Chronicle of Aquatic Science

https://chronicleofaquaticscience.in/

Chronicle of Aquatic Science
Open Access Peer Reviewed Journal
Vol. 1, Issue, 9

Popular Article
Tari et al. (2024)
Manuscript ID: CoAS_V1IS9_06

OPEN ACCESS

Enhancing Aquaculture Sustainability Through Nanobubble Technology: A Comprehensive Overview

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(Received- 26.02.2024, Revised- 27.02.2024, Accepted- 27.02.2024, Published:29.02.2024)

How to cite this article:

Tari, T. S. and Ramasre, J. R. 2024. Enhancing Aquaculture Sustainability Through Nanobubble Technology: A Comprehensive Overview. *Chronicle of Aquatic Science* 1(9): 38-42

ABSTRACT

Nanobubble technology has emerged as a promising tool in aquaculture to address key challenges related to water quality, oxygenation, and pathogen control. This study explores the applications and benefits of nanobubbles in aquaculture systems. Nanobubbles offer enhanced oxygen transfer efficiency, improved pathogen control through hydroxyl radical release, and effective removal of contaminants and pollutants. By optimizing aeration, nanobubbles contribute to maintaining optimal dissolved oxygen levels, reducing stress levels, and enhancing overall productivity in aquaculture operations. This paper highlights the potential of nanobubble technology to revolutionize aquaculture practices and promote sustainable growth in the industry. Additionally, nanobubbles have the potential to transport larvae transport and disinfect water, providing non-invasive methods to improve aquaculture practices. While further research is needed to address potential drawbacks and optimize application methods, nanobubbles hold immense promise for advancing sustainable aquaculture and ensuring global food security.

KEYWORDS

Aquaculture, Nanobubble, Oxygen Nanobubble, Fish health

Introduction:

In the twenty-first century, the fisheries and aquaculture industries have come to be acknowledged for their critical role in ensuring global food security and nutrition. From 1961 to 2019, global apparent consumption of aquatic foods increased at an average annual rate of 3.0 percent, almost twice as of annual world population growth (1.6 percent) for the same period (FAO, 2022). Capture fisheries have remained stagnant for the past few years, leading to more focus on aquaculture for the increasing demand. Because of limited land and aquatic resources, there is a focus on intensifying aquaculture. Dissolved oxygen is one of the most critical factors in intensive and superintensive cultures, limiting the stocking density. Lower concentrations of dissolved oxygen (DO) can impact on the ability of aquatic bodies to sustain biological entities. Low oxygen levels cause hypoxemia in fish while limiting nitrifying bacteria from breaking down organic waste. In aquatic organisms, maximum growth occurs when the dissolved oxygen (DO) content is almost at saturation. Therefore, increasing the concentration of DO is of primary concern, and increasing the dissolved oxygen level of water has been a focus of research. Numerous factors, such as diet and water quality, affect the health of aquatic organisms, where dissolved oxygen governs the overall health of aquatic animals. An increase in dissolved oxygen (DO) increases the fish's metabolic rate, which in turn increases its growth rate. Researchers are actively working to enhance water quality parameters by employing various aeration strategies. Various biotic and abiotic factors, like photosynthesis, respiration, diffusion, etc., affects the concentration of oxygen in the water. The solubility of oxygen is affected by factors like temperature, atmospheric air, and water pressure. The traditional concept of aeration includes agitating the water surface, allowing the atmospheric oxygen to dissolve into the topmost layer of the water, or diffusing the gas in the form of bubbles. The size of the bubbles affects the solubility of oxygen in the water. Large bubbles rise to the surface more quickly than smaller bubbles because they have high buoyancy, giving less time for the dissolution of oxygen.

Nano bubble technology includes creating bubbles of less than 100nm in size to increase the efficiency of the dissolution of oxygen. This helps to increase the density of fish without affecting the quality of the water. Furthermore, it helps to alleviate the negative effects of pathogens on fish. Nanobubbles also have higher dissolving efficiency than conventional methods. The oxygen dissolving efficiency in the nanobubble is 85 percent, which is significantly higher than that of conventional aeration by over three times. This technology has various applications, not only in aquaculture, but also in other sectors like sewage treatment plants, agriculture, chemistry, medicine and industry.

Characteristics of Nano Bubble:

The nanobubble's modest size is what gives it its special qualities. They have properties closer to colloidal particles than bubbles in terms of their longevity, negative surface charge, low buoyancy and high gas solubility. Due to their low buoyancy, nanobubbles are capable of diffusing oxygen into the ambient water at a gradual rate. The size of nanobubbles is extremely small; it provides a larger surface area for the diffusion of oxygen. Nanobubbles in water exhibit Brownian motion and can remain in the water for a longer period of time. Nanobubbles have been shown to have a lifespan ranging from a few hours to several months. Due to their small size, they have a high surface area-to-volume ratio and an internal pressure higher than the surrounding pressure. According to electrostatic forces, zeta potential is a physical property that quantifies the strength of the attraction or repulsion of molecules and bubbles. The longevity of nanobubbles in the system is determined by their properties. Nanobubbles typically carry a net electrical charge on their surface. Zeta potential arises from the potential difference between the surface charge of nanobubbles and the surrounding liquid. A higher zeta potential indicates strong electrostatic repulsion between nanobubbles, which avoids aggregation and increases the lifespan of nanobubbles. Lower zeta potential may cause the aggregation and eventual coalescence of nanobubbles.

Methods for nanobubble production:

The production of nanobubbles heavily relies on the pressure and velocity of the liquid. There are three main processes for producing nanobubbles: pressure, dissolution, and electrolysis. Gas-liquid and wave-pressure methods are widely used methods.

Gas-liquid pressure method:

It includes pressurizing a gas-liquid mixture to induce the formation of nanoscale bubbles within the liquid. Gas is introduced into a liquid under high pressure conditions in a pressurised camber. The pressure is suddenly released to convert supersaturated gas in liquid form into nanobubbles due to the rapid expansion and decrease in solubility of gas in liquid. This technique is controlled to produce bubbles of the required size.

Wave-pressure Method:

It involves utilizing wave energy for the formation of nanobubbles. Ultrasound transducers generate oxygen molecules in water by compressing and rarefying acoustic waves. Due to this, covalent bonds in water break to form a tiny gas bubble containing hydroxyl free radicals, which act as antipathogens. This method is usually used for eradicating algae.

Electrolysis:

In this method, bubbles are created by sampling and passing an electric current through a liquid medium. Electrodes made of platinum or titanium are utilized. When electric current is passed through the electrodes, the formation of bubbles takes place at the electrodes due to the electrolysis of water and dissolved gases. By controlling the current, it is possible to control the size of the bubble.

Nanobubbles in Fish Culture:

Nanobubbles are used in aquaculture to optimise dissolved oxygen levels. Nanobubbles have been shown to increase oxygen levels from 6.5 to 25 mg/l in a short period of time. Comparative studies conducted by Mauladani et al. (2020) showed that when white leg shrimp (*Litopenaeus vannamei)* were stocked at a density of 400 shrimp/m^2 in 800 m^2 HDPE ponds, one with nanobubble treatment and another without nanobubble, the shrimp showed a survival rate of 92% in nanobubbles as compared to 75% in shrimp without nanobubble treatment. The results showed that the nanobubble treatment outperformed diffuser-type aeration in terms of results. In particular, there were improvements in feed conversion ratio, overall harvest, productivity, and survival rate with the nanobubble treatment. Furthermore, fewer overall pathogens were present after using the nanobubble aeration approach. Nanobubbles also help in reducing the ammonia and CO_2 levels in the water. It is also very economical compared to conventional aerators and has a payback period of 1.5 years.

Nanobubbles in larval transport:

There are two methods of fish transport: closed and open. In practical applications, oxygen-filled polythene bags and water tanks with supplied air or oxygen are used. However, transportation over long- distances causes mortality in larvae. Nanobubbles can be used to increase the survival rate of the larvae during transportation. It also helps to reduce the stress levels and keep the water oxygenated. Combining nanobubbles with activated charcoal also increases the survival rate as charcoal absorbs the carbon dioxide produced. The nanobubble treatment had a highly significant effect, and the interaction of both had a highly significant effect on the survival rate of prawn seeds after 24Hrs.

NB in Fish Health Management:

In aquaculture, oxygen nanobubbles are generally used to increase the oxygen concentration and promote the growth of aquatic animals. Oxygen nanobubbles keep the system aerated, thereby preventing the growth of anaerobic bacteria. They have also been shown to increase the attachment of bacteriophages to the fish. However, nanobubble technology also has applications in closed and open circulating aquaculture systems towards controlling the growth of facultative and anaerobic microbes, regulating dissolved oxygen levels, disinfecting water, and consequently, promoting the rapid growth of species. Methods like UV used in the disinfection of water have the major disadvantage that they require clear water for their disinfection. Shadowing causes this phenomenon. When water contains a lot of suspended solids or sediments, it blocks the UV rays from reaching the microorganisms. As a result, pond cultures cannot utilize it. Using ozone nanobubbles is the same as using the conventional method of using ozone, just as nanobubbles provide higher solubility. Ozone nanobubbles, however, have been found to be effective at reducing concentrations of pathogenic bacteria in water and modulating fish immunity against pathogens. A 10-minute treatment with ozone nanobubbles has been shown to reduce bacteria in Nile tilapia culture (Jhunkeaw et al., 2021).

Impact of nanobubbles on fish physiology:

For aquatic organisms, the respiratory system plays a critical role in defining their physiological condition. When the size of nanobubbles in the water is less than 0.2 micrometres, aquatic organisms undergo branchial and cellular respiration. They can still diffuse from the skin to the underlying tissue, even when the pores in the skin have shrunk dramatically. Tissues absorb large amounts of nanobubbles to support branchial and cellular respiration. The nanobubbles' rising temperature within the tissue causes the blood vessels to expand and increases the flow of oxygen to the gills. This is essential for the proper physiological functioning of the fish. Thus, nanobubbles have a positive impact on the fish.

Conclusion:

Nanobubble technology provides a groundbreaking solution to address key challenges in aquaculture, particularly regarding dissolved oxygen levels, pathogen control, and water quality management. With their unique characteristics and versatile applications, nanobubbles offer unprecedented opportunities to enhance fish culture efficiency, improve survival rates, and promote overall aquatic health. Further research is necessary to refine application methods and mitigate potential drawbacks, but the undeniable benefits of nanobubbles for sustainable aquaculture remain. By harnessing this innovative technology, we can pave the way for a more resilient and productive aquaculture industry.

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