Key Solution

CHEN 490 – Fundamentals of Petroleum Engineering
HW #6– Due 10/12/2013

Pressure Drop Problem

To illustrate the pressure loss calculations for each system component, let us work the following complete example. As stated in the equation

$$\Delta P_t = \Delta P_s + \Delta P_p + \Delta P_c + \Delta P_b + \Delta P_{ac} + \Delta P_{ap}$$

Where ΔPt = pump discharge pressure
ΔPs = Pressure loss in surface stand pipe, piping, and mud hose
ΔPp = Pressure loss In drill pipe
ΔPc = Pressure loss inside drill collars
ΔPb = Pressure loss across nozzles
ΔPac = Pressure loss in annulus around collars
ΔPap + Pressure loss in annulus around drill pipe

Operating Data
Depth = 6000 ft (5500 ft drill pipe, 500 ft drill collars)
Drill pipe = 4 ½ in. internal flush, 16.6 lb/ft (i. d. = 3.826 in)
Drill collars = 6 ¾ in (i. d. = 2.813 in)
Mud density = 10 lb/gal
μ_p = 30 cp
Y_b = 10 lb/100ft^2
Bit = 7 7/8 in 3 cone, jet rock bit
Nozzle velocity = at least 25 ft/sec per in of bit diameter (this value is obtained by a commonly applied rule of thumb).

What hydraulic (pump output) horse power will be required for these conditions?

Assumptions:
Circulation rate: This is a fast drilling, soft rock area and that 180 ft/min (3 ft/sec) upward velocity based on a gauge hole is required.
Q = annulus area X velocity, nozzle size is 13/32 in. This nozzle allows an actual velocity V_{act},
$V_{act} = (q/3)/(2.45d^2)$
Surface equipment losses (standpipe, swivel, Kelly joint, and the piping between the pump and stand pipe). Since this part of the system causes only a small fraction of the total losses, it will be satisfactory to choose an approximate the actual case. Assume ΔPs = 27 psi
For pressure drop inside drill pipe, calculate the critical velocity.
Pressure drop across bit. This is a jet bit with a nozzle coefficient of 90%.

Calculation Steps :

1. This is obtained from the desired annular velocity necessary for proper hole cleaning (cutting removal). As given, this is a fast drilling, soft rock and that 180 ft/min (3 ft/sec) upward velocity.

2. The flow rate q is in gal/min

$$q = (\text{annulus area})(\text{velocity})$$
$$= 2.45\,(d_h^2 - d_p^2)\,v$$
$$= 2.45\,(62 - 20.25)(3)$$
$$= 308 \text{ gal/min}$$

3. Nozzle Size :

3 nozzles (one for each cone will be used), hence $1/3\, q$ will flow through each.
For $v = 250$ ft/sec thru each

$v = \frac{q}{n} =$ ~~[illegible]~~ x

Common field Units : $v = \text{ft/sec}$
$q = \text{gal/min}$
$A = \frac{\pi}{4} d^2 = (.7854) d^2$; $d = \text{in}$

Then, $v = \frac{q}{(.7854) d^2}$, where q in gal/min must be equivalent to q in ft^3/sec and d must be equivalent to d in feet in order for v to be in ft/sec then, $$ft/sec = \frac{\dfrac{gal}{7.48\,gal/ft^3} \times \dfrac{1}{min(60\,sec/min)}}{(.7854)\left(\frac{in}{12}\right)^2}$$

where $\frac{gal}{7.48} = ft^3$

$Min\ (60) = sec$

$(12/12)^2 = ft^2$

or

$$\frac{ft}{sec} = \frac{gal/min}{(7.854)(60)} \times \frac{144}{(.7854)(in^2)} = 0.4085\ \frac{gal/min}{in^2}$$

in Common form,

$$ft/sec = \frac{1}{2.45}\ \frac{gal/min}{in^2}$$

or

$$v = \frac{q}{2.45\,d^2},\quad \text{where } v = ft/sec,\ q = gal/min,\ d = in$$

then,

$$(2.45)(v)(d^2) = q$$

$$d = \sqrt{\frac{q}{2.45\,v}} = \sqrt{\frac{\frac{1}{3}q}{2.45\,v}}$$

$$= \sqrt{\frac{\frac{308}{3}}{(2.45)(250)}}$$

$$d = 0.41\ in$$

The nearest stock nozzle is $\frac{13}{32}$ in (given)

$$v = \frac{103}{(2.45)(13/32)^2}$$

$$\cong 225\ ft/sec$$

4. surface equipment losses: The surface equipment consists of the standpipe, swivel, Kelly joint, and the piping between the pump and standpipe. Since this part of the system causes only a small fraction of the ~~total~~ losses, it will be satisfactory to choose the one assumed which closely approximates the actual case ($q \doteq 308 \rightarrow \Delta p \cong 30\,psi$) -

then assume $\Delta P_s \cong 27$ psi

5. Pressure drop inside drill pipe:

The critical velocity is calculated using the eqn.

$$v_c = \frac{1.08\mu_p + 1.08\sqrt{\mu_p^2 + 9.3\,\rho_m d^2 Y_b}}{\rho_m d}$$

$$= \frac{(1.08)(30) + 1.08\sqrt{(30)^2 + (9.3)(10)(3.826)^2(10)}}{(10)(3.826)}$$

$$= 4.2 \ \text{ft/sec}$$

The V_{act} inside drill pipe is:

$$v_{act} = \frac{q}{(2.45)(d^2)} = \frac{308}{(2.45)(3.826)^2} = 8.58 \ \text{ft/sec}$$

Since $8.58 > 4.2$, flow is turbulent and the equation (equivalent), $N_{Re} = \frac{2970\,\rho\, v_{act}\, d}{\mu_p}$

$$= \frac{(2970)(10)(8.58)(3.826)}{30}$$

$$= 32{,}500$$

From chart, Fannin friction factor Vs NRe, Curve II

$f \cong 0.0066$

For turbulent flow, use Fannin equation

$$\Delta P_f = \frac{f \rho L v^2}{25.8 d}$$

$$= \frac{(0.0066)(10)(5500)(8.58)^2}{(25.8)(3.826)}$$

$$= 270 \text{ psi}$$

6. Pressure drop inside chill collar:

$$v_{dc} = \frac{308}{(2.45)(2.813)^2} = 15.9 \text{ ft/sec}$$

∴, flow is turbulent, by inspection

$$N_{Re} = \frac{(2970)(10)(15.9)(2.813)}{30}$$

$$= 44300$$

$$f \cong 0.0062$$

$$\Delta P_{fc} = \frac{(0.0062)(10)(500)(15.9)^2}{(25.8)(2.813)}$$

$$= 108 \text{ psi}$$

7. Pressure drop across bit:

This is a jet bit with a nozzle coefficient of 0.95, ∴, equation $d_e = \sqrt{n d^2}$ corrected for multiple nozzles, is used

$$d = \sqrt{(3)(13/32)^2} = 0.704 \text{ in}$$

$$\Delta P_{fb} = \frac{q^2 \rho_m}{7430 c^2 d^4}$$

$$= \frac{(308)^2 (10)}{(7430)(.95)^2 (0.704)^2} = 580 \text{ psi}$$

8. Annular loss around drill collars:

$$V_c = \frac{(1.08)(30) + 1.08\sqrt{(30)^2 + (9.3)(10)(1.125)^2(10)}}{(10)(1.125)}$$

$$= 7.25 \text{ ft/sec}$$

Note: The hydraulically equivalent diameter, de, of the annulus

$$7.875 - 6.750 = 1.125 \text{ in}$$

$$\text{The } V_{act} = \frac{308}{(2.45)[(7.875)^2 - (6.75)^2]}$$

$$= 7.6 \text{ ft/sec}$$

$\therefore$ Flow is turbulent

and $$N_{Re} = \frac{(2970)(10)(7.6)(1.125)}{30} = 8450$$

$f = 0.0098$, Curve II

$$\therefore, \quad \Delta P_{fac} = \frac{(0.0098)(10)(500)(7.6)^2}{(25.8)(1.125)} = 97 \text{ psi}$$

9. Annular loss around drill pipe:

$$V_c = \frac{(1.08)(30) + 1.08\sqrt{(30)^2 + (9.3)(10)(3.375)^2(10)}}{(10)(3.375)}$$

$$= 4.39 \text{ ft/sec}.$$

$\therefore$, flow is laminar, since circulation volume was calculated from annular velocity of 3 ft/sec;

Use equation

$$\Delta P_{fadp} = \frac{L Y_b}{300 d} + \frac{\mu_p V_{act} L}{1500 d^2}$$

$$= \frac{(5500)(10)}{(300)(3.375)} + \frac{(30)(3)(5500)}{1500(3.375)^2}$$

$$= 83 \text{ psi}$$

The total Pressure drop in the system:

$$\Delta P_t = 27+270+108+580+97+83$$

$$\cong 1165 \text{ psi}$$

The horsepower output at the pump is

$$Hp = \frac{QP}{1714}$$

$$Hp = \frac{(308)(1165)}{1714} = 209$$

The input power from engine to pump (90% pump volumetric efficiency and 85% mechanical efficiency) is:

$$Hp = \frac{209}{(0.9)(.85)} = \underline{273}$$