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Original Research Paper

Sulphur Removal with Controllable Fan Structure Design and Performance Prediction Research

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ABSTRACT

In order to obtain the sulphur removal with controllable fan's optimal control structure, we designed the structure according to the given conditions, determined the structure and performance indicators, and got the fan structure parameters which are used for the three-dimensional entity modelling. The fan flow field was studied by numerical simulation. Designing the fan's L9(3^4) orthogonal test table, choosing the impeller diameter, blade import installation angle and outlet blade installation angle for the orthogonal experiment of four factors, completed the orthogonal experiment and analysed the experimental results to get the process parameters optimization direction of each evaluation index influence situation. By using genetic algorithm to multi-objective optimization of fan noise and efficiency, we obtained the optimum technological parameters of centrifugal fan impeller combination as: the impeller diameter 1.18 mm, the impeller diameter imported 0.33 mm, inlet installation angle 31.69°, and the outlet blade installation angle 82.66°. Based on the flow field simulation and use of the numerical analysis principle, the performance prediction model of fan efficiency desulphurization and dust removal was obtained.

INTRODUCTION

With today's rapid economic development, the huge global energy consumption and the growing environmental pollution, the world has put a green, sustainable development as a basic state policy. Huge energy consumption and serious noise pollution of fluid machinery design, whose main purpose is to improve the efficiency and reduce the noise. High efficiency and high reliability of centrifugal fan are of great significance to save energy. At the same time, developing the high efficiency and low noise fan is the need of the whole society, and another direction of fan industry.

Computational fluid dynamics is an emerging discipline based on classical fluid dynamics, numerical methods and computer technology and taking the numerical analysis method hydrodynamic phenomena. Internal flow centrifugal fan is a high Reynolds number with low viscosity, highly complex three-dimensional unsteady compressible flow. Because it contains rotating parts, describing its flow control equations contain the centrifugal and Coriolis force term items, but also consider the actual situation distortion into the circumferential flow, axial and radial clearance, fluid-structure coupling, multiphase flow, and chemical reactions and real gas effects. The particularity and the extreme complexity of the internal flow of fan put forward a very high request to the numerical calculation, and the internal flow numerical simulation accuracy depends mainly on the control equations,turbulence model and numerical calculation method (Ju 2002, Bradley et al. 2000, Jacqueline et al. 2004, Huang et al. 1995, Li, 1988, Lan et al. 2006). Research literature on the structural parameters of the fan impeller performance impact is limited to a single structure parameters affecting the efficiency of the fan, but did not establish objectives including the number of impeller blades, blade outlet installation angle, the impeller outlet width and other key structural parameters on the performance of the fan function, and not established the performance prediction model of the dust desulphurization removal fan (Lan et al. 2006, Tisza 2004). This paper using the desulphurization dust removal fan as the research object, gives the fan flow field numerical simulation and experiments to optimize the combination of methods to analyse the desulphurization impeller centrifugal fan with its structural parameters that affect performance, and structural design of the orthogonal experimental samples. The experiment used the genetic algorithm to optimize the parameters of the fan structure to find the optimal combination of structural parameters. According to the relationship between fan efficiency and structural parameters, used the data regression method to derive empirical equation to predict the performance of desulphurization dust removal fan.

FLOW FIELD SIMULATION OF THE DESULPHURIZATION DUST REMOVAL FAN

Centrifugal fan flow field includes the inlet flow field, impeller and volute flow field. Assemble the three flow

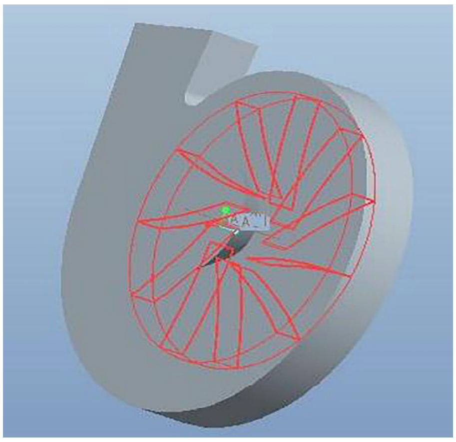

Fig. 1: Centrifugal fan overall flow model.

model according to the method for assembling a solid model, and get the overall flow model centrifugal fan (Fig. 1).

Fluent software was used to the desulphurization dust removal fan flow field numerical simulation to get the desulphurization dust removal fan flow field numerical simulation of the static pressure (Fig. 2), dynamic pressure (Fig. 3) and total pressure (Fig. 4). Fig. 2 shows the impeller and through the outlet in contact position, the static pressure is negative. Because of the rotation of the impeller, the air flowing along the impeller volute air reduction, the pressure is reduced. In the volute basin, further away from the axis of rotation of the greater static pressure, indicates that when the volume changes with the large passage and the velocity decreases, the gas is converted to kinetic energy part of the potential energy (pressure energy).

Fig. 3 shows that the inflow of gas from the inlet after the impeller, the dynamic pressure will increase along the impeller, and a slightly higher pressure region is formed in the working surface of the blade, the pressure is higher than the leaf blade on the back. After air entering the volute, the dynamic pressure is reduced; the closer it is from the outlet, the greater the watershed boundary area, and the area of reduced dynamic pressure is also increased.

Fig. 4 is a superimposed effect diagram of Fig. 2 and 3. The total pressure is equal to the sum of the dynamic pressure and static pressure. Total pressure and therefore the flow field through maps; if we know the outlet flow field within the fan total pressure and total pressure of imports, we can know the fans total pressure, and thus predict the performance of the fan.

Table 1: Factors and levels of the Orthogonal test.

Factor	Level 1	Level 2	Level 3
A/mm	0.2	0.3	0.4
B/mm	1.0	1.1	1.2
C°	28	30	32
D°	78	80	82

DESULPHURIZATION DUST REMOVAL FAN FLOW FIELD ORTHOGONAL EXPERIMENT AND RESULT ANALYSIS

Orthogonal Test

This paper chooses the sulphur removal efficiency and the noise of the fan as evaluation indexes of orthogonal experiment. The impeller inlet diameter, impeller diameter, blade inlet installation angle, blade outlet installation angle for the four-factor orthogonal experiment were selected and are represented by A, B, C, D. According to the results of the theoretical design of centrifugal fan, each factor takes three levels. The factor level is given in Table 1.

After determine the value of factors and levels of the orthogonal experiment,according to the interaction between orthogonal experimental factors and levels and factors to select the appropriate table of orthogonal experiment, this experiment is a 4 factors 3 levels experiment, which select the fan efficiency, noise as fan performance evaluation index and investigated by the orthogonal experiment, and the results are shown in Table 2.

Analysis of Experimental Results

To analyse the results of the orthogonal experiment, often the range analysis method is used. Range analysis formula is as follows:

$$\left.\begin{aligned} K_{mn} &= \sum Q_{mn} \\ k_{mn} &= K_{mn}/2 \\ R_m &= k_{m\max} - k_{m\min} \end{aligned}\right\} \qquad \ldots(1)$$

Where,

K_{mn} - The first m factors corresponding to the sum of the comprehensive index of n levels

Q_{mn} - The first under the m a n level comprehensive index

k_{mn} - The average of the Kmn

R_m - Range m-th factor

km_{max} - Mean maximum value of the m-th level of the various factors

km_{min} - Mean minimum m-th factor under various levels.

***The fan efficiency of trend analysis of structural parameters*:** According to the formula (1), and range analysis Table 2, we get the size of the influence of process parameters

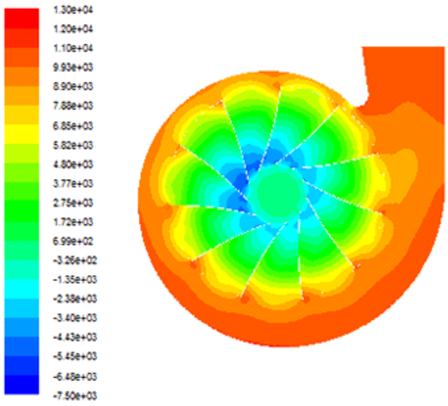

Fig. 2: Desulphurization fan static pressure flow field.

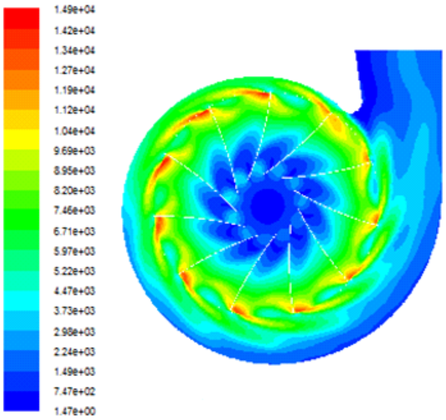

Fig. 3: Hydrodynamic flow field desulfurization dust blower.

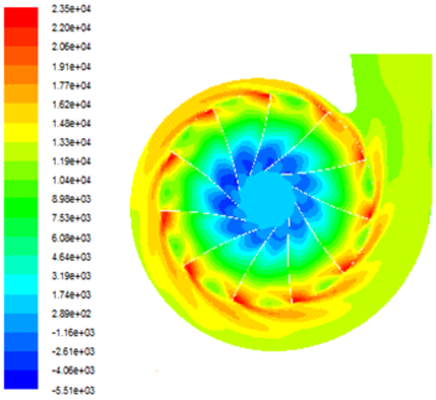

Fig. 4: Desulphurization fan total pressure flow field.

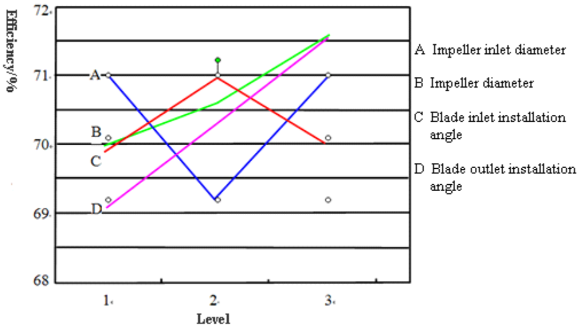

Fig. 5: The influence of various factors on the efficiency trend chart.

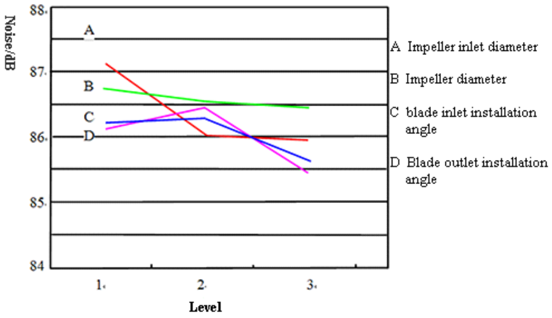

Fig. 6: The influence of factors on the noise figure.

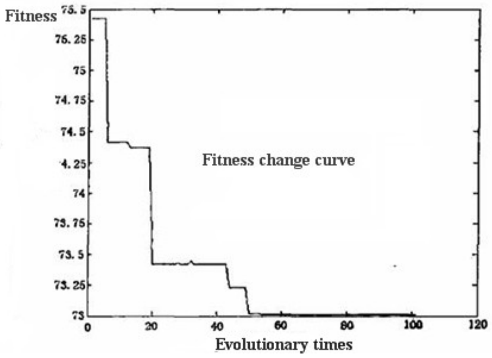

Fig. 7: The fan efficiency optimization process.

Table 2: $L_9(3^4)$ orthogonal test table.

Num	Factors				Evaluation Index	
	A	B	C	D	Efficiency %	Noise db
1	0.2	1.0	28	78	68.918	88.34
2	0.2	1.1	30	80	69.156	87.26
3	0.2	1.2	32	82	69.326	84.52
4	0.3	1.0	30	82	71.156	84.86
5	0.3	1.1	32	80	71.269	86.69
6	0.3	1.2	28	78	70.126	85.47
7	0.4	1.0	32	80	71.153	85.50
8	0.4	1.1	30	78	69.517.	86.49
9	0.4	1.2	28	82	71.340	84.58

on the fan efficiency. Range analysis process parameters on the efficiency of the analysis of the results are given in Table 3.

In Table 3, the R_m reflects the range of experimental indicators with changes in the level of the first m factors. The greater the value of R_m, that illustrates the impact of the factors on the experiment index, the more important it is. Table 3 shows that the effect of experimental factors on the efficiency of the evaluation index sequence is: D > B > A > C. The blade outlet angle has the most profound effect on the efficiency and then the impeller diameter and impeller inlet diameter, while blade inlet angle has the minimal impact. The influence of various factors on the efficiency is shown in Fig. 5.

***The influence of structure parameters on the fan noise trend analysis*:** According to the results of formula (1), and range analysis Table 2, we get the influence of various process parameters on the fan noise in size. The results are depicted in Table 4.

As can be seen from Table 4, the experimental evaluation of noise factors effect has the order of: D> A> B> C.

Fig. 6 shows that the blade outlet angle has the largest influence of noise than the impeller diameter while the blade inlet angle is the minimal.

FAN STRUCTURE PARAMETER MULTIOBJECTIVE OPTIMIZATION

The Objective Function

Established a comprehensive weighted objective function as:

$$Y_j^* = \sum_{j=1}^{4}\left[Y(j)\times Wi\right] \qquad ...(2)$$

Where,

Y_j^* - Comprehensive weighted score values

Y(j) - Experimental results on the number of points

Wi - Experimental evaluation index weight

The author has used the knowledge of mathematical statistics to analyse the results score. The experiment of each evaluation index score value respectively, according to the importance of the evaluation index, and multiplied by the appropriate weighting coefficient as the experimental evaluation index score, the score is obtained as each experiment comprehensive weighted score values.

On the basis of orthogonal experiment table, the structural parameters of centrifugal fan impeller combination generated by the fan structure were carried out in nine flow field numerical simulation experiment. Adopting comprehensive weighted score evaluation results, we get nine fan impeller structure parameters of the experimental group evaluation results. Numerical experiments on the index number of each experiment were percentile comparisoned score, and the score value is expressed as Y(j), where j represents the jth experiment number. Press percentile calculation, the experimental results for the maximum Aj_{max} 100 points, the lowest value Aj_{min} for 84 points, and according to the size of the respective values are arranged, a difference of two values of two adjacent points.

Nine comprehensive sets of orthogonal experimental weighted score results are given in Table 5. From Table 5 we known that No. 5 has the highest value of the overall weighted score, which is 98.8, process parameters for A3B1C3D2.

Centrifugal Fan Performance Hybrid Optimization Method

To get the best multi-index structure parameter, need a comprehensive orthogonal weighted scores for statistical analysis in order to quickly find the optimum combination of pa-

Table 3: Range analysis table of process parameters on efficiency.

Average	Factors			
	A	B	C	D
K1	218.6	222.4	221.6	218.9
K2	220.9	218.2	218.8	220.9
K3	224.0	224.8	225.0	226.8
k1	69.9	71	69.8	69.1
k2	70.6	68.7	70.9	70.3
k3	71.7	70.9	70	71.6
R	1.8	2.3	1.1	2.5

Table 4: Range analysis table of process parameters on noise.

Average	Factors			
	A	B	C	D
K1	262.11	258.7	258.39	260.30
K2	257.01	260.4	258.61	259.45
K3	256.56	255.5	256.91	253.96
k1	87.37	86.23	86.18	86.76
k2	85.67	86.80	86.20	86.48
k3	85.52	85.16	85.63	84.65
R	1.85	1.64	0.57	2.11

rameters stable, and get a reasonable optimization. Select 4 out of 9 groups of weighted composite scores that have been made in the highest four orthogonal groups and use them as a composite shape optimization of complex-shaped initial vertex, and use a composite shape optimization method to optimize the parameters of the fan structure.

First, using the formula to synthetically weight score of orthogonal experiment index numerical in each experiment, and to optimize the error within 0.01 (Chen et al. 2010). Calculated at 100 on the experiment index Aj_{max} meter as a maximum of 100 points and the lowest Aj_{min} meter for 80 points. According to the size of the various numerical arrangement, the adjacent two numerical difference between two points. The fan performance complex method to optimize the process and results are given in Table 6.

Table 6 shows that group 8 scores the highest. That is, the best combination is the eighth group, which is 97 points.

Centrifugal Fan Genetic Algorithm to Optimize Performance

Genetic algorithm is the most widely used ways of intelligent optimization methods and the most successful algorithm. Its basic idea is to construct a fitted function according to the objective function. In order to get the optimal solution of the problem, evaluate population, genetic arithmetic, choose through many generations of breeding the composed of multiple solutions and obtain the best individual adaptive value (Zhou and Sun, 1999).

***Fitness function*:** There are two optimized goals in this paper, fan efficiency and fan noise. So this is a multi-objective optimized problem. Linear summation of the fitness function, multiplying the weight on two targets respectively, so that the multi-objective problem can be transformed into single objective problem. With the change of weight, optimization results vary. In view of the actual situation, choose the right weights to obtain the optimal solution.

Global optimization fitness function is as follows:

$$\min F=-m\eta-nl+k \qquad \ldots(3)$$

Where,

η - The fan efficiency

l - The fan noise

m,n - The weight of the fan efficiency and total pressure, $m+n=1$

k - Constant

***Optimization of parameters and constraints*:** The impact of the fan's structural parameter on its performance varies greatly, such as the impeller inlet, outlet diameter of the impeller inlet, outlet installation angle, blade inlet, outlet width, shape and collector volute tongue clearance, etc. (Peng 2001). Their influence on the performance vary significantly. According to theoretical analysis and actual situation, under the premise that leaf type, spiral case and current collector are unchanged, select impeller's inlet and outlet diameter, install at the inlet and outlet of the blades as optimized variables. All variables change within the scope which was defined by orthogonal test before.

***The optimized results*:** Genetic algorithm chooses real number coding, sets the population size of 100, the evolution algebra for 100 times, crossover probability 0.8, mutation probability 0.01. Considering the actual case, after running for a while, some fan would lead to fan flow or pressures' insufficience, because of the increasing resistance of pipelines. The optimized goal is to make performance curve constant and the fan efficiency at the same time, while the noise is reduced. Therefore, the efficiency and noise weights are selected as 0.7 and 0.3, respectively.

Fig. 7 is the process of fan efficiency optimization. It shows that after 50 times evolutionary computation, we can find the optimal value of the total pressure and efficiency. The optimal structural parameters of fan impeller are: outlet blade installation angle of 83.26, the impeller import width of 0.31, blade inlet installation angle 32.34 , impeller width of 1.15, efficiency and the noise of the optimization results are 73.02% and 85.55 respectively.

Table 5: The results of orthogonal experiment and comprehensive weighted score.

Num	Efficiency of the fan(%)		Noise of the fan (dB)		Comprehensive weighted score Y*
	Numerical	Evaluat-ion	Numerical	Evaluation	
1	71.118	94	85.85	92	93.4
2	70.456	92	87.63	100	94.4
3	72.326	96	83.24	84	92.4
4	70.156	90	84.71	86	88.8
5	73.569	100	86.91	96	98.8
6	73.226	98	86.60	94	96.8
7	70.153	88	85.31	88	88
8	69.517	86	85.72	90	87.2
9	68.340	84	87.22	98	88.2

Table 6: Complex method for fan performance comprehensive weighted score experimental process.

Num	Point	Inlet Diameter (mm)	Impeller Diameter (mm)	Import Installati on Angle (℃)	Export Instal-lation Angle (℃)	Efficiency (%)		Noise (mm)		Com-prehensive Weighted Score Y*
						Num-erical	Eval-uation	Num-erical	Eval-uation	
1	Vertx	0.30	1.10	29	81	70.40	84	87.65	98	88.2
2	Vertx	0.30	1.10	30	81	70.56	80	87.34	96	84.8
3	Vertx	0.31	1.20	31	82	71.65	88	85.65	92	89.2
4	Vertx	0.31	1.20	32	82	72.30	96	85.62	92	94.8
5	Vertx	0.32	1.20	32	82	72.32	98	84.20	80	92.6
6	Reflection point	0.313	1.103	31.04	81.13	71.55	86	84.32	82	84.8
7	Reflection point	0.318	1.132	30.26	81.65	71.63	88	85.32	88	88
8	Reflection point	0.329	1.186	31.69	82.66	72.68	100	84.59	90	97
9	Reflection point	0.327	1.152	31.56	81.46	71.36	86	84.88	86	86
10	Reflection point	0.338	1.069	30.71	80.24	70.46	84	87.75	100	88.8
11	Contract points	0.316	1.263	31.87	81.96	72.03	90	86.32	94	91.2
12	Contract points	0.320	1.149	31.18	82.05	72.15	94	84.55	84	91
13	Contract points	0.326	1.229	31.20	82.07	72.14	92	84.56	82	89

***The box optimization and genetic algorithm optimization*:** The optimized result of desulphurization dust removal fan structure parameters of the complex optimization and genetic algorithm are given in Table 7.

From Table 7 we can find that: (1) The fan efficiency obtained from the optimized genetic algorithm is higher than the box optimized results. On the condition that other structural dimensions are the same, the optimization of genetic algorithm is a little better than the box method. (2) By comparing the noise, genetic optimization algorithm's ability to reduce noise is better than the box method. Genetic optimization design is more suitable on desulphurization fan structural parameters than box.

SULPHUR REMOVAL CENTRIFUGAL FAN PERFORMANCE PREDICTION

Considering the information and research experience of fan design in home and abroad, we set model as:

$$\eta = KD_0^{x} D_2^{y} \beta_{b_1}^{h} \beta_{b_2}^{z} \quad ...(4)$$

Where,

η - Sulphur removal efficiency of centrifugal fan

K - The discharge coefficient

D_0 - Sulphur removal centrifugal fan impeller entrance diameter (m)

D_2 - Sulphur removal centrifugal fan impeller diameter (m)

Table 7: Compound optimization algorithm with genetic algorithm optimization results contrast table.

	Impeller diameter (mm)	Blade installation Angle of imports(°)	Impeller diameter imported(mm)	Outlet blade installation Angle (°)	Efficiency(%)	Noise(db)
Box Optimization	1.18	31.69	0.33	82.66	72.68%	84.59
Genetic Algorithm	1.15	32.34	0.31	83.26	73.02%	83.02

Table 8: The relationship between surface impeller structural parameters and efficiency.

Impeller inlet diameter (m)	Impeller diameter (m)	Leaf blade outlet Angle (°)	Leaf blade inlet Angle (°)	Efficiency(%)
0.30	1.10	81	30	70.56
0.31	1.10	82	30	71.65
0.31	1.20	82	32	72.30
0.32	1.20	82	32	72.52
0.326	1.129	82.07	31.69	72.14
0.329	1.186	83.66	31.56	72.58

β_{b_1} - Leaf blade inlet angle (degree)

β_{b_2} - Leaf blade outlet angle (degree)

We get the flow law of sulphur removal with the centrifugal fan flow field. And through the range analysis, we get the influence trend of sulphur removal with the structure parameters on the performance of centrifugal fan. The blade outlet angle has the most profound effect on the efficiency and then the impeller diameter and impeller inlet diameter, while blade inlet angle has the minimal effect. Through the process of dealing with data of the parameters affecting the fan efficiency, get the factors' trend of the efficiency of desulphurization dust removal fan. Also we can get the expression of desulphurization dust removal fan impeller structure parameters from deducing, that is the performance prediction formula of sulphur removal.

Through the fan flow field numerical simulation results, we can obtain the efficiency relation of the structural parameters of centrifugal fan impeller and the fan efficiency (Table 8). According to the Table 8 data, we can get each specific numerical parameters.

$$K1.1^{x}0.3^{y}81^{z}30^{\mathrm{h}} = 70.56$$

$$K1.2^{x}0.32^{y}82^{z}32^{\mathrm{h}} = 72.52$$

$$K1.2^{x}0.31^{y}82^{z}32^{\mathrm{h}} = 72.30$$

$$K1.186^{x}0.329^{y}83.66^{z}31.69^{\mathrm{h}} = 72.88$$

Simultaneous equations are obtained as:

$$x = 0.84$$

$$y = -1.46$$

$$z = 0.7e - 1$$

$$h = 0.34$$

In summary, the desulphurization efficiency of dust removal fan performance prediction model is:

$$\eta = KD_0^{0.84} D_2^{-1.46} \beta_{\mathrm{b1}}^{0.34} \beta_{\mathrm{b}_2}^{0.7\mathrm{e}-1} \quad ...(5)$$

CONCLUSION

(1) In order to design fan's turbine structures and to study fan's performance, we numerically simulate desulphurization centrifugal fan flow field.

(2) From the Design L9 (34) orthogonal experiment table, select the impeller of the imported diameter, impeller diameter, blade installation angle and outlet blade installation angle, as four factors of orthogonal experiment; choose efficiency and noise as the evaluation index; do the orthogonal experiment to sulphur removal centrifugal fan flow field, and range analyse the results. The effects of experimental factors on the efficiency of the order is: leaf blade outlet angle > impeller diameter > impeller inlet diameter > impeller blade inlet angle. The impact on the noise sequence is: Leaf blade outlet angle > impeller inlet diameter > impeller diameter> blade inlet angle.

(3) Optimizing sulphur removal centrifugal fan structure parameters by genetic algorithm, get the best process parameter combination for the impeller diameter of 1.15 mm, impeller import 0.31 mm in diameter, inlet installation angle of 32.34°, the outlet blade installation Angle of 83.26°.

(4) Based on numerical simulation of desulphurization internal flow field of centrifugal fan, get a list of desulphurization fan curve structural parameters and performance. Use data regression method to deduce the

desulphur-ization dust removal with the fan efficiency and performance prediction model between flow and structure parameters.

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