Drilling Hydraulics

$$P_p = P_s + P_{idp} + P_{ic} + P_{bit} + P_{ac} + P_{adp}$$

Design Criteria

Must annular velocity high enough to pick up cuttings

Need laminar flow

To high will also cause hole erosion

Pressure drop across the bit for maximum efficiency

Hydraulic Power

Hydraulic Impact Force

Fluids

Both Newtonian and Nonnewtonian fluids are used in drilling systems.

Flow regimes

Laminar in the annulus

Turbulent in the drill string

Assumptions for flow in pipe and annulus

Isothermal flow

Incompressible flow

Concentric circular annulus

Nonrotating drill string

Layers adjacent to walls are stationary

Shear rate is a function of shear stress at that point

Steady state flow

N_{Rp} < 2100 the flow is Laminar

For Newtonian fluids $N_{Rp} = \frac{\rho \bar{v} \ d_{ip}}{\mu}$

In Field units

$$N_{Rp} = \frac{928 \rho v d_{ip}}{\mu}$$

ρ in #/gal v in ft/sec d_{ip} in inches

For laminar flow in pipe

$$\Delta P_{fp} = \frac{\mu v_p}{1500 d_{ip}^2}$$

μ fluid viscosity cp v_p ave velocity in the pipe ft/sec d_{ip} Pipe ID inches
ΔP_{fp} friction gradient in the pipe psi/ft

For laminar flow in the annulus

$$N_{\mathrm{Re}} = \frac{757 \rho \bar{v} (d_2 - d_1)}{\mu}$$

d_1 outside diameter of the pipe d_2 diameter of the hole, inches

$$\Delta P_{fa} = \frac{\mu \bar{v}}{1000 (d_2 - d_1)^2}$$

ΔP_{fa} friction pressure gradient in the annulus psi/ft

Example

Data

TD 10,000’ Hole size 8.875”

DP 5” OD 4” ID Collars 7” OD 4”ID

Mud μ 40 cp ρ 8.5#/gal

Minimum annular velocity 100 ft/min

Find flow rate Q

$$Q = v_{a\min} A_{a\max} = v\frac{\pi}{4}\left(d_{hd}^2 - d_{pod}^2\right)$$

$$Q = 100\frac{\pi}{4}\left(.74_{hd}^2 - .417_{pod}^2\right) = 29.3\,ft^3/\min$$

$$Q = 100\frac{\pi}{4}\left(8.875_{hd}^2 - 5_{pod}^2\right).052 \approx 219\,gpm$$

Since d_{iddp} is equal to d_{idc}

$$\Delta P_{dpc} = \frac{\mu v_p}{1500 d_{id}^2}$$

$$v_p = \frac{Q}{A_{id}} = \frac{.488\,ft^3/\sec}{8.73E-2\,ft^2} = 5.6\,ft/\sec$$

$$\Delta P_{dpc} = \frac{40 \cdot 5.6}{1500 \cdot 4^2} = .009\,psi/\ ft$$

$$P_{fp} = \Delta P_{dpc} TD = .009 \cdot 10000 = 90\,psi$$

$$\Delta P_{ac} = \frac{\mu v_p}{1500\left(d_h^2 - d_{cod}^2\right)}$$

$$v_{ac} = \frac{Q}{A_{ac}} = \frac{.488\,ft^3/\sec}{.162\,ft^2} = 3\,ft/\sec$$

$$\Delta P_{ac} = \frac{40 \cdot 3}{1500\left(8.875^2 - 7^2\right)} = .0026\,psi/\ ft$$

$$\Delta P_{adp} = \frac{\mu v_p}{1500\left(d_h^2 - d_{dpod}^2\right)}$$

$$\Delta P_{adp} = \frac{40 \cdot 1.67}{1500\left(8.875^2 - 5^2\right)} = 8.27E-4\, psi/\ ft$$

$$P = P_{fp} + \Delta P_{ac} LC + \Delta P_{adp} LDP$$

$$P = 90 + .0026 \cdot 1000 + 8.27E-4 \cdot\ \ 9000 = 100\, psi$$

$$HHP = \frac{QP}{1714} = \frac{219 \cdot 100}{1714} = 12.7$$

Homework

Data

TD 10,000’ Hole size 9”

DP 5” OD 4” ID Collars 7” OD 3.5”ID

1000’ of collars in the drill string

Fluid is water

Minimum annular velocity 150 ft/min

For Newtonian Turbulent Flow

$$N_{re} > 2100$$

In pipe

$$\Delta P_f = \frac{f\rho v^2}{25.8d} \qquad f \text{ is the fanning friction factor}$$

$$\frac{1}{\sqrt{f}} = 2.28 - 4\log\left(\frac{\varepsilon}{d_{ip}} + \frac{21.25}{N_{Rp}^{.9}}\right)$$

$$f = \frac{.0791}{N_{\mathrm{Re}}^{.25}} \quad \text{for smooth wall pipe}$$

or $$\Delta P_f = \frac{\rho^{.75} v^{1.75} \mu^{.25}}{1800 d^{1.25}}$$

In annulus

$$\Delta P_f = \frac{f\rho v^2}{21.1\left(d_h^2 - d_{pod}^2\right)}$$

or $$\Delta P_f = \frac{\rho^{.75} v^{1.75} \mu^{.25}}{1398\left(d_h^2 - d_{pod}^2\right)^{1.25}}$$

Example
Data

TD 10,000’ Hole size 8.875”
DP 5” OD 4” ID Collars 7” OD 4”ID
Mud μ 40 cp ρ 8.5#/gal
Pump rate of 300 gpm

$$v_p = \frac{Q}{A_{id}} = \frac{.668\, ft^3/\sec}{8.73E-2\, ft^2} = 7.65\, ft/\sec$$

$$N_{Rp} = \frac{928\rho v d_{ip}}{\mu} = \frac{928 \cdot 8.5 \cdot 7.65 \cdot 4}{40} = 6035$$

$$f = \frac{.0791}{N_{\mathrm{Re}}^{.25}} = .\frac{.0791}{6035^{.25}} = .008$$

$$\Delta P_f = \frac{f\rho v^2}{25.8d} = \frac{.008 \cdot 8.5 \cdot 7.65^2}{25.8 \cdot 4} = .043 psi/\ ft$$

$$\Delta P_f = \frac{\rho^{.75} v^{1.75} \mu^{.25}}{1800 d^{1.25}} = \frac{8.5^{.75} 7.65^{1.75} \cdot 40^{.25}}{1800 \cdot 4^{1.25}} = .043 psi/\ ft$$

For the annulus
Collars

$$v_{ac} = \frac{Q}{A_{ac}} = \frac{.668\, ft^3/\sec}{.162\, ft^2} = 4.12\, ft/\sec$$

$$\Delta P_{ac} = \frac{40 \cdot 4.12}{1500\left(8.875^2 - 7^2\right)} = .0037\, psi/\ ft$$

Drill pipe

$$v_{adpc} = \frac{Q}{A_{ac}} = \frac{.488\,ft^3/\sec}{.293\,ft^2} = 1.66\,ft/\sec$$

$$N_{\mathrm{Re}} = \frac{757\rho\bar{v}(d_2 - d_1)}{\mu} = \frac{757 \cdot 8.5 \cdot 1.66(8.875 - 5)}{40} = 1035$$

Laminar Flow