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Analysis of blade erosion characteristics of FCC flue gas turbine under different conditions

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Abstract

The working state of flue gas turbine directly affects the energy recovery rate and profit of refinery. In order to accurately understand the gas-solid law of flue gas turbine, six groups of different flue gas density models are designed with reference to the field gas phase data. Based on the theory of computational fluid dynamics, the flow field of moving and stator blades is numerically simulated by using the discrete phase (DPM) model in ANSYS FLUENT software. The results show that the particles of the stator blade mainly gather on the pressure surface of the stator blade, and the concentration on the suction surface of the stator blade is low. And the greater the flue gas density, the higher the pressure surface concentration. The particle concentration on the pressure surface of the rotor blade first decreases and then increases with the flue gas density, and the suction inside shows a gradual increasing trend. The concentration at the leading edge of the suction surface of the rotor blade is greater than that at the trailing edge. Part of the simulation results are compared with the PIV Experimental results of flue gas turbine and the erosion results of flue gas turbine in industrial application, which verifies the reliability of the simulation results.

Keywords

Flue gas turbine; Flue gas density; Blade; Numerical simulation.

1. Introduction

Flue gas turbine is the main pressure energy and heat energy recovery device in catalytic cracking equipment (FCC), which can recover about one quarter of heat energy and almost all pressure energy. Compared with other types of steam turbines, the working conditions of flue gas turbine are extremely bad. Its working efficiency directly affects the energy consumption level of catalytic cracking unit, and then affects the economic benefits of refinery. In recent years, with the increasing ratio of FCC feed oil to slag, the working environment of flue gas turbine has been further deteriorated. Due to the complexity of the work of the flue gas turbine, it is difficult to study the internal gas-solid direction law through experimental methods. Scholars mainly study the flue gas turbine through numerical simulation. Du Yupeng et al. [1-2] studied the internal flow field of the smoke machine by establishing a two-dimensional model at the middle diameter of the flow channel, and found that different particle sizes have different effects on the flow field, erosion and scaling of the smoke machine. Tan Huimin et al.[3] selected K- ε model simulates the gas-solid two-phase in the smoke machine. It is found that there is secondary flow on the pressure surface of the rotor blade, the content of water vapor on the pressure surface of the rotor blade is generally greater than that on the suction surface, and the molecular viscosity on the pressure surface of the rotor blade is slightly greater than that on the suction surface. Zhang Xiaoxiao[4] established the flue gas turbine channel model with blade tip clearance. It was found that in the stator blade, the decrease of gap flow pressure energy and heat energy and the increase of speed were smaller than those of the mainstream. The gap flow speed was roughly equal to that of the mainstream. Affected by the mainstream, the gap flow began to decrease, but the decrease was smaller than that of the mainstream. Han Bai [5] et al. Studied the influence of flow change on gas and solid flow field in flue gas engine. The conclusion is that when the flow in the flue gas turbine increases, the flow parameters in the stator blade will increase in varying degrees. Under different flue gas flow, the position of catalyst particles arriving at the flue gas machine is different. When the flow rate increases, the trajectory of catalyst particles will be closer to the blade. Xu Weiwei et al.[6] established the deposition model of flue gas turbine and investigated the particle deposition characteristics of flue gas turbine under different blade wall roughness by numerical simulation. It was found that the maximum deposition position and overall distribution of particles changed under different roughness, indicating that the particle trajectory changed under the influence of different roughness, and the position of particles hitting the blade also changed. Kodancha et al. Revealed the influence of tip surface roughness on tip leakage flow characteristics and compressor performance. It is found that after adding the blade tip surface roughness, the compressor blade load shows an upward trend, and the maximum stall margin and pressure increase significantly[7].

At present, scholars focus on the internal flow of flue gas and study its flow field distribution, particle distribution and particle deposition characteristics. They usually study the gas-solid flow field of flue gas turbine under specific working conditions without considering the influence of flue gas properties on the flow field of flue gas turbine. In fact, the gas-solid flow field of flue gas turbine is related to flue gas properties, and the change of flue gas properties will affect the flow speed of flue gas.

In view of the less research on the influence of flue gas properties on the gas-solid phase of flue gas turbine, this paper analyzes the influence of flue gas properties on the gas-solid phase in the flue gas turbine channel by numerical calculation method, and simulates the internal flow field of flue gas turbine on the basis of existing literature and computational fluid dynamics. It is expected to provide reference for improving the flow field optimization of flue gas turbine and promoting the improvement of blade shape.

2. Numerical calculation method

The internal flow of flue gas turbine belongs to large curvature and strong torsion. For this kind of motion, three turbulence models are widely used in engineering circles: Standard K- ε Model, realizable K- ε Model, and Reynolds stress model (RSM). standard k- ε It has good robustness and high stability, and can better simulate the internal flow field of flue gas turbine after verification. Standard k is adopted in this work- ε The continuous phase and discrete phase are coupled by simple algorithm, and the main equations are as follows.

Mass conservation equation:

$$\partial \frac{p}{\partial t}+\frac{\partial}{\partial x_i}(pu_i)=0 \tag{1}$$

momentum conservation equation:

$$\frac{\partial}{\partial t}(\rho u_i)+\frac{\partial}{\partial x_j}(\rho u_i u_j)=-\frac{\partial p}{\partial x_i}x_i+\frac{\partial \tau_{ij}}{\partial x_j}+\rho g_i \tag{2}$$

Navier-Stokes equation:

$$\rho\frac{d\vec{u}}{dt}+\nabla p-\mu\nabla^2\vec{u}-\frac{1}{3}\mu\nabla(\nabla\vec{u})-\rho\vec{F}=0 \tag{3}$$

Where, t is the time, u_i is the velocity in the i direction, p and τ_{ij} is the static pressure and stress tensor respectively, g_i indicate the gravity volume force in the i direction. μ is hydrodynamic viscosity. $\bar{u}$ is the average velocity and $\vec{F}$ is the external volume force.

Particle collision with the wall will be accompanied by the loss of particle kinetic energy. Tabacoff has done a lot of experimental research on the wall rebound of rotating machinery [9]. The rebound coefficient of flue gas turbine blade is set according to the experimental data of tabacoff et al. The relationship between tangential and normal rebound coefficient and collision angle is as follows:

$$e_t = \frac{u_{t2}}{u_{t1}} = 1 - 2.12\alpha_1 + 3.0775\alpha_1^2 - 1.1\alpha_1^3 \tag{8}$$

$$e_n = \frac{u_{n2}}{u_{n1}} = 1 - 0.4159\alpha_1 - 0.4994\alpha_1^2 + 0.292\alpha_1^3 \tag{9}$$

Where, u_{t2} is the tangential velocity of particles after collision, u_{t1} is the tangential velocity of particles before collision, u_{n2} is the normal velocity of particles after collision, u_{n1} is the normal velocity of particles before collision, α is the particle collision angle.

3. Model and boundary conditions

3.1. Section Headings

The flue gas turbine blades include stator blades and rotor blades. As the flue gas turbine is a rotary turbomachinery, the flue gas enters the flue gas turbine channel under the guidance of the guide cone, and the adjacent channels are highly repetitive. In this work, the flue gas turbine in document [10] is modeled, two groups of stator blades and rotor blades are selected, and the geometric model is established by SCDM software. The setting is shown in Figure 1, and the interface interaction mode is set as periodic repeat, The flow field data between adjacent blades are transmitted through periodic boundaries.

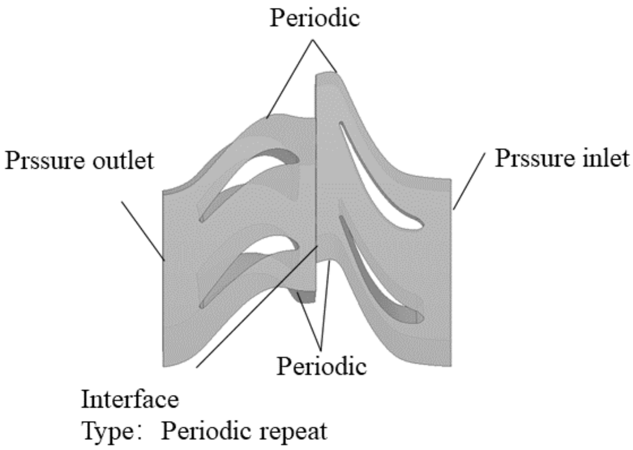


Fig. 1 Calculation model and boundary type

3.2. Condition setting

The stator blade, the connected wheel hub and the casing are set as static non sliding wall surfaces; The rotor blade and the connected hub and casing are set as rotating wall. The specific condition parameter settings are shown in Table 1.

Table 1 Condition parameters

Working parameters	Numerical value	Unit
Total inlet pressure	313000	Pa
Inlet temperature	973	K
Inlet turbulence intensity	3.7%	-
Hydraulic diameter	83.14	mm
Total outlet pressure	213000	Pa
outlet temperature	874	k
Rotating speed of blade	5700	Rpm
Maximum particle size	50.78	μm
Minimum particle size	5.75	μm
Dispersion coefficient	3.2	-
Mass flow rate	0.000213	g/s

3.3. Flue gas parameters

The gas phase of the flue gas turbine is the flue gas produced by the coke burning of the regenerated catalyst, and the density range of the regenerated flue gas is large. In order to make the results universal, five groups of flue gas models with different densities are designed according to the flue gas composition sampled on site and the single factor variable method. The specific parameters are shown in Table 2.

Table 2 Condition parameters

Density number	Numerical value	Unit
A1	0.7049	Kg/m^3
A2	1.0647	Kg/m^3
A3	1.4245	Kg/m^3
A4	1.7843	Kg/m^3
A5	2.1441	Kg/m^3
A6	2.5039	Kg/m^3

4. Result analysis and discussion

4.1. Feasibility verification

At present, no scholar has studied the influence of flue gas properties through experiments, and it is difficult for flue gas turbine to study through experiments. Now, the gas phase velocity of flue gas under A1 working condition is compared with literature[12]. The literature describes the gas phase velocity by dimensionless velocity and dimensionless meridian (the intersection line between pitch diameter section and the middle plane of adjacent blades). Figure 2 shows the comparison between simulation and experimental data. The overall distribution law of simulated data and experimental data is basically consistent. The results show that the model can better predict the gas phase flow field in the flue gas passage.

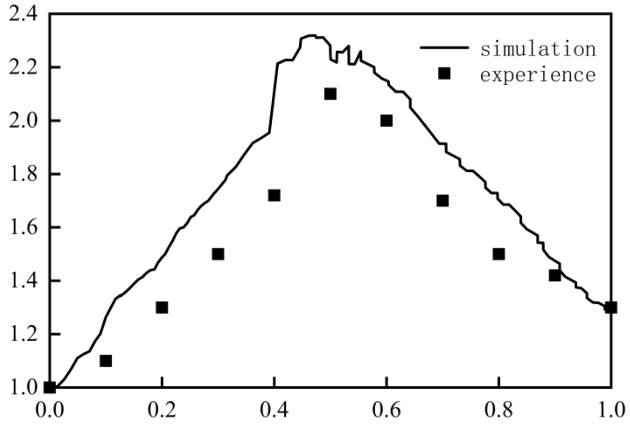


Fig. 2 Simulation data and literature experimental data of gas phase velocity change

4.2. Static pressure characteristics under different flue gas conditions

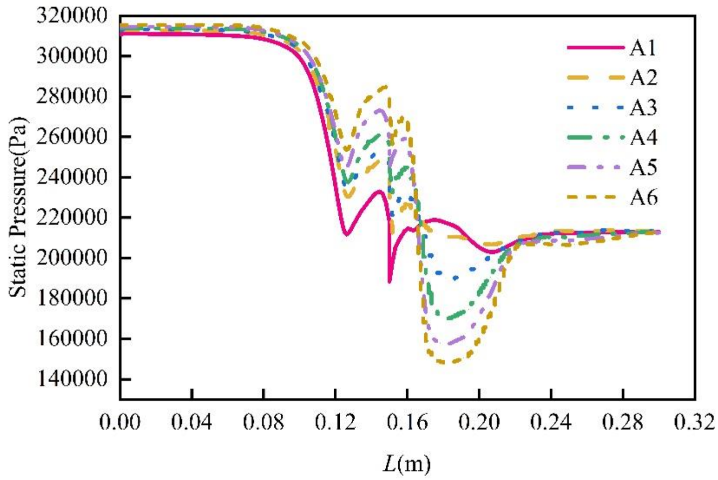
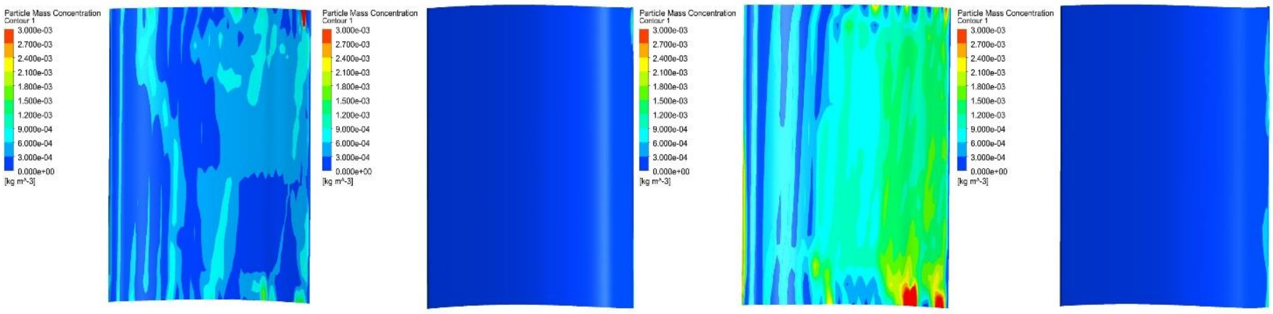


Fig. 3 Variation diagram of static pressure along meridian under different flue gas conditions

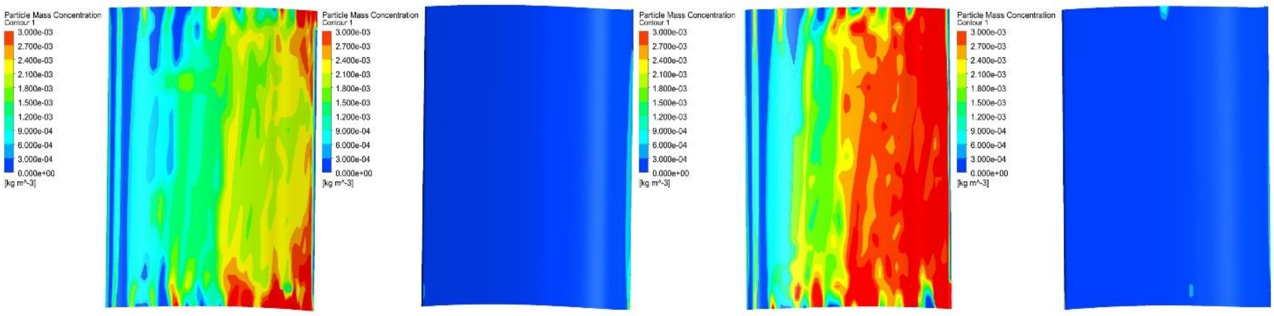
The gas pressure drop is an important parameter of the gas phase flow field of the flue gas machine. Fig 3 shows the variation of the pressure along the meridian in the middle diameter section of the flue gas machine channel under different flue gas conditions. It can be seen from Fig 3 that the pressure of flue gas remains stable before entering the stator blade area and after flowing out of the rotor blade. After entering the stator blade area, the pressure of fluid decreases in a cliff along the meridian direction, and the lowest pressure at the outlet of the stator blade can reach 223690Pa. This is because the stator blade is designed as a nozzle type, and the flue gas pressure can be converted into gas kinetic energy under the drainage of the stator blade. The pressure drop at the tail of the stator blade slows down obviously, and the pressure drop further decreases with the increase of the rough height. On the interface between the moving and stator blades, the pressure fluctuates, which is very easy to affect the flow uniformity and increase the erosion of particles on the blades. At the inlet of the stator blade and the inlet of the rotor blade, the static pressure decreases. When the flue gas density is higher, the decrease range is more obvious, but then it rises, and the flow field tends to be stable. The general trend of meridional static pressure under different flue gas conditions remains unchanged

4.3. Static pressure characteristics under different flue gas conditions

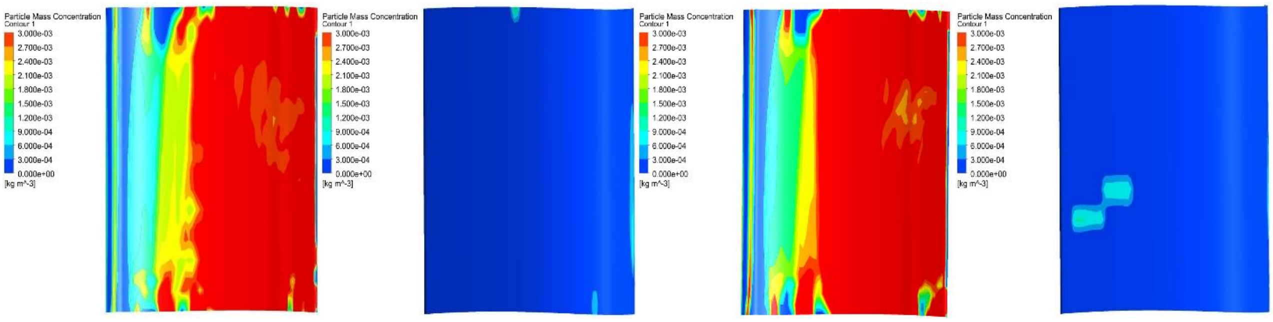
Near wall particle concentration is an important index to measure the working state of flue gas turbine blades. Figure 4 shows the cloud diagram of particle concentration of stator blade under different flue gas conditions. It can be seen from Figure 4 (a) ~ (b) that the particles on the pressure surface of stator blade mainly stay at the trailing edge of blade, the concentration at the contact position of stator blade hub and blade top is high, the suction surface mainly stays at the leading edge of blade, and the concentration at other positions is low, indicating that the particles are easier to flow to the pressure surface of stator blade between blades, resulting in the increase of pressure surface concentration. It can be seen from Figure 7 that the particles are mainly accumulated on the pressure surface of the stator blade, and the main particles are collected at the trailing edge of the suction surface, which is caused by the nozzle design of the stator blade. The concentration of flue gas on the wall increases with the increase of density. The change of the leading edge is small, and the particle aggregation at the trailing edge is serious. The concentration of suction surface of stator blade is low, but with the increase of flue gas density, the concentration of suction surface also increases gradually.



(a) A1 Pressure surface (b) A1 suction surface (c) A2 Pressure surface (d) A2 suction surface



(e) A3 Pressure surface (f) A3 suction surface (g) A4 Pressure surface (h) A4 suction surface

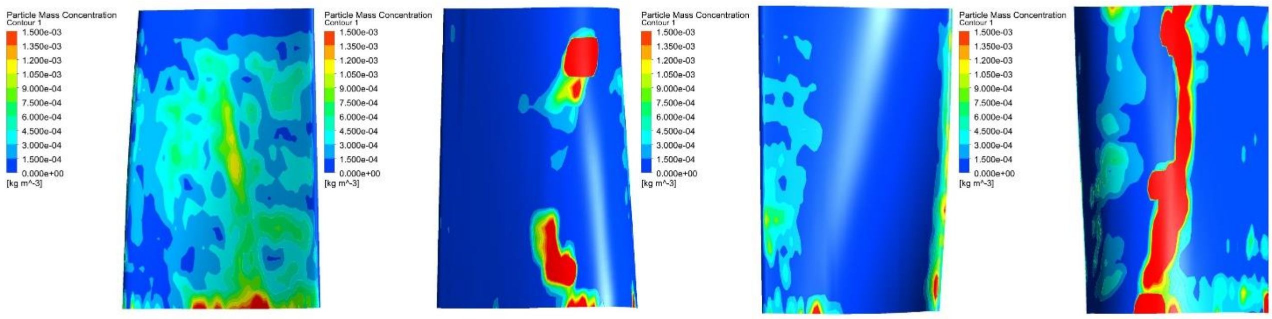


(i) A5 Pressure surface (j) A5 suction surface (k) A6 Pressure surface (l) A6 suction surface

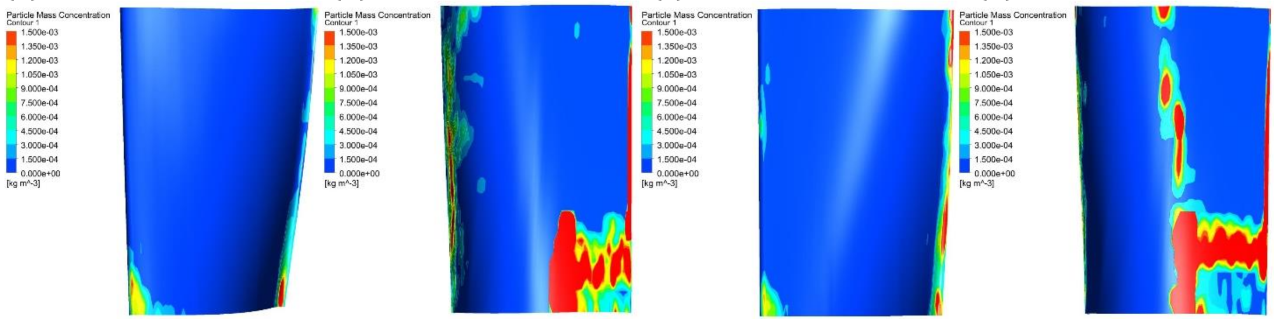
Fig. 4 Cloud diagram of particle concentration of stator blade under different flue gas conditions

4.4. Static pressure characteristics under different flue gas conditions

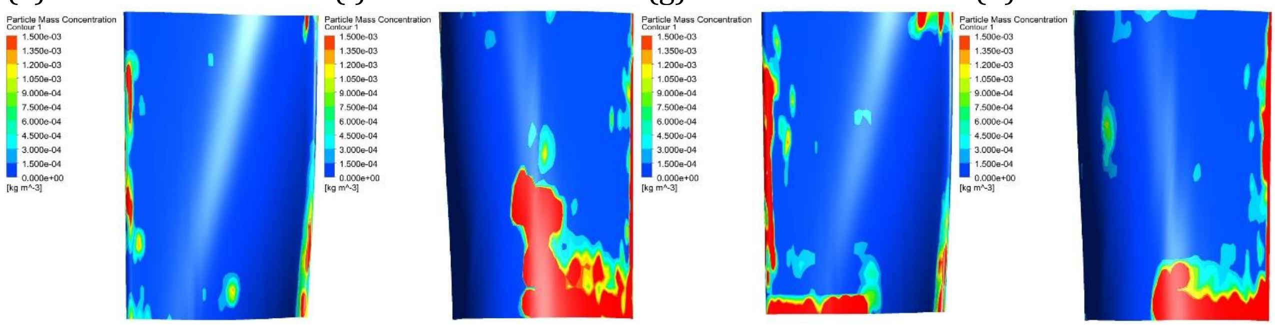
Figure 5 shows the cloud diagram of particle concentration of rotor blade under different flue gas conditions. Figure 5 (a) ~ (b) shows that the concentration in the middle of rotor blade pressure surface and blade top is high, and the concentration from blade root to blade top mainly increases first and then decreases. At the same time, the concentration in blade tip area is large, and the particle concentration on rotor blade pressure surface is lower than that on stator blade pressure surface as a whole. This is due to the fast speed of particles in rotor blade area and the rotor blade area is in motion, which is not conducive to particle aggregation. But at the same time, the erosion of rotor blades is also greater than that of stator blades. The particle concentration on the pressure surface of the rotor blade first decreases and then increases with the flue gas density, and the suction inside shows a gradual increasing trend.The concentration of the leading edge of the suction surface of the rotor blade is greater than that of the trailing edge, and there is only a small amount of accumulation in the middle area of the blade, and the concentration of the suction surface gradually increases from the blade root to the blade top.



(a) A1 Pressure surface (b) A1 suction surface (c) A2 Pressure surface (d) A2 suction surface



(e) A3 Pressure surface (f) A3 suction surface (g) A4 Pressure surface (h) A4 suction surface



(i) A5 Pressure surface (j) A5 suction surface (k) A6 Pressure surface (l) A6 suction surface

Fig. 5 Cloud diagram of particle concentration of rotor blade under different flue gas conditions

5. Summary

The flow simulation of the moving stator blade of the flue gas turbine is carried out, and the variation law of meridian static pressure in the flue gas turbine channel and the concentration distribution near the wall of the blade are obtained, which can provide a theoretical basis for the optimal design of the flue gas turbine blade. The conclusions are as follows:

(1) The static pressure of flue gas decreases along the flow passage area of stator blade, the static pressure rises briefly at the outlet of stator blade, and fluctuates at the inlet of rotor blade. The flue gas density has a great impact on the gas phase results. The influence trend is that the

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greater the flue gas density, the slower the reduction of flue gas static pressure, and the more severe the pressure drop at the outlet of dynamic pressure.

(2) The stator blade particles are mainly concentrated on the pressure surface of the stator blade, and the concentration on the suction surface of the stator blade is low. And the greater the flue gas density, the higher the pressure surface concentration.

(3) The particle concentration on the pressure surface of the rotor blade first decreases and then increases with the flue gas density, and the suction inside shows a gradual increasing trend. The concentration of the leading edge of the suction surface of the rotor blade is greater than that of the trailing edge, and there is only a small amount of accumulation in the middle area of the blade, and the concentration of the suction surface gradually increases from the blade root to the blade top.

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