MAJOR PROJECT REPORT

on

RHEOLOGICAL STUDY OF FLUID FLOW MODEL THROUGH CFD ANALYSIS AND IT'S IMPLICATIONS IN MUD HYDRAULICS

UNDER THE MENTORSHIP OF

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April 2015

CERTIFICATE

This is to certify that this project report titled **"RHEOLOGICAL STUDY OF FLUID FLOW MODEL THROUGH CFD ANALYSIS AND IT'S IMPLICATIONS IN MUD HYDRAULICS"** submitted to **University of Petroleum and Energy Studies, Dehradun** is a bonafide record of work done by **MR. Bhaskar Chakraborty** under my supervision from **"September 2014"** to **"April 2015**" in partial fulfilment of the requirements for the degree of Bachelor of Technology in Applied Petroleum Engineering with specialization in Upstream.

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Finally I want to thank my parents, teachers and friends who have been always there with me throughout as a source of inspiration and did not let me lose focus from my goal.

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CANDIDATE'S DECLARATION

I/We hereby certify that the project work entitled **"RHEOLOGICAL STUDY OF FLUID FLOW MODEL THROUGH COMPUTATIONAL FLOW DYNAMICS ANALYSIS AND IT'S IMPLICATIONS IN MUD HYDRAULICS"** in partial fulfilment of the requirements for the award of the Degree of BACHELOR OF TECHNOLOGY in APPLIED PETROLEUM ENGINEERING with specialization in UPSTREAM and submitted to the Department of Department of Petroleum Engineering and Earth Sciences, College of Engineering(COES), University of Petroleum & Energy Studies, Dehradun, is an authentic record of my/ our work carried out during a period from **September**, **2015** to **April, 2015** under the supervision of **Dr. Pushpa Sharma.**

The matter presented in this project has not been submitted by me/ us for the award of any other degree of this or any other University.

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This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

Date: 29-04-2015 **(Dr. Pushpa Sharma)**

Abstract

Oil and Gas drilling is not a simple fundamental procedure, never the less it accounts a lot of subsurface uncertainties to deal with. The primary objective of an efficient and optimized drilling program is to analyse the formation uncertainties and chose a systematic and logical approach to pursue drilling operations to overcome any problem encountered. Wellbore stability is the most important and cardinal part of drilling as mentioned:

a. Maintaining wellbore stability limits the Non Productive Time (NPT) for a well

b. Analysing the GTO to select a logical and effective approach for drilling saves time and allows remedial measures to get prepared for instability if encountered

Well bore stability is the prevention of brittle failure or plastic deformation of the rock surrounding the wellbore due to mechanical stress or chemical imbalance. After drilling, the rock surrounding the wellbore undergoes changes in tension, compression and shear loads as the rock forming the core of the hole is removed. Chemical reactions also occur with exposure with drilling fluids. Excessive rock stress can collapse the borehole resulting in stuck pipe. Cavings from falling formation makes hole cleaning more difficult and increases the mud and cementing cost.

The project deals in accord with developing an understanding of the problems associated with wellbore instabilities and focuses on designing of proper drilling fluids formulations to counter these problems. The major experiments conducted are for analysis of formulating mud ,namely:

a. KCL-Polymer mud system

b. Salt saturated mud system

Designing of drilling fluid is done for Water Based Mud Systems only using additives in different proportions to maximize control and ensure cost effectiveness of the mud.

Apart from the above oil well cleaning has been approached by the Navier stoke's equation, power model, continuity equation to develop a mathematical model to help us understand the lifting of the cuttings as a function of fluid viscosity, density, fluid velocity. This in turn helps us to generate the flow regimes near the wellbore around the tubing while transporting the cuttings.The phase of CFD analyses has been initiated with the motto of understanding the flow models and verifying the graphs generated from the simulation on the conventional softwares.

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MODULE 1

BASIC MUD

Drill Mud: Any of a number of liquid and gaseous fluids and mixtures of fluids and solids (as solid suspensions, mixtures and emulsions of liquids, gases and solids) used in operations to drill boreholes into the earth.

Major functions of drilling fluids are:

1. **Remove Cuttings from the Well**

Cuttings removal, termed as hole cleaning is a function of cutting's shape, size and density together combined with Rate of Penetration, drillstring rotation and the viscosity, density and annular velocity of the drilling fluid.

a. **Viscosity:**
    - Cuttings settle rapidly in low viscosity fluids (e.g. Water) and are difficult to circulate out of well. Increased viscosity of drilling fluids improves cuttings transport.
    - Muds are mostly thixotropic, i.e. they gel under static condition.
    - Fluids that are shear thinning and have elevated viscosities at low annular velocities are best for efficient hole cleaning

b. **Velocity:**
    - Higher annular velocity improves cuttings removal
    - With thinner drilling fluid, high velocities may cause turbulent flow, which helps clean the hole but may cause drilling or wellbore problems.
    - The rate at which cuttings settle in a fluid is called the slip velocity.
    - Slip velocity: Function of cutting's density, shape and size and drilling mud's viscosity, density and velocity.
    - Cuttings are transported to the surface if Annular Velocity > Slip Velocity
    - The net velocity at which the cuttings move to the surface is called transport velocity.
    - In a vertical Well,
      Transport velocity = Annular Velocity – Slip Velocity
    - The transport velocity as defined for vertical wells is not relevant for the deviated or horizontal wells, since cuttings settle down to the low side of the hole across the fluids flow path.
    - Cuttings beds are formed at the bottom side of the wellbore, restricts flow, increase torque and are difficult to remove.

        a. **Density:**
        - Increased density fluids aid hole cleaning by increasing the buoyancy forces acting on the cuttings.
        - High density fluids can clean the whole adequately at even lower annular velocities and lower rheological properties.
        - Mud weight in excess of what is needed to balance the pressure has a negative impact on the drilling operation, therefore it should never be increased for hole cleaning.

b. **Drillstring Rotation :**

- High rotary speeds also aid to hole cleaning by providing circular component to annular flow path, this helical flow around the drillstring causes drill cuttings near the wall of the hole where poor hole cleaning conditions exist to be moved back into the higher transport regions of the annulus.

2. **Controlling Formation Pressure:**

- Typically as formation pressure increases, drilling fluid density is increased with barite to balance pressures and maintain wellbore stability. This keeps formation fluids from flowing into the wellbore and prevents pressured formation fluids from causing blowout.
- In static conditions, pressure exerted by the drilling fluid column is equal to the hydrostatic pressure and is a function of mud density and TVD.
- Hydrostatic pressure also controls stress regimes in formations other than those exerted by formation fluids.

  e.g. in case of geologically active regions, tectonic forces impose stress and make wellbore instable. Also orientation of the wellbore in high angle and horizontal wells can cause decreased wellbore stability and can be controlled with hydrostatic pressure.

  Mud Window Limitation: the mud weight is needed to control the formation pressure and the maximum mud weight that will not fracture the formation.

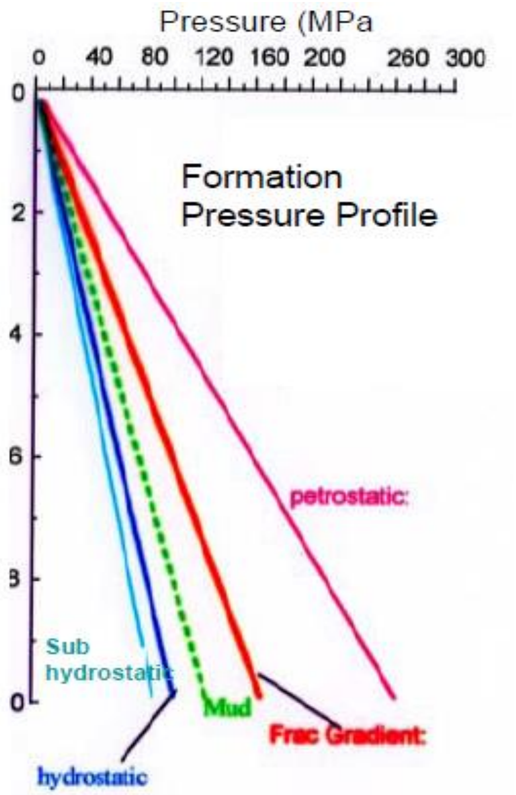


Fig1.1: Formation Pressure Profile

3. **Suspend & Release Cuttings**
   - Drill cuttings that settle during static conditions can cause bridges and fill, which can cause stuck pipe or lost circulation.
   - Weight material which settles is called as sag and causes a wide variation in the density of the drilling fluid.
   - Sag occurs most often under dynamic condition in high angle wells, at low annular velocities.
   - Drilling fluid properties that suspend cuttings must be balanced with those that aid in cuttings removal by solids- control equipment.
   - Cuttings suspension requires :
     - High viscosity
     - Shear thinning thixotropic properties
   - One easy way to determine whether drill solids are being removed is to compare the sand content of the mud at the flow line and at the suction pit.

4. **Seal Permeable Formations**
   - When mud column pressure is more than formation pressure mud will invade in the formation and a mud filter cake of mud solids will be deposited on the wall of the wellbore.
   - Drilling fluid systems should be designed to deposit a thin, low permeable filter cake on the formation to limit the invasion of mud filtrate.
   - Problems related to thick mud filter cakes and excessive filtration includes;

a. Tight hole conditions
b. Poor log quality
c. High torque and drag
d. Stuck pipe
e. Lost circulation
f. Formation damage

- In case of high permeable formation with large pore throats, whole mud may invade in the formation depending on the size of the mud solids. For such situation bridging agents must be used to block large openings so that mud solids form a seal.
- Bridging agent includes calcium carbonate, ground cellulose, seepage loss and fine LCM
- Additives can be applied to improve filter cake, like bentonite, natural and synthetic polymers, organic deflocculating additives, asphalt, gilsonite etc.

5. Maintain Wellbore Stability

- Complex balance of mechanical (Pressure and Stress) and chemical factors.
- Chemical composition and mud properties must combine to provide a stable well bore until casing can be run and cemented.
- The weight of the mud must be within necessary range to balance the mechanical forces acting on the wellbore, i.e. formation pressure and wellbore stress related to orientation and tectonics.
- Wellbore instability is greatest when hole maintain its original shape and size, once its enlarged or eroded it becomes weaker and more difficult to stabilize leading to;
  a. Low annular velocity
  b. Poor hole cleaning
  c. Increased solids loading
  d. Fill
  e. High treating cost
  f. Poor formation evaluation
- Hole enlargement through sand and sandstone formation is due largely to mechanical actions;
  a. Erosion caused by hydraulic forces
  b. Excessive bit nozzle velocities
- More conservative hydraulic program, particularly with regard to impact force and nozzle velocities must be carried.
- Poor consolidated sands require overbalance to limit the wellbore enlargement and a good quality filter cake containing bentonite .
- In shales, with WBM, chemical differences cause interactions between the drilling fluid and shale that leads to swelling or softening.
- Highly fractured, dry and brittle shales with high dip can be extremely unstable when drilled. (failure mainly due to mechanical instability)

- Chemical inhibitors are added to help control mud/shale interactions.
- System with high calcium, potassium and other chemical inhibitors are best for drilling in water sensitive formations.
- Salts, polymers, glycols, oils, asphaltic materials, surfactants are used in WBM to inhibit shale swelling.
- OBM or SOBM are used to drill the most water sensitive shale areas with difficult drilling conditions.
- Emulsified brine reduces water activity and creates osmotic forces that prevent adsorption of water by shales.

6. Minimize Formation Damage

(Any reduction in a producing formation's natural porosity and permeability)

- Can happen as a result of plugging of mud or drill solids or through chemical (mud) and mechanical (drilling assembly) interaction with the formation.
- Reported as skin damage value or by amount of pressure drop that occurs while the well is producing.
- Example:
  a. When a hole is cased, cemented and perforated, perforation depth allows efficient production, even if near wellbore damage exists.
  b. When horizontal well is completed with one of the open hole techniques, a 'reservoir drill- in' fluid specially designed to minimize damage is required.
- Most common mechanism for formation damage are:
  a. Mud or drill solids invading formation matrix and plugging pores.
  b. Precipitation of mud filtrate and formation fluids being incompatible.
  c. Precipitation of solids from the mud filtrates with other fluids, such as brines or acids during completion or stimulation procedures.
  d. Swelling of formation clays within the reservoir, reducing permeability.
  e. Mud filtrate and formation fluid forming and emulsion restricting permeability.

7. Cool, Lubricate and Support the Bit and Drilling Assembly

- Circulation of drilling fluids cools the bit and drilling assembly, transferring the heat away from the source, distributing it throughout the well
- Drilling fluids cools the drillstring to temperature lower than bottom hole temperature.
- Drilling fluids lubricates the drillstring further reducing frictional heat.
- The lubricity of any fluid is a measure of its coefficient of friction (COF)
- OBM and SOBM lubricate better than WBM, but lubricants can also be added to WBM
- Amount of lubrication provided depends on ;
  a. Types and quantity of drill solids
  b. Weight material

c. Chemical composition; pH, salinity and hardness

- Drilling fluids help to support portion of the drillstring or casing string weight through buoyancy.
- If a drillstring , liner or casing string is suspended in the drilling fluid, it is buoyed by a force equivalent to the weight of the mud displaced, thereby displacing hook load on the derrick.

8. Transmit Hydraulics Energy to Tools and Bit

- Hydraulic energy can be used to maximize ROP by improving cuttings removal at the bit.
- Also provides power for mud motors to rotate the bit and for LWD and MWD tools
- Hydraulics program are based on ;

  Sizing the bit nozzles property to use available mud pump horse power to generate maximized pressure drop at the bit or optimize jet impact force on the bottom of the well.
- Drill string pressure losses are higher in the fluids with high density, plastic viscosity and solids.
- Use of small ID drill pipe or tool joints, mud motors and MWD/LWD tools all reduce the amount of pressure available for use at the bit.
- Low solids, shear thinning DF or those that have drag reducing characteristics, such as polymer fluids, are most efficient at transmitting hydraulic energy to drilling bit and tools.

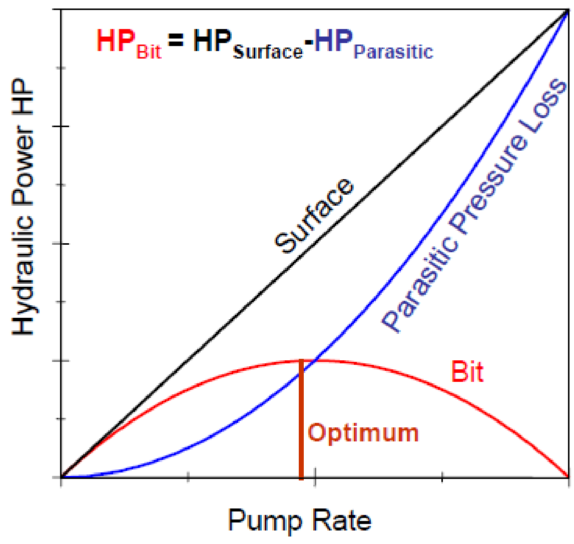


Fig1.2: Bit hydraulics curve

9. Ensure Adequate Formation Evaluation

- Chemical and physical properties of mud affect formation evaluation.
- During drilling the circulation of mud and cuttings is monitored for signs of O&G by technicians called mud loggers.

- They examine cuttings for mineral composition, paleontology and visual signs of HC.
- Potentially productive zones are isolated and evaluated by performing Formation Testing (FT) or Drill Stem Testing (DST) to obtain pressure and fluid samples.
- Importance of mud in Formation Evaluation:
    a. If cuttings disperse in mud there will be nothing for the mud logger to evaluate at the surface.
    b. If cuttings transport is poor it will be difficult for the mud logger to determine the depth at which cuttings originated.
    c. Certain electric logs works in conductive fluids while others in non conductive. DF properties affect the measurement of rock properties by electrical wireline tools.
    d. Excessive mud filtrate can flush O&G samples from near the wellbore region, adversely affecting logs, FT and DST samples.
    e. Mud containing high potassium interfere logging of natural formations radioactivity.
    f. For optimum wireline logging mud must not be too thick.

10. Control Corrosion

- Dissolved gases like oxygen, carbon dioxide, hydrogen sulfide can cause corrosion problems.
- Low pH aggravates corrosion

11. Facilitate Cementing and Completion

- During casing run, the mud must remain fluid and minimize pressure surges so that fracture induced lost circulation do not occur.
- No cavings, cuttings and bridging.
- Thin, slick filter cake
- Effective mud displacement requires;
    a. hole to be near gauge
    b. low viscosity mud
    c. non- progressive gel strength

1.1 CLASSIFICATION OF DRILLING FLUIDS

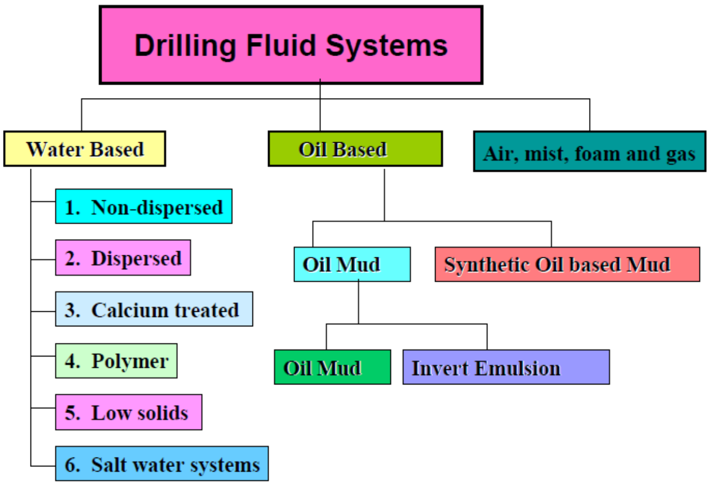


Fig1.3: Classification of DF System

Water Base Fluids (WBM)

Polymer Fluids:

- Muds incorporating long chain, high molecular weight polymers are utilized to either encapsulate drill solids to prevent dispersion and coat shales for inhibition.
- Various types of polymers are available,
  a. Acrylamide
  b. Cellulose
  c. Natural gum based products
- Frequently inhibiting salts such as KCl or NaCl used for greater stability
- Minimum amount of bentonite
- Temp. limits < 150deg. C

Low Solid Fluids:

- Amount (volume) and type of solids are controlled
- Total solids should not range higher than about 6% to 10% by volume.
- Polymer additive used as viscosifier or bentonite extender
- Improves ROP

Oil Base Fluids

- Used for applications where fluid stability and inhibition are necessary such as;
  a. High temperature Wells
  b. Deep holes
  c. Slicking and hole stabilizing problems

- **OBM**: formulated with oil as continuous phase and often used as coring fluids
- No additional water or brine is added
- Special OBM additives includes;
  a. Emulsifiers and wetting agents (fatty acids and amine derivatives)
  b. High molecular wt. soaps
  c. Surfactants
  d. Amine treated OM
  e. Organic clays
- **Inver Emulsion Muds**: water in oil emulsions typically with calcium chloride brine as the emulsified phase and oil as continuous phase

Synthetic Oil Based Muds (SOBM)

- Designed to mirror OBM performance without environmental hazards
- Primarily esters, ethers, poly alpha olefins, isomerised alpha olefins
- Environmental friendly, canbe discharged offshore , non sheening and biodegradable

AIR, MIST, FOAM, GAS SYSTEM

(Reduced DF weight category)

- **Dry Air Drilling:** injecting dry air or gas into wellbore at rates capable of achieving annular velocities that will remove cutting
- **Mist Drilling:** injecting foaming agent into the air stream which mixes with produced water and coats the cutting which prevents mud rings allowing drill solids to be removed
- **Foam:** uses surfactants and possibly clays or polymers to form a high carrying capacity foam
- **Aerated Fluids:** mud with injected air (reduces hydrostatic head) to remove drilled solids from wellbore.

MONITORING OF DRILLING FLUIDS

1. **Specific Gravity**: using mud balance
2. **Viscosity**: Plastic Viscosity (PV) – frictional resistance in fluid in motion
   Yield Point (YP)- electrical resistance in the fluid motion
   Measured by marsh funnel and Fann VG meter)

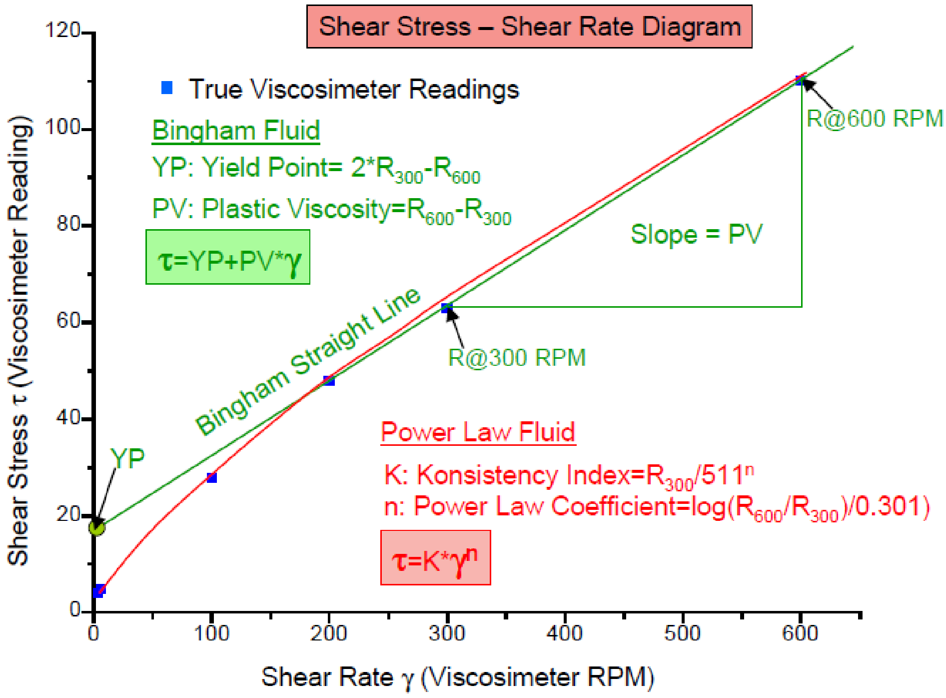


Fig1.4: Shear Stress Vs Shear Rate Curve

3. **Sand Content:**
   a. Abrasive and harmful to equipments
   b. High sand content contributes to undesired thick filter cake; raise unwanted sp. Gravity, lost circulation, formation invasion etc.

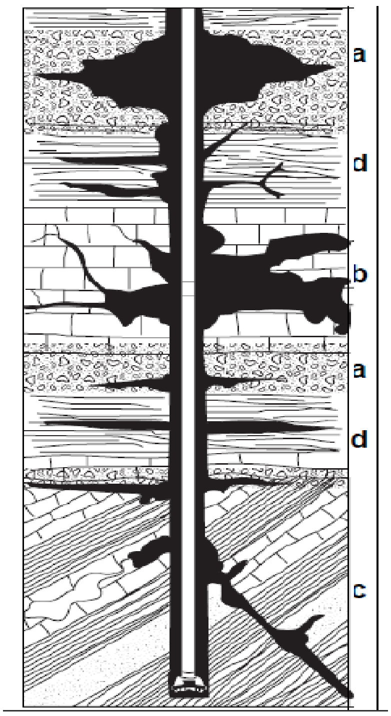


Fig1.5: Lost Circulation

4. **Filter Cake**
5. **Solid Contents** : Removal equipments;
   a. Shale Shaker
   b. D-Sander
   c. D-Silter
   d. Mud Cleaners
   e. Centrifuge

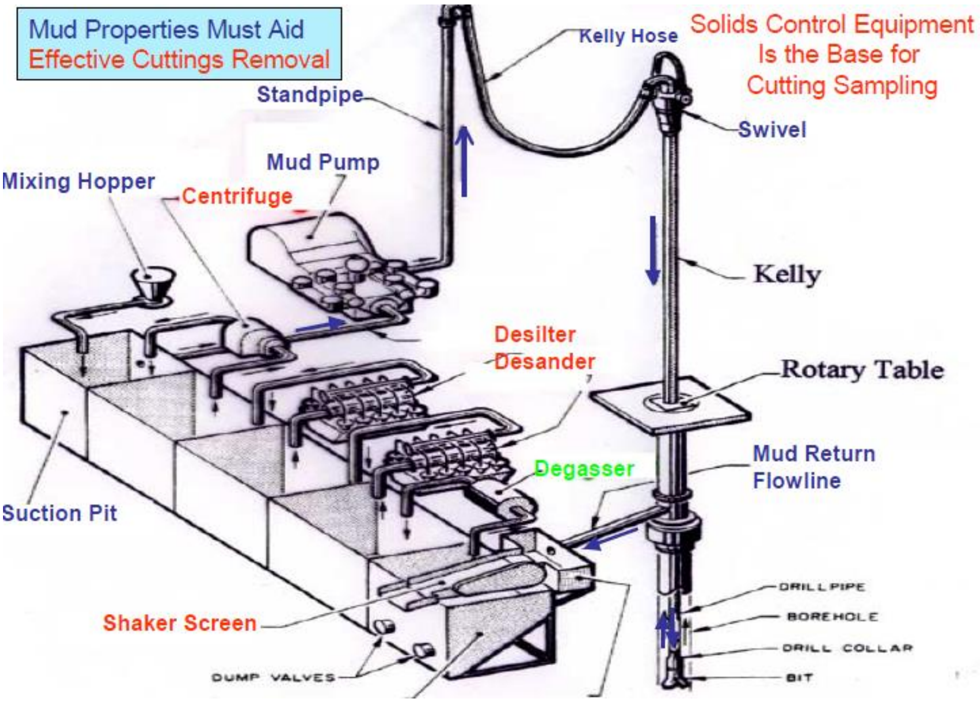


Fig1.6: Solid Control

6. **Salinity** (Potassium Ion/ PHPA Estimation)
   - Precipitate method – filtrate
   - Salinity- Potassium chromate and silver nitrate
   - Potassium Ion- sodium perchlorate

MODULE 2

RHEOLOGY

RHEOLOGY:

- It is the study of how matter deforms and flows
- It is possible to determine how a fluid will flow under conditions, including ;
  a. Temperature
  b. Pressure
  c. Shear Rate
- Viscosity: Substance resistance to flow

  Viscosity= Shear Stress/ Shear Rate
  - Dependent on the average velocity of the fluid in the geometries it is flowing. Shear rate is more in small geometries (inside drill string) and lower in larger geometries (casing and riser annuli)
  - Higher shear rate causes a greater resistive force of shear stress
  - Relation between shear stress and shear rate describes how a fluid flows
  - **Shear Rate = V2-V1/d**

    Where; V2= Velocity of layer B

    V1= Velocity of layer A

    D= distance between the layers

CONVERSION FACTOR:

Shear Rate = RPM * 1.703

  - **Shear Stress**: Force required to sustain shear rate

CONVERSION FACTOR:

Shear Stress = VG Reading * 1.0678

It is stated in types;

1. **Funnel Viscosity :**
   a. Measured using a Marsh Funnel
   b. Used to detect the relative changes in the fluid's properties
2. **Apparent Viscosity**
   a. Mud viscometer reading at 300 RPM or half of meter reading at 600 RPM
   b. AV = 300*ϴ/ω
3. **Effective Viscosity**
   a. It is the fluid's viscosity under specific conditions that includes shear rate, pressure and temperature.

4. **Plastic Viscosity**
    a. PV= ϴ600-ϴ300
    b. Part of resistance to flow caused by mechanical friction
    c. Affected by ; solids concentration, size and shape of solids, viscosity of fluid phase, presence of long chain polymers
    d. Changes in PV can cause change in the pump pressure
    e. Lower PV should be kept because;
        1. Greater energy at the bit
        2. Greater flow in the annulus for hole cleaning
        3. Less wear and tear on equipment
5. **Yield Point**
    a. YP= ϴ300- PV
    b. Measurement of electro-chemical or attractive forces, result of opposite charges in the fluids
    c. Dependent upon;
        1. Surface properties of the fluid solids
        2. Volume concentration of the solids
        3. Electrical environment of these solids (ions)
6. **Low Shear Rate Viscosity (LSRV)**

7. **Gel Strength**
    a. Gel strength readings taken at 10-sec and 10-min intervals, and in critical situations at 30-min intervals, on the Fann VG meter provide a measure of the degree of thixotropy present in the fluid.
    b. The strength of the gel formed is a function of the amount and type of solids in suspension, time, temperature and chemical treatment.
    c. Excessive gel strengths can cause complications, such as the following:

        1. Entrapment of air or gas in the fluid.
        2. Excessive pressures when breaking circulation after a trip.
        3. Reduction in the efficiency of solids-removal equipment.
        4. Excessive swabbing while tripping out of the hole.
        5. Excessive pressure surges while tripping in the hole.
        6. Inability to get logging tools to the bottom.

    d. The initial gel strength measures the static attractive forces, while the yield point measures the dynamic attractive forces.

Rheology has a significant influence in controlling the following cardinal factors:

1. **Hole Cleaning** : Controlled by rheological parameters like;
    - Density of mud
    - Viscosity of mud
2. **Suspension of Solids** : Controlled by parameters like;
    - Slip Velocity
    - Annular Velocity (AV increases with decrease in hole size)
    - Viscosity (Buoyancy of mud is affected)
3. **Wellbore Stability**: Achieved by following parameters;
    - Hydrostatic head
    - Hole Cleaning
    - Proper inhibition to shale
    - Rock Matrix Analysis
    - Shale Analysis (XRD,XRF)
    - Shale Reactivity (Capillary Suction Timer (CST))
      Less CST, less will be the reactivity and vice-versa
    - Fluid Filtration: Lesser the fluid loss, better the quality of filter cake which increases well bore stability
4. **Equivalent Circulation Density (ECD)**
    - Equivalent circulating density is the effective density of the circulating fluid in the wellbore resulting from the sum of the hydrostatic pressure imposed by the static fluid column and the friction pressure.
    - It is calculated as;
      ECD= MW+ Pa/ (0.052*D) in lb/gal
    - ECD should not go beyond LOT value
    - In offshore operations maintaining ECD is very crucial because a slight increase in ECD value can cause loss of ~1000gal of mud.

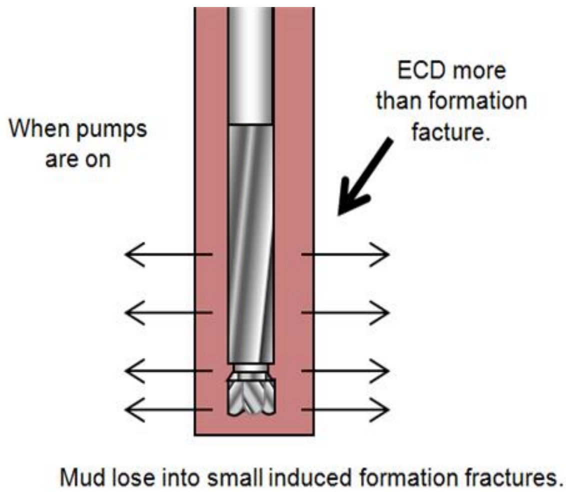


Fig2.0: Impact of increased ECD

5. **Swab and Surge Pressure** : Rheological parameters affecting Swabbing and Surging are;
    - Gel Value : If gel becomes progressive then swabbing and surging occurs and leads to increase in ECD
    - Increase in temperature causes increase in gels values.

FLUID FLOW MODELS:

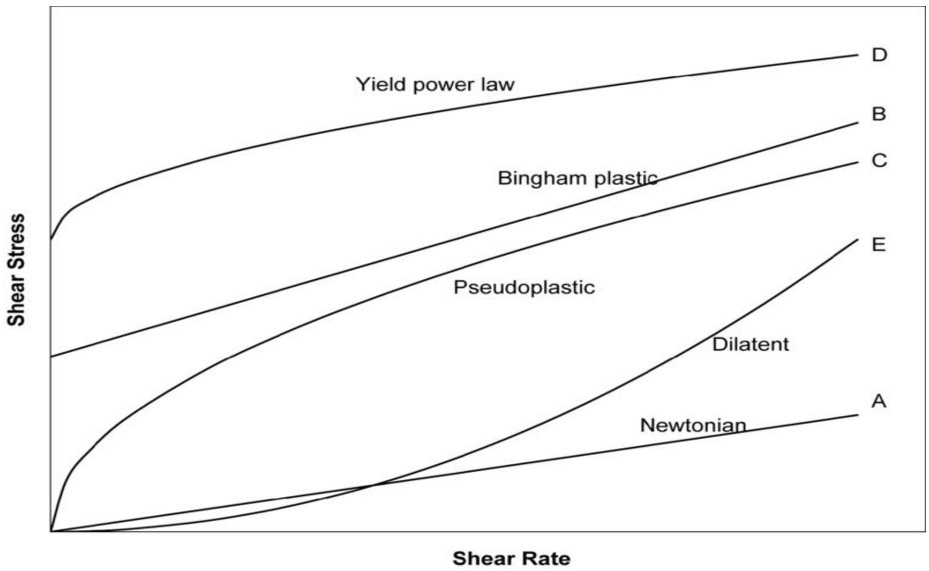


Fig2.1: Fluid Flow Models

- **Bingham Plastic Model**
- **Power Law Model**
- **Herschel- Buckley Model (Modified Power Law)**
- **Casson Robertson –Shift Model**

A. BINGHAM PLASTIC MODEL

These fluids require a finite shear stress, τ_y; below that, they will not flow. Above this finite shear stress, referred to as yield point, the shear rate is linear with shear stress, just like a Newtonian fluid. Bingham fluids behave like a solid until the applied pressure is high enough to break the sheer stress.

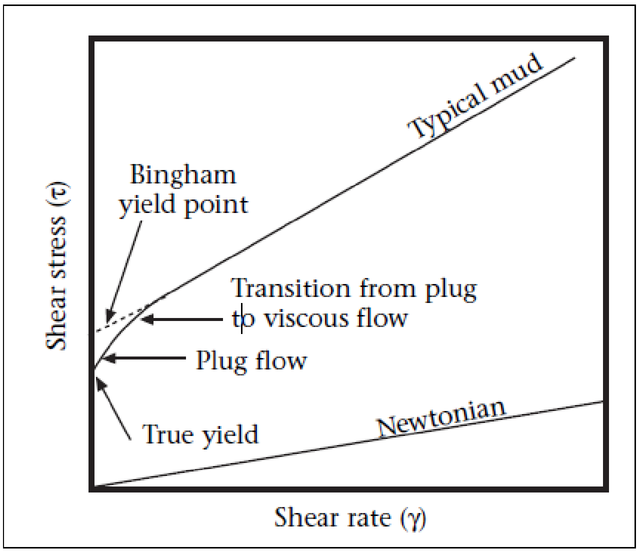


Fig2.2: Illustration of Bingham Plastic Model

Mathematical Expression:

- **F= YP+PV(R/300)**
  Where;
  F= dial radius at speed R
- **PV = R_{600} – R_{300}**
- Mud additives count to Plastic Viscosity especially wetting agents.
- Lesser the size, more will be surface area, more will be the friction
- Increase in PV, leads to increase in Mud weight, causing differential sticking
- Sand control equipments , like centrifuge cuts around half the value of PV
- Factors affecting Yield Point (YP);
  a. Type of formation (carbonates, formation salts)
  b. Reactions of clay (clay carry residual charges that affects YP)

c. Overtreatment of mud chemicals
d. Contaminants like acid gases such as H_2S, CO_2 etc.

- Yield Point can be treated by addition of chemicals; more clay leads to more YP
  a. Dilution Method
  b. Addition of dispersants or thinners
- YP increases, Gel value increases

B. POWER LAW MODEL

These fluids exhibit a linear relationship between shear stress and shear rate when plotted on a log-log paper.

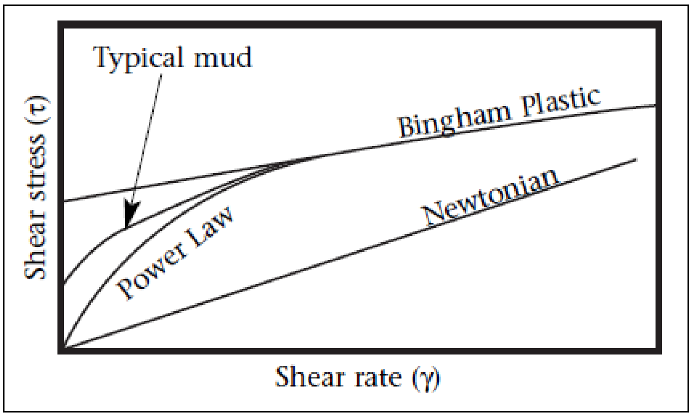


Fig2.3: Illustration of Power Law Model

Mathematical Expression:

Shear Rate = K (Shear Stress) ^{n}

Where; K= Consistency Factor

n= Fluid Flow Index

Depending on the value of "n," three different types of flow profiles and fluid behavior exist: 1. n < 1: The fluid is shear-thinning, non-Newtonian.

2. n = 1: The fluid is Newtonian.

3. n > 1: The fluid is dilatants, shear thickening (drilling fluids are not in this category).

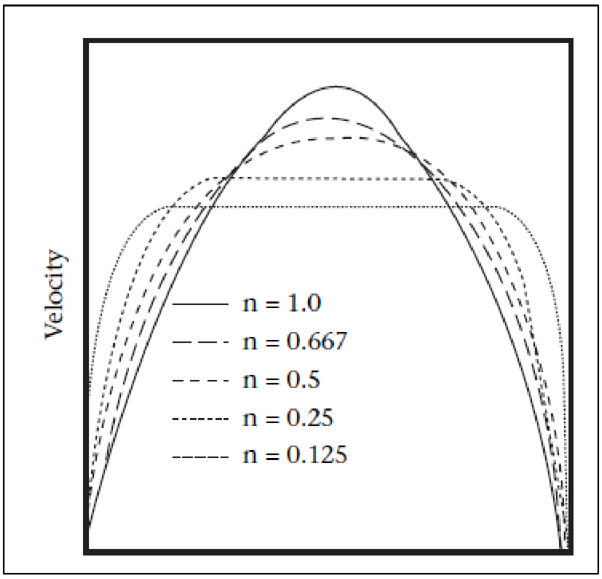


Fig2.4: Velocity Profile depending on “n” value

A fluid’s hole-cleaning and suspension effectiveness can be improved by increasing the “K” value.

$V_{G\ (Reading)}$ * 1.0678= K ($V_{G\ (RPM)}$*1.703)^{n}

n= shear thinning ability of mud (thixotropic property of fluid)

- n_a (annulus) / n_p (pipe)
- $n_p = 3.321 \log Ø_{600} / \log Ø_{300}$
- $n_a = 0.657 * \log Ø_{100} / Ø_6$
- more the value of n, more will be shear thinning, more will be k
- $K_p = 5.11 * R_{600}/1022^{np}$
- $K_a = 5.11 * R_3 / 511^{na}$
- n<1 (always)

C. MODIFIED POWER LAW

Also known as Herschel-Buckley fluids, these fluids require a finite shear stress, τ_y, below which they will not flow. Above this finite shear stress, referred to as yield point, the shear rate is related to the shear stress through a power-law type relationship.

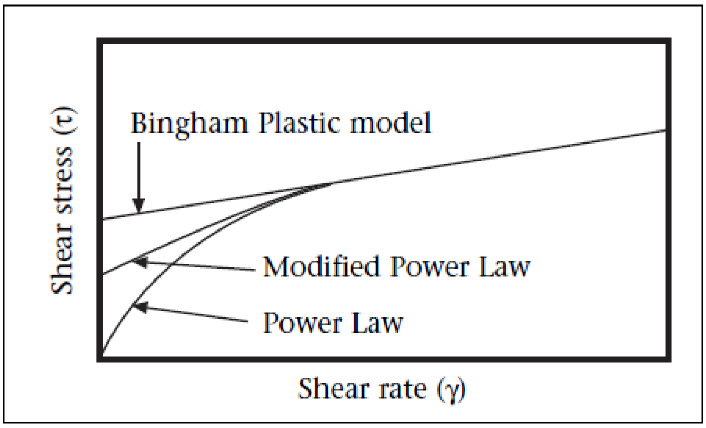


Fig2.5: Illustration of Modified Power law

Mathematical Expression:

Shear Rate = Yield Stress + K (Shear Stress) ^{n}

Where Yield Stress is the R3 Reading

- The yield stress has been accepted to be the value for the 3-RPM reading or initial gel on the VG meter.
- Converting the equations to accept VG meter data gives the equations for "n" and "K."

$$n = \log(\Theta_2 - \Theta_0) - \log(\Theta_1 - \Theta_0) / \log \omega_2 - \log \omega_1$$

$$k = \Theta_1 - \Theta_0 / \omega_1^{n}$$

Where:

n = Power Law index or exponent
K = Power Law consistency index or fluid index (dyne sec–n/cm2)
Q1 = Mud viscometer reading at lower shear rate
Q2 = Mud viscometer reading at higher shear rate
Q0 = Zero gel or 3-RPM reading
w1 = Mud viscometer (RPM) at lower shear rate
w2 = Mud viscometer

MODULE 3

WELL COMPLICATIONS

LOST CIRCULATION:

The losses of mud to the subsurface formation are called lost circulation. It is one of the primary reasons for high mud cost in most of the cases. The other problems like wellbore instability, stuck pipe, inadequate hole cleaning, improper filtration control are some of the factors that can induce lost circulation.

Lost circulation can be broadly classified in to two major categories:

- **Natural:** these occur when formations have very large pores or contain natural fractures or voids.
- **Induced:** these occur when a fracture created in the well due to hydraulic forces in the wellbore exceeding the formation strength.

Natural losses:

1. high matrix permeability formations such as gravels coarse sands
2. Cavernous or vuggy formations.
3. Formations with natural conductive fractures or fault.

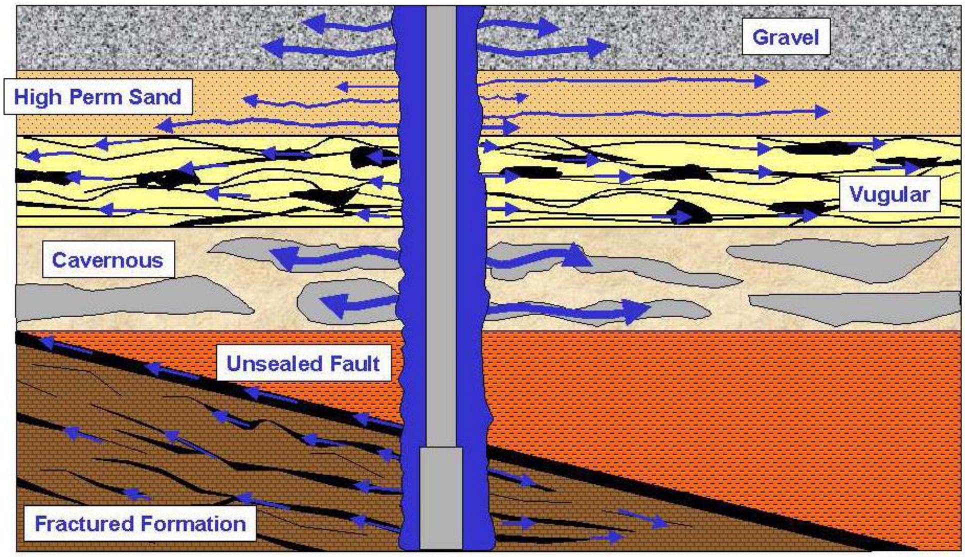


Fig3.0: Natural Lost Circulation

Induced losses:

1. high mud weight and hence high ECD
2. Tripping in tight hole resulting in swabbing and surging.
3. Very tight filtration rate.
4. Inadequate hole cleaning results in reduction in annular clearance.
5. Wellbore instability.
6. High ROP during drilling.
7. High flow rate.

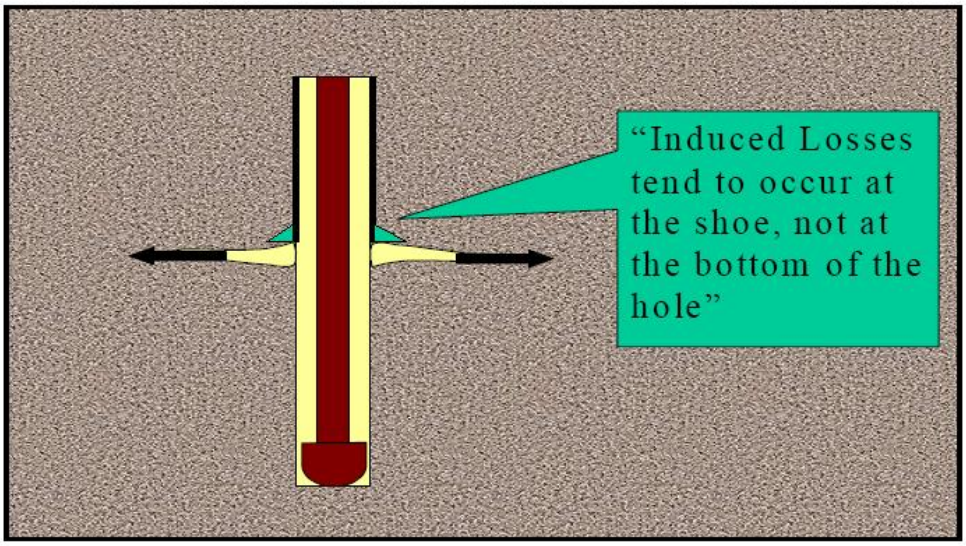


Fig3.1: Induced Lost Circulation

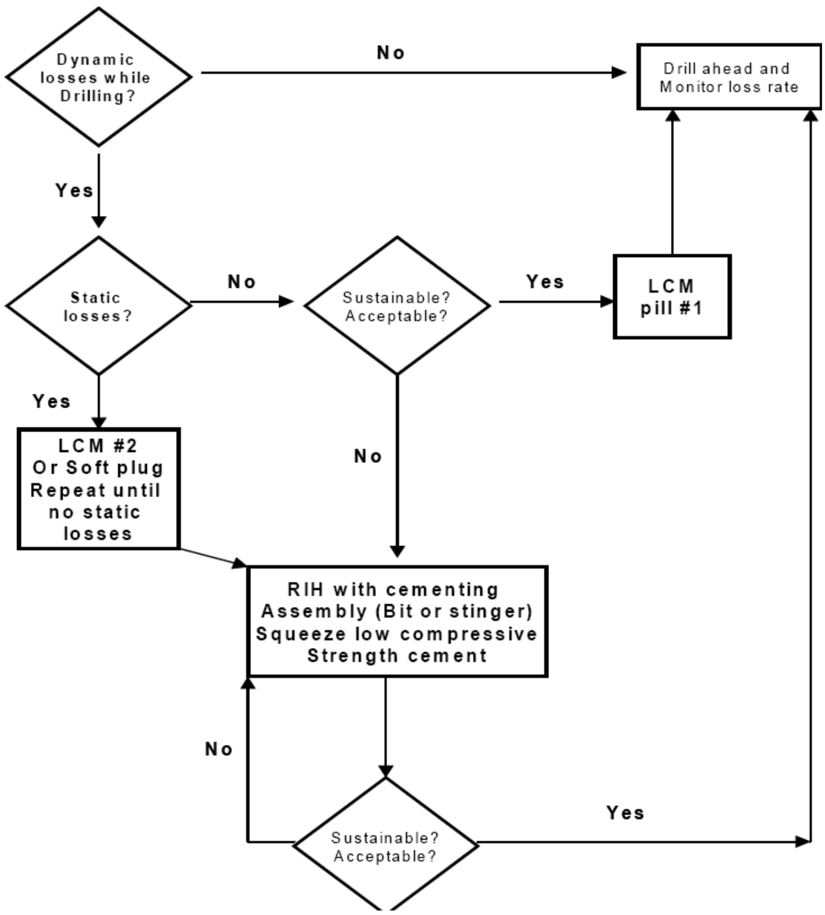


Fig3.2: Lost Circulation Identification and Prevention Workflow

Loss rate definition:

Loss Severity	Loss Rate (bbl/hr)	Loss Rate (m^3/hr)
Seepage	<10	<1.6
Partial	10 - 30	1.6 – 4.8
Severe	30 – 100	4.8 – 16
Total	>100	>16

Fig3.3: Loss Rate Definition

Graphical representation of loss rate definition:

Pit Level Indicators:

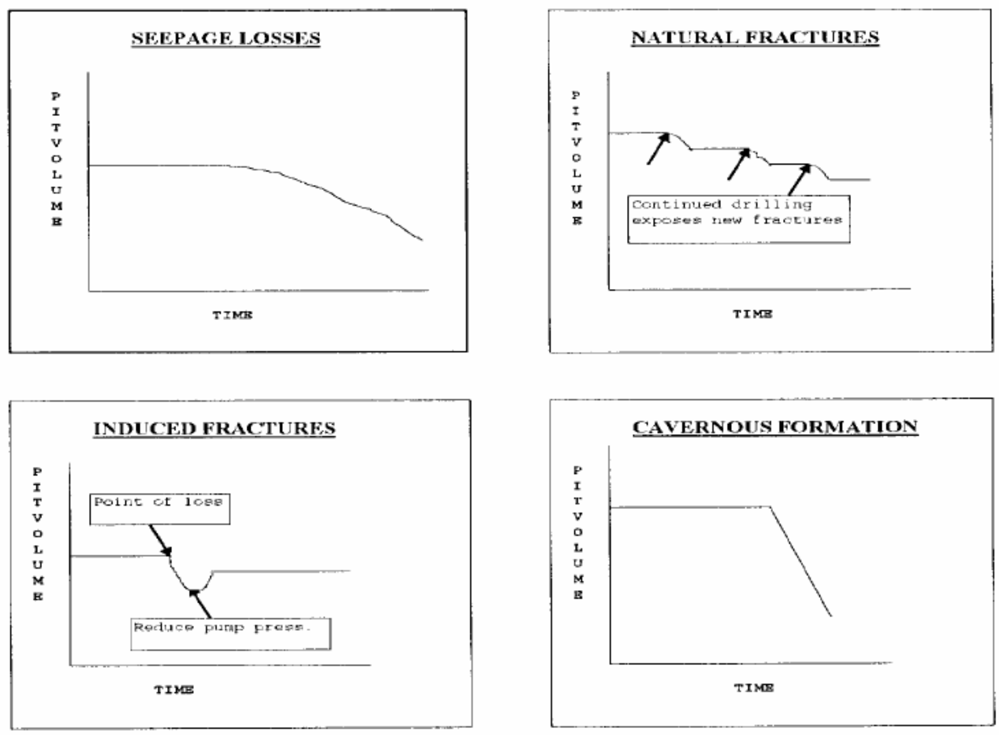


Fig3.4: Pit Level Indicators for Lost Circulation

Preventive Products:

Types of products	***Name of products***
Fibrous	**MIX-II, MI ceder fiber, sawdust, drilling paper and magma fiber.**
Granular	**Nut plug (C / M / F), calcium carbonate (C/M/F), G-Seal (coarse graphite)**
Blends	**Kwick Seal (C/M/F), MI Seal**
Flakes	**Flakes (cellophane), Mica(C/M/F), phenoseal.**

LCM PILL CONCENTRATION:

1. ***For seepage losses (<10bbls/hr)***

   Calcium carbonate (fine) = 15ppb.

Calcium carbonate (medium) = 10ppb.

Kwick seal (medium) = 10ppb

Kwick seal (fine) = 10ppb.

2. ***For partial losses (10-30 bbls/hr):***

   Calcium carbonate (coarse) = 10ppb.

   Calcium carbonate (medium) = 10ppb.

   Calcium carbonate (fine) = 20ppb.

   Kwick seal (medium) = 10ppb.

3. ***For severe losses (30-100 bbls/hr):***

   Calcium carbonate (coarse) = 35ppb.

   Calcium carbonate (medium) = 20ppb.

   Kwick seal (medium) = 15ppb

   Kwick seal (coarse) = 15ppb.

STUCK PIPE

- Drilling a well requires a drill string (pipe & collars) to transmit the torque provided at the surface to rotate the bit, and to transmit the weight necessary to drill the formation. The driller and the directional driller steer the well by adjusting the torque, pulling and rotating the drill string.
- When the drill string is no longer free to move up, down, or rotate as the driller wants it to, the drill pipe is stuck. Sticking can occur while drilling, making a connection, logging, testing, or during any kind of operation which involves leaving the equipment in the hole.

- The drill string is stuck if **BF + FBHA > MO**
  Where,

  MO, maximum overpull: the maximum force that the derrick, hoisting system, or drill pipe can stand, choosing the smallest one

BF, background friction: the amount of friction force created by the side force in the well

FBHA: The force exerted by the sticking mechanism on the BHA (Bottom Hole Assembly)

MECHANISMS OF STUCK PIPE

A. DIFFERENTIAL STICKING

- Differential sticking happen when the drill collar rests against the borehole wall, sinking into the mudcake.
- The area of the drill collar that is embedded into the mudcake has a pressure equal to the formation pressure acting on it.
- The area of the drill collar that is not embedded has pressure acting on it that is equal to the hydrostatic pressure in the drilling mud.
- When the hydrostatic pressure (Ph) in the well bore is higher than the formation pressure (Pf) there will be a net force pushing the collar towards the borehole wall.

Mathematical Expression:

- Overpull due to differential pressure sticking can be calculated from the product of the differential pressure force times the friction factor :

Overpull = Fdp f………………………………………………………………………. (1)

Where Fdp = differential pressure force [psi/in2] and f = friction factor.

- The differential pressure force is defined:
Fdp = (144 in2 / ft2)*Amc* (*Ph* - *Pf*) ………………………………………………..(2)

Where Fdp = differential pressure force [lbf],
Amc = cross section embedded in mud cake [ft2],
Ph = hydrostatic pressure [psi], and Pf = formation pressure [psi].

- The friction factor depends on the formation and the drill collar surface. It varies from 0.15 to 0.50.
- The hydrostatic pressure is defined:

Ph = TVD×Ɣ= TVD×ρ×0.433 psi / ft /8.33ppg……………………………………(3)

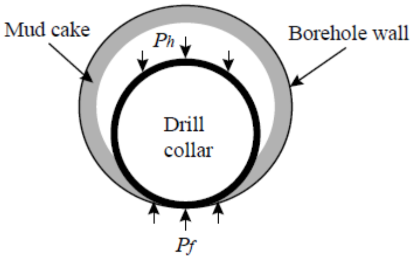


Fig3.5: Differential Sticking

- The thickness of the filter cake is critical in differential sticking. The thicker the filter cake the bigger is the cross sectional area that the formation pressure acts on. Thus, the differential sticking force is higher when the mud cake is thicker.

IDENTIFICATION AND PREVENTION

- **Warning Signs**

  a. Increasing overpull in long connections.
  b. Overpull and torque increases when drillstring is stationary for some time.
  c. Overpull decreases after reaming.

- **Identification**
  a. The pipe was stationary before it got stuck.
  b. Full circulation is possible.
  c. BHA adjacent to thick sand.
  d. Hydrostatic pressure overbalance.

- **Preventive Action**
  a. Keep track of differential pressure in sands if possible.
  b. Don't stop too long for a survey. If necessary continue drilling after the precursor comes up.
  c. Keep the mud weight under control.
  d. Use a short BHA.
  e. Make frequent wiper trips.

B. INADEQUATE HOLE CLEANING

- If the cuttings are not removed from the well properly, they will settle around the drillstring, usually the BHA, causing the drill collars to become stuck.
- The problem is worse in overgauge hole sections where the annular velocity is lower. Cuttings will build up and eventually slump in the hole.

- The cuttings are scraped by the stabilizers and the bit when the BHA is moved up the hole at a connection or a trip out. The cuttings accumulate in front of the bit and stabilizers. The overpull will increase until the cuttings will stick the BHA.

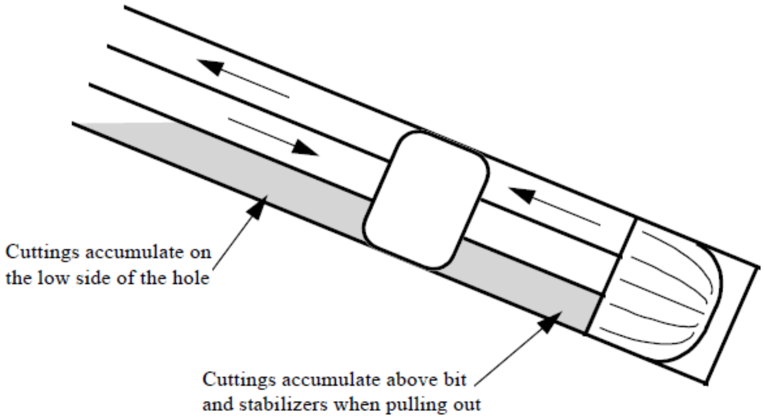


Fig3.6: Cuttings accumulate around BHA to cause increase in overpull

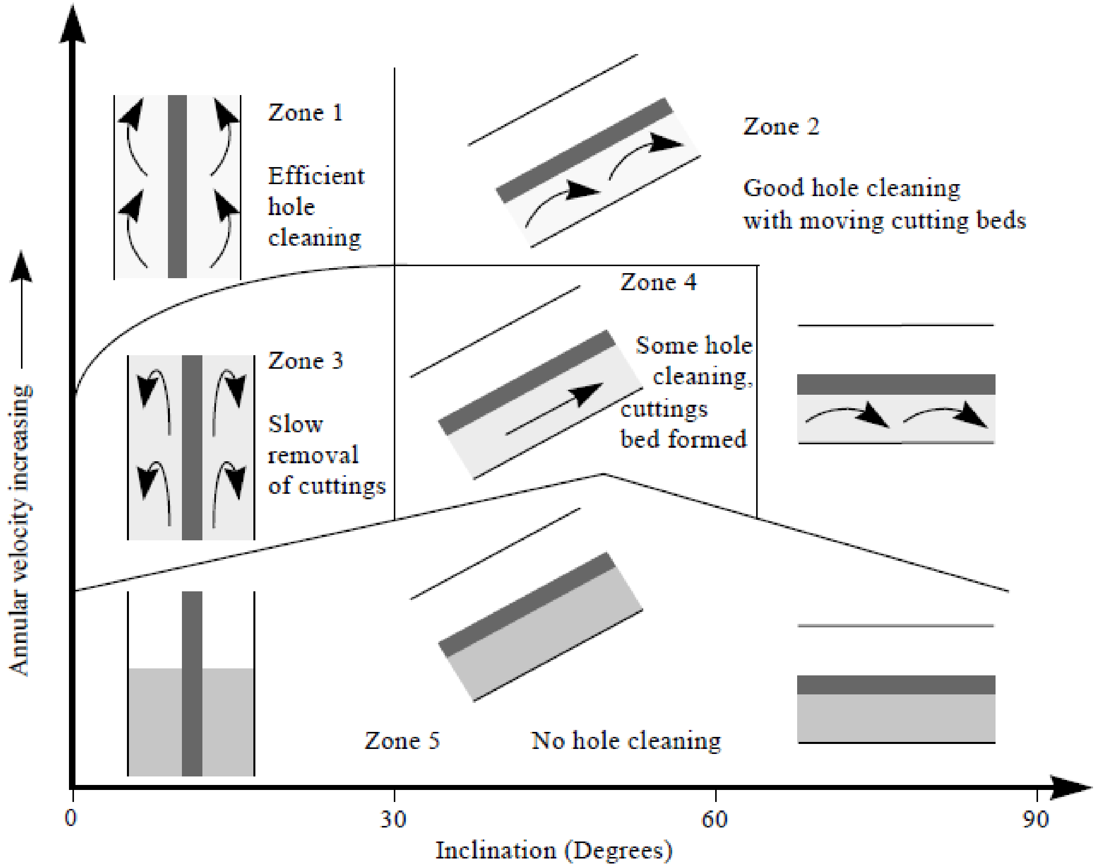


Fig3.7: Flow pattern of Cuttings in Deviated Well

IDENTIFICATION AND PREVENTION:

- **Warning Signs**

  a. Insufficient cuttings on shaker.
  b. Excessive overpull at connections and trips.
  c. Reduced overpull when pumping.
  d. Increase in pump pressure and pressure spikes when hole momentarily plugs up.
  e. Pump pressure much higher than predicted using hydraulics program.

- **Identification**
  a. Stuck shortly after pumps are shut off.
  b. Circulation lost.

- **Preventive action**
  a. Circulate all cuttings out before tripping out.
  b. If motor is used, rotate before tripping out of hole.
  c. Keep the pumps running.
  d. The ROP can be lowered to reduce the amount of cuttings.
  e. Check shale shakers to see if the cuttings are being removed.

C. CHEMICALLY ACTIVE FORMATIONS

- Different formations have a different degree of absorbing water. Some high clay content rocks absorb water and swell.
- The amount of swelling varies from highly reactive "gumbo" (fast absorption rate) to shales, which absorb water very slowly.
- When drilling with water based mud, the water is absorbed into these types of formations (commonly shales), causing them to swell and weaken.
- As a result, chunks of shale will break-off and fall into the borehole. The water-absorbed (hydrated) shale tends to stick to the drill string and accumulate in sufficient quantities to fill the entire annulus around the BHA, causing it to become stuck.

IDENTIFICATION AND PREVENTION:

- **Warning Signs**

  a. Large clumps of hydrated shale (gumbo) coming out of the hole.
  b. Drilling rate is slower as less weight gets to the bit.
  c. BHA packed off with gumbo (inspected at trips).
  d. Increase in pump pressure.
  e. Increase in torque as the hole size is reduced due to swelling.

- **Identification**
  a. Cannot circulate mud.
  b. Sticking can occur during any operation while in open hole.

- **Preventive Action**

  a. Minimize time in open hole.
  b. Maintain mud inhibitors at high enough levels.
  c. Minimize length of BHA and open hole sections.
  d. Avoid additional open hole operation such as wireline logging, survey runs, etc.

D. MECHANICAL STABILITY

- Before the drill bit enters a section of the hole, the rock supports three unequal stresses in four different directions. These are:

  1. **Vertical Stresses**: At depths greater than 1,500 feet, the largest stress on a rock formation is usually the stress imposed on it from the weight of all material above it, which acts in the vertical direction.

  2. **Side Stresses**: The side stresses which act in the horizontal component in both directions. A typical value of these stresses is 0.75 psi/ft.

- The drilling process effectively replaces the cylinder of rock with mud. Usually, the mud weight is balanced to the pore pressure of the formation, however in some instances the mud weight cannot totally support the borehole pressure.
- The rock around the borehole is forced to act as extra support. If the formation is strong, then there will be no problem. However, in younger formations, where the rock is not strong, the rock will not be able to support this extra stress.
- The rock will deform and the wellbore will begin to contract in a small amount.

IDENTIFICATION AND PREVENTION:

- **Warning Signs**

  a. Large cuttings, low shale strength.
  b. Tight hole over long sections during trip.
  c. Large overpulls due to cavings.
  d. Increase in pump pressure due to cavings in borehole.
  e. Slower drilling rate.

- **Identification**
  a. Circulation restricted or impossible.
  b. Sticking can occur during any operation while in open hole.

- **Preventive Action**
  a. Gradually increase mud weight.
  b. Follow hole cleaning procedures.
  c. Complete each hole section fast, therefore minimize time in hole.

E. FRACTURED/FAULTED FORMATIONS:

- Rock near faults can be broken into large or small pieces. If they are loose they can fall into the well bore and jam the string in the hole. Even if the pieces are bonded together, impacts from the BHA due to drill string vibration can cause the formation to fall into the well bore. This type of sticking is particularly unusual in that stuck pipe can occur while drilling.

Fig3.8: Fractured Formation

IDENTIFICATION AND PREVENTIONS:

- **Warning Signs**

  a. Hole fill on connections.
  b. Possible losses or gains.
  c. Fault damaged cavings at shakers.
  d. Increase in pump pressure.

- **Identification**
  a. Sticking can be instantaneous.
  b. Circulation restricted or impossible.

- **Preventative Action**
  a. Minimise drill string vibration.
  b. Choose an alternative RPM or change the BHAconfiguration if high shock vibrations are observed.
  c. Slow the trip speed before the BHA enters a suspected fractured/faulted area.
  d. Generally, fractured formations require time to stabilise. Be prepared to spend time when initially drilling and reaming prior to making significant further progress.
  e. Circulate the hole clean before drilling ahead
  f. Start/stop the drill string slowly to avoid pressure surges to the well bore.
  Anticipate reaming during trips. Ream fractured zones cautiously.

F. OVERPRESSURED FORMATIONS

- An additional stress is applied to the rock if the hydrostatic pressure is less than the formation pore pressure. The formation in this case will tend to “pop” or “heave” into the wellbore.
- The shale pieces can sufficiently accumulate to pack off the BHA and cause sticking. The heaving shale condition occurs only when no permeable sand is present, since permeable sand with a higher pore pressure than mud pressure would cause a kick.

IDENTIFICATION AND PREVENTION:

- **Warning Signs**
  a. Large, brittle, concave shaped carvings.
  b. Recently crossed a fault.
  c. Absence of permeable formations.
  d. Large overpulls at connections.
  e. Restricted circulation due to cavings loading the annulus.
  f. Torque may increase.

- **Identification**
  a. Circulation restricted or impossible.
  b. Stuck shortly after pumps off.

- **Preventative Action**
  a. Monitor all cuttings; be on a lookout for large concave shale pieces.
  b. Monitor Rate of Penetration (ROP - Drilling Rate).
  c. Follow hole cleaning procedures.

G. OTHER FACTORS:

a. Unconsolidated Formations
b. High Dip Sloughing
c. Mobile Formations
d. Undergauge Hole
e. Collapsed Casing etc.

MODULE 4

EXPERIMENTAL ANALYSIS

The experimental analysis to understand the wellbore stability mechanisms is conducted in two different phases namely;

Phase A: Preparation of Drilling Fluid Systems for different targeted stability concepts

Phase B: Testing of the prepared samples on different experimental setups

The targeted area for understanding the wellbore stability is confined only to:

a. Shale Stability
b. Sand Stability
c. Salt Mobility Stabilization

Mud systems prepared for the above three conditions are:

a. KCl Polymer Mud System
b. Bentonite-Gel Mud System
c. Salt saturated Polymer Mud System respectively.

All the experiments are elaborated in details discussing the following components:

A. Drilling Fluid Preparation
B. Working Mechanism
C. Experimental Run
D. Analysis and Inference

S.NO	EXPERIMENT NAME	MUD SYSTEM	CONTROL PARAMETER
1.	SHALE STABILITY ANALYSIS	KCl Polymer	Shale Inhibition
2.	SALT STABILITY ANALYSIS	Salt saturated Polymer	Salt Mobility
3.	SAND STABILITY ANALYSIS	Bentonite-Gel	Unconsolidated sand control

Table1: Experimental Details

EXPERIMENT 1: SHALE STABILITY ANALYSIS

EXPERIMENT DATE: March.19.2015

MUD SYSTEM: Water Based Mud (WBM)

MUD TYPE: KCl Polymer

TEST SPECIMEN: Shale Cuttings

A: DRILLING FLUID PREPARATION

- Water is the continuous phase in the mud.
- Different additives added in definite proportions within water.
- The fluid is mixed using Hamilton Mixer for different time gaps at different speeds.
- The drilling mud is tested for identifying rheological parameters using Rheometer at different RPM's
- The mud weight is determined using Mud balance and reading noted.

B: WORKING MECHANISM

Potassium is one of the most effective ions available to inhibit shale hydration. Potassium performance is based on cation exchange of potassium for sodium or calcium ions on smectite and interlayered clays. Potassium ions work better than other inhibitive ions because of its structure. Potassium ions fit more closely into the clay lattice structure and thereby reducing swelling or hydration of clays. The potassium ions are of proper size to fit into the spaces between the two silica tetrahedral layers which contact each other in the formation of a three layered clay packets. The ionic diameter of potassium ion is 2.66A where as available space between the lattices structure of clay is 2.8A. A cation slightly smaller than 2.8A is desirable to allow for crystalline compaction. When the formation is dominantly montmorillonitic the potassium ion exchange for sodium and calcium results in less hydratable structures. Potassium system work best when polymers are used for encapsulation. During drilling operation shale cuttings should be monitored very carefully for proper inhibition. If the concentration of KCL in the mud is not sufficient then shale cuttings will appear soft and mushy at the shaker.

C: EXPERIMENTAL RUN:

1. **FLUID PROPERTIES:**

MUD FORMULATION

S.NO	MUD CONSTITUENT	CONCENTRATION (ppb/gram)	FUNCTION
1.	Water	289	Continuous Phase
2.	Caustic Soda	0.25	pH Control
3.	Soda Ash	0.25	Treat Calcium/Magnesium
4.	Barite	165	Weighting Agent
5.	Potassium Chloride	35	Shale Inhibitor
6.	Starch	5	Fluid Loss Control Agent
7.	Xanthan Gum	1	Viscosifier

Table2: Mud formulation- KCl Polymer Mud

EXPERIMENTAL READINGS

- **Mud Density (ppg):** 11.8
- **Rheometer Readings:**

S.No	RPM	Reading
1.	R600	71
2.	R300	48
3.	R200	38
4.	R100	26
5.	R6	12
6.	R3	11

Table3: Rheometer Readings- KCl Polymer Mud

- **Parameters Calculated:**

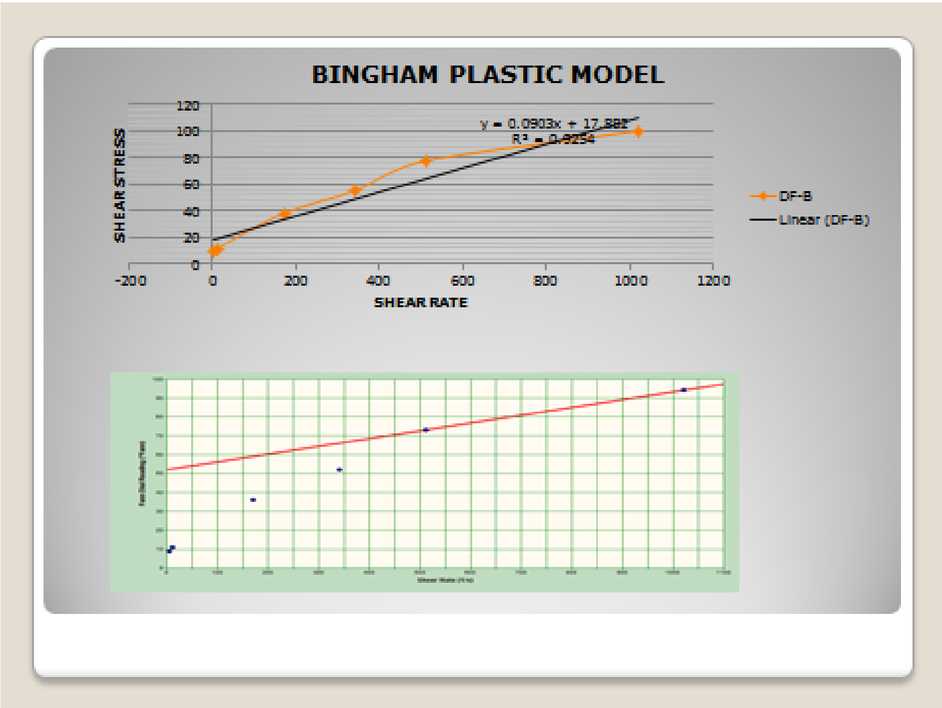
S.No	Mud Parameters	Calculated Values
1.	Plastic Viscosity, cp	23
2.	Yield Point, lb/100ft2	25
3.	Gels, 10sec, lb/100ft2	11
4.	Gels, 10 min, lb/100ft2	22
5.	Gels, 30min, lb/100ft2	28

Table4: Mud Parameters- KCl Polymer Mud

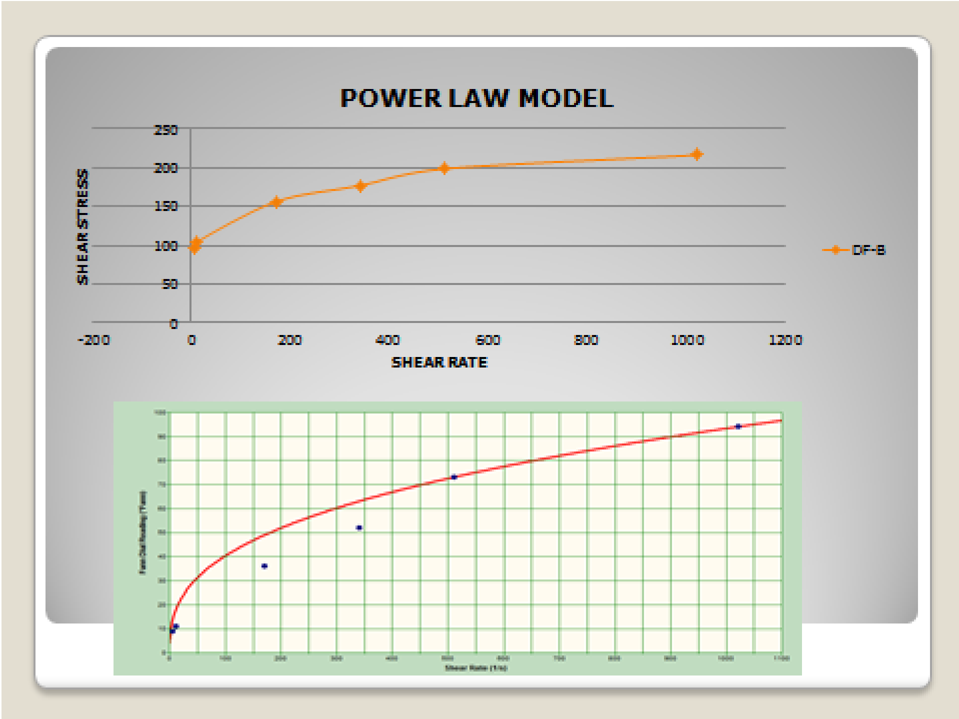
GRAPHS: KCl Polymer Mud System

Software Used: Mudware (Schlumberger Proprietary Software)

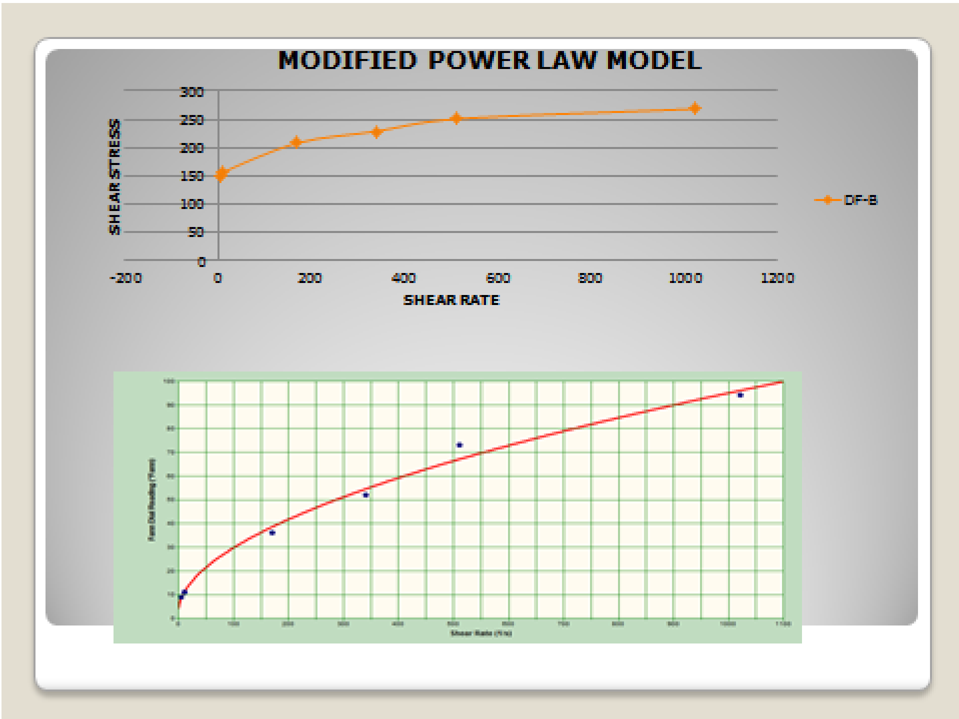
A Comparative study of the mud was done using the software and the graphs were plotted using MS-Excel and following results were obtained.



Graph1: Fann Reading VS Shear Rate: Bingham Plastic Model



Graph2: Fann Reading VS Shear Rate: Power Law Model



Graph3: Fann Reading VS Shear Rate: Herschel Buckley Model

2. FLUID PROPERTIES:

MUD FORMULATION

S.NO	MUD CONSTITUENT	CONCENTRATION (ppb/gram)	FUNCTION
1.	Water	292	Continuous Phase
2.	Caustic Soda	0.25	pH Control
3.	Soda Ash	0.25	Treat Calcium/Magnesium
4.	Barite	11	Weighting Agent
5.	Potassium Chloride	110	Shale Inhibitor
6.	Starch	6	Fluid Loss Control Agent
7.	Xanthan Gum	1.5	Viscosifier

Table2: Mud formulation-Salt Saturated Mud

EXPERIMENTAL READINGS

- **Mud Density (ppg):** 10
- **Rheometer Readings:**

S.No	RPM	Reading
1.	R600	45
2.	R300	34
3.	R200	27
4.	R100	19
5.	R6	10
6.	R3	9

Table3: Rheometer Readings- Salt Saturated Mud

- **Parameters Calculated:**

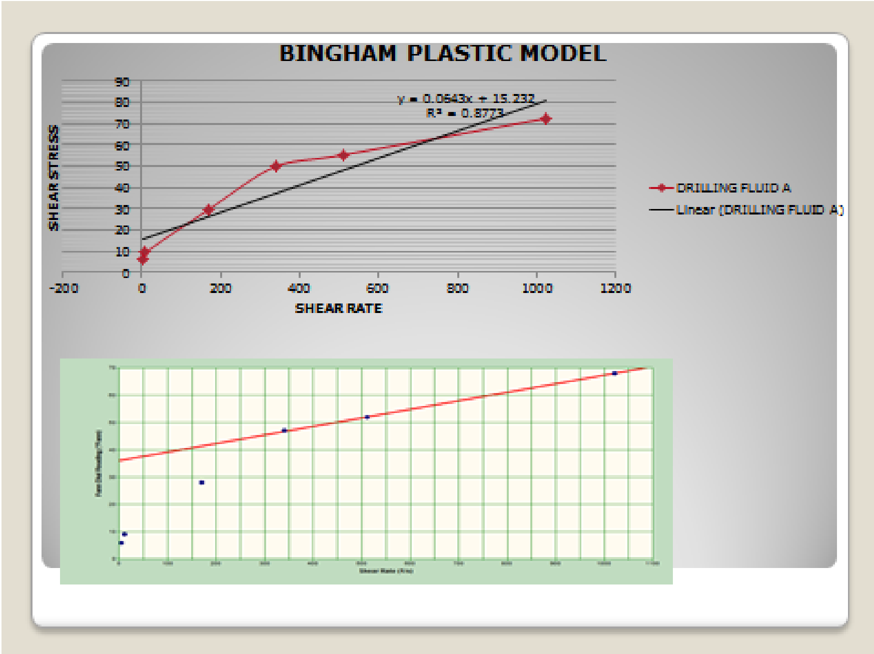
S.No	Mud Parameters	Calculated Values
1.	Plastic Viscosity, cp	11
2.	Yield Point, lb/100ft2	23
3.	Gels, 10sec, lb/100ft2	8
4.	Gels, 10 min, lb/100ft2	9
5.	Gels, 30min, lb/100ft2	11

Table4: Mud Parameters- Salt Saturated Mud

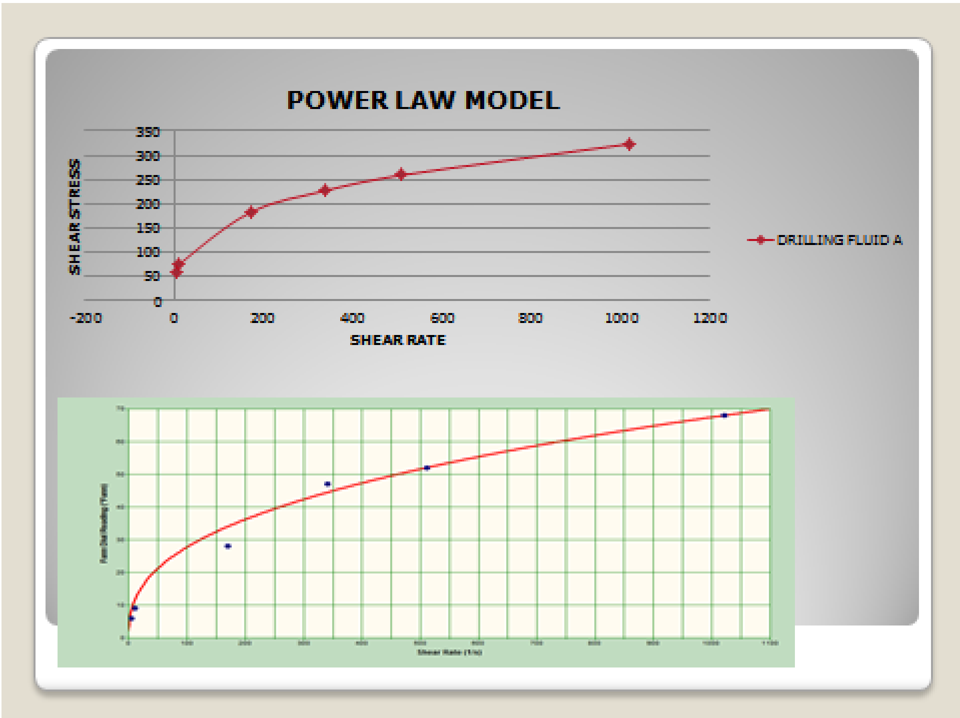
GRAPHS: Water based Mud System

Software Used: Mudware (Schlumberger Proprietary Software)

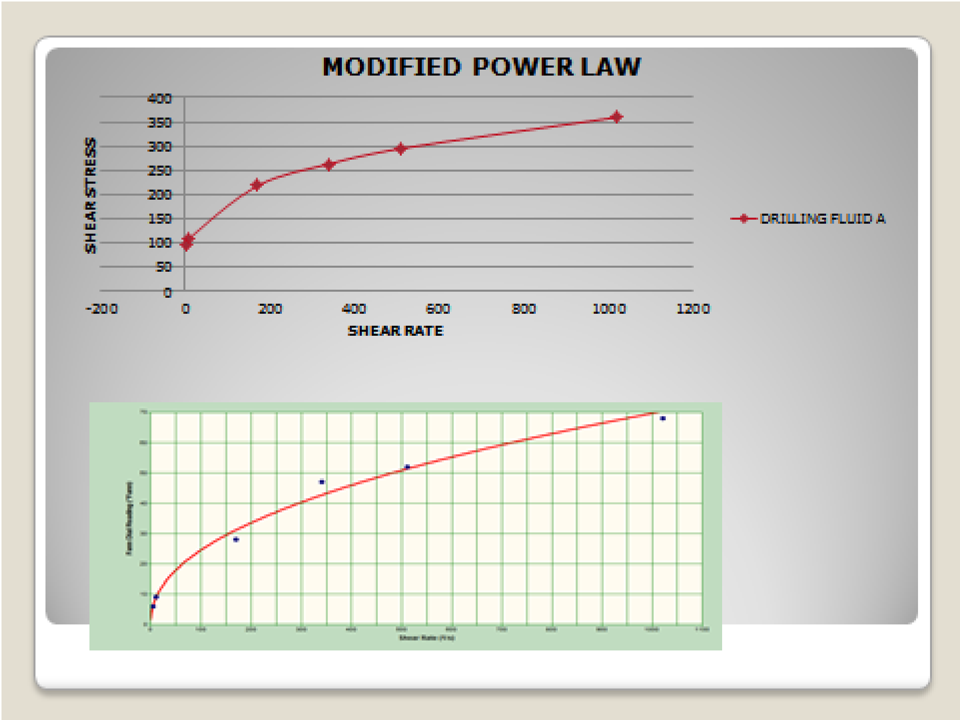
A Comparative study of the mud was done using the software and the graphs were plotted using MS-Excel and following results were obtained.



Graph1: Fann Reading VS Shear Rate: Bingham Plastic Model



Graph2: Fann Reading VS Shear Rate: Power Law Model



Graph3: Fann Reading VS Shear Rate: Herschel Buckley Model

MODULE 5

COMPUTATIONAL FLOW DYNAMICS ANALYSIS

Modelling and CFD Analysis

The physical aspects of any fluid flow are ruled by three basic principle, namely:

- Conservation of mass
- Second law of motion
- Conservation of energy

All the three are expressed in terms of mathematical equations which are partial differential in nature. The computational flow dynamics tries to solve the equations numerically through iterations imposed on by the user till the solution is expected to converge at some point.

The equations used by CFD solver to solve the equations are generally ruled by the fluid flow equations while the mathematical solutions advance in space and time to compute the full fluid flow description.

The various equations governing the CFD Analysis are derived from the Navier-Stokes and continuity equations.

- Continuity equation :- $\partial U_i/\partial z_i = 0$

- Newton's Second Law :-

$$\partial \rho Ui/\partial t + \partial \rho U_i U_j/\partial z_j = - \partial P/\partial z_i + \partial[\mu(\partial U_i/\partial z_i + \partial U_j/\partial z_i)]/\partial z$$

Where $\mu = K\gamma^n/\gamma$

K= consistency factor

Γ = shear rate

n= flow behaviour index

- n<1, shear thining
- n=1, Newtonian Fluid
- n>1, shear thickening fluid

- Conservation of energy :- $\partial L/\partial t + \blacktriangledown . (Lu) + Q = 0.$

Modelling Mechanism:

The modelling mechanism used for cfd analysis uses two stages to compute the overall results. The first step is the use of GAMBIT2.30 software to mark the overall geometry to create the basic structure which includes :

- Edging
- Facing

- Meshing
- Zoning
- Marking boundaries

After these preliminary processes the mesh quality is checked and is assumed to be a fine quality mesh with quality factor as 1.34 e10.

This mesh is then read by FLUENT 14.0 and the models are decided , the materials, the boundary conditions, solution method and then the iteration is initialized and calculations are run.

The circulating drilling fluid rising from the bottom of the well bore carries the cuttings toward the surface. Under the influence of gravity the cuttings tend to sink through the ascending fluid, but by circulating a sufficient volume of mud fast enough to overcome this effect, the cuttings are brought to the surface. The effectiveness of mud in removing the cuttings from the hole depends on several factors such as fluid viscoelastic properties, annular velocity, angle of inclination, drilled cuttings size and their shape.

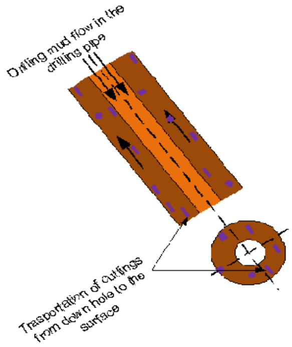


Figure5.0 shows fluid flow in a well bore to lift the cuttings

Experimental Analysis of GAMBIT2.30 :- A Case Study

In this project the 2D geometry of a wellbore has been considered and the geometry was created accordingly which is similar to a concentric cylinders in case of a 3D. The meshing had been done in which a long well of 610 meters was created with 105 meters of 20’ casing and a 12.25’ casing for a 505meters. The inlet, outlet, wall , axis has been specified in the geometry and has been shown in the figures below.

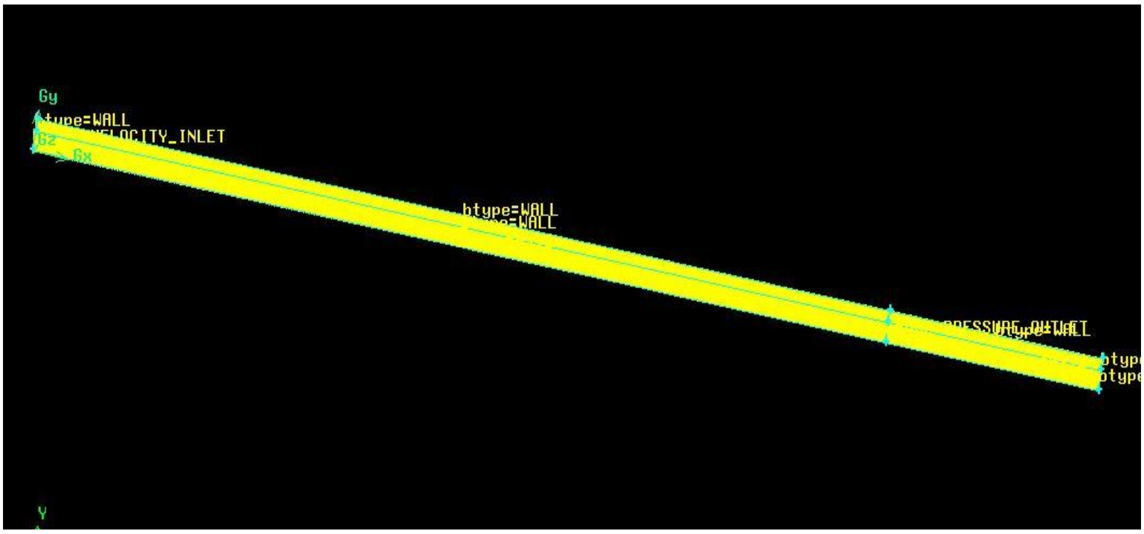


Figure 5.1 shows the various boundary conditions mentioned along the wellbore.

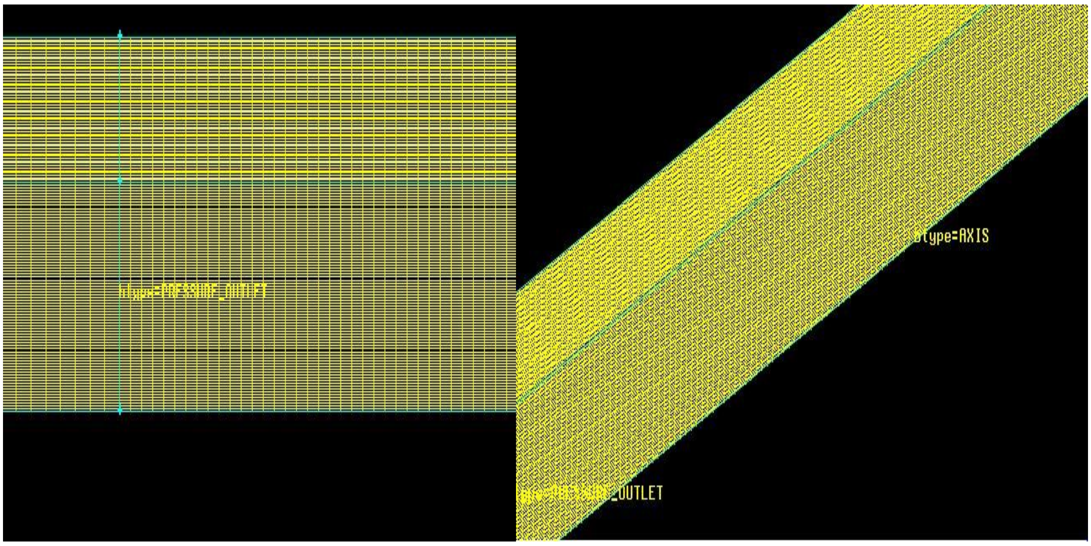


Figure 5.2 showa the cross sectional area of the well bore at the inlet and across the horizontal cross-section

Experimental Analysis of FLUENT 14.0 :- A Case Study

The mesh created in the Gambit 2.30 is imported using fluent14.0 and mesh is read accordingly after which the iterations can be run specifying the boundary conditions accurately.

The values inserted for the **water based mud system** are:

- Density – 1003 kg/m^3
- Pressure drawdown – 470 psi
- Velocity – 2m/s
- Viscosity – 0.00097 m^2/s
- Models – k-ε model for turbulence simulation
- Algorithm – SIMPLEC for pressure-velocity coupling
- Momentum, turbulence- second order upwind.

The results obtained were as follows:-

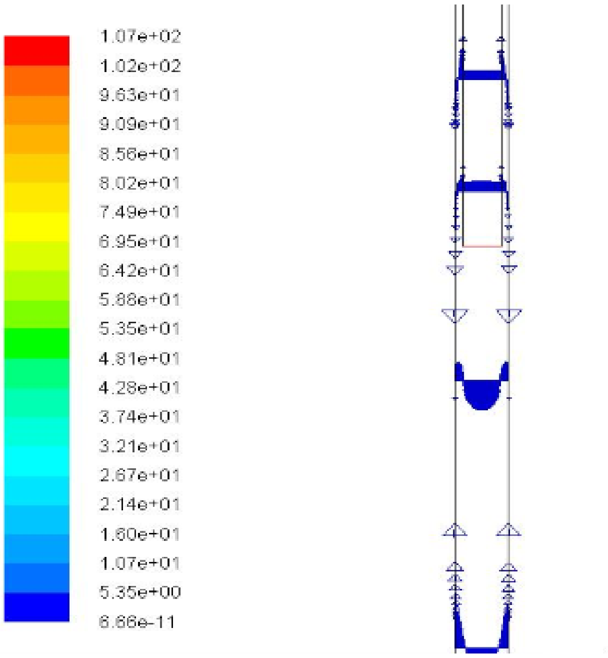


Figure shows the inlet relative velocity through the inlet, 1.7m/s.

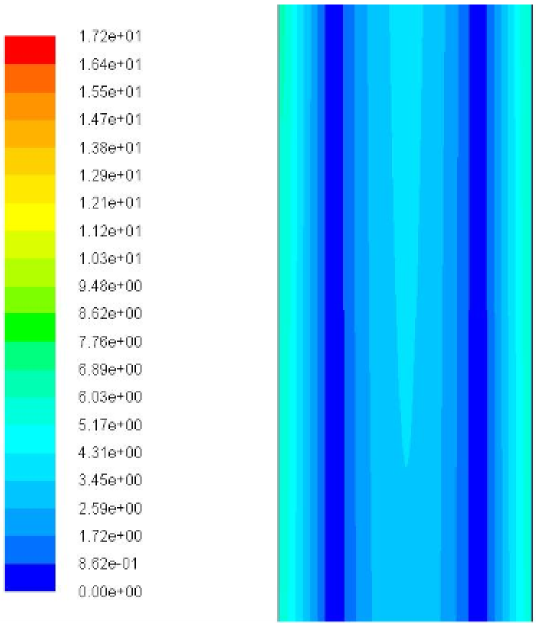


Figure shows the inlet velocity contours.

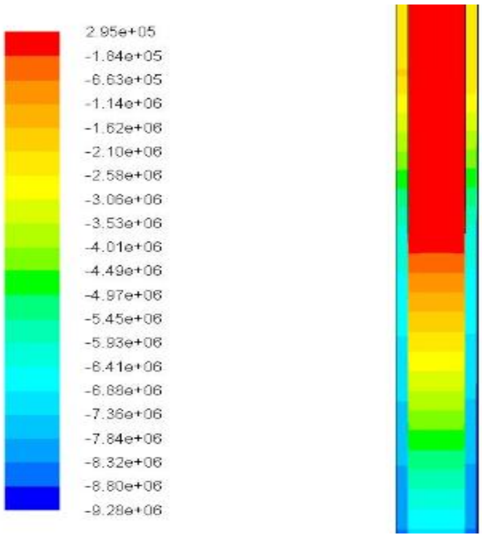


Figure 5.3 shows the temperature variance across the wellbore(high temperature due to fluid friction & drag, negative sign shows the reverse directions).

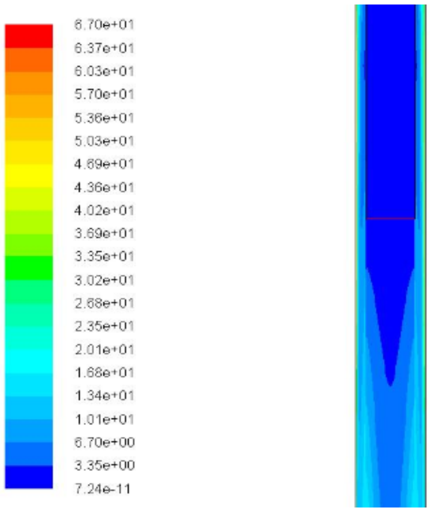


Figure 5.4 shows high turbulence at the outlet as it was mentioned as pressure based in the boundary Conditions & due to reverse flow on striking wall.

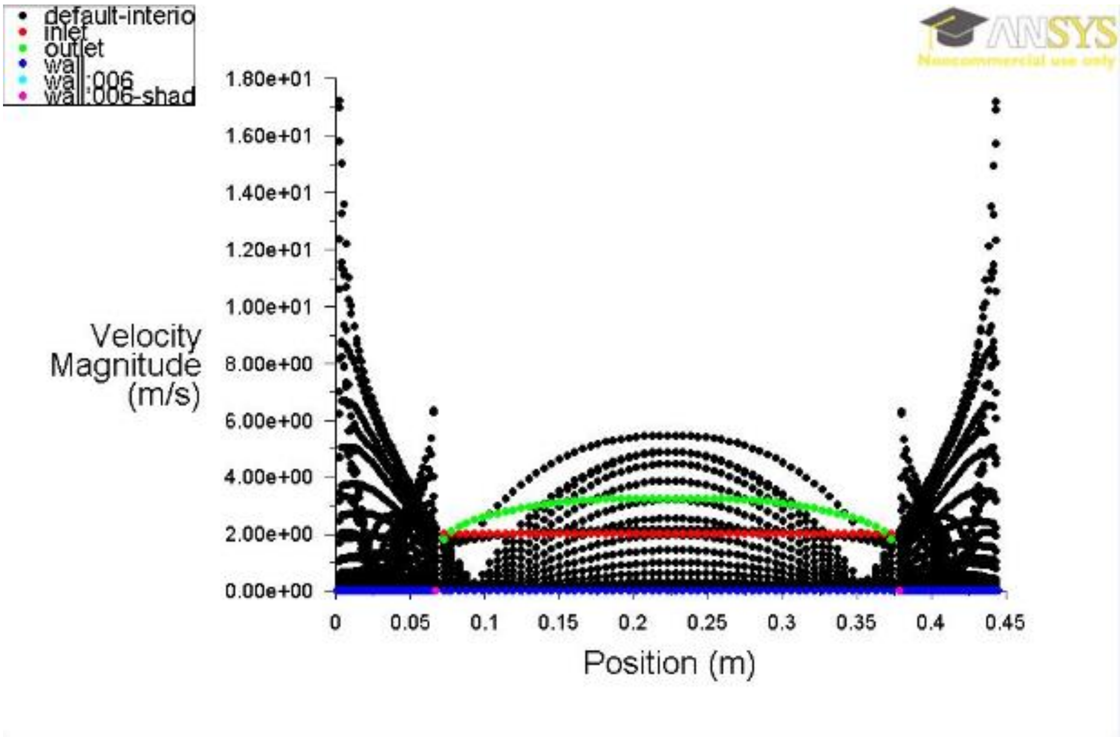


Figure 5.5 shows a low outlet velocity at the initial phase which flows with very high velocity and then again the value reduces while travelling against the gravity and due to other drag forces .The default interior shoots up tohigh values due to the striking against the wall.

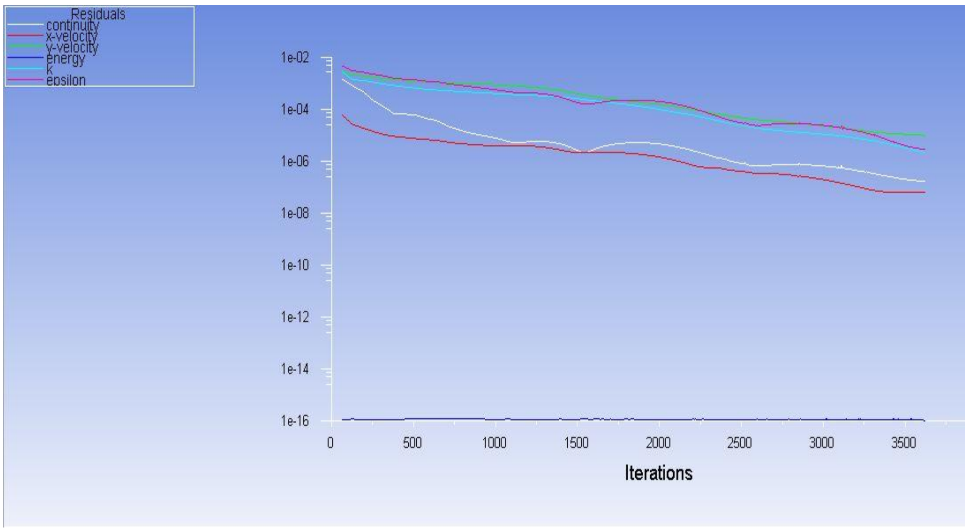


Figure 5.6 shows the solution calculating iterations and converged solution is attained at 3670 iteraion.

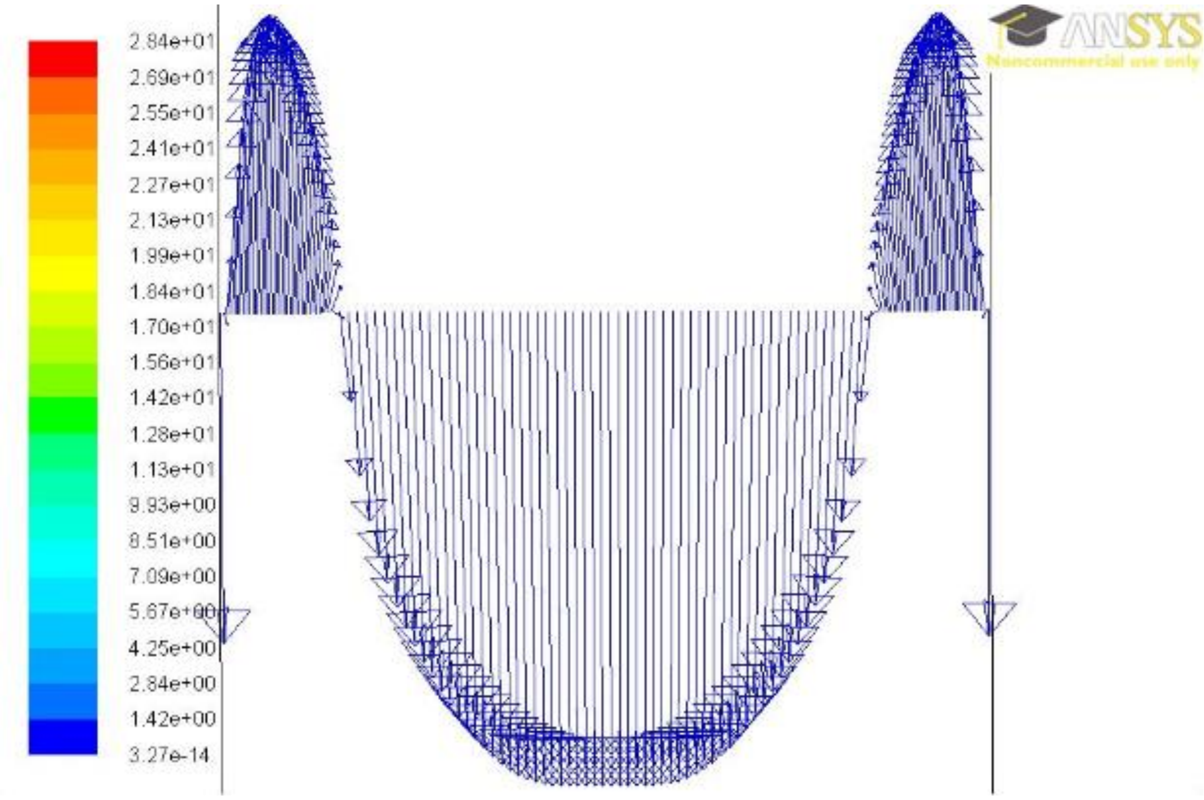


Figure 5.7 shows the vectors showing the downward arrow pointing the inlet flow and the upward arrows at the reverse flow. The arrows shows the turbulent regimes on the walls of the casing and the inner tubing respectively.

Experimental Analysis of FLUENT 14.0 :- A Case Study 2.0

The mesh created in the Gambit 2.30 is imported using fluent14.0 and mesh is read accordingly after which the iterations can be run specifying the boundary conditions accurately.

The values inserted for the **KCL Polymer based mud system** are:

- Density – 840 kg/m^3
- Pressure drawdown – 270 psi
- Velocity – 1.7m/s
- Viscosity – 0.00137 m^2/s
- Models – k-ε model for turbulence simulation
- Algorithm – SIMPLEC for pressure-velocity coupling
- Momentum, turbulence- second order upwind.

Following results were obtained:-

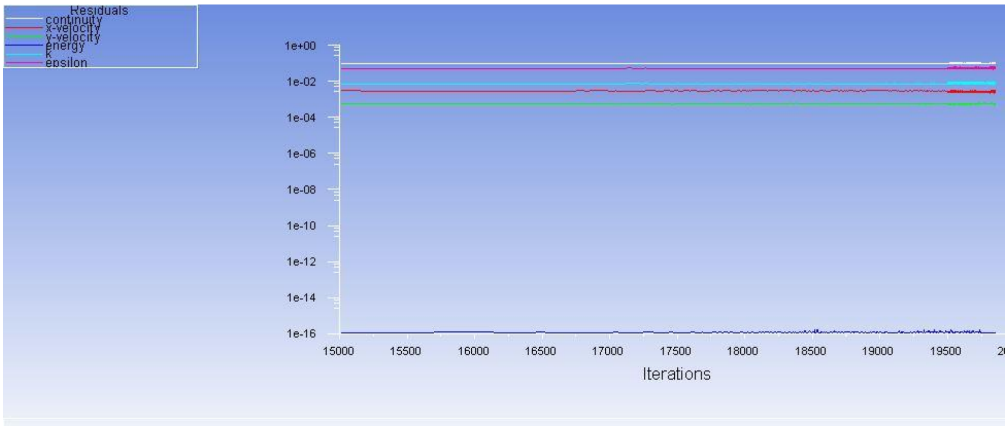


Figure 5.8 shows the iteration calculation carried out for KCL Polymer based system.

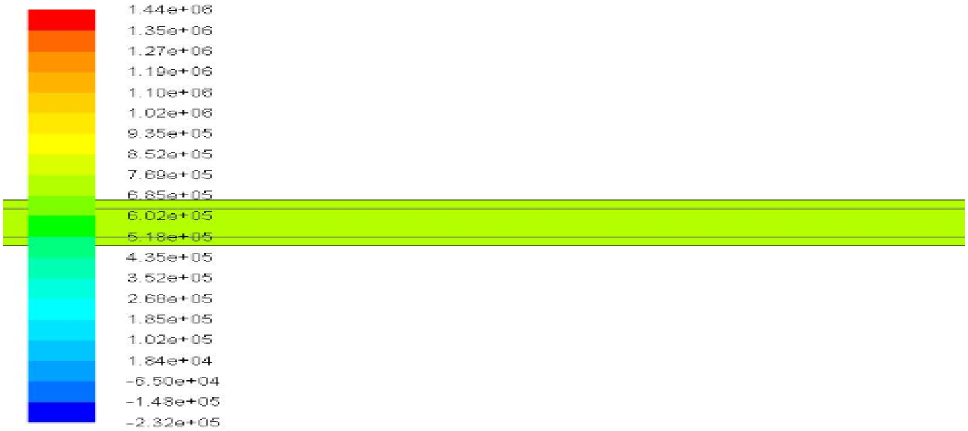


Figure 5.9 shows the variation of static pressure over the contour of the geometry drawn.

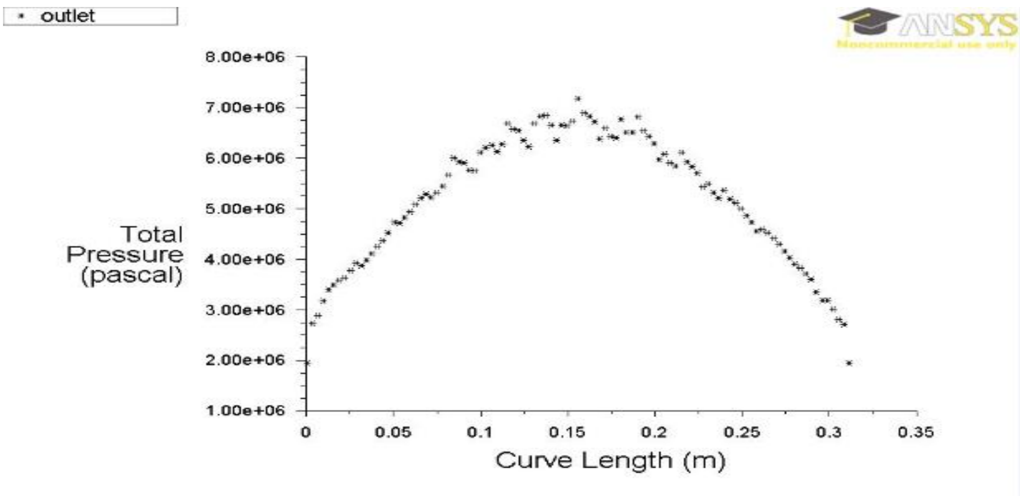


Figure5.10 shows the variation of outlet pressure and the geometry length, the highest pressure of 7000000 pascals.

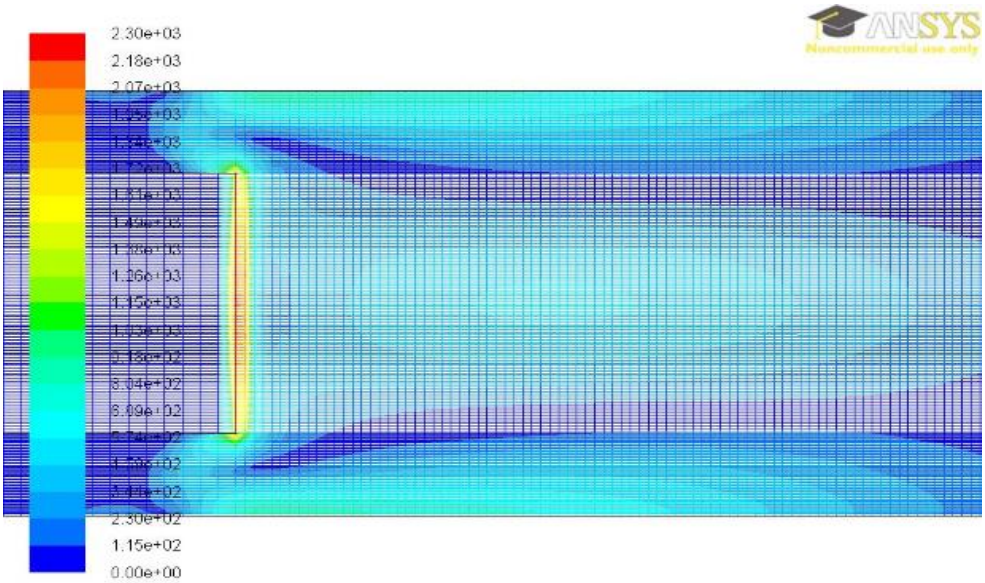


Figure5.11 shows the variation of velocity after striking the wall with a reverse flow.

Outlet velocity is 2490m/s.

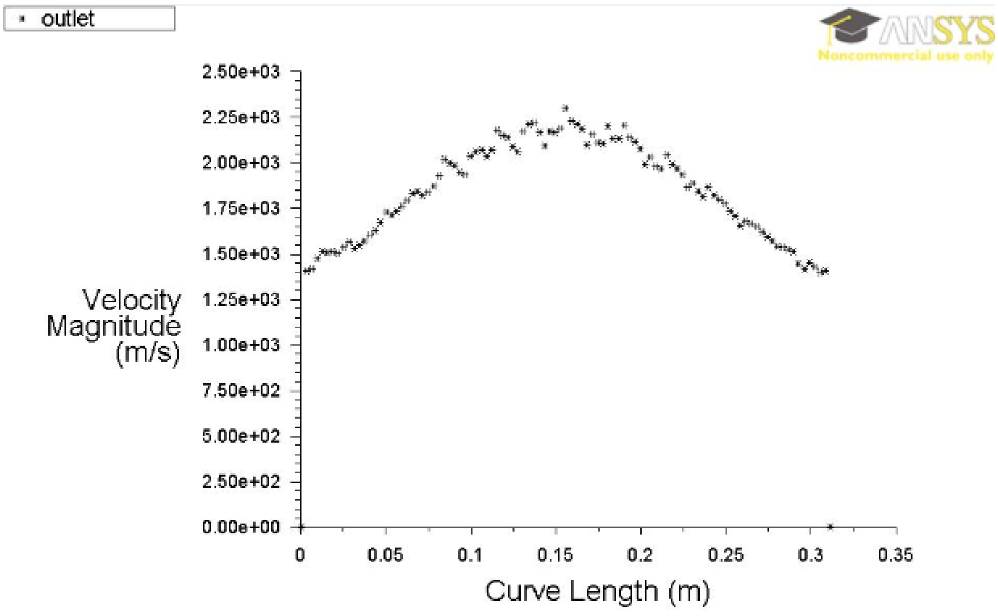


Figure 5.12 shows the highest velocity 2250m/s at the outlet.

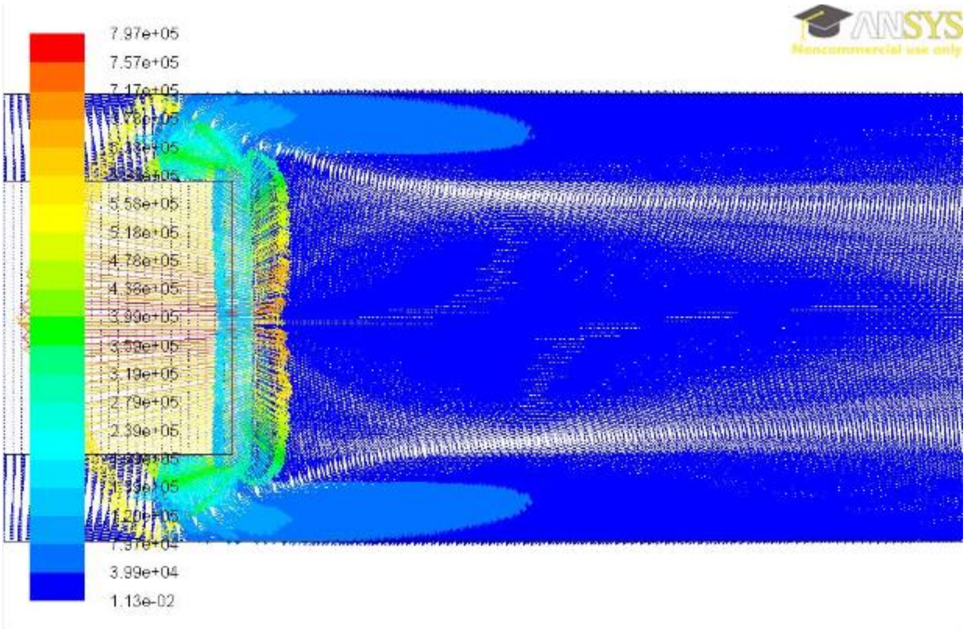


Figure 5.13 shows the vector diagram pointing different forces and depicting various regimes at the outlet and the direction of reverse flow.

CONCLUSIONS & RECOMMENDATIONS

Fluid flow in annular spaces has received a lot of attention from oil industries, both in drilling operations and in petroleum artificial rising. This work integrates theoretical formulation, experimental measurements and CFD simulation to study the performance of the oil well cleaning performance. In the laboratory experimental measurements, the density and non-Newtonian viscosity behavior of drilling mud are evaluated. Reynolds –Averaged Navier-Stocks and continuity equations combined with power low as definer of the viscosity term were identified to derive the theoretical modelling. GAMBIT software was used for the modeling of the annulus and FLUENT software was used for the simulation. The analyses were conducted for various mud feeding velocities ranging from 100-350 ft/min (0.508 m/s – 1.778 m/s), in 2D orientations.

Simulation of the mud flow in the annulus had shown that

- In the turbulent flow, the velocity profile was flattening over wide area of the annulus. This is necessary to produce uniform drag distribution to lift the cuttings during the transportation process.
- Investigation of cutting size were conducted for 3 mm, 5mm and 7mm and the results suggest that fine particles are the easiest one to clean out.
- Cuttings shape with 1.0, 0.9 and 0.85 was investigated and it was found that higher spherecity have better cleaning efficiency.
- Mud rheology plays essential role in cuttings transport. The shear thinning effect of our simulated fluid is relevant in cuttings transportation in horizontal drilling systems. To achieve optimum results for hole cleaning, the best way is with a low viscosity mud in turbulent flow.
- The indication for the wellbore cleaning performance adopted in the present analysis is the concentration of the cuttings at the surface of the well at different operational mud flow rate. This concentration is produced from the particles transported successfully from the well bottom to the surface. There is no energy or mass transfer between particles during the upward motion in the annulus

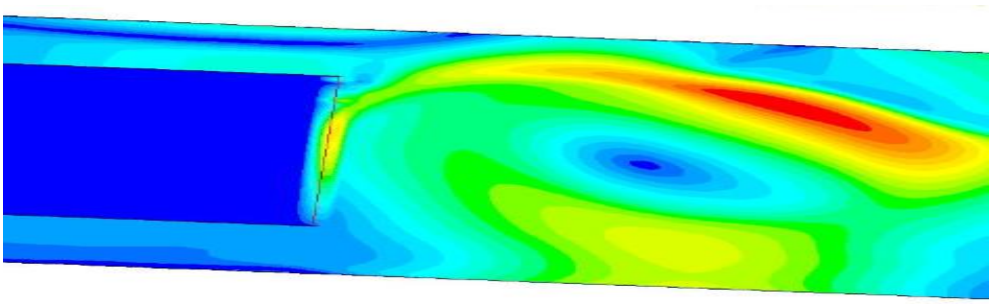


Figure 5.14 shows the lifting mechanism of the fluid with high differential velocity and a vortex generated in the middle and high flowback at the walls of the tubing to the surface.

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