Swab/Surge Pressures

The movement of the drill string when pulling out of the hole will cause the pressure caused by the drilling fluid on the bottom of the hole to decrease. This caused by the friction between the movement of the pipe and the stationary drilling mud. This is referred to as swab pressure, P_{sw}.
The reverse is also true, running in the hole the pressure will increase due to the pipe movement, this is called surge pressure, P_{surge}.
The swab and surge pressure need to be control so the well does not form a kick or break down the formation.

Calculations

The friction gradient caused by the pipe movement using the slot flow approach to laminar flow an equation can be derived

$$\Delta P_{fsp} = \frac{\mu(v_a - .5v_p)}{1000(d_h - d_{pod})^2}$$

taking the Newtonian equation

$$\Delta P_{fs} = \frac{\mu v_a}{1000(d_h - d_{pod})^2}$$

combining

$$\Delta P_{fs} = \frac{\mu v_{ae}}{1000(d_h - d_{pod})^2} \qquad v_{ae} = v_a - .5v_p$$

For non-newtonian fluids clinging factor K_c is introduced

$$v_{ac} = v_a - K_c v_p$$

Laminar

$$K_c = \frac{1}{2\ln\alpha} + \frac{\alpha^2}{1-\alpha^2}$$

Turbulent

$$K_c = \frac{\sqrt{(\alpha^4 + \alpha)/(1+\alpha)} + \alpha^2}{1-\alpha^2}$$

$$\alpha = d_{pod} / d_h$$

There are two cases to consider

Closed end pipe

Open ended pipe

For closed in pipe the flow rate in the annulus is equal to the rate of the fluid being displaced by the pipe.

$$Q_a = \frac{\pi d_{pod}^2 v_p}{4}$$

$$v_a = \frac{d_{pod}^2 v_p}{d_h^2 - d_{pod}^2}$$

Finding the annular velocity for open ended pipe is much more complicated so it is usually ignored.

Example

Depth 10,000' hole size is 7.875"

Drill pipe 4" OD Collars 6" OD

Mud 10#/gal θ_{600} 65 θ_{300} 40

Pressure gradient .5 psi/ft

Frac gradient .56 psi/ft

Determine the max pipe speed for tripping the drill string.

Assume closed ended pipe when a bit is in the hole.

$$v_{adp} = \frac{d_{pod}^2 v_p}{d_h^2 - d_{pod}^2} = \frac{4^2 v_p}{7.845^2 - 4^2} = .35 v_p$$

$$v_{adc} = \frac{d_{pod}^2 v_p}{d_h^2 - d_{pod}^2} = \frac{6^2 v_p}{7.845^2 - 6^2} = .1.38 v_p$$

$\alpha_{dp} = d_{pod} / d_h = 4/7.875 = .51$ $\alpha_{dc} = d_{pod} / d_h = 6/7.875 = .762$

For drill pipe

$$K_{cdp} = \frac{1}{2\ln\alpha} + \frac{\alpha^2}{1-\alpha^2} = \frac{1}{2\ln .51} + \frac{.51^2}{1-.51^2} = -.391 \quad \text{laminar}$$

$$K_{cdp} = \frac{\sqrt{\left(\alpha^4 + \alpha\right)/\left(1+\alpha\right)} + \alpha^2}{1-\alpha^2} = \frac{\sqrt{.51^4 + .51/(1+.51)}.51^2}{1-.51^2} = -.484 \quad \text{turbulent}$$

K_{cdc}=-.453 K_{cdc}=-.5

$$v_{ac} = v_a - K_c v_p \qquad v_{aedp} = .35v_p - (-.391)v_p = .741v_p \quad \text{Laminar}$$

$$v_{aedp} = .35v_p - (-.484)v_p = .384v_p \quad \text{Turbulent}$$

assume a laminar flow around the drill pipe

$$\Delta P_{swab} \le \Delta P_{HM} - \Delta P_{ff} = .52 - .5 = .02\, psi/\, ft$$
$$\Delta P_{surge} \ge \Delta P_{frac} - \Delta P_{HM} = .56 - .53 = .04\, psi/\, ft$$

take the bingham equation

$$\Delta P_{fa} = \frac{\mu_p v_{aedp}}{1000(d_h - d_{od})^2} + \frac{\tau_y}{200\left(d_h - d_{od}\right)}$$

For swab

$$.02 = \frac{25 \cdot .741 v_p}{1000(7.875-4)^2} + \frac{15}{200\left(7.875-4\right)}$$

$$v_p \le 1.5\, ft/s$$

For surge

$$v_p \le 4.3\, ft/s$$

Other details

Remember also the pressure on the formations during drilling is increased by the friction pressure in the annulus.

Buoyancy
The weight of the drill string in the hole is affected by the fluid in the hole. Buoyancy effect will lower the effective weight of the string, and the weight on the bit.

$$W_e = W\left(1 - \frac{\rho_m}{\rho_s}\right)$$

W_e effective weight
W weight in air
ρ_m density of the mud
ρ_s density of steel 65.5#/gal 490#/ft^3

The neutral point in the drill string is ideally just below the top of the drill collars.