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Prediction of Surge Pressure in Extended Reach Well Based on Casson Fluid

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Abstract

In order to solve the problem of bottom hole surge pressure generated during the drilling of high angle wells, the flow model of Casson fluid axial laminar flow in the eccentric annulus of high angle wells was introduced based on the influence of drill string eccentricity on the flow law of drilling fluid, the basic equation of one-dimensional stable flow and the constitutive equation of Casson model, and the prediction model of surge pressure during the drilling of high angle wells was established in combination with the annular flow equation under the actual working condition of drill pipe; A new prediction method of surge pressure in high angle wells based on the Casson reheology model was proposed by solving the model using computer programming software. The calculation results show that this method is simple, fast and accurate, and has important guiding significance for the safe control of surge pressure during the drilling of high angle wells.

Keywords

Surge pressure; High angle well; Casson fluid.

1. INTRODUCTION

Surge pressure is a key parameter to control the bottom hole pressure during the drilling process; Especially in high angle wells and horizontal wells, inaccurate prediction of surge pressure may lead to wellbore instability and other complex downhole conditions [1] [2] [3] [4] [5]. The traditional calculation method of surge pressure mainly applies to vertical wells, while the existing calculation models of wellbore surge pressure in high angle wells and horizontal wells involve complex mathematical theories and are difficult to solve in practical application, resulting in low prediction efficiency [6][7]. Therefore, based on the Casson fluid, which can accurately describe the rheological properties of drilling fluid at high shear rates at the drill pipe and bit nozzle, a new method for effectively predicting the surge pressure of high angle wells was proposed by taking the axial laminar flow rate in the eccentric annulus of high angle wells as the fitting point. This method can be used to calculate the numerical model directly with the corresponding computer software, and can also be used to predict wellbore surge pressure in vertical and horizontal wells.

2. PHYSICAL MODEL OF DRILLING FLUID FLOW IN THE WELLBORE OF HIGH ANGLE WELLS

It is assumed that the drilling fluid used in the drilling process is incompressible non-Newtonian fluid, and its rheological properties are described by the Casson model. In order to ensure that the pressure surge caused by drill pipe movement does not affect the stability of the wellbore pressure system, and to simplify the research problem and facilitate the calculation, it is assumed that drilling fluid flows in eccentric annulus with isothermal and fixed-length axial laminar flow, and that motion parameters at each space point in the flow field do not change with time, that is, the flow is stable [8].

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In high angle wells and horizontal wells, the drill pipe deviates from the central axis of wellbore to varying degrees under the action of gravity, forming an eccentric annulus between the drill pipe and the wellbore; The eccentric annulus affects the flow law of drilling fluid in the wellbore, and the traditional concentric annulus drilling hydraulics no longer applies. Fig. 1 and Fig. 2 show the physical model of flow in eccentric annulus and the simplified model of flow cross-section of eccentric annulus in high angle wells and horizontal wells.

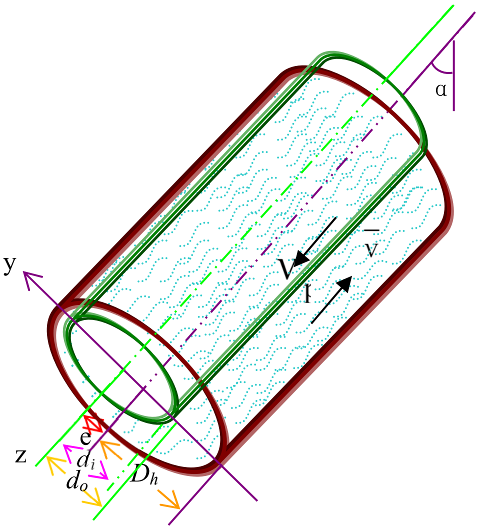

Figure 1. Physical model of flow in eccentric annulus

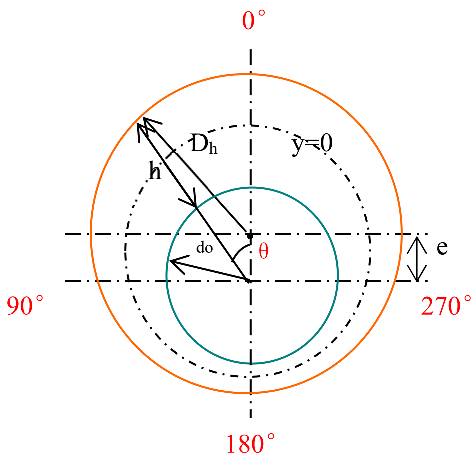

Figure 2. Simplified model of flow cross-section of eccentric annulus

In Fig. 1 and Fig. 2, D_h is the wellbore radius; d_0 is the outer radius of the moving drill pipe; d_i is the inner radius of the drill pipe; α is the angle of inclination; $\bar{v}$ is the average velocity of drilling fluid in the wellbore annulus; $\bar{v}_p$ is the running speed of the drill pipe; e is the eccentricity between the drill pipe and the wellbore axis. The eccentric annular clearance h from the outer wall of the pipe to the borehole wall at any circumferential angle θ is:

$$h = \sqrt{D_h^2 - e^2 \sin^2 \theta} - d_0 + e\cos\theta \tag{1}$$

At a point under any circumferential angle θ in the annular clearance, a tiny hexahedral element was taken along the direction parallel to the flow, as shown in Fig. 3.

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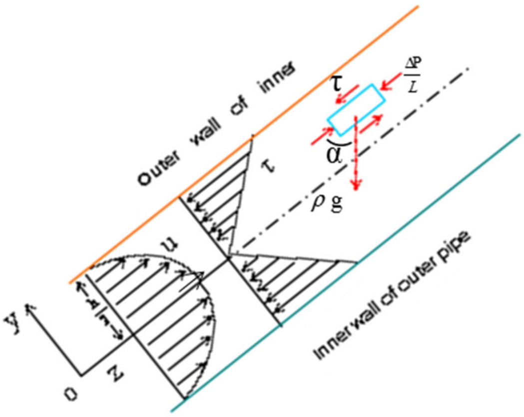

Figure 3. Force analysis of physical model of flow

In Fig. 3, τ is the shear stress between liquid layers; $\frac{\Delta p}{L}$ is the surge pressure gradient in length L along the direction of fluid flow. When the shape of the flow cross-section along the flow direction remains unchanged and the fluid is incompressible, the surge pressure gradient in the wellbore annulus at the angle of inclination α is shown below:

$$\frac{\Delta p}{L}=\frac{\partial p}{\partial z}-\rho g\cos\alpha \tag{2}$$

3. CALCULATION MODEL OF SURGE PRESSURE IN HIGH ANGLE WELLS

3.1. Calculation of axial laminar flow rate in eccentric annulus

For the Casson fluid, its rheological equation can be expressed as [9]:

$$\tau=\left[\eta_\infty^{\frac{1}{2}}\left(-\frac{du}{dy}\right)^{\frac{1}{2}}+\tau_c^{\frac{1}{2}}\right]^2 \tag{3}$$

By integrating Eq. 2 and Eq. 3, the point velocity with different y values at any circumferential angle θ can be obtained:

$$u(\theta,y)=\frac{\Delta p}{2L\eta_\infty}\left[\left(\frac{h}{2}\right)^2-y^2\right]+\frac{\tau_c}{\eta_\infty}\left(\frac{h}{2}-y\right)-\frac{4}{3\eta_\infty}\left(\frac{\Delta p}{L}\right)^{\frac{1}{2}}\tau_c^{\frac{1}{2}}\left[\left(\frac{1}{2}\right)^{\frac{3}{2}}-y^{\frac{3}{2}}\right] \tag{4}$$

The limit surge flow rate of Casson fluid flowing steadily in eccentric annulus of high angle wells and horizontal wells is:

$$Q=\int_0^{2\pi}\mathrm{d}Q=\int_0^{2\pi}v(\theta)ds=\int_0^{2\pi}(2d_o+h)\int_0^{h/2}u(\theta,y)dyd\theta \tag{5}$$

3.2. Flow rate analysis in field conditions

In field conditions, there are four forms of moving drill pipe: plugging pipe pump-on drill pipe, plugging pipe pump-off drill pipe, open pipe pump-on drill pipe, and open pipe pump-off drill pipe. During pump-on of plugging pipe and open pipe, the fluid of their mud pumps is discharged from the

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drill pipe, which affects the average velocity in the well, so it can be considered as the same working condition.

Under the conditions of rigid moving drill pipe and stable flow of drilling fluid, considering the change in annular velocity caused by the adhesion effect of drilling fluid, an equilibrium equation was established between the volume of drilling fluid displaced by drill pipe movement per unit time and the flow rate in the annulus. Then combined with the average velocity $\overline{v}$ of drilling fluid in the annulus and the area S of the annulus flow cross-section under different working conditions, the corresponding surge annular flow rate Q under different working conditions can be obtained, namely:

Plugging pipe pump-on:

$$Q = 4.71[K_c D_h^2 + (1-K_c)d_o^2]\overline{v}_p \tag{6}$$

Open pipe pump-on:

$$Q = 4.71[\frac{(d_o^2-d_i^2)(D_h^2-d_o^2)}{D_h^2-d_o^2+d_i^2} + K_c(D_h^2-d_o^2)]\overline{v}_p \tag{7}$$

Open pipe (plugging pipe) pump-on:

$$Q = 4.71[K_c D_h^2 + (1-K_c)d_o^2]\overline{v}_p + Q_p \tag{8}$$

3.3. Calculation model of surge pressure

Based on interpolation theory and elliptic integral [10], the limit surge flow rate of Casson fluid flowing stably in eccentric annulus of high angle wells was sorted into a form that can be easily calculated by computer software programming, as shown in Eq. 9.

$$\begin{aligned} Q = {} & \frac{\Delta p}{L}\frac{2}{3\eta_\infty}[A\pi + B\varsigma + e^2 d_o\varsigma - \frac{8}{3}d_o\xi + \frac{2e}{3}\xi] + \sqrt{\frac{\Delta p}{L}}\frac{2\sqrt{\tau_c}}{5\eta_\infty}[B\pi + C\varsigma + \frac{8}{3}\xi] \\ & + \frac{\tau_c}{\eta_\infty}[B\pi + C\varsigma + \frac{8}{3}\xi] \end{aligned} \tag{9}$$

Where,

$$A = \frac{1}{2}(D_h^4 - e^3 d_o - d_o^4) + D_h^2 e^2 + D_h^{2.64} e^{2.64} d_o^{-2.2},$$

$$B = d_o^3 - D_h^2 d_o - e^3 - D_h^{2.64} e^{2.64} d_o^{-3.03},$$

$$C = D_h^2 - d_o^2 - e^2,$$

$$\varsigma = D_h E\left(\frac{e^2}{D_h^2}\right) + \sqrt{D_h^2 - e^2}\, E\left(\frac{e^2}{e^2 - D_h^2}\right),$$

$$\xi = D_h\left((D_h^2 + e^2)K(\frac{e^2}{D_h^2}) + (e^2 - D_h^2)K(\frac{e^2}{D_h^2})\right)$$

K(m) is the complete elliptic integral of the first kind, E(m) is the complete elliptic integral of the second kind, and its value can be obtained by computer software programming.

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The model equation was calculated according to the annular flow rate under actual working conditions and the surge pressure. Based on the maximum surge pressure gradient model of each annular segment established above, the i-th annulus segment divided is represented by the letter i. $\left(\frac{\Delta p}{L}\right)_i$ is the surge pressure gradient of the i-th annular segment. Li represents the well depth of the i-th annular segment. Therefore, the expression of the new model for predicting surge pressure at any well depth position (i=n) in high angle wells and horizontal wells is shown below:

$$P_s = \pm\sum_{i=1}^{n}\left(\frac{\Delta P}{L}\right)_i L_i \tag{10}$$

Where, "±" represents the surge pressure and swab pressure generated during the process of RIH (casing running) and POOH (casing lifting), respectively.

4. EXAMPLE PREDICTION OF SURGE PRESSURE

The wellbore of a high angle well was filled with drilling fluid, and the rheological properties were described by the Casson model: τ_c= 1.51Pa, η_∞=15.5mPa·s. The casing with φ_{outer}=244.48 mm (φ_{inner}=222.5 mm) was run to the vertical depth of 600m for whipstocking, and the initial angle of inclination α_1 was 8°. The drill pipe with φ_{outer}=127 mm (φ_{inner}=82 mm) was run at the drilling speed of 1 m/s to the depth of 2204.82m to start angle holding drilling. At this time, the angle of inclination α_2 was 84° and the well depth was 2306.13 m. The drill pipe was set as plugging pipe pump-off state to calculate the surge pressure in the wellbore annulus at the casing shoe (the surge pressure in the drill pipe annulus) and the additional density of drilling fluid required.

Table 1. Example Calculation of Surge Pressure Prediction in High Angle Wells

	Related Steps	Calculation Results
Basic parameters	Refer to the theoretical relation chart between drilling fluid adhesion coefficient and annulus ratio under power law and Bingham model	Annulus ratio: 127/222.5=0.57 (small) Adhesion coefficient K_c = 0.4 Annulus flow rate under plugging pipe pump-off state: Q_t = 0.034 m³/s
Calculation parameters of surge pressure equation	Substitute the basic parameters into the left side of surge pressure calculation equation	Eccentricity=0.5 Eccentric distance e = 0.0239 m A= 0.000110297 B= − 0.000937975 C= 0.007979025
	According to the calculation by computer software programming	E(0.0295)= 1.55914 E(−0.0304)= 1.58267 K(0.0295)= 1.58258 K(−0.0304)= 1.55905 ζ = 0.34691 ζ = 0.00019
Surge pressure and additional density value of drilling fluid in each section	Substitute various parameters into the surge pressure calculation equation	ΔP/L = 0.1917859 kPa/m, Surge pressure gradient at the angle of inclination α: P_s = 0.1917859 cosα Surge pressure of vertical section P_1= 115.072 kPa Surge pressure of building up section P_2= 263.254 kPa Total surge pressure in the annulus at the casing shoe: $P=P_1+P_2$=378.326 kPa Additional density of drilling fluid: ρ=P/(gH)=0.017 5 g/cm³

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5. CONCLUSION

(1) The prediction model of annular surge pressure in high angle wells was established based on the Casson reheology model;

(2) The new model can apply to the surge pressure in the well generated by pipe string movement under different working conditions;

(3) The calculation process of the new model is simple and fast, and the results are accurate and reliable;

(4) After simplification, the new model can be directly transformed into the prediction model of annular surge pressure in vertical wells and directional wells.

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