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An Interactive Analysis of Influencing Factors on the Separation Performance of the Screw Press

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Abstract: In order to optimize the separation performance of the screw press and enable its water removal rate and production to meet the production requirements, the influencing rule of the interactive effect of multi-factor parameters on its separation performance was studied by numerical simulation and experimental means. The internal flow field of the screw press was simulated by Fluent software. The rotation speed of the screw axis, back pressure of the slag outlet, and initial water content were taken as influencing factors, and the water removal rate and production were taken as objective functions. The Box–Behnken method was used to analyze the influencing rules of the interactive factors on the water removal rate and production. The results show that the significant factors affecting the water removal rate of the screw press are in the following order: initial water content > back pressure > rotation speed. The significant factors affecting screw press production are in the following order: rotation speed > back pressure > initial water content. The optimal combination of process parameters for the screw press is an initial water content of 55%, a screw axis rotation speed of 30 r/min, and a 5 kPa back pressure at the slag outlet. The water removal rate of 48.9% and production of 234.2 kg/d were obtained.

Keywords: screw press; solid–liquid separation; response surface method; separation performance

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1. Introduction

Mechanical dewatering equipment is widely applied in the field of solid–liquid separation, and common dewatering equipment includes a belt filter press, a centrifuge, and a screw press. Among them, the screw press is a kind of dewatering equipment capable of continuous production operations. Compared with the belt filter press and the centrifuge, its advantages include less floor space, low noise, and high dewatering efficiency [1,2]. The screw press is used in various situations for solid–liquid separation, such as sludge dewatering, pulp concentration, food waste treatment, and plant dewatering [3–6]. The separation performance of the screw press will be affected by different screw structures, material characteristics, rotation speed of the screw axis, back pressure, and other operating parameters [7,8]. In practical production, finding the optimal parameter combination to achieve a better balance between the water removal rate and production of the screw press is the goal.

Many scholars have studied the separation process of the screw press through theory and experiment. Egenes et al. [9,10] believed that the separation process in the screw space starts when the material flows through the filter screen, and the continuous feeding and volume reduction in the screw space will form a stable compression zone inside the space. Eaves [11] established a dehydration model of a saturated two-phase medium in a screw press based on Darcy's law and Terzaghi's theorem of consolidation and deduced the pressure distribution along the screw axis according to the two-phase rheology. The distribution of the pressure field inside the screw space promotes the seepage of the liquid phase through the filter screen to ensure solid–liquid separation [12–14]. Seker [15] studied the residence time of starch with different water contents in the screw press, and the results showed that the water content of the feed has no significant impact on the residence time and flow pattern. Robert et al. [16] explored the influencing rule of the screw press' dewatering effect on different types of paper pulp through experiments and found that the size of the paper pulp fibers and the degree of contact between the fibers are both important factors affecting the dewatering performance of the equipment. Prat [17] established a dynamic solid–liquid two-phase transport model in a double screw extruder and studied the impact of the rotation speed of the screw axis on material dewatering. Bousquet [18] examined the impact of different screw axis rotation speeds on the filtrate flow rate through experiments, and the results showed that the higher the rotation speed is, the more conducive to the increase in filtrate flow rate it will be. Shirato [19] analyzed the dewatering performance of the screw press on the clay slurry, and the results showed that the radial pressure gradient magnitude in the screw space exerts an important impact on driving dewatering. Rombaut [20] investigated the impact of different rotation speeds on grape seed oil extraction through experiments, and the results showed that the oil extraction yield increased with the increase in rotational speed.

In recent years, many scholars have studied the internal flow field of the screw press in light of computational fluid dynamics (CFD). Zhao [21] used a dual-fluid model to investigate the impact of the interrupted-whorl screw structure on the water content and separation efficiency during the solid–liquid separation of pig manure. The water content of the pig manure is reduced along with the increase in the gap distance of the blade, and the separation efficiency is improved along with the decrease in the gap distance of the blade. Zhang et al. [22] studied the impact of the screw groove depth on the water content of the extrudate through numerical simulation. The results showed that the reduction in the screw groove depth can effectively improve the dewatering effect of the screw press. Bahadar [23] changed the fluid viscosity to explore the material flow process in the screw press oil expeller and determined the maximum rotation speed of the screw through emulation and experimental comparison.

In a word, most existing research is based on a single factor when comparing and analyzing the separation performance of the screw press, which yet cannot reflect the comprehensive impact of the combination of multiple factors. In fact, there are several key factors affecting its separation performance: the rotation speed of the screw axis, the back pressure at the slag outlet, and the initial water content. In order to achieve optimal separation performance when the equipment removes impurities from the emulsion, it is necessary to perform in-depth research on the joint influence of each factor. In this paper, a dual-fluid model is used to carry out numerical simulation research on the solid–liquid separation in the screw press, and the response surface optimization is studied through Box–Behnken designs. The paper also elaborates on the joint effect of different factors on its separation performance, determines the optimal process parameter combination that affects the separation performance of the equipment, and provides a reference for adjusting actual production.

2. Calculation Methodology

2.1. Computational Domain and Mesh Division

The screw press has a structure as shown in Figure 1. Its fluid domain consists of a filter screen section and a screw space and is subjected to mesh division by fluent meshing, with the meshes shown in Figure 2. In order to ensure zero impact of the mesh number on the flow field of the screw press, a test of independence is carried out on the meshes of the fluid domain. The meshes are divided into 300,000, 600,000, 900,000, 1,200,000, and 1,500,000, respectively. By dividing the fluid domain in accordance with different mesh numbers, it shows that when the number of meshes is 1,200,000, the production of the screw press tends to be constant, the maximum skewness is 0.39, and the overall mesh quality meets the requirements.

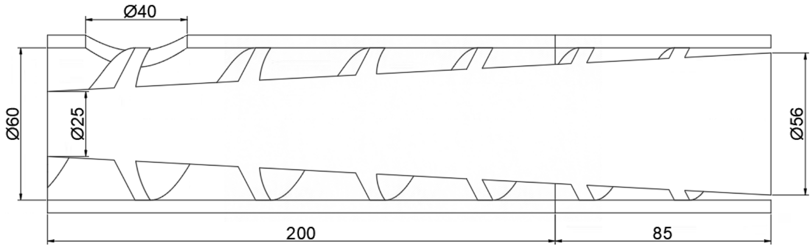

Figure 1. Dimensions of screw press.

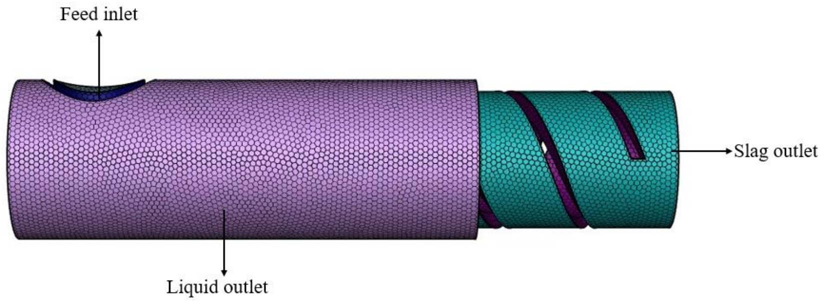

Figure 2. Computational domain mesh of screw press.

2.2. Mathematical Model

The internal flow of the fluid in the screw press follows the principles of mass conservation and momentum conservation. The separation process of the filter screen section of the screw press can be described by Darcy's law [24]. The filtrate flow rate through the filter screen is not only related to the characteristics of the filter screen and those of the filtrate but is also mainly dependent on the pressure difference on both sides of the filter screen, which can be expressed by Darcy's law:

$$Q = \frac{\kappa A}{\mu L} \Delta P \quad (1)$$

In the formula, Q is the flow rate through the porous medium per unit time, m^3/s; κ is the permeability of the porous medium, m^2; μ is the dynamic viscosity of the filtrate, Pa·s; L is the thickness of the porous medium, m; A is the filtration zone, m^2; and ΔP is the pressure difference between the two sides of the porous medium, Pa.

During the numerical simulation, the filter screen is treated as a porous medium model, and a source term of resistance is added to the fluent porous medium model to simulate the resistance loss of the fluid passing through the porous medium zone. The source term equation of the porous medium zone [25] is:

$$S_i = -(C_1 \mu v_i + C_2 \frac{1}{2} \rho |v| v_i) \; (i = x, y, z) \quad (2)$$

In the equation, S_i is the source term of the momentum equation in the $i(x,y,z)$ direction; C_1, the viscous resistance coefficient, m^{-2}; C_2, the inertial resistance coefficient, m^{-1}; ρ, the liquid phase density, kg/m^3; and v, the liquid phase velocity, m/s.

The viscous resistance coefficient C_1 and the inertial resistance coefficient C_2 can be obtained using the Ergun equation [26]:

$$C_1 = \frac{150}{d_p^2} \frac{(1-\varepsilon)^2}{\varepsilon^3} \quad (3)$$

$$C_2 = \frac{1.75}{d_p} \frac{(1-\varepsilon)}{\varepsilon^3} \quad (4)$$

In the equation, d_P is the particle equivalent diameter, m; and ε is the porosity of the porous medium.

2.3. Boundary Condition Setting

The fluent Euler–Euler model is applied to describe the solid–liquid two-phase flow in the screw press. The movement of screw space is simulated by the sliding mesh method. The screw space is set as a moving zone, and the filter screen, as a porous medium zone. The interface surface is used for data transmission between the two zones, and the wall surface is a boundary condition concerning sliding of non-relative velocity. The feed inlet is set as a velocity inlet; the back pressure of the slag outlet, a pressure outlet; and the outside of the filter screen, a normal pressure outlet.

With styrene–acrylic emulsion as the research subject, the liquid phase density is set as 1040 kg/m^3; the liquid phase dynamic viscosity, 0.48 Pa·s; the solid phase particle density, 1200 kg/m^3; and the average grain size of the particle, 49 μm. The filter screen porosity $\varepsilon = 0.3$, the viscous resistance coefficient $C_1 = 1.13 \times 10^{12}\ m^{-2}$, and the inertial resistance coefficient $C_2 = 9.26 \times 10^5\ m^{-1}$.

2.4. Separation Performance Characterization of Screw Press

The main performance of the screw press includes water removal rate and production.

(1) Water removal rate of screw press:

$$W = \frac{C_0 - C}{C_0} \tag{5}$$

In the equation, W is the water removal rate; C_0 is the initial water content of the material before entering the screw press; and C is the water content of the material discharged from the screw press.

(2) Production of screw press [27]:

$$E = \frac{(1 - C)}{(1 - C_1)} q \tag{6}$$

In the equation, E is the production (mass flow of dry slag); C_1 is the water content of the material in the air-dried state, and $C_1 = 17.2\%$ after the test in this paper; q is the output of extrudate at the slag outlet, kg/d.

2.5. Simulation Reliability Verification

To verify the reliability of the numerical simulation, the separation performance test of the screw press was conducted on site. The test device is shown in Figure 3, and the result of material dehydration is shown in Figure 4. As is shown in Figure 4, through the extrusion in the screw space, the extruded material at the slag outlet is of relatively low water content, and the density is relatively high.

The initial water content is 65%, the back pressure is 5 kPa, and the simulation values and test values of the water content of the extrudate at the slag outlet under various operating conditions at different rotation speeds are shown in Figure 5. As is shown in Figure 5, the simulation value of the extrudate's water content at the slag outlet under different operating conditions of screw axis rotation speed is relatively close to the test data. When the rotation speed is 75 r/min, the maximum relative error between the simulation value and test value is 7.34%, less than 10% error compared with the model's predictive value, indicating that the model has relatively high reliability.

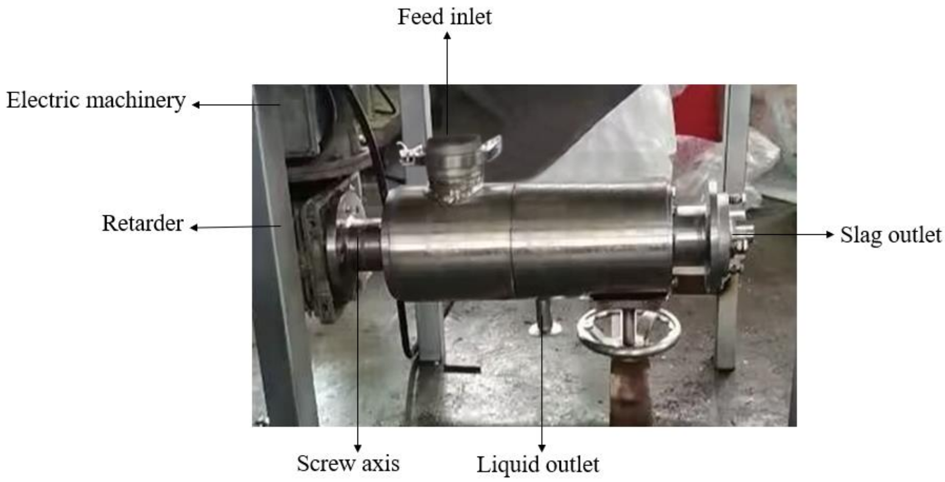

Figure 3. Test device of screw press.

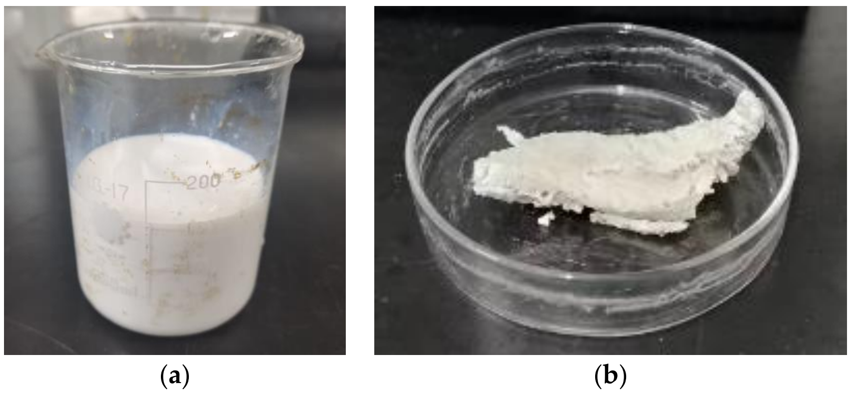

Figure 4. Material comparison before and after experiment. (**a**) Before the experiment. (**b**) After the experiment.

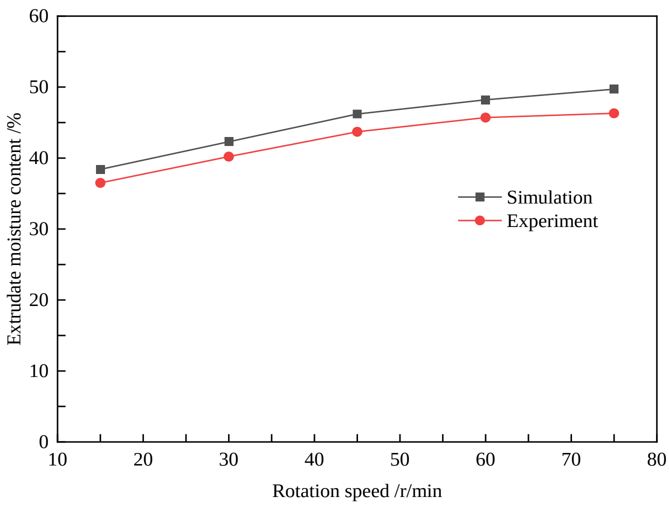

Figure 5. Comparison of simulation and test results.

2.6. Response Surface Method Design

The response surface method is an experimental design that optimizes the interaction of multiple factors by fitting influencing factors and response values by establishing a multiple regression equation and then analyzing and evaluating the interactive effect among the factors according to the response surface model [28]. Crucial parameters affecting the separation performance of the screw press include the rotation speed of the screw axis, back pressure at the slag outlet, and initial water content. The water removal rate represents the dehydration capacity of the screw press, and the production represents the processing capacity of the screw press. Taking the water removal rate W and the production E as objective functions, the response surface research is conducted under three factors: the rotation speed of screw axis N_s, the back pressure of the slag outlet P_{out}, and the initial water content C_0. The influencing factors and levels are shown in Table 1.

Table 1. Influencing factors and levels.

Coding Level	N_s/r/min	P_{out}/kPa	C_0/%
−1	30	5	55
0	45	10	60
1	60	15	65

3. Results and Discussions

3.1. An Analysis of Flow Field Inside the Screw Space

Taking 30 r/min of rotation speed of the screw axis, 5 kPa of the back pressure at the slag outlet, and 65% of the initial water content of the material as the numerical simulation parameters of the screw extrusion dehydration, the pressure inside the screw space and the water content of the material are shown in Figures 6 and 7.

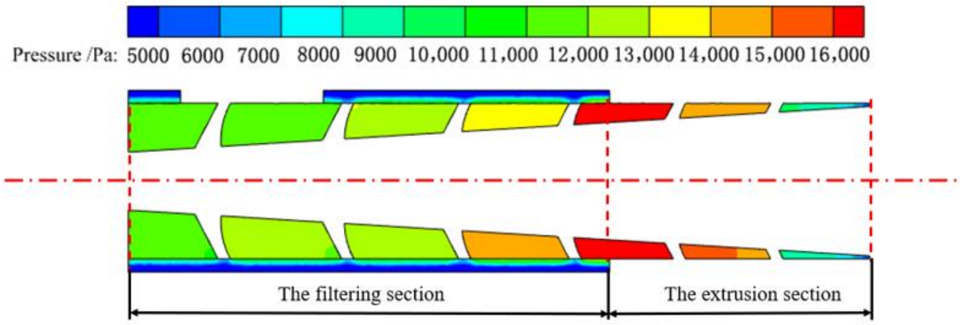

Figure 6. Pressure distribution in spiral cavity.

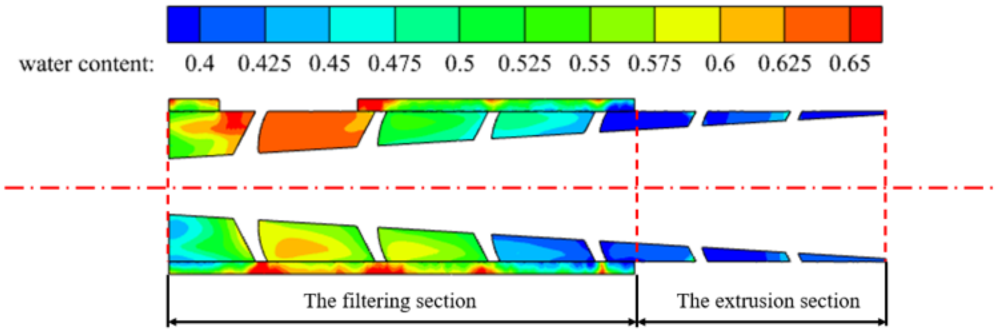

Figure 7. Distribution of water content in spiral cavity.

Combining Figures 6 and 7, it can be seen that:

(1) In the filtering section, the pressure in the screw space gradually increases along the axial direction, which is structured by the gradual decrease in screw channel area and the setting of back pressure, creating conditions for the filter screen to filter. As the liquid continuously flows out through the filter screen, the mass flow rate of the solid–liquid mixture in the screw space reduces accordingly, which also slows down the increase in fluid pressure in the screw space. In the filter section, a pressure difference environment is built on both sides of the filter screen to achieve filtration and dehydration, and the water content of the material gradually decreases along the axial direction.

(2) In the extrusion section, the pressure in the screw space gradually decreases along the axial direction, indicating that back pressure can increase the pressure in the screw space towards the material, reaching a maximum of 16 kPa at the junction between the filter section and the extrusion section. The water content of the material in the extrusion section remains basically unchanged, suggesting that the extrusion section is mainly used to transport materials and seal the material at the end of the axis. Increasing the back pressure of the equipment can raise the pressure in the screw space; increasing the rotation speed of the screw axis can reduce the residence time of the material inside the equipment; and increasing the inlet water content can accelerate the filtration speed. These parameters are likely to exert a considerable impact on the separation performance of the equipment.

3.2. SEM Analysis of Materials in the Screw Space

The SEM diagram in Figure 8a depicts the material in the filtration section after drying. It is evident that the material undergoes compression in the filtration section, resulting in the void space between the solids getting compressed. The liquid is squeezed out of the solid phase and discharged out of the screw space through the filter screen, facilitating the filtration and separation process. Figure 8b shows the SEM image of the materials in the extrusion section after drying. Based on the pressure distribution within the spiral cavity (Figure 6), the pressure in the filtration zone gradually increases, intensifying the squeezing of the material. At the junction between the filtration and squeezing zones, the pressure peaks before gradually decreasing along the axial direction. There is no filter screen in the squeezing zone, so the material does not undergo dewatering, serving only a transportation and sealing function. However, compared to the material in the filtration zone, the material in the squeezing zone has already been subjected to the maximum pressure, resulting in a higher degree of compression.

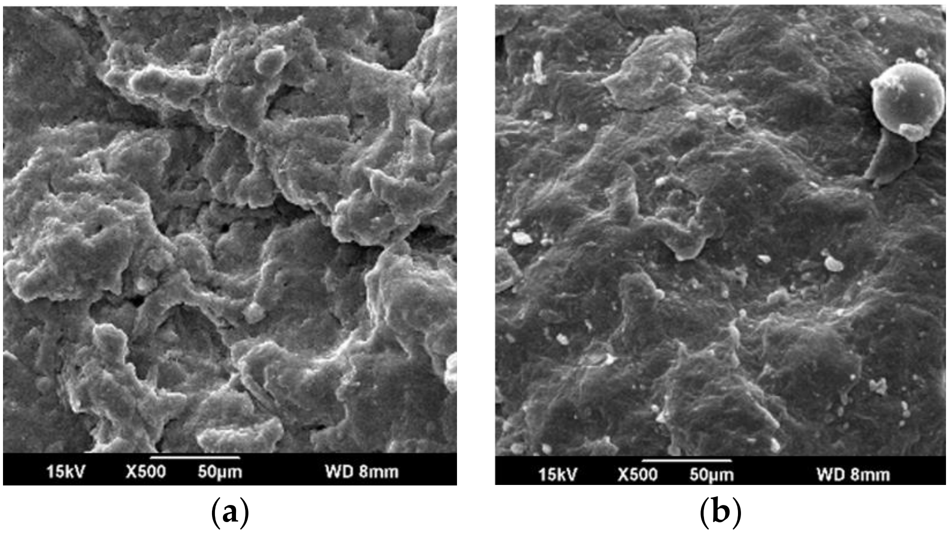

Figure 8. SEM diagram of materials in screw space. (**a**) Material in filtration section. (**b**) Material in extrusion section.

3.3. Influence of Process Parameters on the Separation Performance of Screw Press

Figure 9 shows the effect of single-factor parameters, such as rotation speed, back pressure, and initial water content, on the water removal rate and production of the screw press. As shown in Figure 9a, the water removal rate of the screw press decreases as the rotating speed increases, while the production increases as the rotating speed increases.

The increase in the rotating speed of the screw axis shortens the separation process of the material in the screw space. Therefore, increasing the rotating speed is not a favorable choice for improving the water removal rate. On the contrary, Figure 9b reveals that increasing the back pressure is conducive to improving the water removal rate of the screw press. With the increase in back pressure, the overall pressure level in the screw space increases, and the extrusion pressure acting on the material is greater. The constant compression of the void space between the materials promotes the solid–liquid separation process. However, the increase in back pressure will also increase the residence time of the material in the screw space, which may lead to a reduction in screw press production. Furthermore, Figure 9c illustrates that the initial water content of the material exerts an impact on the water removal rate and separation performance of the screw press. The lower the initial water content, the higher the water removal rate of the device will be. A decrease in initial water content will increase the solid content per unit volume in the screw space, enhancing the mutual extrusion between solids, which is favorable for solid–liquid separation of materials.

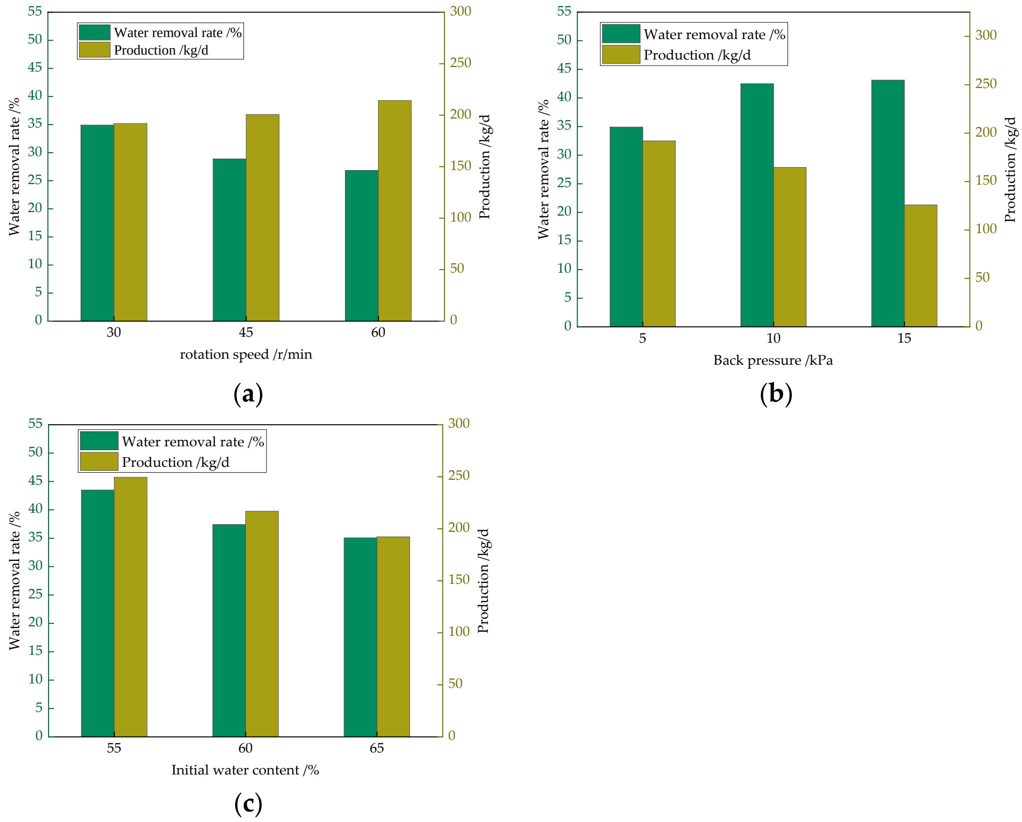

Figure 9. Influence of operation parameters on the separation performance of screw press. (**a**) Effect of rotational speed on separation performance. (**b**) Effect of back pressure on separation performance. (**c**) Effect of initial water content on separation performance.

3.4. Response Surface Optimization

Box–Behnken is one of the response surface design methods with the advantages of fewer tests, higher efficiency, and avoiding all factors being combined at the highest level simultaneously. In order to study the influence of several important parameters such as the rotation speed of the screw axis, back pressure at the slag outlet, and initial water content on the separation performance of the screw press, the Box–Behnken design is used to optimize the response surface and calculate the operating conditions in Table 2.

Table 2. Multi-factor interaction results.

N_s/r/min	P_{out}/kPa	C_0/%	W/%	E/kg/d
0	0	0	29.3	175
0	1	−1	46.9	163
0	0	0	29.3	175
−1	0	−1	44.4	184
1	−1	0	32.5	247
0	−1	−1	37.8	246
0	0	0	29.3	175
−1	1	0	39.3	131
1	0	−1	41.5	224
0	0	0	29.3	175
0	−1	1	28.9	211
−1	0	1	34.2	176
0	0	0	29.3	175
0	1	1	35.8	167
1	0	1	31.1	203
1	1	0	43	188
−1	−1	0	37.5	217

3.4.1. Regression Model and Significance Test

According to the data in Table 2, Design-Expert13 software is used for multiple regression fitting analysis to establish the quadratic polynomial response surface regression model of water removal rate W, production E, and three independent variables of rotation speed N_s, back pressure P_{out}, and initial water content C_0, as follows. The analysis of variance is shown in Table 3.

$$W = 29.3 - 0.9125N_s + 3.54P_{out} - 5.08C_0 + 2.17N_sP_{out} - 0.05N_sC_0 - 0.55P_{out}C_0 + 4.61{N_s}^2 + 4.16{P_{out}}^2 + 3.89{C_0}^2 \quad (7)$$

$$E = 190.12 + 19.25N_s - 34P_{out} - 7.5C_0 + 6.75N_sP_{out} - 3.25N_sC_0 + 9.75P_{out}C_0 + 10.37{N_s}^2 + 10.37{P_{out}}^2 + 11.38{C_0}^2 \quad (8)$$

Table 3. Regression equation variance analysis.

Source	The Water Content of the Extrudate				The Output of the Extrudate			
	Sum of Squares	Df	F-Value	p-Value	Sum of Squares	Df	F-Value	p-Value
Model	585.54	9	100.81	<0.0001	14,888.76	9	127.25	<0.0001
N_s	6.66	1	10.32	0.0148	2964.5	1	228.04	<0.0001
P_{out}	100.11	1	155.13	<0.0001	9248	1	711.38	<0.0001
C_0	206.04	1	319.27	<0.0001	450	1	34.62	0.0006
N_sP_{out}	18.92	1	29.32	0.001	182.25	1	14.02	0.0072
N_sC_0	0.01	1	0.0155	0.9044	42.25	1	3.25	0.1144
$P_{out}C_0$	1.21	1	1.87	0.2132	380.25	1	29.25	0.001
${N_s}^2$	89.58	1	138.81	<0.0001	453.22	1	34.86	0.0006
${P_{out}}^2$	72.95	1	113.04	<0.0001	453.22	1	34.86	0.0006
${C_0}^2$	63.63	1	98.6	<0.0001	544.8	1	41.91	0.0003

Note: $p < 0.01$, very significant; $p < 0.05$, significant.

According to the results in Table 3, the P values of the regression equations W and E are both less than 0.01, indicating that the response surface model is highly significant. In order to optimize the regression equation, independent variables that have little influence on the response variable need to be eliminated. In the water removal rate model W, 6 terms, P_{out}, C_0, N_sP_{out}, ${N_s}^2$, ${P_{out}}^2$, ${C_0}^2$ ($p < 0.01$) are very significant; in the production model E, 8 terms, N_s, P_{out}, C_0, N_sP_{out}, $P_{out}C_0$, ${N_s}^2$, ${P_{out}}^2$, ${C_0}^2$($p < 0.01$), are very significant. After the non-significant regression terms in the two models are removed, the new regression equation is as follows.

$$W = 29.3 - 0.9125N_s + 3.54P_{\text{out}} - 5.08C_0 + 2.17N_sP_{\text{out}} + 4.61{N_s}^2 + 4.16{P_{\text{out}}}^2 + 3.89{C_0}^2 \quad (9)$$

$$E = 190.12 + 19.25N_s - 34P_{\text{out}} - 7.5C_0 + 6.75N_sP_{\text{out}} + 9.75P_{\text{out}}C_0 + 10.37{N_s}^2 + 10.37{P_{\text{out}}}^2 + 11.38{C_0}^2 \quad (10)$$

The p values of the significance test of the optimized model W, E are all less than 0.001, indicating that the model optimization is reliable and can be used to predict and analyze actual production. As shown above, the model can fully describe the two response variables, and the prediction of the response surface model is reasonable and feasible for optimizing the parameters of the dehydration characteristics of the screw press.

3.4.2. An Analysis of the Influencing Pattern of Interactive Factors on the Water Removal Rate

The 3D response surface pattern of the interactive effect of the rotation speed of the screw axis N_s, the back pressure at the slag outlet P_{out}, and the initial water content C_0 on the water removal rate W is shown in Figure 10.

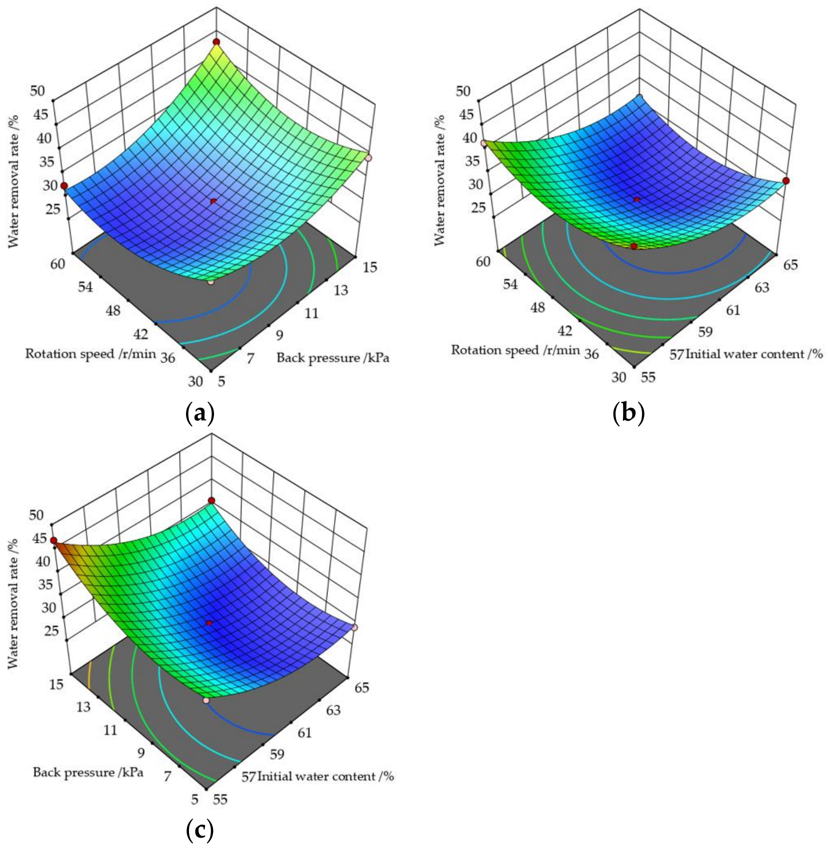

Figure 10. Relationship between water removal rate and interaction factors. (**a**) Interaction between rotation speed and back pressure. (**b**) Interaction between rotation speed and initial water content. (**c**) Interaction between back pressure and initial water content.

It can be seen from Figure 10a that when the initial water content is 60%, the effect of back pressure on the water removal rate of the screw press plays a dominant role. When the back pressure is above 10 kPa, the water removal rate is above 30%. The higher the rotation speed of the screw axis is, the lower the water removal rate will be. This is because the material is quickly pushed to the slag outlet by the screw blade rotating at a high speed, resulting in a decrease in the extrusion force in the filter screen section, which increases the water content of the material in the screw space. The water removal effect of the equipment is also worse. In general, high speed and low back pressure will reduce the water removal rate. In order to increase the water removal rate of the screw press, the rotation speed should be reduced to increase the back pressure.

From Figure 10b, it can be seen that when the back pressure is 10 kPa, the water removal rate changes gently with the rotation speed of the screw axis, and the initial water content has more influence on the water removal rate. This is because the initial water content determines the solid content of the material. The higher the solid content is, the more obvious the mutual extrusion between the materials in every unit volume of the screw space will be, which has a significant impact on the water removal rate. When the rotation speed is 45 r/min and the initial water content is below 60%, the water removal rate is above 35%. In general, the high-level area of the water removal rate is inclined to the direction of low rotation speed and low initial water content, and the effect of initial water content on the water removal rate is particularly obvious.

It can be seen from Figure 10c that when the rotation speed is 45 r/min, the high-level area of water removal rate under the interactive effect of back pressure at the slag outlet and initial water content inclines to the direction of high back pressure and low initial water content. When the back pressure increases to 15 kPa and the initial water content is below 60%, the water removal rate is above 37%. This is because increasing the back pressure results in a stronger extrusion force in the screw space, a higher flow rate of the filtrate in the filter screen section, a lower water content of the material in the space, and thus a higher water removal rate.

From the above analysis, the effect of factors on the water removal rate of the screw press is ranked as: the initial water content C_0 > the back pressure at the slag outlet P_{out} > the rotation speed of the screw axis N_s. For operating conditions that focus on the water removal rate, the material should be pretreated before entering the screw press to reduce the initial water content, which has a significant effect on increasing the water removal rate.

3.4.3. An Analysis of the Influence Pattern of Interactive Factors on the Production

The 3D response surface diagram of the three-factor interactive effect of the screw axis rotation speed N_s, the back pressure at the slag outlet P_{out}, and the initial water content C_0 on the production E is shown in Figure 11.

It can be seen from Figure 11a that when the initial water content is 60%, the high production area under the interactive effect of the screw axis rotation speed and the back pressure at the slag outlet inclines to the area of high rotation speed and low back pressure. When the back pressure is above 10 kPa, the screw axis rotation speed increases from 30 r/min to 60 r/min, and the production increases from 142 kg/d to 205 kg/d. It is because the increase in speed shortens the residence time of material in the screw space, increasing the production. This shows that a higher rotation speed is conducive to increasing the production.

Figure 11b shows that when the back pressure is 10 kPa, the influence of the initial water content on the production is relatively gentle, and the high production area under the interactive effect of the screw axis rotation speed and the initial water content inclines to the area with high speed and low initial water content. When the initial water content is below 60% and the screw axis rotation speed increases from 30 r/min to 60 r/min, the production increases from 166 kg/d to 224 kg/d.

It can be seen from Figure 11c that when the rotation speed is 45 r/min, the high production area, under the interactive effect of slag outlet back pressure and initial water content, inclines to the area with low initial water content and low back pressure. When the back pressure is below 10 kPa, the lower the initial water content, the higher the production will be, and the lowest production level is 176 kg/d. However, the reduction in back pressure will lead to a decrease in the water removal rate of the screw press. Thus, it is necessary to regulate the back pressure to an appropriate level and reduce the initial water content through pretreatment so as to increase the production of the screw press while ensuring a high water removal rate.

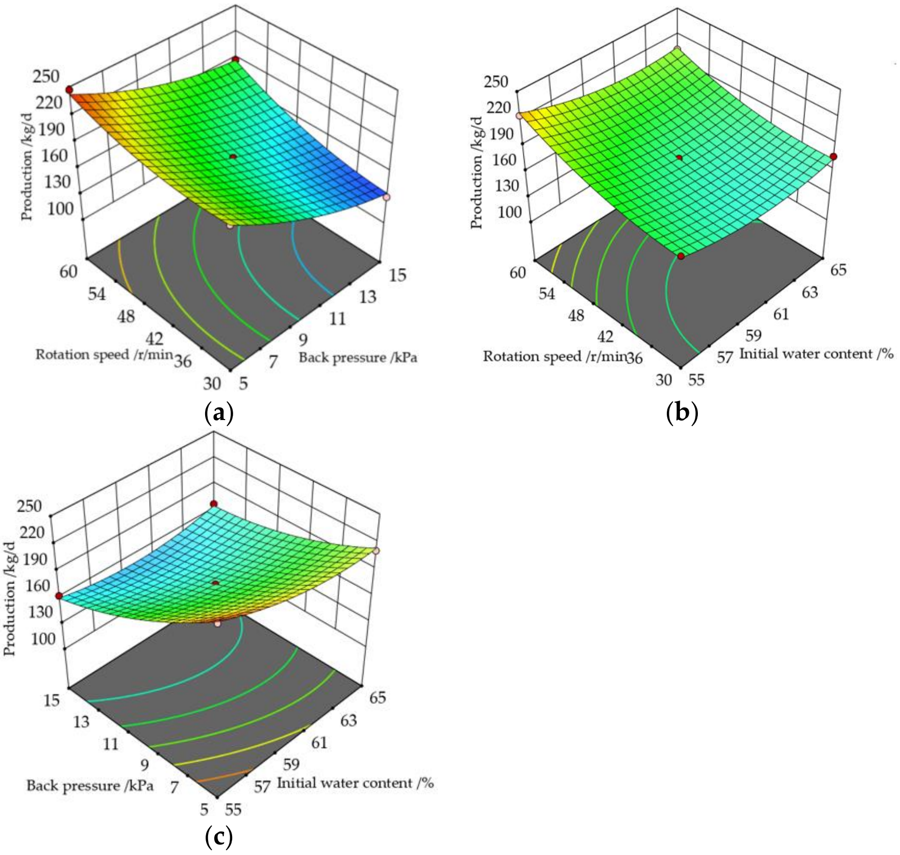

Figure 11. Relationship between production and interactive factors. (**a**) Interaction between rotation speed and back pressure. (**b**) Interaction between rotation speed and initial water content. (**c**) Interaction between back pressure and initial water content.

From the analysis above, it can be seen that the order of the effect of each factor on the production is: the rotation speed of the screw axis N_s > the back pressure at the slag outlet P_{out} > the initial water content C_0. For operating conditions that focus on production, increasing the rotation speed of the screw axis has a significant effect on increasing the production of the screw press.

3.4.4. Optimization Verification Test

Due to the complex influence of the factors on the water removal rate and the production, the Numerical module in Box–Behnken was used to optimize the screw press in order to achieve optimal separation performance in emulsion slag removal applications and to find the best combination of parameters to meet the objectives. According to actual production requirements, when the initial water content of the material is 55%, it is necessary to keep the water removal rate above 45% and keep the production as high as possible. The objective function and the set of constraint equations are as follows:

$$\begin{cases} W \geq 45\text{ , } \max E \\ 30 \leq N_s \leq 60 \\ 5 \leq P_{out} \leq 15 \\ C_0 = 55 \end{cases} \tag{11}$$

The best combination of parameters for the initial moisture content of 55% was obtained with a screw axis rotation speed of 30 r/min and a back pressure of 5 kPa at the slag outlet when the water removal rate was 45% and the production was 242.6 kg/d. In order to verify the reliability of the prediction results, three repeated tests were carried out under the same operating conditions, and the test results are shown in Table 4.

Table 4. Test results of each target under parameter optimization.

Test Serial Number	*W*/%	*E*/kg/d
1	50.2	232.7
2	48.7	236.8
3	47.8	233.1
Average value	48.9	234.2
Relative error	8.67	3.59

It can be seen from Table 4 that the average water removal rate obtained in the field test is 48.9%, the production is 234.2 kg/d, and the relative errors between the test value and the predicted value are 8.67% and 3.59%, respectively, and the error values are all less than 10%, indicating that the response surface model has high precision and the prediction results are relatively accurate.

4. Conclusions

In this paper, the working process of the screw press is simulated by Fluent software, the response surface analysis of the important factors affecting the working characteristics of the screw press is performed by Design-Expert software, and the model prediction results are verified experimentally.

The results indicate:

(1) The technological parameters of the screw press were optimized using Box–Behnken, and the influence of the three factors—the screw axis rotation speed, the back pressure at the slag outlet, and the initial water content—on the water removal rate and the production were studied and analyzed. The order of significant effect of each factor on the water removal rate is the initial water content > the back pressure at the slag outlet > the rotation speed of the screw axis; the order of the significant effect of each factor on the production is the rotation speed of the screw axis > the back pressure at the slag outlet > the initial water content.

(2) Considering the results of response surface optimization and actual production requirements, the optimal combination of process parameters for the screw press is an initial water content of 55%, screw axis speed of 30 rpm, and 5 kPa back pressure at the slag outlet. A water removal rate of 48.9% and a production of 234.2 kg/d were obtained in the field tests conducted according to the optimal combination of parameters.

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