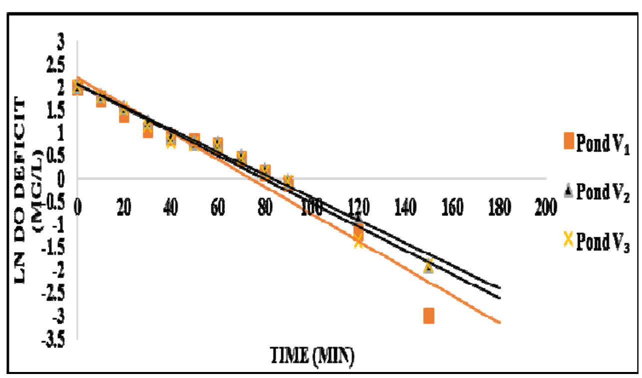

Fig 2: Comparison of Ln DO deficit and time (Vertical perforated cylindrical aerators)

The Overall oxygen-transfer coefficient (K_L a_T) values reached up to 1.778 h^{-1}, 1.602 $h^{-1}$and 1.560 h^{-1}.SOTR measured as 0.167 kg O_2/h, 0.150 kg O_2/h and 0.146 kg O_2/h

3.c. Three tier perforated tray aerator

The ponds water was deoxygenated in the beginning and DO content measured were 0.48 mg/l, 0.35 mg/l and 0.40 mg/l in ponds T_1, T_2 and T_3 respectively. The above aerators were turned on for a duration of three hours and ponds water was increased in DO content and finally it reached the values of 8.52 mg/l, 8.32 mg/l and 8.40 mg/l in above ponds respectively.

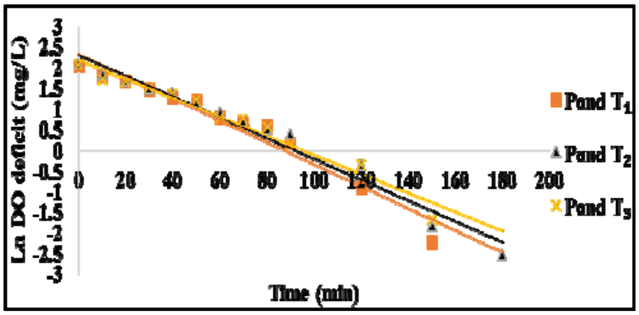

Fig 3: Comparison of Ln DO deficit and time (Three tier perforated tray aerators)

The Overall oxygen-transfer coefficient (K_L a_T) values measured as 1.602 h^{-1}, 1.518 $h^{-1}$and 1.374 h^{-1} and SOTR obtained were 0.156 kg O_2/h, 0.150 kg O_2/h and 0.141 kg O_2/h.

3.d. Rotating wheel aerator

Experiments were carried out in triplicate as R_1, R_2 and R_3. The ponds water was initially deoxygenated and DO content measured were 0.12 mg/l, 0.25 mg/l and 0.40 mg/l in the above ponds. The DO content was measured after three hours and finally it reached the values of 7.40 mg/l, 7.36 mg/l and 7.32 mg/l in the above mentioned ponds respectively.

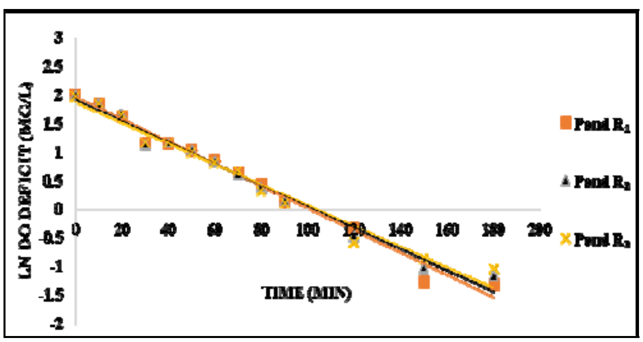

Fig 4: Comparison of Ln DO deficit and time (Rotating wheel aerators)

The Overall oxygen-transfer coefficient (K_L a_T) values obtained were 1.17 h^{-1}, 1.122 $h^{-1}$and 1.086 h^{-1} and SOTR obtained were 0.107 kg O_2/h, 0.102 kg O_2/h and 0.099 kg O_2/h

3.e. Cascading wooden plank aerator

The DO content of the ponds water was measured as 0.03 mg/l, 0.24 mg/l and 0.20 mg/l in ponds C_1, C_2 and C_3 respectively. The increased value of DO measured after three hours of aeration were 7.42 mg/l, 7.21 mg/l and 7.14 mg/l.

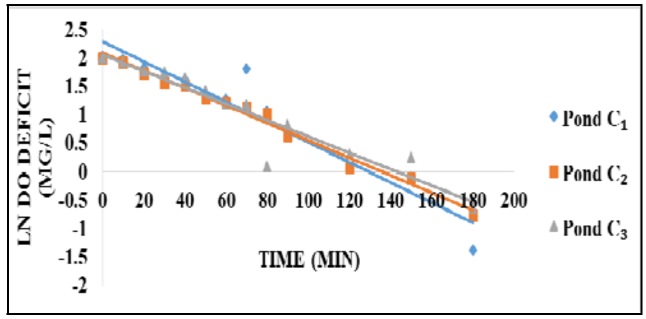

Fig 5: Comparison of Ln DO deficit and time (Cascading wooden plank aerators)

The Overall oxygen-transfer coefficient (K_L a_T) values calculated as 1.062 h^{-1}, 0.924 $h^{-1}$and 0.840 h^{-1} and SOTR measured were 0.167 kg O_2/h, 0.084 kg O_2/h and 0.077 kg O_2/h

4. Discussion

Aeration performance testing is important in selecting design features to provide cost effective yet efficient aquaculture pond aerators. Aerators increase the interfacial area between air and water, thus enhancing the oxygen transfer and simultaneously provide water circulation which prevents the stratification in the water body [6]. Paddle wheel aerators and propeller aspirator pumps are most widely used to increase the dissolved oxygen concentration in the pond water [2, 7] have tested large number of electric aerators such as paddle wheel aerator, propeller-aspirator-pump, vertical pump, pump sprayer and diffused-air to check the oxygen transfer efficiency. The SOTR and SAE values were ranging from 0.6 to 23.2 kg O_2/h and 0.7 to 3.0 kg O_2 kW/h respectively [7] have also tested several tractor-powered pump sprayer and paddle wheel aerators. The SOTR values ranged from 7.8 to 73.8 kg O_2/h respectively [8]. Developed low cost prototype paddle wheel aerator. The performance test was carried out and it showed that the overall oxygen transfer co-efficient (K_L a) as high as 8.19 $h^{-1}$and SOTR and SAE ranged from 1.1 – 1.2 kg O_2/h and 1.1 – 1.3 kg O_2 kW/h respectively [3]. Reported that the SOTR and SAE for twenty four types of the paddle wheel aerators ranged from 1.9 – 8.5 kg O_2/h and 1.2 – 5.2 kg O_2 kW/h respectively [9]. Tested several designs of paddle wheel aerator and reported that the out of all aerators, 91 cm diameter paddle wheel with triangular paddles aerator showed the highest SAE of 2.96 kg O_2 kW/h. The SOTR and SAE for six paddle wheel aerators ranged from 5.2 – 18.5 kg O_2/h and 2.6 – 3.0 kg O_2 kW/h respectively as reported by [7, 10, 6] conducted the experiments on propeller-aspirator pump aerators and found that the SAE ranged between 1.73 and 1.91 kg O_2 kW/h. [11] also reported that the maximum SOTR and SAE values were 0.15 kg O_2/h and 0.42 kg O_2 kW/h respectively for propeller aspirator pump aerator. Many combinations of paddle wheel diameter, speed and paddle depth had SAE values of 2.25 kg O_2 kW/h or higher. These SAE values are superior to values of 0.85-1.64 kg O_2 kW/h as reported by [7, 12] for 2-hp paddle wheel aerators made in Taiwan [7] evaluated six electric paddle wheel aerators which covered a wide range of SAE values from 1.16-2.13 kg O_2 kW/h [6] reported that SAE values for a diffused-air aeration system as 1.08 kg O_2 kW/h, vertical pump surface aerators ranges between 1.34-1.41 kg O_2 kW/h and propeller-aspirator-pump aerators ranges between 1.73-1.91 kg O_2 kW/h. Paddle wheel aerators were considered as the most efficient aerators in terms of standard aeration efficiency and circulation [13, 2].The greatest SAE (2.96 kgO_2kWh^{-1}) was achieved for a 91cm diameter paddle wheel with triangular shape as reported by [14, 15] reported that the Curved Blade Rotor showed the optimum value of K_{La} and AE were 10.33 per hour and 2.269 kg O_2/ kWh respectively [16]. reported the maximum SOTR and SAE of 0.622 kg O_2/h and 1.0 kg O_2/kWh respectively for spiral aerator. Pre-performance evaluation of the original and modified submersible aerator without having a provision to vary (α) and (d) was done and resulted in SAE of 0.320 kg O_2/ kWh. Finally, the optimized value of SAE of 0.616 kg O_2/kWh was achieved. The percentage increase in efficiency after modification was 92.50% as reported by [17, 18] Concluded that out of six different configurations of aerators tested, the curved blade rotor (CBR) emerged as a potential aerator. The overall oxygen transfer co-efficient (K_L a) was observed as 10.33 $hr^{-1}$and the optimum aerator efficiency (AE) was 2.269 kg O_2/kWh [19, 2]. reported that a wide variation in performance of aerators in terms of standard aeration efficiency was found, *viz*. "Taiwanese" aerator (1.17 kg O_2 kW/h), "Japanese" aerator (1.03 kg O_2 kW/h) and Auburn University design (2.25 kg O_2 kW/h) [20]. reported that in an optimum dynamic condition, single hub paddle wheel aerator has produced maximum SAE of 1.65 kg O_2 kW/h [21]. reported that a similar paddle wheel aerator powered by a 50-kW tractor, transferred SOTR of 30 kg O_2/h.

5. Summary

The present experiments were carried out using the fabricated aerators. From the results it was concluded that vertical perforated cylindrical aerator shows better (K_L a_T) and SOTR value followed by three tier perforated tray aerator, rotating wheel aerator and cascading wooden plank aerator respectively. The more increasing in the dissolved oxygen content level may be the higher contacting area between water and air as well as the smaller bubbles produced and raised in the air in vertical perforated cylindrical aerator. The efficiency of aerator depends on the amount of area of contact between air and water, which is controlled primarily by the size of the water drop or air bubble. Considering the cost, aeration cost is the third largest expenditure in intensive aquaculture system after post larvae and feed cost, representing about 15% of total production cost. The cost of mechanical aerators is more and it required more operational and maintenance cost. The present study results suggested that the above conventional fabricated aerators may be used to increase the dissolved oxygen content in the smaller fish ponds.

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