

RIG HYDRAULICS

This chapter covers the following items:

- Pressure losses
- Surface connection losses
- Pressure drop across the bit
- Optimization of bit hydraulics
- Surface pressure drop
- Hydraulic criteria
- Comparison of BHHP and IF
- Optimum flow rate
- Field methods for optimizing bit hydraulics
- A practical check of the efficiency of bit hydraulic program

Pressure Losses

- The circulation system consists of: pump, surface connections (stand pipe, hose, swivel and Kelly), drill pipe, drill collars, bit, annulus between drill collars and hole, annulus between drill pipe and hole, mud return lines, and mud tanks.
- Friction of fluid through these parts causes pressure losses
- The calculation of this pressure losses depend on four parts
 - Surface connection losses
 - Pipe losses
 - Annular losses
 - Losses across the bit
- Losses depend on the type of fluid used and the type of flow

Surface Connection Losses

- Losses caused through surface connections
- Depend on the geometry and dimensions of surface connections
- These dimensions can vary with time
- Evaluated by:

$$P_1 = E\rho^{0.8}Q^{1.8}(PV)^{0.2} \quad \text{psi or bar}$$

P_1 = pressure loss, psi or bar

ρ = Density, ppg or kg/l

Q = flow rate, gpm, l/min

PV = plastic viscosity, cp

E = constant depends type of surface connections

Value of E

Surface Equipment Type	Value of E	
	Imperial Units	Metric Units
1	2.5×10^{-4}	8.8×10^{-6}
2	9.6×10^{-5}	3.3×10^{-6}
3	5.3×10^{-5}	1.8×10^{-6}
4	4.2×10^{-5}	1.4×10^{-6}

Four types of surface equipment

Surface Equipment Type	Stand Pipe		Rotary Hose		Swivel		Kelly	
	Length (Ft)	ID (in)	Length (Ft)	ID (in)	Length (Ft)	ID (in)	Length (Ft)	ID (in)
1	40	3.0	40	2.0	4	2.0	40	2.25
2	40	3.5	55	2.5	5	2.5	40	3.25
3	45	4.0	55	3.0	5	3.5	40	3.25
4	45	4.0	55	3.0	6	3.0	40	4.00

Pipe and Annular Losses

- Pipe losses takes place inside drill pipe and drill collars
- They are designated as P_2 and P_3
- Annular losses takes place around drill collars and drill pipe
- They are designated as P_4 and P_5
- The magnitude of these pressures depends on
 - Dimension of pipe
 - Mud rheological properties, weight, plastic viscosity, and yield point
 - Type of flow, laminar or turbulent
- Several models exist to measure pressure losses
- Only two are models will be used: the Bingham plastic and the power law

The following are the equations used for calculations

Bingham Plastic Model

Pipe Flow

➤ Determine average velocity

$$\text{➤ } V_a = \frac{24.5Q}{D^2} \text{ ft/min}$$

➤ Determine critical velocity

$$\text{➤ } V_c = \frac{97PV + 97\sqrt{(PV)^2 + 8.2\rho D^2 YP}}{\rho D} \text{ ft/min}$$

➤ If $V_a > V_c$, flow is turbulent; use

$$\text{➤ } P = \frac{8.91 \times 10^{-5} \rho^{0.8} Q^{1.8} (PV)^{0.2} L}{D^{4.8}} \text{ psi}$$

➤ If $V_a < V_c$, flow is laminar; use

$$\text{➤ } P = \frac{L}{300D} \left[YP + \frac{(PV)V_a}{5D} \right] \text{ psi}$$

Annular flow

➤ Determine average velocity

$$\text{➤ } V_a = \frac{24.5Q}{D_h^2 - OD_p^2} \text{ ft/min}$$

➤ Determine critical velocity

$$\text{➤ } V_c = \frac{97PV + 97\sqrt{(PV)^2 + 6.2\rho D_e^2 YP}}{\rho(D_h - OD_p)} \text{ ft/min}$$

➤ If $V_a > V_c$, flow is turbulent; use

$$➤ P = \frac{8.91 \times 10^{-5} \rho^{0.8} Q^{1.8} (PV)^{0.2} L}{(D_h - OD)^3 (D_h + OD)^{1.8}} \text{ psi}$$

➤ If $V_a < V_c$, flow is laminar; use

$$➤ P = \frac{L(PV)V_a}{60,000(D_h - OD)^2} + \frac{L(YP)}{200(D_h - OD)^2} \text{ psi}$$

Power Law Model

➤ Determine n and k

$$➤ n = 3.32 \log \left(\frac{\theta_{600}}{\theta_{300}} \right)$$

$$➤ k = \frac{\theta_{300}}{(511)^n}$$

$$➤ V_c = \left[\frac{5.82(10^4)k}{\rho} \right]^{(1/(2-n))} \cdot \left[\frac{1.6}{D} \cdot \frac{3n+1}{4n} \right]^{(n/(2-n))} \text{ ft/min}$$

➤ If $V_a > V_c$ flow is turbulent; use

$$➤ P = \frac{8.91 \times 10^{-5} \rho^{0.8} Q^{1.8} (PV)^{0.2} L}{D^{4.8}} \text{ psi}$$

➤ If $V_a < V_c$ flow is laminar; use

$$➤ P = \frac{kL}{300D} \left[\frac{1.6V_a}{D} \cdot \frac{(3n+1)}{4n} \right]^n \text{ psi}$$

Annular flow

➤ Determine average velocity

$$\text{➤ } V_a = \frac{24.5Q}{D_h^2 - OD_p^2} \text{ ft/min}$$

➤ Determine critical velocity

$$\text{➤ } V_c = \left[\frac{5.82(10^4)k}{\rho} \right]^{(1/(2-n))} \cdot \left[\frac{1.6}{(D_h - OD_p)} \cdot \frac{3n+1}{4n} \right]^{(n/(2-n))} \text{ ft/min}$$

➤ If $V_a > V_c$, flow is turbulent; use

$$\text{➤ } P = \frac{8.91 \times 10^{-5} \rho^{0.8} Q^{1.8} (PV)^{0.2} L}{D_e^{4.8}} \text{ psi}$$

➤ If $V_a < V_c$, flow is laminar; use

$$\text{➤ } P = \frac{kL}{300(D_h - OD)} \left[\frac{1.6V_a}{(D_h - OD)} \cdot \frac{(3n+1)}{4n} \right]^n \text{ psi}$$

Pressure loss across bit

- Need to be optimized to achieve maximum cleaning
- For given length of drill string and given mud properties, pressure from 1 to 5 remain constant
- The smaller the nozzle the greater the pressure drop
- For soft formation, large nozzle is required
- To calculate pressure loss across and nozzle size use

$$\text{➤ } P_{bit} = P_{\text{stand pipe}} - (P_1 + P_2 + P_3 + P_4 + P_5) \text{ psi}$$

➤ Nozzle velocity

$$\text{➤ } V_n = 33.36 \sqrt{\frac{P_{bit}}{\rho}} \text{ ft/s}$$

➤ Total area of nozzles

$$\triangleright A = 0.32 \frac{Q}{Vn} \text{ in}^2$$

➤ Nozzle size

$$\triangleright d_n = \left(\sqrt{\frac{4A}{3\pi}} \right) .32$$

OD = outside diameter, in

D = inside diameter, in

L = length, ft

PV = plastic viscosity, cp

YP = yield value, lb/100ft²

Optimizing bit hydraulics

- All hydraulic programs start by calculating pressure drops in the various parts of the circulating systems
- The pressure loss in the circulating system, except bit, is given the symbol P_c
- Several hydraulic slide rules are available for calculating P_c
- The slide rule is inadequate for calculating annular pressure loss
- Either annular pressure loss is beyond the scale or flow is laminar and most slide rules used turbulent flow

Surface pump pressure

- The system pressure shows how much pressure loss can be tolerated at bit
- The value of P_{bit} is controlled by the maximum allowable surface pump pressure
- Most rigs have limits on maximum surface pressure with high volume rates (500 gpm)
- On land rigs typical limits on surface pressure are in the range 2500 to 3000 psi for well depth of around 12000 ft
- For deep wells, heavy-duty pump can give 5000 psi surface pressure
- Therefore, optimization of bit hydraulics is necessary

Hydraulic criteria

- Two criteria for optimization

- Maximum bit hydraulic horsepower (BHHP)
- Maximum impact force (IF)
- Each criteria yields different value of bit pressure loss
- Engineer is faced with the task to decide which one to choose
- In most drilling operations the circulation rate is kept constant
- P_{bit} is the factor to be optimized

Maximum bit hydraulic horsepower

- The bit pressure is the difference between stand pipe pressure and P_c
- For optimum hydraulic P_{bit} must be fraction of stand pipe pressure
- Surface hydraulic horsepower (HHP_s) is the sum of hydraulic horse power at bit (BHHP) and hydraulic horsepower in the circulating system (HHP_c)

- $BHP_s = BHHP + HHP_c$

- $BHHP = BHP_s - HHP_c$

- Hence $HHP = PQ/1714$

- Then

- $BHHP = \frac{P_s Q}{1714} - \frac{P_c Q}{1714}$

- $P_c = KQ^n$

$K = \text{constant}$

$n = \text{index represents degree of turbulence in the circulating system}$

- $BHHP = \frac{P_s Q}{1714} - \frac{KQ^{n+1}}{1714}$

- Differentiating equation with respect to Q

- $P_s = (n+1)KQ^n$

$$\triangleright P_s = (n+1) P_c$$

➤ Also

$$\triangleright P_c = P_s - P_{bit}$$

$$\triangleright P_{bit} = \frac{n}{n+1} P_s$$

➤ The value of n falls in the range 1.8 – 1.86

➤ For n = 1.86, $P_{bit} = 0.65 P_s$

➤ This means the for optimum hydraulic horsepower, the pressure drop across the bit is 65% of surface pump pressure

➤ The actual value of n can be determined in fields by running the pump pressure at several speeds and reading the resulting pressure

➤ A graph of $P_c = (P_s - P_{bit})$ against Q is then drawn

➤ The slope of the graph is taken as the index n

Maximum impact force

$$\triangleright P_{bit} = \frac{n}{n+2} P_s$$

➤ Impact force is given by

$$\triangleright IF = \frac{Q \sqrt{\rho P_{bit}}}{58}$$

Comparison of BHHP and IF criteria

➤ The ratio R, of pressure drop across bit is given by the BHHP criteria and IF criteria

$$R = \frac{\frac{n}{n+1} P_s}{\frac{n}{n+2} P_s}$$

➤ or

$$R = \frac{n+2}{n+1}$$

- The following table shows the value of n and R
- It shows that R decreases parabolic ally with increasing value of n, but never assumes unity
- It means that the pressure loss calculated by BHHP is greater than that calculated by IF

R as a function of n

N	R
1	1.50
1.2	1.45
1.5	1.40
1.8	1.36
2.0	1.33

Optimum flow rate

- Optimum flow rate is obtained by plotting circulating pressure versus Q
- The intersection of optimum P_c with the curve gives the optimum flow rate

Field method of optimizing bit hydraulics

- Prior to POH current bit for next bit change, run the pump at four or five speeds and record the resulting stand pipe pressure
- From current nozzle size and stand pipe pressure and mud weight determine pressure loss across the bit
- Subtract P_{bit} from stand pipe pressure to get P_c
- Plot a graph of P_c against Q on log-log paper and determine the slope to get n
- For the next bit run calculate P_{bit} using BHHP or IF equations
- Select nozzle size to for the value of P_{bit} calculated
- For particular rig and field the index n will not vary widely if the same parameters are used