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Use of different fabricated aerator models for the assessment of aeration efficiency in aquafarm

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Abstract

Water is a basic resource which is essential for all living entities. The process of enhancing the amount of dissolved oxygen in water is known as aeration. Enhancing oxygen transport is crucial to increase energy efficiency since aeration uses the most energy in water resource facilities. Aerators are indispensable in aquaculture to enhance oxygen levels, which are crucial for aquatic organism health and growth. The fabricated aerator models included wooden perforated plank aerator model, cascading wooden plank aerator model, vertical perforated cylindrical aerator model and three tier perforated sheets aerator models were used for the present study. This study evaluates various conventional aerator models based on their oxygenation efficiency using parameters such as the overall oxygen transfer coefficient $(K_La)_T$ and standard oxygen transfer rate (SOTR). Results indicate that there is a significant improvement in dissolved oxygen content with aerators compared to control conditions without aeration. The Overall Oxygen Transfer Coefficient $(K_La)_T$ ranged from 0.919 h^{-1} to 1.586 h^{-1} , while the corresponding Standard Oxygen Transfer Rate (SOTR) values varied from 0.082 kg O_2/h to 0.160 kg O_2/h among the above mentioned aerator models. These findings underscore the critical role of aerators in maintaining optimal aquatic conditions and suggest practical implications for aerator design and deployment in aquaculture systems.

Keywords: Aquaculture, aerators, dissolved oxygen, oxygen transfer coefficient, standard oxygen transfer rate

Introduction

Dissolved oxygen (DO) concentration in water is an important parameter which significantly affects aquatic life. The survival rate of aquatic species is affected adversely if the dissolved oxygen concentration level falls below 5.0 mg/L (Roy *et al*., 2020) [16]. The fish mortality could be high with dissolved oxygen concentration below 1 to 2 mg/L for a few hours (Boyd and Hanson, 2010; Cheng *et al*., 2019 [3, 6]. Hence, the continuous supply of oxygen for maintaining the adequate DO concentration to the aquaculture ponds is essential for healthy growth and survival of aquatic species. In intensive aquaculture operations, such as ponds or tanks, maintaining adequate dissolved oxygen levels is critical to ensure optimal growth, survival, and overall health of the stocked species. Oxygen is an important component in the aquaculture system for various biological processes, including respiration. Therefore, the DO value is one of the indicative parameters applied for monitoring and controlling the aeration system (Hong prasith *et al*., 2012) [8]. It is crucial to keep oxygen concentrations at a safe threshold and remove carbon dioxide which is created when fish and heterotrophic bacteria respire is taking place (Boyd and Martinson, 1984) [4]. According to Peterson and Patterson(2000) [15], the oxygen concentration of air is 21%, whereas the dissolved oxygen capacity of water is only a few mg/L. Molecular diffusion limits natural re-aeration at a water body's surface unless wind, waves, or currents create turbulence and an expanded surface area. Higher biomass concentrations than those supported in a natural stream are made possible by mechanical aeration. An intensive aquaculture pond's aerators act as its "lungs," drawing oxygen into the water column and expelling carbon dioxide. Aerators are essential devices in aquaculture, primarily designed to enhance oxygen transfer and circulation within water bodies where aquatic organisms are cultivated. An aeration system improves the oxygen transfer required to support a biological process by increasing the air/water contact within a process liquid. The purpose of conventional aerators, such as diffused air systems, submersible aerators, and surface aerators, is to improve oxygenation in aquaculture environments. By producing turbulence at the water's surface, surface aerators encourage gas exchange with the atmosphere (Boyd, 1990) [2]. In contrast, submersible aerators function in underwater, generating bubbles that enhance water circulation and raise oxygen levels (Timmons, 2002) [18]. In order to efficiently oxygenate deeper water layers and maintain consistent DO levels, diffused air systems use air pumps to release tiny bubbles at the bottom of ponds or tanks (Tanveer *et al.*, 2018) [14]. There are operational and financial advantages to use appropriate aerators for the aeration process in both fish production areas and needed areas. There is widespread application for dispersion, spiral, impeller, and compressors. These aerators do, however, have significant running costs and considerable energy consumption (Kelestemur *et al.*, 2024) [9]. This fosters the design and fabrication of an aerator that is relatively cheap to build, has few parts, and requires little maintenance. This study aims to develop conventional aerator models and evaluate oxygenation efficiency in aquafarm.

Theoretical Analysis

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 transfer coefficient

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 as follows (Boyd and Watten, 1989; Lawson, 1995) [5,11].

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

Where,

$(K_La)_T$ = Overall Oxygen Transfer Coefficient (hr^{-1}) at temperature T.

OD_{10} and OD_{70} = Oxygen deficit at 10%and 70% saturation, respectively (mg/L).

T_{70} and t_{10} = Time taken to reach 70 % and 10% dissolved oxygen saturation respectively (min.).

At standard temperature (20˚C), the oxygen transfer coefficient can be expressed as follows:

$$K_La_{20} = K_La_T \div 1.024^{T-20}$$

Where,

$(K_La)_{20}$= Overall Oxygen Transfer Coefficient at 20°C (hr^{-1}).

$(K_La)_T$ = Overall Oxygen Transfer Coefficient (hr^{-1}) at temperature T.

T = Test water temperature (°C).

Estimation of standard oxygen transfer rate (SOTR)

The amount of oxygen that an aerator transfers to water per hour at standard conditions (0 mg/L DO and 20 °C) is called as the standard oxygen transfer rate (SOTR). 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) [11].

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

Where,

SOTR = Standard Oxygen Transfer Rate, kg O_2/hr

$(C_s)_{20}$= DO concentration at saturation and 20°C, g/m^3 = mg/L

V = Volume of water in test basin, m^3

10^{-3} = Converts g to kg.

Materials and Methods

Experimental design: The present study was carried out at the Research and Instructional Fish Farm of the College of Fisheries, Mangaluru, Karnataka. The cement tanks of size (5 × 5 × 1 m) without a soil base were used for the study. The control tank was also used without an aerator model to conduct the experiment. Initially the cement tanks were drained completely, and the surfaces, including the bottom, were cleaned properly. These cement tanks were filled with water to a depth of 0.5 metre. The electrical motor pump of capacity 0.5 HP (Ventura pumps) was used to pump the tank water to the experimental setup. Four aerator models, namely i) Wooden perforated plank aerator model ii) Cascading wooden plank aerator model iii) Vertical perforated cylindrical aerator model and iv) Three tier perforated sheets aerator models were planned, designed and fabricated to determine their oxygenation efficiency.

Design and working mechanism of aerator models

i) Wooden perforated plank aerator model

The design of this aerator model is very simple; plain wooden planks of uniform size were joined closely for the dimension of 90 × 90 × 2.5 cm was used to study the oxygenation efficiency (Fig. 1). These planks have perforations or holes in it (76 x 71 cm). These holes allow the water to pass through it, and naturally it increases aeration efficiency. The water from the experimental tank is made to fall on the surface through a shower which is having 20 cm diameter. The water passes through the holes and splits into minute particles before reaching back to the tank (Fig. 2).

Fig 1: Wooden perforated plank aerator model.

Fig 2: Wooden perforated plank aerator model used in the study.

ii) Cascading wooden plank aerator model

The wooden planks with dimensions of 26 x 95 x 2.5 cm were used to fabricate the cascading wooden plank aerator model of 95×78 x 2.5 cm dimension. The rectangular wooden pieces of size 3×78 ×1.5 cm were aligned on the main board with uniform spacing to create the cascading effect. The water hose is set up in such a way that it falls on the top of the aerator model. When water flows through these numbers of steps on the wooden board, it breaks into tiny particles and increases the efficiency of oxygen transfer before reaching the pond water (Fig. 3).

Fig 3: Cascading wooden plank aerator model

iii) Vertical perforated cylindrical aerator model

The vertical perforated cylindrical aerator model is designed and fabricated using perforated galvanised iron (GI) sheet with a height of 30 cm and 10 cm diameter. One end of the aerator model is fabricated to fit the water supply pipe with the help of an elbow connection (Fig. 4). The water from the tank is pumped to pass through the aerator model. The water gets splashed through these perforations of the aerator model and falls back to the tank. During this process, the water splits into fine particles that trap air present in the atmosphere (Fig. 4).

Fig 4: Vertical perforated cylindrical aerator model used in the study

iv) Three tier perforated sheets aerator model

Three tier perforated sheets aerator model was made using a GI (galvanised iron) perforated sheet for a dimension of 81 × 72 × 5 cm. This type of aerator model was fabricated using GI sheet with holes or perforations in it. Three sheets were arranged one below the other with a vertical spacing of 25 cm. When pond water is allowed to passes through the pores of the aerator model, it splits into minute particles and observes the oxygen content present in the atmosphere before reaching the tank water (Fig. 5).

Fig 5: Three tier perforated sheets aerator model

Results

The present study was taken up to evaluate the oxygenation transferring performance of different fabricated conventional aerator models. The designed and fabricated aerator models were tested for overall oxygen transfer coefficient $(K_La)_T$ and standard oxygen transfer rate (SOTR). From the results of the current study, it is clear that the fabricated aerator models were efficient in increasing the dissolved oxygen content of the water. The control tank where no aerator model was deployed showed the lowest values for overall oxygen transfer coefficient (0.147 hr^{-1}) and standard oxygen transfer rate (0.0145 kg O_2 hr^{-1}). Whereas, the wooden perforated plank aerator model showed an oxygen transfer coefficient of 0.976 hr^{-1} and a standard oxygen transfer rate of 0.0815 kg O_2 hr^{-1}. The cascading wooden plank aerator model showed better performance, where the coefficient of oxygen transfer and SOTR values are 0.9198 hr^{-1} and 0.0844 kg O_2 hr^{-1} respectively. The highest values are obtained for the three tier perforated sheets aerator model, indicating that it is more efficient in oxygenating the water among the aerators tested in the present study. The values of oxygen transfer coefficient and SOTR are 1.586 $hr^{-1}$and 0.160 kg O_2 hr^{-1} respectively. In the case of a vertical perforated cylindrical aerator model, the values of oxygen transfer coefficient and SOTR are 1.167 hr^{-1} and 0.1176 kg O_2 hr^{-1} respectively. However, the vertical perforated cylindrical aerator model is efficient in oxygenation when compared with the control.

Discussion

Understanding the importance of dissolved oxygen in the aquatic system, aerators have become a more useful component of aquaculture systems. Enhancing the habitat for fisheries, treating eutrophication symptoms, and improving drinking water supplies are all possible with aeration (Hasan *et al*., 2014) [7]. In the evaluation of twenty-four different types of paddle wheel aerators, Boyd (1990) [2]found that the standard aerator efficiency and oxygen transfer rate ranged from 1.2 - 5.2 kg O_2 kW^{-1} hr^{-1} and 1.9 - 8.5 kg O_2 hr^{-1}, respectively. The cascading wooden plank aerator model showed better performance than the wooden perforated aerator model. However, an increase in the number of trays may have better aeration efficiency. When water flows from screen to screen, the lattice and perforated sheet gravity aerators transport oxygen more efficiently (Lawson, 1995) [11]. According to Roy *et al*. (2020) [17]**,** for better aeration efficiency in a perforated tray aerator model, three trays are found to be optimal. For a certain tray spacing, the amount of oxygenation increases with the number of trays, albeit usually at a decreasing rate (Boyd and Watten, 1989) [5].

The performance of the cascading wooden plank aerator was consistent with that of previous studies. Mohan *et al.*, (2020) [13] evaluated the cascading type of aerator model and found 0.94 hr^{-1} of oxygen transfer coefficient and 0.1093 kg O_2 hr^{-1} of SOTR. Varadaraju *et al.*,(2024) [20] conducted the comparative study of fabricated conventional aerator models for enhancing oxygenation efficiency in Aqua farm. The findings indicated that the two tier perforated sheets aerator model exhibited better $(K_La)_T$ and SOTR values compared to the single perforated sheet aerator, wooden perforated aerator and wooden flat surface aerator models, in descending order. Kumar *et al*. (2013) [10]conducted a study of four types of aerators; circular stepped cascade (CSC), pooled circular stepped cascade (PCSC), paddle wheel, and propeller aspirator pump. The standard aerator efficiency showed that CSC and PCSC aerators were economical for ponds with an area of <1000 m^3. Among the four aerators studied in the present study, the three tier perforated sheets aerator model showed the better performance. Varadaraju *et al.,* (2024) [19] conducted the study to evaluate the performance of fabricated conventional horizontal perforated sheet aerator models for aqua farm. From the results of the study, it was concluded that the three-tier horizontal perforated sheets aerator model is more efficient in oxygenation when compared with the single horizontal perforated sheet and two-tier horizontal perforated sheets aerator models**.** Previous studies by Maloth *et al.,* (2020) [13]showed that the vertical perforated cylindrical aerator has an average overall coefficient value of 1.646 hr^{-1} and an average SOTR value of 0.154 kg O_2 hr^{-1}. Studies showed that the dissolved oxygen concentration of the water was increased from 6.53 mg/L to 8.02 mg/L (Maloth *et al*., 2022) [12].

Conclusions

The purpose of the present study was to evaluate the efficiency of conventional aerator models in terms of overall oxygen transfer coefficient $(K_La)_T$ and standard oxygen transfer rate (SOTR). From the results, it can be concluded that the aerator models designed can efficiently increase the dissolved oxygen (DO) concentration of the water. Among the four prototypes aerator models tested, the three tier perforated sheets aerator model showed better performance compared to the other aerator models. Further studies can be taken up to understand the effect of these fabricated conventional aerator models on the growth of aquatic organisms.

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