Mud hydraulics fundamentals

Pressure

Pressure is defined as the force acting on a unit area. In the oil field, pressure is commonly measured in pounds per square inch (psi).

At the well site, we are typically concerned with the pressures throughout the circulating system. We may need to know the pressure at a particular point in the wellbore (such as the casing shoe or a lost circulation zone) or we may want to know the total pressure required to pump a certain mud volume at a given rate. Various types of pressures exist due to different mechanisms, and are classified as either **hydrostatic**, **hydraulic**, or **imposed**. All of these pressures result in force acting on a unit area, even though their origins may differ.

Note: *The pressure at any given point in the circulating system is the sum of the hydrostatic, hydraulic, and imposed pressures which exist at that point.*

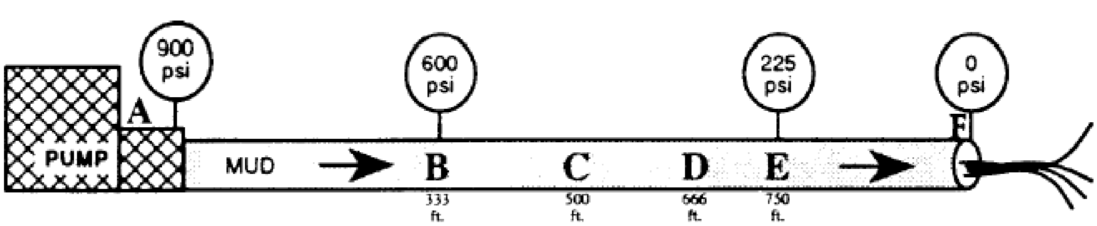
Hydrostatic Pressure

As mentioned earlier, this is the pressure created by a column of fluid due to its density and vertical height. This type of pressure always exists and may be calculated whether the fluid is static or flowing.

Hydraulic Pressure

This is the pressure created (or needed) to move drilling fluid through pipe. In oil field terms, it is the pressure generated by the mud pump in order to move the drilling fluid from the mud pump around the system and back to the flow line. This type of pressure can be calculated at any point in the circulating system.

Pressure drop or pressure loss is the amount of pressure needed to move the fluid over a given distance, for example,



Typically, hydraulic pressures will be calculated in order to:
• Determine the total pressure being exerted at the casing shoe (generally the weakest point in the circulating system); the bottom of the hole; or any other point (such as a lost circulation zone). After this pressure is determined, it is often converted into a mud density equivalent and reported as the E.C.D. (Equivalent Circulating Density) for that depth.
• Determine the anticipated pump pressure, using: تحديد ضغط المضخة المتوقع باستخدام:
- Mud properties
- drill string configuration
- bit size
- Total flow area for the bit
- Flow rate
• Determine the nozzle size for a bit, using:
- Maximum pump pressure allowed
- Mud properties
- drill string configuration
- bit size
- Flow rate

Imposed Pressure

These are external pressures which are "imposed" into the well. Since the well is open to the atmosphere, the well must be "shut-in" for there to be an imposed pressure. This type of pressure will always be felt uniformly throughout the shut-in well. Imposed pressures originate from:
1. The pumps (i.e. when testing a casing shoe)
2. The formation (i.e. when the well kicks يقاوم)

Laminar Flow is usually found in the annulus during drilling operations. This type of flow is generally desired in the annulus since it does not lead to hole erosion and does not produce excessive pressure drops. These pressure drop calculations can be mathematically derived according to the type of flow behavior.

Turbulent Flow is the type of flow regime found inside the drill string during drilling operations. Since high mud velocities are required to achieve turbulent flow, this results in high pressure drops. This type of flow is generally not desired in the annulus due to its tendency to cause excessive hole erosion and high "equivalent circulating densities".

However, turbulent flow can move the mud like a plug, causing the mud to move at approximately the same rate. This provides for better hole cleaning and is sometimes required on high angle holes. Pressure drop calculations for turbulent flow are empirical rather than mathematically derived.

When a force is applied to a static fluid, the layers slide past one another and the frictional drag that occurs between the layers (which offers resistance to flow) is known as "**shear-stress**"

Mud hydraulic: is considered one of the most important factors affecting mud drilling performance.

Hydraulic optimization used to minimize drilling operation coast.

Why the optimization is necessary?

Because /or to make the maximum efficiency. This is achieved by minimizing the energy loss due to friction in the circulating system and using the saved energy to improve bit hydraulic.

Drilling mud classification

Depending on drilling mud behavior, drilling mud can be Newtonian fluid, Bingham plastic fluid, Power law fluid, Herschel-Bulkley model.

To study the hydraulic calculations

Most study pressure losses in flow (drilling string and annulus)

Why is pressure loss occurred?

Its due to the resistance to flow along the wall of a flow conduit

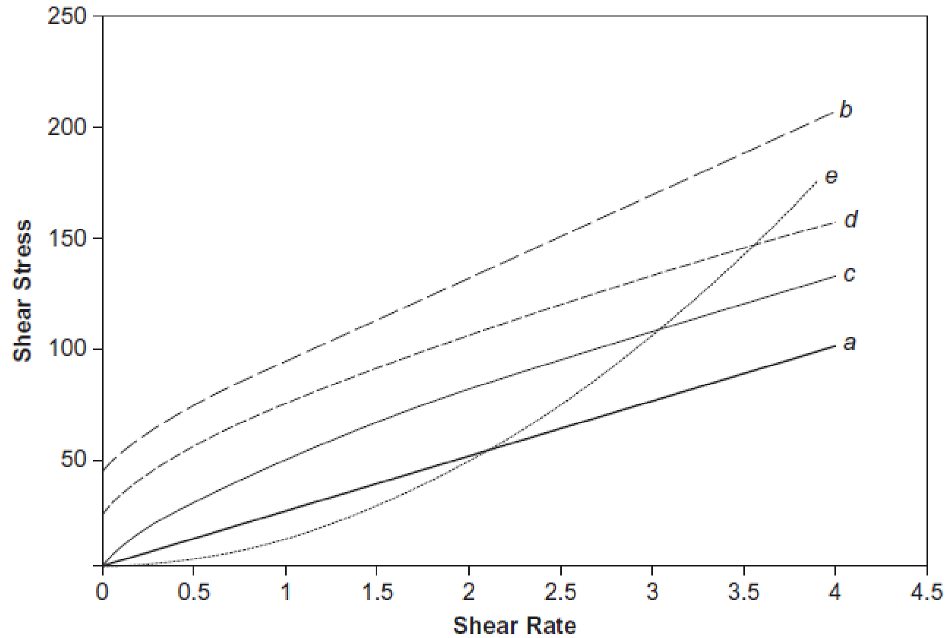
- Friction between the particles themselves.
- Friction between the fluid particles and the wall.

Rheology: Is basically the study of shear rate and shear stress.

Flow or deformation of matter in terms of shear rate and shear stress.

Shear rate: is defined as the flow velocity gradient in the direction perpendicular to the flow direction.

Shear stress: is the friction between particles measured by the shear force per unit area of shearing layer, or shear stress.



a: Newtonian fluids (water or oil)

b: Plastic fluid or Bingham Plastic fluid

c: Power law fluid

d: Herschel and Bulkley fluid

e: Dilatant fluid

Rheological Models

For the Newtonian model:

$$\tau = \mu . \dot{Y}$$

τ=shear stress, Ib/100ft^2

μ=viscosity, cP or Pa.s

$\dot{Y}$=shear rate, s^{-1}

Bingham plastic model:

$$\tau = \tau_{y+}\mu_p . \dot{Y}$$

τ_y=yield point y_p Ib/100ft^2 or Pa

μ_p= plastic viscosity (PV) cP or Pa.s

Power low model :

$$\tau = K . \dot{Y}^n$$

K= consistency index, cP or Pa.s

n=flow behavior index dimension less

When n< 1, the power law model describes the behavior of pseudo plastic fluid or power law fluids.

When n=1, the power law model describes the behavior of Newtonian fluids.

When n>1, the power law model describes the behavior of dilatant fluids

Herschel Bulkley fluids described by their model is expressed as:

$$\tau = \tau_y + K\dot{Y}^n$$

Non-Newtonian fluids are thixotropic because the apparent viscosity (shear stress divided by shear rate) decreases with shear rate increased to a new value.

Shear-thinning property is very desirable in drilling operations because we want low viscosity to reduce the circulating pressure in normal drilling operations, and we want high viscosity during circulation breaks to suspend drill cuttings in the annulus.

Hydraulic models calculations

Newtonian fluids

$$\mu = \frac{300}{\theta}\theta_N$$

N=rotary speed of Fann VG meter, rpm

θ_N=dial reading of Fann VG meter at rotary speed N.

To know fluid's flow regime, we should calculate its Reynolds number.

For Newtonian fluid inside pipe, the Reynolds number is:

$$N_{Re} = \frac{\rho v d}{\mu}$$

ρ=fluid density, Kg/m^3

d=inside diameter of pipe, m

μ=fluid viscosity Pa.s

$$v = \frac{q}{0.7854d^2}$$

v=average flow velocity m/s

q=flow rate, m^3/s

for annular flow, Reynolds number becomes

$$N_{Re} = 0.816.\frac{\rho v(d_2 - d_1)}{\mu}$$

d_2=hole or casing diameter, m

d_1=outside diameter of pipe, m

and

$$v = \frac{q}{0.7854(d_2^2 - d_1^2)}$$

In use field units (ppg, v ft/s, q gpm, d_1,d_2 in and μ in cP)

$N_{Re} = 928.\frac{\rho v d}{\mu}$ pipe

$$v = \frac{q}{2.448 d^2}$$

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

$$v = \frac{q}{2.448(d_2^2 - d_1^2)}$$

Less than 2100 laminar

Greater than 4000 turbulent

Between them is transitional

For Bingham plastic fluids*, the equations for the Newtonian fluids need to be modified by defining an* ***apparent viscosity*** *to account for the* ***plastic viscosity*** *and yield point. For pipe flow, the definition is*

$$\mu_a = \mu_p + \frac{5\tau_y d}{v}$$

$$\mu_a = \mu_p + \frac{5\tau_y (d_2 - d_1)}{v}$$

Example: A 10.5 ppg Newtonian fluid with viscosity of 30 cP is circulating at 250gpm in an (8.75 in) diameter wellbore. Determine the flow regime inside a (4.5 in) OD, 16.60 Ib/ft drill pipe (3.826 in ID), and in the drill pipe/hole annulus.

Inside the drill pipe

$$v = \frac{250}{2.448(3.826)^2} = 6.98\ ft/s$$

$N_{Re} = 928.\frac{(10.5)(6.98)(3.826)}{30} = 8674$

Since Re > 4000, turbulent flow exists inside the drill pipe

In the annulus

$v = \frac{250}{2.448(8.75^2 \ - 4.5^2\ )} = 1.82\ ft/s$

$N_{Re} = 757.\frac{(10.5)(1.82)(8.75-4.5)}{30} = 2038$

Since Re < 2100, laminar flow exists in the annular space.

H.W

Re calculate the example above using Bingham Plastic model (μ_p=20cp, τ_y=5 Ib/ft^2, q=250 gpm)

Pressure losses

For drilling fluid to flow through the circulating system, it must overcome frictional forces between the fluid layers, solid particles, pipe wall, and borehole wall. The pump pressure corresponds to the sum of these forces:

$$Pp = \Delta Ps + \Delta Pdp + \Delta Pdc + \Delta Pmt + \Delta Pb + \Delta Pdca + \Delta Pdpa$$

Where

Pp=pump pressure, psi or kPa

ΔPs=pressure loss in the surface equipment, psi or kPa

ΔPdp=pressure loss inside drill pipe, psi or kPa

ΔPdc=pressure los inside drill collar, psi or kPa

ΔPmt=pressure drop inside mud motor, psi or kPa

ΔPb=pressure drop at bit, psi or kPa

ΔPdca=pressure loss in the drill collar annulus, psi or kPa

ΔPdpa=pressure loss in the drill pipe annulus, psi or kPa

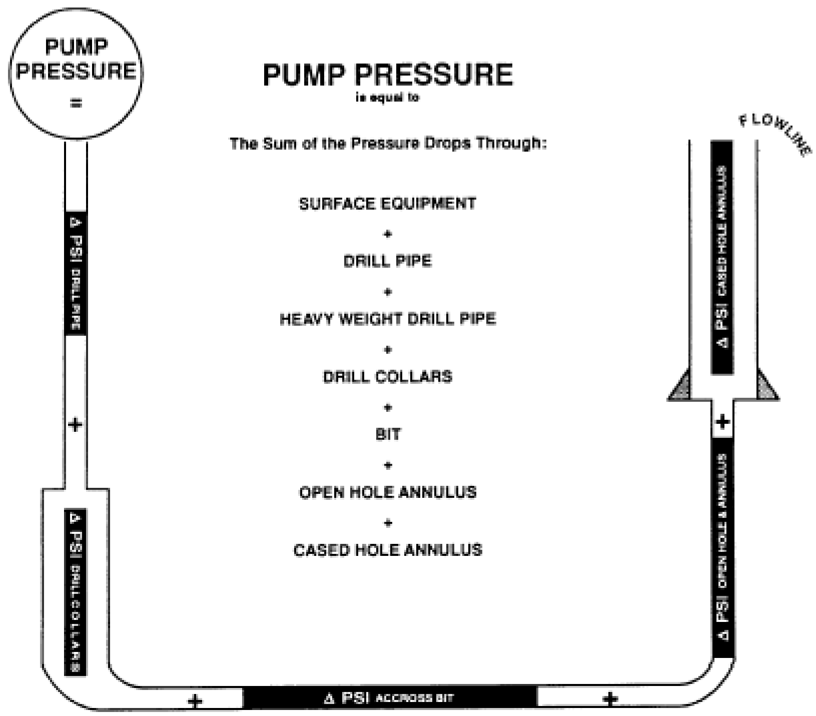
ΔPd=parasitic pressure loss

$$\Delta Pd = \Delta Ps + \Delta Pdp + \Delta Pdc + \Delta Pdca + \Delta Pdpa$$

If no mud motor used

Pp=ΔPb+ΔPd

The surface equipment consists of a stand pipe, a rotary hose, a swivel, and Kelly pipe.



For Newtonian:

Laminar

$\Delta Pf = \frac{\mu v}{1500 d^2} \Delta L$ inside drill string

$\Delta Pf = \frac{\mu v}{1000 (d_2 - d_1)^2} \Delta L$ inside annulus

ΔPf=pressure loss, Psi or kPa

ΔL=length of conduit, ft or m

Turbulent

$\Delta Pf = \frac{\rho^{0.75} v^{1.75} \mu^{0.25}}{1800 d^{1.25}} \Delta L$ inside drill string

$\Delta Pf = \frac{\rho^{0.75} v^{1.75} \mu^{0.25}}{1396 (d_2 - d_1)^{1.25}} \Delta L$ inside annulus

In SI unit the constant 1800 becomes 631.8 and the constant 1396 becomes 490.

For Bingham Plastic fluids

Laminar

$\Delta Pf = (\frac{\mu_p v}{1500 d^2} + \frac{\tau y}{225}) \Delta L$ inside drill string

$\Delta Pf = (\frac{\mu_p v}{1000 (d_2 - d_1)^2} + \frac{\tau y}{200 (d_2 - d_1)}) \Delta L$ inside annulus

Turbulent

$\Delta Pf = \frac{\rho^{0.75} v^{1.75} \mu p^{0.25}}{1800 d^{1.25}} \Delta L$ inside drill string

$\Delta Pf = \frac{\rho^{0.75} v^{1.75} \mu p^{0.25}}{1396 (d_2 - d_1)^{1.25}} \Delta L$ inside annulus

In SI unit the constant 1800 becomes 632 and the constant 1396 becomes 491.

Example) Determine the system pressure loss for the following well.

Total depth : 9950 ft(3036m)

Casing : 9 $^{5/8}$ in , 43.Ib/ft (8.755in D)

Set at 6500 ft (1982m)

Open hole : 8 ½ in from 6500 ft to 9950 ft

Drill pipe: 9500 ft of 4 ½ in, 16.6 Ib/f (3.826 in ID)

Drill collar 450 ft of 6 ¾ in OD and 2 ½ in ID

Surface equipment : combination 3

Mud weight :10.5 ppg

Plastic viscosity : 35 cp

Yield point : 6 Ib/100ft^2

Mud flow rate: 300 gpm

Sol.

According to table 2.2 shown earlier, the pressure loss through the surface equipment is equivalent to that through 479 ft of 4 ½ in, 16.6Ib/ft drill pipe.

Inside drill pipe :

$$v = \frac{300}{2.448 (3.826)^2} = 8.37\ ft/s$$

$$\mu_a = 35 + \frac{6.66(6)(3.826)}{8.37} = 53\ cP$$

$$N_{Re} = 928. \frac{(10.5)(8.37)(3.826)}{53} = 5887 > 2100$$

Turbulent flow

$\Delta Pf = \frac{(10.5)^{0.75} (8.37)^{1.75} (35)^{0.25}}{1800 (3.826)^{1.25}} (9500 + 479)$ = 605 psi inside drill string

Inside the drill collar :

$$v = \frac{300}{2.448 (2.25)^2} = 24.2\ ft/s$$

$$\mu_a = 35 + \frac{6.66(6)(2.25)}{24.2} = 39\ cP$$

$N_{Re} = 928.\frac{(10.5)(24.2)(2.25)}{39} = 13604 > 2100$

Turbulent flow

$\Delta Pf = \frac{(10.5)^{0.75}(24.2)^{1.75}(35)^{0.25}}{1800(2.25)^{1.25}}(450)$ = 340 psi inside drill string

In the cased – hole annulus :

$$v = \frac{300}{2.448(8.75^2 - 4.5^2)} = 2.17\ ft/s$$

$$\mu_a = 35 + \frac{6(6)(8.755 - 4.5)}{2.17} = 94\ cp$$

$N_{Re} = 757.\frac{(10.5)(2.17)(8.75-4.5)}{94} = 781 < 2100$

Laminar flow

$\Delta Pf = \left(\frac{(35)(2.17)}{1000(8.755-4.5)^2} + \frac{6}{200(8.755-4.5)}\right) 6500 = 73\ psi$

In the open hole / drill annulus

$$v = \frac{300}{2.448(8.5^2 - 4.5^2)} = 2.36\ ft/s$$

$$\mu_a = 35 + \frac{5(6)(8.5 - 4.5)}{2.36} = 86\ cP$$

$N_{Re} = 757.\frac{(10.5)(2.36)(8.5-4.5)}{86} = 872 < 2100$

Laminar flow

$\Delta Pf = \left(\frac{(35)(2.36)}{1000(8.5-4.5)^2} + \frac{6}{200(8.5-4.5)}\right) 3000 = 38\ psi$

In open hole/drill collar annulus

$$v = \frac{300}{2.448(8.5^2 - 6.75^2)} = 4.59\ ft/s$$

$$\mu_a = 35 + \frac{5(6)(8.5 - 6.75)}{4.59} = 46\ cP$$

$N_{Re} = 757.\frac{(10.5)(4.59)(8.5-6.75)}{46} = 1388 < 2100$

Laminar flow

$\Delta Pf = \left(\frac{(35)(4.59)}{1000(8.5-6.75)^2} + \frac{6}{200(8.5-6.75)}\right) 450 = 31\ psi$

Total system pressure loss is

ΔPd=605+340+73+38+31=1087psi = 7394 kPa.

Not. 1psi=6.894kPa

Table 2.1 Inner Equipment Diameter and Length for Typical Combinations

	Combination 1				Combination 2				Combination 3				Combination 4			
	ID		Length		ID		Length		ID		Length		ID		Length	
Component	in	cm	ft	m	in	cm	ft	m	in	cm	ft	m	in	cm	ft	m
Standpipe	3	7.6	40	12.2	3.5	8.9	40	12.2	4	10.2	45	13.7	4	10.2	45	13.7
Rotary hose	2	5.1	45	13.7	2.5	6.4	55	16.8	3	7.6	55	16.8	3	7.6	55	16.8
Swivel	2	5.1	4	1.2	2.5	6.4	5	1.5	2.5	6.4	5	1.5	3	7.6	6	1.8
Kelly pipe	2.25	5.7	40	12.2	3.3	8.3	40	12.2	3.3	8.3	40	12.2	4	10.2	40	12.2

Table 2.2 The Equivalent Drill Pipe Length for Typical Equipment Combinations

Equivalent Drill Pipe	Combination 1		Combination 2		Combination 3		Combination 4	
	ft	m	ft	m	ft	m	ft	m
3.5″, 13.3 lb/ft	437	133	161	49				
4.5″, 16.6 lb/ft			761	232	479	146	340	104
5″, 19.5 lb/ft					816	249	576	176

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