ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

NUMERICAL COMPUTATION STUDIES ON THE CUTTING-CARRYING AND LIFTING CAPACITY OF SPIRAL CENTRALIZER IN GAS DRILLING

[1,2]ZHENGMAO CHEN, [3]HONGLIN XU, [4]JIYOU XIONG

[1]Institute of Oil and Gas Resource Development and Oilfield Environmental Protection, China West Normal University, Nanchong 637000, Sichuan, China, zhengmao_chen@yeah.net

[2]Institute of Petroleum Engineering, Southwest Petroleum University, Chengdu 610500, Sichuan, China

[3]Institute of Petroleum Engineering, Southwest Petroleum University, Chengdu 610500, Sichuan, China

[4]Institute of Petroleum Engineering, Southwest Petroleum University, Chengdu 610500, Sichuan, China

ABSTRACT

For gas drilling, hole cleaning is a particularly critical problem. When the spiral centralizer is used in the down hole assembly of gas drilling, it will produce a powerful rotational flow which will be bond to have the influence of different level on the hole cleaning. For this matter, this paper has established a three-dimensional fluid dynamics model in the basis of gas-solid two-phase turbulent theory and got its numerical solution by using the finite volume method, therefore making a quantitative evaluation about the ability of cutting-carrying and lifting of the spiral centralizer. The results have shown that the spiral centralizer has the function of cutting-carrying and lifting; part of the rock debris pellet concentrates in the bottom of the blade, above less instead. The numerical calculation method has some guiding significance for spiral centralizer design in gas drilling.

Keywords: *Gas Drilling, Spiral Centralizer, Cutting-Carrying, Lifting, Deviation Control, Numerical Computation*

1. INTRODUCTION

In the design of gas drilling, it must meet the minimum gas displacement for cutting-carrying. When the spiral centralizer is used in the down-hole assembly of gas drilling, the effect of its cutting-carrying exerts direct influence on the quality of hole cleaning. In the process of gas drilling, cutting with larger diameter in the bottom hole have always been cut repeatly by bit teeth, forming a group of cutting with smaller diameter. If the spiral centralizer has better effect of cutting-carrying, a certain gas displacement can carry these cutting out of the well and maintain the drilling process normal.

Now substantial studies in both theory and experiment about the migration mechanism of cutting in gas drilling have been conducted by scholars both at home and abroad[1-4], produced a lot of important conclusions, however the report about the research on the theory of cutting-carrying ability of the spiral centralizer is rarely, only references[5-9] discussed its flow field and the structure in conventional drilling.

For this matter, this paper has established a three-dimensional fluid dynamics model in the basis of gas-solid two-phase turbulent theory and made a numerical analysis of cutting-carrying ability of the spiral centralizer. Then, this paper has also discussed the density and dynamic pressure distribution when the group of cutting flow through the spiral centralizer and analyzed the basic principal of its cutting-carrying and lifting. The numerical calculation method and the research results can contribute to the design of spiral centralizer in the gas drilling.

2. CUTTING-CARRYING AND LIFTING MECHANICAL MODEL OF THE SPIRAL CENTRALIZER

Annulus hydraulics in gas drilling belongs to the gas-solid two phrase turbulent flow. The migration of cutting in gas drilling belongs to the movement of particles and particle group in the gas-solid two phase flow. In the process of cutting-carrying the principal characteristic is the velocity of solid suspended in the gas phase is different from that of gas, so there exists an interaction force between the two phases, and because both of the velocities are

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

some larger, the flow has some unconventionality turbulence characteristics. Fine particle cutting moves into the spiral centralizer (see Figure 1) in the form of single particle or particle group and then flows towards the spiral flow pass with the guidance of the spiral centralizer. For the time being, the spiral centralizer rotates in high speed and changes the cutting density distribution. After being out of the spiral centralizer, the density and velocity of the cutting will distribute repeatly as result of the influence of the spiral flow. In the whole process of cutting migration, the cutting get kinds of forces including not only gas drag, gravity and buoyancy, but also centrifugal force and a variety of force created by spiral flow.

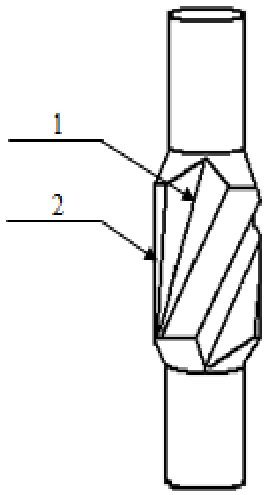

Figure 1: Structure Of The Spiral Centralizer (1-Spiral Flow, 2-Spiral Blade)

Before we establish the cutting-carrying and lifting mechanical model of the spiral centralizer, two problems must be considered firstly. The one is the selection of the turbulent model, and the other is the selection of two phase flow model. Considering the complex boundary condition of the spiral centralizer, this paper have preferred to choose the renormalization group (RNG $k-\varepsilon$)which handles the recent wall well as the turbulent model. Because during the gas-solid two phase turbulent flow in gas drilling, the diameter and density of the cutting are usually small, the Mixture model has been selected as the two phase flow model.

2.1 The Renormalization Group (RNG $k-\varepsilon$) Turbulent Model

So far, the standard $k-\varepsilon$ model that was proposed by Launder and Spalding in 1972 has been widely used in engineering flow field calculation, but it will distortion when used for strong swirling flow or flow with a curved wall. The renormalization group (RNG $k-\varepsilon$) that was proposed by Yakhot and Orzag [10] overcome this disadvantage through improving ε equation, and provides an analytical formula for the Prandtl Number, so this model can be used in the simulation of strong swirling flow or flow with a complex wall in the spiral centralizer. The renormalization group (RNG $k-\varepsilon$) turbulence model is as follows:

K -equation:

$$\frac{\partial}{\partial t}(\rho k)+\frac{\partial}{\partial x_i}(\rho k u_i)=\frac{\partial}{\partial x_j}\left(\alpha_k \mu_{eff}\frac{\partial k}{\partial x_j}\right) + G_k + G_b - \rho\varepsilon - Y_M \tag{1}$$

ε -equation:

$$\frac{\partial}{\partial t}(\rho\varepsilon)+\frac{\partial}{\partial x_i}(\rho\varepsilon u_i)=\frac{\partial}{\partial x_j}\left(\alpha_\varepsilon \mu_{eff}\frac{\partial \varepsilon}{\partial x_j}\right) - + C_{1\varepsilon}\frac{\varepsilon}{k}(G_k + C_{3\varepsilon}G_b) - C_{2\varepsilon}\rho\frac{\varepsilon^2}{k} - R \tag{2}$$

In the equation (1), the left first term is the change rate of turbulent kinetic energy K ; the second term is the convection transport of the time average movement; the right first term is diffusion transport; G_k expresses the kinetic energy caused by velocity gradient, it can be got from the equation (3) to (5).

$$G_k = -\rho\overline{u_i' u_j'}\frac{\partial u_j}{\partial x_i} \tag{3}$$

By Baoxin Nick hypothesis:

$$G_k = \mu_t S^2 \tag{4}$$

S is strain tensor modulus:

$$S \equiv \sqrt{2S_{ij}S_{ij}} \tag{5}$$

G_b expresses the kinetic energy caused by buoyancy:

$$G_b = \beta g_{ki}\frac{\mu_t}{\Pr}\frac{\partial T}{\partial x_i} \tag{6}$$

Where, P_r is turbulent Prandtl number; g_{ki} is the acceleration component of gravity in i direction; β is the coefficient of thermal expansion, it can be got by the state equation of compressible fluid.

$$\beta = -\frac{1}{\rho}\frac{\partial\rho}{\partial T} \tag{7}$$

Substitutes Eq. (7) into Eq. (6) yields:

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

$$G_b = -g_i \frac{\mu_t}{\rho \Pr_t} \frac{\partial \rho}{\partial x_i} \tag{8}$$

Y_M is the turbulent dissipation resulting from compression turbulence.

$$Y_M = 2\rho\varepsilon M_t^2 \tag{9}$$

Where, M_t is Mach number, $M_t = \sqrt{\frac{k}{a^2}}$; a is sound velocity, $a = \sqrt{\gamma RT}$.

In Eq. (1) and Eq.(2), α_k and α_ε are respectively turbulent Prandtl number of K -equation and ε -equation, both approximately equal to 1.393.

μ_{eff} is given by Eq.(10):

$$d\left(\frac{\rho^2 k}{\sqrt{\varepsilon\mu}}\right) = 1.72 \frac{\hat{v}}{\sqrt{\hat{v}^3 - 1 + C_v}} d\hat{v} \tag{10}$$

Where $\hat{v} = \mu_{eff}/\mu$, $C_v \approx 100$. By integrating Eq.(10),the flow field with low or high Reynolds number at wall can be calculated accurately. After integration, we can conclude turbulent viscosity formula at high Reynolds number cases:

$$\mu_t = \rho C_\mu \frac{k^2}{\varepsilon} \tag{11}$$

Where, $C_\mu = 0.0485$, it is close to the value 0.09 of the standard $k-\varepsilon$ equation.

In Eq. (2), the left first term is the change rate of dissipation rate ε , the second term is convection; the right first term is diffusion, others are the generation and damage of dissipation rate. R_ε is given by Eq. (12).

$$R_\varepsilon = \frac{C_\mu \rho \eta^3 (1 - \eta/\eta_0)}{1 + \beta\eta^3} \frac{\varepsilon^2}{k} \tag{12}$$

Where, $\eta \equiv Sk/\varepsilon$, $\eta_0 = 4.38$, $\beta = 0.012$.

To what extent of ε equation is influenced by buoyancy depends on $C_{3\varepsilon}$, it can be given by

$$C_{3\varepsilon} = \tanh\left|\frac{v}{u}\right| \tag{13}$$

Where, v is the fluid velocity component parallel to the gravity direction; u is the fluid velocity component perpendicular to the gravity direction. For the laminar flow which has the same velocity direction with gravity, $C_{3\varepsilon} = 1$; When the buoyancy stress layer is perpendicular to the gravity acceleration, $C_{3\varepsilon} = 0$ .Here, $C_{1\varepsilon} = 1.42$, $C_{2\varepsilon} = 1.68$.

2.2 Mixture Model

Mixture model is mainly used for simulation of two phase flow, it is relatively accurate when the solid particles content of less than 20% at the section. The model conforms preferably to the characteristics with little particle for the cutting-carrying and lifting of the spiral centralizer.

Continuity equation:

$$\frac{\partial}{\partial t}(\rho_m) + \nabla \cdot (\rho_m v_m) = 0 \tag{14}$$

v_m is mean mass flux:

$$v_m = \frac{\sum_{k=1}^{n} \alpha_k \rho_k v_k}{\rho_m} \tag{15}$$

ρ_m is mixed density:

$$\rho_m = \sum_{k=1}^{n} \alpha_k \rho_k \tag{16}$$

Momentum equation:

$$\frac{\partial}{\partial t}(\rho_m v_m) + \nabla \cdot (\rho_m v_m v_m) = -\nabla p + \nabla \cdot \left[\mu_m \left(\nabla \bar{v}_m + \nabla v_m^T\right)\right] + \rho_m g + F \tag{17}$$

Where, F is body force, μ_m is mixed viscosity.

The volume fraction equation of the cutting.

$$\frac{\partial}{\partial t}\left(\alpha_p \rho_p\right) + \nabla \cdot \left(\alpha_p \rho_p v_m\right) = -\nabla \cdot \left(\alpha_p \rho_p v_{dr,p}\right) \tag{18}$$

Where, $v_{dr,p}$ is drift velocity.

2.3 Mixture Model

Inlet boundary: velocity-inlet (decided by displacement), initial cutting density.

Outlet boundary: pressure outlet.

Wall condition: wall_1 adopts solid wall boundary, wall_2 adopts rotating boundary.

Internal fluid: area A and C adopt the fixed coordinate system, area B adopts the rotating coordinate system; the connection grid point between area A, C and B adopts sliding mesh (see Figure 2).

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

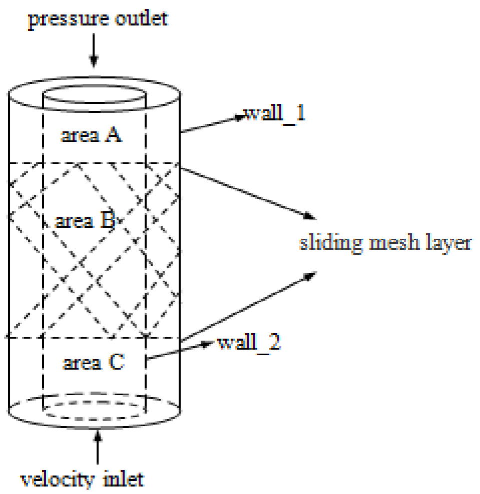

Figure 2: The Boundary Condition Setup

By combining the renormalization group (RNG $k-\varepsilon$) turbulent flow model and the mixture two-phase model, and with the boundary condition a set of closed equations have been established. Then the equations were discretized through the finite element method, at last by adopting the simple algorithm of velocity coupling with pressure, the numerical calculation of cutting-carrying and lifting of the spiral centralizer was completed. The program flow is shown in Figure 3.

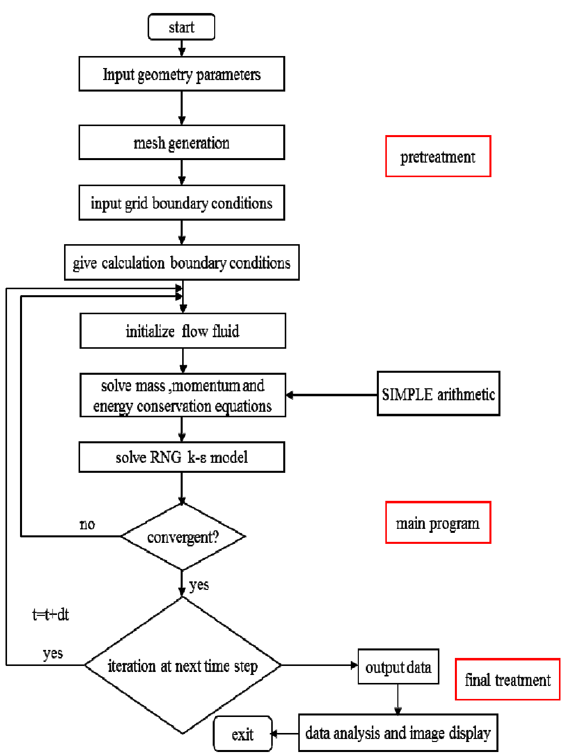

Figure 3: The Program Flow Of The Numerical Calculation

3. EXAMPLE ANALYSIS

3.1 Drilling Parameters

The velocity of gas and cutting particle is15 m/s; the density of the gas is 5 kg/cm^3; well depth is 1000 m; hole diameter is 215.9 mm; the rotational speed is 60 r/min; the diameter of cutting particle is 1mm; the density of cutting is 2500 kg/m^3, the initial inlet concentration of the cutting is 0.1%.

3.2 Drilling Parameters

The calculation results show that the inlet concentration of the cutting is the same as that of outlet and don't appear obvious change ,this states that there is no deep blocking when the cutting particle group flows though the spiral centralizer, meanwhile the bad cutting-carrying will not happen if using the spiral centralizer during gas drilling .At the same time, from the analysis it can be clearly see the distribution of the all cutting group when gas flows through the spiral centralizer. For example, the cutting concentrates below the blade reaches 0.125%, instead nearly 0 above the blade. The main reason for this is that before the annulus gas flows into the spiral pass the cutting particle group is mainly forced by gas drag, gravity and buoyancy, but other forces such as impact between the particles has little effect; after the annulus gas flows into the spiral pass, because the flow pass is narrowed and the velocity improves, this leads to the effect of the gas drag is enhanced, so the ability of cutting-carrying of the gas is increased. At this time, large part of cutting particles suspend above the spiral flow pass, when the spiral centralizer rotates at 60 rpm following the drill string, the spiral blade will force the near cutting particles to move centrifugally, the centrifugal movement results will make large sum of particles concentrate below the blade and no cutting appears above the blade instead.

The calculation results can also get the law of the full flow field. After the annulus gas from the bottom flows into the spiral flow pass, the pressure changes obviously and the maximum appears nearly below the blade; but when the annulus gas nearly flows out of the spiral flow pass, the maximum dynamic pressure appears nearly above the blade, so the change of the gas movement at this two area is the most fierce areas. Meanwhile, the minimum dynamic pressure still lies nearly above and below the blade, the reason is that the two areas are exactly under or over the spiral blade, when the gas from the bottom flows into or out of the spiral flow pass, it is obstructed by the root segment of the spiral blade, thus leading to the reduction of the

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

dynamic pressure. So considerations about the shape of the root segment of the blade during design must be taken, we suggest design into arc-shaped blade for avoiding producing much low dynamic pressure.

4. CONCLUSION

(1)The numerical calculation results show that the spiral centralizer has the function of cutting carrying and lifting in gas drilling.

(2)A part of cutting particles concentrates below the spiral blade, fewer above instead.

(3)The law of flow field near the spiral centralizer has been concluded.

(4) The numerical calculation method and the research results have some guiding significance for spiral centralizer design in gas drilling.

ACKNOWLEDGEMENTS

This work was supported by Natural Science Foundation of China “Leak Prevention and Control Physically Whiling Drilling about Oil and Gas Deep Well in West China”(project number is 90610013)

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