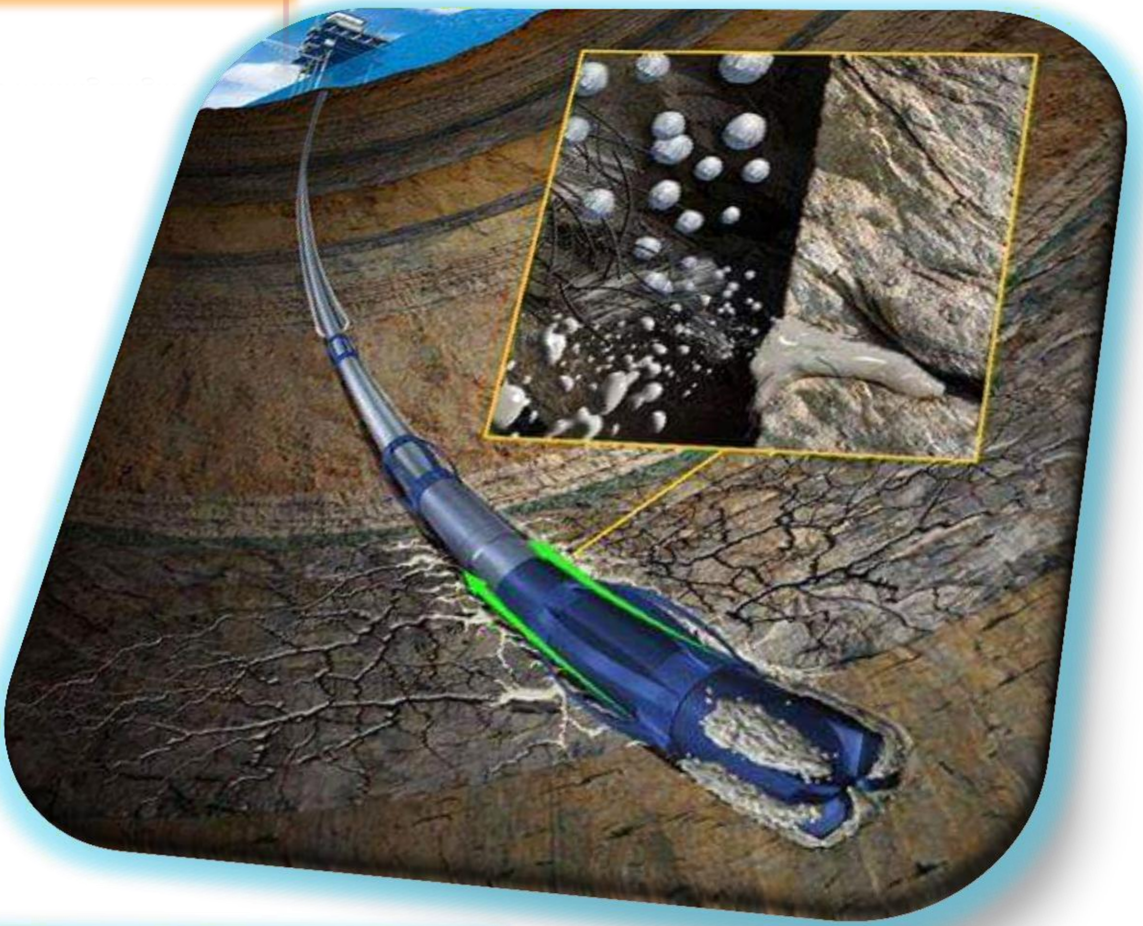
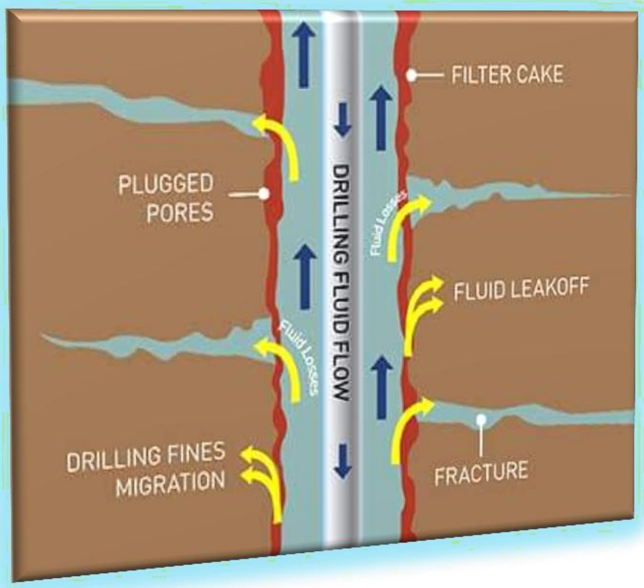
MOSUL UNIVERSITY
College of Petroleum & Mining Engineering
3rd Stage
2024/2025





Dr. MOHAMMED ALI ALRASHEDI

Drilling Fluids Engineering:

Initially, the primary purpose of drilling fluids was to clean, cool and lubricate the bit and continuously remove cuttings from the borehole. But with progress came sophistication, and more was expected from the drilling fluid (mud). Many additives for any conceivable purpose were introduced, so what started out as a simple fluid has becomea complicated mixture of liquids, solids and chemicals for which “mud engineers” are contracted by the operating company to maintain. Today, the drilling fluid must permit thesecuring of all information necessary for evaluating the productive possibilities of the formations penetrated. The fluids' characteristics must be such that good cores, wireline logs and drill returns logs can be obtained. Drilling fluid is discussed here from the standpoint of:

- Technology.
- Chemistry.
- Additives.
- material Balance Equation.
- Mud Conditioning Equipment.

Drilling Fluid Technology:

Numerous types of mud are available due to the varied hole conditions. Factors such as depth, types of formations, local structural conditions, etc., all enter into the choice of a particular mud. The functions and corresponding properties of a drilling mud are to:

- Control subsurface pressures and prevent caving (mud density).
- Remove cuttings from the borehole (viscosity).
- Suspend cuttings when circulation stops (gel strength).
- Cool and lubricate the bit and drill string (additive content).
- Wall the borehole with an impermeable filter cake (water loss).
- Release the cuttings at the surface (viscosity/gel strength).
- Help support the weight of the drill string/casing (density).
- Ensure maximum information from the formation.
- Do all of the above, without damage to the circulation system.

Controlling Subsurface Pressures: The pressure of the mud column at the bottom of the borehole is a function of the mud density and column height. This pressure must be adequate at all times to prevent the flow of formation fluids into the borehole. Should muddensity fall below that which is necessary to hold back formation pressures, then formationfluids can enter the well. This is termed a “kick”. If this condition is allowed to continue unchecked for even a short period of time, the mud density may be reduced (cut) so severely that uncontrolled flow will result. This is termed a “blowout”.

On the other hand, it is not practical or economical to have the mud weight too high. Excessive mud weights result in low rates of penetration and in the fracturing of weak formations, and may cause the loss of drilling mud into them (lost circulation).

Density is also important in preventing unconsolidated formations from caving into the borehole.

The effect of mud weight on drill returns logging:

• Hydrostatic pressure in excess of formation pressure will cause formation fluids to be flushed back into the formation being penetrated, either at the bit or just ahead of it. This flushing occurs at all times, whether marginally or greatly overbalanced. If circulation is lost, then the cuttings, drilling mud and any formation fluids they may contain are also lost.

The way in which a lost circulation zone behaves generally indicates the type ofporosity of the formation into which the fluid is being lost.

Examples are:

a) Coarse, permeable unconsolidated formations: There is normally some loss by filtration into these formations, until an impermeable filter cake if formed. If pore openings are large enough, then loss of whole mud occurs. Other than in extreme cases, this is a slow, regular seepage loss. Partial returns are maintained.

b) Cavernous and vugular formations: Loss is usually sudden and of a finite amount, after which full returns are maintained.

c) Fissured or fractured formations: Fractures may be natural or induced and opened by the hydrostatic pressure. Losses of drilling mud are large and continuous.

• Formation pressures that approximate or are greater than the hydrostatic pressure may allow entry of formation fluids, depending on permeability. In low permeability formations (shales), cavings may occur, making cuttings analysis difficult.

Removing and Suspending the Cuttings: The drilling mud must carry the cuttings up the borehole and suspend them when circulation is stopped. The most important factorsinvolved are the speed at which the mud travels up the borehole (annular velocity), and theviscosity and gel strength of the drilling mud.

1. Viscosity

Applied to drilling fluids, viscosity may be regarded as the resistance that the drilling fluid offers to flow when pumped. The viscosity affects the ability of the drilling fluid to lift the rock cuttings out of the borehole. The viscosity is dependent on the amount and character of the suspended solids. Viscosity is ordinarily measured in the field using a “Marsh Funnel”. The funnel is filled with one quart of drilling fluid, and the elapsed time to emptythe funnel is recorded in seconds. The measurement of “funnel viscosity” is “sec/qt” (seconds per quart). This value can range from 20 to 80, but is normally maintained between 40 and 50.

2. Gel Strength

Gel strength refers to the ability of the drilling fluid to develop a gel as soon as it stops moving. Its purpose is to suspend the cuttings and mud solids (weight material), while they are in the borehole and not permit them to settle around the bit when circulation is halted. In general, gel strength should be low
enough to:

- Allow the cuttings to be removed at the surface
- Permit entrained gas to be removed at the surface
- Minimize swabbing when the pipe is pulled from the borehole
- Permit starting of circulation without high pump pressures

The gel strength is most commonly determined with a “Fann VG (Viscosity/Gel) Meter” and is expressed in lbs/100ft2 (pounds per 100 square feet). Drilling muds ordinarily have gel strengths between 5 and 30 lbs/100ft2.

The effect of viscosity and gel strength on drill returns logging:

- If the viscosity or gel strength (or both) is too high, the drilling fluid tends to retain any entrained gas as it passes through the surface mud cleaning equipment, with the effect that the gas may be recycled several times. Swabbing of the borehole may also introduce extraneous gas anomalies.
- Fine cuttings may be held in suspension so they cannot be removed at the shale shakers and settling pits, thus recycling and contaminating the cuttings samples. Also, cuttings consisting of clays or other dispersible material may be dissolved.

Cooling and Lubricating the Bit and Drill string: Practically any fluid that can be circulated through the drill string will serve to cool the bit and drill string. Lubrication, however, commonly requires special mud characteristics that are gained by adding oil, chemicals and other materials.

Walling the Borehole with an Impermeable Filter Cake: The hydrostatic pressure of the column of drilling fluid exerted against the walls of the borehole helps prevent the caving of unconsolidated formations. A plastering effect, or the ability to line permeable portions of the borehole with a thin, tough filter cake, is also produced.

Control of the filtration rate (water loss) is necessary for two reasons:

1. A poor quality filter cake may cause excessive water loss and produce an excessively thick filter cake, thereby reducing the diameter of the borehole which increases the possibility of sticking the drill string and the swabbing effect when pulling the drill pipe.
2. High water loss can cause deep invasion of the formations, making it difficult to interpret wireline logs.

Drilling Fluid Chemistry:

A drilling fluid can be classified by the nature of its continuous fluid phase. There are three types of drilling fluids:

1. **Water Based Muds (Water/clay muds).**
2. **Oil Based Muds (Oil/water clay muds).**
3. **Gas Based Muds (Compressed gases).**

Water Based Muds:

This is the major type of mud system. It consists of a continuous liquid phase of water in which clay materials are suspended. A number of reactive and nonreactive solids are added to obtain special properties. A water-based mud system is a three-component system consisting of water, and reactive and inert solids.

1. Water

This may be fresh water or salt water. Seawater is commonly used in offshore drilling and saturated saltwater may be used for drilling thick evaporate sequences to prevent them from dissolving and causing washouts. Saturated saltwater is also used for shale inhibition.

2. Reactive Solids

Clays: this basic material of mud is commonly referred to as “gel”. It affects the viscosity, gel strength and water loss. Common clays are:

- Bentonite - for fresh water muds
- Attapulgite - for saltwater muds
- Natural formation clays which hydrate and enter the mud system

Dispersants: they reduce viscosity by adsorption onto clay particles, reducing the attraction between particles. Examples are tannins, quebracho, phosphates, lignite and lignosulphonates.

Filtration Control Agents: they control the amount of water loss into permeable formations, due to the pressure differential, by ensuring the development of a firm impermeable filter cake.

Some are:

- starch - pregelatinized to prevent fermentation
- sodium carboxy-methyl cellulose (CMC) - organic colloid, long chain molecules which can be polymerized into different lengths or "grades". The grades depend on the desired viscosity.
- polymers - for example cypan, drispac, used under special conditions

Detergents, Emulsifiers and Lubricants: to assist in cooling and lubricating. Also used for a spotting fluid in order to free stuck pipe.

Defoamers: these prevent mud foaming at the surface in treatment equipment.

Sodium Compounds: precipitate or suppress calcium or magnesium which decreases the yield of the clays.

Calcium Compounds: they inhibit formation clays and prevent them from hydrating or swelling.

3. Inert Solids

Weight Material: these are finely ground, high-density minerals held in suspension to control mud density. Common weight materials are barite, hematite and galena.

Lost Circulation Material (L.C.M.): this is added to the mud system in order to bridge-over or plug the point of loss. It is available in many sizes and types to suit particular circulation loss:

- Fibrous: wood fiber, leather fiber.
- Granular: walnut shells (nut plug), fine, medium, coarse.
- Flakes: cellophane, mica (fine, coarse).
- Reinforcing Plugs: bentonite with diesel oil, time setting clays, attapulgite and granular (squeeze).

If none of these materials successfully plug the lost circulation zone, the zone must be cemented off.

Anti-friction material: this is added to the mud system to reduce torque and decrease the possibility of differential sticking. The most frequently used material is inert polyurethane spheres. More frequently it is used on high angle directional wells, where torque and differential sticking are a problem.

Oil Based Muds:

Two basic types of oil/water mud systems are used:

1. Emulsion (oil/water) System, in which diesel or crude oil is dispersed in a continuous phase of water.
2. Invert Emulsion (water/oil) System, in which water is dispersed in a continuous phase of diesel/crude oil.

These mud systems have desirable properties as completion fluids or when drilling production wells. They are nonreactive with clays and their filtrate will not damage the formations. Their high cost and difficulty of running, and complication of geological evaluation preclude their use on exploratory wells, other than in certain troublesome evaporate and clay sections. Apart from these emulsions containing roughly equal portions of oil and water, there are true oil-based muds which may contain only 5 percent water.

When oil-based mud systems are in use, special considerations must be made regarding formation evaluation.

Gas Based Mud:

Compressed air or natural gas is occasionally used as a drilling fluid (at times with a foaming agent to improve carrying capacity), but its use is applicable only in areas where there is little formation water. The compressed air or gas is circulated the same as conventional drilling mud, except compressors are used instead of mud pumps.

Work-over Mud Systems:

Also called completion fluids, these are specialized systems designed to **1)** Minimize formation damage, **2)** Be compatible with acidizing and fracturing fluids, and **3)** Reduce clay/shale hydration. They are usually highly treated brines and blended salt fluids.

Drilling Fluid Additives:

Many substances, both reactive and inert, are added to drilling fluids to perform specialized functions. The most common functions are:

Alkalinity and pH Control

Designed to control the degree of acidity or alkalinity of the drilling fluid. Most common are lime, caustic soda and bicarbonate of soda.

Bactericides

Used to reduce the bacteria count. Paraformaldehyde, caustic soda, lime and starch preservatives are the most common.

Calcium Reducers

These are used to prevent, reduce and overcome the contamination effects of calcium sulfates (anhydrite and gypsum). The most common are caustic soda, soda ash, bicarbonate of soda and certain polyphosphates.

Corrosion Inhibitors

Used to control the effects of oxygen and hydrogen sulfide corrosion. Hydrated lime and amine salts are often added to check this type of corrosion. Oil-based muds have excellent corrosion inhibition properties.

Defoamers

These are used to reduce the foaming action in salt and saturated saltwater mud systems, by reducing the surface tension.

Emulsifiers

Added to a mud system to create a homogeneous mixture of two liquids (oil and water). The most common are modified lignosulfonates, fatty acids and amine derivatives.

Filtrate Reducers

These are used to reduce the amount of water lost to the formations. The most common are bentonite clays, CMC (sodium carboxymethylcellulose) and pre-gelatinized starch.

Flocculants

These are used to cause the colloidal particles in suspension to form into bunches, causing solids to settle out. The most common are salt, hydrated lime, gypsum and sodium tetraphosphates.

Foaming Agents

Most commonly used in air drilling operations. They act as surfactants, to foam in the presence of water.

Lost Circulation Materials

These inert solids are used to plug large openings in the formations, to prevent the loss of whole drilling fluid. Nut plug (nut shells), and mica flakes are commonly used.

Lubricants

These are used to reduce torque at the bit by reducing the coefficient of friction. Certain oils and soaps are commonly used.

Pipe-Freeing Agents

Used as spotting fluids in areas of stuck pipe to reduce friction, increase lubricity and inhibit formation hydration. Commonly used are oils, detergents, surfactants and soaps.

Shale-Control Inhibitors

These are used to control the hydration, caving and disintegration of clay/ shale formations. Commonly used are gypsum, sodium silicate and calcium lignosulfonates.

Surfactants

These are used to reduce the interfacial tension between contacting surfaces (oil/water, water/solids, water/air, etc.).

Weighting Agents

Used to provide a weighted fluid higher than the fluids specific gravity. Materials are barite, hematite, calcium carbonate and galena.

Material Balance Equations:

Material balance equations are used for calculating volumes and densities when two or more insoluble materials are mixed together. The Material Balance Equation is:

V1W1 + V2W2 ..... = VFWF   where: V1 + V2...... = VF

where: V1 = Volume of first material to be mixed together.
W1 = Density of first material.
V2 = Volume of second material to be mixed together.
W2 = Density of second material.
VF = Total or sum of all volumes mixed together.
WF = Density of total mixture. Proportional.

The most commonly used variables in material balance equations are:

Barite

1. Weight of a barrel of barite ($BaSO_4$) s.g. = 4.2 g/cc
   42 gal/bbl x 8.33 lb/gal x 4.2 = 1470 lb/bbl

   * since barite comes in 100 lb sacks, one barrel contains 14.70 sacks
2. Weight of a gallon of barite
   8.33 lb/gal x 4.2 = 34.9 lb/gal

Hematite

1. Weight of a barrel of hematite (Fe_2O_3) s.g. = 5.0 g/cc
   42 gal/bbl x 8.33 lb/gal x 5.0 = 1749 lb/bbl
2. Weight of a gallon of hematite
   8.33 lb/gal x 5.0 = 41.65 lb/gal

Light Oil

1. Example - (41° API Gravity) s.g. = 0.82 g/cc
2. Weight of a gallon of oil
   8.33 lb/gal x 0.82 = 6.8 lb/gal

Example Problem #1-1:

Calculate how many sacks of barite are required to increase the density of an 800 barrel mud system from 12.7 lb/gal to 14.5 lb/gal.

Using: $V1W1 + V2W2 = VFWF$

where: $V1 = 800$ bbls

$W1 = 12.7$ lb/gal

$V2$ = unknown volume of barite

$W2 = 34.9$ lb/gal (density of barite)

$VF = V1 + V2$ (or $800 + V2$)

$WF = 14.5$ lb/gal

therefore: $800(12.7) + V2(34.9) = (800 + V2) \times 14.5$

$10,160 + 34.9V2 = 11,600 + 14.5V2$

$20.4V2 = 1440$

$V2 = 70.6$ bbls of barite

70.6 bbls x 14.7 sk/bbl = 1038 sacks of barite

Example Problem #1-2:

Calculate how much water and barite are required to make 800 barrels of a 10.5 lb/gal water-based drilling mud.

Using: $V1W1 + V2W2 = VFWF$

where: $V1$ = unknown volume of water

$W1 = 8.33$ lb/gal

$V2$ = unknown volume of barite or $(800 - V1)$

$W2 = 34.9$ lb/gal

$VF = 800$ bbls

$WF = 10.5$ lb/gal

therefore: $V1(8.33) + (800 - V1)34.9 = 800(10.5)$

$8.33V1 + 27920 - 34.9V1 = 8400$

$-26.57V1 = -19520$

$V1 = 735$ bbls of water.

$V2 = 800$ bbls - 735 bbls = 65 bbls of barite @ 14.7 sk/bbl or 956 sacks.

Drilling Fluid Conditioning Equipment

Drilling fluid returning from the borehole contains drilled cuttings, mud solids, other particles, and sometimes hydrocarbons - all of which must be removed before the mud is suitable for recirculating in the well. Also, treatment chemicals and clays must be added to the mud system from time to time to maintain the required properties. The equipment necessary to perform these functions is presented and listed in Figure 1 .

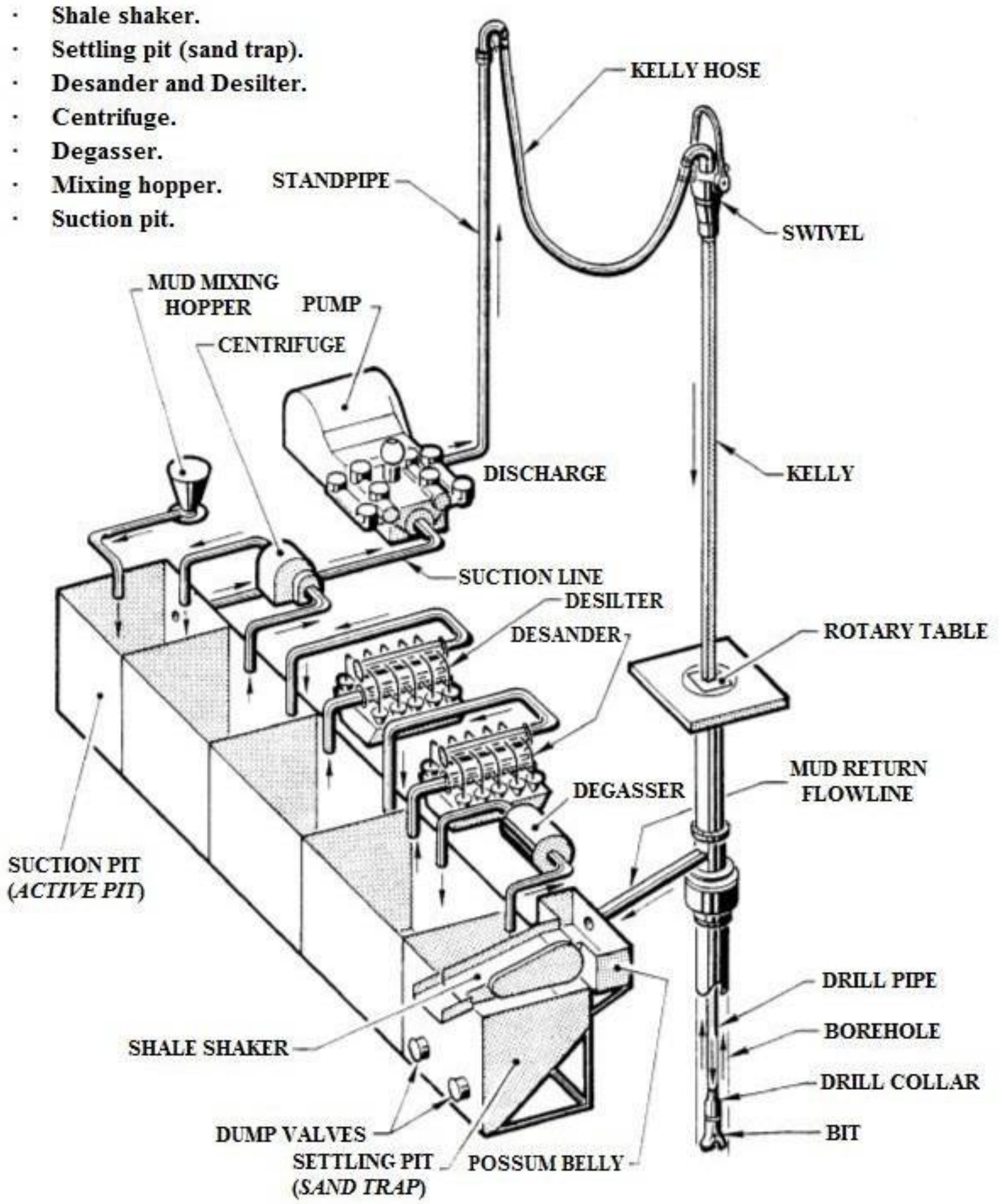


Fig .1. Mud Conditioning Equipment.

Newtonian and Non-Newtonian Fluids:

Newtonian fluids are characterized by a constant viscosity at a given temperature and pressure.

Common Newtonian fluids include:

- Water
- Diesel
- Glycerin
- Clear brine

Non-Newtonian fluids have viscosities that depend on measured shear rates for a given temperature and pressure. Example of Non-Newtonian drilling fluids:

- Most drilling fluids.
- Cement slurries.

In drilling operations, practically all drilling fluids are Non-Newtonian. Even brines which are used as completion fluids are not truly Newtonian fluids, as the dissolved solids in them behave in a Non-Newtonian manner.

Flow Regimes:

There are three basic types of flow regimes:

- Laminar
- Turbulent
- Transitional

Laminar flow: In laminar flow, fluid layers flow parallel to each other in an orderly fashion. This flow occurs at low to moderate shear rates when friction between the fluid and the channel walls is at its lowest. This is a typical flow in the annulus of most wells.

Turbulent flow: This flow occurs at high shear rates where the fluid particle move in a disorderly and chaotic manner and particles are pushed forward by current eddies. Friction between the fluid and the channel walls is highest for this type of flow. This is a typical flow inside the drillpipe and drillcollars.

Unlike laminar flow, mud parameters (viscosity and yield point) are not significant in calculating frictional pressure losses for muds in turbulent flow.

Transitional flow occurs when the fluid flow changes from laminar to turbulent or vice versa.

Drilling Mud Properties:

Mud weight or Mud density:

Unit: pounds per gallon (ppg or lb/gal).

Alternatives: Specific Gravity SG (g/cm^3), kpa/m, psi/ft.

$$\text{Density} = \frac{\text{Weight}}{\text{Volume}} \quad \rho = \frac{W}{V}$$

ppg = sg x 8.33

= psi/ft x 1/0.052

= kpa/m x 1.176

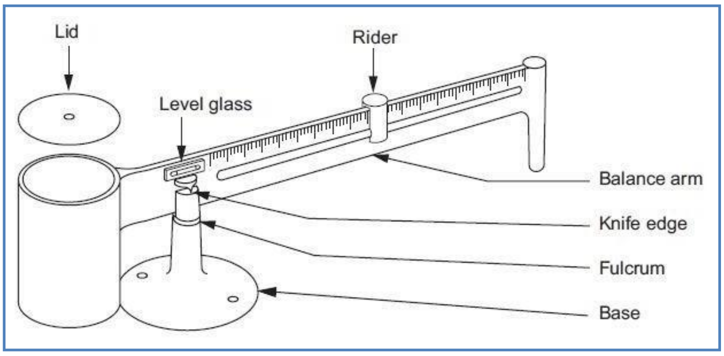


Fig. 2 Mud Balance

Apparatus: Mud balance: The nomenclature used to describe mud balance is shown in (Fig. 2). The test consists essentially of filling the cup with mud sample and determining the rider position required for balance The balance is calibrated by adding lead shot to calibration chamber at the end of the scale Water usually is used for the calibration fluid The density of fresh water is 8.33 Ibm/gal(Fig. 3). The drilling fluid should be degassed before being placed in the mud balance to ensure an accurate measurement.

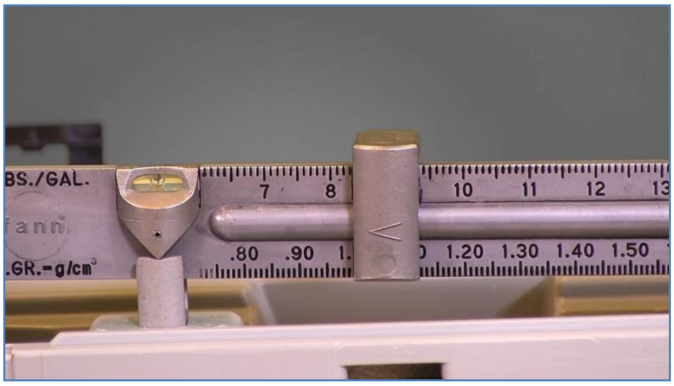


Fig. 3 calibrate, mud balance

Viscosity μ: (cps) (statement of fluid's resistance to flow).

Funnel Viscosity:

Unit: Seconds per quart (sec/qt).

Alternatives: Seconds per liter (sec/lt).

Apparatus: Marsh funnel (Fig. 4). This is usually calibrated to read 26 ± 0.5 seconds when testing with fresh water.

the marsh funnel is a simple device used for the routine monitoring of the viscosity, and should be performed alongside the mud weight check. marsh funnel reading are affected by mud weight, solids content and temperature. the valve from the marsh funnel should only be used for comparison purposes and for monitoring trends.

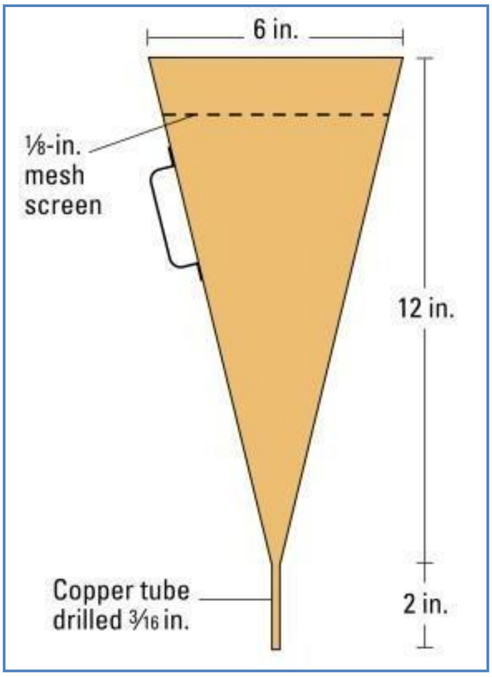


Fig. 4 Marsh Funnel

Plastic Viscosity (PV):

Apparatus: viscometer or rheometer is a device used to measure the viscosity and yield point of mud (Fig. 5). A sample of mud is placed in slurry cup and rotation of sleeve in themud gives readings which can be mathematically converted into plastic viscosity (PV) andYield point (YP). Multi-speed rheometer are recommended whenever possible since reading can be obtained at 600, 300, 100, 6, 3 rpm. PV (in cP) is measured by taking the difference between the dial reading taken at the two highest speeds of 600 rpm and 300 rpm.

$PV = \Theta\ 600 - \Theta\ 300$ .... (1)

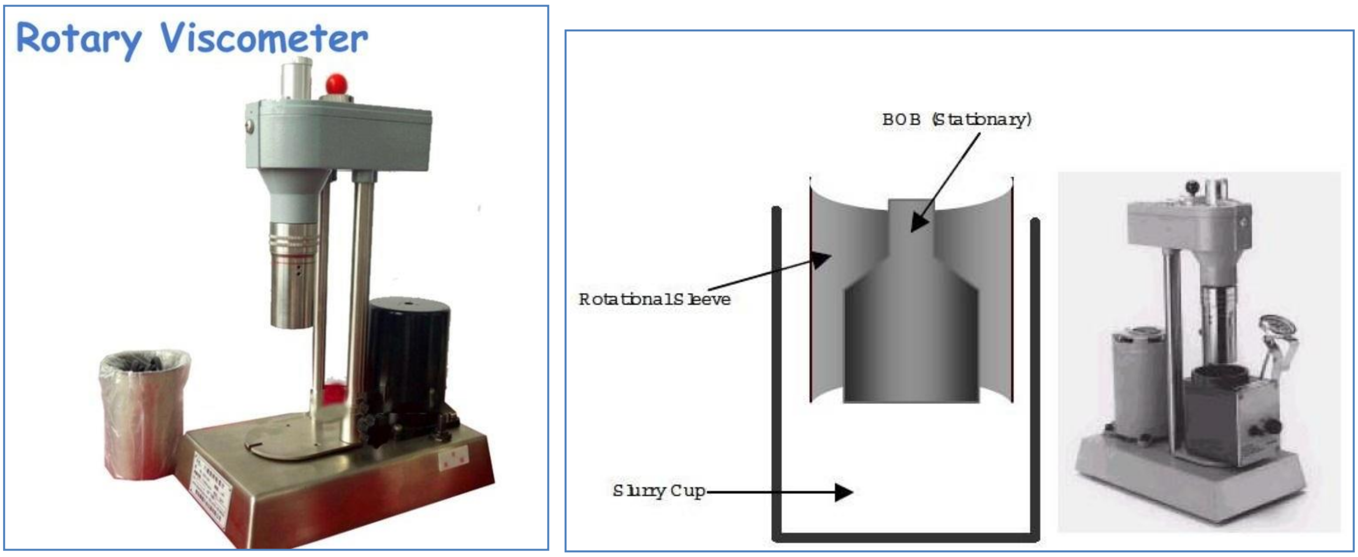


Fig. 5 viscometer

Yield Point (YP):

Unit: lbf/100 ft^2

Alternatives: Pascals (Pa) = lbs/100 ft^2 * 0.48

Apparatus: Same equipment as used for measurement of Plastic Viscosity. Yield Point (YP) is calculated from the following:

YP = ϴ 300 – PV........................ (2)

Example: mud sample in rotational viscometer equipped with standard torsion spring gives dial reading of 46 when operated at 600 rpm and dial reading of 28 when operated at300 rpm. **compute** the plastic viscosity and yield point.

Solution:

1- plastic viscosity

PV = ϴ 600 – ϴ 300

PV = 46 – 28

PV = 18 cp.

2- yield point

YP = ϴ 300 – PV

YP = 28 – 18

YP = 10 lb/100 ft^2

Gel Strengths:

Unit: Same as Yield Point.

Alternatives: Same as Yield Point.

Apparatus: Six speed Viscometer. There are two readings for gel strengths, 10 second and 10 minute with the speed of the viscometer set at 3 rpm. The fluid must have remained static prior to each test, and the highest peak reading will be reported.

Application: The gel strength quantifies the thixotropic behavior of a fluid; its ability to have strength when static, in order to suspend cuttings, and flow when put under enough force. Ideally the two values of gel strength should be close rather than progressively far apart.

Bingham Plastic Models:

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

$$\tau = YP + PV \times (\gamma)$$

where

τ = measured shear stress in lb/100 ft^2

YP = yield point in lb/100 ft^2

PV = plastic viscosity in cP

γ = shear rate in sec^{-1}

Figure 5 Bingham Plastic model