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Analysis of Erosion wear of Super Vortex Quick Separation system based on CFD

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Abstract

Wall wear is an important factor in the failure of Super Vortex Quick Separation(SVQS) system and the study of wear is of great significance to improve the service life of it. In this paper, based on the computational fluid dynamics research method, the internal flow field of SVQS system was coupled by FLUENT software, and the wall wear of the system was numerically simulated by using the DPM erosion model. It is determined that the main wear parts of the system are the cyclone arm, the position near the jet outlet, the middle and lower part of the settlement section, the top of the riser and the position of the baffle of the separator, and get the system speed and wear map, analysis the reason of the quick separation system of the wall wear and the factor that may affect the wear and tear in combination with the wear distribution regularity. In this paper, the accuracy and reliability of the numerical simulation results are verified by comparing the wear condition of the SVQS system with the actual wear condition in the industrial application.

Keywords

SVQS; Erosion; Wear; Simulated analysis.

1. Introduction

Catalytic cracking (FCC) is the core processing method for the lightening of heavy oil, and the riser end cyclone fast subsystem is the key equipment in FCC process, and its excellent performance directly affects the separation efficiency of the system.In industrial application, wall erosion wear caused by solid particles in fluid has become one of the main failure modes of SVQS system, which seriously restricts its application and development.In order to improve the service life and working reliability of the separator, scholars have done more research on the wear of the traditional cyclone separator and hydrocyclone, but little research on the erosion wear of the new SVQS system.Yuan Huixin [1], Xia Xingxiang [2], Zhao Merchant [3], Liu Jiahai [4], Qian Chengwei[5] analyzed the position of wall wear of cyclone separator, and analyzed the causes of wall wear from the aspects of gas-solid two-phase flow characteristics, solid-phase particle characteristics, separator structure and wall material.Jin Youhai and Zhao Xinxue[6] used CFD software to track the particles in the flow field inside the cyclone separator and analyzed the wall wear.Xia Mingchuan[7] conducted a theoretical analysis on the wear and crack of the catalytic cracking reactor.

SVQS system, which is widely used in industry, has excellent performance, the highest separation efficiency can reach 97.12%, and can better eliminate the "short-circuit flow" problem, and the average residence time of oil and gas is short, so it has a strong representative [8]. In order to promote the industrial application of SVQS system, the numerical simulation of SVQS system is carried out by using CFD technology based on the research results of these scholars. To wall wear analysis of SVQS fast subsystem, tracking trajectory of solid particles, the analysis of the wear rule of the fast subsystem of wear parts and the factor that may affect the wear, wear distribution analysis the reason, for the fast subsystem optimization of the structure, performance and the theoretical basis for safe and efficient operation, in order to improve the service life of the fast subsystem.

2. Theoretical basis of wear research

The influence of gas-solid two-phase flow on the wall wear of the separator is very complex, which is a complex erosion wear phenomenon. The change of any factor can change the wall wear and change the wear mechanism [9].The two types of wall wear are scour wear and impact wear. The difference between them mainly lies in the different impact angles of particles on the wall. For different materials, the wear mechanism and form are different. Erosion wear, also known as erosion or erosion wear, can be divided into gas-solid erosion wear, liquid-solid erosion wear, droplet erosion wear and cavitation erosion wear according to the flow medium. The simulation of the erosion wear problem of gas-solid two-phase flow mainly adopts the discrete phase model (DPM), which is established by the Euler-Lagrange method. The model can effectively describe the computational medium in the Euler coordinate system, and the ideal analysis results can be obtained through numerical calculation.The wear rate can be defined as [10]:

$$R_{erosion}=\sum_{p=1}^{N_p}\frac{\dot{m}_p C\left(d_p\right)f\left(\alpha\right)V_p^{b\left(V_P\right)}}{A_{face}}$$

In formula， $R_{erosion}$is erosion rate; $C\left(d_p\right)$is the particle size function of solid particles; $f\left(\alpha\right)$is the impact Angle function; V_p is the velocity of particle relative to the wall surface; $b\left(V_p\right)$is the function of the relative velocity of solid particles; $A_{face}$is the surface area of the wear rate; N_p is the number of erosion particles; $\dot{m}_p$ is the mass flow rate of particles.the particle size function is $C(d)=1559\,(HB)^{-0.59}F_S$， F_S is the shape coefficient of the particle, and its value is determined by the scouring ability of the particle shape on the material surface. For round particle, semicircular particle and sharp-angle particle, its value is 0.2, 0.53 and 1 respectively. In this paper, the diversity of the particle shape is taken into account, and the value is calculated $F_S=0.53$.

3. Numerical simulation analysis

3.1. Physical model

The model and structural diagram of SVQS system are shown in Figure 1. Its main structural dimensions are as follows: closed cover length 4000mm, closed cover diameter 600mm, riser diameter 100mm, cyclone arm nozzle length 88mm, cyclone arm nozzle width 29mm. The model is Z-axis along the axial direction, the top plane of the cyclone arm is Z=0 plane, and the downward plane is positive.

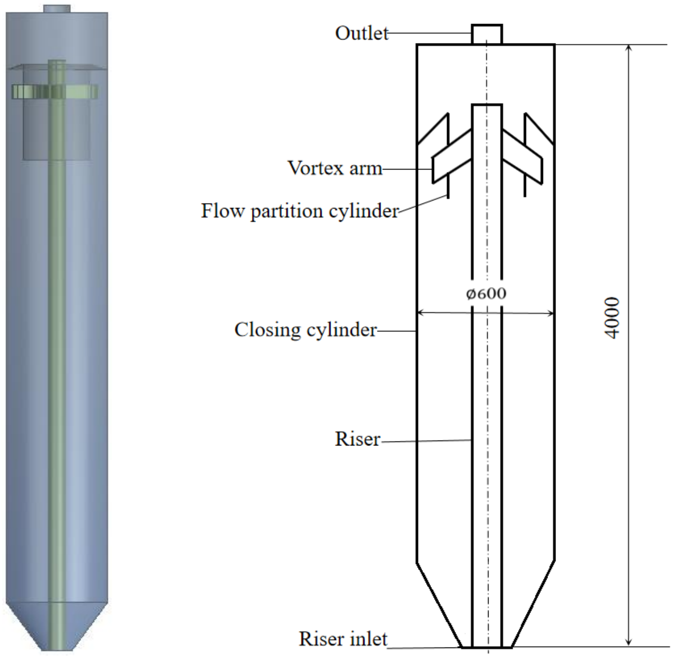

Fig. 1 SVQS fast subsystem model and structure diagram

The fluid in the system is gas-solid two-phase flow, and the gas-phase medium is air (temperature is 20℃, density is 1.225 kg/m3, viscosity is 1.7894×10-5 kg/m·s). The particle density of the solid phase medium is about 1450 kg/m3, the concentration is 5kg/m3, the particle enters the system as a discrete phase and mixes with the gas, and the particle size distribution conforms to the double R distribution. According to the Rosin-Rammler exponential equation, the spread parameter of the particles is 1.897, and the average particle size is 66.9 μm.

3.2. Boundary conditions

The system riser inlet uses Velocity Inlet. Since solid particles have good following property when they enter the system and there is no relative slip, it is considered that the gas-solid inlet velocity is the same. The solid particle concentration is $5kg/m^3$, and the inlet boundary condition is that the inlet jet source is set as the surface source. In the calculation process, the inlet turbulence has been fully developed, the inlet flow is perpendicular to the inlet section, and the inlet air velocity is uniformly distributed on the section, and the riser inlet velocity is $v_i = 19.5m/s$.See Table 1 for specific entry boundary parameter values.

Table 1 Entry boundary parameter values

Parameter	Value	Unit
Entrance velocity (vi)	19.5	m/s
Hydraulic diameter	0.1	m
Reynolds number	133494.467	-
Turbulence intensity	3.66%	-
Tubulence energy	0.7639	m^2/s^2
Mass flow rate	0.765	$kg \cdot s$

According to the experience of scholars in relevant fields and combined with the particularity of Flow field of fast sub-system, The gas phase boundary is set as OUTFLOW (Flow rate weighting=0) and particle boundary is set as Trap. According to fully developed OUTFLOW conditions, gas phase boundary is set as OUTFLOW (Flow rate Weighting =1) and particle boundary is set as Escape. The gas-phase flow field at the wall surface is set as the no-slip boundary, and the particle phase boundary is set as the reflectional boundary

4. Simulation results and wear analysis

4.1. Wall wear analysis

The flow field movement of SVQS system is relatively special, and the wear condition of the wall surface is relatively complex. This paper mainly analyzes the wear distribution law of the severely worn parts. The wall wear cloud diagram of the fast subsystem in different directions is shown in Fig. 4. It can be seen from the figure that the wear of the wall near the outlet of the cyclone arm is the most serious, and the wear track of the closed cover wall is a spiral wear zone distribution, and the distance between the spiral wear zones increases gradually in the top-down movement. With the increase of the axial distance, the tangential velocity of particles decreases gradually, the impact on the wall decreases, the wear degree decreases, and the wear rate decreases. After the fluid enters the settlement section from the separation section, the wear rate in the settlement section increases first and then decreases along the axial direction, and the wear rate reaches the maximum in the middle and lower part, where the wear failure is easy to occur. The distribution of wear nephograms in different directions is different, which indicates that the wall wear is affected by tangential velocity. The wear distribution of the wall surface is consistent with the movement of particles.

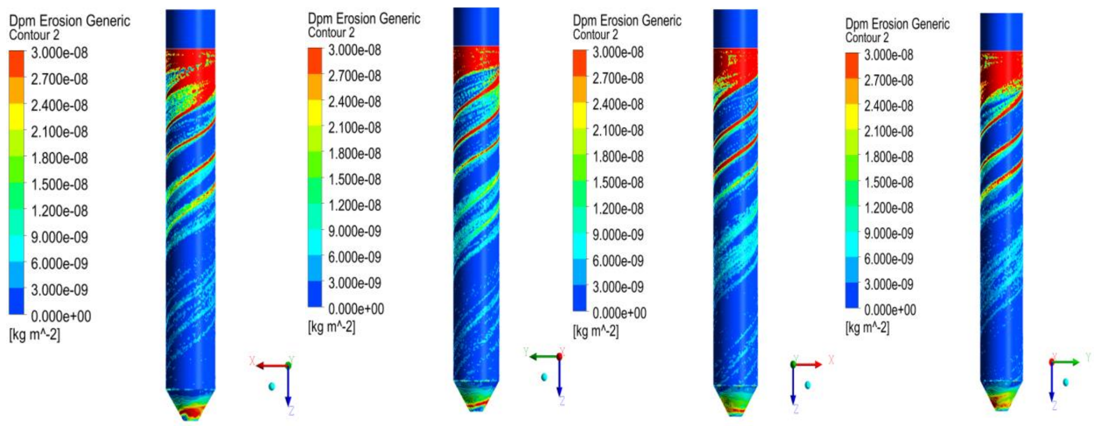

Fig. 4 Wall wear nephogram of fast sub-system

In order to accurately analyze the change rule of the wall wear rate, several planes (the same as the above velocity section) were intersected along different axial positions at equal distances. At the same position of the wall of each section, the point ABC with relatively large wear rate and the point DEF with relatively small wear rate were respectively selected, as shown in Fig.5. The wear rate values of each point were analyzed respectively, and the change rule of wear rate was obtained, as shown in Fig. 6. It can be seen that the wear rate of the wall shows alternating peaks and troughs, indicating that the wear value is distributed in intervals, which is consistent with the distribution of spiral wear zones in the wear cloud image. With the increase of axial distance, the wear rate decreases and the change rate of wear value also decreases.

The wall wear rates of SVQS system are different in different circumferential directions. The positive half axis of the X axis is taken as the starting point of the circumferential Angle, and the values are respectively calculated at the position of 30° clockwise distance. The circumferential change curves of the wall wear rates at different axial positions in the annular space of the fast subsystem are obtained, as shown in Fig. 7.It can be seen from the figure that the wear rate of each section of the wall is mainly local wear, and the change of wear rate is a "wave" change. With the increase of axial distance, the wear value on the circumference of each section decreases.Due to the influence of the tangential velocity inside the system, the wear rate on the

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circumference is almost symmetric about 180°.The wear rate of Z=200mm and Z=700mm sections is obviously larger than that of other sections. The plane Z=200mm wears more seriously when the inscribed Angle is 30°, 150° and 270°, and the plane Z=700-2200mm wears more seriously when the inscribed Angle is 150-180°, near the bottom of the enclosure, and the wear decreases and approaches 0.

The wear nephogram of swirl head is shown in Fig. 8. It can be seen from the figure that the wear distribution of the three swirling arms is almost the same, which is consistent with the symmetrical distribution of tangential velocity of the flow field inside the system. The wear of the cyclone arm is mainly concentrated on the arc section of the outer wall, and part of the wear is concentrated on the upper and lower part of the cyclone arm. There is almost no wear phenomenon on the inner wall, and the wear value is the largest in the middle of the arc section, where the wear damage is easy to occur. The wear distribution of the outer wall of the cyclone arm in the straight section is not regular, and the wear is mainly concentrated in the joint position between the wall and the upper plane and the nearby area, which is related to the velocity distribution of the flow field.

The wear cloud diagram of the separator tube is shown in Fig. 9. It can be seen from the figure that the wear distribution of the separator cylinder is relatively concentrated, mainly concentrated on the upper baffle. The wear value on the outer edge of the baffle is large, and the wear value near the inner edge is almost zero. The overall wear distribution in the circumscribed direction has uniform symmetry. At the positions of 0°, 90°, 180° and 270° around the circle, the wear values of the wall surface were extracted along the axial direction, and the change curves of the wear values in different circumferential directions with the axial distance were obtained, as shown in Fig.10. As can be seen from the figure, the wear value gradually increases from the inner edge to the outer edge, and the wear rate at the outer edge of the baffle appears the maximum value in different circular directions, and the wear rate also presents a "waveform" change. It can be seen from the wear results that the wall wear is most likely to occur at the outer edge of the baffle.

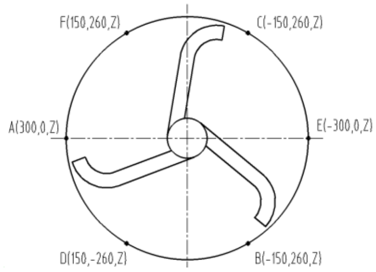


Fig. 5 The location of the point

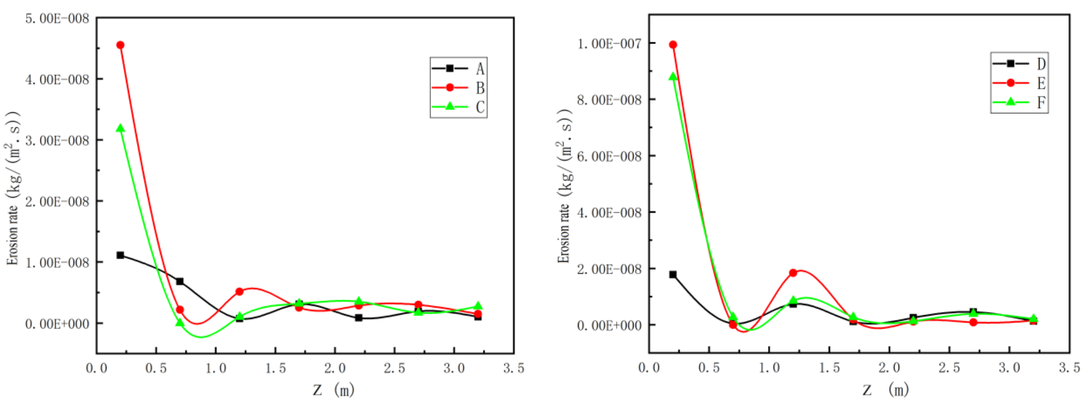


Fig. 6 Change curve of wall wear rate

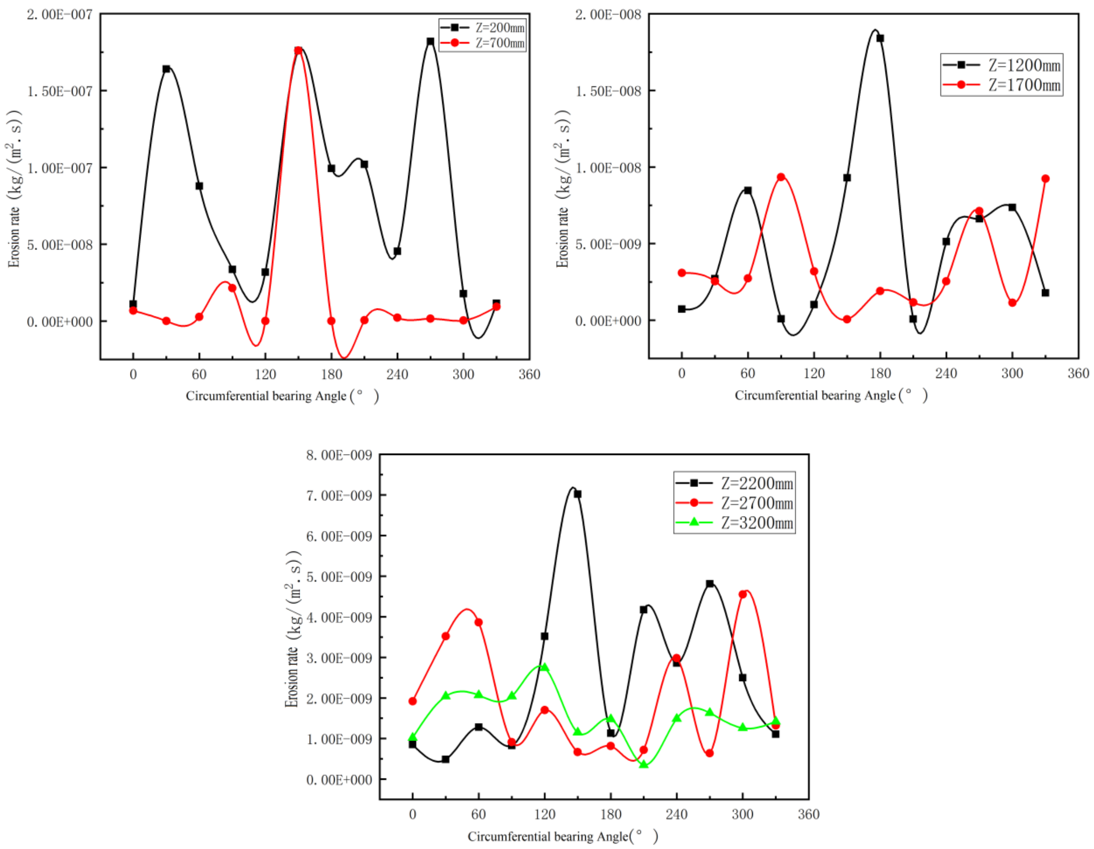


Fig. 7 Circumferential change curve of wear rate in annular space

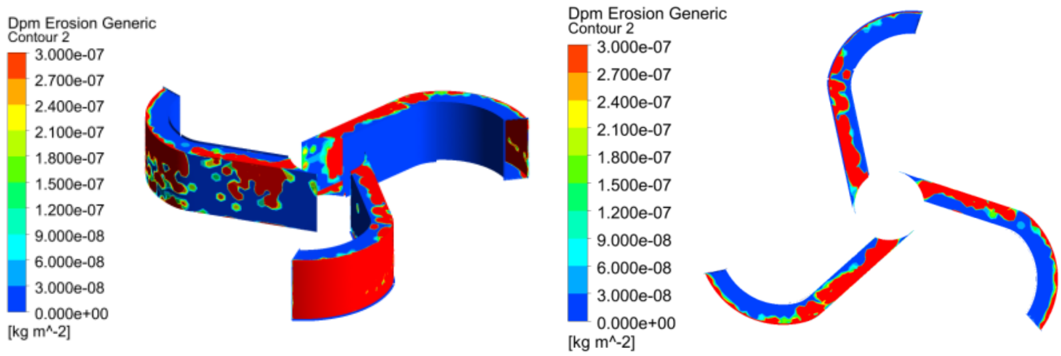


Fig. 8 Wear nephogram of cyclone arm

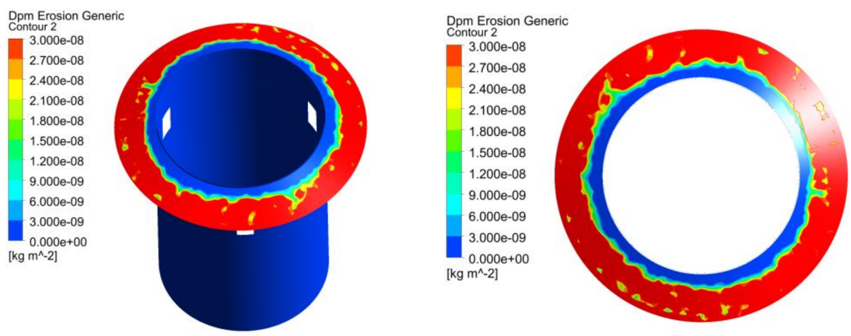


Fig. 9 Wear nephogram of closure

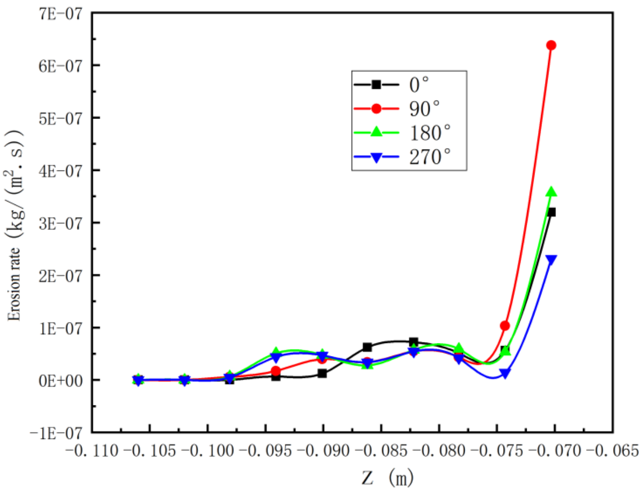


Fig. 10 Curve of baffle wear rate changing with axial distance

The wall wear nephogram of the settlement section is shown in Fig. 11. It can be seen from the figure that the change of wall wear in the settlement section increases gradually from top to bottom, and the wear is relatively serious in the middle and lower part near the exit, where wear and damage are easy to occur. There are differences in the distribution of wear cloud images in different directions, and the wear trajectories generally show oblique downward distribution, which is consistent with the spiral downward movement trajectories of particles.

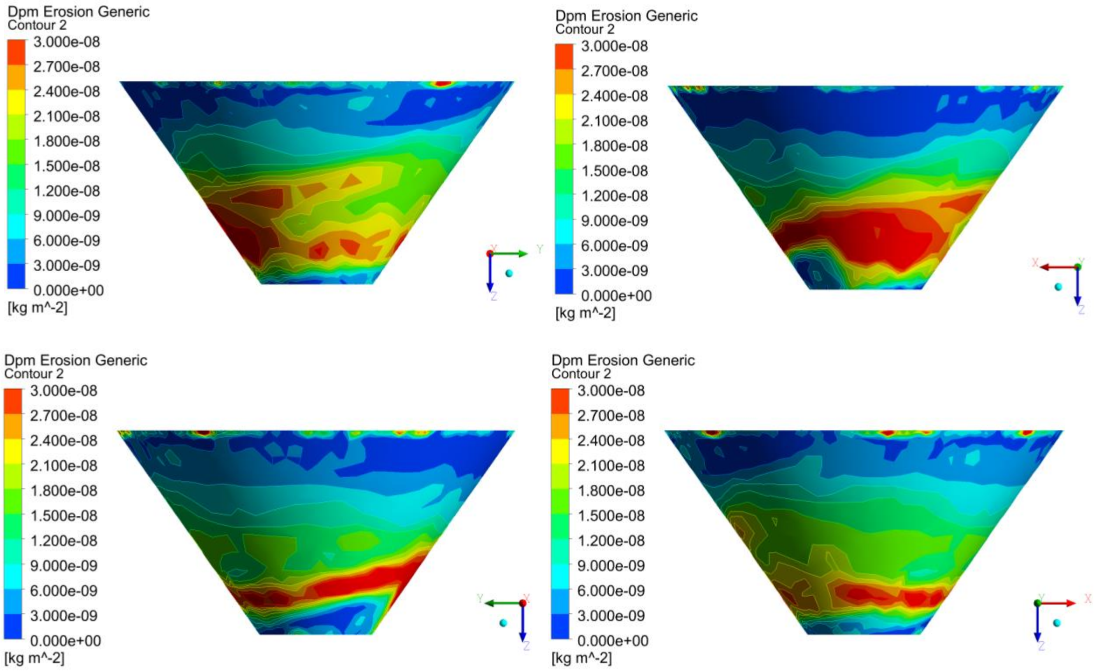


Fig. 11 Wear nephogram of subsidence section

The change of the wear rate of the wall surface in the settlement section can be qualitatively analyzed from the wear cloud map, but the change law of the wear rate cannot be quantitatively analyzed. Wear values were extracted at different axial positions along the circumferential direction of 0°, 90°, 180° and 270°, and the change curves of wear rates with axial distances in different circumferential directions were obtained, as shown in Fig. 12. The figure shows that in with conical section of a separate section of the contact point of wear and tear, settlement of wear upper tends to 0, with the increase of axial distance, the wear value overall first increases and then decreases, near the Z = 3.4 m, the wear value changes obviously, wear maximum value near the Z = 3.5 m, show the most serious wear and tear, and the closer the exports, at the bottom of the wall wear value is smaller.

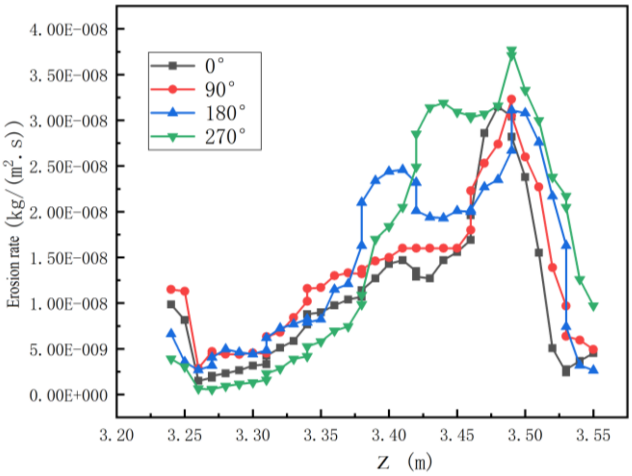


Fig. 12 Curve of wear value of cone section with axial distance

In summary, through the numerical simulation analysis of the fast subsystem, the main wear parts of the system are the arc-shaped section of the cyclone arm, the position of the wall near the spray outlet, the middle and lower part of the settlement section, the baffle of the separator and the top of the riser. The wear law of the wall is as follows: the wear is mainly local wear, and the wear rate of the wall decreases with the increase of axial distance. At the same time, by synthetically analyzing the velocity distribution and the wear distribution law of the system, we can get the conclusion that the wear rate of the wall is related to the erosion velocity.

4.2. Wear cause analysis

According to the wall wear analysis results of the fast subsystem, the wear value of the part with high tangential velocity of the fluid is also large, indicating that velocity is also one of the influencing factors of wear. The high-speed flow fluid enters the swirl head through the riser. At this time, the airflow has a large tangential velocity. The swirl head produces a large centrifugal force, which makes the particles in the fluid constantly impact the wall surface of the swirl arm under the centrifugal force and inertia action, resulting in wall wear. Closed hood wall wear is also caused by particles in wall under the action of centrifugal force impact, with fluid downward spiral motion, the tangential velocity is more and more small, the impact of the wall is also more and more small, so show wall wear rate trends to smaller and smaller, and the particles without area, its wear rate to converge to zero, so wall wear a spiral belt distribution.

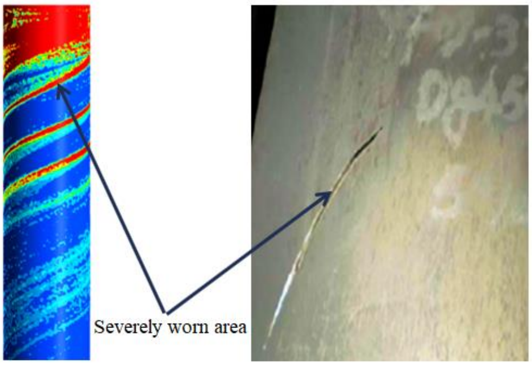
Isolating cylinder baffle wear with nearby area of the fluid flow characteristics of has much to do, due to the influence of the axial velocity and tangential velocity, solid particles was resistance, the action of gravity, centrifugal force, the force balance can appear some of these particles and suspended near the baffle, in airflow and damper under the action of surface erosion "formed by the erosion wear. In addition, due to the downward slope of its structure, when the fluid is ejected from the jet outlet of the cyclone arm, the velocity is relatively high, and some particles impact on the surface of the baffle will also cause wear. Therefore, it can be considered to improve the structure to reduce wear.

The wear in the settlement section is due to the decrease of the radius of the cone after the fluid enters the settlement section through the separation section, the centrifugal force on the particles gradually increases, and the impact effect between the particles and the wall becomes more obvious, so the wear caused by the particles on the wall gradually increases. At the same time, the separated particles concentrated impact on the cone plate, so that the concentration of particles in the cone plate concentration is large, and with the decrease of the radius, the particle is subjected to the increase of centrifugal force, resulting in wear and damage under the continuous particle impact.

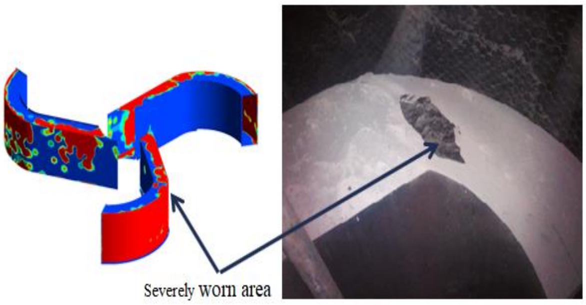
It can be seen that the wall wear is related to the effect of particles on the wall, and the wear rate is also related to the velocity and particle concentration. According to the analysis of wear causes and mechanisms, erosion wear is mainly caused by the long-term impact between particles and wall materials, and the nature of the material itself fundamentally determines the ability to resist wear. Therefore, the use of materials with high wear resistance can effectively reduce wall wear and improve the service life of the equipment.

5. Reliability demonstration

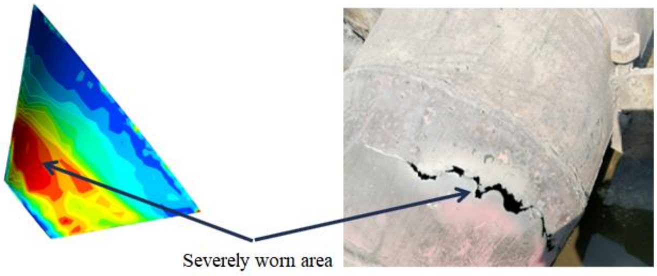
In order to ensure the reliability of the analysis results, the numerical simulation results were compared with the wall wear of the fast sub-system in industrial application. SVQS system in the industrial use of a long period of operation will eventually appear serious wall damage, seriously affect the efficiency of its work. As shown in figure 13 is an enterprise in the process of catalytic cracking of local wall damage SVQS system compared with simulation results in this paper, this system putting-in-service in 2008. During the overhaul in 2019, it was found that under the long-term wear of the fast sub-system, the outer wall surface of the arc section of the cyclone arm, the settlement section and the outer wall surface of the closed cover appeared local wear through phenomenon.



(a)Wear failure of closed cover wall surface



(b)Wear failure of outer wall of cyclone arm



(c)Wear failure of taper plate in settlement section

Fig. 13 Comparison between simulation results and actual wear

As can be seen from Fig. 13 (a), the closed cover wall surface of the fast sub-system used for a long period of time has worn through phenomenon, and its failure opening marks are relatively concentrated, showing a linear seam with spiral downward oblique direction. As can be seen from Fig. 13 (b), the wear phenomenon appears on the top of the outer wall surface of the cyclone arm. The wear position is concentrated in the arc segment of the cyclone arm, which proves that the impact of particles is serious here. As can be seen from Fig. 13 (c), a wide range of wall wear occurs in the middle and lower parts of the conical plate in the settlement section of the fast sub-system. By comparing the worn parts with the simulation results, it is found that the wear concentration locations, possible wear damage locations and the opening shapes of wear damage obtained by the simulation are basically consistent with the actual situation, which effectively verifies the reliability of the wear simulation results.

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6. Conclusion

In this paper, the software Fluent is used to simulate the SVQS system and analyze the wall wear of its internal flow field. By analyzing the wear distribution of the system, the damage of the wall surface can be predicted effectively, and the wear influencing factors can be analyzed, which lays a solid theoretical foundation for the structural optimization of the fast subsystem. The specific conclusions are as follows:

The velocity distribution law of the internal flow field in the fast subsystem is obtained, and the velocity distribution is uniform. The tangential velocities in different directions on the circumference are the same in magnitude but opposite in direction, which has strict symmetry. As the fluid moves downward, the velocity of the outer swirl decreases gradually. As the gas moves upward, the velocity of the inner swirl decreases.

The main wear parts of the system are the arc-shaped section of the cyclone arm, the position of the wall near the spray outlet, the middle and lower part of the settlement section, the baffle of the separator cylinder and the top of the riser, and the wear values of each part can be obtained. The wear value of the wall decreases with the increase of the axial distance, and the change rate of the wear rate becomes smaller and smaller.

Combined with the velocity distribution and wear distribution, the wear rate of the parts with high velocity is relatively high; By analyzing the wear distribution in the subsidence section, it can be seen that the part with large particle concentration wears more seriously. The degree of erosion wear on the wall is related to the velocity and particle concentration.

By analyzing the wear causes and wear distribution rules, it can be seen that, without considering other factors, the wear degree mainly depends on the material characteristics of the wall, and the service life of the equipment can be improved by improving the material.

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