PROJECT REPORT

ON

DRILLING HYDRAULICS

AT

INSTITUTE OF DRILLING TECHNOLOGY

ONGC, DEHRADUN

TRAINING DURATION

5 July 2021 – 6 August 2021

PROJECT MENTOR

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INSTITUTE OF DRILLING TECHNOLOGY

OIL AND NATURAL GAS CORPORATION, DEHRADUN

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Content

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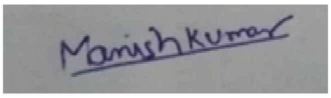
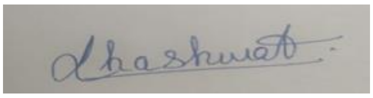
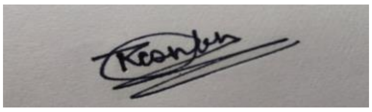
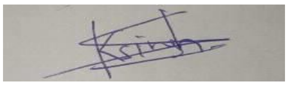
We are honored to get this opportunity of internship at one of the Navratnas of our country. It increased our exposure towards research and practical aspects of the petroleum field. We would also like to express our deepest regards to all those who are directly or indirectly involved in the success of this project work and encouraged us in various ways to carry out this internship.

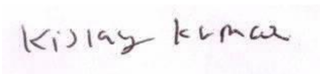


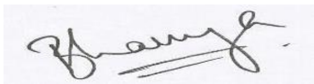




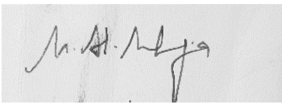
Manish Kumar | Shashwat Harsh | Rishabh Bharadwaj







Shashwat Singh | Kislay Kumar | Bhavya Kumari



Patel Astha | Abdul Kiberiya

CERTIFICATES

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1. About the Institute

The Institute of Drilling Technology (IDT) was set up in 1978 at Dehradun. Located in the picturesque Doon valley between the green Shivaliks and the lower Himalayas, it is engaged in relentless effort in R&D and has rendered excellent services in the area of oil and gas well drilling technology. Over the years, the Institute has emerged as a premier R&D center in South East Asia, capable of providing advance technical knowledge through training and offering plausible solution to field problems.

The Institute with highly qualified and experienced scientists and engineers carry out applied research in all facets of drilling related activities to achieve technical excellence in R&D efforts and assimilation of emerging technologies.

The infrastructure for applied R&S has been developed with the state-of-the-art equipment and ~~machines~~ simulators to achieve qualitative results. Focus of R&D is directed towards drilling technology, drilling fluid engineering and cementation and cementing materials to meet the challenges of drilling industry. The technologists and scientists working here provide solutions to the down-hole drilling problems, improving design of the systems thereby contributing towards the development of excellent, efficient and cost-effective drilling operations.

IDT is internationally recognized and accredited by the International Well Control Forum (IWCF), International Alliance for Well Control (IAWC), The Netherlands & International Association of Drilling Contractors (IADC), US.

IDT has one working rig installed at its campus for imparting hands-on training to its new recruits and a walk around visit for university students from petroleum discipline.

2. INTRODUCTION

This project is related to role of drilling fluid hydraulics in drilling oil and gas wells . Designing a bit hydraulic program to attain maximum Rate of Penetration (ROP)with the available equipment on site is crucial for any drilling project. This includes calculating pressure losses in various sections of the mud circulation system using realistic approaches and determining the best suitable nozzle size for the selected discharge and pump capacity. There are several models for the Pressure losses in pipes and annuli, which are calculated. Each model is built on a set of assumptions. In different drilling circumstances, some of the assumptions may be satisfied

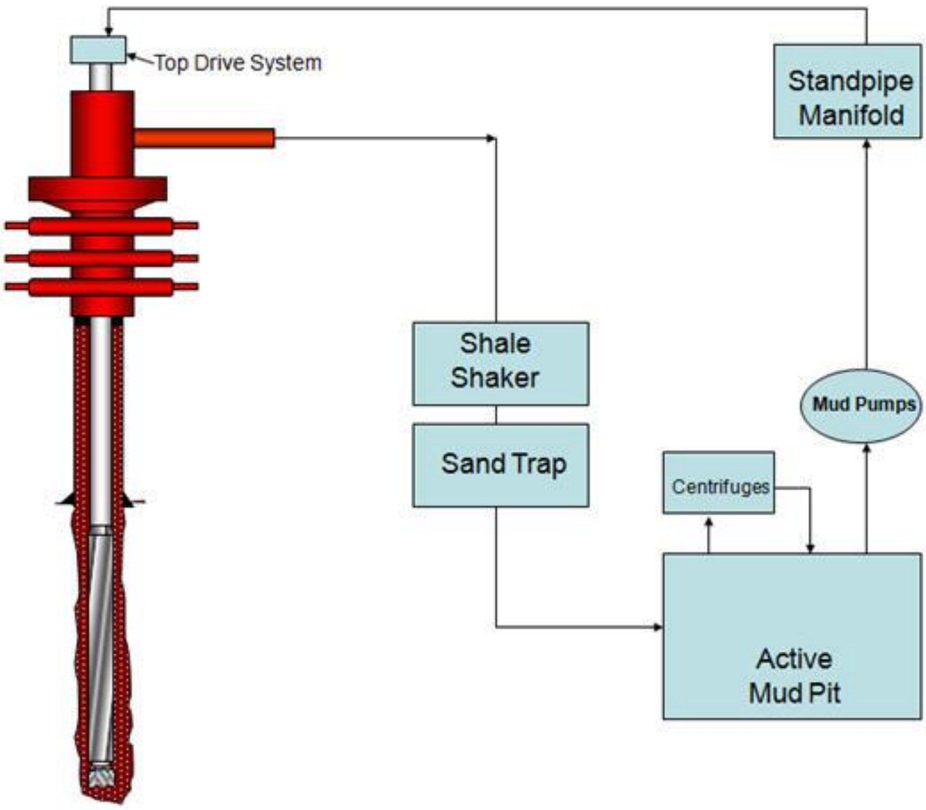

Figure 1: Schematic diagram of Circulation System

Drilling hydraulics is considered the most important factor in improving drilling performance. Using cutting-edge hydraulics optimization techniques, the rate of penetration (ROP)can be greatly increased resulting into reduced drilling cost. The purpose of the optimization is to make the most of the pump's power in order to assist the bit in drilling as efficiently as possible. This is accomplished by reducing energy loss in the circulating system owing to friction and repurposing the saved energy to improve bit hydraulics.

3. PRESSURE LOSSES

Circulating system can be divided into 4 components:

1. Surface Equipment
2. Pipes including drill pipe, heavy weight drill pipe (HWDP)and drill collars.
3. Annular areas around drill pipes, HWDP, drill collars, etc.
4. Drill bit.

Total pressure energy losses in every part of the circulating system are calculated and total system losses are determined, which in turn determines the pumping requirements from the rig pumps and in turn the horse power requirements.

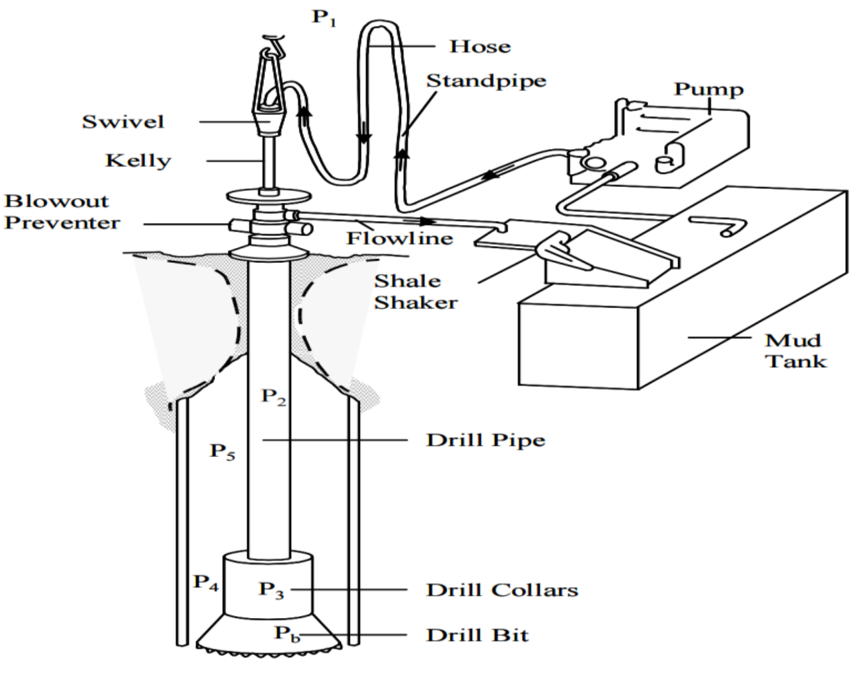

Figure 2: Schematic of Circulation Syste

3.1 SURFACE CONNECTION LOSSES (P1)

Pressure losses (P1) are losses in standpipe, rotary hose, swivel and Kelly. Estimating these losses is difficult as these are dependent on the dimensions and geometries of surface connections and these dimensions can vary with time due to continuous wear of surfaces by the drilling fluids.

The following general equation may be used to evaluate pressure losses in surface connections:

$$P_1 = E \times \rho^{0.8} \times Q^{1.8} \times PV^{0.2} \text{ psi}$$

where, ρ = mud weight (lbm/gal)

Q = volume rate (gpm)

E = a constant depending on type of surface equipment used

PV = plastic viscosity (cP)

In practice, there are only four types of surface equipment; each type is characterized by the dimensions of standpipe, Kelly, rotary hose and swivel. Table 1 summarizes the four types of surface equipment.

Case	Standpipe	Hose	Swivel, etc.	Kelly	Eq. Length 3.826-in. ID
1	40 ft long, 3-in. ID	45 ft long, 2-in. ID	20 ft long, 2-in. ID	40 ft long, 2.25-in. ID	2,600 ft
2	40 ft long, 3.5-in. ID	55 ft long, 2.5-in. ID	25 ft long, 2.5-in. ID	40 ft long, 3.25-in. ID	946 ft
3	45 ft long, 4-in. ID	55 ft long, 3-in. ID	25 ft long, 2.5-in. ID	40 ft long, 3.25-in. ID	610 ft
4	45 ft long, 4-in. ID	55 ft long, 3-in. ID	30 ft long, 3-in. ID	40 ft long, 4-in. ID	424 ft

Table 1: Types of Surface equipment

Values of constant E can be obtained from Table 2:

Surface equipment type	Value of E	
	Imperial units	Metric units
1	2.5 x 10-4	8.8 x 10-6
2	9.6 x 10-5	3.3 x 10-6
3	5.3 x 10-5	1.8 x 10-6
4	4.2 x 10-5	1.4 x 10-6

Table 2: Values of constant E

3.2 PIPE AND ANNULAR PRESSURE LOSSES

Pressure losses inside the drillpipe and drill collars are shown in Fig.2 as P2 and P3, respectively. Annular losses around the drill collar and drillpipe are shown as P4 and P5 in Fig.2.

The magnitudes of P2, P3, P4 and P5 depend on:

1. dimensions of drillpipe (or drill collars), e.g., inside and outside diameter and length
2. mud rheological properties, which include mud weight, plastic viscosity and yield point; and
3. type of flow, which can be laminar, or turbulent.

Power law and Bingham Plastic models will be used to calculate the annular pressure losses. They are chosen primarily because they are widely applied in the oil drilling industry.

Note:

1. These models approximate the annulus as two parallel plates, with the effects of rotation being ignored.

2. There is a possibility of large discrepancy between the pressure values calculated using the annular flow models.

3.3 PRESSURE DROP ACROSS BIT

For a given length of drill string and given mud properties, pressure losses P1, P2, P3, P4 and P5 will remain constant. However, the pressure loss across the bit is greatly influenced by the sizes of nozzles used, and volumetric flow rate. For a given flow rate, the smaller the nozzles the greater the pressure drop and, in, turn the greater the nozzle velocity.

For a given maximum pump pressure(or maximum standpipe pressure), the pressure drop across the bit is obtained by subtracting Pc (= P1 + P2 + P3 + P4 + P5) from the pump pressure(for practical purposes standpipe pressure)

This pressure drop must be around 60 - 65 % of maximum allowable working pressure(standpipe pressure).

4. HYDRAULICS FUNDAMENTALS

The terms needed to comprehend the various hydraulics equations a,b,c is defined here. The definitions of the symbols and units are included.

- **Shear rate γ (sec^{-1})** is a term used to describe laminar flow. In laminar flow, it is defined as the change in fluid velocity divided by the width of the channel through which the fluid is flowing.
- **Shear stress τ ($lb/100\ ft^2$):** The force required to move a fluid at a certain shear rate per unit area.
- **Plastic viscosity, PV (cP):** Plastic viscosity is a measure of a fluid's contribution to total fluid viscosity when it flows dynamically. Plastic viscosity is a property of flowing fluids that is dependent on the size, shape, and quantity of particles.

PV is determined by shear stresses. The Fann 35 viscometer was measured at 600 and 300 rpm.

- **Effective viscosity, μ (cP):** This word takes into account the geometry of the fluid's flow and is thus a more descriptive term for the fluid's flowing viscosity.
- **The yield point, YP (lb/100 ft 2):** is the force required to commence flow; for further information, see the Bingham Plastic model.
- **Stress on yield (lb/100 ft2):** This value represents the calculated force required to commence flow and is determined by extrapolating the rheogram (a plot of shear stress versus shear rate) to the y-axis at = 0 sec -1.

  (Note: Yield stress is a time-independent quantity that is commonly abbreviated as YP in the Herschel-Bulkley (yield-power law [YPL]) and Bingham models. Additionally, it can be thought of as a gel strength at zero time.)
- **Gel strength (lb/100 ft2):** When at rest, all drilling fluids form a structure. Gel strength is a time-dependent parameter that indicates the fluid shear stress in static settings. Gel strengths are frequently determined at intervals of 10 seconds, 10 minutes, and 30 minutes.
- **The Reynolds number, Re,** is a dimensionless number that indicates whether a fluid is flowing laminarly or turbulently. In most drilling fluids, a Reynolds number greater than 2,100 indicates the commencement of turbulent flow. For laminar flow (Re less than 2,100) and turbulent flow (Re greater than 2,100).
- T**he critical Reynolds number, Rec,** is the value at which laminar flow transitions to turbulent flow.
- **Friction factor (f):** This is a dimensionless term that is used to describe power law fluids in turbulent flow and is used to relate the fluid Reynolds number to the pipe's "roughness" factor.

5. FLOW REGIMES

There are three basic types of flow regimes:

1. Laminar
2. Turbulent
3. Transitional

Laminar flow: When fluid layers flow parallel to one another in an orderly pattern, this is referred to as laminar flow.

When the friction between the fluid and the channel walls is at its lowest, this flow occurs at low to moderate shear rates. This is a common flow pattern in the annulus of the majority of wells.

Turbulent flow: This flow occurs at high shear rates and is characterized by the disorganized and chaotic movement of fluid particles. Particles are pushed ahead by current eddies. For this sort of flow, the friction between the fluid and the channel walls is greatest. This is an illustration of the usual flow inside the drillpipe and drillcollars.

In turbulent flow, unlike in laminar flow, mud properties (viscosity and yield point) have no effect on the calculation of frictional pressure losses for muds.

Transitional Flow: When the fluid flow shifts from laminar to turbulent or vice versa, transitional flow occurs.

6. FLUID TYPES

Newtonian and non-Newtonian fluids are the two most common varieties. The viscosity of Newtonian fluids remains constant at a given temperature and pressure. Common Newtonian fluids include:

- Water
- Diesel
- Glycerin
- Clear brines

Viscosities of non-Newtonian fluids are determined by observed shear rates at a particular temperature and pressure. Non-Newtonian fluids include the following:

- Most drilling fluids
- Cement slurries

Almost all drilling operations utilize non-Newtonian drilling fluids. Even completion fluids, like as brines, are not completely Newtonian fluids because to the dissolved minerals in them.

7.RHEOLOGICAL MODELS

Almost all drilling fluids show non-Newtonian behavior because they contain dissolved and undissolved solids, clays or colloidal particles that result in time dependent or shear dependent behavior of the mud. The term ‘Viscosity’ can no longer define the flow characteristics of the drilling fluid now., as it will keep on varying indefinitely.
To predict the fluid behavior of non-Newtonian fluids (or Drilling Fluids in this case), the term ‘Rheology’ is considered. Certain Rheological Models have been developed for this purpose. These are mathematical equations used across a wide range of shear rates and provide practical means of calculating pumping (pressure) requirements for a given fluid. They use a number of approximations to arrive at practical equations.

There are three rheological models that are currently being used in the industry:

1. Bingham Plastic Model
2. Power Law Model
3. Hershel-Buckley Model

The use of these models requires measurements of shear stress at two or more shear rates. From these measurements, the shear stress at any other shear rate can be calculated.

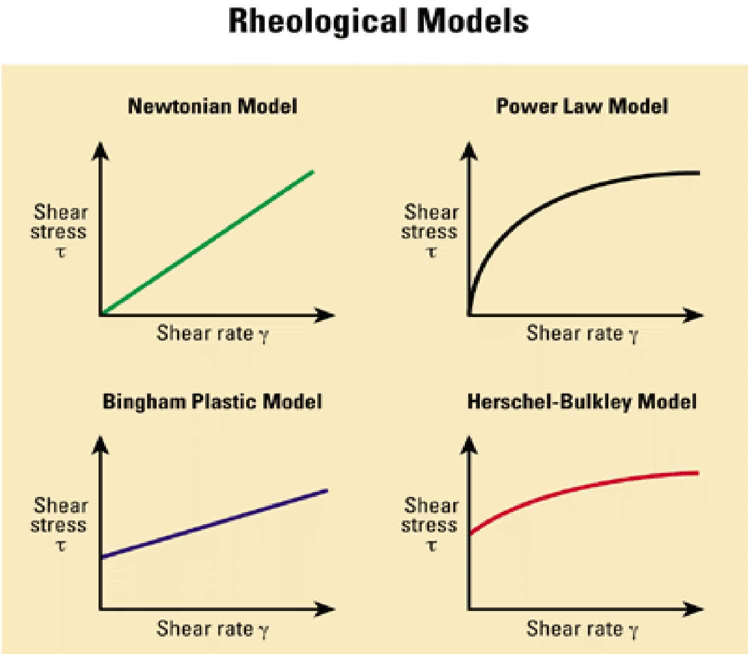

Figure 3: Shear stress vs. Shear rate plots of different Rheological Models

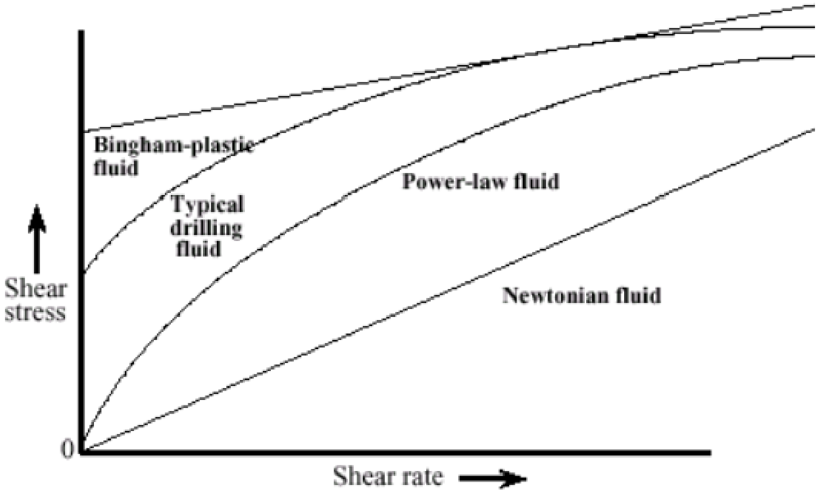

Figure 4: Comparative plots of Rheological Models w.r.t Drilling fluid behavior

7.1BINGHAM PLASTIC MODEL

Bingham Plastic Model is an old model currently in use. This model describes a fluid in which a finite force is required to initiate flow (yield point) and which then exhibits a constant viscosity with increasing shear rate (plastic viscosity).

The Bingham Plastic model describes laminar flow using the following equation:

$$\tau = \mathbf{YP + PV\ x\ (\gamma)}$$

where,τ = measured Shear Stress in lb/100 ft2

YP = Yield Point (minimum force to initiate flow) in lb/100 ft2

PV = Plastic Viscosity in cP

γ = Shear Rate in sec -1

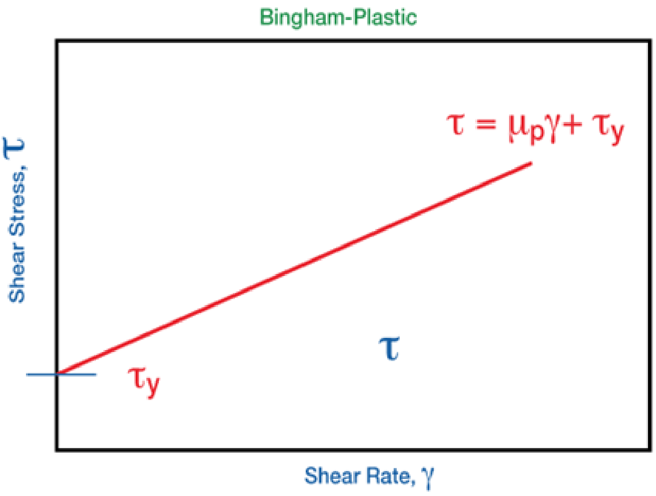

Figure 5: Bingham Plastic Model

The two-speed viscometer was designed to measure the Bingham Plastic rheological values for yield point and plastic viscosity.

The values of YP and PV are calculated using the following equations:

1. Plastic viscosity (PV or μ p), cp = $\phi_{600} - \phi_{300}$
2. Yield point (YP), lb/100 ft 2 = ϕ_{300} - PV
3. Apparent viscosity (AV or μ a), cp = ϕ_{600} /2

4. Gel Strength (10 sec and 10 min) is also calculated

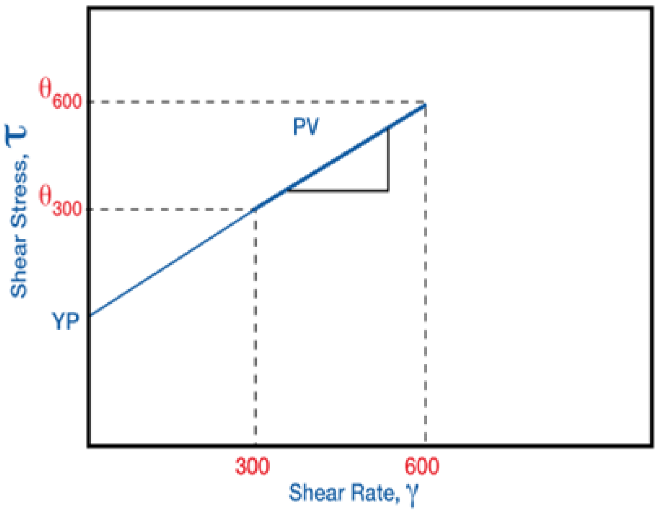

Figure 6: Consistency Curve obtained through Viscometer

The slope of the straight-line portion of this consistency curve is plastic viscosity.

As gel strengths develop, the minimal force necessary to break gels and initiate flow leads the y-intercept to occur at a point above the origin. As the force is increased, plug flow occurs, in which a gelled fluid flows as a "plug" with a flat viscosity profile. There is a transition from plug to viscous flow when the shear rate increases. Later, equal increments of shear rate will produce equal increments of shear stress, and the system assumes the flow pattern of a Newtonian fluid.

7.2POWER LAW MODEL

The power law model is another fluid model (assuming that all fluids are pseudoplastic in nature) to describe a characteristic of non-Newtonian fluid in which the shear stress and shear rate curve, called “a consistency curve”, has the exponential equation as described below:

Shear stress = K x (shear rate) ^{n}

$$\tau = K(\gamma)^n$$

where, τ = shear stress (dynes/cm^2)

K = consistency index

γ = shear rate (sec^{-1})

n = power law index

Shear stress increases as a function of the shear rate mathematically raised to some power.

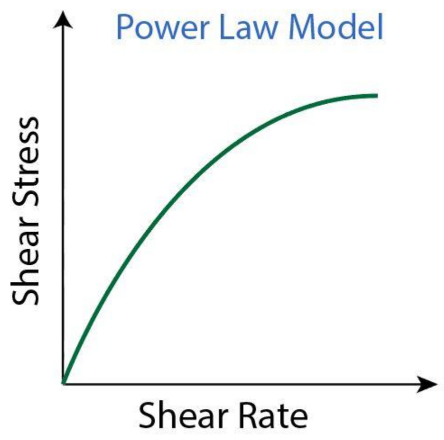

Figure 7: Power Law Model

The power law sought to overcome the shortcomings of the Bingham Plastic model at low shear rates. Thus, this law is ideal for shear-thinning, relatively mobile fluids such as weak gels and low-viscosity dispersions.

The Power Law model is more complex than the Bingham Plastic model in that it does not assume a linear relationship between shear stress and shear rate. However, like Newtonian fluids, the graph of shear stress vs. shear rate for Power Law fluids passes through the origin.

Consistency index (K), a constant, is a measure of the thickness of the mud. Mathematically, the constant 'K' can be defined as the shear stress at a shear rate of one reciprocal second. It is related to a fluid's viscosity at low shear rates. Units of 'K' can be any of these: lbs/100ft^2, dynes-sec, N/cm^2.

Increase in value of 'K' indicates better hole cleaning effectiveness of the fluid.

The power law index (n), a constant, indicates the degree of non-Newtonian behaviour of the fluid over a given shear rate range. The constant 'n' has no units.

Depending on the value of "n", power law model can mathematically describe three different types of fluid profiles:

1. n = 1: the behaviour of the fluid resembles that of a Newtonian, shear thinning
2. n < 1: the behaviour of the fluid is more of a non-Newtonian as 'n' decreases and the viscosity decreases with increase in shear rate
3. n > 1: the behaviour of the fluid is said to be of Dilatant, shear thickening (drilling fluids are not in this category)

In conclusion, lower the value of 'n', the more shear thinning a fluid is over that shear rate range and the more curved the shear-stress vs shear-rate relationship

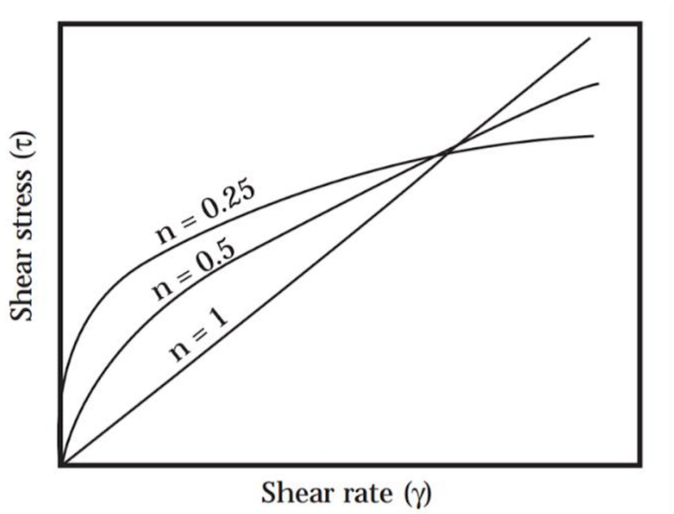

Figure 8: Effect of power law index 'n' on the shape of flow profile

Plotting the Power Law fluid shear-stress vs shear-rate on the log-log graph paper, the relationship forms a straight line as can be seen in the figure given below. The slope of this line is 'n' and 'K' is the intercept of this line.

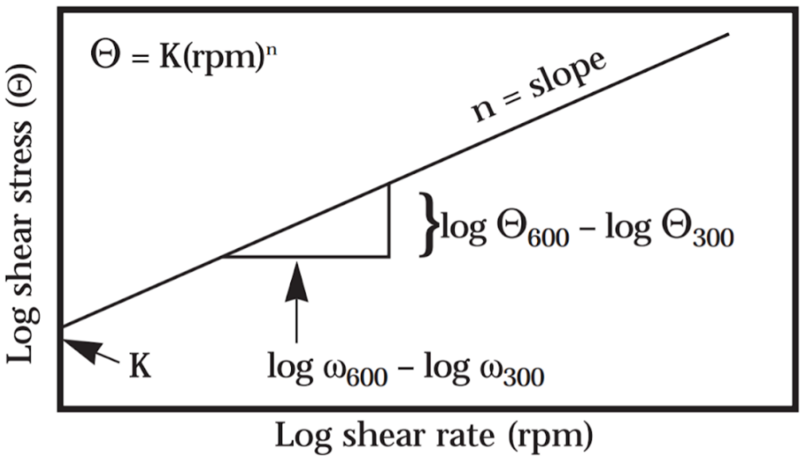

Figure 9: Log plot of Power Law model

$n = 3.32 \log(\Theta_{600}/\Theta_{300})$ and $K = \Theta_{300}/(511^n)$

where, Θ_{600} = mud viscometer reading at 600 rpm

Θ_{300} = mud viscometer reading at 300 rpm

The values of Θ_{600} and Θ_{300} can be calculated at the speed of 600 rpm and 300 rpm respectively,from Fann viscometer.

The drawback of the Power Law fluid model is that at zero shear rate, the shear stress is zero. This doesn't truly represent drilling mud because drilling mud has a residual shear strength at a zero-shear rate.

7.3 Herschel-Bulkley (Yield-Power Law [YPL]) Model

The Power Law model doesn't fully describe drilling fluids because it does not have a yield stress and underestimates LSRV. Thus, Herschel-Bulkley [YPL] model is the modified Power Law model which also accounts for the stress required to initiate fluid movement.

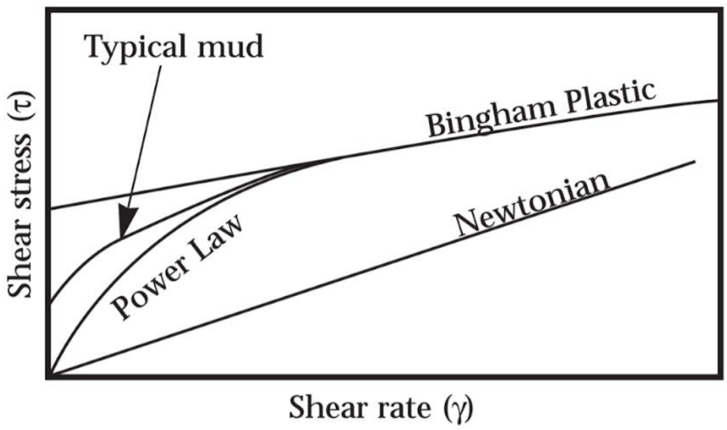

Figure 9: Log plot of Power Law model

The model can be mathematically written as:

$$\tau = \tau_0 + K(\gamma)^n$$

where, τ = measured shear stress (lb/100ft^2)

τ_0 = yield stress of the fluid to initiate flow (shear stress at zero shear rate) (lb/100ft^2)

K = consistency index of the fluid (cP or lb/100ft sec^2)

n = flow index of the fluid

γ = shear rate (sec^{-1})

On close observations one can clearly figure out that the YPL model reduces to the Bingham Plastic model when n = 1 and it reduces to the Power Law model when τ_0=0.

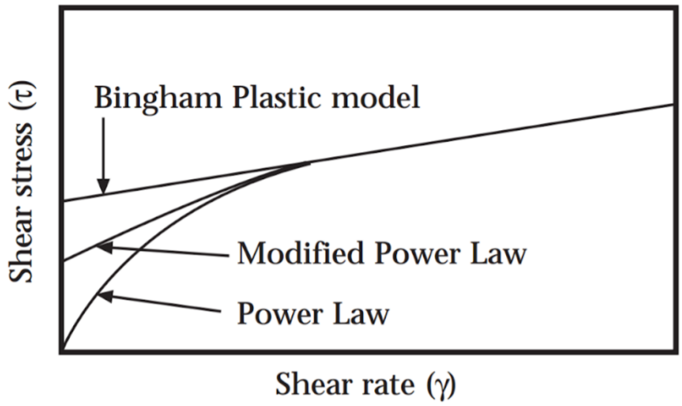

Figure 10: Rheological model comparison

The YPL model is the most complex and requires minimum three shear stress vs shear rate measurements for the solution. A Fann VG meter is to be used to get the dial readings at 600 rpm (Θ_{600}: mud viscometer reading at 600 rpm), 300 rpm (Θ_{300}: mud viscometer reading at 300 rpm)and 3 rpm (zero gel).

8.PRACTICAL HYDRAULICS EQUATIONS

Steps to calculate various pressure losses in a circulatory system:

1. First calculate surface pressure loss using the equation given below:

$$P_1 = E \text{ x } \boldsymbol{\rho}^{0.8} \text{ x } Q^{1.8} \text{ x } PV^{0.2} \text{ psi}$$

2.Then select which rheological model will apply (Bingham plastic model or power law model)

3. In next steps we measure the pressure loss inside the drill pipe first and then inside the drill collars.For this measure the critical velocity and actual average velocity of flow.Find out the nature of flow i.e. whether it is turbulent or laminar. If the average velocity is less than critical velocity then the flow is laminar,if average velocity is more

than critical velocity then the flow is turbulent.Apply the adequate equation to calculate the pressure drop.

4. Then annulus is to be divided between cased and open sections.

5. For calculation of annular velocity around drill collars we go through following methods.Find out critical velocity of annular flow and actual average velocity of flow in the annulus.After that find out whether flow is annulus or turbulent by comparison . Calculate the pressure drop.

6.Repeat process number 4.

7.Add the values from step 1 to 5, this will give you system losses.

8.Using the equation pressure drop in the bit = pump pressure - system losses.

9.Find out nozzle velocity, total flow area and nozzle sizes.

UNITS USED IN THE FOLLOWING EQUATIONS ARE:

Table 3: FIELD UNITS OF DIFFERENT PARAMETERS USED IN CALCULATIONS

Parameters	Field Units
OD (outside diameter)	inches
ID (inside diameter)	inches
L (length)	ft
ρ (density)	ppg
V (velocity)	ft/sec or ft/min
PV (Viscosity)	cp
YP (yield point)	lbf/100ft2

BINGHAM PLASTIC MODEL:

a. Pipe flow

Critical velocity is given as:

$$V_c = \frac{97xPV + 97\sqrt{PV^2 + 8.2\rho D^2 YP}}{\rho D}$$

If average velocity is more than critical velocity, flow is turbulent;use

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

If average velocity is less than critical velocity, flow is laminar; use

$$P = \frac{L \times PV \times V'}{90,000 \times D^2} + \frac{L \times YP}{225 \times D}$$

Where average velocity is given as:

$$V' = \frac{24.5Q}{D^2}$$

b. Annular flow

Critical velocity is given as:

$$V_c = \frac{97PV + 97\sqrt{PV^2 + 6.2\rho D_e{}^2 YP}}{\rho D_e}$$

where $De = D_h - OD$

If average velocity is more than critical velocity, flow is turbulent;use

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

If average velocity is less than critical velocity, flow is laminar; use

$$P = \frac{L \times PV \times V'}{60,000 \times D_e^{\;2}} + \frac{L \times YP}{225 \times D_e}$$

Where average velocity is given as

$$V' = \frac{24.5Q}{D_h^{\;2} - OD^2}$$

POWER LAW MODEL:

Determine n and K from:

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

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

where $\theta600 = 2$ PV + YP and $\theta300 =$ PV + YP

a. Pipe flow

Critical velocity is given as

Determine average velocity and critical velocity(V' and Vc)

$$V' = \frac{24.5Q}{D^2}$$

$$V_c = \left(\frac{5.82 \times 10^4 \times K}{\rho}\right)^{\left(\frac{1}{2-n}\right)} \times \left(\frac{1.6 \times (3n+1)}{D \times 4n}\right)^{\left(\frac{n}{1-n}\right)}$$

:If $V' > Vc$, flow is turbulent; use

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

If $V' < V_{c,}$ flow is laminar; use

$$P = \left(\frac{KL}{300D}\right) \times \left(\frac{1.6V' \times (3n+1)}{D \times 4n}\right)^n$$

Where average velocity is given as:

$$V' = \frac{24.5Q}{D^2}$$

b. Annular flow

Determine average velocity and critical velocity(V' and Vc):

$$V' = \frac{24.5Q}{D_h^{\ 2} - OD^2}$$

$$V_c = \left(\frac{3.878 \times 10^4 \times K}{\rho}\right)^{\left(\frac{1}{2-n}\right)} \times \left(\frac{2.4 \times (2n+1)}{D_e \times 3n}\right)^{\left(\frac{n}{1-n}\right)}$$

where $D_e = D_h - OD$

If $V' > V_c$, flow is turbulent; use

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

If$V' < Vc$, flow is laminar; use:

$$P = \left(\frac{KL}{300D_e}\right) \times \left(\frac{2.4V' \times (2n+1)}{D_e \times 3n}\right)^n$$

If average velocity is more than critical velocity, flow is turbulent;use

$$V_c = \frac{97xPV + 97\sqrt{PV^2 + 8.2\rho D^2 YP}}{\rho D}$$

If average velocity is less than critical velocity, flow is laminar; use

$$P = \left(\frac{KL}{300D_e}\right) \times \left(\frac{2.4V' \times (2n+1)}{D_e \times 3n}\right)^n$$

PRESSURE LOSS ACROSS BIT:

The main objective of the hydraulic programme is to achieve maximum hole cleaning by adjusting the pressure drop across the bit.

Pressure loss remains constant for a particular drill string length and mud properties. Size of nozzle used greatly influence the power across the bit and it also determine the amount of hydraulic power available to bit. Nozzle velocity is directly proportional to pressure drop and inversely to the size of nozzle.

In some cases, depending on rock hardness (from soft to hard) the main focus is on maximum hole cleaning not on the maximum jetting action. For this purpose we use high flow rate from bigger nozzles.

By adding the total pressure drop across the system we get the pressure drop across the bit.

PROCEDURE:

A. Determine the pressure drop across the bit using:

$$P_{bit} = P_{standpipe} - (P_1 + P_2 + P_3 + P_4 + P_5)$$

B. Determine nozzle velocity (ft/s):

$$V_n = 33.36\sqrt{\frac{P_{bit}}{\rho}}$$

C. Determine total area of nozzles (in2):

$$A = 0.32\frac{Q}{V_n}$$

D. Determine nozzle sizes in multiples of 32 seconds

9.OPTIMISATION OF BIT HYDRAULICS

Pressure drops in various portions of the circulation system are calculated in the hydraulics program. The overall pressure loss in the circulation system, excluding the bit, is estimated by adding pressure losses in surface connections, within and around the drillpipe, and inside and around drill collars. Pc is the standard abbreviation for pressure loss.

9.1SURFACE PRESSURE

The question is how much pressure drop can be sustained at the bit (P_{Bit}) once the system pressure losses, Pc, have been known. The maximum permissible surface pump pressure determines the value of P_{Bit}.

The maximum surface pressure on most of the rigs is limited, especially when high volume rates (in excess of 1000 gpm) are used. Two or three pumps are used to provide this enormous volume of flow in this situation. For well depths of around 12,000 feet, normal surface pressure limits on land rigs are in the range of 2,500 to 3000 psi. Heavy-duty pumps with high pressure ratings are employed in deep wells.

As a result, there is a limit on surface pump pressure for most drilling operations, and the criteria for optimizing bit hydraulics must take this limitation into account.

9.2 HYDRAULIC CRITERIA

For bit hydraulics optimization, there are two criteria:

(1) Maximum Bit Hydraulic Horsepower (BHHP); and
(2) Maximum Impact Force (IF).

Each criterion results in distinct bit pressure drop values and, as a result, different nozzle sizes. The engineer is tasked with determining which criterion to use. Furthermore, in most drilling operations, the flow rate for each hole segment has previously been determined in order to achieve the best annular velocity and hole cleaning. Only one variable remains to be optimized: the pressure drop across the bit, P_{Bit}. We'll go through each criterion in depth and present a short way for improving bit hydraulics.

9.3 MAXIMUM BIT HYDRAULIC HORSEPOWER

The difference between the standpipe pressure (Ps) and the system pressure losses (Pc) is the pressure loss across the bit (P_{Bit}). However, for optimal hydraulics, the bit pressure drop must be a small percentage of the total system pressure losses. The ideal hydraulics for a given volumetric flow rate is when a particular percentage of the available hydraulic horsepower is assumed by the bit hydraulic horsepower at the surface.

When surface pressure is limited, the maximum pressure drop across the bit as a function of available surface pressure yields maximum hydraulic horsepower at the bit for the best flow rate, as shown below:

$$P_{bit} = \frac{n}{(n+1)} \times P_s$$

Several n values have been offered in the literature, all of which lie between 1.8 and 1.86. As a result, with n = 1.86, the calculation above yields P_{Bit} = 0.65 Ps. In other words, the pressure drop across the bit should be 65 percent of the total available surface pressure for optimal hydraulics.

In the field, the true value of n can be determined by running the mud pump at various flow rates and monitoring the pressure results. After that, a graph of Pc(=Ps - P_{Bit}) vs. Q is drawn. The index n is used to represent the slope of this graph.

9.4 MAXIMUM IMPACT FORCE

In the situation of restricted surface pressure, it can be proven that the pressure drop across the bit (P_{Bit}) for maximum impact force is provided by:

$$P_{bit} = \frac{n}{(n+2)} \times P_s$$

where, n = slope of Pc VS Q

Ps = maximum available surface pressure.

According to the following equation, the bit impact force (IF) is a function of Q and P_{bit}.

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

where, ρ = mud weight (ppg)

9.5 NOZZLE SELECTION

When the maximum BHHP approach is utilized, smaller nozzle diameters are always obtained since the maximum BHHP method yields greater Pbit values than the maximum IF method. To calculate total flow area and nozzle diameters, apply the following equations:

$$d_n = 32\sqrt{\frac{4xTFA}{3x\pi}}$$

$$TFA = (0.0096 \times Q)\sqrt{\frac{\rho}{P_{bit}}}$$

where, TFA = total flow area (in^2)

d_n = nozzle size in multiples of 1/32 in.

9.6 OPTIMUM FLOW RATE

The maximum surface pressure, Ps, and the optimum value of Pc, n are used to calculate the optimal flow rate. Pc is calculated using the maximal BHHP criterion, for example.

$$P_c = \left(\frac{1}{n+1}\right)P_s$$

$$P_c = P_s - \left(\frac{n}{n+1}\right)P_s$$

The slope of the Pc - Q graph is equal to the value of n. The intersection of the Pc value with the Pc - Q graph yields Q_{opt}, the optimum flow rate value.

10.MUD CARRYING CAPACITY

Circulation of the drilling fluid causes cuttings to rise from the bottom of the hole to the surface for removal from the mud. Cuttings must be removed effectively in each cycle to avoid **problems** like:

1. Mud contamination
2. Slower penetration rates and decreased bit life from regrinding of solids
3. Pipe stuck up due to hole pack off/bridging in the annulus
4. Increased Non-productive time
5. Increase in annular density, and therefore, annular hydrostatic head which may result in to formation fracture and mud loss.
6. Formation of hole fills near the bottom of the borehole during trips when the mud pump is off.

Circulation rates should be sufficient enough to override the force of gravity acting upon the cuttings, for efficient cuttings removal.

The cuttings carrying capacity of mud or indirectly the hole cleaning capacity of mud depends on factors such as Hole size&profile ,fluid density, cuttings density, rheology, type of flow, annulus size, yield point, annular speed, particle shape and particle diameter. Other factors such as pipe rotation, pipe eccentricity also affect the carrying capacity of mud.

Depending on the above-mentioned parameters, the **favorable conditions for good lifting capacity** are:

1. For lifting of cuttings, annular velocity is kept about or more than twice the slip velocity.
2. In turbulent flow hole cleaning is better (Drill collar annulus flow - Turbulent; Drill pipe annulus flow- Laminar).
3. Low viscosity, low gel strength are desirable properties for effective removal.
4. High mud density helps lifting cuttings better.
5. Pipe rotation aids the removal of cutting
6. For larger holes, directional and high angle wells, discharge requirement is more

There are also some **challenges** that needs to be countered simultaneously:

1. In turbulent flow, hole erosion may take place while drilling soft formations.
2. In turbulent flow pressure losses are more
3. In case of very high annular velocity, due to ECD effect, bottom hole pressure may exceed fracture pressure of some formations leading to induced fractures and risk of lost circulation.

Thus, we need optimum annular velocity and accordingly discharge for proper hole cleaningdepending upon hole profile.

10.1SLIP VELOCITY

The slip velocity (also known as terminal velocity) is the constant rate (zero acceleration) at which a cuttingsettle in a fluid. A cutting's slip velocity is determined by following factors:

1. Density of the cutting particle
2. Size of the cutting particle
3. Shape of the cutting particle
4. Viscosity of the fluid

5. Density of the fluid
6. velocity of the drilling fluid

Slip velocity (v_s) for transitional flow:

$$V_s = 174.7 \frac{d_p \times (\rho_p - \rho_f)^{0.667}}{\rho_f^{0.333} x \mu_e^{0.333}}$$

Slip velocity (v_s) for turbulent flow:

$$V_s = 92.6 \times \frac{((\rho_p - \rho_f) \times d_p)^{0.5}}{\rho_f}$$

where, ρ_p = density of the cutting particle (ppg)

ρ_f = density of the fluid (ppg)

μ_e = effective viscosity of the fluid (cp)

d_p = equivalent diameter of cutting particles (in.)

10.2TRANSPORT VELOCITY

The transport velocity (also called lift velocity) is the net velocity at which a cutting moves up the annulus.

In a vertical well:

Transport velocity = Annular velocity – slip velocity

$v_t = v_a - v_s$

where, v_t = transport velocity

v_a = annular velocity = $24.5Q/(D_h^2 - OD_p^2)$

v_s = slip velocity

D_h = diameter of the wellbore

OD_p = outside diameter of pipe

The cutting will be delivered to the surface if the annular velocity of the drilling fluid is greater than the slip velocity of the cutting. During drilling annular velocity is kept more than twice the slip velocity for lifting of cutting to surface.

It is observed that for less than 100ft/min of annular velocities, slip velocity of the cutting particles is independent of the fluid annular velocity in both Newtonian and non-Newtonian fluids. Above an annular velocity of 100ft/min, dependence of slip velocity on annular velocity is observed.

10.3DRILL CUTTINGS CONCENTRATION

It is generally observed &accepted that, to prevent borehole problems during drilling, volume fraction (concentration) of the cuttings in the annulus should not exceed the percentage of 5. Therefore, to ensure the volume doesn't exceed the maximum limit, the equation included in the design program for drill cuttings concentration (C_a)is as follows:

$$C_a = \frac{1}{60} \times \frac{ROP x D_h^{\,2}}{(V_a - V_s) \times (D_h^{\,2} - OD_p^{\,2})}$$

where, ROP = rate of penetration (ft/hr)

D_h = diameter of the wellbore

OD_p = outside diameter of pipe

v_a = annular velocity = $24.5Q/(D_h^2 - OD_p^2)$

v_s = slip velocity

11.Hydraulic program design CASE PROBLEM

Designing Hydraulic Program by finding out suitable Nozzle size:

Well name: IIPE-1(Vertical)

Hole size: 17 ½ inch

S.G of mud: 1.2

Depth interval: 0-500 m

Drill String data:

Type	Size	Length (m)
Drill Pipe	OD-5 in; 19.5 ppf XH	392
Drill collar 1	OD-9 ½ in, ID-3 in	54
Drill collar 2	OD-8 in, ID- 3in	27
Drill collar 3	OD-6 ½ in, ID- 2 13/16 in	27

Pump available: Oilwell Triplex A-1700PT, Two nos.

Operating Pressure Limit: 180 kg/cm^2

Surface equipment: Type 3

Solution:

Case	Annular Velocity (in ft/min)	Circulation Rate (LPM)
1	80	3473
2	90	3907
3	100	4340

Case	Losses in (kg/cm^2)					
	Surface Equipment	Drill Pipe bore	Drill Pipe Annulus	Drill Collar bore	Drill collar Annulus	Cumulative Loss
1	9.105	14.37	0.0784	25.78	0.124	49.4574
2	11.337	17.97	0.0784	32.1	0.186	61.6714
3	13.784	21.79	0.0784	38.64	0.2484	74.5408

Loss In Bit Nozzles (Kg/cm2)	% BHHP	Jet Velocity (m/sec)	BHHP/sq inch	Selected Nozzle size
130.5426	72.52367	134.9202416	4.13290443	17-17-17
118.3286	65.55556	125.5664318	4.214358324	18-18-20
105.4592	58.33333	121.8147583	4.172271133	20-20-20

Pump selected		
Liner size	No of Pumps	Pump Type
7''	1	A-1700-PT
7''	1	A-1700-PT
7''	2	A-1700-PT

12.CONCLUSION

Entire Mud Hydraulics is based on the different aspects of study and calculations relating to flow of drilling fluid in drill string and annular space between drill string and open hole/cased hole. Designing an efficient drilling mud hydraulics program is essential for optimizing the drilling performance through proper hole cleaning resulting in to maximum Rate of Penetration (ROP), wellbore stability and avoiding down hole complications like stuck ups and mud loss etc.

Mud Hydraulics program mainly deals with annular velocity, slip velocity, Critical velocity, ECD, pressure losses through different sections of circulating system, hydraulic horsepower/sq inch and impact force which affects hole cleaning and ROP.

With the help of IDT's lecture on the Hydraulics and Hole Cleaning, we could attain deep understanding about all the aspects of drilling Hydraulics. Learning about the Hole cleaning concept for vertical, directional, and high angle wells; different flow regimes followed by pressure losses in all the sections of the drilling string inside and in the annulus; Criteria for Hydraulic Program and theories behind Hydraulics Optimization and various other topics definitely helped us gain a lot in the subject of Drilling and hydraulic design.

While working on this project, we designed a Hydraulics Program for drilling 17 ½" hole at 500m (open vertical hole phase from 0-500m) of an example well IIPE1, wherein the calculation of Circulation System Pressure Losses to find out the suitable nozzle size became our key learning.

A very important aspect of Mud hydraulics is cuttings removal and hole cleaning capacity. A particular annular velocity for the given hole size and well profile (vertical/directional) is the most important parameter for designing a hydraulic program. Discharge corresponding to that annular velocity considering hole size and drill pipe diameter is selected for calculating pressure losses in the well. Other important factors are number, discharge capacity and pressure rating of mud pumps, pressure rating of surface equipment, mud rheology and rotation of drill pipe. Flow regimes, slip velocity of cuttings and hole angle are also important factors in transport of cuttings to the surface and provide a good hole cleaning capacity.

All this summed up this project report and has been a great learning experience of .technical knowledge and work experience in drilling operations leading to design of an efficient hydraulic program.

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