The Improvments of RBOP's Plastic Core Strutural and Numerical Simulation of which Gas-Solid Two-Phase Flow in RBOP

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Abstract

Taking XK-II RBOP as simulation object, based on the solid model, combined with field work data, and to consider the impact of plastic core expansion on Flow field when a drill pipe or drill through the joints in the core rubber sealant. Making circumferentially equidistant vertical slot on the outer surface of interior sealant core in RBOP.And the different flow model was established.With the fluid analysis software FLUENT, based on solid flow behavior and fluid mechanics, numerical simulation BOP housing phase flow under different rubber core structure. Studies have shown that: the new plastic core structure can improve chip flow capacity of the housing, reducing the concentration of debris particles inside the casing annulus, reduce erosion housing. The velocity of Gas and the distribution turbulent kinetic energy is the most evenly.The peak curve ofFluctuations in the concentration of debris particles is least.The transport of debris particles is most efficiency.the performance of the housing diversion is stable, And compared to the original case erosion rate,the peak decreased, it is recommended for the best design number of slots is 5 .

Keywords

Shell of RBOP; Gas-Solid Two-Phase Flow; Diversion Performance; Erosion; Structural Optimization.

1. Introduction

As a low-pressure gas drilling underbalanced drilling technology, which has greatly improved the ROP , shorten drilling cycle, extended bit life and reduce downhole, etc [1-2]. In gas drilling wellhead safety control equipment system, the rotary blowout preventer is a key device for packer wellbore annulus and the drill string, provide safe and effective pressure control in drilling operations, and act to the wellbore with high-speed transport of drill cuttings gas particles from the wellhead quick lead role [3-5].At present, domestic and foreign scholars on the rotating BOP focused primarily on the dynamic sealing structure, study the structure of the housing and the rotary seal assembly locking structure and plastic core [6-8], while the study of gas drilling rotation BOP casing the flow of gas and debris particles and debris particle transport characteristics [9-11] of the erosion of the inner wall surface of the housing law to carry out much [12-14]. This paper mainly through fluid analysis software FLUENT, based on theoretical knowledge of fluid mechanics, with rotating BOP housing failure mechanism for rotating BOP housing interior core outer surface sealant circumferentially equidistant vertical slot treatment, and establish different flow model, carry out the rotating BOP casing phase flow numerical simulation analysis, the rotating BOP casing instructive phase flow study [15]. The existing problems of BOP housing for rotation flow field inside the original structure , to type XK-II rotary blowout preventer φ182mm [16] side outlet check diversion, for example, in the fast drilling conditions to improve the structure of the plastic core, and carry out Numerical simulation of the flow field inside the housing structure optimization, in order to achieve enhanced conductivity of the housing, reduce the amount of erosion housing purposes.

2. Model and equations

2.1 Physical Model

Rock breaking gas drilling cuttings generated by the airflow into the rotary blowout preventer carried inside the housing with the housing wall cuttings, drill pipe and rubber core repeatedly collide, BOP housing causing rotation of erosion damage. Currently on gas drilling cuttings cleaning tools research and field experience have proved to increase the turbulence of the circulating medium, can effectively improve the volume concentration of debris particles in the wellbore, wellbore clean play an active role. In this paper, XK series rotary blowout preventer for the study, shown in Figure 1.

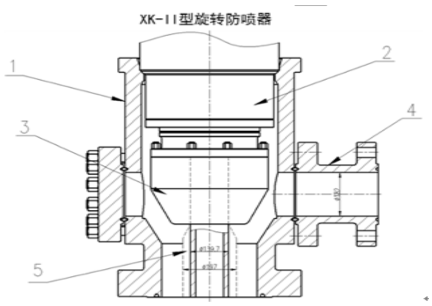


Figure 1. XK-II rotary BOP Schematic

Combined with field work data and based on the idea of the existing hole cleaning and cuttings breaking tools, Make structural improvements on rotary blowout preventer housing interior sealants core, Action by turbulence and mechanical removal of way, To achieve the purpose to improve chip flow capacity of the housing, reducing the concentration of debris particles inside the annular housing, thereby to reduce erosion of the housing. As shown in Figure 2, the outer surface of the plastic core circumferentially equidistant vertically open slots n, depth h, a width of 1. When gas drilling, the vertical groove of plastic core surface with the rotating drill pipe casing agitated violently turbulent flow field. Stirred up debris after being caught vertical slot can play the debris to the side with a higher rate of export gas transport action.

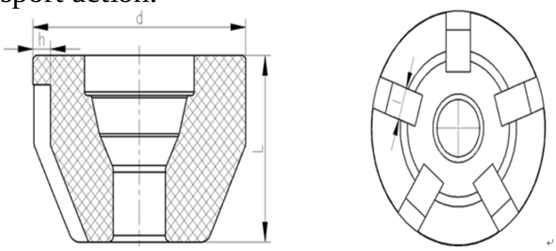


Figure 2. A schematic view of the new rubber core geometry (n = 5)

2.2 Equations

In the context of Newtonian fluid, the fluid motion will be subject to the conservation of mass, momentum, energy conservation dominated the three physics conservation laws, and mathematical equations that describe these conservation laws. In addition, if the flow is in a turbulent state, also subject to turbulent transport equation [17-19].

(1) The mass conservation equation

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{V}) = 0 \tag{1}$$

In formula ρ —— Fluid density(kg/m^3); $\mathbf{V}$ —— Fluid velocity(m/s); ∇ —— Divergence, $\nabla = \frac{\partial}{\partial x} + \frac{\partial}{\partial y} + \frac{\partial}{\partial z}$.

(2) The momentum conservation equation

$$\frac{\partial(\rho\mathbf{V})}{\partial t}=\nabla\cdot(\rho\mathbf{VV})=\nabla\cdot\left(\ddot{\boldsymbol{\tau}}^{*}\right)+\rho\mathbf{f} \tag{2}$$

In formula $\mathbf{f}$ —— Acting on a unit mass of fluid volume infinitesimal force(N); $\ddot{\boldsymbol{\tau}}^{*}=-p\ddot{\mathbf{I}}+\ddot{\boldsymbol{\tau}}$, $\ddot{\mathbf{I}}$ As a unit tensor; p —— Pressure(Pa); $\ddot{\boldsymbol{\tau}}$ —— Viscous stress tensor, In the Cartesian coordinate system expressed as

$$\begin{aligned}
\tau_{xx}&=\lambda(\nabla\cdot\mathbf{V})+2\mu\frac{\partial u}{\partial x}\\
\tau_{yy}&=\lambda(\nabla\cdot\mathbf{V})+2\mu\frac{\partial v}{\partial y}\\
\tau_{zz}&=\lambda(\nabla\cdot\mathbf{V})+2\mu\frac{\partial w}{\partial z}\\
\tau_{xy}&=\tau_{yx}=\mu\left(\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x}\right)\\
\tau_{xz}&=\tau_{zx}=\mu\left(\frac{\partial u}{\partial z}+\frac{\partial w}{\partial x}\right)\\
\tau_{yz}&=\tau_{zy}=\mu\left(\frac{\partial v}{\partial z}+\frac{\partial w}{\partial y}\right)
\end{aligned} \tag{3}$$

In formula, u, v, w is the velocity vector on x, y, z Component direction, μ is Viscosity coefficient, $\mathrm{Pa\cdot s}$; $\lambda=-\frac{2}{3}\mu$.

(3) Energy conservation equation

$$\frac{\partial(\rho E)}{\partial t}+\nabla\cdot(\rho E\mathbf{V})=\nabla\cdot\left(\ddot{\boldsymbol{\tau}}^{*}\cdot\mathbf{V}\right)-\nabla\cdot\mathbf{q}+\rho\mathbf{f}\cdot\mathbf{V} \tag{4}$$

In formula $\rho E=\rho e+\frac{\rho}{2}V^{2}$, E —— Gas always(J); e —— Gas internal energy(J); $\mathbf{q}$ —— Through heat(w/m^2),According to the Fourier heat conduction law of expression is:

$$\mathbf{q}=-\kappa_T\nabla T \tag{5}$$

Among them , κ_T is thermal conductivity, $\mathrm{J/(m\cdot s\cdot K)}$; T is Gas temperature.

Moreover, In order to make the equation (1), (2), (4) closed, also need to add fluid equation of state, its expression is

$$p=\rho R_g T \tag{6}$$

$$\rho e=\frac{p}{\gamma-1} \tag{7}$$

Among them, R_g is Gas constant, $\mathrm{J/(kg\cdot K)}$.

(4) Turbulence equations

In the standard model of turbulent eddy viscosity model Reynolds stress expression is:

$$\tau_{tij}=-\rho\bar{u}u_j=2\mu_t\left(S_{ij}-\frac{S_{nn}\delta_{ij}}{3}\right)-\frac{2}{3}\rho k\delta_{ij} \tag{8}$$

In formula S_{ij} - The average rate of strain rate tensor;

δ_{ij} - Kronecker operator;

k - Turbulent kinetic energy;

μ_t - Eddy viscosity, defined as the turbulent kinetic energy and turbulent dissipation rate function:

$$\mu_t = \frac{c_\mu f_\mu \rho k^2}{\varepsilon} \tag{9}$$

Based on dimensional analysis, Eddy viscosity is scaled by the fluid density ρ ,turbulence velocity scale k^2 and length scale $k^{3/2}/\varepsilon$, Attenuation function f is modeled by turbulence Reynolds $\mathrm{Re}_t = \rho k^2/\varepsilon\mu$.

Turbulent transport equation expressions is

$$\frac{\partial(\rho k)}{\partial t}+\frac{\partial}{\partial x_j}\left(\rho u_j\frac{\partial k}{\partial x_j}-\left(\mu+\frac{\mu_\tau}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right)=\tau_{tij}S_{ij}-\rho\varepsilon+\phi_k \tag{10}$$

$$\frac{\partial(\rho\varepsilon)}{\partial t}+\frac{\partial}{\partial x_j}\left(\rho u_j\varepsilon-\left(\mu+\frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial\varepsilon}{\partial x_j}\right)=c_{\varepsilon 1}\frac{\varepsilon}{k}\tau_{tij}S_{ij}-c_{\varepsilon 2}f_2\rho\frac{\varepsilon^2}{k}+\phi_\varepsilon \tag{11}$$

Among them, (10)is turbulent energy transport equation, (11)is Energy dissipation transport equation, right hand side of the two equations represent generate items, dissipation term and wall items. In model, each constant is defined as: $c_\mu = 0.09$, $c_{\varepsilon 1} = 1.45$, $c_{\varepsilon 2} = 1.92$, $\sigma_k = 1.0$, $\sigma_\varepsilon = 1.3$.

Near the wall attenuation function f_μ and f_2 expressioned as follows:

$$f_\mu = \exp\left(-3.4/(1+0.02\,\mathrm{Re}_t)^2\right) \tag{13}$$

$$f_2 = 1-0.3\exp\left(-\mathrm{Re}_t^2\right) \tag{14}$$

Wall entry ϕ_k and ϕ_ε expressioned as follows:

$$\phi_k = 2\mu\left(\frac{\partial\sqrt{k}}{\partial y}\right)^2 \tag{15}$$

$$\phi_\varepsilon = 2\mu\frac{\mu_t}{\rho}\left(\frac{\partial^2 u_s}{\partial y^2}\right)^2 \tag{16}$$

Among them, u_s is the flow velocity that Parallel to the wall surface ,m/s.

2.3 Set the boundary conditions

2.3.1 Basic boundary conditions

Establish numerical model in the inertial coordinate system, Choose SIMPLE algorithm, In order to clearly observe the laws erosion debris particles in different periods and movement of the housing, In this paper, adopting the transient solver transport processes inside the casing of the gas-solid flow field, Time Step is 0.05s,The total time step is 100, A single time step maximum number of iterations is 20.

(1)Housing inlet using velocity inlet boundary condition, In the numerical calculation process, Casing annulus to connect the base and drill the lower BOP formed as computational domain entry, At the same time in order to improve the accuracy of numerical calculation, Based on the field measured gas emissions, To make a preliminary calculation on the entrance of the gas velocity, turbulent kinetic energy, the hydraulic diameter. And regarded them as the entrance to the initial conditions set, As shown in Table 1.

Table 1. Housing inlet initial conditions

Shell model	The inlet gas volume flow(m^3/s)	Inlet velocity(m/s)	Turbulent kinetic energy(%)	Hydraulic diameter(mm)
XK-II	3.00	37.04	3.80	421.00
	2.50	30.86	3.90	

(2)Housing outlet using pressure outlet boundary condition. Under normal circumstances wellhead annulus pressure is about 0.3MPa, Therefore, this paper adopt 0.3MPa as working pressure of the flow field, In order to eliminate the outlet end of recirculating flow field flow, Set outlet pressure 0Pa.

(3)In the case of wall boundary conditions, Rotating BOP housing standard is slip-free smooth wall, Center pipe, plastic core, drill or rotary drill with no slip joints smooth wall, Rotating speed is 50r/min.

2.3.2 DPM wall boundaries set

Research shows: Granular debris particles belonging corners, Form factor is generally between 0.50~0.70[20], Therefore it takes cuttings particle shape factor(F_S)as 0.60, XK series rotary blowout preventer is used in metal alloy structural steel 35CrMo, This article take the shell material hardness as 230. By formula (17) for housing DPM wall parameter values were calculated.

$$f(\alpha)=f(\theta)=\begin{cases}-38.4\theta^2+22.7\theta \ , \theta\le 0.261799\\ 3.147\cos^2\theta\sin\theta+0.3609\sin^2\theta+2.532 \ , \theta>0.261799\end{cases}$$

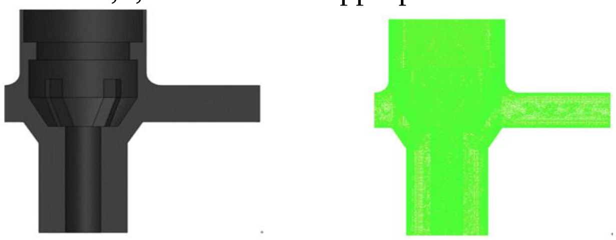
$$v_{pn}'^{\,b(v'_{pn})}=v_{pn}'^{\,1.73} \tag{17}$$

2.3.3 Phase settings

Article reference to the relationship between Loose bulk density and Density(The bulk density generally 2 times density), Based on the measured data, Doing conversion of Rotating BOP debris particles mass flow inlet, obtaining results that Fast drill cuttings particle mass flow is 1.2kg/s,Slow cuttings particle mass flow rate is 0.2kg / s.

2.4 Numerical Model and mesh

To obtain the new plastic core structure on erosion housing laws air ring body and the debris particles flow of migration law and housing, in order to better Compare with Procapsid simulation results, In this paper, the housing body internal loop air flow velocity, turbulent kinetic energy, the concentration of debris particles annulus and the casing erosion amount was evaluated in four areas. Making circumferentially equidistant vertical slot on the outer surface of interior sealant core in RBOP. Select new plastic core structure (n=5,h=35mm,l=60mm)as the initial parameters that Establish casing annulus flow model, As the picture 3(a) shows. In view of the special nature of the new plastic core structure. Making Casing annulus flow field geometry Unstructured tetrahedral (Tetra / Mixed) meshing by ICEM pre-processing software. As the picture 3. Then it was established the different flow model with n = 3,4,6. And do the appropriate simulation.



(a)The new plastic core structure flow model (b) Meshing

Figure 3. The new plastic core structure flow model and meshing

3. Model solution and Simulation results analysis

To obtain the influence of the new plastic slotted core structure with different number which affact the internal movement of the gas flow field housing, the movement of debris particles and the amount of erosion . Under the new rubber core initial structural parameters, Do comparative analysis of numerical simulation results about new plastic core structure annulus flow field with different Number of slot (n = 3, 4, 6). Meshing and boundary conditions as above. In this paper, in order to characterize the flow field overall transport performance of gas velocity and turbulence kinetic energy peak and peak-side outlet of the gas velocity distribution and turbulent kinetic energy distribution of the evaluation criteria.Under Rapid drilling conditions do research on the number of new rubber core structures of different slot on the body which affect the movement of the air inside the ring housing. Simultaneously, To characterize the housing diversion and anti-erosion performance of annular cuttings particle size distribution and the amount of housing Erosion Evaluation Criteria. To obtain the recommended number of slots.

3.1 Gas flow simulation analysis

Figure 4 is a fast drilling speed internal loop air turbulent kinetic energy peak body condition contrast the new plastic slotted core structure housing different numbers and graphs.

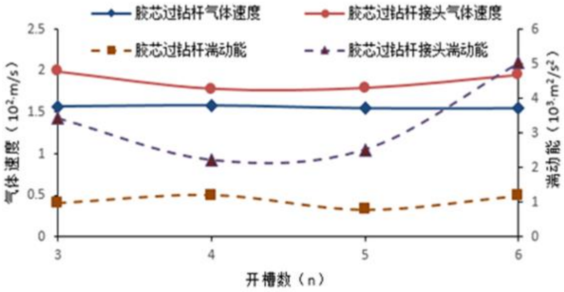
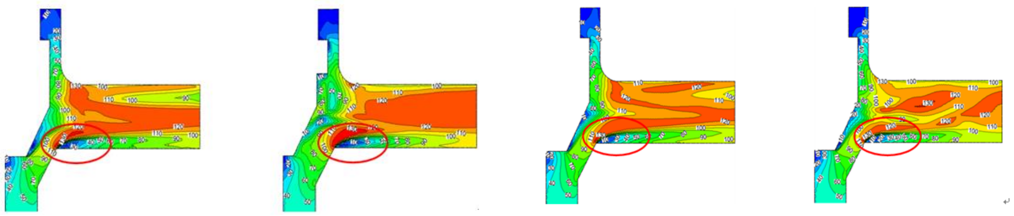


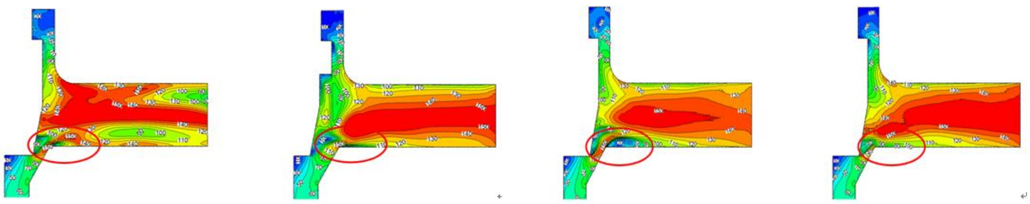
Figure 4. Different numbers slotted gas velocity and turbulent kinetic energy peak curve

The results show : ① When a plastic core through drill the different number of slots have little effect on Gas flow rate Peak. Peak curve is smooth, Gas turbulent kinetic energy peaks at n = 3 is gradually increased; ② When the tool joint through rubber core, Gas velocity begins to decrease at n = 4, Began to rise when n> 5, Peak curve less volatile, Gas turbulent kinetic energy peaks at n = 4 and n = 5 has tiny gap, At n = 6 reached the maximum $5.03 \times 10^3 m^2/s^2$.



(1) n=3 (2)n=4 (3)n=5 (4)n=6

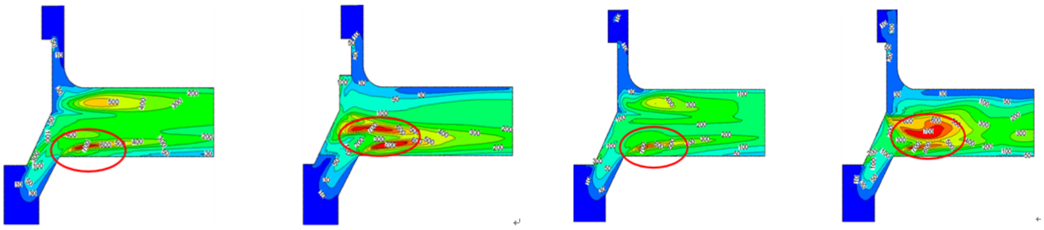
Figure 5 Side exit gas velocity contour plots at different numbers slotted plastic core drill under the same scale



(1)n=3 (2)n=4 (3)n=5 (4)n=6

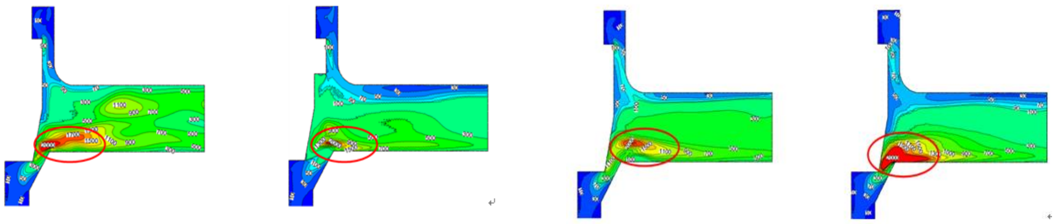
Figure 6 In the drill pipe joints side exit gas velocity contour maps through plastic core slot at the same time the number of different scale

Figure 5 and 6 Side exit gas velocity contour plots at the same scale figure below 6 with different numbers in the drill pipe joints grooved plastic core. The figure shows, When the plastic core through drill, The lower side of the wall outlet are partial reflux separator structure, With the number n increase in the recirculation region narrow . Side outlet occur within three recirculation region when number n is 3, The local area of reflux separator wall outlet lower side is larger when number n is 5, The lower side of the wall outlet partial recirculation region disappeared when number n is 6. However, the inner side of the outlet gas velocity red minimum peak area, the flow velocity distribution is uniform when number n is 5.



(1) n=3 (2)n=4 (3)n=5 (4)n=6

Figure 7. In the drill pipe side exit gas turbulent kinetic energy contour maps through several different plastic core slot at the same scale



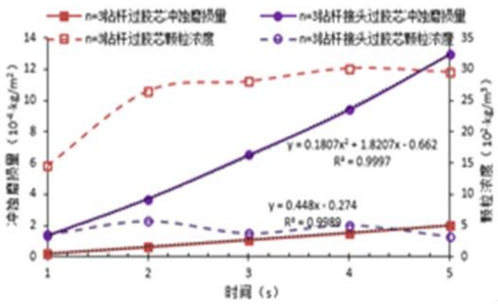
(1)n=3 (2)n=4 (3)n=5 (4)n=6

Figure 8. In the drill pipe joints-side outlet gas turbulent kinetic energy contour maps through several different plastic core slot at the same scale

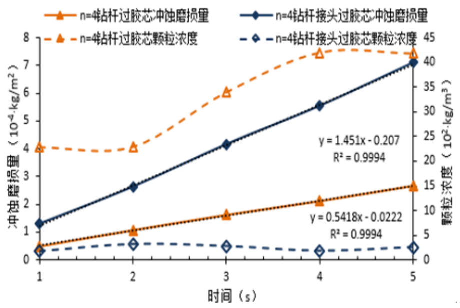
Figure 7-8 for the different number of slot-side outlet gas turbulent kinetic energy contour maps through the drill pipe and drill pipe when fitting the new rubber core structure under the same ruler scale. The figure shows, When n is 4 and 6 drill through the plastic core , Side outlet gas turbulent kinetic energy within the local Red Peak area is larger. When n is 5, the inner side of the outlet gas turbulent kinetic energy overall is lower and distribution. When the tool joint through rubber core, Gas turbulent kinetic energy exports overall increased local peak area within the side exit move sideways around the corner. When n is 6, the side outlet in the local gas turbulent kinetic energy peak red region is largest . When n is 5 drill through local turbulent kinetic energy peak area under rubber core cases increased more obvious .When n is 4, the local turbulent kinetic energy peak region is smallest.

3.2 DPM Simulation results analysis

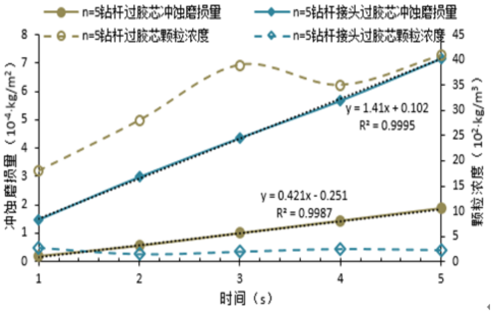
Figure 9 for different number of conditions for the rapid drilling of the new plastic slotted core structure within the housing annulus 5s peak particle concentration and volume erosion peak curve when passing through the drill pipe and tool joints.



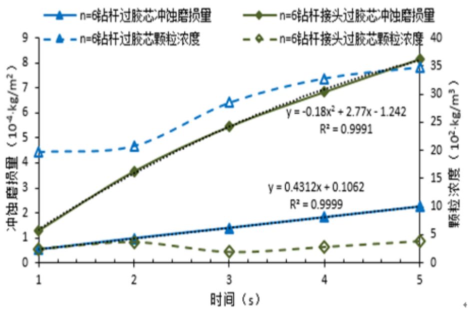
(1)n=3



(2)n=4



(3)n=5



(4)n=6

Figure 9. Within 5s the drill pipe joints rubber core debris after the peak concentration of particles and the amount of erosion peak curve

Figure 9 shows: Within 5s different number of slot debris particles during peak higher plastic drill core . Peak curve basic upward trend, And erosion same amount of peak curve shows a linear increase.

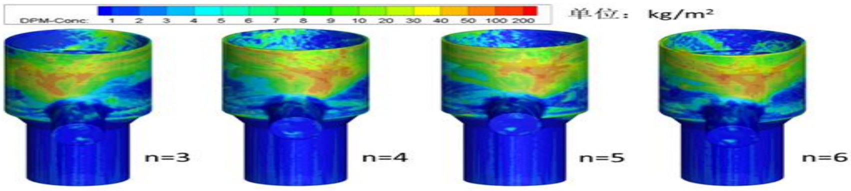


Figure 10. When t = 5s time drill through the drill cuttings particle concentration contours

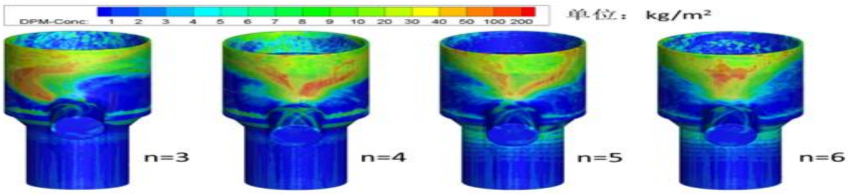


Figure 11. When t = 5s time over the tool joint drill cuttings particle concentration contours

Figure 10, 11 conditions for the rapid drilling time for the new rubber core slot structure in a number of different and passes through the drill pipe tool joints cuttings particle concentration contours when time is 5s. The figure shows, The new plastic core structure of the different number of slots, Can significantly reduce the concentration of particles annular cuttings on housing, Its local red high concentration region disappeared debris particles, Annular Cuttings particle concentrations remained between 7-40 kg / m3, Local particle concentrations higher particle concentration area of about 50-100 kg / m3. When drill through the plastic core, Annular cuttings on the overall distribution of particle concentration in the same trend. When the tool joint through rubber core, There on the housing annular cuttings particle concentration distribution of certain changes. The annulus area of local high particle concentrations cuttings are densely distributed when n are 3, 4, 6.

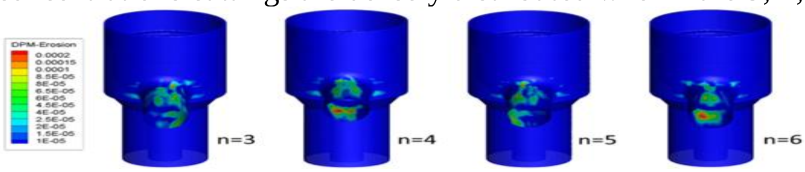


Figure 12. When t=5s drill through the plastic core erosion amount cloud

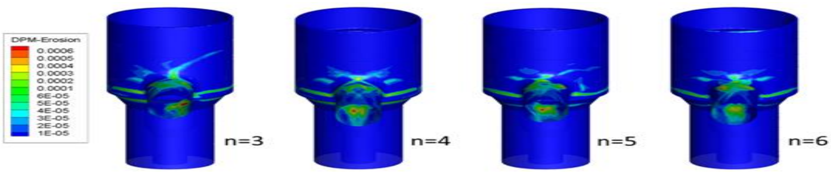


Figure 13. When t=5s tool joint through rubber core erosion amount cloud

Figure 12 and 13 is that new plastic core drilling in different conditions in several slotted structure passes through the drill pipe and the amount of cloud connector housing Erosion When t is 5s. The figure shows, In the same scale ruler, New plastic core structure housing wear debris particle erosion occurs mainly in the inner wall surface of the outlet side. Side of the case body and outlet connections, annular erosion region disappeared. And slotted rear side exit of local red high erosion significantly reduced the amount of generation region. In the drill through plastic core when n is 3 and 5, The amount of local high erosion area extending mainly to export. The lower side wall of local red erosion export volume peak position is basically the same regional distribution when n is 4 and 6. The amount of erosion and the red peak area of the original housing is relatively large compared to the amount of erosion when t is 5s. At n = 3, n = 5, the erosion rate of the peak decreased by 5%, 11%. At n = 4, n = 6, the erosion rate of the peak were increased by 28%, 7%. When the tool joint through rubber core, With the increase of the number of exit side slotted wall erosion area decreases. In addition to n = 3 outside the local high amount of erosion occurring position appears in the middle of the side wall exit.When time t = 5s erosion compared with the original amount of the housing, the number four slot erosion rate peak decreased by 36%, 65%, 65%, 60%.

4. In Conclusion

In this paper, XK-II rotary BOP housing (side exit: φ182mm- one way diversion) as an example. Further carry out the improvement and optimization of the rotating BOP housing flow structures. Rotary blowout preventer rubber core structure were optimized through CFD simulation technology. And reference gas drilling cuttings Cleanup tool structural features present a new plastic core structure.

The main conclusions are as follows:

(1) In the same condition, New plastic core structure (n = 5) debris particles can improve transport efficiency annulus inside the casing.Shorter residence time of the particles of debris. Reduce particulate volume concentration annulus cuttings. Slow down the speed of debris particles impact the wall. The effect of enhance the rotating BOP housing and anti-erosion chip diversion capability is remarkable.

(2) In the same condition, The new plastic core structures of different number of slots have a greater impact on erosion laws casing annulus flow field transport properties and housing. The new plastic core structures of different slot numbers can significantly reduce the concentration of particles annular cuttings on housing . In the slot number n = 3, n = 5, the housing decline significantly Erosion. The amount of local high erosion area extending mainly to export. And the number of slots n = 5 in the gas velocity and turbulent kinetic energy distribution of the most evenly. Fluctuations in the concentration of debris particles minimum peak curve. Highest debris particles transport efficiency. Diversion stable performance of the housing. And compared to the original case erosion rate decreased to peak. It is recommended for the best design n = 5 number of slots.

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