Analysis of Annular Pressure Loss Accounting the effects of Pipe Rotation, Flow rate, Tool Joint, Swab and Surge

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Abstract -*This review paper studies the correlation between various causes and corresponding changes in annular pressure loss of drilling fluid, using response in stand pipe pressure as pressure indicator. Loss in ECD can not be merely explained by frictional head losses. There are factor that factor into pressure loss causes such viscosity, tool joints and density changes. The new models for each parameter predicts the changes in pressure of drilling mud more accurately. Together they help to predict wellbore pressure with enhanced accuracy. As flow-rate and well depth increases, calculating well bore pressure has never been more important. This culminative model helps in accurate prediction ECD which is very important in hydrauliccalculation for managed pressure drilling*

Key Words:**flow-rate, tool-joint, drill pipe rotation, annular pressure loss,**

1. INTRODUCTION

Oil and gas wells are getting more and more complex with progression of time due to the deeper depths and shorter mud windows requiring more accurate mud pressure control in the well. The margin between pore and fracture pressure can be very narrow. An integral part of well control is understanding how the bottomhole pressure(BHP) profile is affected by change in drilling parameters. As a result, wellbore pressure and drilling fluid equivalent circulating density (ECD) must be predicted accurately and maintained within the narrow margin to avoid kicks and circulation losses.

Drilling hydraulics is largely affected by friction in drillpipe, annulus, bottom-hole assembly(BHA) and across bit. Apart from these conventional friction loses other parameters such as flow rate, string rotation, surge and swab have a significant effect on annular pressure reduction. Other factors like cutting generation and transportation, installed stand-off devices, tool joints and change in mud properties also cause wellbore pressure loss.

In this dissertation we present an accumulated theoretical study of the parameters affecting BHP and the frictional pipe and annular losses.

2. FLUID RHEOLOGY

Drilling fluids are a complex mixture of various components and compounds added to achieve the desired characteristics and properties needed for specific operations. Fluid flow behavior can be illustrated by the following flow models.

- Newtonian Model : τ is the shear stress, μ the fluid viscosity, and Γ the shear rate.

$$\tau = \mu\Gamma ,$$

- Non-Newtonian Model : deviation from the Newtonian fluid behavior occurs when the simple shear data σ –

Γ does not pass through the origin and/ or does not result into a linear relationship between σ and Γ.

Drilling mud is non-Newtonian in behaviour and can be further classsified into Bingham plastic, Power law model and Herschel-Bulkley model which are time independent in nature.

i. Bingham plastic model: τy is the yield point which defines the minimum shear stress needed to enable flow, while μpl is the plastic viscosity.

$$\tau = \tau y + \mu pl\Gamma ,$$

ii. Power law model: K is the consistency index and n is the flow behaviour index (n < 1 for drilling fluids).

$$\tau = K\Gamma n ,$$

i. Herschel-Bulkley fluid : Referred to as a yield power law fluid (YPL), has a yield point below which the fluid will not flow. This yield point, or shear stress is theoretically equal to the yield point in the Bingham Plastic model, but has a different calculated value [Hemphill et al., 1993]. Model parameters n and K can be derived from the plastic viscosity (PL), yield point (YP), and yield stress (τy).

$$\tau = \tau y + K\Gamma n ,$$

These are the relevant fluid flow models taken into account for calculation of annular pressure loss.

3. ANALYSIS OF THEORETICAL MODELS FOR ANNULAR PRESSURE LOSS

Pressure depletion in annulus can be affected by various parameters. The following theoretical evaluation show the approach for accurate calculation of annular pressure losses at every part of the well. Of-course there are some factors that transition beyond available techniques. We will overlook those factor in our theoretical analysis.

3.1 Flow Rate

From the knowledge of conventional frictional loss in hydro-static head, it can be drawn that the pressure loss through the drill string, bit, RSS and annulus are proportional to the flow rate squared, q2m. Alterations in the flow rate has a significant impact on SPP and ECD. If flow-rate is altered, change in pressure will be immediate. Is is only reasonable to assume that an interval with constant flow-rate will be unaffected by any previous alterations to the flow-rate. However when changing the flow-rate a short delay is observed. This can be explained by the compressibility of the mud and bore hole, where the length of this delay depends on the well length. A measuring error in the flow rate may also be the cause for this delay.

3.2 String Rotation

The annular flow patterns will differ from those when there is no rotation and when the drill string is rotated. Rotation yields a tangential velocity in addition to the axial velocity from circulation. Due to the shear forces between the drilling fluid and pipe, a helical flow pattern may form in the annulus as a result of the tangential and axial velocity as illustrated in the left part of figure 3. The rotation can cause altered velocity that can affect the friction pressure loss in different ways. Laboratory studies on the effect of pipe rotation on friction pressure loss show that rotation can cause a decrease in friction pressure [Ahmed and Miska, 2008]. Drilling fluids are generally non-Newtonian fluids with shear-thinning behaviour. Rotation of the drill string causes decrease in drilling fluid viscosity, as the shear rate is increased.

The apparent viscosity μ for a Herschel-Bulkley fluid can be derived from Herschel-Bulkley model, yielding

$$\mu = \frac{\tau_0}{\dot{\gamma}} + K\dot{\gamma}^{n-1}.$$

As seen from the above equation, viscosity μ decreases with an increasing shear rate Γ. The shear rate, Γ, which is the case during rotation [Ahmed and Miska, 2008]. A decrease in viscosity yields a high Reynolds number, resulting in low friction factor and eventually low annular pressure losses.

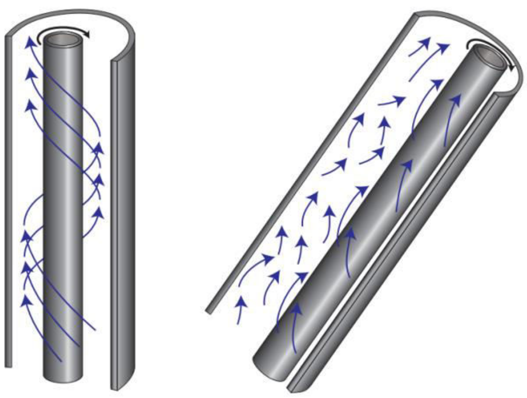

Figure 1: Left: Helical flow patterns generated by annular flow and rotation of the drill string in a concentric annulus. **Right**: Eccentric annulus where the drill string is located of centre in the annular cross section. This contributes to changing the direction and acceleration of the annular flow, causing turbulence and reducing the shear thinning effect.

3.3 Surge and Swab

When the drill string is run into the the wellbore, the pipe displaces some amount of mud around it. This displaced mud increases the flow velocity of mud around the pipe leading to increased frictional pressure losses. This additional contribution too BHP is called surge pressure.

Similarly when the drill string is pulled out of the wellbore it creates a vacuum and the adjuscent mud rushes in to equalize the pressure. This movement of mud causes a decrease in the annular flow velocity leading to reduced friction factor and hence reduced frictional pressure loss. This reduction from BHP is termed as swab pressure.

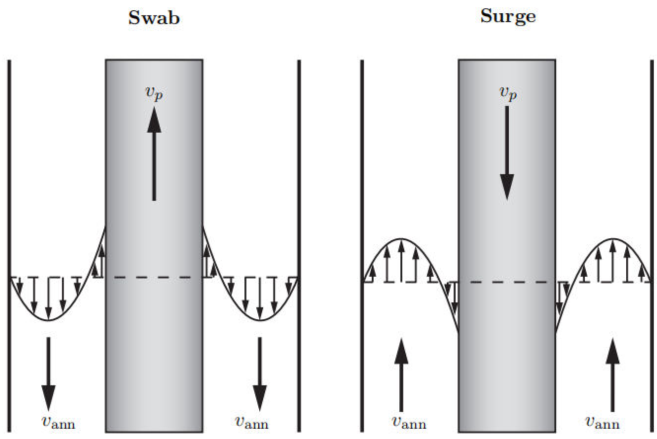

Figure 2 : Swabbing and Surging

When calculating for swab and surge pressure and calculating well bore storage are it is assumed that the drill string is closed at the end to make calculations of displaced mud much easier.

$$q_{tot}^{\text{ann}} = q_m + \dot{V} = q_m + v_p A_p + q_{\text{cling}}$$

qm is the pump rate of the drilling fluid, V is the volume rate being displaced by the drill string during swab or surge respectively. vp is the tripping velocity. qcling accounts for the mud that clings to the string when pulling or running the pipe. Ap is the cross sectional area of the closed drill pipe.

By dividing the total flow rate by the annular cross section, the annular velocity caused by circulation and drill string movement can be expressed:

$$v_{tot}^{\text{ann}} = \frac{q_{tot}^{\text{ann}}}{A_{\text{ann}}} = \frac{q_m + v_p \frac{\pi}{4} {d_p}^2 + q_{\text{cling}}}{\frac{\pi}{4}(d_o^2 - d_p^2)}$$

do is the diameter of the borehole or casing and dp is the outer diameter of the drill pipe.

Steady state flow conditions are assumed meaning that while evaluation there was no alteration of flow-rate. In order for this assumption to sit right the annular geometry is assumed to be concentric, which is generally not the case. Experimental results indicate that pressure loss due swab and surge can be reduced by 40% due to eccentricity[Crespo et al., 2012].

The pressure change experienced during surge and swab is given by equation below [Crespo et al., 2012].

$$\Delta p_{s\&s} = \frac{f}{2}\frac{\rho(v_{ann} + \frac{v_p}{2})^2}{g(d_o - d_p)} L$$

f is the fanning friction factor, vann is the annular velocity from the mud pumps, do is the diameter of the bore hole and L is the measured depth from surface to bit.The friction factor can be calculated by using the Haaland equation given below:

$$\frac{1}{\sqrt{f}} = -1.8\log_{10}\left[\left(\frac{\epsilon/d}{3.7}\right)^{1.11} + \frac{6.9}{\text{Re}}\right]$$

3.4 Tool Joint Effect

Total annular frictional losses due to tool joint including:

i) pressure loss across the tool-joint that doesn't account for the contraction and expansion losses; and

ii) ii) pressure loss due to tool-joint contraction and expansion, as shown in Figure 3.

Hence: $$\Delta P_f = \Delta P_{f1} + \Delta P_{f2} \quad ...(1)$$

The pressure loss ΔPf1 includes pressure losses in the narrow and wide regions of the tool joint. Therefore, ΔPf1 is calculated as the sum of these two components:

$$\Delta P_{f1} = \Delta P_N + \Delta P_W = \frac{4\tau_{w,N} L_N}{D_{hyd,N}} + \frac{4\tau_{w,W} L_W}{D_{hyd,W}} \quad ...(2)$$

Under laminar flow condition, for power law fluids, the wall shear stress in the annulus can be estimated using the narrow slot approximation method as:

$$\tau_w = K\left[\frac{12v}{D_{hyd}}\left(\frac{2n+1}{3n}\right)\right]^n \quad ...(3)$$

For turbulent flow, wall shear stress is calculated as:

$$\tau_w = \frac{1}{2} f \rho v^2 \quad ...(4)$$

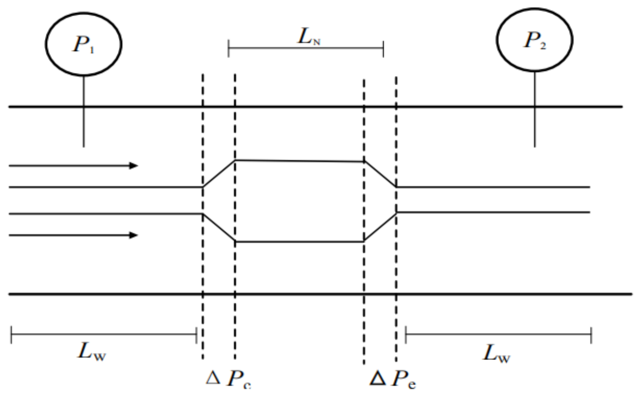

Figure 3 : Tool joint section of drill string

Wheref is the fanning friction factor. It can be estimated using the following correlation. For smooth pipe, friction factorcan be calculated by Dodge and Metzner equation [13]:

$$\frac{1}{f^{0.5}} = \frac{4}{n^{0.75}}\log\left[\text{Re}\, f^{\left(1-\frac{n}{2}\right)}\right] - \frac{0.4}{n^{1.2}} \quad ...(5)$$

For rough pipe, fanning friction factor is calculated as:

$$\frac{1}{\sqrt{f}} = -4\log_{10}\left(\frac{1.255}{\text{Re}\sqrt{f}} + \frac{\varepsilon}{3.7d}\right) \quad ...(6)$$

The hydraulic diameters of the narrow and wide parts of the tool-joint are determined as:

$$D_{hyd,N} = D_{ci} - D_{TJ}$$
$$D_{hyd,W} = D_{ci} - D_{po} \quad ...(7)$$

The pressure loss ΔPf2 includes pressure losses due to tool-joint contraction and expansion. Hence:

$$\Delta P_{f2} = \Delta P_c + \Delta P_e \quad ...(8)$$

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Dci - the inner diameter of casing, m; Dpo, DTJ - the outer diameters of the drillpipe and tool-joint, respectively, m; ΔPc - the pressure loss due to tool-joint contraction and expansion, respectively, Pa; Contraction and expansion effects of the tool-joint are modeled using the same definition as Jeong and Shah.

Accordingly, the contraction pressure loss, ΔPc, is:

$$\Delta P_c = \rho \times K_c \left(\frac{v_N^2}{2g} \right) \quad ...(9)$$

where, Kc is the contraction head loss coefficient. For squared tool-joint, the contraction head loss coefficient is:

$$K_c = \left(1 - \frac{A_N}{A_W} \right)^2 \quad ...(10)$$

For tapered tool-joint, the contraction head loss coefficient is calculated as:

$$K_c = 0.5 \sqrt{\sin \frac{\theta}{2} \left(1 - k^2 \right)} \quad ...(11)$$

Similarly, the expansion pressure loss ΔPe can be defined as:

$$\Delta P_e = \rho \times K_e \left(\frac{v_W^2}{2g} \right) \quad ...(12)$$

where, Ke is the expansion head loss coefficient, which can be determined for both squared and tapered tool-joint as:

$$K_e = \left(\frac{A_W}{A_N} - 1 \right)^2 \quad ...(13)$$

Applying the energy balance, the pressure difference between Point 1 and Point 2 (i.e. pressure loss) is expressed as:

$$\Delta P = \frac{\rho}{2g} v_N^2 \left\{ K_c + K_e \left(\frac{A_N}{A_W} \right)^2 \right\} + \Delta P_{f1} \quad ...(14)$$

where, ρ - density of the fluid, kg/m3; vN - the fluid mean velocity in the narrow area around the tool-joint, m/s. AN, AW - the areas of the narrow and wide sections of the tool joints, respectively, m2.

4. CONCLUSIONS

From this study the following conclusions can be drawn:

i. A correlation between changes in ROP and standpipe pressure is observed in all four sections.

ii. Friction factor is directly related to flow rate. A steady flow rate reduces frictional losses in mud.

iii. Friction factor is low during swabbing and high during surging giving rise to low and high frictional losses respectively.

iv. As pipe rotation increases, annular pressure loss slightly decreases at low flow rates. However, at high low rates, the annular pressure loss increase.

v. . As pipe rotation increases, there is no apparent trend at low flow rates in tool-joint pressure loss. At high flow rates, the pressure loss may increase or decrease depending on the result of inertial effect and shear thinning.

vi. In order to accurately predict ECD and maintain wellbore pressure within the narrow margin to avoid kicks and circulation losses, the effect of tool-joint, drill string rotation, flow-rate, surge and swab on wellbore hydraulics should be considered.

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