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A new model for computing surge/swab pressure in horizontal wells and analysis of influencing factors

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ABSTRACT

In the drilling of horizontal wells in complex formations such as subsalt fractural formation, factors such as high drilling liquid density, rheological uncontrollability, and narrow safety density window of drilling fluid may lead to downhole pressure fluctuation, which, however slightly gives rise to complex downhole problems. In order to accurately calculate the surge/swab pressure of horizontal wells in such formations, this paper, based on hydromechanics and a width-variable flat-plate flow model, introduce a new model for computing surge/swab pressure in horizontal wells. This model takes the effects of velocity drilling string on the boundary conditions of surge/swab pressure into consideration, as no previous model has. With the tripping of drilling string under consideration, and when the annular flow remains the same, we find that, in the computation of swab pressure, the velocity in the inside and outside velocity zones are both larger than those produced by previous ones, and that in the computation of surge pressure, while the velocity in the inside velocity zone is first smaller and then turns greater, the velocity in the outside velocity zone is always larger. A comparison with previous models also reveals larger surge pressure, larger swab pressure at low rate and smaller swab pressure when annular flow rate reaches a certain level.

An analysis of major factors that influence surge/swab pressure in this model shows that pressure drop is at the mercy of a number of factors; the surge pressure drop decreases with the increased eccentricity whereas the swab pressure drop increases with the rising eccentricity at low annular flow rate; the surge pressure drop decreases with the rising yield point whereas the swab pressure drop increases with the rising yield point; the surge pressure drop increases largely with the increase of plastic viscosity whereas the swab pressure drop largely decreases with the dropping plastic viscosity; the surge pressure drop increases with run in hole (RIH)speed; the swab pressure drop increases with pull out of hole (POOH) speed at small annular flow rate whereas the swab pressure drop decreases with the POOH speed when the annular flow rate reaches a certain level.

The analysis also indicates that the surge/swab pressure is most sensitive to the plastic viscosity of drilling fluid. Then, it is of great significance to monitor the plastic viscosity during the drilling process when other factors are well controlled.

1. Introduction

High-density drilling fluid is generally used in drilling the subsalt fractured horizontal wells, but it possesses a hard-to-control rheology. Moreover, the well-developed fissures in subsalt formations result in a low pressure-bearing capacity and a narrow safe density window for drilling fluid. Consequently, even slight pressure variation in the drilling is likely to produce further downhole problems.

The surge/swab pressure has been extensively studied to build computation models based on different drilling characteristics and working conditions. A lot of researchers built a steady surge/swab pressure computation model (Burkhardt, 1961; Fontenot and Clark, 1974; Schuh, 1964). With this model, effects of the rheological behaviors of drilling liquid and the geometric conditions of well bore on surge/swab pressure were studied (Clark, 1956; Moore, 1965). Dynamic surge/swab pressure computation models were built (Lubinski et al., 2006; Mitchell, 1988; Zhong, 1996) and found that the computed results were smaller than the steady model. Surge/swab pressure computation model under different flow patterns in the eccentric annuli were developed by narrow slot method (Deniz,

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1989; Vaughn, 1965), but they only considered the effect of trip velocity on annular flow and disregarded the movement of drilling string.

Using downhole measuring tools accurately measured the downhole surge/swab pressure under different working conditions (Isambourg et al., 1999; Rommetveit et al., 2005; Samuel et al., 2003; Ward and Andreassen, 1998; White et al., 1997; Zhong et al., 1995), and based on this, they studied the effects of tripping velocity, geometric conditions of borehole, and rheological behaviors of drilling liquid. An experimental setup (Freddy and Ramadan, 2013) was used to study the effects of drill pipe movement on surge/swab pressure, but did not consider the effects of annular eccentricity on surge/swab pressure, and that annular flow rate was only caused by pipe movement, namely, there is no pump. Dynamic Testing Facility (Ahmed, 2006; Diaz et al., 2004) was used to test surge/swab pressure in eccentric/concentric annulus with effects of drill pipe rotation, varying concentrations of Xanthan Gum (XCD) and Polyanionic Cellulose (PAC) was used in the experiment, but did not consider the effects of pipe movement on surge/swab pressure.

The existing surge/swab pressure computation models only consider the effects of drilling string movement on annular flow rate (or average annular velocity), but ignore the effects of drilling string movement speed on boundary conditions of annular flow field. In this paper, based on the width-variable flat-plate flow model, and considering the effects of drilling string movement on boundary conditions, we built a new model for computation of surge/swab pressure in horizontal wells, and analyzed the major influencing factors.

2. New model for computation of surge/swab pressure in horizontal wells

2.1. Hypotheses in the model

1. The annular space is rigid with smooth walls; no mass transfer is conducted between borehole annular space and formations, to put it another way, no drilling fluid enters the formations, and no formation fluid flows into the borehole.
2. The vertical shaft sections are concentric annular spaces, while the inclined and horizontal sections are eccentric annular spaces.
3. The drilling liquid is incompressible.
4. The effects of borehole diameter expansion on annular flowing section are overlooked.
5. Since the inverted drilling tool combination is used in all the horizontal wells, typically only 1–2 drill collars are used at horizontal section; the main drilling tools are drill pipes and heavy weight drill pipes; the annular clearance is large, and the annular space is supposed to be laminar flow.
6. A width-variable flat-plate flow model is used to approximately replace eccentric annular flow model, velocity profile for Bingham fluid through slot is showing in Fig. 1.
7. The drilling liquid is in Bingham flow pattern.
8. The effects of cuttings bed on eccentric annular flowing area in horizontal and inclined sections are disregarded.
9. The effect of temperature on drilling liquid rheology is disregarded.

2.2. Flowing pressure drop in eccentric annular

Distance form drilling string center to borehole wall (Deniz, 1989) for any angle (θ) is:

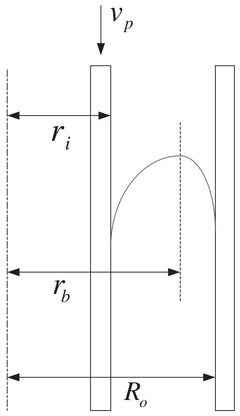

Fig. 1. Velocity profile for Bingham fluid through slot.

$$h = r(\theta) = \sqrt{R_0^2 - e^2\sin^2\theta} + e\cos\theta \tag{1}$$

where, h is distance form drilling string center to borehole wall for any angle (θ), m; r_{i} is outer radius of drill pipe, m; R_{O} is inner radius of casing or borehole, m; e is eccentric distance, m; θ is azimuth of eccentric annular,°; ε is eccentricity ratio, $\varepsilon = e/R_{\mathrm{o}} - r_i$, $0 \le \varepsilon \le 1$.

According to the theory of incompressible steady laminar flow (Dou, 1998), and considering that $(1/r)(\partial\tau_\theta/\partial\theta)$ is very small and can be overlooked (Гукасов, 1979), then:

$$\frac{\Delta p}{L_s} + \frac{\partial \tau_r}{\partial r} + \frac{\tau_r}{r} = 0 \tag{2}$$

where, p is total pressure, Pa, $p = p' + \rho g L_s \cos\alpha$; p' is pressure caused by fluid flowing, Pa; Δp is pressure drop between length L_s, Pa; ρ is mud density, g/cm^3; α is hole deviation angle,°; g is gravitational acceleration, 9.8 m/s^2; L_s is annular flow length for calculation, m; r is distance form drilling string center to calculation point, m; τ_{r} is radial shearing force, Pa.

The Bingham constitutive equation in the inside velocity zone is:

$$\tau_r = \tau + \mu\frac{\mathrm{d}v}{\mathrm{d}r} \tag{3}$$

where, μ is mud plastic viscosity, Pa s; τ is mud yield point, Pa; v is point velocity (r,θ) in annular, m/s.

Since this model take into account the effects of drilling string movement on annular flow field, then the boundary condition in the inside velocity zone is:

$$\begin{cases} v = v_{\mathrm{p}} & (r = r_i) \\ \dfrac{\partial v}{\partial r} = 0 & (r = r_{\mathrm{b}}) \end{cases} \tag{4}$$

where, v_{p} is drill pipe movement speed (surge pressure is caused by pipe running in the hole, in this case, $v_{\mathrm{p}} < 0$; swab pressure is caused by pipe pulling out of the hole, in this case, $v_{\mathrm{p}} > 0$.), m/s; r_{b} is demarcation point of inner and outer flow zone, m.

Since the previous model (Zheng, 1996) overlooks the effects of drilling string movement on annular flow field, then the boundary condition in the inside velocity zone in the original model is:

$$\begin{cases} v = 0 & (r = r_i) \\ \dfrac{\partial v}{\partial r} = 0 & (r = r_{\mathrm{b}}) \end{cases} \tag{5}$$