# Flow field simulation and structural optimization design of cyclone separator based on Fluent

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# 플루언트(Fluent) 기반의 사이클론 분리기의 유동장 시뮬레이션 및 구조 최적화 설계

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**Abstract** In recent years, China has been committed to promoting energy-saving and emission-reduction measures across various industries. In the steel production process, wet dust removal technology is widely adopted. However, the existing dust removal equipment, particularly the cyclone separator, suffers from insufficient dewatering efficiency, leading to a "rain" phenomenon during waste gas emission, which in turn causes secondary environmental pollution. The design of the guide vane wheel is crucial for enhancing the dewatering efficiency of the cyclone separator. Therefore, this study, based on fluid mechanics and flow field analysis theories, utilizes the FLUENT software to simulate and analyze the blade angle and flow area of the guide vane wheel. By combining the flow field analysis and simulation results with the specific parameters of the equipment, the structure of the cyclone separator's guide vanes was optimized and applied to actual production. Practice has proven that the optimized cyclone separator significantly improved dewatering efficiency and effectively reduced the rain phenomenon around the chimney, thereby enhancing environmental quality. The research of this project is conducive to the later application of artificial intelligence, the Internet of Things, big data, cloud computing, and other technologies in the 5G+ smart steel factory of the steel industry. It lays the foundation for using digital twin technology to carry out 3D modeling of the plant area, in order to facilitate the reappearance and simulation of the entire production process.

**Key Words :** cyclone separator; guide impeller; dewatering efficiency; flow field simulation; structural optimization.

**요 약** 최근 중국은 여러 산업에서 에너지 절약과 배출 감소 조치를 적극적으로 추진하고 있다. 철강 생산 과정에서는 습식 집진 기술이 널리 사용되고 있다. 그러나 기존의 집진 장비 중에서 사이클론 분리기의 탈수 효율이 부족하여 배기가스 배출 시 '낙우' 현상이 발생하고, 이는 환경에 2차 오염을 유발한다. 유도 임펠러의 설계는 사이클론 분리기의 탈수 효율을 향상시키는 데 매우 중요하다. 따라서 본 연구는 유체 역학 및 유동장 분석 이론을 기반으로 FLUENT 소프트웨어를 사용하여 유도 임펠러의 블레이드 경사각과 유동 면적을 시뮬레이션 분석하였다. 유동장 분석 및 시뮬레이션 결과를 통해 장비의 구체적인 파라미터와 결합하여 사이클론 분리기의 유도 블레이드 구조를 최적화하고 이를 실제 생산에 적용하였다. 실험 결과, 최적화된 사이클론 분리기는 탈수 효율을 크게 향상시켰고, 동시에 굴뚝 주변의 낙우 현상을 효과적으로 감소시켜 환경 질을 개선했다. 이 프로젝트의 연구는 철강 산업의 5G+ 스마트 철강 공장에 인공지능, 사물인터넷, 빅데이터, 클라우드 컴퓨팅 등의 기술을 향후 적용하는 데 기여한다. 디지털 트윈 기술을 사용하여 공장 지역의 3D 모델링을 수행하는 기초를 마련하고, 전체 생산 과정을 재현하고 시뮬레이션하는 데 도움이 된다.

**주제어 :** 사이클론 분리기; 유도 임펠러; 탈수 효율; 유동장 시뮬레이션; 구조 최적화

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# 1. Introduction

In the current context of rapid global economic development, as one of the basic industries, the steel industry is facing increasing environmental protection pressures while promoting social progress. Especially the dust and harmful gases produced in the converter steelmaking process will directly lead to environmental pollution, so dust removal in the steelmaking process is crucial. There are two traditional steelmaking dust removal methods: dry dust removal and wet dust removal, and the current mainstream is wet dust removal. The swirl separator is an important piece of equipment for wet dust removal, installed between the fan and the emission chimney in the wet dust removal system, mainly used to remove mechanical water from flue gas and reduce the dust content in the emitted flue gas. After visiting and investigating many enterprises, it is found that the existing swirl separators have a low dehydration efficiency, and the emitted flue gas contains a large amount of mechanical water, which falls on the ground around the chimney after being discharged. When the environmental temperature is low, a "rain" phenomenon similar to rain will occur, and a thin layer of ice will form on the ground in winter, causing negative impacts on production work and there are certain hidden safety hazards. Therefore, it is very important to improve the separation efficiency of the swirl separator. The study of swirl separators based on FLUENT is beneficial for later three-dimensional modeling and data monitoring of flue gas separation systems, laying a certain foundation for real-time monitoring of separation efficiency, thereby promoting the construction of production process simulation systems.

Through literature review and research, it is found that the main factors affecting the separation efficiency of the swirl separator include the blade angle of the guide vane wheel, the flow area of the guide vane wheel, the height of the swirl section, the insertion depth of the exhaust pipe, and the flue gas treatment volume. This paper only analyzes the factors related to the guide vane wheel and takes the swirl separator of a certain steel enterprise as an example for experimental verification. Based on fluid mechanics and flow field analysis, a three-dimensional model of a certain swirl separator is created, and fluid analysis software such as MESH, FLUENT, and CFD-POST is used to simulate the flow field of the blade angle and flow area of the guide vane wheel, and analyze the impact of changes in the parameters of the swirl separator on the separation efficiency of droplets under different states, and then optimize the structure of the guide vane wheel, and then verify the experiment, in order to solve the "rain" problem near the chimney emission port and reduce the dust content in the emitted flue gas, and reduce environmental pollution.

[Fig. 1] Rain phenomenon around the chimney

# 2. Swirl Separator and Flow Field Analysis Foundation

## 2.1 Structure and Working Principle of Swirl Separator

The structure of the swirl separator will vary depending on the application. This paper takes the swirl separator used for water vapor separation in the metallurgical industry as the research object. The equipment mainly consists of an exhaust pipe, a water baffle, a cylinder, a guide vane wheel, an intake pipe, a drainage pipe, etc. The flue gas from the converter wet dust removal system contains a large amount of mechanical water. The flue gas containing mechanical water enters the device through the intake pipe of the swirl separator, and the flue gas mixed with mechanical water moves upward along a spiral line, passing through the guide vane wheel arranged in the middle of the device. The flow area becomes smaller, the flue gas velocity increases, the droplets are thrown towards the cylinder wall of the swirl separator under the action of centrifugal force, and the small droplets coalesce into large droplets. Then the large droplets flow down along the cylinder wall under the action of gravity and are discharged through the drainage pipe. In addition, some small droplets, after hitting the cylinder wall, flow up along the cylinder wall to the water baffle under the action of the flue gas, coalesce into large droplets and are removed by the separator. The separation efficiency is the most important performance evaluation index of the swirl separator. For gas-liquid swirl separators (continuous phase is gas, separation phase is liquid), the ratio of the mass of the separated phase at the inlet and outlet is usually used to define the separation efficiency[1]. The formula is as follows.

$$\eta 1 = \frac{m1 - m2}{m1} \times 100\% \quad (1)$$

Where $\eta 1$ is Gas-liquid swirl separator separation efficiency; m1 is the total mass flow rate of liquid particles at the inlet of the gas-liquid swirl separator, kg/s; m2 is the total mass flow rate of liquid particles at the outlet of the gas-liquid swirl separator, kg/s.

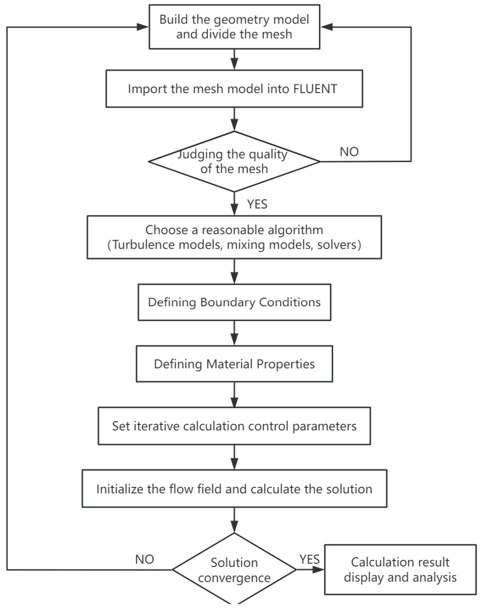
In this paper, the concept of grade efficiency will be used during the research process, and each structure will be analyzed separately for six different droplet sizes of 1μm, 10μm, 20μm, 30μm, 40μm, and 50μm to analyze the separation efficiency. After adopting the grade efficiency, since the droplet sizes are all the same size, the ratio of the mass of droplets at the inlet and outlet is equal to the ratio of the number of droplets, so this paper will use the droplet tracking method to calculate the separation efficiency of the swirl separator for droplets during the simulation process, and the specific calculation formula is as follows:

$$\eta 3 = \frac{n1}{n2} \times 100\% \quad (2)$$

Where $\eta 3$ is the separation efficiency of the gas-liquid swirl separator using the droplet tracking method; n1 is the number of collected droplets, pieces; n2 is the total number of tracked droplets, pieces.

## 2.2 Computational Fluid Dynamics

Computational Fluid Dynamics (CFD) is a tool that uses electronic computers and discrete numerical analysis methods to numerically simulate and analyze fluid mechanics problems. The basic idea of solving problems by computational fluid dynamics is as follows: The physical quantities on the time domain are discretized by mathematical methods, represented by differential and difference equations, and the corresponding differential equations are transformed into a set of multivariate linear equations, which are solved by computers[2]. Then FLUENT is used for data simulation and simulation, and the calculation process is shown in Figure 2.




[Fig. 2] Calculation flow chart of FLUENT

### 2.3 Establishment of Swirl Separator Internal Flow Field Geometric Model

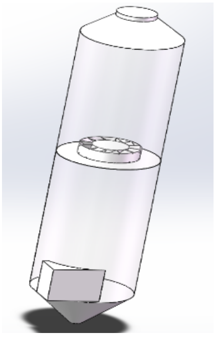
According to the equipment drawings of a certain steelmaking enterprise, the flow field inside the swirl separator is preliminarily three-dimensionally modeled, and the specific parameters are shown in Table 1, and the three-dimensional model is shown in Figure 3. During the simulation, the model will be adjusted according to the specific changes in parameters.

〈Table 1〉 Summary table of cyclone separator dimensions

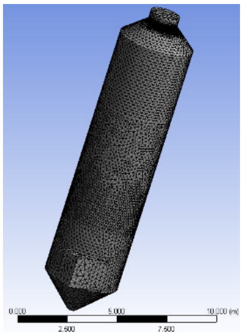
| Parameter Name | Parameter Value | Unit | Parameter Name | Parameter Value | Unit |
|---|---|---|---|---|---|
| Inlet pipe size | 1,200×1600 | mm | Upper cone total height | 1,000 | mm |
| Flue gas treatment volume | 127,000 | $m^3/h$ | Upper cone angle | 96 | ° |
| Lower cone total height | 1,700 | mm | Guide vane wheel blade angle | 45 | ° |
| Lower cone angle | 88 | ° | Guide vane wheel flow area | 2.52 | $m^2$ |
| Cylinder total height | 13,000 | mm | Exhaust pipe diameter | Φ1,500 | mm |
| Swirl section height | 5,600 | mm | Exhaust pipe insertion depth | 300 | mm |

### 2.4 Mesh Division and Independence Verification

Mesh division is the foundation of computer flow field analysis and is also the basic unit of related equation calculations. In this paper, the flow field inside the swirl separator is divided into a mesh using the MESH module in ANSYS Workbench, and an unstructured mesh is selected. During the mesh division process, a global mesh control method is used, and the size function is set to Adaptive. After the mesh division, the average value of the mesh orthogonal quality is checked to be 0.72, and the total number of elements is 225,442. There are no negative values for the minimum mesh, and the mesh division meets the analysis requirements.



[Fig. 3] Internal flow field model of the cyclone separator



[Fig. 4] The divided mesh

The sparsity of the mesh division will affect the accuracy of the simulation results and the reliability of the flow field analysis, and the mesh division is too dense, which does not significantly improve the calculation accuracy and will increase the simulation cost and extend the calculation time.

In order to improve the accuracy of the simulation, four mesh division precisions of 200 thousand, 300 thousand, 400 thousand and 500 thousand are used to analyze the separation efficiency of the swirl separator, and the analysis results are shown in Table 2. The simulation results show that under different precisions of 300 thousand, 400 thousand and 500 thousand, the separation efficiency is basically close, so to ensure the accuracy of the analysis, 400 thousand mesh division precision is used for simulation in the later stage.

〈Table 2〉 Droplet separation efficiency of different mesh generation

| Average droplet diameter | Model mesh quantity | | | |
|---|---|---|---|---|
| | 200,000 | 300,000 | 400,000 | 500,000 |
| 20㎛ | 62.41% | 70.69% | 71.38% | 71.85% |
| 30㎛ | 100.00% | 96.55% | 97.12% | 97.54% |
| Pressure loss/Pa | 974.99 | 884.32 | 885.21 | 885.41 |

## 2.5 Universal Settings and Boundary Condition Settings

a. Selection of flow model: In nature, the flow state of fluids is generally divided into two forms: laminar flow and turbulent flow. When the Reynolds number is ≤2,300, the flow state is defined as laminar flow; when the Reynolds number is ≥(8,000~12,000), the flow state is defined as turbulent flow; when the Reynolds number is between (23008,000), the flow state of the fluid is between the transition state of laminar flow and turbulent flow[3]. Most of the fluid flows seen in everyday life are turbulent, and the turbulent model is used for simulation in this paper.

b. Turbulence numerical simulation method: The current turbulence numerical simulation methods mainly include direct numerical simulation method, large eddy simulation method, Reynolds average method, and statistical average method[4]. The two-equation model uses a two-equation calculation form during the calculation, and it is the most widely used. The commonly used turbulence model is the $\kappa$-$\varepsilon$ model, which introduces a new variable, the turbulence dissipation rate $\varepsilon$, on the basis of the single-equation model, and establishes a new set of equations[5]. The common forms include the standard $\kappa$-$\varepsilon$ model, RNG $\kappa$-$\varepsilon$ model, and realizable $\kappa$-$\varepsilon$ model[6]. The standard $\kappa$-$\varepsilon$ model is used in this simulation.

c. Setting of boundary conditions: Boundary conditions are the known conditions of the flow field analysis problem. Only after determining the relevant parameters of the boundary conditions can the coupled equations have a definite analysis conclusion that meets the user's requirements. Boundary conditions and related control equations together form a complete flow field analysis solution process. In the simulation analysis of computational fluid dynamics, the boundary conditions that need to be confirmed include import boundaries, export boundaries, symmetric boundaries, wall boundaries, and periodic boundaries[7]. The fluid analyzed in this paper is flue gas carrying droplets. In the analysis process, the fluid can be regarded as a uniform fluid, so the velocity import boundary is used to define the parameters such as density, velocity, and pressure of the fluid. In the setting process of the flow field boundary conditions, the specially named and distinguished boundary system is the wall boundary condition.

d. Determination of the calculation model: When FLUENT software analyzes multiphase fluid problems, there are generally three models to choose from: the mixture model (Mixture), VOF model (Volume of Fluid), and Euler model (Eulerian). The swirl separator analyzed in this paper is a gas-liquid mixture, and the volume fraction of droplets in the mixture is far less than

10%. The droplets are considered as discrete phases, and the main phase gas has a significant impact on the movement of droplets, while the discrete phase droplets have no effect on the movement of the main phase gas. The discrete phase is used as the calculation model for the mixture phase in the subsequent flow field analysis. First, the main phase flue gas is analyzed alone, and then the related DPM discrete phase parameters are set at the inlet, including droplet diameter, droplet velocity, mass flow rate, etc., and then the iteration calculation is performed again to output the corresponding analysis results.

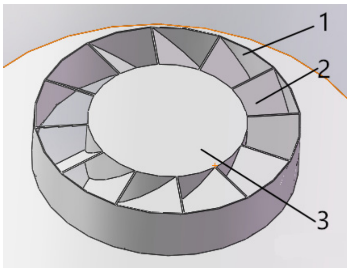
The flue gas carried by the converter wet dust removal system in this paper is water containing a small amount of dust, and the actual physical parameters such as density and viscosity are different from pure water. However, due to the influence of smelting process parameters and the performance of the dust ring water filtration system, the physical parameters of the dust ring water cannot be accurately measured. Therefore, pure water from the software material library is used to replace the droplets in the simulation analysis.

e. Setting of the solver: In this research, the SIMPLE method is mainly used for related analysis and solution.

f. Judging the convergence of the solution: In this paper, the continuity residual of the solution result is required to be below 10-4 to judge that the solution result is convergent[8].

## 3. Swirl Separator Guide Vane Wheel Structural Parameter Simulation

The guide vane wheel is the main component of the swirl separator studied in this paper, and its main structure is shown in Figure 5. After the flue gas enters the swirl separator, it spirals upward under the action of the guide vane wheel. During the process, the droplets will be separated from the main phase flue gas and thrown towards the side wall of the swirl separator under the action of centrifugal force. Now, the impact of two factors, the blade angle and the flow area of the guide vane wheel, on the dehydration efficiency of the swirl separator is mainly analyzed.




1-Outer cylinder 2-Guide blade 3-Inner cylinder

[Fig. 5] Schematic diagram of the guide impeller

### 3.1 Simulation Analysis of Blade Angle

The blade angle of the guide vane wheel is the angle between the surface of the blade and the horizontal plane[9]. The blade angle of the guide vane wheel directly affects the spiral ascending angle and the subsequent trajectory in the swirl section, and has a direct impact on the separation effect of the droplets.

In the research process, according to the parameters in Table 3, five different guide vane wheel blade angles are selected to analyze the separation efficiency of the swirl separator, and the specific guide vane wheel blade angle parameters are shown in Table 3.

〈Table 3〉 Blade angle of the guide impeller

| Angle1 | Angle2 | Angle3 | Angle4 | Angle5 |
|---|---|---|---|---|
| 37° | 40° | 45° | 50° | 55° |

The blade welding base of the guide vane wheel is the inner cylinder of the guide vane wheel. Considering that the total height of the vane wheel is 500mm and the inner radius of the inner cylinder is 680mm, the minimum angle of the vane wheel is arctan(500/680), and the calculation result is rounded to get the minimum angle of the vane wheel as 37°.

Integrating the previous Table 2 and Table 3, the internal flow field of the swirl separator is three-dimensionally modeled, meshed, and analyzed and solved. In order to study the separation efficiency of the swirl separator for droplets of different sizes in more detail, in addition to distinguishing the angle of the guide blades, the separation efficiency of droplets with an average diameter of 1μm, 10μm, 20μm, 30μm, 40μm, and 50μm needs to be calculated during the analysis process.

## 3.2 Simulation Analysis of Guide Vane Wheel Flow Area

The flow area of the guide vane wheel indirectly reflects the flow speed of the flue gas passing through the guide blades. The size of this speed value is directly proportional to the centrifugal force received by the droplets, which directly affects the separation efficiency of the droplets in the mixture[9].

The area between the inner and outer cylinders is the flow area of the guide vane wheel[11], and its calculation formula is as follows:

$$S = \pi R_1^2 - \pi R_2^2 \tag{3}$$

Where is S is the flow area of the guide vane wheel, mm2; R1 is the inner diameter of the outer cylinder of the guide vane wheel, mm; R2 is the outer diameter of the inner cylinder of the guide vane wheel, mm.

Under the condition that the total amount of flue gas treated by the swirl separator remains the same, the different flow areas of the guide vane wheel indirectly reflect the speed of the flue gas at the outlet of the guide vane wheel. The smaller the flow area, the greater the flue gas velocity[12], and vice versa, the flue gas velocity will decrease. The calculation formula is as follows:

$$v = \frac{10^6 - Q}{3600S} \tag{4}$$

Where v is the flue gas velocity at the outlet of the guide vane wheel, m/s; Q is the total flue gas volume, m3/h; S is the flow area of the guide vane wheel, mm2.

### 3.2.1 Different Blade Flow Area Parameters

In the research process, according to the parameters in the previous Table 2 unchanged, the guide blade angle is selected as the optimal solution of 37° obtained from the previous analysis. Five different guide vane wheel flow areas are selected to analyze the separation efficiency of the swirl separator, and the specific guide vane wheel flow area parameters are shown in Table 4.

In the Table 2 and Table 3, the internal flow field of the swirl separator is three-dimensionally modeled, meshed, and analyzed and solved. In order to study the separation efficiency of the swirl separator for droplets of different sizes in more detail, each type of swirl separator should be analyzed separately for droplets with an average diameter of 1μm, 10μm, 20μm, 30μm, 40 μm, and 50μm.

〈Table 4〉 Flow area of the guide impeller

| Paramete code | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Inner diameter of the outer cylinder $R_1$/mm | 680 | 680 | 680 | 680 | 680 |
| Outer diameter of the inner cylinder $R_2$/mm | 1,218 | 1,190 | 1,160 | 1,125 | 1,110 |
| Flow area S/$m^2$ | 3.20 | 2.99 | 2.77 | 2.52 | 2.41 |
| Outlet flue gas velocity v/(m/s) | 11 | 12 | 13 | 14 | 15 |

### 3.2.2 Different Flow Area Guide Vane Wheel Simulation

Through the flow field analysis of five groups of swirl separators with different guide vane wheel flow areas, the separation efficiency for droplets of different average diameters and the corresponding pressure loss are summarized in Table 5.

〈Table 5〉 Droplet separation efficiency of different blade flow areas

| Average droplet diameter | Blade flow area/$m^2$ | | | | |
|---|---|---|---|---|---|
| | 3.20 | 2.99 | 2.77 | 2.52 | 2.41 |
| 1㎛ | 41.37% | 43.10% | 43.10% | 37.93% | 46.55% |
| 10㎛ | 48.27% | 58.62% | 50.00% | 53.45% | 37.93% |
| 20㎛ | 68.96% | 70.68% | 58.62% | 72.41% | 68.96% |
| 30㎛ | 96.55% | 98.27% | 100.00% | 100.00% | 96.55% |
| 40㎛ | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% |
| 50㎛ | 100.00% | 100.00% | 100.00% | 100.00% | 100.00% |
| Pressure loss/Pa | 564.17 | 649.17 | 699.26 | 974.99 | 902.05 |

### 3.2.3 Trend Analysis of Droplet Separation Efficiency

With the blade inclination angle as the horizontal coordinate and the separation efficiency of the droplets as the vertical coordinate, a line chart 6 is established. With the flow area of the guide vane wheel as the horizontal coordinate and the separation efficiency of the droplets as the vertical coordinate, a line chart 7 is established. From the charts, the following conclusions can be drawn.:

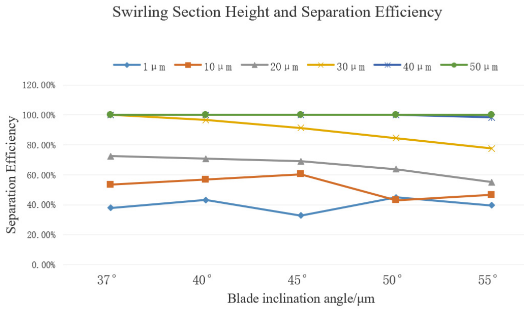
a. For 1㎛ droplets, the separation efficiency of different flow areas of the guide vane wheel is relatively low.

b. For 10㎛ and 20㎛ droplets, as the flow area of the vane wheel increases, the separation efficiency shows a trend of first increasing and then decreasing, and then increasing and then decreasing in an M-shaped trend. For 10㎛ droplets, the separation efficiency is the highest when the flow area is 2.99$m^2$, and for 20㎛ droplets, the separation efficiency is the highest when the flow area is 2.52$m^2$.

c. For 30㎛ droplets, as the flow area increases, the separation efficiency shows a trend of first increasing and then decreasing, and the separation efficiency is the highest when the flow area is 2.52$m^2$.

d. For 40㎛ and 50㎛ droplets, the separation efficiency of different flow areas of the guide vane wheel can all reach 100%.

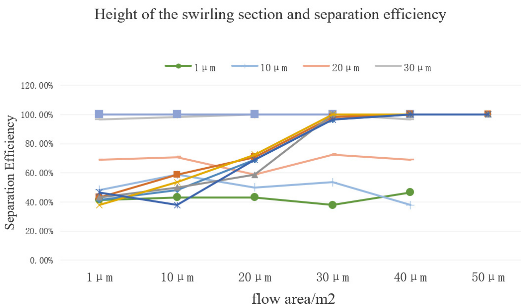
e. As the flow area of the guide vane wheel increases, the pressure loss of the swirl separator shows a trend of first increasing and then decreasing, and the pressure loss is the highest when the flow area is 2.52$m^2$. This trend is consistent with the trend of separation efficiency mentioned in the third point, which verifies the positive correlation between the separation efficiency of the swirl separator and the equipment pressure loss.




[Fig. 6] Droplet separation efficiency at different blade angles

In the Figure 8 and Figure 9, from the static pressure cloud map of different flow areas, it can be compared and analyzed that the static pressure distribution inside the swirl separator gradually increases from the center of the equipment to the cylinder wall.

In the area below the impeller, as the flow area of the vane wheel increases, the overall pressure drop value first increases and then decreases, and the pressure difference is the largest when the flow area is 2.52$m^2$. The pressure difference between the upper and lower parts of the impeller reflects the pressure loss of the equipment[12]. As the flow area of the vane wheel increases, it first increases and then decreases; in the area above the impeller, the pressure distribution gradually increases from the center to the outside, and when the flow area of the vane wheel is 2.52$m^2$, the pressure difference between the center and the outside of the equipment is the largest, and the high-pressure area is concentrated near the cylinder wall of the equipment.




[Fig. 7] Droplet separation efficiency with different flow area

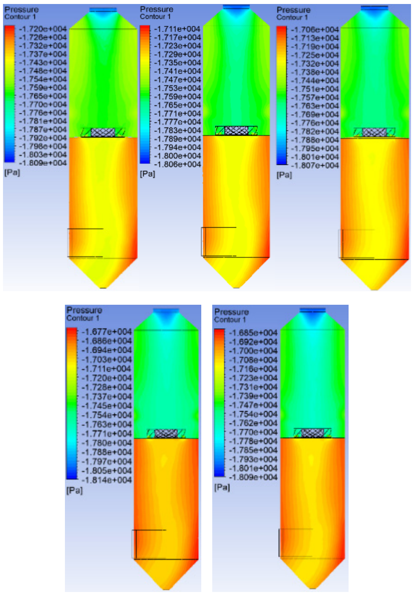
In Figure 10 and Figure 11 from the velocity cloud map of different flow areas, it can be compared and analyzed that as the flow area of the vane wheel increases, the velocity of the flue gas in the area below the impeller gradually increases from the center to the outside, and the overall velocity is relatively low; for the swirl separator with a flow area of 2.52m$^2$ of the vane wheel, it can be seen from the velocity cloud map that the velocity distribution in the area below the impeller is mainly the blue area in the center (low-speed area) and the green area near the outside of the equipment (high-speed area). The flue gas containing droplets has a greater flow speed in this equipment, and the droplets are subjected to greater centrifugal force, which is easier to be separated. Therefore, among the 5 sets of data analyzed, the guide vane wheel with a flow area of 2.52m$^2$ has the highest separation efficiency for droplets of 20$\mu$m and above.

From the gas trajectory in Figure 12 comparison analysis of different flow areas, it can be seen that the number of rotations of the flue gas in the area below the impeller increases and then decreases as the flow area of the vane wheel increases. This is because the flue gas enters the equipment horizontally and tangentially, and the swirl separator with a large inclination angle has a smaller pressure difference before and after the impeller, the upward movement of the flue gas is small, and the upward velocity component of the flue gas decreases accordingly, so the flue gas has more rotation circles in the area below the impeller; however, for the guide vane wheel with a flow area of 2.52m$^2$, the flue gas has a greater flow speed under the action of the large pressure difference before and after the impeller, and the droplets in the flue gas are subjected to greater centrifugal force, and the equipment has better droplet separation ability and higher separation efficiency[13].

For the same flue gas treatment volume, the initial velocity of the flue gas after passing through the impeller gradually increases as the flow area decreases, and the horizontal velocity of the flue gas after the action of the guide vane wheel is also greater, which helps to improve the droplet separation efficiency of the equipment. In this example, the guide vane wheel with a flow area of 2.52m$^2$ has a higher separation efficiency for droplets than the first three groups of impellers. In this example, although the guide vane wheel with a flow area of 2.41m$^2$ has a high flue gas velocity, the pressure difference before and after the impeller is small, and the acceleration of the droplets in the vertical direction is small, which is the reason for the low separation efficiency of this impeller for droplets.

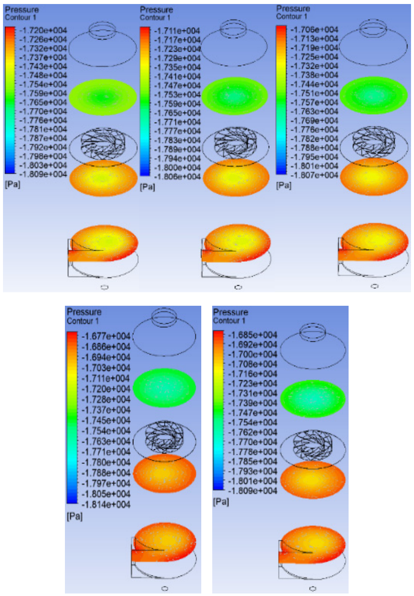
In summary, under the premise that other parameters of the swirl separator remain unchanged, when the flow area of the vane wheel is 2.52m$^2$, the swirl separator has a higher separation efficiency for droplets of 20$\mu$m and above.

Comprehensive CFD analysis of various cloud maps shows that when the flow area of the vane wheel is 2.52m$^2$, the static pressure value in the area below the guide vane wheel is smaller, the pressure difference before and after the impeller is larger, the flue gas velocity in the area below the impeller is greater, and the centrifugal force on the droplets in the flue gas is also greater, resulting in higher separation efficiency.



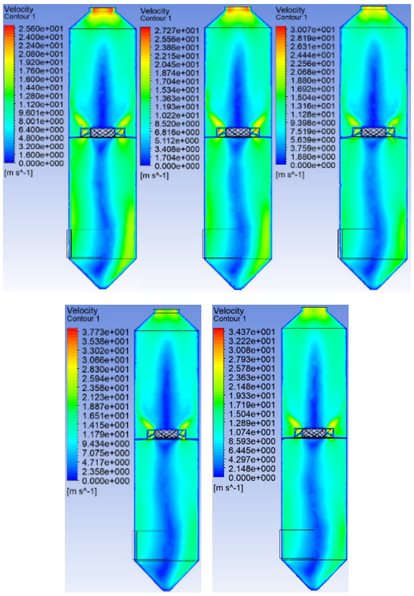
(a) 3.20m$^2$ (b) 2.99m$^2$ (c) 2.77m$^2$
(d) 2.52m$^2$ (e) 2.41m$^2$

[Fig. 8] Static pressure cloud image at different flow area



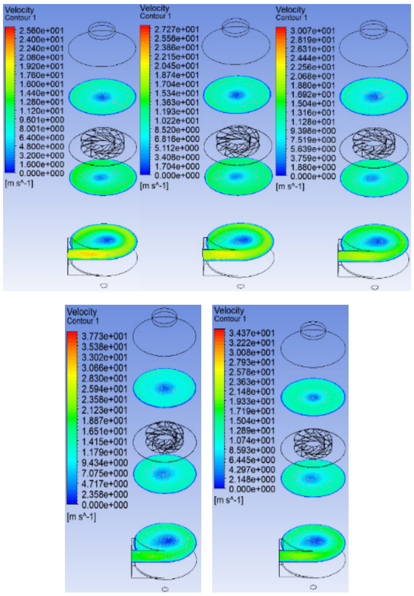
(a) 3.20m$^2$ (b) 2.99m$^2$ (c) 2.77m$^2$
(d) 2.52m$^2$ (e) 2.41m$^2$

[Fig. 9] Static pressure cloud image at different flow area



(a) 3.20m$^2$ (b) 2.99m$^2$ (c) 2.77m$^2$
(d) 2.52m$^2$ (e) 2.41m$^2$

[Fig. 10] Static velocity cloud image at different flow area



(a) 3.20m$^2$ (b) 2.99m$^2$ (c) 2.77m$^2$
(d) 2.52m$^2$ (e) 2.41m$^2$

[Fig. 11] Static velocity cloud image at different flow area

Comprehensive analysis of the previous, in this example, when the flow area of the vane wheel is 2.52m$^2$, the swirl separator has the highest separation efficiency for droplets of 20$\mu$m and above, and the corresponding flue gas velocity through the guide vane wheel is 14m/s.

As mentioned in the previous analysis, as the separation efficiency of the swirl separator increases, the pressure loss of the equipment will also increase accordingly. In actual structural design, it is necessary to comprehensively consider the relationship between the separation efficiency of the equipment for droplets and the pressure loss of the equipment, and choose the flow area of the vane wheel with high separation efficiency under the premise of the system allowing.

In this example, the full pressure of the wet dust removal fan is 28KPa, and the pressure distribution of the wet dust removal system is about 20KPa. Considering factors such as pipeline loss, etc., the equipment pressure loss corresponding to the vane wheel flow area of 2.52m$^2$ selected in this paper is 974.99Pa, and the system can meet the pressure loss of this swirl separator, so the vane wheel flow area of 2.52m$^2$ is selected as the optimal flow area of the guide vane wheel in this example.

## 4. Equipment Structural Optimization

### 4.1 Optimization Measures

According to the previous simulation analysis, the liquid droplet separation efficiency of the original swirl separator structure parameters is relatively low, and the blade angle of the guide vane wheel, the insertion depth of the exhaust pipe, and the flue gas treatment volume of the original swirl separator are all optimizable items. Comprehensively[14], this paper only carries out optimization and improvement on the guide vane wheel blade structure factors of the original swirl separator according to the previous simulation results. According to the previous simulation results, the combination of a blade angle of 37° and a vane wheel flow area of 2.25m$^2$ is the optimal solution for the structure of the swirl separator.

The specific transformation process is to remanufacture the guide vanes according to the optimized parameters, and complete the replacement of the blades during the maintenance time coordinated with the steel mill. The structural parameters of the swirl separator before and after the improvement and the corresponding separation efficiency for droplets of different sizes are shown in Table 6.

〈Table 6〉 The improvement of cyclone separator structure and corresponding separation efficiency

| | | Before improvement | After improvement |
|---|---|---|---|
| Guide vane wheel blade angle/° | | 45 | 37 |
| Separation efficiency of droplets of different sizes/% | 1$\mu$m | 32.76% | 37.93% |
| | 10$\mu$m | 43.10% | 53.45% |
| | 20$\mu$m | 60.34% | 72.41% |
| | 30$\mu$m | 89.65% | 100.00% |
| | 40$\mu$m | 98.28% | 100.00% |
| | 50$\mu$m | 100.00% | 100.00% |
| Pressure loss | | 1092.75 | 974.99 |


(a) Removal of old blade


(b)Install new blade

[Fig. 12] Modification of cyclone separator

### 4.2 Optimization Effect

According to Table 5, the original structure of the swirl separator was improved. On-site tracking observations found that the "rain" phenomenon around the emission chimney after the improvement was significantly reduced, and there was basically no slippery phenomenon on the ground during the entire smelting cycle of the converter, indicating that the separation efficiency of the flue gas for droplets by the improved swirl separator was significantly increased[15].


[Fig. 13] Comparison of ground rain before and after renovation

The water flow at the bottom of the separator, which is the drainage water seal, was also observed to be significantly increased after the modification, roughly doubling the flow rate based on a rough estimate of the water flow area in Figure 14, confirming the increase in the separation efficiency of the swirl separator for droplets.


(a) Before modification (b) After modification

[Fig. 14] The displacement before and after the modification of cyclone separator

## 5. Conclusion

The swirl separator studied in this paper is mainly a gas-liquid swirl separator used in the wet dust removal system of the converter steel plant. The separator had a low droplet separation efficiency at the beginning of its application. In this paper, the blade angle and flow area of the guide vane wheel of the swirl separator were analyzed using FLUENT software, and the following conclusions were drawn: when other parameters remain unchanged, the swirl separator has the highest droplet separation efficiency when the guide vane wheel blade angle is 37° and the guide vane wheel flow area is $2.52m^2$ (corresponding to a flue gas velocity of 14m/s through the guide vane wheel).

Based on the above simulation analysis results, the structure of the guide vane wheel of the swirl separator studied in this paper was modified. The modified swirl separator significantly improved the separation efficiency of droplets, and the "rain" phenomenon around the emission chimney basically disappeared, and the water flow at the bottom of the separator increased by about twice. Through the simulation analysis of the impact of various structural parameters of the swirl separator on the separation efficiency of droplets in this paper, it can provide theoretical guidance and design basis for the design of similar equipment in the future.

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