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A Comprehensive Study on Paddle Wheel Aerator

Suranjit Roy[1], Avinash Kumar[2]*

[1]*Research Scholar, Department of Agricultural Engineering, Assam University, Silchar, Assam, India.*

[2]*Assistant Professor, Department of Agricultural Engineering, Assam University, Silchar, Assam, India.*

Emails: *suranjitroy856@gmail.com[1], avinashiitkgp86@gmail.com[2]*

***Corresponding Author Orcid ID:** https://orcid.org/0009-0004-1483-6447*

Abstract

The aquatic biome is greatly impacted by the rise in demand brought on by the current worldwide population growth. The demand for fish is steadily rising with population growth and the prevalence of water contamination is rising alarmingly. Several aerators have been utilized to evaluate the normal aeration effectiveness at different conditions. In terms of oxygen transmission and water circulation, paddle wheel aerators fared better than the rest. The oxygen transfer capacity of the double-hub paddle wheel aerator was the same as that of the single-hub paddle wheel aerator but consumed more energy under similar geometric and dynamic properties. The dimensional analysis of the aeration process highlighted that the absorption process' determining parameter is KLA20 and the main characteristic of a paddle wheel aerator is its geometric variables. Generally, Paddle wheel design typically takes into account a variety of dimensions from 50 to 90 cm for the diameter, 75 to 135 rpm for speed, and 8 to 25 cm for paddle depth of submergence but certain performance losses were seen in the models. The power-to-volume ratio was calculated and found to be between 0.01 and 0.04 kW/m3 but the aeration process is affected by several geometrical and material variables. Despite the different kinds of aerators available in the market, the main issue is that farmers and other small stakeholders cannot afford them. Paddle wheel aerators with single or double hubs are pricey, while their counterparts need a significant initial outlay with lack of Automation and AI in aquaculture domain. Photovoltaic aerators also could not mitigate such anomalies completely as it outperforms in overcast days. This study highlighted the comparison and effectiveness of different types of aerators used and suggested that there is a pressing need to design aerators to solve these issues and make it affordable for small stakeholders.

Keywords: *Aerator, Automation, Aquaculture, Dissolved Oxygen, Paddle Wheel Aerator*

1. Introduction

Population explosion is a major global concern nowadays and with the increase in demand, the aquatic biome is very much affected. With the increase in population, the demand for fish is gradually increasing day by day [1]. The water pollution rate also increasing at an alarming rate. To mitigate several aforesaid related problems, the optimal solution might be a proper aeration system. Our country is an agrarian economy and the small-scale farmers hardly have access to any aeration system in very remote locations. If some of them have access, then also that system might not be affordable to the budget [2]. Oxygen is the most vital element for the survival and sustainability of both plants and animals not only in the lithosphere but also in the hydrosphere. A slight variation in dissolved oxygen hurdles the growth of phytoplankton zooplankton and all the aquatic life forms. To maintain the desired optimum level of dissolved oxygen aeration is provided. A liquid or material is aerated when air is pumped through it, combined with it, or dissolved in it. Aeration is the process of increasing the area of contact between water and air, either naturally or artificially, in its widest definition. [3] However, the phrase has been used more narrowly to refer particularly to the employment of mechanical tools or processes in everyday water works practice. Aeration establishes itself as a therapeutic strategy rather than only changing the local environment at the source of supply in this constrained meaning. Large bodies of water that are slowly aerated naturally are referred to as "natural aeration" or "re-aeration," which are non-mechanical processes. The D.O. level in prawn cultivation operations must be maintained using aerators. (Jayanthi et al., 2021) Although several different aerator types are touted as being appropriate for prawn farming, their relative efficacies and water circulation patterns are little understood [4]. The typical aeration efficiency at various saline conditions with the frequently used paddle wheel aerator was compared using the aerators, including modified paddle wheel, Scorpion jet, Venture jet, and Wave surge. Zhu et al developed a new aeration adsorption system using fiber balls for the treatment of nitrogen and phosphorus content in black odorous water and did inclusion of aeration increases the degree of nitrogen removal. (Zhu et al 2022). The most common types of aerators are probably propeller-aspirator pump aerators and paddle wheel aerators. Aeration rates range from as little as 1-2 kW/ha for various fish culture types to as high as 15 or 20 kW/ha for marine prawn culture which is done intensively (Boyd, 1998) [5].

2. Performance and Efficiency of Commonly used Aerators

Paddle wheel aerators outperformed the other three aerator types, including Venturi jet, Scorpion jet, and Wave surge, in terms of oxygen transfer and water circulation. The oxygen transfer rate of the aerators was higher at medium salinities than at low or high salinities, proving that the size of the aerators for prawn farming should change depending on the salinity of the water. (Jayanthi et al., 2021). In the Rectangular stepped cascade aeration system aeration efficiency is generally affected by the number of steps and hydraulic loading rate. Aeration efficiency decreases with the increase in hydraulic load and it increases with the number of steps of the aerator. The 3.0 m tall rectangular stepped cascade that may be designed using the best possible design criterion acquired from this study can be used as either a pre- or post-aeration unit (Moulick. S., 2010) [6]. The double-hub paddle wheel aerator's oxygen transport was equivalent to that of the single-hub paddle wheel. However, despite the geometric and dynamic parameters staying the same, a double-hub paddle wheel aerator uses more energy than a single-hub. As a result, the power consumption for the double hub significantly differed from that of the single-hub paddle wheel aerator. The highest SAE-producing dynamic condition for a single hub, N3d2= 2.7443682, is likewise relevant to the case of a double hub since the oxygen transfer simulation equation is identical in both cases. (Moulick. S., 2005). Small paddle wheel aerators made according to this design would be slightly less efficient in transferring oxygen to pond water than large wheel aerators commonly used in channel catfish ponds, but they would be more efficient than most other types of small aerators. (Michael et. al 1992) [7]. The newly installed paddle wheel was quite good, the sound of the motor was smooth, the flow range was longer, the coverage area was more expansive than the existing waterwheel and the DO and Oxygen saturation of the new waterwheel were better than the existing paddle wheel. (Nugroho et al 2021). Chaowann et al designed a standalone floating PV/BES-powered paddle wheel aerator to reduce the operating cost and enhance the power ratio of the paddle wheel aerator. The Optimal size of the PV/BES system was found to be 450 W. PV capacity and changing PV generation slightly affected LCOE (Chaowann, J et al. 2022).

3. Analysis Of Different Types Of Paddle Wheel Aerators

In this section operation and speculative analysis of some commonly used paddle wheel aerators have been discussed [8].

4. Theoretical Analysis

Many researchers like Eckenfelder in 1956, Horvath in 1977, and Zlokarnik in 1979 have presented the dimensional analysis of the aeration process. Moulick et al. in 2002 found that the absorption rate coefficient as denoted in his study as K_LA_{20} is the determining parameter of the absorption process. The expression for this parameter found in their study is

$$K_L A_{20} \times V = \frac{SOTR}{\Delta C}$$

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The overall oxygen transfer coefficient at 20°C, denoted as KLA20, and the oxygen deficiency (ΔC) at any given time are key parameters in aerator performance. The volume of water under aeration (V) and the standard oxygen transfer rate (SOTR) also play crucial roles. Achieving maximum standard aeration efficiency (SAE) requires careful consideration of factors such as the number of revolutions (N) and the diameter (d) of the paddle wheel to meet the desired SOTR. For example, to achieve a SOTR of approximately 10 kg O2/h, an input power (P) of 6.04 kW is needed. The equation for determining the paddle wheel diameter can be derived using the optimal power value and substituting it into the expression for the revolution of the paddle wheel [9]. Research indicates key parameters for paddle wheel aerators, including wheel diameter, paddle blade geometry, rotational speed, submergence depth, and power rating. Typically, paddle wheel diameters range from 50 to 90 cm, rotational speeds from 75 to 135 rpm, and submergence depths from 8 to 25 cm. Power ratings vary from 2 to 10 kW, depending on speed and depth. Different paddle wheel aerator models, such as the "Taiwanese" and "Japanese," exhibit [10] variations in Standard Aeration Efficiency (SAE). Performance losses have been noted in these models, and design parameters may not be optimal for other sizes of paddle wheels, as they do not account for variations in water volume under different conditions. It has been suggested that the power-volume ratio should fall between 0.01 to 0.04 kW/m3 [11].

5. Dimensional Analysis

Several factors influence the aeration process, such as water volume, paddle wheel characteristics (including diameter and blade size), and the presence of baffles in the aeration tank [12]. These factors need to be considered in their dimensionless form, often derived through dimensional analysis, to assess the performance of aerator systems effectively. When designing a paddle [13] wheel aerator, various variables must be accounted for, including geometric factors such as depth of submergence, blade breadth, bent angle, horizontal projection length, impeller pitch, water volume under aeration, blade length, and rotor diameter [14]. Material variables, such as air density, water density, oxygen diffusivity in air, water viscosity, and surface tension, also play a crucial role. Additionally, process variables like rotational speed, gravitational acceleration, blade revolutions, aerator runtime, and operational costs (including labor and electricity) must be considered in the design process [15].

6. Economic Analysis

Numerous aerator options have been introduced, yet selecting the most suitable one for farmers or stakeholders remains a significant challenge. Despite the availability [16, 17] of different aerator types in the market, affordability is a predominant issue. Both single-hub and double-hub paddle wheel aerators, as well as Cascade and Venturi aerators, require substantial capital investments, making them less accessible to farmers and small stakeholders. Additionally, operating costs vary based on factors such as pond volume and initial oxygen concentration of the water, with labor expenses being a major consideration. There is a pressing need for the development of cost-effective aerators that can minimize operating expenses, alongside advancements in automation technology [18].

Conclusion

Several aerators have been designed and developed so far starting from compact-sized aerators to large setup-type aerators [19]. Standard aeration efficiency and Standard oxygen transfer rate are great predictors for designing any type of aerator. These parameters vary from aerator to aerator. Inclusion of AI and Automation have been seen in various fields of science and agricultural science is also not an exception. But in the aquaculture field, there lacks these benefits of modern development. Capital investment is a concern but there is also a hindrance that cannot be overlooked while designing a novel aeration system which is its operating cost. With the development of mankind, there arises a surge in unemployment as well as a shortage of skilled labour. So labour cost is also increasing gradually with a deficit in demand of availability of labour. To alleviate such anomalies photo voltaic type aerators have been also developed [20]. However, it did not culminate in the addressed problem as its efficiency reduces during cloudy days. So there is an urgent need for the development of such type aerators that address these problems and also ensure that the aerator is accessible and affordable for small stakeholders and farmers [21].

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