Research Article

Multiobjective Optimization Design and Experimental Study of Desulfurization Dust Removal Centrifugal Pump Based on Immune Particle Swarm Algorithm

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In view of the problems of low efficiency, poor anticavitation performance, and curve hump for current centrifugal pump in the process of desulfurization and dust removal, the desulfurization dust removal centrifugal pump was designed. The velocity coefficient method was used for hydraulic design of centrifugal pump, and the three-dimensional modeling and numerical simulation of flow field of centrifugal pump were carried out by using computational fluid dynamics technology (CFD). The optimal mathematical model with the highest efficiency and the lowest pump net positive suction head (NPSH_r) as the objective function was established under the condition of no curve hump. The immune particle swarm optimization algorithm was used to optimize the multiobjective function, and the optimal combination of the main parameters was obtained. The simulation results showed that, compared with the traditional centrifugal pump, the performance of the optimized centrifugal pump had been greatly improved, which eliminated the phenomenon of curve hump. Based on IH model chemical pump to build a prototype test platform, the experimental results of the external characteristics of the prototype pump and the optimization pump under different working conditions were obtained. At the rated flow rate, the optimization pump efficiency was increased by 13.30%, the head was increased by 11.52%, and NPSH_r was decreased by 10.14%. The experimental results showed that the optimized indexes met the design requirements and improved the performance of centrifugal pump. At the same time, the accuracy of the immune particle swarm control method was verified, which provided some reference for the design of desulfurization dust removal centrifugal pump.

1. Introduction

Centrifugal pump is a widely used general machinery, mainly used in petrochemical, urban water supply and drainage, aerospace, and other fields [1]. At present, there are some problems in centrifugal pumps, such as low efficiency, poor anticavitation performance, and curve hump, especially in low speed centrifugal pumps. The early centrifugal pump development is mainly based on the Euler theory, univariate theory, binary theory, and flow similarity theory and other methods for hydraulic design and model conversion, whether the designer has a wealth of engineering experience is the key to determine the success of centrifugal pump design [2–8]. Industries, in order to achieve the

function of desulfurization, usually to improve the chemical pump, but the improved efficiency of the chemical pump was low, could not meet the requirements of energy saving and environmental protection, and the operating conditions were not suitable for the desulfurization dust removal pump requirements. Aiming at the shortage of traditional centrifugal pump in this aspect, the structure design of desulfurization dust removal centrifugal pump was carried out by CFD technology, with the highest efficiency, the NPSH_r as the objective function, and the no curve hump as the constraint conditions for multiobjective optimization, and the immune particle swarm control algorithm was used to optimize the calculation, so as to get a centrifugal pump with good performance.

2. Calculation of Mathematical Model for Desulfurization Dust Removal Centrifugal Pump

2.1. Hydraulic Design. The hydraulic design of desulfurization dust removal centrifugal pump is carried out by the velocity coefficient method [9], in which rotational speed $n = 1450$ r/min, flow rate $Q = 50$ m³/h, and head $H = 20$ m.

The design of desulfurization dust removal centrifugal pump is a single suction impeller: pump specific speed $n_s = (3.65n\sqrt{Q})/H^{3/4} = 65.95$, hydraulic efficiency $\eta_h = 1 + 0.0835\lg(Q/n)^{1/3} = 0.860$, volumetric efficiency $\eta_v = 1/(1 + 0.68n_s^{-2/3}) = 0.960$, and mechanical efficiency $\eta_m = 1 - 0.07(1/(n_s/100)^{7/6}) = 0.886$.

2.2. Impeller Design. Considering that the fluid in the desulfurization dust removal centrifugal pump is alkaline medium, the rigid polyvinyl chloride with good corrosion resistance and high mechanical strength is selected as the material of impeller.

- (1) Calculation of the suction port and outlet diameter of centrifugal pump

Pump inlet flow rate $V_s = 2.76$ m/s, pump suction port diameter $D_s = \sqrt{4Q/\pi V_s} = 80$ mm, and pump outlet diameter $D_d = (1 - 0.7)D_s = 80 - 56$ mm.

- (2) Determination of impeller inlet diameter D_1

Impeller equivalent diameter is

$$D_0 = k_0 \left(\frac{Q}{n} \right)^{1/3} = 84.9 \text{ mm}, \quad (1)$$

where k_0 is the impeller inlet coefficient, taking into account the cavitation and efficiency of centrifugal pump, and k_0 takes 4.0.

Hub diameter is

$$d_h = 1.4d = 28 \text{ mm}, \quad (2)$$

in which pump shaft diameter $d = 20$ mm.

Impeller inlet diameter $D_1 = \sqrt{D_0^2 + d_h^2} = 89.4$ mm.

- (3) Determination of impeller outlet diameter D_2

Impeller outlet diameter is

$$D_2 = K_{D_2} \left(\frac{Q}{n} \right)^{1/3} = 256.7 \text{ mm}, \quad (3)$$

where $K_{D_2} = 12.09$.

- (4) Determination of impeller outlet width b_2

The calculation formula of impeller outlet width is [9]

$$b_2 = K_{b_2} \left(\frac{Q}{n} \right)^{1/3} = 12.1 \text{ mm}, \quad (4)$$

where $K_{b_2} = 0.7(n_s/100)^{5/6} = 0.57$.

- (5) Determination of impeller inlet width b_1

First, the impeller inlet velocity v_0 is determined, and then the impeller inlet width b_1 is calculated:

TABLE 1: The main structural parameters of impeller.

Parameters	Calculation results	Final results
D_s (mm)	80	80
D_d (mm)	56–80	65
D_1 (mm)	89.4	90
D_2 (mm)	256.6	260
b_1 (mm)	12.1	12.5
b_2 (mm)	22.9	23
β_1 (°)	23–40	30
β_2 (°)	16–40	30
Z	5.2	6
S (mm)	2.13	3
φ (°)	90–120	120

$$v_0 = k_0 \sqrt{2gH} = 2.06 \text{ m/s}, \quad (5)$$

where $k_0 = 0.026542 + 0.001247n_s - 0.000001n_s^2 = 0.104$.

Impeller inlet width is $b_1 = \eta_v Q / \pi D_1 v_0 = 22.9$ mm.

- (6) Determination of blade inlet and outlet angle

The recommended blade inlet angle is $\beta'_1 = 20^\circ - 25^\circ$, and the impact angle is $\Delta\beta = 3^\circ - 15^\circ$.

Due to $\beta_1 = \beta'_1 + \Delta\beta = 23^\circ - 40^\circ$, the selected inlet angle is $\beta_1 = 30^\circ$.

Considering that the value of β_2 is usually within the range of $16^\circ - 40^\circ$, the outlet angle $\beta_1 = 30^\circ$ for this design is selected.

- (7) Determination of the number of blades Z

$$Z = 6.5 \left(\frac{D_2 + D_1}{D_2 - D_1} \right) \sin \frac{\beta_1 + \beta_2}{2} = 5.2. \quad (6)$$

- (8) Calculation of blade thickness and selection of blade packing angle

Calculation of blade thickness is

$$S = AD_2 \sqrt{\frac{H}{Z}} = 2.13 \text{ mm}, \quad (7)$$

where the coefficient A is related to specific speed and material, and $A = 4.5$ is desirable by look-up table [9].

Generally, the value range of the blade angle φ is $90^\circ - 120^\circ$ because the specific speed of the pump is lower, and φ takes 120° .

- (9) Determination of impeller structure parameters

In summary, the main structural parameters of impeller are shown in Table 1.

2.3. Calculation of Main Structural Parameters of Vortex Chamber.

- (1) Calculation of base circle diameter and vortex chamber inlet width

Since the base circle diameter calculation formula is: $D_3 = (1.03 - 1.08)D_2 = 267.8 - 280.8$ mm, the selected base circle diameter $D_3 = 270$ mm.

TABLE 2: Vortex section area.

Section	1	2	3	4	5	6	7	8
Area (cm ²)	1.91	3.81	5.72	7.63	9.53	11.44	13.34	15.25

FIGURE 1: Centrifugal pump three-dimensional model.

Vortex chamber inlet width is $b_3 = b_2 + 0.05D_2 = 25.5$ mm.

(2) Calculation of each section area of vortex chamber

For convenience of calculation and drawing, circular vortex chamber and 8 equal parts are selected. The average velocity v_3 of the vortex chamber is

$$v_3 = k_3 \sqrt{2gH} = 9.11 \text{ m/s}, \quad (8)$$

in which the velocity coefficient $k_3 = 0.46$.

The calculation formula of each section area is

$$F_i = \frac{i}{8} \cdot \frac{Q}{v_3}, \quad (9)$$

where i takes 1 to 8, respectively.

The calculation results of each section area of vortex chamber are shown in Table 2.

3. Three-Dimensional Modeling and Flow Field Analysis of Desulfurization Dust Removal Centrifugal Pump

3.1. Centrifugal Pump Three-Dimensional Model. CFTurbo is a professional impeller and volute design software, easy to operate, widely used in centrifugal pumps, centrifugal fans, turbines, and other rotating machinery designs [10–12]. The above design parameters are introduced into the CFTurbo 10.0 software, and the three-dimensional model of centrifugal pump is shown in Figure 1 through the parameter setting.

3.2. Grid Division. Pumplinx is a software developed for the hydraulic simulation and calculation of pump, which provides engineers with fast and accurate calculation results. The three-dimensional model of centrifugal pump is imported into the Pumplinx 3.4 software, and the Cartesian grid is divided, as shown in Figure 2; a total of 78668 grids are obtained.

In order to further verify the effect of grid number on the numerical simulation performance of centrifugal pump, six groups of grid numbers are selected to simulate the changes of centrifugal pump η , H , and NPSH_r under the same

FIGURE 2: Grid division.

TABLE 3: Grid independence analysis.

Schemes	Grid numbers	η (%)	H (m)	NPSH_r (m)
1	60000	81.63	16.76	1.03912
2	65000	81.75	18.65	1.03961
3	70000	82.23	19.24	1.04022
4	75000	82.25	19.28	1.04026
5	80000	82.27	19.32	1.04033
6	85000	82.29	19.33	1.04035

working conditions. Grid independence analysis is shown in Table 3 [13].

As can be seen from Table 3, when the number of grids is between 60000 and 70000, the number of grids has a great influence on each index of centrifugal pump. When the number of grids is between 70000 and 85000, the variation range of each index is small. Therefore, when the number of grids is more than 70000, the sensitivity of the external characteristics of centrifugal pump to the number of grids is small, and each index value tends to be stable. Visible, the number of selected impeller grids is reasonable.

3.3. Boundary Condition Setting. Before the flow field simulation, the boundary conditions are set. The rotating speed of impeller is $n = 1450$ r/min, the flow rate of pump is $Q = 50$ m³/h, the fluid medium is selected by water, and the turbulence model is selected as the $k - \epsilon$ model. The interface coupling between impeller and volute is coupled with dynamic-static interface. The inlet adopts the speed inlet boundary condition, the outlet boundary adopts the free outlet, and the surface of the solid wall has no slip.

3.4. Flow Field Simulation. After setting the parameters, the flow field is simulated by Pumplinx 3.4 software. Figure 3 shows the pressure contour diagram, velocity contour diagram, and cavitation contour diagram of desulfurization dust removal centrifugal pump, respectively.

According to Figure 3(a), the pressure from the center of the impeller to the volute is gradually increased, reaching the maximum at the volute outlet, so that the fluid has enough energy to reach the specified head. However, the uneven pressure distribution on the volute and the reaction to the impeller may cause the vortex phenomenon among the blades.

As shown in Figure 3(b), the velocity from the center of the impeller to the outlet of the impeller is gradually increasing, the velocity distribution of impeller near the volute

FIGURE 3: Prototype pump flow field simulation. (a) Pressure contour diagram. (b) Velocity contour diagram. (c) Cavitation contour diagram.

wall is uneven, and the vortex phenomenon is easy to appear, which affects the normal flow of fluid.

As shown in Figure 3(c), there is a large range of cavitation in the blades near the impeller inlet. This is because the impeller inlet pressure is very low, to reach the critical pressure of fluid at room temperature, resulting in cavitation phenomenon.

4. Centrifugal Pump Optimization Mathematical Model Establishment

In view of the above flow field simulation, with the highest efficiency and the lowest NPSH_r as the objective function, the centrifugal pump was optimized with the constraint conditions of no curve hump.

4.1. Maximum Efficiency Model of Centrifugal Pump. According to the Stodola formula, when the inlet has no prerotating, the theoretical head of the centrifugal pump is [14]

$$H_T = \frac{1}{g} \left[\sigma \left(\frac{\pi n D_2}{60} \right)^2 - \frac{Qn}{60 \eta_v b_2 \psi_2 \tan \beta_2} \right], \quad (10)$$

where $\sigma = 1 - \pi/Z \sin \beta_2$, σ denotes the slip coefficient, and ψ_2 denotes the impeller outlet exclusion coefficient.

The total efficiency of centrifugal pump is expressed as

$$\frac{1}{\eta} = \frac{P_m}{\rho g Q H} + \frac{H_T}{A(H_T - S_1)}, \quad (11)$$

where P_m is the centrifugal pump mechanical loss and S_1 is the hydraulic loss.

When η is the largest, $1/\eta$ is the smallest, and the highest efficiency objective function is

$$\min f_1(x) = \frac{1}{\eta} = \frac{P_m}{\rho g Q H} + \frac{H_T}{A(H_T - S_1)}. \quad (12)$$

4.2. Centrifugal Pump Minimum NPSH_r Model. The expression of centrifugal pump NPSH_r is [15]

$$\text{NPSH}_r = \frac{1}{2g} (1 + \lambda) \frac{k_2^2 4^2 Q^2}{D_0^4 \pi^2 \eta_v^2} + \lambda \frac{k_1^2 \pi^2 n^2 D_0^2}{60^2 \times 2g}, \quad (13)$$

where λ is the inlet pressure drop coefficient of the blade, and k_1 and k_2 are the coefficients.

Centrifugal pump NPSH_r objective function is

$$\min f_2(x) = \text{NPSH}_r. \quad (14)$$

In summary, the total objective function is

$$\min f(x) = \sum_{i=1}^2 \omega_i \left[\frac{f_i(x) - f_i^*}{f_i^*} \right], \quad (15)$$

where ω_i is the weight coefficient and f_i^* is the ideal value of corresponding subobjective function.

4.3. Constraint Conditions. In order to avoid the problem of curve hump in centrifugal pump, according to empirical function, the following should be satisfied [16]:

$$\beta_2 Z^{0.773} < 90. \quad (16)$$

According to the requirements of optimization design, the scope of design variables is adjusted appropriately, and other constraints can be obtained:

$$3\sqrt[3]{\frac{Q}{n}} < D_1 < 4.5\sqrt[3]{\frac{Q}{n}},$$

$$\frac{Q}{4.5\sqrt[3]{(Q/n)K_{m1}\sqrt{2gH}}} < b_1 < \frac{Q}{3\sqrt[3]{(Q/n)K_{m1}\sqrt{2gH}}},$$

$$9\left(\frac{n_s}{100}\right)^{-1/2}\sqrt[3]{\frac{Q}{n}} < D_2 < 10.5\left(\frac{n_s}{100}\right)^{-1/2}\sqrt[3]{\frac{Q}{n}},$$

$$0.6\left(\frac{n_s}{100}\right)^{5/6}\sqrt[3]{\frac{Q}{n}} < b_2 < 0.9\left(\frac{n_s}{100}\right)^{5/6}\sqrt[3]{\frac{Q}{n}}, \quad (17)$$

$$23^\circ < \beta_1 < 40^\circ, 10^\circ < \beta_2 < 40^\circ,$$

$$90^\circ < \varphi < 130^\circ,$$

$$4 < Z < 9.$$

5. Immune Particle Swarm Control Algorithm Design

The immune particle swarm algorithm is a new improved particle swarm algorithm based on the immune mechanism of the biological system. The control effect is obvious, which has the characteristics of fast convergence speed, high convergence precision, and strong adjustment ability. In this paper, Matlab 7.0 software is used to write immune particle swarm optimization algorithm to optimize the multiobjective function.

Determine the optimal solution for the parameter selection:

$$J = \int_0^\infty (\omega_1 |e(t)| + \omega_2 u^2(t)) dt, \quad (18)$$

where $e(t)$ is the system error, $u(t)$ is the output of the immune controller, and t is the time.

In order to avoid the overshoot phenomenon, using the penalty function, the optimal solution is

$$\text{if } ey(t) < 0, \quad (19)$$

$$J = \int_0^\infty (\omega_1 |e(t)| + \omega_2 u^2(t) + \omega_3 |ey(t)|) dt.$$

where $ey(t) = y(t) - y(t-1)$ and $y(t)$ is the system output.

Fitness function $f = 1/J$, and the greater the fitness, the higher the accuracy of particles.

FIGURE 4: Parameter optimization process.

FIGURE 5: Optimal solution iterative process.

The parameter optimization process is shown in Figure 4 [17, 18].

6. Optimization Design of Desulfurization Dust Removal Centrifugal Pump

6.1. Parameter Determination. By calculating, the constraints could be obtained as follows: $63.7 \text{ mm} < D_1 < 95.6 \text{ mm}$, $21.6 \text{ mm} < b_1 < 32.4 \text{ mm}$, $235.4 \text{ mm} < D_2 < 274.6 \text{ mm}$, $9.0 \text{ mm} < b_2 < 13.5 \text{ mm}$, $23^\circ < \beta_1 < 40^\circ$, $10^\circ < \beta_2 < 40^\circ$, $90^\circ < \varphi < 130^\circ$, and $4 < Z < 9$.

TABLE 4: Impeller parameter optimization results.

Parameters	D_1 (mm)	b_1 (mm)	D_2 (mm)	b_2 (mm)	β_1 (°)	β_2 (°)	φ (°)	Z
Prototype pump	90	23	260	12.5	30	30	120	6
Optimization pump	94	26	262	11	28	18	110	6

FIGURE 6: Optimization pump flow field simulation. (a) Optimized pressure contour diagram. (b) Optimized velocity contour diagram. (c) Optimized cavitation contour diagram.

Particle size $N = 60$, maximum number of iterations $\max DT = 200$, learning factor $c_1 = c_2 = 1.624$, inertia weight coefficient $\omega = 0.628$, crossover probability $p_c = 0.576$, mutation probability $p_m = 0.01 - [1 : 1 : N] * 0.01 / N$, and weight $\omega_1 = 0.003$, $\omega_2 = 0.87$, and $\omega_3 = 96$.

6.2. Analysis of Results after Optimization. The immune particle swarm algorithm is programmed by Matlab 7.0 software, and the iterative result of optimal solution is shown in Figure 5.

The optimized parameters of impeller are shown in Table 4.

6.3. Simulation of Flow Field after Optimization. According to the optimized parameters, the parameters are remodeled, and the CFD analysis is carried out, as shown in Figure 6.

As can be seen from Figure 6(a), the pressure distribution on the volute of the optimization pump is relatively uniform, the energy loss in the volute is small, and the vortex phenomenon between blades is avoided.

As can be seen from Figure 6(b), the velocity of the fluid near the volute wall of the optimization pump is relatively uniform, and the vortex phenomenon is avoided.

As can be seen from Figure 6(c), the cavitation near the inlet of the impeller of the optimization pump is obviously reduced, and the cavitation phenomenon is basically eliminated.

From the optimized pressure contour diagram, velocity contour diagram, and cavitation contour diagram, it can be seen that the effect of the initial design structure of centrifugal pump has been significantly improved, and the overall performance of centrifugal pump has a certain promotion.

6.4. Simulation of External Characteristics. In order to verify the feasibility of the optimization scheme, the external characteristics of the prototype pump and the optimization pump under rated operating conditions are simulated respectively (where rated flow $Q_d = 50 \text{ m}^3/\text{h}$), and the simulation results are shown in Table 5.

According to the simulation results of the external characteristics, the optimization pump efficiency is improved by

TABLE 5: Simulation results of external characteristics.

Optimization index	Prototype pump	Optimization pump	Optimization rate (%)
η (%)	82.28	92.23	12.09
H (m)	19.31	21.43	10.98
$NPSH_r$ (m)	1.04030	0.94876	8.80

FIGURE 7: IH model chemical pump.

FIGURE 8: External characteristic test bench. (1) Water tank, (2) vacuum control valve, (3) inlet control valve, (4) vacuum table, (5) pressure gauge, (6) flow meter, (7) flow control valve, (8) test pump, (9) motor, and (10) water tank.

12.09%, the head is increased by 10.98%, and $NPSH_r$ is reduced by 8.80%. At the same time, $\beta_2 Z^{0.773}$ before and after optimization are 119.85 and 71.91, respectively, and the curve hump is eliminated.

7. Experimental Verification

In order to verify the accuracy of immune particle swarm optimization, an external characteristic test bench is built with IH model horizontal stainless steel chemical centrifugal pump, as shown in Figures 7 and 8, respectively. IH model chemical pump is mainly composed of pump body, shaft key, impeller nut, packing ring, brake pad, packing gland, shaft, pump cover, and suspension bearing components. The chemical pump has the advantages of reasonable and reliable

layout of water conservancy, small size, light weight, good anticavitation performance, low power consumption, easy maintenance, and high work efficiency.

Based on the optimized impeller structure parameters given in Table 4, the impeller is made as shown in Figure 9, and the impeller material is made of transparent rigid polyvinyl chloride. The internal flow field of centrifugal pump is measured under 6 working conditions of $0.2Q_d$, $0.4Q_d$, $0.6Q_d$, $0.8Q_d$, $1.0Q_d$, and $1.2Q_d$. Figure 10 shows the external characteristic curves of the prototype pump and the optimization pump.

According to the pump characteristic curves, the experimental values of the optimization pump and the prototype pump are in good agreement, which can accurately reflect the change trend of η , H , and $NPSH_r$ with the variation of flow rate.

FIGURE 9: Test impeller.

FIGURE 10: External characteristic curves of prototype pump and optimization pump. (a) η - Q , (b) H - Q , and (c) NPSH_r - Q .

There is a small error between the simulation value and the experimental value; the main reason is that, in the numerical simulation experiment of centrifugal pump hydraulic design, the leakage of impeller sealing ring, volume loss caused by axial force, and mechanical loss caused by centrifugal pump in the working process is not considered.

The experimental results of each index of prototype pump and optimization pump under different working conditions are extracted from Figure 10, as shown in Table 6.

As can be seen from Table 6, under different working conditions, the optimization pump efficiency and head are all larger than the prototype pump, and the optimization pump NPSH_r is less than the prototype pump. At the rated flow rate,

the optimization pump efficiency is increased by 13.30%, the head is increased by 11.52%, and NPSH_r is decreased by 10.14%, which achieve the desired optimization goal.

In summary, every index of the optimization pump has been significantly improved, and it can be concluded that the immune particle swarm optimization algorithm is feasible; the control strategy is further verified by the centrifugal pump external characteristic test.

8. Conclusion

- (1) The hydraulic design of desulfurization dust removal centrifugal pump was carried out by the velocity

TABLE 6: Experimental results of prototype pump and optimization pump.

Indexes	Q (m ³ /h)					
	10	20	30	40	50	60
Prototype pump η (%)	32.12	51.77	63.36	72.69	74.43	71.24
Optimization pump η (%)	33.46	55.06	69.44	79.17	84.33	79.71
$\Delta\eta$ (%)	4.17	6.36	9.60	8.91	13.30	11.89
Prototype pump H (m)	20.36	20.11	19.49	18.53	18.06	15.97
Optimization pump H (m)	22.97	22.22	21.55	21.41	20.14	17.64
ΔH (%)	12.82	10.49	10.57	15.54	11.52	10.46
Prototype pump NPSH _r (m)	1.09198	1.05678	1.02558	1.01914	0.95987	0.84287
Optimization pump NPSH _r (m)	0.97007	0.9584	0.92943	0.88455	0.86255	0.76461
Δ NPSH _r (%)	11.16	9.31	9.38	13.21	10.14	9.28

coefficient method, and the main structural parameters of impeller and volute were obtained. The three-dimensional model of centrifugal pump was established by CFTurbo 10.0 software, and the centrifugal pump was numerically simulated and analyzed by PumpLinx 3.4 software.

- (2) An optimization mathematical model with the highest efficiency and the lowest NPSH_r as the objective function was established under the condition of no curve hump. A total of eight indexes of D_1 , b_1 , D_2 , b_2 , β_1 , β_2 , ϕ , and Z were optimized by the immune particle swarm algorithm.
- (3) Through the simulation and analysis of the optimization results, the optimization pump efficiency was increased from 82.28% to 92.23%, the head was increased from 19.31 m to 21.43 m, and NPSH_r was decreased from 1.04030 m to 0.94876 m; the curve hump problem was eliminated. The overall performance of centrifugal pump was improved significantly, and the feasibility of immune particle swarm optimization was verified.
- (4) Based on the IH model chemical pump, the external characteristic test bench was built, and the external characteristic curves of each index parameter of centrifugal pump under different working conditions were obtained. The variation law of experimental values of all index parameters was basically consistent before and after optimization, and compared with the prototype pump, the experimental values of the optimization pump were significantly improved. The accuracy of the immune particle swarm optimization control strategy was verified, which provided some reference value for the structural optimization design of desulfurization dust removal centrifugal pump in the future.
- (5) Taking centrifugal pump as the research object, the main indexes of centrifugal pump were optimized by immune particle swarm optimization algorithm, which improved the hydraulic performance of centrifugal pump. Due to the limitation of research conditions, this paper only studied the optimization of pump efficiency, head, and NPSH_r, without considering the optimization of other indicators. In the following research work, based on immune

particle swarm optimization control strategy, the influence of the main geometric parameters of centrifugal pump on the pump characteristics will be considered comprehensively, in order to improve the working performance of centrifugal pump.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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