The Role of Nanobubble Aeration in Improving Aquaculture Productivity

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Abstract

Nanobubble technology is an innovative approach that enhances dissolved oxygen levels in aquaculture, wastewater treatment, and other industries. This study explores the role of nanobubbles in improving aquaculture productivity by optimizing oxygenation, reducing disease outbreaks, and increasing survival rates. Nanobubbles, less than 100 nm in diameter, exhibit high stability and solubility, making them more efficient than traditional aeration methods. Various production techniques are discussed, including gas-liquid pressure, wave pressure, and electrolysis. Applications in aquaculture include fish culture, live fish transport, and health management, where nanobubbles significantly improve fish growth, water quality, and pathogen control. Additionally, their use in wastewater treatment enhances pollutant removal through oxidation and flotation processes. Despite their potential, challenges such as high initial costs and optimization issues remain. Future research should focus on scaling up commercial applications, improving generation techniques, and integrating nanobubble systems with smart monitoring technologies for sustainable implementation.

Introduction

Aquatic organisms raised in a regulated environment as a sustainable food source for human consumption are also known as aquaculture. This has a significant role in decreasing the strain on natural ecosystems from overfishing and is beginning to get recognition on a global scale for its environmental benefits. Despite the decline of capture fisheries, aquaculture is now seen as a vital solution to satisfy the growing international demand for fish (FAO, 2019). Today, it stands as one of the fastest-growing industries globally. In fact, in 2018 alone, the world produced a record 214 MMT of fisheries and aquaculture products, with 87.5 million tons coming specifically from aquaculture (FAO, 2022). As land and water resources become scarce, technologies to increase aquaculture production are becoming increasingly important. Dissolved oxygen is one of the most significant factors in intensive and super-intensive aquaculture systems, affecting stocking density directly. The aquatic ecosystem cannot support life anymore when oxygen levels fall. Fish suffer from hypoxemia (low oxygen in their blood), and nitrifying bacteria cannot effectively break down organic waste, degrading water quality. Maximum growth in aquatic organisms occurs when the dissolved oxygen (DO) concentration is optimum. Many aspects can impact aquatic species' lives, such as good nutrition and water quality; one of the aspects is dissolved oxygen. Higher Dissolved Oxygen (DO) increases the metabolism rate of the fish, which in turn improves the growth rate of fish. Therefore, the enhancement of DO concentration in water has become a key research focus in increasing the oxygen level in water. Several biological and non-biological factors affect the solubility of substances in aquatic environments. Respiration, photosynthesis, and diffusion are examples of these processes through which DO remains dynamically soluble. Gas solubility is determined in addition to the temperature of water, surrounding air, and water pressure; these factors depend on each other and are naturally kept at equilibrium. Consequently, the DO levels continue to decline below the desirable condition, which is dangerous to the ecology of the aquatic environment. The aeration technology indicates innovation in the water aeration field, suggesting attempts to remedy the pond's toxic status. According to the general belief, 70% of all gas injected into water diffuses into the atmosphere. However, bubbling gas, or disturbing the water surface, to enable atmospheric oxygen to diffuse into the water surface layer are among the conventional aeration techniques. The amount of oxygen diffusion to water depends on the size of the bubbles. Larger bubbles have increased buoyancy properties, allowing them to reach the surface quicker than smaller bubbles and minimizing the time oxygen can be dissolved in the water. Nanobubble technology is a novel method that has been widely studied and proposed to improve the oxygenation level in intensive aquaculture. This helps stock fish with more stocking density without degrading the pond environment and reduces disease impact. Nanobubble technology is three times more effective than conventional techniques by 85% oxygen dissolving efficiency. Apart from Aquaculture, this technology has a wide range of applications, including sewage treatment, agriculture, medicine, and other industries.

Fundamentals of Nano Bubble Technology

The International Organisation for Standardization (ISO) says that Bubbles less than 100 nm in diameter are called nanobubbles and are also referred to as fine bubbles. These nanobubbles are physically stable compared to macro and micro bubbles because they are neutrally buoyant, hence remaining in the water for some days. The bubble's surface area to volume ratio increases exponentially, producing adequate oxygen solubility in the water column. When submerged in water, nanobubbles move in a Brownian motion and have a longer half-life. Nanobubbles have been demonstrated to have a lifetime of a few hours to many months. They have a high surface area-to-volume ratio and internal pressure that is more significant than ambient pressure because of their tiny size. Zeta potential is a physical characteristic that measures how strongly molecules and bubbles are attracted to or repelled by one another in accordance with electrostatic forces. The characteristics of the nanobubbles in the system dictate how long they last. On their surface, nanobubbles usually have a net electrical charge. The potential difference between the surface charge of nanobubbles and the surrounding liquid causes zeta potential. Strong electrostatic repulsion between nanobubbles, which prevents aggregation and lengthens their longevity, indicates a more significant zeta potential. Nanobubbles may aggregate and eventually coalesce as a result of lower zeta potential.

Methods for nanobubble production:

The Nano bubble production system depends significantly on the pressure and velocity of the liquid. When the velocity of the gas increases, its internal pressure decreases, which impacts the bubble relationship. The NB production system can be divided into three main processes: pressure, dissolution, and electrolysis. Cavitation actions are commonly observed using gas-liquid and wave-pressure methods. The gas-liquid method involves introducing a substantial liquid or gas pressure into a gas-liquid medium to produce NBs. Below are the details of the NB production methods.

Gas-liquid pressure method

This process involves pressurizing a gas-liquid mixture to create nanoscale bubbles within the liquid. Gas is introduced into the liquid under high-pressure conditions in a pressurized chamber. When the pressure is suddenly released, the supersaturated gas in the liquid converts into nanobubbles due to rapid expansion and the subsequent decrease in the gas's solubility in the liquid. This technique is precisely controlled to produce bubbles of the desired size.

Wave-pressure Method

This technique involves using wave energy to create nanobubbles. Ultrasound transducers generate oxygen molecules in water by compressing and rarefying acoustic waves. This process breaks covalent bonds in the water, forming tiny gas bubbles containing hydroxyl free radicals that act as antipathogens. This method is commonly used to eradicate algae.

Electrolysis

In this process, bubbles are generated by passing an electric current through a liquid medium. Electrodes made from platinum or titanium are used. When the electric current flows through these electrodes, bubbles form at the electrodes due to the electrolysis of water and dissolved gases. By adjusting the current, the size of the bubbles can be controlled.

Applications of Nano Bubbles in Fisheries

Fish Culture

`Nanobubbles play a crucial role in aquaculture by optimizing dissolved oxygen levels, rapidly increasing them from 6.5 to 25 mg/l. According to a study by Mauladani *et al*., (2020), white leg shrimp (*Litopenaeus vannamei*) stocked at a density of 400 shrimp/m² in 800 m² HDPE ponds exhibited a 92% survival rate with nanobubble treatment, compared to a 75% survival rate without it. The study demonstrated that nanobubble treatment outperformed diffuser-type aeration, resulting in improved feed conversion ratios, higher overall harvests, increased productivity, and better survival rates. Additionally, the nanobubble approach reduced the presence of pathogens, ammonia, and CO_2 levels in the water. Economically, nanobubble aerators are more cost-effective than conventional aerators.

live fish transport

Various studies on fish transportation methods indicate that using proper aeration systems and pretreated water, like nanobubble oxygen, significantly enhances fish health and lowers mortality rates during transport. Traditional methods often led to higher mortality due to inadequate aeration. Experiments have shown that using oxygen supplements, especially in nanobubble form, and carbon dioxide sedation can make long-distance transport more efficient and safer for the fish, with some methods increasing survival rates and fish quality by up to four times compared to regular water.

Fish Health Management

In aquaculture, oxygen nanobubbles increase oxygen concentration and promote aquatic animal growth by keeping systems aerated and preventing anaerobic bacteria growth. They also enhance bacteriophage attachment to fish. Nanobubble technology is effective in both closed and open aquaculture systems for controlling microbial growth, regulating dissolved oxygen levels, disinfecting water, and promoting rapid species growth. Unlike UV disinfection, which requires clear water and is ineffective in pond cultures with suspended solids, ozone nanobubbles offer higher solubility and do not face such limitations. Ozone nanobubbles (NB) have shown promise in aquaculture by increasing dissolved oxygen (DO) levels and reducing bacterial populations. Research on Nile tilapia (*Oreochromis niloticus*) by Linh *et al*., (2021) found that NB-ozone (NB-O_3) treatment enhances immune gene expression, potentially preventing infections. Jhunkeaw *et al*., (2020) demonstrated thatsss NB-O_3 protects tilapia from harmful pathogens, reducing bacterial counts by 99.29%. Both studies indicate that NB-O_3 technology can improve fish health and prevent diseases in aquaculture systems.

Fish physiology:

The respiratory function in aquatic species is central to their overall physiological state, involving cellular and branchial respiration. The presence of nanoscale bubbles (NB) in water, specifically below 0.2 micrometers, plays a crucial role in this process. These tiny bubbles can diffuse through the skin into underlying tissues, significantly aiding cellular and branchial respiration. The stress on fish due to low dissolved oxygen (DO) levels in the water triggers catecholamine release, causing elevated plasma cortisol and increased heart rate and gill function, which may still be inadequate to meet the body's oxygen needs. Under extreme conditions, NB behavior includes explosive bursting, which assists blood vessel expansion and oxygen delivery to the gills. Integrating NB technology has a positive impact, enhancing physiological functions such as respiration, blood purification, and the excretion of toxins, thereby supporting the overall health of aquatic species.

Applications in Waste Water Treatment

Nanobubbles offer a highly efficient approach to wastewater treatment due to their superior gas transfer, enhanced oxidation, and improved flotation capabilities. They significantly boost ozonation by increasing ozone dissolution, making disinfection, dye degradation, and heavy metal oxidation more effective. In flotation and dissolved air flotation (DAF), MNBs improve the removal of oil, grease, and heavy metals by enhancing particle attachment. Additionally, MNB aeration provides higher dissolved oxygen levels, supporting microbial activity in biological treatment, while their ability to generate reactive oxygen species (ROS) aids in breaking down pollutants. With their sustainability and efficiency, MNBs present a promising alternative to conventional wastewater treatment methods, though further research is needed for large-scale optimization.

Environmental Impact and Sustainability

In aquaculture, nanobubbles enhance dissolved oxygen levels, reducing fish stress, improving survival rates, and minimizing disease outbreaks. Their slow rising velocity and high oxygen dissolution efficiency contribute to maintaining optimal water quality, reducing the need for artificial aeration and antibiotics. This not only improves fish health but also supports sustainable seafood production. Nanobubble (NB) technology has emerged as an innovative and sustainable solution for wastewater treatment and aquaculture, significantly reducing environmental impact. By enhancing gas transfer efficiency, NBs improve oxidation, flotation, and aeration processes, leading to better pollutant removal without relying on excessive chemical treatments. Their ability to generate reactive oxygen species (ROS) further aids in breaking down organic contaminants, making wastewater treatment more energy-efficient and eco-friendly.

Challenges and Future Direction

Nanobubble technology significantly benefits aquaculture by improving water quality, oxygen levels, and fish health. However, challenges such as limited knowledge of long-term effects, high initial costs, and optimization of application conditions hinder its widespread adoption. Additionally, its effectiveness varies across species, and its interactions with microbial communities and pollutants need further study. Future research should focus on scaling up commercial applications, improving nanobubble generation methods, and exploring its use in other sectors like wastewater treatment and hydroponics. Standardizing measurement protocols and integrating nanobubble systems with smart monitoring technologies will enhance efficiency. In conclusion, while nanobubble technology is promising for sustainable aquaculture, addressing technical and economic challenges is crucial for its broader implementation.

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