Design and component simulation study of a hydraulic razor clam seedling dispensing device

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Abstract. Razor clams are a type of economically farmed shellfish widely cultivated in China's coastal areas. Currently, seedling dispersion is still done manually, which requires high labor intensity and incurs high costs. To address this issue, this paper designs a hydraulic razor clam seedling dispensing device and conducts simulation studies using Fluent software to investigate the effects of flow rate ratio q, area ratio m, and the diffusion angle β of the diffusion tube on the pressure ratio h and efficiency η. With the goal of optimizing seedling dispersion efficiency, the optimal parameters for the jet pump were determined. Under the conditions of a flow rate ratio of 0.03, an area ratio of 2, and a diffusion angle of 8°, the simulated seedling dispersion efficiency was found to be 9.60%. A test bench was set up, and bench tests were conducted. The results showed that the actual measured efficiency of the device was 10.40%, with a deviation between the simulated and actual values of 8.33%. The simulation model established in this paper is essentially consistent with actual conditions, providing a reference for the design and improvement of hydraulic seedling dispensing devices.

Keywords: Razor clams, Seedling dispensing device, Annular jet pump, Fluent

1. Introduction

Razor clams are deliciously flavored and are extensively cultivated in coastal areas of our country [1], with a production reaching 847,600 tons and a cultivation area of 42,800 hectares in 2022 [2]. Currently, razor clam cultivation relies on manual seedling dispersion during the spring and autumn seasons, characterized by harsh working conditions, low efficiency, poor uniformity, and high labor costs, urgently necessitating a mechanized razor clam seedling dispensing device.

Scholars both domestically and internationally have conducted numerous studies on seeding and jet pumps. Wang Yongmei et al. [3] replaced the straight-groove wheel with a spiral-groove wheel, which cushions the seed group and increases the uniformity of seed distribution. Gai Miaomiao et al. [4] designed a guide-type horizontal disc precision seeder that takes full advantage of the long seeding stroke of the horizontal disc seeder. A guide groove formed by a guide plate on the outer side of the mold hole was designed to achieve orderly seeding of multiple seeds. Liu Chunbo et al. [5] studied the correlation between the seed discharge shaft's rotational speed and the seeding amount, and conducted experiments on the impact of spiral angle on seeding uniformity, the impact of the opening degree of the spiral seed discharge wheel on the seeding amount, and the impact of rice seeds on the seeding amount. Internationally, the development of seeding machinery in agriculturally advanced countries such as the United States, the United Kingdom, and Germany has been the main focus [6]. The United States has successfully developed a series of seed filling with both type-hole discs and round-hole discs. Italy improved the suction holes on the seed discharge disc into pedestal shapes, enhancing seed fluidity, reducing the probability of friction between seeds and the seed discharge disc, and decreasing the variability among seeds. Elger et al. [7] analyzed the situation of jet pump placement under different areas and concluded that the formation of the recirculation zone is closely related to the momentum ratio. Gazzar et al. [8] used CFX-TASC to simulate the flow characteristics inside the pump. Shimizu et al. [9] found through experiments that annular jet pumps have advantages over central jet pumps in terms of performance and structure. Kwon et al. [10] based on numerical simulations, determined that the pump efficiency of the annular jet pump is highest when the suction chamber's contraction angle is 12°. Yamazaki et al. [11] established through research that the relationship between energy loss and surface roughness is linear.

This paper designs an annular jet-type razor clam seedling dispensing device based on the technical requirements for tidal flat razor clam seedling cultivation, establishes a three-dimensional model of the device, optimizes the parameters of the jet pump through Fluent simulation, and verifies the accuracy of the simulation results through experiments.

2. Design of a Hydraulic Razor Clam Seedling Dispensing Device

2.1. Overall Structure of the Hydraulic Razor Clam Seedling Dispensing Device

The razor clam seedling dispensing device designed in this paper is shown in Figure 1. When in operation, the device is placed on the water surface and manually propelled. It mainly includes a hopper, frame, trough wheel falling mechanism, jet pump, DC motor, etc. The surfaces of the hopper, trough wheel falling mechanism, and premix chamber are wrapped in a flexible material to prevent the seedlings from being damaged upon impact. The hopper is fixed to the trough wheel falling mechanism, the upper end of the falling mechanism is connected to the hopper, and the lower end is connected to the premix chamber. The DC motor is securely mounted on the frame, and the jet pump is fixed to one side of the overall device alongside the water pipe through a rack. During seeding, the razor clam seedlings are poured into the hopper, the DC motor is powered on, and the seedlings, under the effect of their own gravity, enter the premix chamber through the falling mechanism. Inside the premix chamber, under the effect of the internal fluid, they are taken into the jet pump and finally sprayed into the designated area, completing the seeding process as shown in Figure 2.

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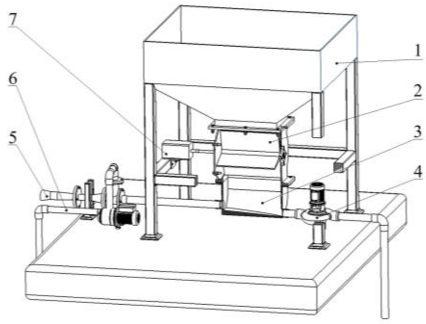

Figure 1. Overall Structure Diagram of the Seedling Dispensing Device (1. Hopper 2. Trough Wheel Falling Mechanism 3. Premix Chamber 4. Centrifugal Pump 5. Jet Pump 6. Inlet Pipe 7. DC Motor)

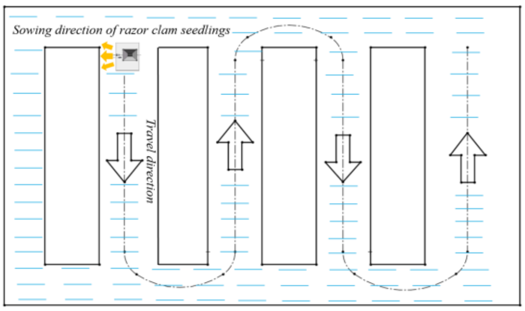

Figure 2. Schematic Diagram of the Seeding Operation

2.2. Jet Seeding Mechanism Design

The jet seeding mechanism primarily consists of a nozzle, suction chamber, throat tube, and diffusion tube, with the three-dimensional model shown in Figure 3. The nozzle of the annular jet pump is placed at the inlet pipe of the sucked fluid, creating an unobstructed channel throughout the pump body, suitable for conveying a mixture of razor clam seedlings and water [12], providing conditions for hydraulic transportation.

During seeding, the mixture of razor clam seedlings and water is the sucked fluid, while high-pressure water serves as the working fluid. When high-pressure water rapidly passes through the suction chamber, a negative pressure is generated between the suction chamber and the nozzle, extracting the mixture of water and seedlings. After being ejected from the nozzle, the mixture passes through the throat tube and is then sprayed out through the diffusion tube.

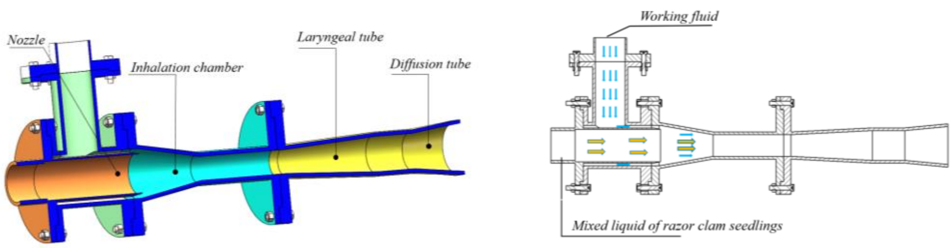

Figure 3. Three-Dimensional Diagram of the Jet Pump

When using a jet pump for seeding, it is essential to ensure that the razor clam seedlings can pass through the nozzle and throat tube; otherwise, it would cause blockage, making seeding impossible. Therefore, based on the above operational conditions, an annular jet pump structure was designed with specific dimensions and structure as shown in Table 1.

Table 1. Specific Dimensions of the Jet Pump

Main Structure	Dimensions
Inlet Diameter	33mm
Contraction Angle	7°
Seedling Entrance Diameter	33mm
Nozzle Diameter	16mm
Suction Chamber Length	103mm
Throat Tube Diameter	20mm
Diffusion Angle	7°
Diffusion Tube Diameter	37mm
Total Length	455mm

3. Fluent Simulation Optimization

3.1. Experimental Design

(1) Mesh Division

The mesh division adopts an automated method, requiring a higher density of mesh in complex stress areas. Therefore, the mesh size was chosen to be 3mm, as shown in Figure 4. The average quality of the mesh division is 0.84, with the lowest quality displayed in the mesh quality assessment panel being 0.27. The best quality of the mesh is 1, indicating that the mesh division quality is good when the average mesh quality is greater than 0.7.

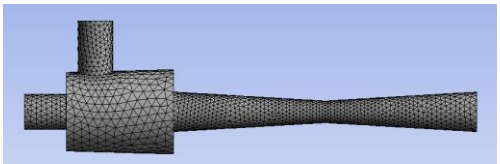

Figure 4. Jet Pump Mesh Diagram

(2) Boundary Conditions

Both the working fluid and the sucked fluid inlets of the jet pump are set as velocity inlets, the outlet is set as a pressure outlet, and the remaining boundaries are set as no-slip walls. The inlet flow rates for both the water inlet and seedling inlet are set, increasing from 1m/s to 5 m/s, with an increment of 0.5 m/s; the flow rate of the water-seedling mixture is fixed at 0.5 m/s.

3.2. Results Analysis

The pressure ratio h is the ratio of the jet pump pressure to the working pressure, and the efficiency η is the ratio of the useful power obtained by the pumped fluid to the power expended by the working fluid. Both reflect the changes in energy within the pump and the impact of the main components on the performance of the jet pump. Therefore, the pressure ratio h and efficiency η of the jet pump are used as evaluation indicators to measure the relationship curves between the flow rate ratio q, diffusion angle β, area ratio m, and pressure ratio h, efficiency η.

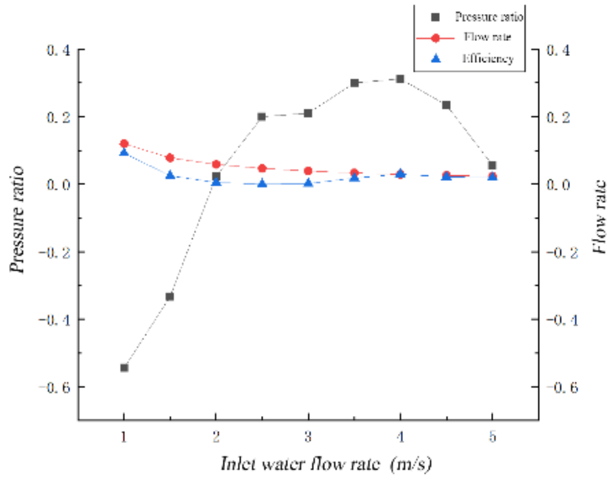

Figure 5. Relationship between Flow Rate Ratio *q* and Pressure Ratio, Efficiency

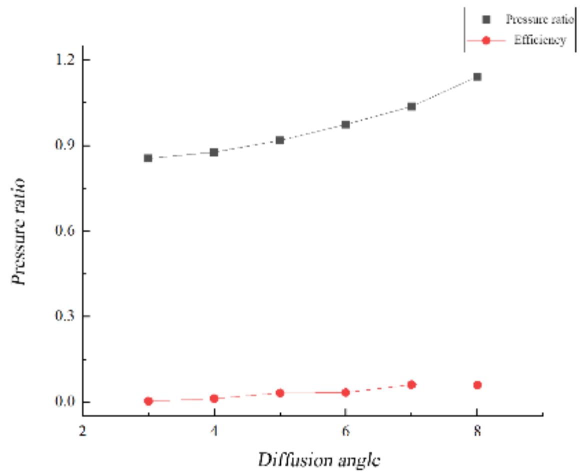

Figure 6. Relationship between Diffusion Angle β and Pressure Ratio, Efficiency

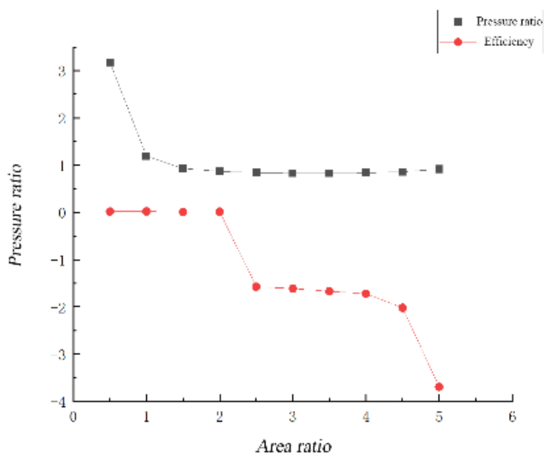

Figure 7. Relationship between Area Ratio *m* and Pressure Ratio, Efficiency

From Figure 5, it is known that the flow rate ratio decreases with an increase in the working fluid's velocity, eventually stabilizing, with a maximum value of 0.12. The pressure ratio shows a trend of first increasing and then decreasing with the increase in water flow velocity (working fluid) at the inlet, with a maximum value of 0.31 at around 4m/s. Efficiency shows a trend of first increasing and then decreasing with the increase in working fluid velocity, with a maximum value of 3% at around 4 m/s.

From Figure 6, with the inlet flow velocity set at 4m/s and the flow rate ratio set at 0.03, as the diffusion angle increases, the pressure ratio shows a gradual increasing trend, reaching a maximum value of 1.14 at a diffusion angle of 8°. Efficiency increases with the increase of the diffusion angle, with a maximum value of 9.60% at a diffusion angle of 8°.

From Figure 7, with the inlet flow velocity set at 4m/s and the flow rate ratio set at 0.03, as the area ratio increases, the pressure ratio shows a decreasing trend, with a maximum value of 3.18 at an area ratio of 0.50. Efficiency decreases with the increase of the area ratio, with a maximum value of 1.58% at an area ratio of 2.

The above three sets of experiments conducted a Fluent fluid dynamics simulation study on the relationship between the flow rate ratio, diffusion angle, area ratio, pressure ratio, and efficiency in the structure of the jet seeding pump. It was found that when the working fluid velocity is 4m/s, the flow rate ratio is 0.03, the diffusion angle is 8°, and the area ratio is 2, the efficiency of the jet pump can reach 9.60%, which can meet the actual production needs.

3.3. Experimental Verification

To validate the operational performance of the designed razor clam seedling dispensing device, a jet seeding mechanism was fabricated based on simulation results and subjected to seeding experiments. The experimental setup and process are shown in Figure 8. The experiment was conducted on September 7, 2023, at the Innovation Workshop of Dalian Ocean University. The day of the experiment was clear and windless, and the razor clam seedlings used were of the specification 4800 seedlings/kg. During the experiment, the seedling dispensing device was fixed to the ground, and the working water pressure was set to 10Mpa. The experiment was repeated three times. The results show that the efficiency of the jet pump can reach 10.40%, and the furthest scattering distance can reach about 2.5m, meeting the operational requirements for seeding.

Figure 8. Experimental Components and Effects

4. Conclusions

(1) The flow rate ratio decreases with an increase in the velocity of the working fluid, reaching a maximum value of 0.12. The pressure ratio increases and then decreases with an increase in the working fluid, reaching a maximum value of 0.31; at this point, efficiency increases and then decreases with an increase in the velocity of the working fluid, reaching a maximum of 3%. When the flow rate ratio is set at 0.03, the larger the diffusion angle, the greater the pressure ratio, with a maximum value of 1.14 at a diffusion angle of 8°; at this point, efficiency increases with an increase in the diffusion angle, reaching a maximum of 9.60%, also at a diffusion angle of 8°. With the flow rate ratio set at 0.03, as the area ratio increases, the pressure ratio shows a decreasing trend, with a maximum value of 3.18 at an area ratio of 0.50; efficiency decreases with an increase in the area ratio, reaching a maximum of 1.58% at an area ratio of 2.

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(2) The efficiency of the jet pump for the razor clam seeding device during testing was 10.40%, with a deviation from the simulation results of 8.33%, indicating that the finite element simulation analysis method can be used for the design and parameter optimization of the razor clam seeding device. The designed razor clam seeding device can provide a reference for the mechanization and scale development of the shellfish industry.

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