RESEARCH AND EXPERIMENT ON EFFICIENT MIXING MODES OF DIFFERENT FORMS OF WATER AND FERTILIZER
/
不同形态水肥高效混合模式研究与试验

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ABSTRACT

This paper proposes a fertilizer mixing device that combines pressure relief return and mechanical agitation to address the issues in the current water-fertilizer integration equipment related to limited fertilizer mixing methods and inconvenient irrigation pressure regulation. The device employs different mixing modes for various fertilizer forms and uses pressure relief return to adjust irrigation pressure, thereby enhancing the efficiency of water-fertilizer mixing and optimizing energy consumption. The experimental results indicate that the reflux mode is suitable for liquid-type fertilizers which are fast dissolving and easy to diffuse, and its EC value is stable at about 6.60 mS/cm, which is close to the calibrated value of 6.80 mS/cm. The stirring paddle mode compensates for the reflux mode's weak mixing effect, making it suitable for solid powder-type fertilizers' mixing operation. The EC value remains stable at approximately 8.60 mS/cm when calibrated at 8.70 mS/cm. The "stirring paddle + two-way reflux" mode demonstrates the most robust mixing effect and is suitable for mixing solid granular fertilizers. When calibrated at 8.20 mS/cm, it stabilizes at approximately the calibration value after 105 s. This research provides technical support and a theoretical basis to accomplish efficient, energy-saving, and rational application of water-fertilizer integration across diverse fertilizer forms.

摘要

本文提出了一种泄压回流与机械搅拌相结合的混肥装置，旨在解决水肥一体化设备在混肥方式和灌溉调压方面存在的问题。该装置针对不同形态的肥料采用不同的混肥模式，通过泄压回流调节灌溉压力，提高水肥混合效率和能源利用效率。试验结果表明，回流模式适合溶解快、易扩散的液态型肥料，其 EC 值稳定在 6.60mS/cm 左右，与标定值 6.80mS/cm 接近。搅拌桨模式弥补了回流模式混肥作用较弱的缺点，适合固态粉末型肥料的混肥作业，当标定值为 8.70mS/cm 时，EC 值稳定在 8.60mS/cm 左右。"搅拌桨+双向回流"模式混肥作用最强，适合固态颗粒型肥料的混肥作业，当 EC 标定值为 8.20mS/cm 时，经过 105s 稳定在标定值左右。该研究为实现不同形态肥料的水肥一体化合理、高效、节能应用提供了技术支撑和理论依据。

INTRODUCTION

Water-fertilizer integration equipment is extensively used in agricultural production. Its principle involves mixing fertilizer and water and delivering the mixture to the crop roots area through drip irrigation equipment, thereby conserving both water and fertilizer (*Kapoor et al., 2022; Singh et al., 2023*). Efficient integration of water and fertilizer is a prerequisite for integrated irrigation and fertilizer application. A reliable and efficient fertilizer mixing device is thus an important guarantee for effective fertilizer integration. Currently, artificial fertilizer mixing is expensive and not very efficient. Additionally, water-fertilizer mixing uniformity often fails to meet the demands of precise fertilizer application. Traditional industrial mixing methods such as high-speed mixing, mixing tanks, or blenders are unsuitable for agricultural applications because of their high-power consumption *(Yin et al., 2017).*

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Thus, it is necessary to thoroughly study the mechanical characteristics of the fertilizer-mixing process, and develop suitable fertilizer-mixing devices for agricultural production. This will meet the requirements of precise fertilizer application and help conserve energy.

As the importance of sustainable development of global agriculture gradually increases, water and fertilizer integration has become one of the focuses of agricultural research at home and abroad *(Garcia et al., 2023).* Priva B.V., a Dutch company, has developed three different types of irrigation and fertilizer applicators - the Priva NutriFit, Priva NutriFlex, and Priva NutriJet - all capable of performing sprinkler, drip, and tidal irrigation while accommodating various fertilizer distribution programs as needed (*Wang et al., 2016*). Meanwhile, Israel's NETAFIM company has created an automatic water and fertilizer control system that includes a pumping station, filtration centre, fertilizer irrigation system, valve control system, and field irrigation network. This innovative technology automatically mixes liquid fertilizers with filtered water in specific proportions before entering the field's drip irrigation network (*Zhang et al., 2011*).

Domestic fertilization equipment is also developing, Zhang Zhiyang et al. designed two solid fertilizer dissolution mixed application of water and fertilizer integration device, which can directly apply solid fertilizer, can effectively reduce the cost of integrated use of water and fertilizer (*Zhang et al., 2019*). Liu Lin et al. developed a field mobile precision fertilizer irrigation and fertilization integrated machine for applying solid fertilizer, which realized the precise regulation of mother liquor concentration and automatic irrigation and fertilization (*Liu et al., 2019*). Li Jianian et al. combined pulse width technology to control the solenoid valve, which improved the fertilizer absorption control accuracy of the venturi tube (*Li et al., 2012*). Li Zhizhong et al. research on embedded irrigation controller to improve the water-saving effect of integrated irrigation of water and fertilizer (*Li et al., 2006*). Liu Yonghua et al. applied CFD numerical calculation to the key core components affecting the performance of fertilizer suction to carry out a one-factor performance optimization design, which improved the fertilizer suction flow rate (*Liu et al.,2015*). Chen Feng et al. designed a PLC-based irrigation water-saving controller, which provides a new device for water-saving irrigation technology (*Chen et al., 2010*). The existing integrated water and fertilizer facilities mostly adopt mechanical mixing fertilizer mixing method (*Liu et al., 2018*), while different forms of fertilizer are often applied in actual production in China, and the unified fertilizer mixing method is bound to fail to meet the requirements of reasonable, efficient and energy-saving.

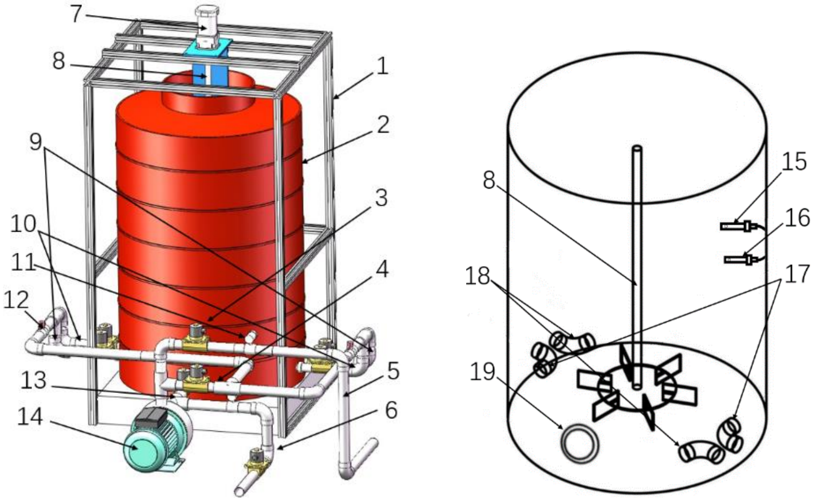
Therefore, this paper designs a fertilizer mixing device combining pressure relief reflux and mechanical stirring to realize the fertilizer mixing operation of different types of fertilizers. Firstly, the numerical solution model of the fertilizer mixing process is established, and the numerical simulation of different types of fertilizer mixing operations is carried out. Then, the relevant flow field parameters such as speed, vortex and flow line are extracted, the hydrodynamic characteristics of different fertilizer mixing modes are analysed, and the fertilizer mixing modes matched by different material forms and fertilizers are proposed. Finally, the reliability of the numerical model and mechanical analysis, and the rationality of the fertilizer mixing device are verified by experiments.

MATERIALS AND METHODS

General structure and operational principle

The fertilizer mixing device is shown in Figure 1a, the device is mainly composed of fertilizer mixing barrel, water pump, six-blade disc *stirring* paddle, mixing motor, fertilizer output pipeline, return pipe group, irrigation pipeline, water injection pipeline, solenoid valve, ball valve, PH sensor, EC sensor, flow meter, etc., which can realize three fertilizer mixing working modes of return, *stirring* paddle and "stirring paddle + two-way reflux".

The internal layout of the fertilizer mixing device is shown in Figure 1b, the stirring paddle is installed inside the fertilizer barrel, the first reflux outlet group and the second reflux outlet group are opened at the bottom, the reflux outlet group is composed of two reflux ports placed at 180°, the first reflux outlet group is placed in a counterclockwise direction, the second reflux outlet group is placed clockwise, and the direction of the reflux elbow is tangentially consistent with the barrel wall, which enhances the guiding effect on the water flow movement. The main return pipeline connects two tributaries, distributed on both sides of the fertilizer barrel, and the tributaries on each side are then divided into two small tributaries and connected with the return port on the side wall of the fertilizer barrel, and the first return pipe and the second return outlet group are connected respectively.



a) b)

Fig. 1 - The schematic of fertigation

a) Device structure diagram; b) Layout diagram

1. Bracket; 2. Fertilizer buckets; 3. Solenoid valve; 4. Main reflow pipe; 5. Irrigation pipes; 6. Water injection pipes; 7. Stirring motor; 8. Stirring paddle; 9. First return pipe; 10. Second return pipe; 11. Flowmeter; 12. Ball valve; 13. Fertilizer pipe; 14. Water pump; 15. PH sensor; 16. EC sensors; 17. First return port group; 18. Second return port group; 19. Fat outlet

Operational principle

When the fertilizer mixing device is in operation, the water pump is started first, and the electromechanical valves on the main reflux pipeline, water injection pipeline, and the first reflux pipeline are opened. The water pump begins injecting water into the water injection pipeline. The water flows through the water injection pipeline and enters the fertilizer mixing tank, causing the water and fertilizer inside the tank to rotate counterclockwise, completing the initial stirring. Simultaneously, the water injection flow meter is responsible for monitoring the amount of water injected. When the set value of water injection is reached, the electromechanical valve on the water injection pipeline is closed to complete the water injection process.

Upon completing the water injection, the electromechanical valve on the fertilizer outlet pipeline is opened, enabling the mixture of water and fertilizer to enter the water pump and return to the fertilizer mixing tank through the first reflux pipeline. The counterclockwise rotation of water and fertilizer in the mixing bucket achieves reflux work. In reflux mode, activate the stirring motor to rotate counterclockwise so that "stirring paddle + reflux" occurs simultaneously. After a period of stirring, close the solenoid valve on the first return line and open that on the second return line. This will cause a clockwise rotation of water and fertilizer in the mixing bucket while still maintaining counterclockwise stirring by mixing the paddle, thereby achieving "stirring paddle + reverse reflux". If the mechanical stirring mode is selected, all solenoid valves are closed, the stirring motor is started, and the mixing paddle is stirred counterclockwise. The sensor on the inner wall of the fertilizer barrel detects the pH and EC value of the water and fertilizer to determine whether it meets the standard of the fertilizer. After finishing the fertilizer mixing work, close the mixing paddle and all solenoid valves.

When carrying out irrigation work, open the solenoid valve on the fertilizer outlet pipe and the irrigation pipe, and the water and fertilizer in the fertilizer barrel are transported to the irrigation area through the irrigation pipeline through the pump. If it is necessary to adjust the irrigation pressure, open the solenoid valve on the main return pipeline and the first return pipeline, currently, the water and fertilizer coming out of the fertilizer pipeline enter the irrigation pipeline to complete the fertilization work. The other part re-enters the fertilizer mixing barrel through the reflux pipeline, which regulates the irrigation pressure and promotes the flow of fertilizer liquid in the barrel to prevent the crystallization of fertilizer during fertilization, and the ball valves on both sides are used to control the amount of water and fertilizer entering the reflux pipeline.

Build numerical model

Ignoring the influence of free liquid on fertilizer mixing, the geometric model of fertilizer mixing device is established under the three-dimensional modelling platform. Considering the fluid-structure interaction between the paddle and the fluid, the motion of the impeller is defined and embedded by a user-defined function (UDF) of the fluid analysis software Fluent. The dynamic grid setting is performed by the fluid-structure interaction method (FSI) near the *stirring* paddle and the return port, and the position is updated according to the preset speed of each time step.

The corresponding fluid domain grid is redivided by tetrahedral elements to simulate the change process of the fluid calculation region and express the flow characteristics in the flow field *(Banu et al., 2019; Ferrari et al., 2022).* To verify the rationality of meshing, 1×10^5, 2×10^5, 5×10^5, 7×10^5, 8×10^5 and 1×10^6 meshes were carried out for the fluid domain, respectively. By comparing and analysing the numerical results under various mesh densities, it is proved that the numerical results of the fluid domain meshing of 7×10^5, 8×10^5 and 1×10^6 are less different. With the further increase of the number of grids, the computing resources and computing time consumption increase significantly, so the grid division scheme of 7×10^5 is suitable.

The viscous and non-compressible fluids covered in this paper can be described using the Navier-Stokes (N-S) equation. Under the Fluent platform, the finite volume method is used to solve the N-S equation discretely. Since the finite volume method can use various irregular control body units, it has great advantages for dealing with complex dynamic boundary problems in the fertilizer mixing process.

The N-S equation is shown in the following equation:

$$\rho\left(\frac{\partial u}{\partial t}+u\cdot\nabla u\right)=-\nabla p+\mu\nabla^2 u \tag{1}$$

$$\nabla\cdot u=0 \tag{2}$$

where u is the velocity vector of the flow field; ρ is the density of the fluid; p is the fluid pressure; μ is the kinetic viscosity of the fluid; ∇ is the Hamiltonian operator. In the actual fertilizer dissolution and mixing process, the physical characteristics of different types of fertilizers vary greatly, and the research focus of this paper is to analyse the flow field characteristics and mechanical characteristics of the fertilizer mixing process, so the fluid is treated as a single-phase fluid in numerical modelling, ignoring the dissolution of fertilizer and the interaction between different components. In the numerical modelling, the aqueous medium is used as the research object, the fertilizer bucket and the stirring paddle are set as the wall boundary conditions without slip, and the turbulence model adopts the k-ε model *(Song et al., 2018; Murthy et al., 2012)*.

In the k-ε model, the k-equation for turbulent kinetic energy and the equation for the dispersion of turbulence energy dissipation ε are expressed as follows:

$$\frac{D(\rho k)}{Dt}=P-\rho\varepsilon+D_k \tag{3}$$

$$\frac{D(\rho\varepsilon)}{Dt}=C_1\frac{P\varepsilon}{k}-C_2\rho\frac{\varepsilon^2}{k}+C_3\rho\varepsilon(\nabla\cdot u)+D_\varepsilon \tag{4}$$

In equations (3) and (4), D/Dt is the derivative of matter and u is the average velocity vector; D_k and D_ε are turbulent kinetic energy diffusion terms, respectively:

$$D_k=\frac{\partial}{\partial x_j}\left(\alpha_k\mu\frac{\partial k}{\partial x_j}\right) \tag{5}$$

$$D_\varepsilon=\frac{\partial}{\partial x_j}\left(\alpha_\varepsilon\mu\frac{\partial \varepsilon}{\partial x_j}\right) \tag{6}$$

In the equation μ is the effective viscosity coefficient $\mu=\nu_0+\nu_t$, ν_0 is the molecular viscosity coefficient, and ν_t is the eddy current viscosity coefficient $\nu_t=C\mu k^2/\varepsilon$.

In equations (3) and (4), P is the turbulent kinetic energy generation term, and the equation is:

$$P=-\rho u_i u_j S_{ij} \tag{7}$$

$$u_i u_j-\frac{2}{3}k\delta_{ij}=-2\nu_t\left(S_{ij}-\frac{1}{3}(\nabla\cdot\overline{u})\delta_{ij}\right) \tag{8}$$

In equations (7) and (8), $S_{ij}=(\partial u_i/\partial x_j+\partial u_j/\partial x_i)/2$ is the average strain rate tensor of the fluid; δ_{ij} is the Kronek symbol (δ_{ij}=1 when i=j; δ_{ij}=0 when i≠j); C_μ is the empirical constant of the turbulence model. In the equation, C_1, C_2, C_μ, α_k, α_ε are empirical constants, and coefficient C_3 is a correction term that considers the effect of turbulent compressibility.

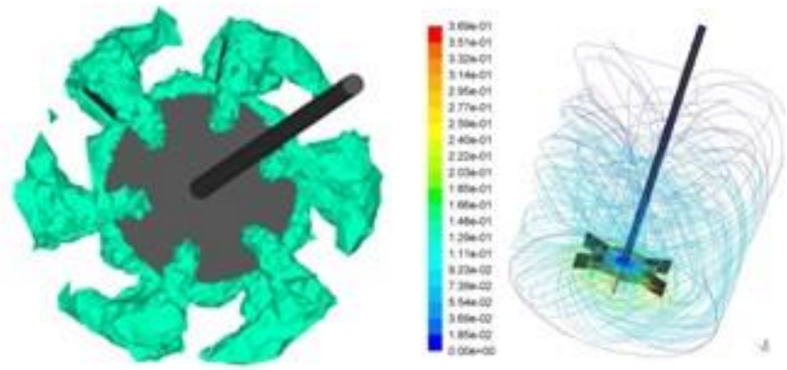
In the solution process, the time term adopts the first order fully hidden format discrete, the convection term and viscous term adopt the second order windward discrete format, and the pressure-velocity coupling algorithm adopts the SIMPLE algorithm. One rotation period of the *stirring* paddle is about 2.512 s, divided into 100-time steps, each with 0.02512 s.

Numerical simulation analysis

Based on numerical models, different types of fertilizer mixing processes are numerically simulated. Set the capacity of the fertilizer drum to be 150 L, the diameter is 530 mm, and the height is 720 mm. The diameter of the bottom opening is 40 mm, and the centre of the opening is 50 mm from the bottom of the barrel. The diameter of the *stirring* paddle shaft is 17 mm, the diameter of the disc part is 160 mm, the thickness is 3 mm, the length, width and thickness of the blade are 70 mm, 40 mm and 3 mm, and the size of the blade and the disc part is 25 mm. The speed of the stirring motor can be adjusted from 0-10 rad/s, and the flow rate of liquid return is adjustable from 0-1.5 m/s. By extracting the flow field data such as the moment of the *stirring* paddle, speed, vortex amount, streamline line and pressure, the flow field characteristics of different fertilizer mixing modes are analysed and compared, which provides theoretical support for the applicability of different fertilizer mixing methods and future structural optimization.

Analysis of fertilizer mixing process in stirring paddle mode

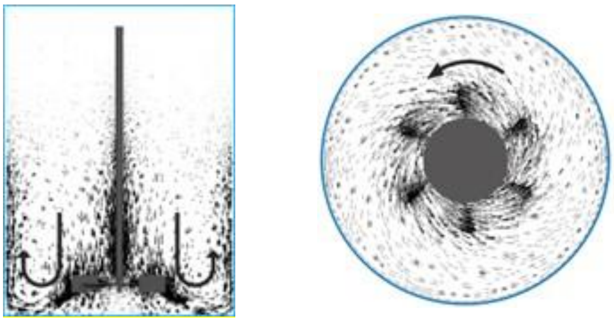
For medium and low speed stirring, set the speed of the *stirring* paddle to 2.5 rad/s. The vortex structure of the fluid in the fertilizer barrel is shown in Figure 2a, there is a more regular three-dimensional vortex structure around the *stirring* paddle, the fluid tends to flow to the inside of the paddle, and the liquid movement near the *stirring* paddle blade is more intense, which is easy to form a vortex. The flow chart of the fluid in the fertilizer barrel is shown in Figure 2b, from which the stirring process is the liquid rotating around the axis and churning up and down coupling motion, to achieve the effect of mixing and mixing liquid and fertilizer. However, under the action of viscous resistance, the intensity of movement decreases sharply when the fluid movement spreads near the barrel wall, and laminar flow is formed near the barrel wall, which is not conducive to mixing fertilizer and water in the fertilizer mixing barrel.



a) Vortex structure b) Streamline

Fig. 2 - Flow Field Characteristic around *Stirring* Paddle

The radial and axial velocity vectors of the fluid in the fertilizer tank are shown in Figure 3a. It can be seen from the radial vector diagram that due to the viscosity of the liquid, the energy loss during the motion transfer process is achieved, the intensity of the movement gradually decreases, and the movement speed of the fluid near the barrel wall is seriously attenuated. It can be seen from the axial vector figure 3b that the fluid in the barrel has tumbling movement in the axial direction, but the range of movement is limited to the middle and lower parts of the barrel, and the movement intensity of the upper solution of the barrel is low, which is not conducive to the uniformity of fertilizer.



a) Axial b) Radial

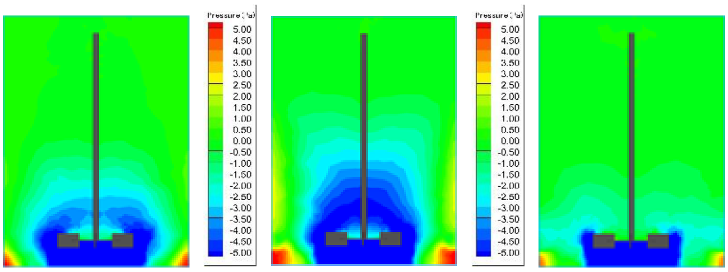
Fig. 3 - Velocity vector of flow field

Analysis of fertilizer mixing process in " stirring paddle + two-way reflux " mode

The mixing process of "stirring paddle + two-way reflux" was numerically simulated, and the rotation direction of the reflux was selected in the same direction and reverse with the rotation direction of the stirring paddle, respectively. By extracting the corresponding flow field characteristics, the fluid behaviour and mechanical characteristics of the two modes were analysed.

Stress analysis

Referring to the mixing process of the stirring paddle mode, set the reflux speed of the liquid to 0.4 m/s, the speed of the stirring paddle to 2.5 rad/s, and set the rotation direction of the return flow to be opposite and consistent with the rotation direction of the impeller. The pressure distribution of the stirring paddle mode, "stirring paddle + co-directional reflux" mode and "stirring paddle + reverse reflux" mode is in the same coordinate bar, as shown in Figure 4. It can be seen from the pressure cloud diagram that the negative pressure zone value at the bottom of the stirring paddle is the largest, followed by near the blade, and the value of the upper negative pressure zone gradually decreases with the increase of height. A range of pressure differences are formed between the negative pressure zone and the positive pressure area, which provides power for liquid exchange in different areas, thereby promoting fertilizer dissolution and mixing. Compared with the stirring paddle mode, the axial range of "stirring paddle + co-directional reflux" mode increases in the low-pressure area, and the axial distribution level of the pressure zone is more obvious, which promotes the connection between axial liquids. Compared with the stirring paddle mode, the radial range of "stirring paddle + reverse reflux" mode increases in the low-pressure area, the pressure difference between each pressure zone increases, the pressure gradient distribution is obvious and there is high pressure at the edge, which promotes the fierce exchange of liquid in the radial direction, so that the solute collides with the stirring paddle.



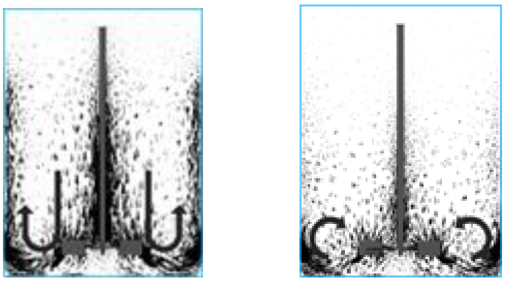
a) Stirring paddle b) Stirring paddle + co-directional reflux circumfluence
c) Stirring paddle + reverse reflux circumfluence

Fig. 4 -Comparison of pressure

Speed vector analysis

The axial velocity vectors for the "Stirring Paddle + Co-directional reflux" mode and the "Stirring Paddle + Reverse reflux" mode are shown in Figure 5. As can be seen from the axial vector diagram, the velocity of the fluid area in the barrel is mainly axial velocity. The axial speed promotes the churning of the liquid in the fertilizer barrel, so that the overall concentration of the fertilizer liquid in the barrel tends to be uniform. The radial velocity is mainly distributed around the paddles and converted into axial velocity after forming a vortex under the action of the barrel wall.

Compared with the stirring paddle mode, the axial velocity vector size and action area of the "stirring paddle + co-directional reflux" mode are significantly increased, which means that the movement of the liquid along the axial direction in the barrel is more violent, which better promotes the range and strength of the liquid churning up and down. The radial velocity vector size increases significantly in the "stirring paddle + reverse reflux" mode, especially near the bottom corner of the barrel, forming a violent tumble and winding the liquid again towards the paddle.

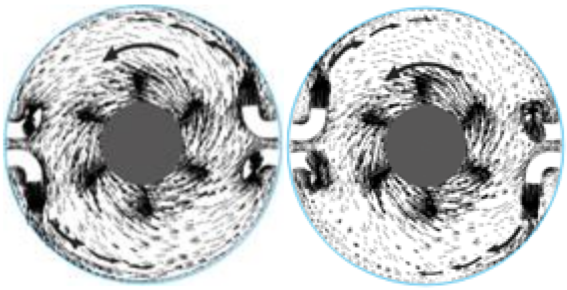


a. Co-rotating *b. Counter-rotating*

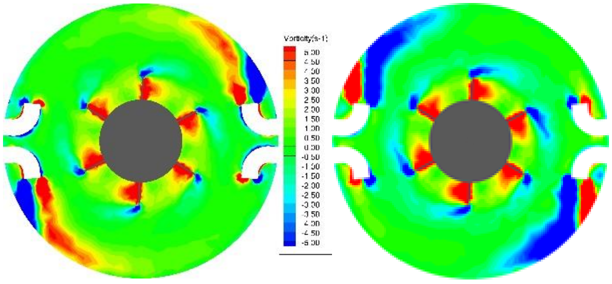
Fig. 5 - Comparison of Axial Velocity Vector

Analysis of flow field characteristics around the blade

The radial velocity vector plot and two-position vortex plot around the blade in the "stirring paddle + co-directional reflux" mode and the "stirring paddle + reverse reflux" mode are shown in Figure 6. It can be seen from the velocity vector diagram that the co-directional reflux enhances the overall velocity vector of the cross-section, enhances the rotational motion of the fluid, and promotes the axial convection of the liquid. The reverse reflux intensifies the convection of the liquid in the radial direction, the turbulent effect of the fluid is obvious, and the mixing effect of small scale is enhanced. It can be seen from the two-dimensional vortex diagram that the forward vortex is mostly in the flow field after superimposed co-directional reflux, and the positive vortex intensity increases compared with the positive vortex intensity in the reverse reflux, which enhances the overall rotational motion of the liquid. The eddies in different rotation directions in the flow field after superimposed reverse reflux increase, mainly around the blades and reflux ports. Positive and negative vortices exist in pairs, enhancing the shear effect of the liquid. The jet directly induced by the positive and negative vortex can collide with the barrel wall or paddle blade at high speed, accelerate the dissolution speed of granular fertilizer, and improve the dissolution efficiency of fertilizer.



a) Co-rotating velocity vector b) Counter-rotating velocity vector



c) Co-rotating vortex d) Counter-rotating vortex

Fig. 6 - Flow field characteristic around stirring paddle

Through numerical simulation analysis, it can be concluded that the reflux direction has a significant influence on the fertilizer mixing process. The "stirring paddle + co-directional reflux" mode can promote the overall convection of liquid and improve the efficiency of fertilizer-liquid mixing operation; The "stirring paddle + reverse reflux" mode promotes the entry of deposited solutions or particles around the paddle at the bottom of the barrel for intensive dissolution. From this, the "stirring paddle + two-way reflux" mode not only improves the efficiency of fertilizer mixing, but also prevents granular fertilizer from accumulating on the wall of the barrel.

RESULTS

Trial design and analysis of results

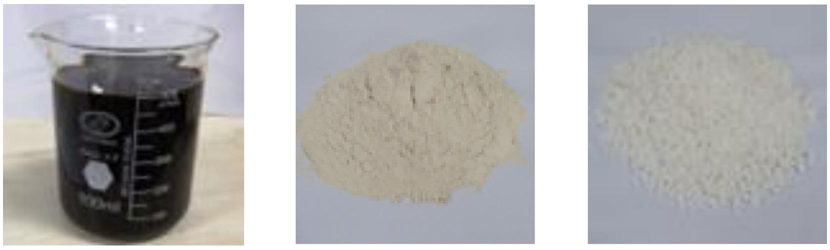
In order to verify the rationality of numerical model, solution method and fluid analysis, different fertilizer mixing methods were experimentally studied. The implementation site is shown in Figure 7a. Based on MCGS industrial control configuration software, the data acquisition system and motor, solenoid valve and pump control system are built for data collection and the realization of different fertilizer mixing operation modes. The data acquisition system stores data every 1 s to record the EC value of the fertilizer liquid in the fertilizer barrel during different tests. The layout of the barrel is shown in Figure 7b, the test parameters are consistent with the simulation parameters, and EC (conductivity) sensors are placed at the distance of 60 mm, 420 mm and 580 mm from the bottom of the barrel, corresponding to the three different positions of the upper, middle and lower fertilizer barrel in turn, which are used to detect the EC value of the fertilizer liquid in the fertilizer barrel.

a) Device diagram b) Layout diagram

Fig. 7 - Photo of test site

1. Motor; 2. Conductivity sensors; 3. Pump; 4. Electrical cabinet; 5. Stirring paddle; 6. Inlet; 7. Outlet

In the experimental design, the diffusion of liquid fertilizer is used to achieve the ideal fertilizer mixing effect by stirring, so only the reflux mode test is set; The difficulty of dissolving solid powder fertilizer is increased compared with liquid fertilizer, but the difficulty of dissolution is low compared with solid granular fertilizer, and two sets of tests are set up: reflux mode and stirring paddle mode. Due to its special spherical structure, solid granular fertilizer is more difficult to dissolve, so two sets of tests are set up in the stirring paddle mode and the "stirring paddle + two-way reflux" mode to verify the rationality of the "stirring paddle + two-way reflux" mode. The experimental fertilizers are liquid, solid and granular. The fertilizers with different physical forms are shown in Figure 8.



a) Liquid fertilizer b) Powder fertilizer c) Granular-fertilizer

Fig. 8 - Fertilizer of Different Forms

Liquid fertilizer mixing test

Drip irrigation fertilizer was selected as the test material, and the reference mode of drip irrigation was 200-250 times dilution. According to the fertilizer application guidance method, 150 L of water requires 5.0 kg of fertilizer for dissolution and dilution. Before the test, 50 g of test liquid fertilizer was dissolved in 1.5 L clean water, and the EC value of the solution was stable at about 6.80 mS/cm after manual stirring. During the test, 5.0 kg of liquid fertilizer was added to the fertilizer tank at a uniform speed through the funnel device, and the reflux mode of the fertilizer mixing device was started, and the sensor measured the EC value of the fertilizer liquid at different positions of the fertilizer barrel in real time. The data acquisition system stores the data, makes the EC value change curve, and compares the change trend of the EC value of liquid fertilizer at various positions in the fertilizer barrel in the reflux mode. The test results are shown in Figure 9.

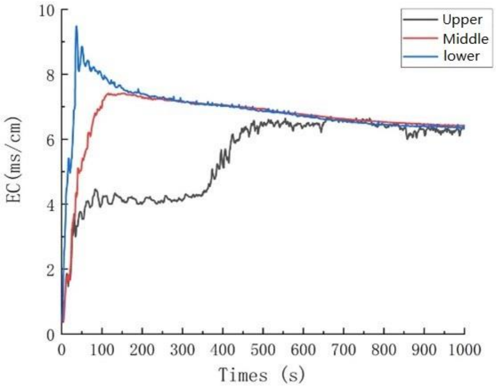
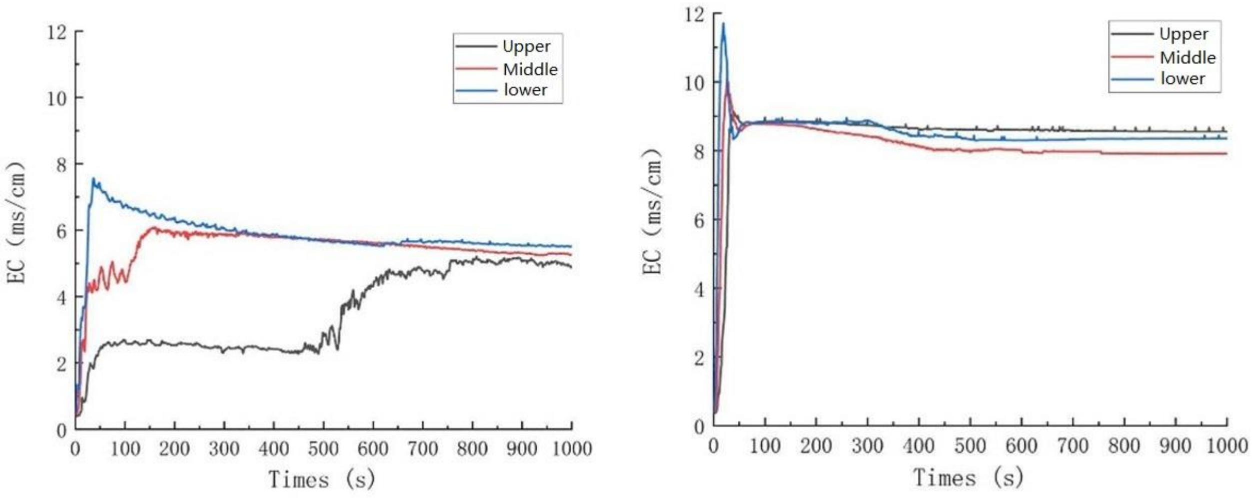


Fig. 9 - Conductivity Graph of Liquid fertilizer

It can be seen from the figure that at the initial stage, the EC value of fertilizer liquid in the upper middle and lower positions of the fertilizer barrel increased significantly. The top position of the fertilizer tank only relies on liquid diffusion to increase the concentration of fertilizer, so the fertilizer EC is stable at a low level. The bottom of the fertilizer barrel was deposited obviously, so the EC of the bottom fertilizer liquid increased the most rapidly and the value was the highest. Part of the liquid fertilizer deposited at the bottom of the fertilizer barrel moves with the water flow under the action of reflux, which accelerates the diffusion of liquid fertilizer in water, resulting in a gradual decrease in the EC value at the bottom of the fertilizer barrel, and a slow decrease after the intermediate position of the fertilizer liquid EC increases to a certain value. With the progress of reflux fertilizer mixing, the bottom reflux gradually affected the top position after a certain period of time, and the EC of the top fertilizer solution in the corresponding test results gradually increased after 350 s until it was consistent with the EC value of the bottom and middle fertilizer solution. After full mixing, the EC value of fertilizer liquid at different positions of the fertilizer mixing barrel was stable at about 6.60 mS/cm, which was basically consistent with the data measured by manual full stirring before the test.

Solid powder fertilizer mixing test

Potassium sulphate water-soluble fertilizer is selected as the test material, the product is bagged white solid powder, according to the fertilizer application method, 1.2 kg fertilizer needs 150 L of water for dissolution and dilution. Before the test, 12 g of test powder fertilizer was dissolved in 1.5 L of clean water, and the EC of the solution was stable at about 8.70 mS/cm after manual stirring. During the test, the reflux mode and stirring paddle mode fertilizer mixing tests were carried out respectively, and 1.2 kg of potassium sulphate powder was added to the fertilizer tank filled with 150 L of water, and the sensor measured the EC value of the fertilizer liquid in the upper, middle and lower positions of the fertilizer barrel in real time. According to the change curve of EC value, the change trend of EC value of fertilizer liquid in the fertilizer barrel was analysed, and the mixing characteristics of fertilizer liquid in reflux mode and stirring paddle mode were compared. The test results are shown in Figure 10.



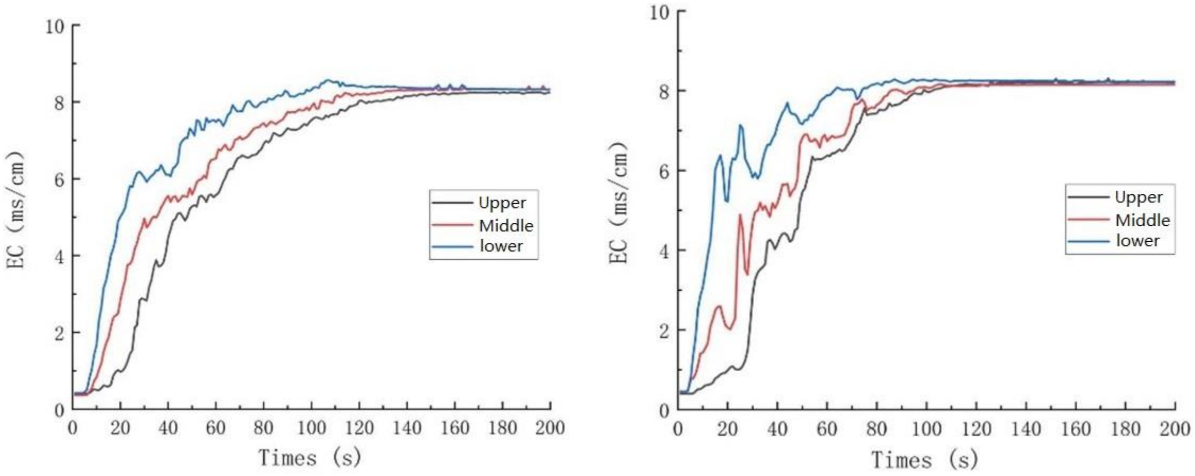
a) Circumfluence b) *Stirring* Paddle

Fig. 10 - Conductivity Graph of Powder fertilizer

In the process of dissolving and mixing, solid powder fertilizer needs to go through the process of first dissolving and then diffusion, which is lower than that of liquid fertilizer. It can be seen from the test results that the EC value of solid powder fertilizer and liquid fertilizer in the mixing process of solid powder fertilizer and liquid fertilizer in the reflux mode is similar, the bottom EC value increases the most rapidly, the top EC value increases the slowest, and finally the EC of the three positions reaches the same value when it is stable. In the stirring paddle mode, the EC values of fertilizer liquid in the upper, middle and lower positions of the fertilizer barrel increased rapidly, and quickly converged. Compared with the test data of reflux mode and stirring paddle mode, it was found that the EC value of fertilizer liquid in the fertilizer barrel was stable at about 5.50 mS/cm in the reflux mode, and the EC value of fertilizer liquid in the fertilizer barrel in the stirring paddle mode was stable at about 8.60 mS/cm.

Solid granular fertilizer mixing test

The compound potassium fertilizer with white spherical particles was selected as the test material, and according to the fertilizer application guidance method, 150 L of water needed 1.3 kg of fertilizer for dissolution and dilution. Before the test, 13g of test granular fertilizer was dissolved in 1.5 L of clean water, and the EC of the solution was stable at about 8.20 mS/cm after manual stirring. The mixing test of mixing paddle mode and "stirring paddle + two-way reflux" mode were carried out respectively. The "stirring paddle + two-way reflux" fertilizer mixing test changes the reflow direction every 10 s. During the test, take 1.3 kg of compound potassium fertilizer and add it to a fertilizer barrel filled with 150 L of clean water at a uniform rate. The sensor measures the EC value of the fertilizer liquid in real time at the upper, middle and lower positions of the fertilizer mixer barrel. Comparing the mixing characteristics of fertilizer liquid in the stirring paddle mode and the "stirring paddle + two-way reflux" mode, the test results are shown in Figure 11.



a) Stirring Paddle b) Stirring paddle + two-way reflux

Fig. 11 - Conductivity Graph of Granular fertilizer

From the analysis of the test results, after the granular fertilizer is added to the fertilizer drum, the particles are dissolved and deposited, resulting in different EC values in the upper, middle and lower positions in the fertilizer drum, the EC value of the fertilizer liquid at the bottom position is the highest, and the EC value of the fertilizer in the top position is the lowest. With the progress of the mixing operation, the EC value of the fertilizer liquid in different positions of the mixing barrel increased, and finally stabilized at about 8.20 mS/cm. In the "stirring paddle + two-way reflux" mode, every time the reflow direction is changed, the EC value curve in the corresponding figure fluctuates once, indicating that there is fertilizer accumulation at the bottom of the fertilizer barrel. Comparing the mixing curves of stirring paddle mode and "stirring paddle + two-way reflux" mode, it is found that the EC value tends to be stable at about 150 s in the stirring paddle mode, and the EC value tends to be stable at about 105 s in the "stirring paddle + two-way reflux" mode.

Experimental analysis

The experiment shows that the EC value of the liquid-type fertilizer in reflux mixing mode was stable at approximately 6.60 mS/cm when the liquid reflux speed was set at 0.4 m/s, which is close to the calibrated value of 6.80 mS/cm. The results demonstrate that the reflux mixing achieves the desired fertilizer mixing effect. It only requires the original pump for power and does not require the activation of other functional modules, resulting in low energy consumption costs.

Solid powder-type fertilizer in reflux mode and stirring paddle mode, the liquid reflux speed was set to 0.4 m/s and the stirring paddle speed to 2.5 rad/s. When the calibration value is 8.70 mS/cm, the EC value is stable at around 5.50 mS/cm and 8.60 mS/cm respectively. The test results show that the solid powder fertilizer is more difficult to dissolve than a liquid fertilizer, and it is difficult to achieve the ideal fertilizer mixing effect in reflux mode. While using the stirring paddle mode for fertilizer mixing, the axial and radial liquid velocity formed by the stirring paddle can quickly make the fertilizer liquid converge to a uniform state.

Solid granular fertilizers in stirring paddle mode and "stirring paddle + two-way reflux" mode, the liquid reflux speed was set at 0.4 m/s and the stirring paddle speed at 2.5 rad/s. When the EC calibration value was 8.20 mS/cm, it was stabilized around the calibration value after 150 s and 105 s respectively.

The test results showed that solid granular fertilizers are the most difficult to dissolve, due to their special spherical structure, the mixing process needs to destroy their spherical physical properties before mixing the concentration uniformity of the whole liquid area. A single mixing paddle works to achieve the fertilizer mixing requirements, but the mixing time is long. When using the "stirring paddle + two-way reflux" mode, radial high-intensity mixing is carried out first in the "stirring paddle + reverse reflux" mode.

The use of jets between positive and negative vortices causes the particles to collide with the barrel walls or paddles, thus destroying the spherical shape of the particles. The mixing is then carried out in the axial direction through the "stirring paddle + co-directional reflux" mode so that the concentration of the fertilizer in the drum tends to be homogenized. Alternating between reverse and co-directional modes can effectively solve the problem of low dissolution efficiency and uneven mixing of solid granular-type fertilizers.

CONCLUSIONS

This article presents a hybrid fertilizer mixing device that combines pressure relief reflux with mechanical agitation. The contributions of this device are mainly reflected in three aspects.

(1) The structure and working principle of the entire machine are determined, and three mixing modes of the fertilizer mixing device are designed and explained.

(2) A numerical simulation analysis was conducted to investigate the flow field characteristics and mechanical attributes of the fertilizer mixing process. The findings suggest that the direction of reflux has a notable influence on the efficiency of the fertilizer mixing process. Specifically, employing the “stirring paddle + same direction return” mode enhances the overall convection of the liquid, resulting in improved fertilizer-liquid mixing efficiency. On the other hand, employing the “Stirring Paddle + Reverse Reflux” mode facilitates the dissolution of sedimentary solution or particles by directing them to enter around the stirring paddle.

(3) A mixture of three forms of fertilizer was tested using a development prototype. The experimental results indicate that the reflux mode is suitable for liquid-type fertilizers which are fast dissolving and easy to diffuse, and its EC value is stable at about 6.60 mS/cm, which is close to the calibrated value of 6.80 mS/cm. The stirring paddle mode compensates for the reflux mode's weak mixing effect, making it suitable for solid powder-type fertilizers' mixing operation. The EC value remains stable at approximately 8.60 mS/cm when calibrated at 8.70 mS/cm. The” stirring paddle + two-way reflux” mode demonstrates the most robust mixing effect and is suitable for mixing solid granular fertilizers. When calibrated at 8.20 mS/cm, it stabilizes at approximately the calibration value after 105 s.

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