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Experimental Investigation on the Effect of Disc-shaped Microporous Aeration Tube Configuration on the Waste Collection Efficiency in Circular Aquaculture Tanks

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Abstract: The proper configuration of aeration equipment is crucial for maintaining a healthy hydrodynamic environment and efficient self-cleaning in circular Recirculating Aquaculture Systems (RAS). While disc-shaped microporous aeration tubes are widely used in commercial tanks, their optimal layout for solid waste removal remains under-researched. This study systematically investigated the effects of aerator layout position (different quadrants and radial distances of 1/2r, 3/4r, and r), aerator quantity, and air intake volume on waste collection efficiency. Using solid waste substitutes and video analysis, the time required for complete particle removal was quantitatively evaluated. The results demonstrate that placing the aeration disc on the side opposite the water inlet yields the optimal waste collection performance, improving efficiency by approximately 60% compared to other locations. Radially, placements closer to the tank center (1/2r) significantly outperformed near-wall positions, which tended to push waste to accumulate at the tank boundary. Furthermore, under a constant total air supply, reducing the number of aerators enhanced the initial mobilization of waste particles. However, increasing the air intake volume excessively disrupted the primary circulating flow field, which is vital for waste transport, ultimately leading to a deterioration in overall collection capacity. It is therefore recommended to position disc-shaped aerators opposite the water inlet and closer to the center in circular RAS tanks, while strictly controlling the air intake to balance oxygenation and hydrodynamics. These findings provide practical, data-driven guidelines for aquaculture practitioners to optimize aeration configurations and enhance self-cleaning efficiency.

Keywords: Disc-shaped aeration tube; RAS; Waste collection efficiency; Layout optimization; Bubble plume

1. Introduction

With the growth of the global population and economic development, the demand for high-protein aquatic products is continuously increasing, making the aquaculture industry a crucial sector for meeting this need [1]. However, traditional aquaculture models are often accompanied by issues such as environmental degradation and resource waste, which has prompted the development of the Recirculating Aquaculture System (RAS)[2]. RAS employs advanced circulating water treatment technology, effectively reducing water consumption during the farming process and lowering the risk of water pollution.

In RAS, oxygenating the aquaculture tank is essential for maintaining the healthy growth of cultured organisms; currently, the mainstream oxygenation methods include pure oxygen and aeration [3]. Microporous aeration technology is gaining increasing attention from RAS practitioners due to its advantages of low energy consumption and simple installation [4-5]. Consequently, microporous aeration tubes have gradually become one of the most common oxygenation devices in these systems. Currently, the majority of research regarding microporous aeration tubes focuses on how factors like pore size, air intake volume, installation depth, temperature, and impurities in the water affect aeration performance [6-7]. In the design of circulating aquaculture tanks, the bottom is frequently utilized for the collection and discharge of solid waste [8]. Since microporous aeration tubes are also installed at the tank bottom, their placement inevitably affects the tank's waste collection performance.

In earlier studies, Groves evaluated the impact of diffuser types and layouts on oxygen transfer, demonstrating that grid layouts exhibit higher oxygen transfer efficiency than spiral configurations [9]. This conclusion was highly significant during the early development of RAS, enabling designers and operators to use accurate oxygen transfer data to make aeration systems as energy-efficient as possible, thereby significantly reducing overall facility energy costs. More recently, Du used CFD technology to study the effects of different shapes of microporous aeration tubes on sewage collection and aeration performance in rectangular aquaculture tanks [10]. Their results indicated that a four-corner aeration tube layout maximizes sewage collection efficiency in rectangular tanks, while distributed diffusers provide the best aeration performance. Although this study innovatively combined sewage collection and aeration performance with the layout shapes of microporous tubes, its focus remained on sewage collection and oxygenation efficiency, without addressing solid waste removal and water mixing.

In summary, previous studies have not addressed comprehensive research regarding the impact of microporous aeration tubes on the waste collection and water mixing performance of circular recirculating aquaculture tanks. This specific area remains a gap in the literature, unable to provide sufficient theoretical support for the current development of the aquaculture industry. Therefore, this study utilizes the disc-shaped microporous aeration tube, the most common type in commercial RAS, to analyze how differences in layout position, layout quantity, and air intake volume inevitably affect the tank's waste collection performance.

2. Materials and Methods

2.1 Water Circulation System

The experimental apparatus, as shown in Fig. 1, mainly consists of an aquaculture tank, a water circulation system, a water and gas flow measurement system, and an image/video acquisition system.

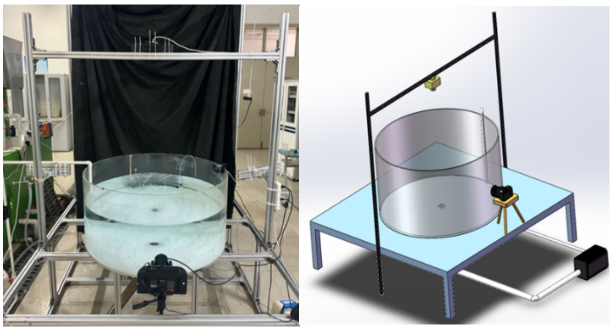
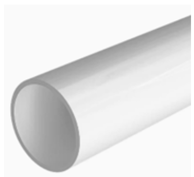
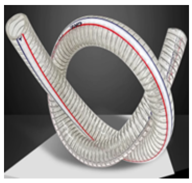


Figure 1: Photography (left) and Schematic Diagram (right) of the Circular Recirculating Aquaculture System.

The circular recirculating aquaculture tank is made of transparent acrylic. It was designed with reference to existing commercial RAS tanks and scaled down proportionally. The tank has a radius of r=50 cm and a wall height of h=50 cm, resting on a frame constructed from spliced aluminum profiles. To ensure clear image capture, a white film was laid at the bottom of the tank.

The water circulation system is powered by a water pump (Yafeng YF-9220, 40W), which provides sufficient power to meet the tank's water circulation needs. It drives the water flow throughout the system, ensuring effective circulation. PVC pipes (outer diameter 20 mm) are used due to their excellent corrosion resistance, long lifespan, and relatively low cost. Water is discharged from the waste collection port at the bottom of the tank and connects to the pump via a steel wire reinforced pipe, chosen for its good pressure resistance and durability. The pump then sends the water back into the inlet pipe, forming a closed-loop water circulation system. A valve is installed on the water pipe; adjusting this valve controls the water flow velocity and intake volume to accommodate different aquaculture requirements. The inlet velocity is critical for maintaining the stability of the farming environment.

Table 1: Water Circulation System Components and Functions.

Component	Specifications	Function	Photography
Water Pump	Yafeng YF-9220, Power: 40W	Drives water flow, ensures effective circulation from the tank	
PVC Pipe	Outer diameter 20 mm	Transports water; corrosion-resistant with a long lifespan	
Steel Wire Pipe	Outer diameter 40 mm	Ensures unobstructed water flow from the tank to the pump	

Valve	Inner diameter 40 mm	Maintains a stable aquaculture environment	

The flowmeter (KEYENCE FD-Q20C) used in this experiment is installed outside the inlet pipe; it does not require direct contact with the fluid, thereby preventing any impact on the flow rate and avoiding pressure loss. It provides real-time monitoring of the inlet flow (L/min) entering the aquaculture tank, and a valve on the water pipe controls this inlet flow.

Figure 2: Schematic Diagram of the Ultrasonic Flowmeter.

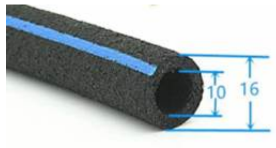
An ultrasonic clamp-on flowmeter is a device used to measure liquid flow velocity inside a pipe by utilizing the propagation characteristics of ultrasonic waves. Its primary advantage is easy installation; sensors are mounted externally, meaning there is no need to cut the pipe or halt fluid flow. The device typically uses the time-difference method, functioning as follows: the flowmeter has a pair of ultrasonic sensors acting as a transmitter and a receiver. These are installed outside the pipe, either diametrically opposed or diagonally. They alternately emit and receive ultrasonic pulses. When a pulse travels in the direction of fluid flow (downstream), its speed is faster than in still fluid; when it travels against the flow (upstream), its speed is slower. The flowmeter calculates the time difference between the downstream and upstream propagation times, which is directly proportional to fluid velocity. Based on this velocity, the pipe's cross-sectional area, and fluid properties (like density), it calculates the fluid flow rate.

2.2 Microporous Aeration System

The aeration system consists of an aeration pump, aeration tubes, quick-connect tees, quick-connect ball valves, a gas flowmeter, and aeration inserts. Nano microporous aeration tubes are cut to various lengths based on different operating conditions and connected to quick-connect tees. The tee's branch pipes regulate and distribute the gas flow. The main gas pipe connects to a quick-connect ball valve to adjust the target flow rate, which is then measured by a flowmeter (Keyence FD-V40).

Table 2: Aeration System Components and Functions.

Component	**Specifications**	**Function**	**Photography**

Aeration Pump	Model: LP-100, Power: 100W, Flow: 140 *L*/min	The power source of the system; provides necessary power to ensure air is effectively pushed into the system.	
Nano Microporous Tube	Outer dia: 16 mm, Inner dia: 10 mm	Key equipment for generating fine bubbles; can be cut to different lengths as needed.	
Quick-Connect Tee	Tube outer dia: 12 mm	Connects and distributes aeration lines; branches regulate airflow for even distribution.	
Quick-Connect Ball Valve	Tube outer dia: 12 mm	Device for precisely controlling airflow volume.	
Aeration Insert	10mm	Installed according to requirements.	

2.3. Waste Collection Experiment Process

The waste collection experiment primarily investigates the impact of different operating conditions on the tank's waste collection capacity, analyzed through the spatial distribution of waste at different times and the total time required for discharge. Davidson et al. quantified tank self-cleaning capacity by introducing sinking feed into the water and using a stopwatch to measure the time it took for the solid feed to exit the tank.

The experimental procedure is illustrated in Fig. 3 and follows these steps:

(1) Adjust the designed experimental conditions (tune the aeration tube layout and the inlet flow rate).

(2) Adjust the water level in the tank and activate the water circulation system. After waiting 30 min to reach a stable state, turn on the camera and quickly drop the solid waste substitutes into the tank using a fixed-position funnel (Fig 3).

(3) Monitor the solid waste removal process visually. The maximum monitoring time is set to 20 min. If the solid waste is not completely discharged after 20 min, halt the experimental system. Alternatively, if removal is completed within 20 minutes, the trial is stopped immediately upon completion.

(4) Analyze the solid waste removal process using the captured images.

(5) Record for the full 20 min or until completion, turn off the camera, save the video data, and

prepare for the next set of trials.

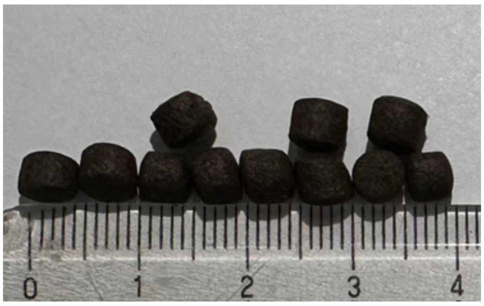


Figure 3: Solid Waste Substitute (length 5 mm, diameter 4 mm, density 1.3 g/cm3).

3. Results

3.1 Aeration Tube Layout Position

For the different layout position conditions, assuming a single tube air inlet, the experiments were divided into three sections: the upper side, the right side, and the lower side (with the left side serving as the water inlet). For each side, three positions—1/2r, 3/4r, and near the wall—were investigated to explore the impact of layout placement on the waste collection performance of the circular tank.

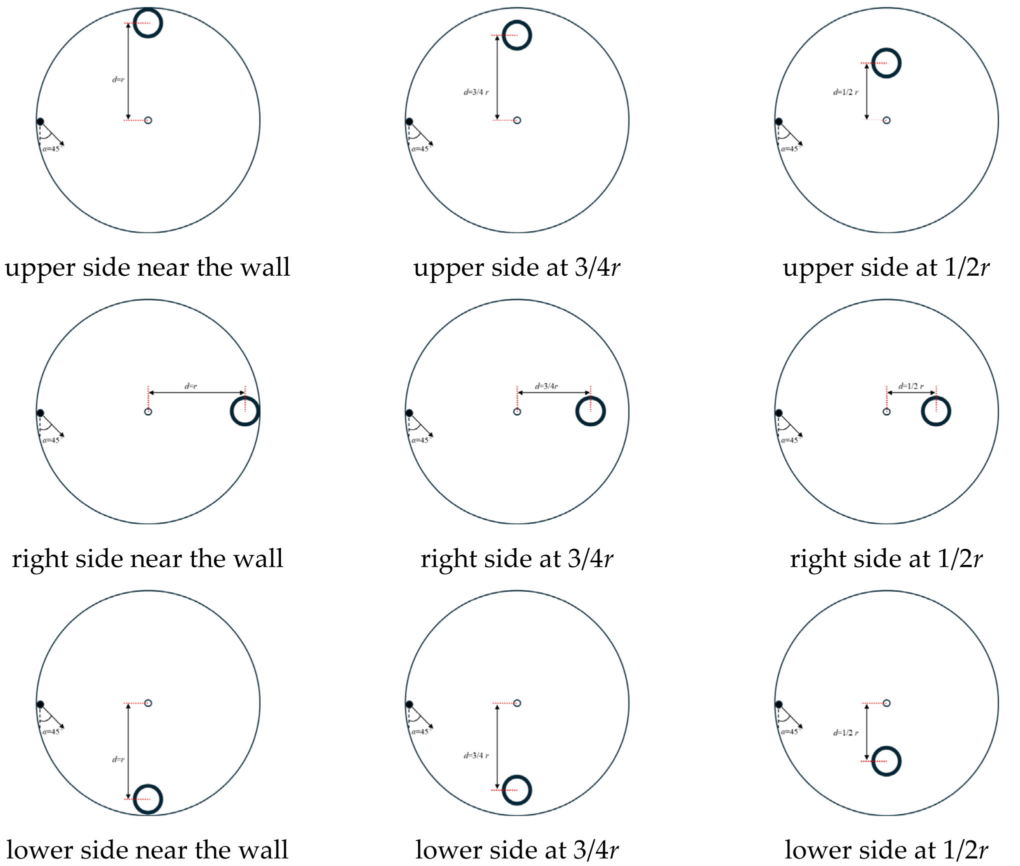
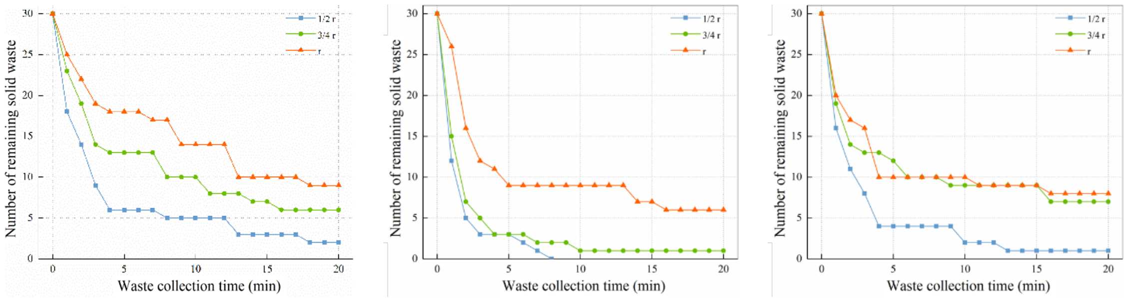


Figure 4: Schematic Diagram of Different Layout Positions of Disc-shaped Aeration Tubes.

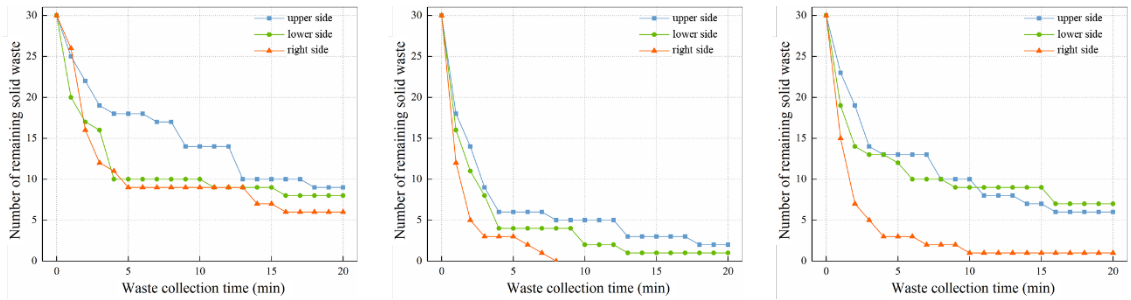
In this study, to accurately assess collection efficiency under different operational conditions, we utilized a video recording method to observe the gathering process of suspended matter in the water. By recording these processes in detail, we could precisely determine the time required to collect waste under varying aeration tube configurations. These times are crucial metrics for measuring collection efficiency, directly reflecting the speed and effectiveness of suspended matter removal. Subsequently, based on the video analysis, we compiled and calculated the required collection times for each condition, detailed in the table below. This data provides an intuitive method to compare the specific impacts of different aeration tube configurations on collection efficiency.



upper side right side lower side

Figure 5: Comparison of Disc-shaped Aeration Tubes in Different Quadrant Positions.

As seen in the figures above, regardless of which side the aeration tube is placed on, the 1/2r position consistently completes waste collection first and yields the best results. This indicates that the closer the aeration tube is to the center of the tank, the less it disrupts the primary flow field, minimizing negative impacts on collection capacity and resulting in optimal waste gathering.



near the wall at 1/2*r* at 3/4*r*

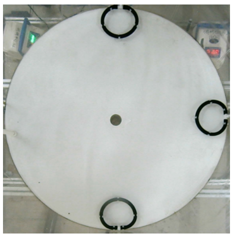
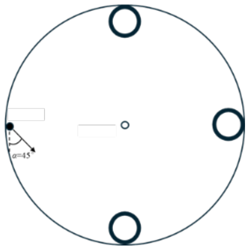
Figure 6: Comparison of Disc-shaped Aeration Tubes at Different Radial Positions.

Regarding the different side positions, the collection effect on the right side is significantly superior to the other two sides. This is because the right side is located directly opposite the water inlet. The lower side is too close to the inlet, preventing the formation of an effective flow field. The upper side is too far from the inlet, resulting in lower velocity and a flow field that is too stable to effectively gather waste. In contrast, the right side, being opposite the inlet, benefits from optimal flow velocity and field structure, granting it the strongest waste collection capacity.

3.2. Aeration Tube Quantity

Adjusting the number of aeration tubes alters the characteristics of the bubble plume and significantly increases dissolved oxygen levels; however, excessively dense bubbles may disturb internal water flow patterns, negatively affecting pollutant gathering efficiency. To understand in detail how aeration tube quantity impacts collection capacity, the following experimental scheme was designed.

Table 3: Aeration Tube Quantity Conditions.

	Number of tubes	Photography	Schematic diagram
Effect of aeration tube quantity on waste collection efficiency	2		
	3		

To isolate the variable of tube quantity, when measuring the effect of 2 inlet tubes, the tube on the right side was deactivated. The upper and lower tubes operated simultaneously with an air intake of 3.3 L/min each, totaling 6.6 L/min. For the 3-tube condition, all three operated simultaneously with an intake of 2.2 L/min each, maintaining the same total intake of 6.6 L/min. The results are shown below.

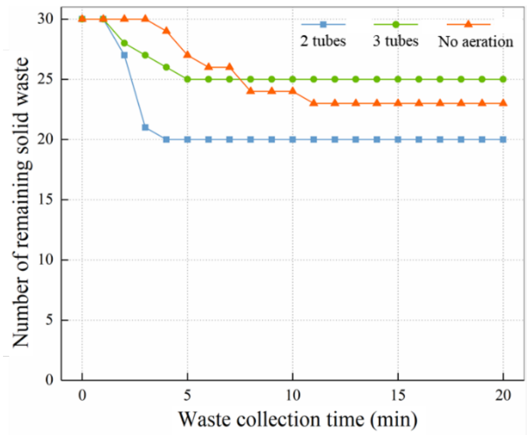


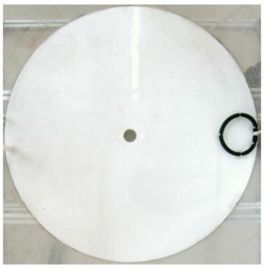
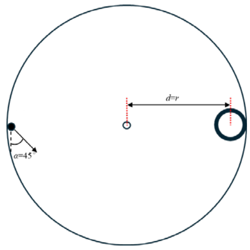
Figure 7: Variation of Remaining Waste Particles with Time Under Different Tube Quantities.

The figure shows that, under the premise of a consistent total air intake volume, reducing the number of aeration tubes increases the individual intake volume per tube, thereby improving the collection effect. This acts as an initial starting mechanism for the waste particles. However, an excessively large air intake volume per tube can cause severe disruption to the flow field, which lowers the tank's waste collection capacity. Therefore, provided the air intake of a single aeration tube is not high enough to aggressively destroy the flow field, reducing the total number of tubes effectively improves the tank's self-cleaning capability.

3.3. Aeration tube air intake volume

Changing the air intake volume alters the bubble plume's characteristics and significantly raises dissolved oxygen levels, but excessive intake will destroy the original water flow field, leading to poor waste collection. To explore this impact, the following experiment was designed:

Table 4: Air Intake Volume Conditions

	Air intake volume	**Photography**	**Schematic diagram**
Effect of air intake volume on waste collection efficiency	3.3 *L*/min		
	5.0 *L*/min		
	6.6 *L*/min		

Ensuring the aeration tube length and position remained constant, the right-side placement was selected. A 40 cm long aeration tube was coiled into a disc shape and placed near the wall to test the effects of varying air intake volumes on waste collection.

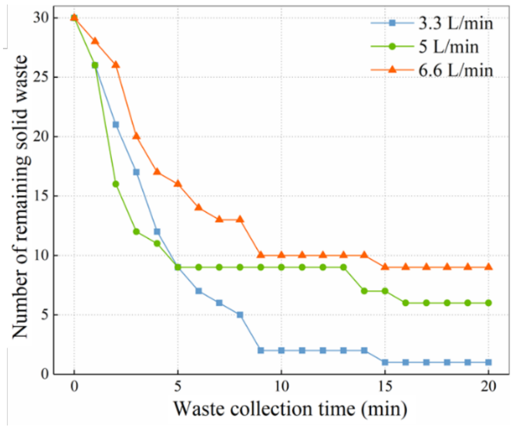
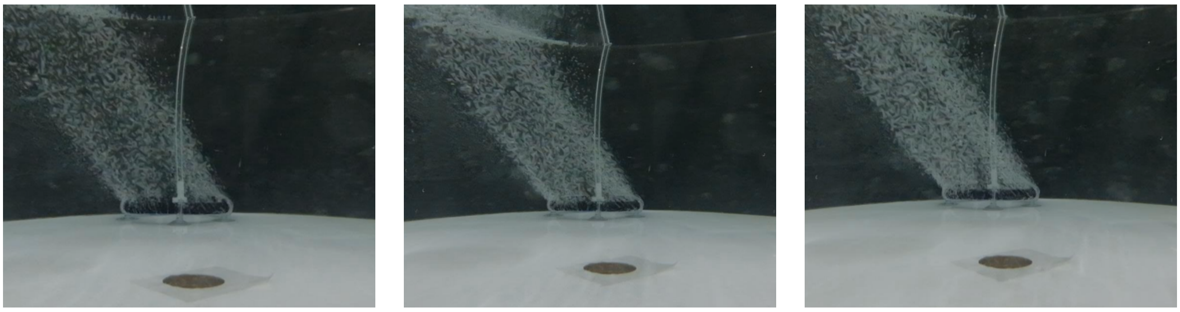


Figure 8: Variation of Remaining Waste Particles with Time Under Different Intake Volumes.

A larger air intake volume results in higher gas velocity, which exerts a stronger destructive force on the flow field. Although higher intake helps activate stubborn, hard-to-move waste initially, it simultaneously causes massive disruption to the circulating flow field. Because a healthy flow field is directly and positively correlated with waste collection capacity, increasing air intake ultimately deteriorates flow conditions and reduces collection efficiency.



Q = 3.3 *L*/min Q = 5.0 *L*/min Q = 6.6 *L*/min

Figure 9: Bubble Plume Comparison Under Different Intake Volumes (Q = 3.3, 5.0, and 6.6 *L*/min).

4. Conclusion

This study conducted an in-depth exploration of the waste collection capacities of disc-shaped aeration tubes against various configuration parameters (position, quantity, and air intake volume). Through a series of detailed experimental trials, we determined the best placement positions and clearly defined the impact trends for aeration tube quantity, and air intake volume.

Experimental analysis revealed that placing the aeration disc on the side directly opposite the water inlet achieves optimal waste collection efficiency, improving performance by approximately 60% compared to other side locations. Further observation indicated that if the aeration tube is placed too close to the tank wall, collection efficiency drops. This is likely because near-wall aeration pushes a portion of the waste to accumulate directly against the boundary wall, hindering effective gathering. Conversely, an aeration tube positioned closer to the center of the tank efficiently activates surrounding waste, drawing it into the internal circulation system for successful discharge. Thus, a layout positioned opposite the inlet and closer to the center yields the best self-cleaning results.

Regarding the number of aeration tubes, research shows that when total air intake volume is kept constant, reducing the number of tubes increases the air volume per individual tube, thus improving initial waste movement and overall collection. However, system designers must note that overly large individual air volumes will excessively destroy the primary flow field.

Finally, regarding air intake volume, while high intake somewhat aids in mobilizing stubborn waste for discharge, it heavily disrupts the flow field. Because a stable flow field is positively correlated with waste collection efficiency, continuously increasing the air intake ultimately degrades the hydrodynamic environment, resulting in lowered collection capacity.

In summary, the findings of this study not only provide crucial theoretical support for the design of aeration systems in RAS tanks but also offer specific, practical guidance for operational optimization in the aquaculture practices.

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