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Experimental Research on a Gas Liquid Mixing Oxygen Increasing Device based on Microbubbles

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ABSTRACT

With the development of large-scale and high-density aquaculture, higher requirements have been put forward for the effectiveness of water oxygenation. In response to the problems of low oxygenation efficiency and high energy consumption of oxygenation devices on the market, a new type of oxygenation device was designed based on the theory of microbubble generation technology, and its oxygenation performance was studied through clear water oxygenation experiments. The experimental results show that under the action of microbubbles, the oxygenation device has the best oxygenation effect when the water flow rate and oxygen flow rate are 2.4m3/h and 0.4L/min, respectively. After adding oxygen to clean water with an initial oxygen concentration of 5.3mg/L through the device, the oxygen concentration increased to 11.2mg/L, reaching a supersaturated state. The oxygen absorption rate was 41.2%, and the oxygenation capacity was 6.68kg/h. Compared to traditional oxygenation machinery, under the premise of achieving the same oxygenation effect, the oxygenation time is shorter, effectively improving the oxygenation efficiency.

KEYWORDS

Oxygen Increasing Device; Microbubble; Oxygen Absorption Rate; Oxygenation Performa.

1. INTRODUCTION

China is a major aquaculture country in the world. With the progress of science and technology, as well as the industrialization and scale development of the aquaculture industry, many breakthroughs have been made in aquaculture technology. The application of various mechanical oxygen increasing devices has greatly promoted the development of the industry. Under the current aquaculture model, increasing the dissolved oxygen content in water is a prerequisite and key to ensuring the normal growth of aquatic organisms. Low concentrations of dissolved oxygen can bring high mortality rates to aquaculture objects. One of the most effective measures to increase the dissolved oxygen content in water is to use an oxygenation device to oxygenate the water.

Traditional oxygenation devices include water jet aerators, water wheel aerators, and impeller aerators. These devices have a large body size that is not conducive to transportation and installation, and most of them have problems such as high energy consumption and low oxygenation efficiency. They require frequent maintenance and repair, greatly increasing manpower and labor time. Therefore, exploring advanced and novel mechanical oxygenation technologies is of great practical significance for promoting sustainable and healthy development of aquaculture, improving aquaculture yield and quality. In recent years, experimental studies both domestically and internationally have shown that the dissolved oxygen content of water can be increased by generating a large number of microbubbles [1]. Microbubbles have the characteristics of large specific surface area , slow buoyancy rate, high gas solubility, and high mass transfer efficiency. Therefore, microbubbles can stay in water for a long time, increasing the exchange time between oxygen and water, thereby greatly improving the efficiency of oxygenation and improving water quality.

This article is based on the theory of microbubble generation technology, integrating the concepts of air jet and gas-liquid mixing pump shear technology, and designs a new type of oxygenation equipment. Using this as the research object, the oxygenation performance of the equipment and the influence of gas-liquid flow rate on the oxygenation performance of the equipment were studied through clear water oxygenation experiments.

2. PRINCIPLE OF MICROBUBBLE GENERATION

In nature, the generation of bubbles is very common, and various shapes and sizes of bubbles can be generated through methods such as being subjected to liquid shear force, liquid electrolysis, filling the liquid with gas, and injecting ultrasound. When a gas moves in a liquid, when it is subjected to a certain degree of shear force from the liquid, the bubble will split multiple times to form small bubbles, known as microbubbles [2].

The use of microbubble aeration in aquaculture has the function of increasing oxygen, which not only increases the dissolved oxygen at the bottom, but also provides sufficient supply of dissolved oxygen in the entire aquaculture environment as the bubbles slowly rise and float; On the other hand, microbubbles can also bring harmful substances such as hydrogen sulfide and ammonia nitrogen out of the water surface, comprehensively improving the water environment [3]. Therefore, the research on microbubble generation technology has brought new research ideas to the oxygenation technology in the current industrial aquaculture field, and has profound research significance. At present, according to the foaming mechanism and method, the existing microbubble generation technologies can be divided into dissolved gas release type, air jet type [4], electro analytical release type [5], gas-liquid mixing pump shear type, etc.

In order to solve the problems of poor foaming quality and low oxygenation efficiency in traditional aerators, a large amount of research has been conducted both domestically and internationally. Chang Hun Lee et al. [6] studied the Venturi structure aerator based on the air jet technology and obtained a considerable number of tiny bubbles. The results showed that the size of the microbubbles generated by this structure depends on the flow rates of air and water; Seok Yun Jeon et al. [7] proposed a microbubble pump with a regenerative pump impeller, and experimentally studied the relationship between the bubble size generated by the microbubble pump and the intake flow rate and pump pressure; Yun Shuai et al. [8] designed a jet impact microbubble generator. When the diameter of the baffle is greater than the jet width at the nozzle position, an impact zone and a radial wall jet zone will be formed, thereby promoting the generation and diffusion of microbubbles. The above research provides new research ideas for the development of microbubble generation technology in the future.

Based on the preliminary research of microbubbles, this article proposes a new type of oxygenation equipment by integrating the technology of air jet and gas-liquid mixing pump shear in the device design. The working principle of the air jet system mainly utilizes the turbulent shear effect generated by the high-speed gas-liquid flow, which causes the deformation and splitting of bubbles and the generation of microbubbles.

3. TEST EQUIPMENT

3.1. Device Structure Based

on the principle of microbubble generation, the designed oxygenation device structure is shown in Figures 2 and 3, mainly including centrifugal pump, Laval pipe, intake pipe, water pipe, reflux oxygenation pipe, gas-liquid mixing tank, pry body, etc.

3.2. Working Principle

This device undergoes three rounds of bubble crushing during operation to fully reduce bubble size and improve oxygenation efficiency. (1) Gas liquid collision and fragmentation: The basic structure of microbubbles formed at the pump outlet of a centrifugal pump based on the principle of causing jet flow is shown in Figure 4. The liquid phase is introduced horizontally, while the gas phase is introduced by an embedded Laval tube perpendicular to the liquid phase pipeline. The two collide and shear into the pump chamber at the pump port. The Laval tube can change the velocity of the passing airflow due to changes in cross-sectional area, accelerating the airflow from subsonic to supersonic. In the figure, QG represents gas flow rate, and QL represents liquid flow rate.(2) Centrifugal pump shear crushing: After the bubbles enter the pump chamber with the water flow, they are sheared by the high-speed rotation of the impeller. A large number of liquid droplets in the pump chamber rotate at high speed with the impeller and continuously collide with the surrounding gas molecules, further crushing the bubbles. The bubbles disperse in the water and form a bubble flow from the pump outlet into the gas-liquid mixing tank.

4. EXPERIMENTAL RESULTS AND ANALYSIS

Using clear water oxygenation experiment to detect and study the oxygenation capacity of the device, factors affecting the oxygenation performance of the device, oxygen utilization rate, etc., in order to comprehensively evaluate the oxygenation performance of the device.

4.1. The influence of Gas-liquid Flow Rate on the Oxygenation Performance of the Device

The initial oxygen concentration of the test water at room temperature was measured to be 5.3mg/L, and the water temperature was 27 ℃. The experiment used liquid flow rates of 1.8m^3/h, 2.4m^3/h, and 3m^3/h to explore the effects of liquid flow rate and oxygen flow rate on the oxygenation performance of the device. The experimental results are shown below:

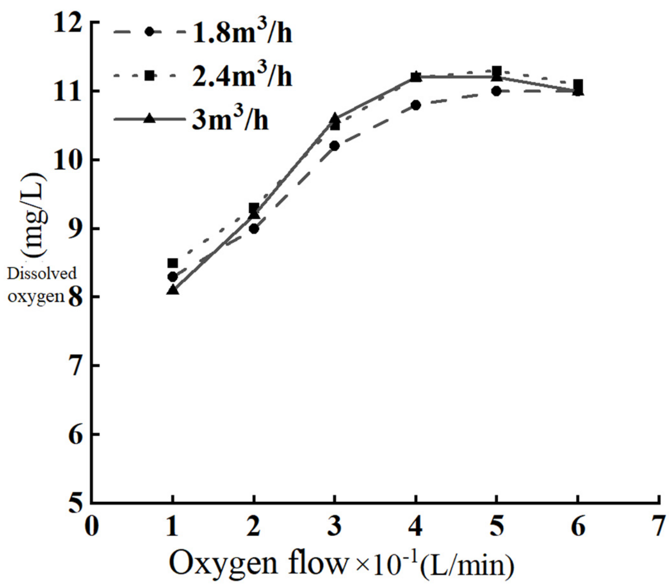

Figure 1. Changes in dissolved oxygen with liquid flow rate and oxygen flow rate

From Figure 1, it can be seen that the oxygen flow rate and liquid flow rate have a certain influence on the dissolved oxygen effect of the device. When the flow rates of both are large, the dissolved oxygen effect is good. This is because the larger the flow rate, the greater the impact force of the gas-liquid phase, which is conducive to the breaking of bubbles and increasing the dissolved oxygen content. But when the flow rate increases to a certain value, the dissolved oxygen slightly decreases. This may be because as the gas flow rate increases, the number density of microbubbles in water increases, and the probability of bubble aggregation increases, which can easily form large bubbles and affect the oxygenation effect; As the liquid flow rate increases, the contact time between bubbles and water becomes shorter, and there is no time to effectively mix with water, which will also affect the oxygenation effect to a certain extent.

4.2. The Impact of Different Combinations on the Oxygenation Performance of the Device

To further explore the oxygenation effect of the experimental device, several different combinations were adjusted on the basis of the original experimental device for comparative testing. Combination 1: On the basis of the experimental device, remove other pipelines and only use the centrifugal pump impeller to stir the mixed gas and liquid; Combination 2: Close the reflux oxygenation pipeline valve on the basis of the experimental device; Combination three: On the basis of the experimental device, remove the Laval tube and open the valve of the reflux oxygenation pipeline; Combination 4: Original structure of the experimental device. For ease of expression, the above structures are numbered A, B, C, and D in sequence, and the experimental conditions are selected at water and oxygen flow rates of 2.4m^3/h and 0.4L/min, respectively.

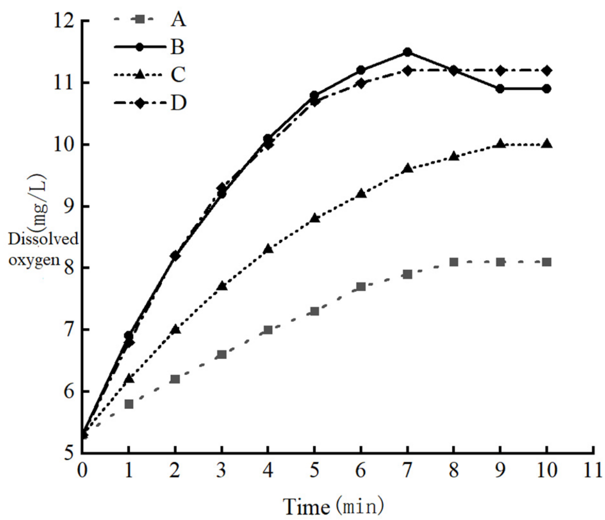

Figure 2. Oxygen enhancement performance of devices under different combinations

From Figure 2, it can be seen that A has the lowest dissolved oxygen content, followed by C. The dissolved oxygen content of B and D has significantly increased compared to A and C, but the difference between the two is not significant. At 7 minutes, the highest dissolved oxygen level of B is greater than D. After 7 minutes, the dissolved oxygen level slightly decreases, and finally the highest dissolved oxygen level is less than D. The following conclusions can be drawn from the analysis: The ability to increase oxygen in the mixed gas-liquid mixture is limited by relying solely on the impeller of the centrifugal pump. After removing the Laval tube, the maximum dissolved oxygen has significantly decreased compared to the original device. It can be seen that after oxygen is accelerated through the Laval tube and enters the pump, the liquid is collided with the accelerated gas, and the huge shear force generated by the two helps to break the bubbles. After closing the valve of the reflux oxygenation pipe, the maximum dissolved oxygen increased slightly compared to the original device, but after a period of time, the dissolved oxygen slightly decreased and finally decreased below the maximum dissolved oxygen of the original device. This is because as oxygen is continuously inhaled, there may be insufficient gas-liquid mixing in the device, leading to the formation of large bubbles. It can be seen that the reflux oxygenation tube can transport oxygen that is not completely dissolved in water back to the intake pipe, preventing excessive gas volume from affecting the gas dissolution effect.

4.3. Performance Comparison Based

on the results of the clear water oxygenation test of the oxygenation device, taking into account the oxygenation effect and economic benefits, it was determined that the best effect was achieved at a water flow rate of 2.4m^3/h and an oxygen flow rate of 0.4L/min, respectively, with a dissolved oxygen content of 11.2mg/L.

4.3.1. Oxygen Utilization Rate

According to the principle of material balance, the oxygen utilization rate P is[9]:

$$P = \frac{Q_1\left(DO_2 - DO_1\right)}{\left(1.43 \cdot Q_2\right)}$$

In the formula: Q1- water flow rate, m3/h; Q2- Oxygen flow rate, L/min; DO1- dissolved oxygen in water during oxygen input, mg/L; DO2- dissolved oxygen in water when outputting oxygen, mg/L; Oxygen bulk density -1.43kg/m3; The initial dissolved oxygen in water is 5.3mg/L, and the calculated P=41.3%.

4.3.2. Oxygen Increasing Ability

Oxygen mass transfer coefficient at any water temperature:

$$K_{La}\left(T\right) = \frac{\ln\left[\left(C_S - C_1\right)/\left(C_S - C_2\right)\right]}{t_2 - t_1}$$

In the formula, T - test water temperature, ℃; Cs - saturated dissolved oxygen value of test water, mg/L; Dissolved oxygen values at C1, C2-t1, t2, mg/L; Reading time of t1, t2-C1, C2, min; According to Figure 4, numbered D, it can be calculated that KLa (27)=27.5 (min-1)

Oxygen mass transfer coefficient at standard water temperature:

$$K_{La}\left(20\right) = \frac{K_{La}\left(T\right)}{1.024^{T-20}} = 23$$

Oxygenation capacity:

$$Q_S = K_{La}\left(20\right) \times V \times C_S \times 10^{-3} \times 60$$

In the formula, V - volume of test water, m3; The saturated dissolved oxygen value at a water temperature of Cs ≈ 20 ℃ is 0.6 m3 in this experiment. The saturated dissolved oxygen value at 20 ℃ is 7.96mg/L, and Qs=6.68kg/h can be calculated. it can be seen that the oxygenation capacity has been significantly improved compared to traditional oxygenation machinery such as impeller and water wheel.

5. CONCLUSION

This article designs a new type of oxygenation device based on the current situation of aquaculture in China, and studies the oxygenation performance of the device under different working conditions and structures through clear water oxygenation experiments. The experimental results show that:(1)

The oxygenation performance of this device is affected by the gas liquid flow rate. When the oxygen flow rate and liquid flow rate increase, the dissolved oxygen content increases. If it continues to increase to a certain value, the dissolved oxygen content actually slightly decreases. Taking into account both the oxygenation effect and economic benefits, the optimal dissolved oxygen effect of this device is that the liquid flow rate and oxygen flow rate are 2.4m3/h and 0.4L/min, respectively.(2) The use of Laval tubes can effectively improve the dissolved oxygen effect; The effect of the reflux oxygenation pipeline on the dissolved oxygen is not significant, but it can to some extent reduce the size of bubbles. Closing the valve of the reflux oxygenation pipeline will result in a slightly lower maximum dissolved oxygen value than opening the valve.(3) This oxygenation device has a significant oxygenation effect. At water flow rates of $2.4m^3/h$ and oxygen flow rates of 0.4L/min, the experimental water with an initial oxygen concentration of 5.3mg/L increased to 11.2mg/L after being oxygenated by the device. The dissolved oxygen concentration doubled compared to the initial value, exceeding the saturated dissolved oxygen value at 27 ℃ and reaching a supersaturated state. The calculated oxygen utilization rate was 41.3%. Compared to traditional oxygenation machinery, under the premise of achieving the same oxygenation effect, its oxygenation time is shorter, effectively reducing energy consumption and improving oxygenation efficiency.

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