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Performance evaluation of fabricated conventional horizontal perforated sheet aerator models for aquafarm

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Abstract
Aerators are the major component of any aquaculture system because dissolved oxygen is the basic component of the aquatic flora and fauna. The dissolved oxygen has a direct influence on the production and well-being of the aquatic ecosystems. In the present study, the efficiency of the horizontal perforated sheet aerator models with a different number of trays was evaluated for diffusion of oxygen into the water. The results showed that the three-tier perforated horizontal sheets aerator model was more efficient in increasing the dissolved oxygen content of the pond water. The average overall oxygen transfer coefficient [$(K_La)_T$] values for control, single sheet, two-tier and three tier-aerator models are 0.23 h^{-1}, 1.52 h^{-1}, 1.71 h^{-1} and 2.01 h^{-1} respectively. The standard oxygen transfer rate (SOTR) values are 0.022 kg O_2/h, 0.144 kg O_2/h, 0.16 kg O_2/h and 0.182 kg O_2/h respectively for control, single sheet, two-tier and three tier-aerator models.

Keywords: Aeration efficiency, aeration, dissolved oxygen, fabricated aerators

Introduction

Nearly half of the world's fish consumption comes from aquaculture by which it is positioned to play a critical role in meeting global food and nutritional demands **(**Kobayashi *et al*., 2015) [13]. So by utilizing intensive culture practices to produce a variety of aquatic species to meet demand due to the depletion of marine fish population and the increasing human population, land-based aquaculture plays an important role in providing nutritious food, increasing economic growth, expanding employment opportunities, and reducing poverty (Jasmin *et al*., 2022) [9]. The effectiveness of intensive and semi-intensive aquaculture systems is influenced by a variety of water quality parameters and aquatic health depends critically on the optimal concentration of dissolved oxygen (Baylar *et al*., 2006; Roy *et al*., 2020a) **[3, 19]**. Dissolved oxygen (DO) is necessary for the maintenance of aquatic ecosystems; hence, it is one of the most important criteria in the assessment and monitoring of water quality in aquaculture (Jeong *et al*., 2024; Baylar and Bagatur, 2000) **[11,2]**. Because aquatic creatures carry out a variety of physiological functions in water, including feeding, respiration, excretion and reproduction, the water quality of an aquatic environment has a direct impact on the quantity and quality of aquatic products. According to Troell *et al*. (2014) [26], aquaculture has the potential to coexist well with agriculture despite its rapid expansion. The growth of the fish is directly correlated with the dissolved oxygen in the culture system. Low DO levels (below 3 mg/L) cause stress to the fish (Boyd and Hanson, 2010; Nguyen *et al.,* 2021) [5, 17], and prolonged exposure to low levels of oxygen (0.5 mg/L) may cause mortality of fish in mass (Eltawil and ElSbaay, 2016) [7]. So it is very essential to increase the dissolved oxygen content in the pond water. Aeration is a process in which atmospheric air is diffused into the water. Aeration is achieved by the principle that the oxygen pressure in the air drives oxygen into the water until the pressure of oxygen in the water becomes equal to the pressure of oxygen in the air. When it attains equilibrium, the movement of oxygen from the atmosphere to the water ceases (Boyd, 1998) **[4]**. The dissolved oxygen in the aquatic environment can be increased by natural or artificial methods (Tien *et al*., 2019) [25]. Natural methods involve atmospheric diffusion and photosynthesis by aquatic fauna (Roy *et al*., 2017) [18], and artificial aeration can be achieved by three methods (i) surface aeration using paddle wheel aerators, spiral aerators, pump-sprayers and vertical pumps (ii) diffused aeration using propeller-aspirators and submersible aerators and (iii) gravity aeration by using cascade aerators (Roy *et al*., 2022) [21]. Around 15% of the total production cost is from aeration alone in an intensive aquaculture system after post-larvae and feed costs (Kumar *et al.*, 2013) [12]. However, the surface and diffused aeration systems require high initial investments along with high energy input and frequent maintenance that eventually add to the operating cost. Hence, there is a need for more economical and user-friendly aerators (Roy *et al*., 2020a) [19]. A more functional solution to this issue is provided by the perforated tray aerator (PTA) (Eltawil and ElSbaay, 2016) [7]. These aerators are one of the gravity aeration systems that offer greater aeration because of the strong turbulent mixing, extended exposure time and significant air bubble entrainment in the tank-based aquaculture system (Roy *et al*., 2021b; Jayraj *et al*., 2018) [20, 10]. The perforated tray aerator model is planned, designed and fabricated with a number of perforated sheets arranged horizontally in series with uniform vertical spacing. These trays have numerous holes that are uniform in number and diameter and have a significant effect on oxygenation efficiency. Using a centrifugal pump, the water is pumped to the top most tray in the series. When water passes through these small holes, it splits and forms a fine spray. This fine spray increases the water-air interface area, which results in increasing the aeration efficiency when it passes through consecutive trays (El-Zahaby and El-Gendy, 2016; Roy *et al*., 2020) [8, 19]. However, the aeration efficiency is also dependent on various factors like the number of trays, the diameter of the holes, water flow rate, the vertical spacing of the trays, tray area and volume of water in the tank (Tchobanoglous *et al.*, 2004, El-Zahaby and El-Gendy, 2016 and Roy *et al*., 2020) [24, 8,19] respectively. In this context, the present study was conducted to evaluate the oxygenation efficiency of perforated tray aerator models when horizontal perforated sheets are arranged one below the other at equidistant.

Materials and Methods

Experimental setup

The study was carried out at the Research and Instructional Fish Farm of the College of Fisheries, Mangaluru, Karnataka, making use of cement tanks of 5 × 5 × 1 m (without a soil base). Three aerator models, namely i) Single horizontal perforated sheet aerator model ii) Two-tier horizontal perforated sheets aerator model and iii) Three-tier horizontal perforated sheets aerator model were planned, designed, fabricated and set up in triplicates (T_1, T_2, and T_3) to determine their oxygenation efficiency. The water is pumped to the aerator model using a 1 HP pump (V-Guard Industries, Ltd.) with a control valve to regulate the flow. The experimental tanks were drained completely and the surfaces were also cleaned. Later, all the tanks were filled with fresh water to a depth of 0.5 metre. Proper outlets were provided to drain the pond water whenever necessary. A control tank (C_1, C_2 and C_3) was set up in a similar way without an aerator model.

Experimental aerator design

i) Single horizontal perforated sheet aerator model

Single horizontal perforated sheet aerator model design of 81 × 72 × 5 cm was made using a GI (galvanised iron) perforated sheet. This type of aerator model is designed using a single sheet of GI material with holes or perforations in it. When pond water passes through the pores of the tray, it splits into minute sprays and observes the oxygen content present in the atmosphere before reaching the tank water (Fig. 1).

Fig 1: Experimental set up with single horizontal perforated sheet aerator model.

ii) Two-tier horizontal perforated sheets aerator model

The two-tier horizontal perforated sheets aerator model was designed with a dimension of 81 × 72 × 5 cm, similar to that of the single tray aerator model, where an additional sheet was added below, with a vertical spacing of 25 cm. The water passes through the first tray to the second tray before reaching the tank. The purpose of using multiple sheets is to increase the contact area between the air and the water, which maximizes the effectiveness of the aeration process (Fig. 2).

Fig 2: Experimental set up with two-tier horizontal perforated sheets aerator model.

iii) Three-tier horizontal perforated sheets aerator model

An additional perforated sheet with similar dimensions was added below the second tray with the same vertical spacing. Water pumped to the top of the tray will pass through the successive trays before reaching the tank. In this aerator model, the water passes through 3 perforated trays, providing more surface area for water-air interaction that facilitates more oxygen diffusion into the water (Fig. 3).

Fig 3: Experimental set up with three-tier horizontal perforated sheets aerator model.

De-oxygenation of tank water

The standard tests for the aerator models were carried out in the cement concrete tanks filled with fresh water at standard temperature and pressure (20 ˚C and 760 mm Hg). Sodium sulphite (Na_2SO_3) solution along with cobalt chloride ($CoCl_2$ $6H_2O$) was used as a catalyst for deoxygenating the water (APHA, 1980) [1]. The change in DO concentration is measured as the water is re-oxygenated with the aerator being evaluated. This procedure is termed as unsteady-state testing since the amount of oxygen transferred and the DO concentration change during the test. Two sampling stations were selected in the test tanks. Care has been taken while selecting the sampling stations in such a way that, sampling points should be away from the walls and floor of the tank. For deoxygenating the tank water 7.88 mg/L of sodium sulphite (Na_2SO_3) was used to remove 1.0 mg/L of oxygen. The cobalt chloride at a concentration of 0.25 mg/L was used as a catalyst. Chemical slurries were first made by mixing the respective chemicals with a small amount of pond water.

The chemical slurries are mixed until the tank water DO drops below 0.5 mg/L. The cobalt chloride catalyst is added to the tank water first and mixed with the pond water manually for a period of 30 minutes to ensure complete mixing. The sodium sulphite solution is then splashed into the tank and mixed thoroughly with the help of manpower. After 20-30 minutes of mixing the DO of the tank water was measured and ensured to be less than 0.5 mg/L. The aerator is turned on to increase the DO concentration of the tank water. Dissolved oxygen readings are then taken simultaneously at timed intervals (0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 120, 150, and 180 minutes) while the DO increases to at least 90 % saturation.

Estimation of oxygen deficit

The DO deficit is computed for each interval that DO was measured during re-aeration

$$OD = DO_s - DO_m$$

Where,

DO_s = Theoretical oxygen saturation concentration (mg/L)

DO_m = Measured oxygen saturation concentration (mg/L)

Using regression analysis, the best-fit line is obtained by plotting a graph for the time of aeration (X) and the natural logarithms of DO deficits (Y). The coefficient of oxygen transfer is calculated using points representing 10% and 70% oxygen saturation from the above graph as follows (Boyd and Watten, 1989; Lawson, 1995) [6, 14].

$$(K_L a)_T = \frac{\ln(OD_{10}) - \ln(OD_{70})}{(t_{70} - t_{10})/60}$$

Where,

$(K_L a)_T$ = Overall Oxygen Transfer Co-efficient (hr^{-1}) at temperature T

ln = Natural logarithm

OD_{10} = Oxygen deficit at 10 % saturation (mg/L)

OD_{70} = Oxygen deficit at 70 % saturation (mg/L)

t_{10} = Time taken to reach 10 % dissolved oxygen concentration saturation (min.)

t_{70} = Time taken to reach 70 % dissolved oxygen concentration saturation (min.)

The Oxygen Transfer Coefficient is adjusted to 20 ^{0}C with the following equation

$$(K_L a)_{20} = (K_L a)_T \div 1.024^{T-20}$$

Where,

$K_L a_{20}$ = Overall Oxygen Transfer Coefficient at 20°C (hr^{-1})

$(K_L a)_T$ = Overall Oxygen Transfer coefficient at t °C (hr^{-1}) and

T = Test water temperature (°C).

Estimation of standard oxygen transfer rate (SOTR)

Under standard conditions (0 mg/L DO and 20^{0}C), the amount of oxygen transferred to water by an aerator per hour is known as the standard oxygen transfer rate (SOTR). The SOTR of an aerator is calculated by using the oxygen transfer coefficient obtained from the above equation. The formula to calculate the SOTR of an aerator is as follows (Lawson, T. B. 1995) [14].

$$SOTR = (K_L a_{20})(Cs_{20})(V)(10^{-3})$$

Where,

SOTR = Standard Oxygen Transfer Rate (kg Oxygen h^{-1})

$K_L a_{20}$ = Overall oxygen transfer coefficient

Cs_{20} = DO concentration at saturation and 20 ^{0}C (gm^{-3} which equals mg/L)

V = Tank volume (m^3) and

10^{-3} = Factor for converting g to kg.

Results

Considering the importance of dissolved oxygen in the aquatic environment, the present study was taken to evaluate the oxygenation efficiency of perforated tray aerator models. The dissolved oxygen concentration was reduced to 0.5 mg/L before starting the aerators. It is observed that the rate of oxygen transfer was high initially and slowed down gradually.

Without using aerator (Control)

The experimental cement tanks devoid of aerators were used as control tanks, marked as C_1, C_2 and C_3. The control tanks were deoxygenated initially for concentrations of 0.43

mg/L, 0.43 mg/L and 0.50 mg/L respectively. The tank water was checked for dissolved oxygen concentration at regular intervals and after 180 minutes (3 hours), the dissolved oxygen concentration was determined to be 4.20 mg/L, 4.15 mg/L and 4.16 mg/L respectively. The overall oxygen transfer coefficient [$(K_La)_T$] values were found to be 0.25 h^{-1}, 0.24 $h^{-1}$and 0.21 h^{-1} respectively. The standard oxygen transfer rate (SOTR) for control tanks was 0.024 kg O_2/h, 0.023 kg O_2/h and 0.020 kg O_2/h respectively.

The single horizontal perforated sheet aerator model

The single horizontal perforated sheet aerator model was set up in cement tanks and marked as T_1, T_2 and T_3. The initial dissolved oxygen concentration was 0.5 mg/L, 0.4 mg/L and 0.3 mg/L respectively. After 180 minutes, the dissolved oxygen concentration of the tank water was 7.9 mg/L, 7.85 mg/L and 7.9 mg/L respectively. The overall oxygen transfer coefficient [$(K_La)_T$] for the single horizontal perforated sheet aerator model is determined as 1.54 h^{-1}, 1.53 h^{-1} and 1.48 h^{-1} respectively, for tanks T_1, T_2 and T_3. The SOTR values for the single horizontal perforated aerator model were 0.146 kg O_2/h, 0.145 kg O_2/h and 0.141 kg O_2/h respectively.

Two-tier horizontal perforated sheets aerator model

In this aerator model, an additional perforated sheet was added below the first sheet with a similar design and dimensions. Here, the water splits twice before reaching the tank, encouraging more oxygen diffusion. A similar procedure was followed for deoxygenation of the tank water, and the DO values were found to be 0.5 mg/L, 0.6 mg/L and 0.5 mg/L for tanks T_1, T_2 and T_3. After 180 minutes, the dissolved oxygen concentration of the tank water was 7.8 mg/L, 7.80 mg/L and 7.95 mg/L respectively. The oxygen transfer coefficients for tanks T_1, T_2 and T_3 are 1.64 h^{-1}, 1.68 h^{-1}, and 1.8 h^{-1} respectively. The SOTR values for these two-tier aerator models are 0.154 kg O_2/h, 0.159 kg O_2/h and 0.167 kg O_2/h respectively.

Three-tier perforated horizontal sheets aerator model

In this aerator model, three horizontal perforated sheets are arranged one below the other with a regular, equal vertical spacing of 25 cm. Because the water disperses into tiny particles, increasing oxygen diffusion, the oxygen transfer rate is higher in this case. The initial dissolved oxygen concentrations of the tank water are 0.45 mg/L, 0.3 mg/L and 0.4 mg/L and the final dissolved oxygen concentrations after 180 minutes of aerator run-time are 8.3 mg/L, 8.25 mg/L and 8.45 mg/L for tanks T_1, T_2 and T_3. The SOTR values for the three-tier aerator models are 0.187 kg O_2/h, 0.184 kg O_2/h and 0.176 kg O2/h with oxygen transfer coefficients of 2.06 h^{-1}, 2.04 h^{-1} and 1.92 h^{-1} respectively, for tanks T_1, T_2 and T_3.

Discussion

The dependence on aeration systems has increased exponentially due to the intensification of the aquaculture sector to meet global demand. In intensive and semi-intensive aquaculture systems, natural aeration alone cannot fulfil the oxygen demand, hence artificial aeration is necessary (Kumar *et al.*, 2013) [12]. In the current study, aeration tests were conducted using different numbers of horizontal perforated sheets arranged one above the other to check the oxygenation efficiency. The lattice and perforated sheet gravity aerators are more efficient in oxygen transfer as water falls from screen to screen (Lawson, 1995) **[14].** The amount of oxygenation rises with the number of trays for a certain tray spacing, although typically at a decreasing rate (Boyd and Watten, 1989) **[6].** From the results, the highest values of SOTR and oxygen transfer coefficient are observed in the three-tier aerator model, indicating that the three-tier horizontal perforated sheets aerator model is more efficient than the two-tier and single-sheet aerator models. Roy *et al*. (2020) [19]**,** conducted an aeration test on a perforated tray aerator model with different numbers of trays attached and concluded that for efficient aeration, the optimum number of trays is three. The average $(K_La)_T$ values are 0.23 h^{-1}, 1.52 h^{-1}, 1.71 h^{-1} and 2.01 h^{-1} for the control, single sheet, two-tier and three tier-aerator models tested. According to Maloth *et al.* (2022) [15]**,** the three-tier perforated aerator model was more efficient in oxygen dissolving during day and night hours in the aquaculture ponds. The overall aeration efficiency $(K_La)_T$ increases with the number of steps for a particular height of the stepped cascade, because of the increased surface area. For a rectangular stepped cascade structure of height 3.0 m, the overall aeration efficiency at standard conditions, (i.e., E_{20}) approaches maximum when the number of steps, the slope of the entire stepped cascade, and hydraulic loading rate are 14, 0.351, and 0.009 m^2/s, respectively (Moulick *et al.*, 2010) [16].

The average SOTR values for control, single sheet, two-tier and three tier aerator models are 0.022 kg O_2/h, 0.144 kg O_2/h, 0.16 kg O_2/h, and 0.182 kg O_2/h, respectively. The findings of Roy *et al*. (2020) [19], on perforated tray aerators attached to different numbers of trays showed the highest values of SOTR for three tier aerator models. The studies on the performance of a perforated pooled circular stepped cascading aerator model showed that the SOTR and SAE values are directly proportional to the discharge rate and radius of the tray (Roy *et al*., 2024) [22]. The three-tier aerator model is efficient in increasing the oxygen levels in the water.

However, the oxygenation efficiency of the aerators also depends on various factors like the area of the ponds, the rate of discharge, the diameter of the perforations on the trays, the area of the trays used and the number of trays. Based on observations from their study, Shukla and Goel (2018) [23], concluded that the maximum oxygen-transfer efficiency of 21.53 kg O_2/kW hr was obtained for a single nozzle aerator at a discharge of 1.11 L/s; however, for an aerator with eight numbers of openings totalling 594.96 mm^2, a maximum oxygen-transfer factor of 2.0 x 10^{-2} s^{-1} was obtained at a discharge of 4.69 L/s. Conversely, at a discharge rate of 1.11 L/s, an aerator with a single opening demonstrated the highest oxygen transfer efficiency of 10.93 kg O_2/kW hr, and at a discharge rate of 4.69 L/s, an aerator with eight openings yielded the highest oxygen transfer factor of 7.83x $10^{-3}s^{-1}$. These aerators belong to a set of aerators whose opening area makes up 246.30 mm^2.

Conclusions

The study was undertaken to evaluate the efficiency of the horizontal perforated sheet aerator models against the overall oxygen transfer coefficient [$(K_L\ a)_T$] and standard oxygen transfer rate (SOTR). From the results of the study, it is concluded that the three-tier horizontal perforated sheets aerator model is more efficient in oxygenation when compared with the single horizontal perforated sheet aerator model and two-tier horizontal perforated sheets aerator models**.** The highest overall oxygen transfer coefficient [$(K_La)_T$] and standard oxygen transfer rate (SOTR) values are obtained in the three-tier horizontal perforated sheets aerator model, which indicates more oxygen diffusion. It may be indicating that as the area of contact between air and water increases, oxygen transfer to the water is also increases. Further studies can be taken up in the direction of evaluating the three tier perforated aerator model against changes in discharge diameters, and dimensions of the trays.

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References
1. APHA. Standard methods for examination of water and wastewater (ed. 20th). American Public Health Association. Washington, D.C. U.S.A; c1980.
2. Baylar A, Bagatur T. Study of aeration efficiency at weirs. Turkish Journal of Engineering and Environmental Sciences/Turk Muhendislik ve Cevre Bilimleri Dergisi. 2000;24(4):255-264.
3. Baylar A, Emiroglu ME, Bagatur T. An experimental investigation of aeration performance in stepped spillways. Water and Environment Journal. 2006;20(1):35-42.
4. Boyd CE. Pond water aeration systems. Aquacultural Engineering. 1998;18(1):9-40.
5. Boyd CE, Hanson T. Dissolved-oxygen concentrations in pond aquaculture. Ratio. 2010;2:42.
6. Boyd CE, Watten BJ. Aeration systems in aquaculture. 1989.
7. Eltawil MA, ElSbaay AM. Utilisation of solar photovoltaic pumping for aeration systems in aquaculture ponds. International Journal of Sustainable Energy. 2016;35(7):629-644.
8. El-Zahaby AM, El-Gendy AS. Passive aeration of wastewater treated by an anaerobic process-a design approach. Journal of Environmental Chemical Engineering. 2016;4(4):4565-4573.
9. Jasmin SA, Ramesh P, Tanveer M. An intelligent framework for prediction and forecasting of dissolved oxygen level and biofloc amount in a shrimp culture system using machine learning techniques. Expert Systems with Applications. 2022;199:117160.
10. Jayraj P, Roy SM, Mukherjee CK, Mal BC. Design characteristics of the submersible aerator. Turkish Journal of Fisheries and Aquatic Sciences. 2018;18(9):1017-1023.
11. Jeong J, Awosile B, Thakur KK, Stryhn H, Boyce B, Vanderstichel R. Longitudinal dissolved oxygen patterns in Atlantic salmon aquaculture sites in British Columbia, Canada. Frontiers in Marine Science. 2024;1289375.
12. Kumar A, Moulick S, Mal BC. Selection of aerators for intensive aquacultural pond. Aquacultural Engineering. 2013;56:71-78.
13. Kobayashi M, Msangi S, Batka M, Vannuccini S, Dey MM, Anderson JL. Fish to 2030: the role and opportunity for aquaculture. Aquaculture Economics and Management. 2015;19(3):282-300.
14. Lawson TB. Fundamentals of Aquacultural Engineering. Chapman-Hall, an International Thomson Publishing Company; c1995. p. 335.
15. Mohan M, Prasad GS, Dash RK, Vijay K, Prakash NMM, Barik P, Varadaraju S. Fabricated aerators influence the oxygen dissolution in pond water during day and night. The Pharma Innovation. 2022;11(10):2351-2358.
16. Moulick S, Tambada NV, Singh BK, Mal BC. Aeration characteristics of a rectangular stepped cascade system. Water Science and Technology. 2010;61(2):415-420.
17. Nguyen NT, Matsuhashi R, Vo TTBC. A design on sustainable hybrid energy systems by multi-objective optimization for aquaculture industry. Renewable Energy. 2021;163:1878-1894.
18. Roy SM, Moulick S, Mal BC. Design characteristics of spiral aerator. Journal of the World Aquaculture Society. 2017;48(6):898-908.
19. Roy SM, Moulick S, Mukherjee CK. Design characteristics of perforated pooled circular stepped cascade (PPCSC) aeration system. Water Supply. 2020;20(5):1692-1705.
20. Roy SM, Gupta D, Pareek CM, Tanveer M, Mal BC. Prediction of aeration efficiency of diffuser aerator using artificial neural network and response surface methodology. Journal of Water Science and Technology–Water Supply; c2021.
21. Roy SM, Tanveer M, Machavaram R. Applications of gravity aeration system in aquaculture—a systematic review. Aquaculture International. 2022;30(3):1593-1621.
22. Roy SM, Machavaram R, Pareek CM, Kim T. Investigating the performance of a perforated pooled circular stepped cascade aeration system for intensive aquaculture. Heliyon; c2024.
23. Shukla BK, Goel A. Study on oxygen transfer by solid jet aerator with multiple openings. Engineering Science and Technology, an International Journal. 2018;21(2):255-260.
24. Tchobanoglous G, Burton FL, Stensel HD. Wastewater Engineering. Management. 1991;7(1):4.
25. Tien NN, Matsuhashi R, Chau VTTB. A sustainable energy model for shrimp farms in the Mekong Delta. Energy Procedia. 2019;157:926-938.
26. Troell M, Naylor RL, Metian M, Beveridge M, Tyedmers PH, Folke C, De Zeeuw A. Does aquaculture add resilience to the global food system? Proceedings of the National Academy of Sciences. 2014;111(37):13257-13263.