POLITECNICO DI TORINO

Department of Environment Land and Infrastructure

MASTER OF SCIENCE IN PETROLEUM ENGINEERING

MODELLING OF SURGE AND SWAB PRESSURE

A thesis

By

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March 2021

ABSTRACT

Surge and swab pressures have been for a while an issue in the drilling of an oil well. The drill string causes a flow for displaced fluid and a pressure change in the borehole when running in or pulling out of the hole. When the string moves upward creates a swab pressure and it creates a surge pressures when moves downward. They will reduce the mud hydrostatic pressure below the formation pressure and induce a kick if swab pressures are high enough. The formation can be fractured by high surge pressures and lead to circulation loss. It is always important to remove the drill string during the drilling operations specially to change the bit. For other purposes, such as for conducting desired logging operations, it may also be appropriate to remove the drill string. The drill string must return to the borehole after the bit is replaced or after certain logging operations are performed.

The main aim of the thesis is to show the models with the affecting parameters of surge and swab pressures, to explore their effect on the fluid behavior models. The Bingham plastic model, the Power Law model, and the Herschel-Bulkley model are utilized to get the best outcomes.

In general, surge and swab pressures depending on the speed of tripping of the drill pipe, the geometry of the wellbore, flow regimes, rheology of fluid, and whether the pipe is close or open. Various flow phenomena, including eccentricity of pipe, geometric irregularities, and dynamic effects, are attributed to the increase in surge or swab pressure.

ACKNOWLEDGEMENT

This thesis is the final work in the Master of Petroleum engineering, and it is relating to drilling engineering, working on this thesis has been very intriguing and instructive. I like to express my gratitude and appreciation to my thesis supervisor Professor Romagnoli Raffaele, for allowing me the opportunity to work on this topic, and for his valuable directions on my work. finally, I want to thank my family which provided me the help and support during my study at Politecnico di Torino University and makes it a worthwhile experience.

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NOMENCLATURE

BHA	Bottom Hole Assembly
ECD	Equivalent Circulating Density
MWD	Measurement While Drilling
OBM	Oil-Based Mud
PV	Plastic Viscosity
YP	Yield Point
Re	Reynolds number
BP	Bingham Fluid Model
HB	Herschel Bulkely Fluid Model
PL	Power Law Fluid Model
YPL	Yield-power-law
WOB	Weight on bit
a	Constant
g	Gravitation constant
Kc	Clinging constant
L	Length
N	Flow behavior index
P	Pressure
Q	Flow rate
v	Velocity
Δ	Difference
Y	Shear rate
ϴ	Dial read from viscometer

ρ	Density
σ	Shear stress
A	Area
b	Constant
C1	Constant
C2	Constant
D	Diameter
K	Power Law Constant
Rc	Radius Cling
V	Volume
μ	Viscosity
$\boldsymbol{f}$	Fanning friction factor
h	Length of segment
$\boldsymbol{q}$	Velocity of drill string
r	Radius of pipe
R	Radius of borehole
V	Mud flow
$\boldsymbol{vp}$	Tripping velocity
z	True vertical depth
$\Delta\boldsymbol{P}$	Pressure gradient

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1 CHAPTER ONE: INTRODUCTION

1.1 Background

Pressure surges were known for causing problems with well control for a long time. Cannon recognized pressure changes caused by swabbing of pipe in 1934 as a potential causing for fluid influx and blowouts in bad cases. Goins et al. evaluated positive pressure surges in 1951 and connected surge pressures with problems with loss of circulation. The pressure surges magnitude is not critical in most wells because an appropriate mud program and casing design leave sufficiently large margins between pressures of formation and fracture pressures. However, with a large margin of surge-pressure, a certain wells fraction cannot be designed. Pressure surges must be limited within a narrow range in these critical wells. Margins of pressure can be large in other critical wells, but pressure surges might stay as a concern. Some activities are especially susceptible to large surge pressure, such as the operation of small clearance liners used in deep wells.

Many models of wellbore fluid flow have been generated by the need to estimate surge pressure in critical wells. Burkhardt, Clark, Fontenot, and Schuh demonstrate the best examples of the models of pressure-surge "steady-flow". The drilling fluid is properly displaced by the motion of the pipe in these models. Pressures of fluid are measured to be compatible with fluid motion-induced frictional pressure drops. Fluid inertia and the compressibility of the wellbore and fluid are neglected by these models. The non-Newtonian flow complexities of drilling mud are considered by these models.

All these models are complicated enough to involve using a computer program for efficient use. A conservative assumption is the lack of fluid compressibility because a higher flow rate is predicted, which generates a greater drop in frictional pressure. It's not a conservative assumption to neglect fluid inertia. A steady-flow model, notably the negative surge pressure arising from the backflow of fluid when the pipe is pulled out, cannot predict the dynamic surge pressures measured by Burkhardt. The first fully dynamic surge pressure model, formed by Lubinski et al., highlighted the importance of pressure calculation compressibility. Several shortcomings in the Lubinski et ai were corrected by Lal. Model and started an investigation into parameters that affect surge pressures. Field data of surge is less common than models of surge pressure. Data of surge is, understandably, even less prevalent in critical wells (Mitchell et al, 1988).

1.2 Surge and swab pressure definition

1.2.1 Drilling operations and Tripping

Drilling activities are costly, consuming time, and possibly dangerous for individuals and the environment. Running in and pulling out the drill string in the hole is one of the most frequent drilling activities. Such operations are called tripping. A pressure drop is usually referred to as a swab pressure when the pipe moved upward. And for a downward pipe motion, a pressure rise, is called a surge pressure. In the drilling operation, the pressure changes because surge and swab have been a concern for many years. The swab and surge pressures during tripping operations are one of the most common reasons for well-known issues such as kick, circulation loss, and fracturing.

In these operations, the string axial motion creates pressure oscillations that, if the speed of tripping is too high, may violate the well pressure margins. On the other side, it takes time to run the string at unnecessary low velocities and extends this non-productive time. A good understanding of swab and surge pressure is needed to minimize such drilling problems, especially understand the parameters which affect them, like the velocity of the drill string, mud, and formation properties.

With wells that have small windows between fracture and pore pressure, the operation of drilling becomes more challenging. We can name it the margin of pressure. In any drilling operation, this margin of pressure considers as a safety boundary. The pressure of the bottom hole should be located between the margin limits. If not, damage to the formation or flow of fluid may start. Without running any simulation, many companies consider addition a margin of tripping to predict any pressure decrease in the wellbore. Depending on the type of the well, this value is normally between (100-300) psi (Al-Abduljabbar et al., 2018).

The challenge of optimizing and automating drilling rig tripping operations is to define mathematical solutions which accurately refer to all specified parameters. It is a bit complicated to find a good parameter, due to many uncertainties. Simultaneously, to enable automated real-time solutions, the solution must be performed within the available short time. This result is useful for the development of an advanced controller of tripping velocity. (Kuswana et al., 2019)

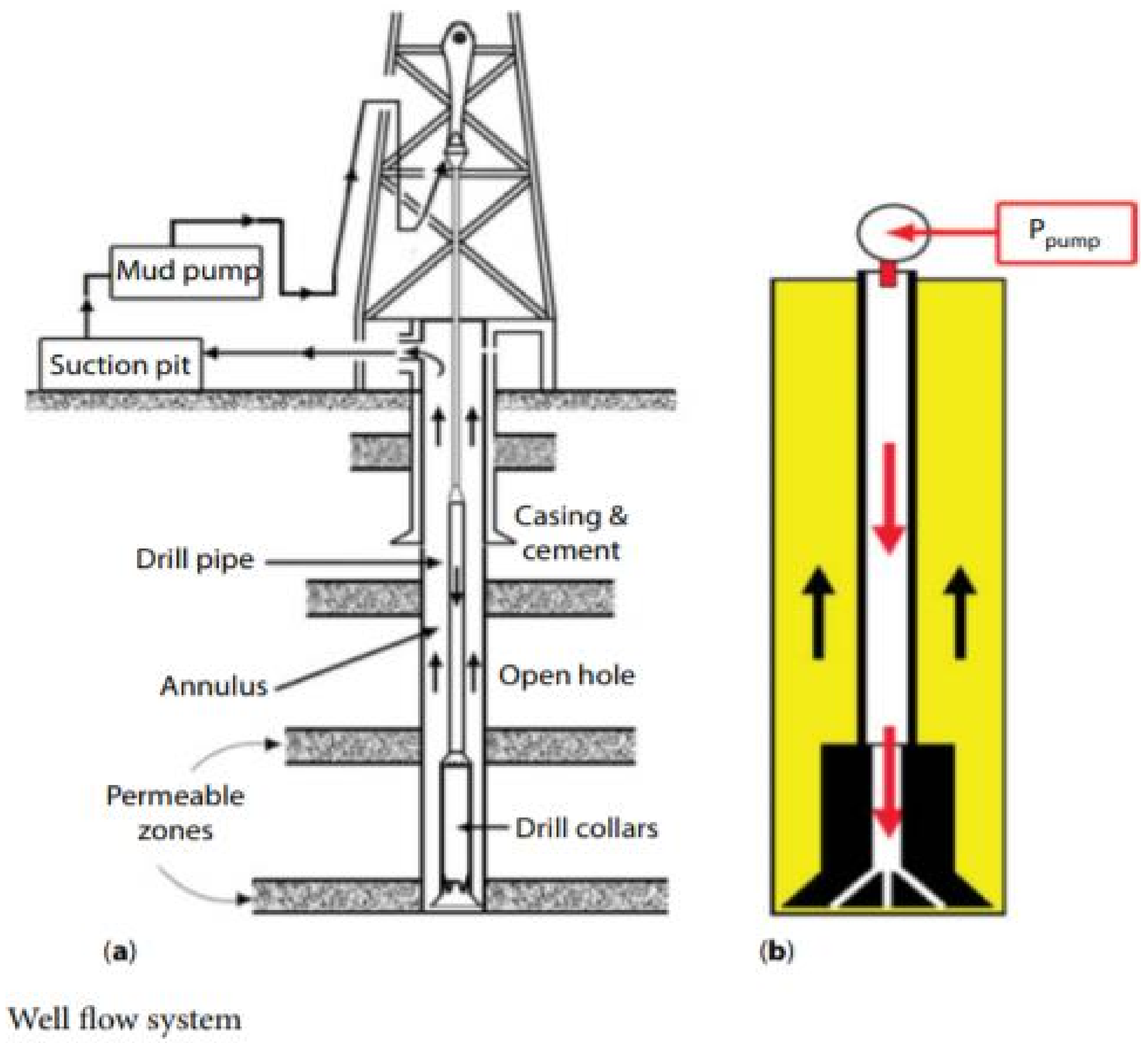

Fig. 1.1 Well flow system (Hossain, 2016)

1.2.2 Formation pressure measurement from drilling data

For the calculation of formation pressure, a set of drilling equations have been suggested. They are good and effective techniques of pressure extracted from logs. While one equation that will work in all circumstances is probably not possible, one of them should work where good practices of drilling are used. In drilling regions, measurements have been made using these techniques, and the achieved accuracies reaching 0.2 lb/gal.

It seems there are two explanations why the equation of pressure must work. Because of porosity or compaction, the basic theory of abnormal pressure suggests that when the bit reaches the zone of high pressure, the rock is more translucent and less dense than it was. The methods of assessing pressure from well-logs, seismic velocities, and shale densities have proven this. Hottman and Johnson suggested in 1965 the concept of variance from normal. Not only they determined that the deviation from normal is an indication of high pressure, But the velocity departure from being normal velocity for depth consideration might quantify the high pressure.

The differential pressure is the key factor affecting the drilling rate. The drilling rate increases as the differential pressure between the borehole and the formation are reduced. The reduction in differential pressure helps to increase the porosity of the entry into the over-pressured zone and increase the drilling rate. It seems, that the more sensitive feature is the differential pressure phenomenon. These findings contributed to the assumption that it was not only possible to assess over-pressured areas, but that the key challenge in overcoming the sensitivities involved in the drilling rate feature seemed to be assessing formation pressures from the drilling rate (Rehm & McClendon, 1971).

1.2.3 Drilling string

A significant element of rotary drilling is the drill-string, which is often called drill stem. A standard drill string consists of the connection of drill bit, drill collar, and drill pipe. Two main objectives of the drill string are:

- It creates a channel into which the drilling fluid is pumped down and circulates back up through the annulus.
- For cutting the rock, it supplies torque to the bit.

The main roles of the string of the drill.

- Suspending the bit.
- To transfer Kelly's rotary torque to the bit.
- Providing a conduit for the drilling mud circulating.
- To give more weight on bit (WOB).
- The bit in the well should be lowered and lifted.
- Can be used as a specialized tool for
  the assessment of the formation when the logging tools can`t be run in the hole.

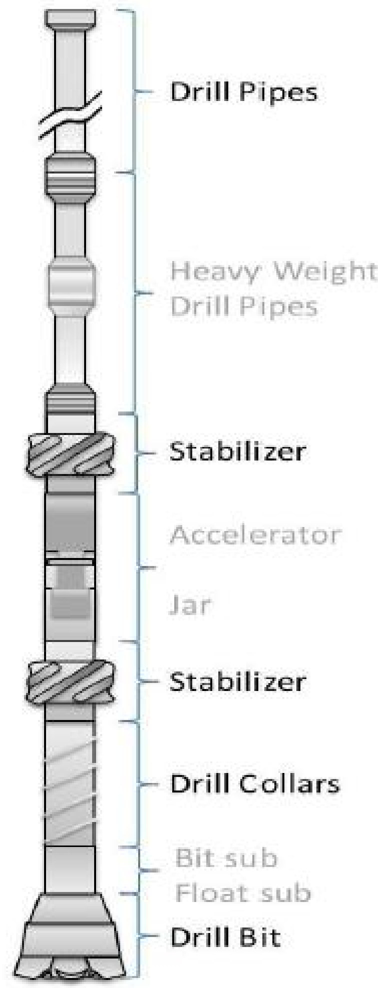

Fig. 1.2 Bottom Hole assembly (Marcelie et al., 2019)

Heavy Weight Drill Pipe

There are pipes with thicker walls than an ordinary drill pipe which is called heavy-weight drill pipes, making them a lot heavier. Their key functions are to provide the drill pipe with a versatile transition, and extra weight to the bit.

Drill Collar

The drill collar, like the heavy-weight drill pipe, is a part that adds weight to the bit, typically made of carbon steel. To prevent contact with the wellbore wall, some drill collars have a spiral shape on the outside, to allow more space for the full fluid to flow.

MWD

Drilling measurement is a drilling logging tool that provides real-time data such as the location of the wellbore, directional data, and drill bit information.

Stabilizers

Due to the goal of preventing sidetracking and vibrations while drilling the well, stabilizers are used in the BHA. Above the bit between heavy-weight drill pipe and drill collars, there may be multiple stabilizers. They consist of a cylindrical hollow body and stabilization blades. These are usually made of hard materials such as high-strength steel.

Drill Bit

The drill bit is at the lowest part of the BHA consists of rotating cones made up of very hard material to cut the formation. The bit also has multiple nozzles, where the drilling fluid falls out and into the well through the drill string. Owing to geometry, the dimensions of the drill bit are difficult to consider in calculations. (M. Enmal, 2017; Marcelie et al., 2019).

1.2.4 Surge and Swab Pressure

The string volume displaces the drilling mud upwards along the wellbore annulus while running a drill string or a casing in the borehole filled by fluid. The flow of fluid associated with the displacement induces a frictional pressure superimposed on the hydrostatic pressure in the wellbore. This raises the pressure of the borehole. Fluid flows into the wellbore when pulling the string from the hole to fill the gap produced by pulling the string. This reduces or swabs the fluid pressure, as the drilling mud flows between the string and the annulus . "swab and surge" are commonly referred to as the effects created by and string tripping. A steady flow profile of fluid in the axial direction is formed in the annulus when the pipe is pushed at a stationary velocity. Because of the force of friction between the flowing fluid and the surface of the annulus.

The forces acting against the flow, like the fluid shear stress, are forces that adjust the pressure in the well. Additional pressure in the wellbore must be included in the pressure analysis.

The acceleration process is intermittent motions, until the pipe movement and fluid flow become stationary, the acceleration stage is typically a small percentage of the total time, but after the string movement of steady-state is formed, the induced pressure waves continue to exist. If the effective pressure is not always held within the limits provided by the formation while tripping in and out of an open hole, fluid inflow or formation damage may start. The safe operation must be preserved when the operation of tripping is optimized to decrease the overall tripping time. This objective includes detailed knowledge of the physics of the tripping mechanism to be planned. For optimizing the tripping speed software, accurate prediction of the pressure shift from the axial movement of a pipe is essential. The borehole and drill string diameters, fluid properties, running speeds, and eccentricity affect the tripping operation. Tripping speed and acceleration, however, are operating parameters that can be changed easily at the rig location.

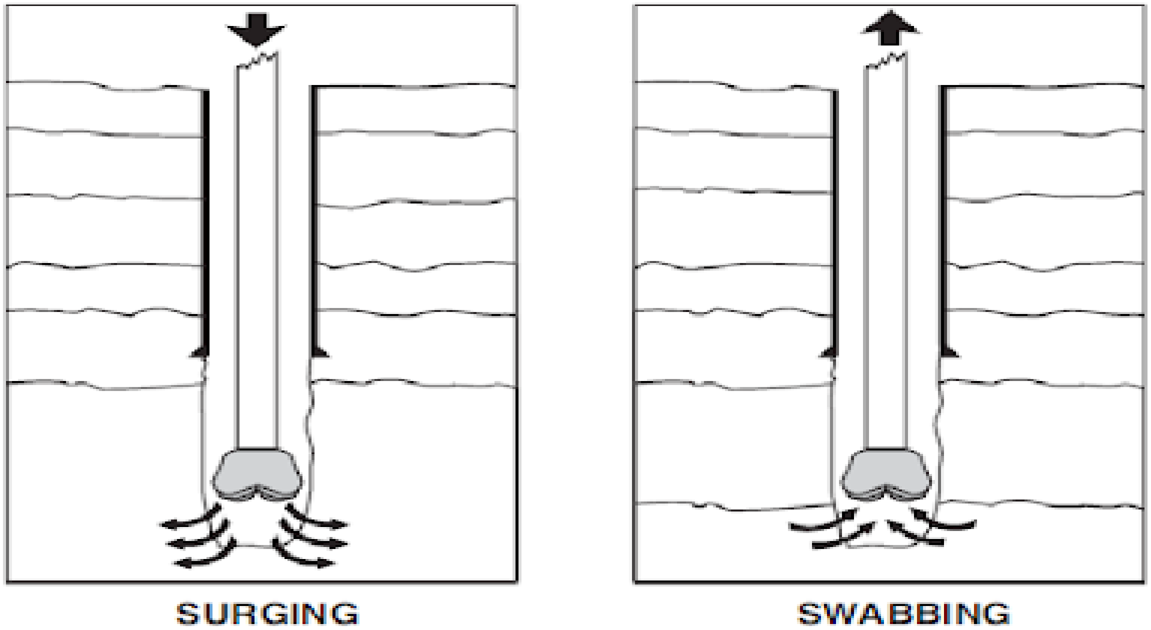

Fig. 1.3 **Swabbing and Surging**

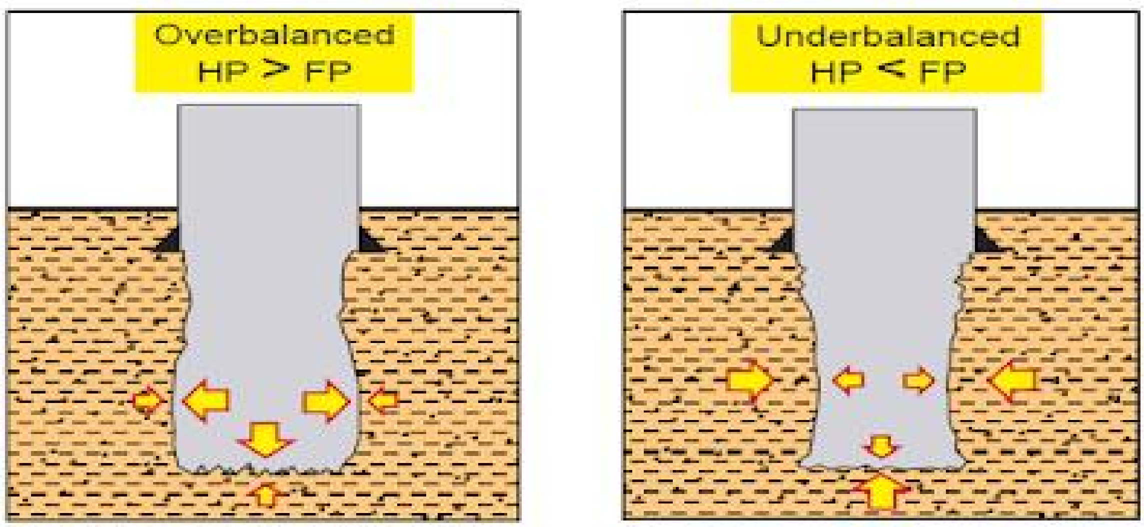

Fig. 1.4 **Hole Pressure vs Formation Pressure**

2 CHAPTER TWO: PROBLEMS OF SURGE AND SWAB PRESSURE

Numerous studies were carried out to examine the impacts of surge and swab pressure. Early research recorded that due to high tripping speeds, wellbore issues such as lost circulation, formation fracturing, kick, wellbore damage, etc. were associated with a swab and surge pressures. When the string is run in a hole, it pushes the drilling mud out of the well. Meanwhile, the mud, which is immediately adjacent to the drill string, is dragged down. The resultant effect of the piston creates a surge pressure which is added to the mud hydrostatic pressure. Excessive pressure surge will raise borehole pressure to a degree which can result in loss of circulation. Conversely, as the drill string is removed out of the wellbore, the fluid runs down the hole to fill the resulting space. This induces a suction force, creating a swab pressure that will reduce the differential pressure and probably bring the fluid of the formation to the borehole.

Surge and swab pressure can lead to unsafe conditions. When swab pressure is too large, then the pressure of formation may exceed the pressure of the wellbore and cause a flow into the borehole. This occurs because the formation pressure can no longer be controlled by the swabbed hydrostatic mud column. This is a serious concern, understanding that some gain of fluid in the borehole leading to blowing out. On the other hand, additional hydrostatic pressure is exerted to the surge pressure. If the margin of pore formation and fracture pressure is narrow, and therefore any additional pressure, like surging pressure, is added to the hydrostatic mud pressure allowing the fracturing of the formation. Getting a formation fracturing allows the mud column within the formation to get lost. This decreases the hydrostatic pressure exerted on the formation, thus encouraging the well for flowing and creating a significant problem of well control (Al-Abduljabbar et al., 2018).

2.1 Losses of drilling fluid

Surging happens as the pressure of the bottom hole is raised due to the impact of moving the drill string too quickly through the hole. If caution is not taken and fracture pressure is exceeded while run in the hole, the drilling mud losses may occur. Proper monitoring with the trip tank of the displacement volume is always needed.

Loss circulation is a big topic and many research and initiatives have been implemented to tackle it in the oil industry. In depleted reservoirs, rocks of high permeable, and fractured formations, lost circulation is a frequent drilling problem. In the shallow, unconsolidated deposits, the range of lost circulation issues starts and extends into the consolidated formations which are fractured by the mud hydrostatic pressure.

Loss circulation could be characterized as the decreased or complete absence of drilling mud flow through the annulus when the fluid is pumped into the wellbore Every year, the industry spends too much money to hold loss circulation and the associated adverse consequences, such as waste of rig time, blowouts, stuck pipe, and the abandonment of costly wells less regularly. The pressure in the borehole should surpass the pore pressure and a flow path for the losses to happen. Two conditions are also required to create a lost circulation downhole. Pathways in the subsurface that cause circulation losses can be categorized as follows:

Induced fractures, cavernous formations, unconsolidated formations or extremely permeable ones, normal fractures in the rock formations. Circulation could be lost even though the fluid density within the normal safety margin is less dense than the fracturing density of the formation (Alkinani et al., 2018).

To avoid well accidents in gas and oil wells, the drilling fluid is the most significant barrier factor. The equivalent circulating density of mud should be maintained between the fracture gradient and pore pressure. Occasionally, this difference is very small, the drilling mud fractures the formation, and the fracture begins to increase; a circumstance called a loss of circulation. sometimes, the path of the crosses natural formation fractures. Although the density of the drilling mud is higher than the pressure gradient of the formation, large amounts of drilling fluid are lost in these natural fractures (Khalifeh et al., 2019).

2.2 Fluid influx

When pulling up the drill string there will always be a reduction to bottom hole pressure. This reduction in the pressure is caused by friction, the friction between the drilling fluid and the drill string is pulled. Swabbing may also be induced by pulling up the downhole tools (bits, stabilizers, reamers, core barrels, etc.). When they are pulled through mud, this can generate a “piston-like” effect. This form of swabbing can have serious implications on the pressure of the bottom hole. If the formation pore pressure exceeds the pressure of the drilling fluid in the borehole, the fluids of formation will enter the well. This may be the result of the swabbing, which allows the pressure to decrease when the drill string is pulling out of a hole. the influx of formation fluid may develop into a kick or a blowout.

2.2.1 Kick

A kick is the consequence of a fluid influx. the fluid of formation enters the borehole, and kicking the drilling fluid out of the wellbore, increasing the volume of the mud. Two different types of kicks, induced and underbalanced, exist.

If the mud weight is too low to hold the formation fluids in place, the kick is underbalanced. In tripping operations, this is normally not a concern, unless formation fluid enters the well and the weight of the mud is not enough to control the well. When dynamic or intermittent pressure effects lower the well pressure, such as swab pressure, the induced kick occurs. Considering the serious effects, it is important to monitor the fluid influx, thereby detecting kicks. The drillers must take the proper action if a kick is observed on the floor and destroy the well. Typically, this is achieved either by circulation the kick out before pumping down mud with an increment density called kill mud, or by using the kill mud to pump out the kick fluid in one circulation.

2.2.2 Blowout

If appropriate action is not taken when the kick happens, it can lead to a blowout, a completely uncontrolled flow of formation fluid in the well. There are three major categories of blowouts:

Surface, subsurface, and underground. Surface blowouts are the most popular, and the pressure of the fluid flow to the surface could be strong enough to destroy the drilling rig and the surrounding area. The subsurface blowout is the most difficult to deal with because of the extreme environmental effects when the fluids of formation are mixed with water. Underground blowouts are uncommon and occur as uncontrolled fluid flows from highly pressurized zones to lower pressure zones. It can take quite a long time to get control after occurring a blowout and the risk to human lives, environmental and material destruction, and economic losses make it a high priority to prevent some sort of blowout (Karlsen, 2014).

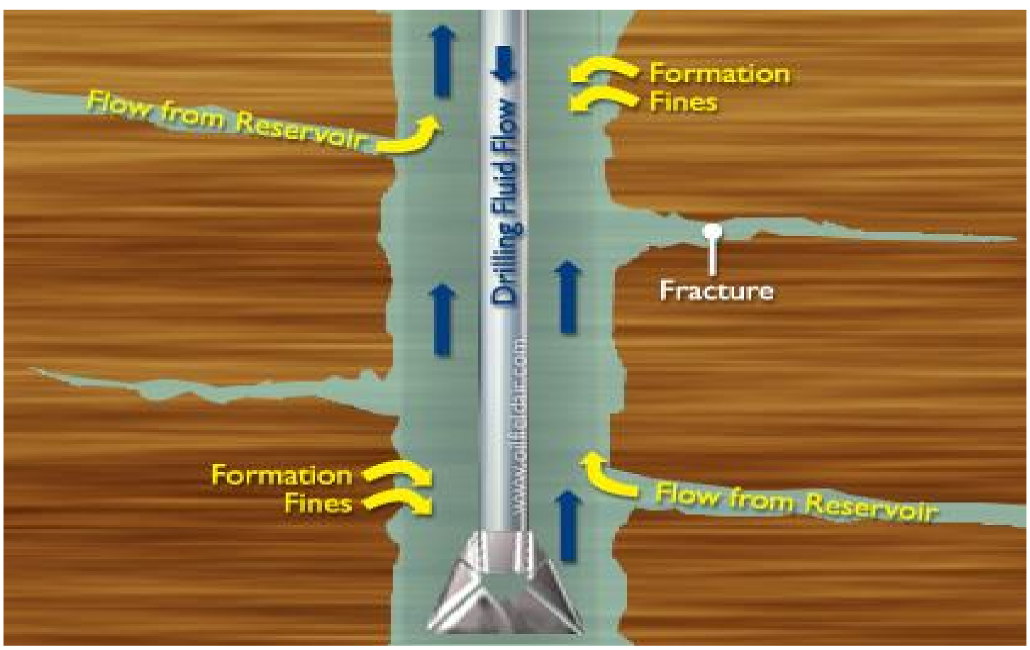

Fig. 2.1 Fluid Influx

The problems of wellbore instability will increase significantly if the downhole pressure fluctuates due to surge and swab effects during the tripping of the drill string. Although the geomechanical model correctly estimated the borehole pressure, the improper tripping variables may minimize the proposed pressure to mechanically keep the wellbore wall stable (Alsubaih et al., 2018).

Tensile spalling may happen since the pressure of the wellbore across a zone. The imbalance between the formation pore pressure and the wellbore will drag loose rock out of the wall if the formation has an extremely low strength or pre-fractured. Surge pressures may also be led to rapid pore pressure excesses cause an abrupt loss of rock strength that can eventually result in disaster. Other pore pressure penetration-associated phenomena can help to stabilize wellbore, e.g. filter cake performance in permeable formation, capillary threshold pressure for oil-based mud (Pašić et al., 2007).

Borehole instability is defined as an undesirable condition of the open-hole interval which does not preserve the size and form of its gauge and its mechanical strength. Wellbore instability issues increase the non-productive time and the costs when drilling unstable formations.

3 CHAPTER THREE: PARAMETERS AFFECTING SURGE AND SWAB PRESSURE

3.1 Tripping speed

Several field experts and researchers have confirmed which simple wells are already drilled, and we only have difficult wells left. Such problems contain the narrow gap among fracture and pore pressure, wellbore stability, and depleted formations. The quick and unexpected motion of the "drill string" when tripping out of the hole reduces the pressure of the wellbore. Also because of the force of friction between the upward moving of pipe and the stationary drilling mud, defined as the "swab" pressure. The reverse case is also true, it will lead to an increase the pressure by moving rapidly within the wellbore, and this is considered as the "surge" pressure. Both the "swab & surge" pressures can contribute to several drilling troubles like drilling fluid losses and influx of wellbore. An extra bottom hole pressure is induced when the "BHA" is running in the wellbore, it is named surge pressure. When this pressure is sufficiently high, several of the previously described troubles may happen. from a different view, if there is a rapid pressure decrease within the wellbore, swab pressure happens. To skip these drilling problems, the best estimation of "surge & swab" pressures is necessary specifically the parameters that influence them for example the tripping speed.

For wells having a limited gap between fracture pressure and formation pressure, the difficulty becomes greater. In deep wells, the speed of tripping will become so crucial as it needs longer time and hence higher costs. It would also be very beneficial to have a model to measure or simulate the maximum speed of pipe running, thus which we are the attention of the difference pressure we are applying. for calculating any pressure dropping in the wellbore without a tripping margin, which is recommended to be added

without simulation. based on the kind of the well, the value is usually among (100-300) psi. The drawback is not recognizing the optimal tripping speed that will save money and time, or not understanding whether the value of the tripping margin is adequate. For choosing the tripping speed, the wellbore stability must also be considered. It will help to clarify whether it is within the boundaries of well-bore geo-mechanics. The high value of surge pressure may lead to fracture formation, which leads to loss of the hydrostatic mud column. Getting the "fractured formation" allows the column of mud inside the formation for being lost.

Decreasing the hydrostatic pressure exerted on the formation, allowing the well for flowing and creating a well control issue. Pulling the drill string out of the well, simulates the piston or syringe effect in which the mud is raised upwards. This occurs. The formation pressure can no longer be resolved by the swabbed hydrostatic mud column. any fluid that gets in the borehole generates a kick contributing to a blowout is a critical threat. (Al-Abduljabbar et al., 2018)

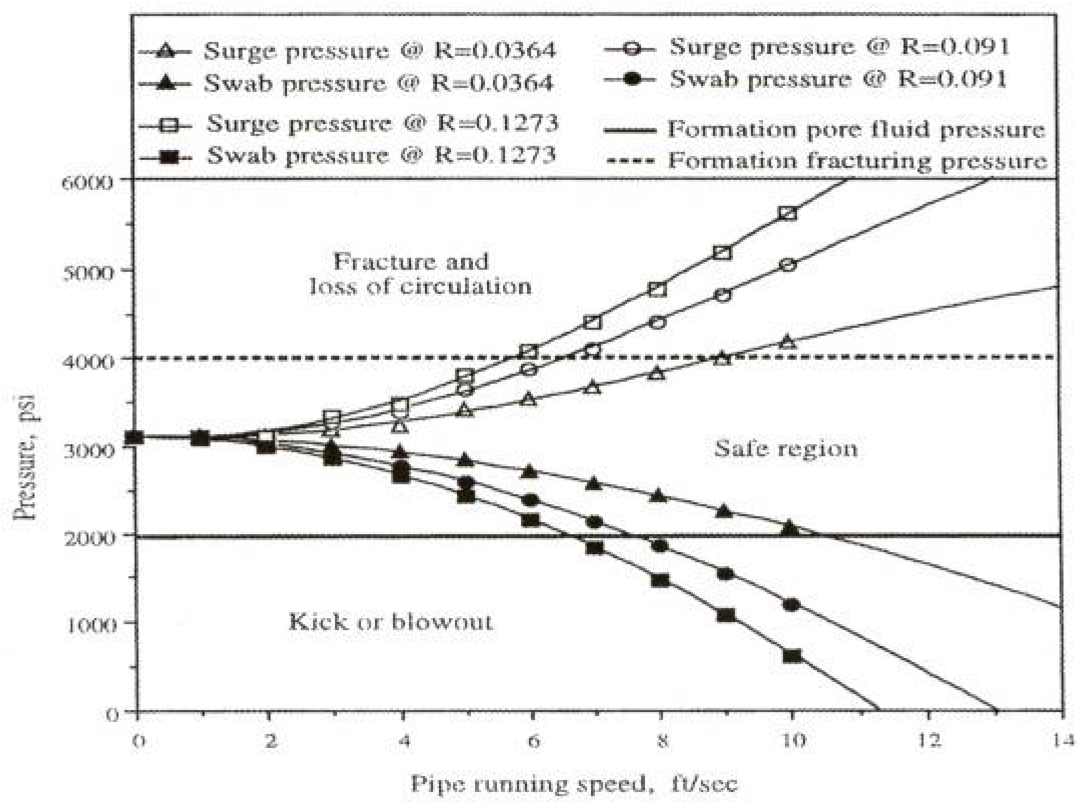

Fig. 3.1 pipe running speed vs surge pressure (Al-Awad, 1999)

3.2 Fluid Properties

3.2.1 Drilling fluid

In drilling engineering, the mud system has many important functions. It is pumped through the drill string, then out from the bit nozzles, and brings the formation cuttings through the annulus from the bottom hole to the surface. It goes to a shaker, where the cuttings are washed out, and the mud goes back to the mud tank. Thus, the removal of cuttings and the cleaning of the hole is not the mud's only feature. The drilling mud is usually made of water, clay, and additives. Oil is often used as the continuous phase to obtain specific properties, the aim of using drilling fluids is to lift the formation cuttings. However, drilling fluids also are similarly critical in maintaining the pressure of formation in the well underneath control. The pressure exerted by mud on the well wall depending on the mud's density. The heavy it is, the further pressure it imposes on it. Thus the weighting materials like "barite" could be added to raise the pressure which the mud imposes (Coussot et al., 2004).

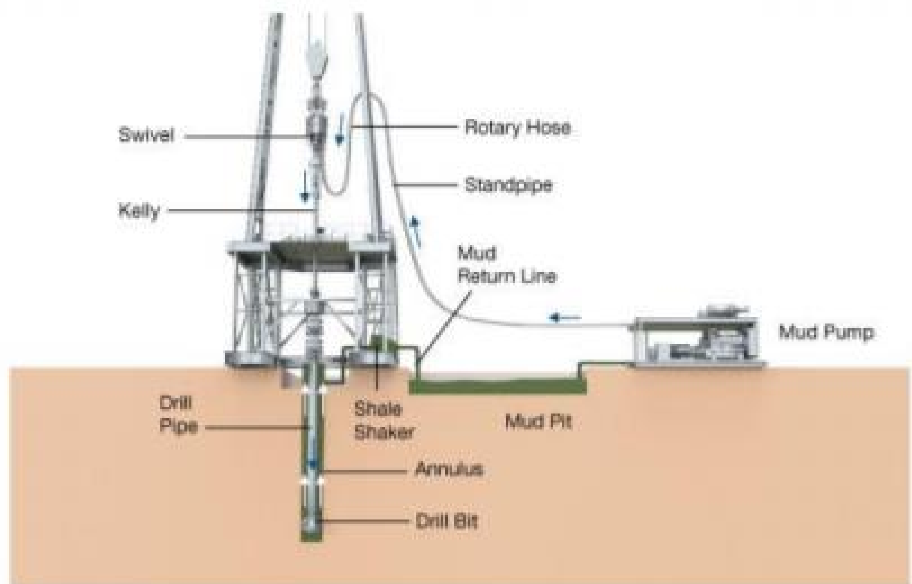

Fig. 3.2 Illustration showing mud circulation (S. Naman, 2017)

3.2.2 Advantages of Drilling Fluids

- Move the cuttings of drilling mechanically from the well until they are recycled in the wellbore again to maintain the hole clean.
- Maintain a controlled formation pressure and prevent any overwhelming hydrostatic forces which might damage the activity of the drilling.
- supply the wellbore walls until cemented or the equipment is mounted and completed.
- For lubricating and cooling the drill string and bit.

- Hydraulic horsepower transmission for the bit.

Enable the knowledge about the wellbore through the study of the cutting's transportation.

3.2.3 Water-Based Muds

There are typically four components of water-based mud: water, inert solids, active colloidal solids, and chemicals. The continuous phase of any water-based mud represents water. It is used to make the initial viscosity, and the rheological properties can be changed by additions. In the continuous phase, reactive solids like bentonite and inert solids like barite are also suspended, For the transport of the horsepower from the surface to the bit, water serves as a medium. and used for chemicals in drilling fluids. Clay is usually used to increase the viscosity of the water-based mud because it raises the density, consistency of the gel, and yield point, and reduces the loss of fluid. In drilling fluids, the clay divided into three parts:

- Montmorillonites (bentonite).
- Kaolinite.
- Illite.

3.2.4 Oil-Based Muds

The oil-based mud is any drilling mud that has appropriate oil as a continuous phase. There are two types of the system where oil is a continuous phase: inverted mud emulsion and real mud oil consist of. The following components:

- Suitable oil.
- Water.
- Asphalt.
- Surfactants.
- Emulsifiers.
- Weighting materials.
- Calcium hydroxide.
- Other chemical additives.

For the functioning of oil-based mud, the first one is necessary among all these components. Some basic rheological properties and plastering features are only applied to the remaining components to improve. Even though water is not needed between the constituent with oil mud systems, few unique rheological properties are also usually applied with several other chemical additives for improvement. To find a particular filtration loss feature, various body additives are utilized in oil muds. These bodily activities can be divided into two groups:

- The size of colloidal materials.
- the more molecular weight of metal soaps Asphalt, one of the organophilic substances of the colloidal size, has been used in oil muds to reduce fluid loss due to its absorption features. It is fundamentally the same principle of clay in water mud. In the meantime, emulsifiers are added to the oil muds for the inverted emulsion operation in the kind of heavy metal fatty acid soaps. The purposes of oil mud emulsifiers are as follows:

- To still be able for suspending the cuttings within the gel, pass on the strength to the oil muds.
- Through the drilling process, every droplet of the water in the oil mud is emulsified.
- Consequently, regulating the tightening of any water emulsion resulting from water pollution controls the loss of fluid.

3.2.5 Synthetic-based mud

It is based on synthetic oil, which has the same features of an "OBM " with the same factors but it is much less utilized and has less toxicity.

3.2.6 Drilling fluid properties

The "surge and swab" pressure is based on the fluid flowing. The high viscosity makes the fluid difficult to flow, so a slower speed of the tripping is required to permit fluid to flow. The high strength of the gel limits flow from static conditions and increases the risk of surge & swab throughout running in and pulling out of the hole, the density represents the most essential purpose (Forutan & Hashemi, 2011). When The mud density is too high or too low which affects the tripping speed that contributes to the surge and swab impact.

to get a good drilling procedure; the various characteristics of the drilling mud always play a vital role which are the simplest modifiable parameters of the operation. For both the individual circumstances of the well and the mud method utilized to drill a well is built. the drilling fluid parameters that are required to identify the key features according to the American Petroleum Institute (API) are:

- Density.
- Viscosity and Gel Strength.
- Filtration.
- The concentration of sand.
- Methylene Blue Capacity.
- pH.
- Chemical analysis.

The important characteristics will be defined in more detail underneath

3.2.6.1 Density

To maintain the wellbore pressure within acceptable limits, the density regulation of the drilling fluid is important. The formation will fracture if the density is too high. And if it is very low, it can contribute to the inflow of fluids from the formation. Fluid density is the mass per volume, and it is linked to the solid specific gravity in the fluid mud weight, expressed in (lb/ft3), (lb/gal), (kg/m3). With low-density muds, such as 1000 kg/m3, solid formations can be drilled, but shale under high pressure, for example, can require a mud density over 2000 kg/m3. The figure below shows the influence of density on the pressure of the surge and swab. The surge pressure is increased when density is increased, while it decreases with density reduction. A swab, on the other hand.

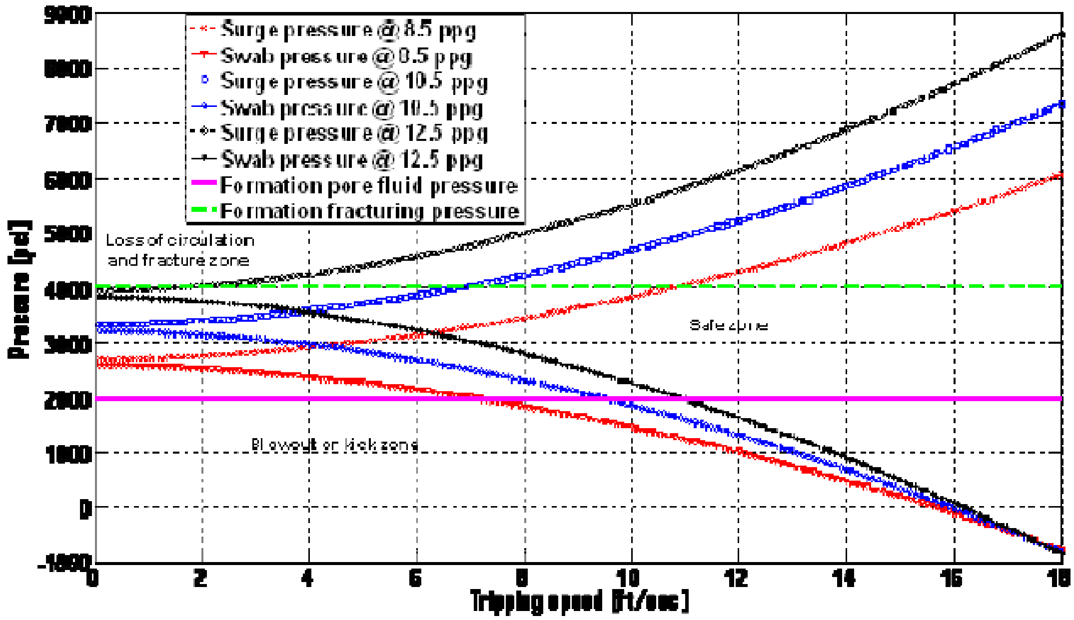

Fig. 3.3 The effect of mud weight on surge and swab pressure magnitude (Mme & Skalle, 2012).

3.2.6.2 Viscosity

During the deformation through "shear stress" the viscosity is the measure of the resistance of a fluid to flow. The greater the viscosity, the greater the fluid's "thickness". The viscometer is often used to determine a fluid's viscosity by calculating the "shear strength" sufficient to crack the fluid's internal tension. This device is continuously regulated at six normal speeds as a “600, 300, 200, 100, 6, and 3 “RPM, and the shear stress is calculated for every velocity. The Viscosity is described by centipoise (cp), equivalent to one "millipascal" multiply by second (mPa s). The viscosity of the drilling fluid may be improved through the drilling process by adding polymers or clay or reduced by adding water or chemical thinners.

We can determine the Bingham plastic viscosity by the dial read using the viscometer. at 600 and 300 RPM.

$$PV = \Theta 600 - \Theta 300 \tag{3-1}$$

Accordingly, There's more viscous cream than water. Indeed, adding a small amount of material to the suspension or solution will dramatically increase the liquid's viscosity. μ is denoted by molecular viscosity; it is expressed in Pa.s or (poise). In general, the viscosity of liquids is greater than that of gas. Since the molecules in liquids are closer together, more frequent interactions are formed between them that increase the cohesion of the assembly. viscosity varies inversely with temperature.

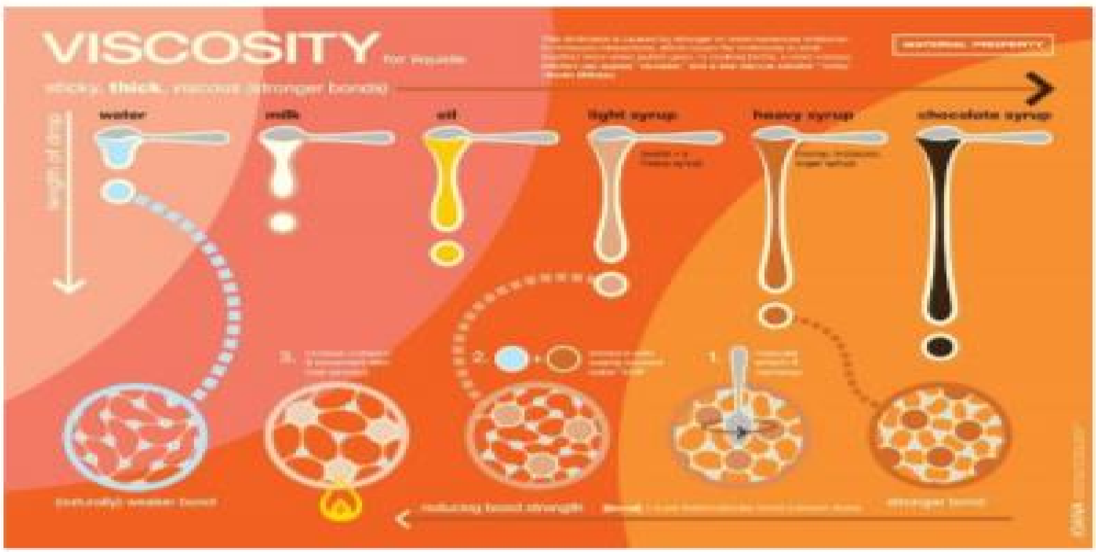

Fig. 3.4 Viscosity of different fluids

3.2.6.3 Yield Point

The stress needed to trigger the flow of the fluid is the yield point. The yield point can be easily derived from the viscometer's measured values of shear stress and is expressed in pounds per square foot (lbs/ft2). When it moves, it is a calculation of the electrical forces in the fluid. The yield point can be determined from the dial read from the viscometer, according to Bingham (Marcelie et al., 2019).

$$YP = \theta 300 - PV \qquad (3\text{-}2)$$

$\theta 300$ = Dial reading when the viscometer is running at 300 RPM

PV = Plastic Viscosity

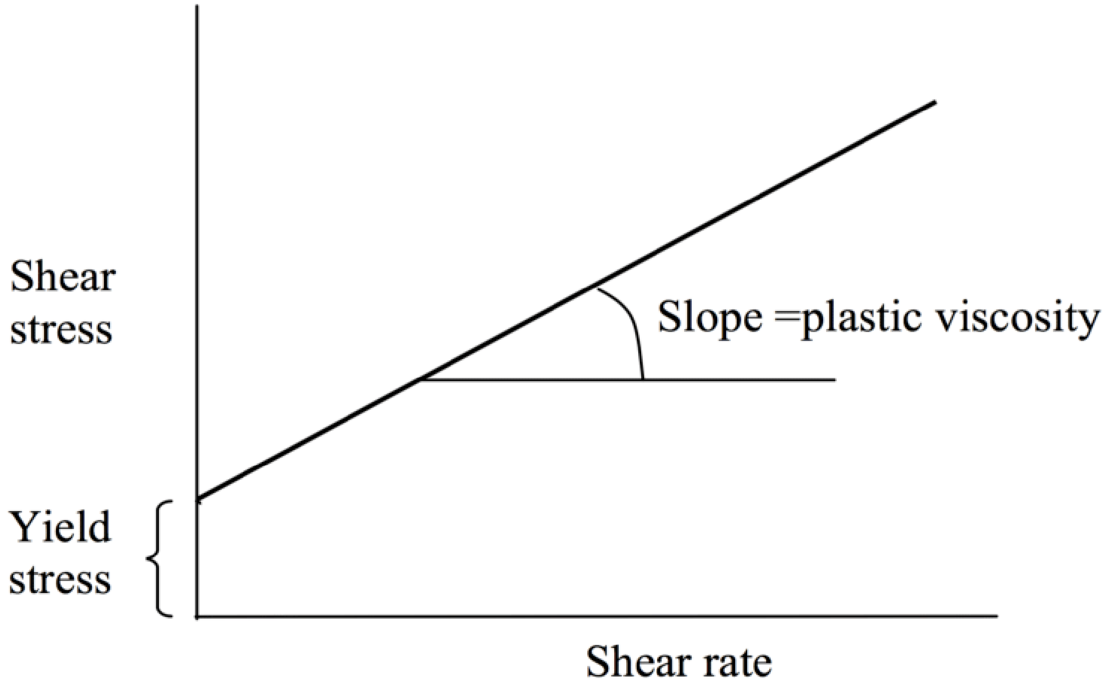

Fig. 3.5 Relationship between shear rate, shear stress, and yield point

3.2.6.4 Rheology

Rheology deals with the movement of material, deformation and, the viscosity under the action of stresses Rheology can incorporate the analysis of all liquid or solid substances. But in most situations, issues related to pasty solids or dense liquids must be dealt with by the formulator. The words used here are purposely vague. That is, one must be mindful that all liquids such as water are included in the word liquid, Chemical solvents, solutions, and dilute dispersions, but also, in pasty, semi-solid, or even solid appearance, much more consistent and viscous substances. Such variations are also due to the wide variety of time scales associated with the flow process. Under the influence of gravity, the movement of a fluid such as water occurs immediately. In certain situations, it can take a few hours to observe the start of a large flow. Not only is viscosity the only quantity to be found, but most materials also often have more marked elastic properties than a complex molecular organization. Viscoelasticity explores the viscous and elastic properties of materials in concert. Rheometers make it possible to obtain curves called Rheograms that define the material's flow properties. To begin with, the shear movement, which is the type of movement being applied in rheology, needs to be described. To undergo the rheology of fluid, here are some main words that should be well understood.

3.2.6.5 Deformation:

Deformation is defined as the relative displacement of points when a force is applied to a substance. Reversible or irreversible deformation could be. if the original shape of the component is not changed after the force applied to it has been removed. The substance is said to have elastic properties. The irreversible deformation is a substance that does not have elastic properties that will flow when a force is applied to it. Before the application of tension, the points would not comply with their previous shape.

3.2.7 Types of fluid:

3.2.7.1 Newtonian Fluids:

If the viscosity of this fluid is not depending on the pressure exerted on it, it is considered a Newtonian fluid. The deformations are relative to the stresses. The best example is the water. Newtonian fluids do not occur completely in real life. Fluids like water or air in normal circumstances are Newtonian (In extreme pressure conditions, water appears non-Newtonian). The Newtonian fluid definition is very limited: the "shear stresses" are relative to the variance of velocity, which contains as follow: -

- The only limitations are generated by a flow "shear stress" in a simple shear flow.

- The viscosity is not depending on the rate of shear.

- The viscosity is time-independent and when the flow is ended, the stresses directly.

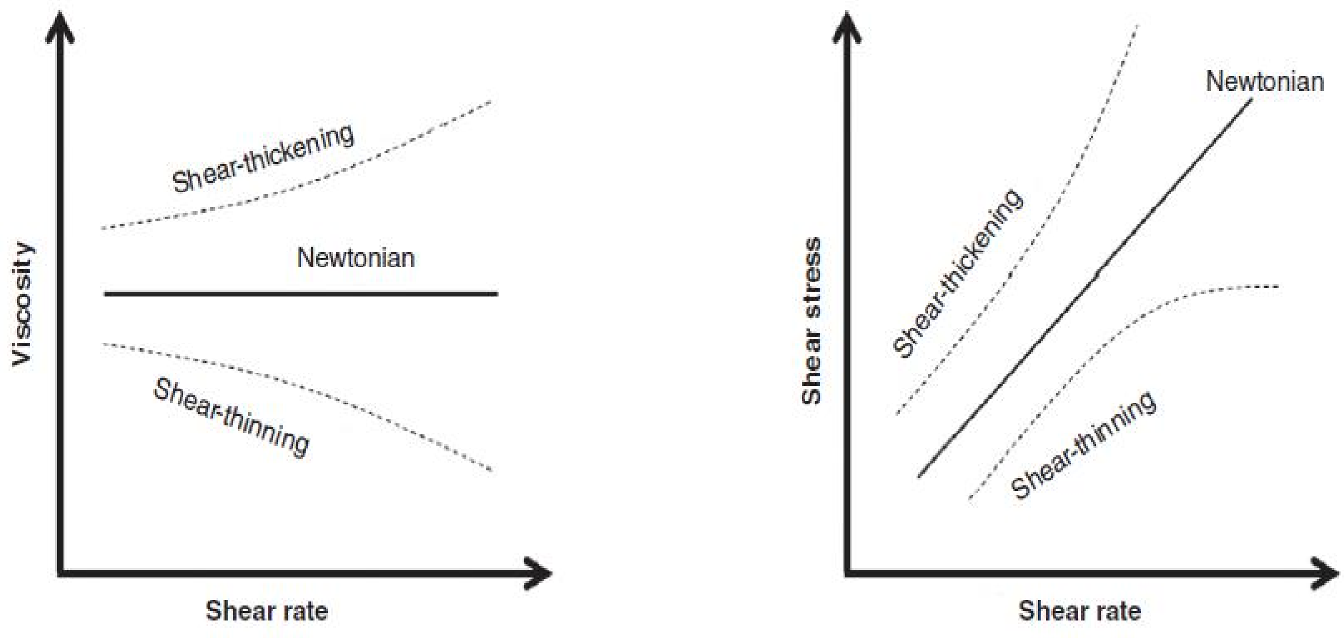

Fig. 3.6 Graphs showing properties a of Newtonian fluid (H. Ebrahim et al., 2019)

3.2.7.2 Non-Newtonian Fluids:

The non-Newtonian fluids are liquids (or other deformable substance) which alter their viscosity with variation in the mechanical stress exerted, or the time when the stress is used, unlike Newtonian fluids. while opposing "shear stress" and the shear rate in comparison with the Newtonian fluids, the non-Newtonian fluids also have a nonlinear diagram. There are many kinds of non-Newtonian fluids. the "viscoelastic, pseudoplastic, dilatant, and thixotropic" fluids can be named. Pseudo-plastic fluid happens when the shear rate increases, creating a desire to become thinner before the viscosity limit is reached. The continuous rise in shear rate would induce a distortion only at the level of the fluid form, rendering it difficult to further raise viscosity.

These fluids, moreover, are non-memory substances, which indicates that the fluid cannot restore its original form if the framework is changed because of the force applied. Ketchup is an example of a pseudoplastic fluid. "Viscoelastic" fluids have a known stress level for flowing. The fluid goes through (high to low) viscosity after the level has been met or exceeded. A form of this is "Bingham plastic" which needs a minimum yield of stress to flow, once the relationship between the shear stress and the shear rate is achieved, its linearity will be found. The Blood, an example of the "Bingham “plastic. The "Dilatant" fluid acts in the opposite of Pseudoplastic fluid, which indicates when an elevated shear rate is placed on it, it is becoming thicker. Similarly, to the "pseudoplastic" fluid, the length of stress is not influenced by it. Therefore, the substance will restore its natural structure until it is disturbed or demolished. cement and honey are examples.

The thixotropic fluid is normally distributed, which indicates that, because of the structure of a framework of intermolecular forces, the substance thickens, and its viscosity increases as the fluid settled. for that, these intermolecular bindings can be solved by exceeding the yield stress with sufficiently strong external energy to make the fluid flow again. The viscosity will decrease concerning a constant shear rate until it reaches the minimum. Thixotropic fluid, however, is time-dependent in comparison with pseudoplastic and dilatant fluids: this means that when it comes to rest, the fluid can restore its previous structure.

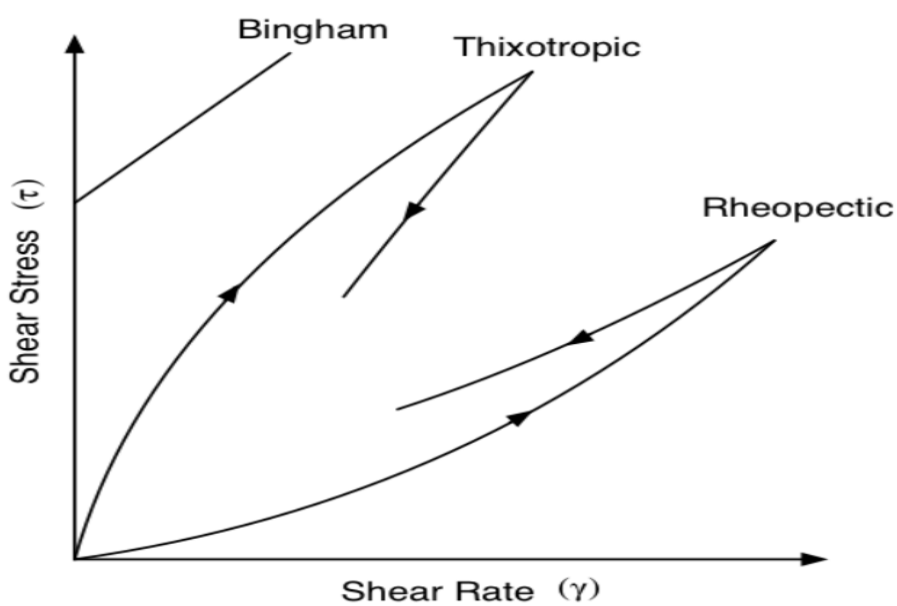

Fig. 3.7 Graphs showing properties of non-Newtonian fluids.

3.2.7.3 Emulsion:

Oil does not necessarily dissolve in water. Two separate layers of both fluids can form when poured into a container filled with water. because of the influence of buoyancy, the oil is less dense than water, allowing it to float. Consequently, the emulsion is when two immiscible fluids are forced to blend to form a mixture. Generally, emulsions are more viscous than the two fluids that come from. An emulsifier is needed to stabilize the mixture and prevent separation again to attain this condition. Lecithin is an example of an emulsifier found in eggs. The water-loving head dissolves in water and the water-hating tail dissolves in oil, for example, rendering the mixture incapable of separation. Lecithin has a water-loving head and a water-hating tail (Bonn et al., 2008).

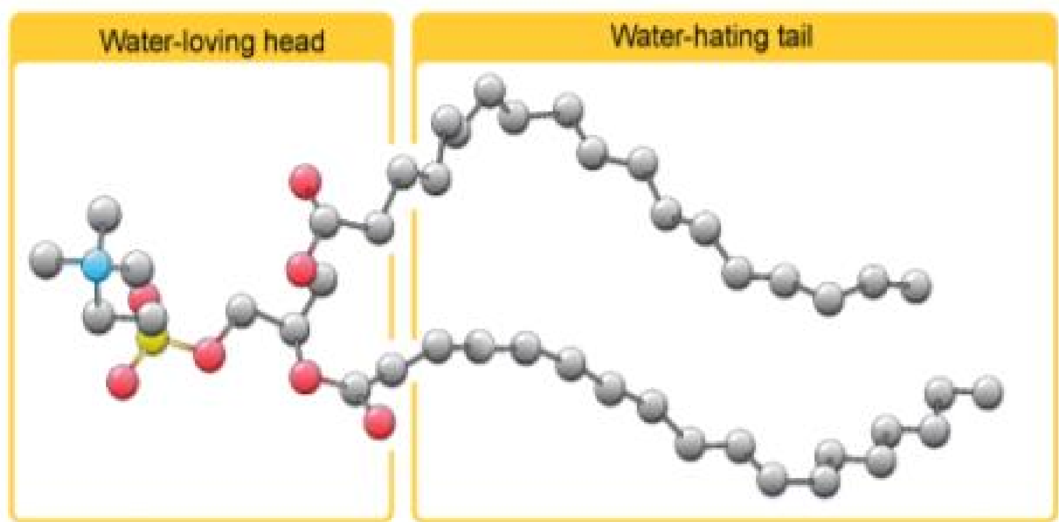

Fig. 3.8 Structure of Lecithin.

3.2.7.4 Invert Emulsion:

If we use the "backward" emulsion, the inverted emulsion means that the usually continuous phase becomes the scattered phase and vice versa. For instance, if we prepare a water-in-oil emulsion, we will proceed with an inverted emulsion. In oil drilling, this method is commonly used. When good wellbore stability and high-temperature tolerance are needed, they use an inverted emulsion drilling fluid.(Bonn et al., 2008)

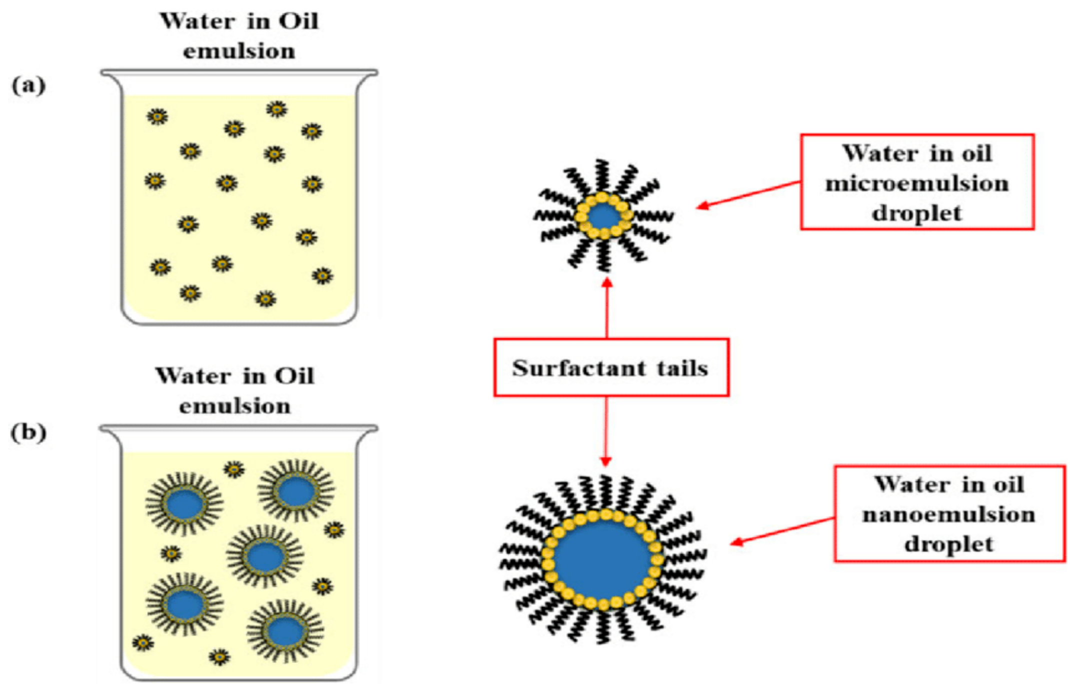

Fig. 3.9 Image showing Water-in-oil and oil-in-water emulsions (N.H Marzuki et al, 2019)

3.2.8 Flow conditions

Based on the value defined as "Reynolds" number (the dimensionless quantity), the fluid flow types are laminar, transition, or turbulent which can be computed from:(Al-Abduljabbar et al., 2018)

$$Re = \rho\ v\ D \qquad (3\text{-}3)$$

Where:

ρ = density of a fluid.

v = velocity.

D = Pipe diameter.

μ = dynamic viscosity.

The flow pattern is described as

- Laminar for Re < 2300
- Transient for 2300 < Re < 4000

- Turbulent for Re > 4000

Laminar flow:

Is always detected in the low-velocity patterns. In the smooth layer formation, the fluid flows and the movement of molecules is regular, flowing across straight lines parallel to the wall of the pipe.

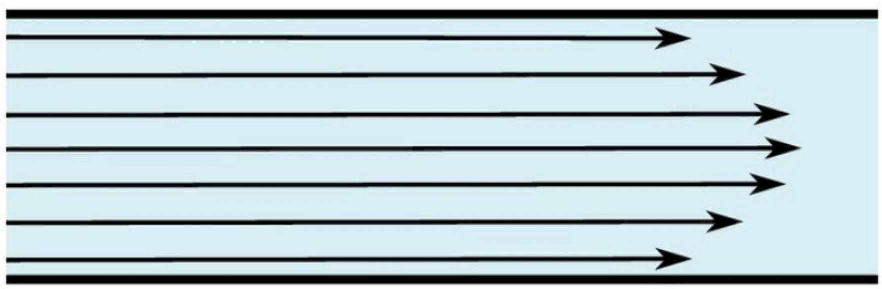

Fig. 3.10 Laminar flow (Hossain, 2016)

The transition zone:

The condition in which the fluid is passing through the laminar to turbulent flow is. Both flow systems can be found.

Turbulent flow:

It happens at higher speeds and wider pipes. In random and chaotic movements, the flow is out of control. It is only possible to find a thin layer of order close to the wall.

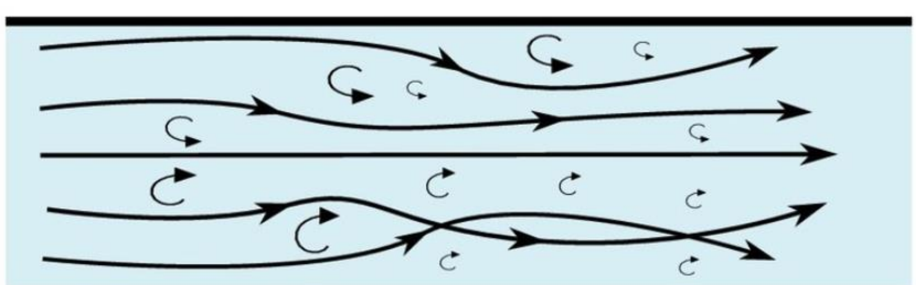

Fig. 3.11 Turbulent flow (Tveit, 2016)

The pressure increases significantly whenever the flow varies from the laminar to turbulent flow.

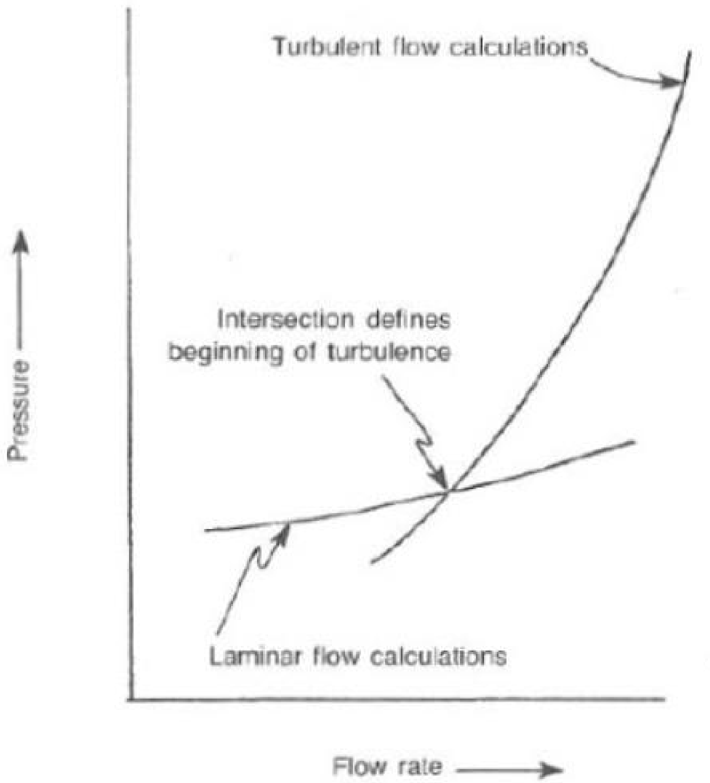

Fig. 3.12 *Development from laminar to turbulent flow*

3.2.9 Frictional pressure

There will always be a significant pressure loss due to the friction of the fluids, between the wall of the wellbore and the drill pipe while drilling mud is circulated inside the well. The "flow rate, wellbore/drill pipe structure, fluid rheology and property, and flow pattern are a feature of frictional pressure loss.

The friction element f could be determined whenever the "Reynolds" number is defined.

$$f = 0.0791/NRe^{0.25} \quad (3\text{-}4)$$

laminar flow, and

$$f = 16/NRe \quad (3\text{-}5)$$

where NRe < 2,100 for transient and turbulent flow conditions.

we can calculate the total loss of frictional pressure in the annulus

$$(\Delta p/\Delta L)_f = f\ \rho\ \mathcal{V}avg^2/25.8\ (D_2 - D_1) \quad (3\text{-}6)$$

Where ρ = fluid density, f = friction factor, Vavg = average velocity of the fluid, D2 = inner diameter of wellbore wall, and D1 = outer diameter of drill pipe (J. P. Langlinais et al., 1985).

3.2.10 Fluid velocity

An estimate of the average fluid flow velocity is needed to measure frictional pressure loss. Velocity is the relation of the conducting channel with the flow rate and cross-sectional, in this case between the wall of the wellbore and the drill pipe:

$$vavg = Q/A = 4\ Q/\pi\ (D_1^2 - D_2^2) \quad (3\text{-}7)$$

Were

Q = flow rate,

A = flow area,

D1 = diameter of drill pipe,

D2 = inner diameter of wellbore wall.

3.2.11 Equivalent Circulating Density

When adding friction from the annulus to the actual fluid density, the equivalent circulating density, ECD, is known as the apparent density of the drilling mud. This is particularly critical because there is a small window between fracture pressure and pore pressure.

The down-hole pressure and temperature levels will impact the density of the mud and must be considered. The density will be decreased by high temperatures and increases with low temperatures. The fluid will be squeezed, the volume will decrease, and the density will increase as the pressure increases (Karlsen, 2014).

ECD is a function of pressure losses.

$ECD = \rho mud + \Delta Pannual\ friction + \Delta Pcuttings + \Delta Psurge\ \&\ swab + \Delta Protation + \Delta Pacceleration / g\ z$ (3-8)

Where g = 9.81 m/s2

and z is the length of the section in meters.

Only because of the small effect of surge and swab pressure. It is possible to rewrite the ECD formula to:

$ECD\ [ppg] = \rho mud + \Delta Pannular\ friction / 0.052 * TVD$ (3-9)

It is an essential feature of surge and swab predictions to estimate ECD. which is directly influenced by the shift in pressure and reads a lower value when swabbing happens than the real density and a higher value for the surge.

3.2.12 Clinging Constant

The constant of Clinging K_C, describes the mud sticking to the wall of the wellbore, producing a "new" diameter. Via the use of complex equations derived from the Bingham Plastic Model, Burkhardt obtained the K_C correlation. For small annular clearances, where the value of K_C was close to 0.5, surge and swab pressure would be most significant. It must be articulated as (Marcelie et al., 2019):

$K_C = (a^2 - 2a^2 lna - 1)/2(1 - a^2)\ lna$ (3-10)

if the flow is laminar, it is the pipe diameter to hole diameter ratio a. but for a turbulent flow, it is possible to express the Clinging constant as:

$K_C = (\sqrt{a^4 + a.1 + a} - a^2)/1 - a^2$ (3-11)

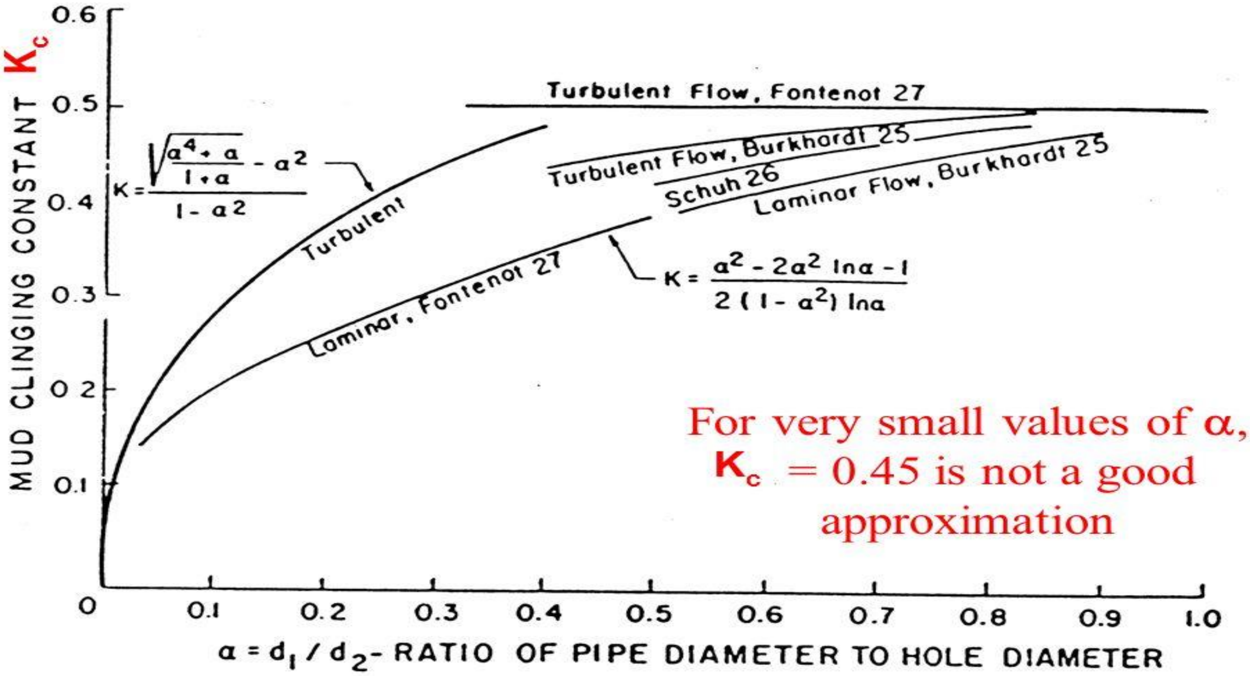

Fig. 3.13 Clinging illustration (Jr. et al., 1987)

3.3 The geometry of the wellbore

The clearance between the drill string and the borehole is so important, the low the clearance, the more fluid flow must be overcome by restriction. The surge and the swab pressure increase when the annular clearance decreased that it is influenced by many factors such as balling, BHA volume, doglegs, hole angle, swelling formations, and stabilizer numbers. Depending on the diameter ratio and annular eccentricity, the tripping speed varies. The large size of the hole enables the drilling mud to fill rapidly while tripping out of the hole in the position that was occupied by the drill string. It is then easy to monitor the formation of pore pressure, and blowouts are prevented. A wide hole can provide the mud with a wider passage area when tripping in. The piston-cylinder movement acting counter to the formation is reduced and it is possible to prevent fracturing of the formation in inclined and horizontal wells, eccentricity mainly affects the surge and swab pressure. The pipe can be moved more easily than expected by concentric models and can still function safely. This is because the loss of differential pressure in a concentric annulus is greater than in an eccentric annulus (Srivastav et al., 2012). The section at the end of the drilling string is the bottom hole assembly (hereinafter referred to as BHA). The drill bit is at the bottom of the BHA. A drill collar, stabilizer, reamer, heavyweight drill pipe, jarring unit, mud engine, directional drilling equipment, MWD, and logging tools may also be used. The functions of the BHA components are to penetrate the formation, stabilize the drilling, improve directional control, and optimize the efficiency of the drilling. Most of the pressure loss in the well is shown to occur around the BHA, especially where the annular space is limited (Tveit, 2016).

4 CHAPTER FOUR: RHEOLOGICAL FLUID MODELS

Many mathematical models have been developed to explain the flowing reaction of the fluid, depending on the use of shear rate versus shear stress. A general relationship of shear stress and shear rate for non-Newtonian fluids does not present, because it is depending on the composition of every single fluid. The mathematical methods are a very close approximation of the behavior of the non-Newtonian fluid. In the petroleum industry, the most well-known models for non-Newtonian fluids are the Herschel-Bulkley model, Power-law model, and Bingham Plastic model:

4.1 Bingham Plastic Model

This model can be defined as a two-parameter model which is commonly known in drilling mud to show the characteristics of flow in several mud types. making finite shear stress, which below this value, they will not flow. And above it there is the yield point, just like a Newtonian fluid, the shear rate is a linear relationship with shear stress. The shear stress/shear rate graphic is shown in Fig.4.1 The Bingham fluids act like solids till the applied pressure breaks the shear stress. The shear stress can be written as the following:

$$\tau = \tau_y + \mu_p \gamma \tag{4-1}$$

Where: τ = The Yield Point (YP), lb./100ft.

μp = fluid Plastic Viscosity (PV), Pa.s or cp.

γ = The shear rate (sec).

It is possible to determine the two parameters (τy and μp) from the previous equations above. The Bingham Plastic fluids behavior is described by a shear rate-independent plastic viscosity and yield point this behavior is exhibited by most of the water-based cement slurries and water-based drilling fluids. Drilling muds with YP and PV are characterized. This model does not accurately represent the fluid behavior when the shear rate in the annulus and across the bit is very low or very high (Lauzon and Reid, 1979; Adewale et al., 2018).

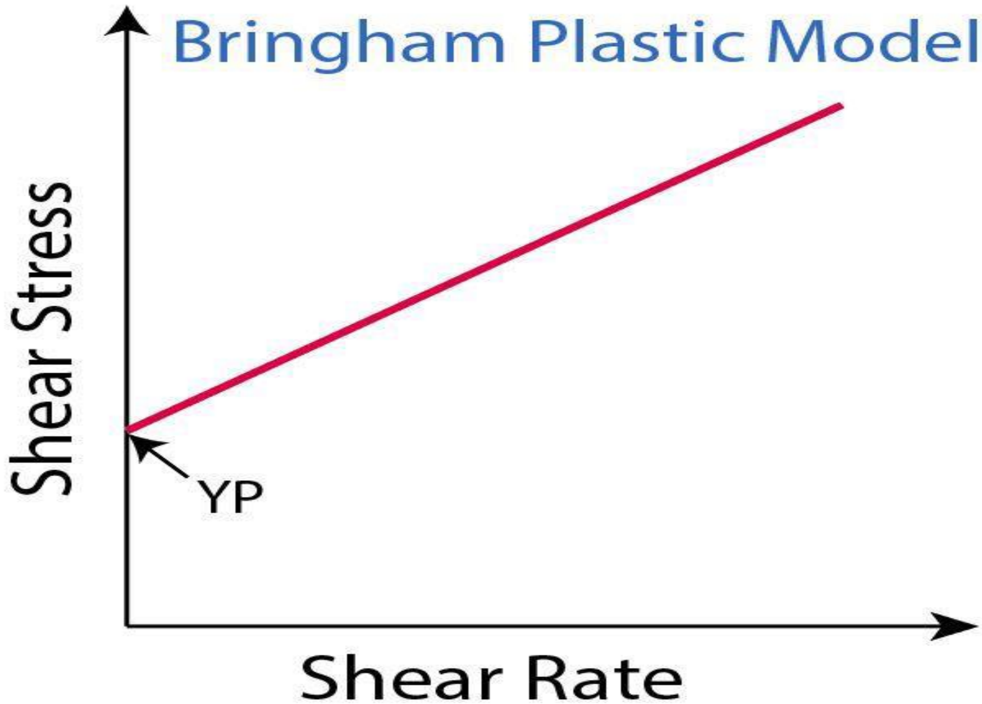

Fig. 4.1 Bingham plastic model

4.2 Power Law Model

The model of power-law can be defined by:

$$\tau = K\gamma^{n} \tag{4-2}$$

The term "K" is described as the index of consistency and identifies the drilling fluid's thickness. The "n" exponent is called the index of flow behavior. There is no concept for the yield point and when the shear rate is zero, fluids following this model have no shear stress. The index of flow behavior "n" shows the non-Newtonian degree. When 'n' values are equal to 1, the model decreases to Newtonian fluids. The fluid demonstrates properties of shear-thinning and is identified as pseudo-plastic fluid as the values of "n" become smaller than 1. The fluid shows shear thickening properties at values higher than unity n and is described as dilatant. These rheological properties aid to assess the effects of fluid flow behavior and continuously make critical decisions based on these parameters (Muherei & Basaleh, 2016; Ugochukwu, 2015).

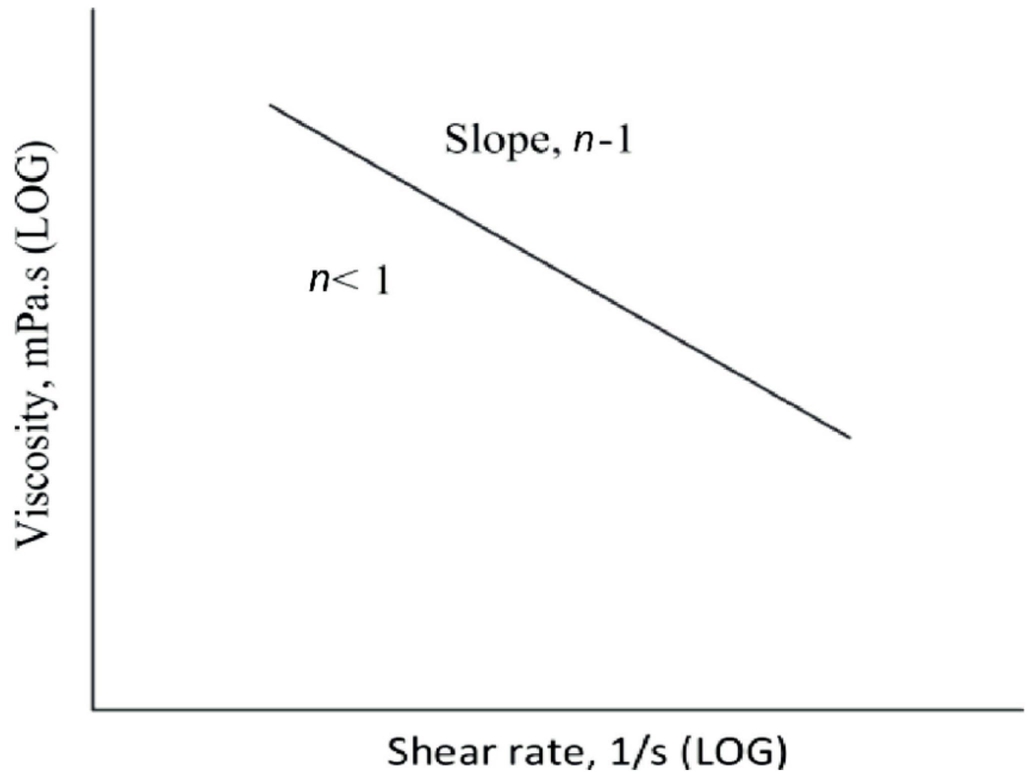

Fig. 4.2 Power-law model

4.3 Yield Power Law (Herschel-Bulkley) Model

The model is named after Herschel and Bulkley outlined how the viscous flow curves will respond with high certainty. The shear stress τ associated with a yield stress, τy, a consistency factor, k, and the shear rate, γ, as in the equation 4-3 (Marcelie et al., 2019).

$$\tau = \tau_y + k\dot{\gamma}^n. \tag{4-3}$$

The minimum shear stress creates a flow which is the yield stress. The material will behave as a solid for any shear pressure lower than the yield stress. The consistency factor, k, is dependent on the exponent of the curve, n. Consequently, k = k (n). we cannot determine the consistency parameter directly from the measurements of the fluid. It must be identified by algebraic operations and, besides, it cannot contain information on the fluid's physical dependencies alone. We can find an example for the combinations of k and n with flow curves is given in Table 4-1, showing the values obtained if the parameters of the fitting curve are dictated using various shear rate ranges from the same data set.

This table is an example of parameters for Herschel-Bulkley determined from the curve of flow by used drilling mud at 25 ◦C, with a rheometer.

Table 4.1 Herschel-Bulkley parameters

Shear Rate Range (1/s)	τ_y (Pa)	k (Pa·s^n)	n
0–1000	0.2	0.0229	0.9806
0–300	0.2	0.0548	0.8269

When we determine the yield, stress values we use the least square fit data of the rheometer to calculate Herschel-Bulkley parameters. If the measurement values up to 1000 1/s are used in the fit, the numerical results values of the consistency parameter founded by fitting measurement values from the shear rate domain up to 300 1/s are less than half of the obtained value. This example shows the fluid property parameter, k will not be used alone. Its numerical value is always dependent on the index of the curvature, n. That's why it is irrelevant to tabulate the k parameter for other perspectives than to reproduce numerical calculations (Saasen & Ytrehus, 2020)

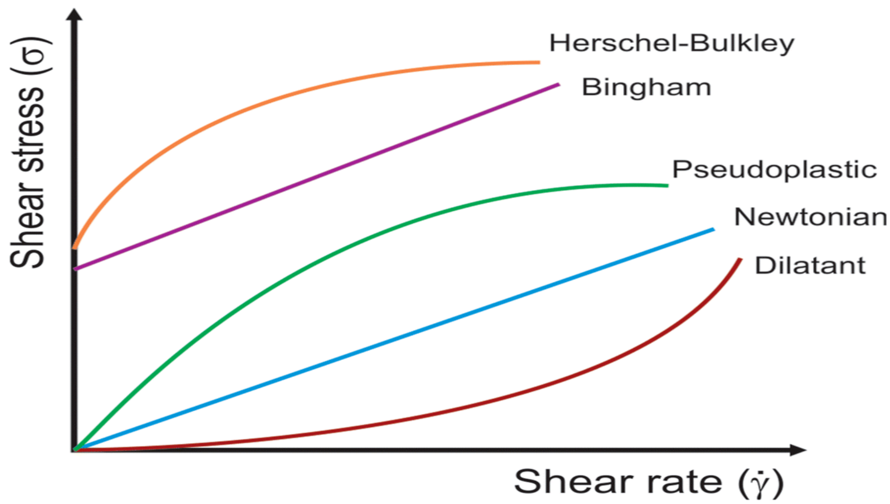

Fig. 4.3 Fluid behavior relative to shear rate and shear stress

4.4 Lumped element model

In the lumped element model, we consider a vertical drill string (L) consisting of several pipes, Like drill collar, drill pipes, and heavy-weight drill pipes. Drill collars are rigid pipes that are positioned at the bottom of the drill string above the bit for the compression forces to give extra weight on the bit while drilling. The bottom hole assembly (BHA). Modeled as a set of n numbers of blocks connected by n numbers of elements of the spring, see Fig. 4.4. The blocks are with zero length and the distance across each block is h = L/n, such as in the figure. There are many cross-section areas of the blocks, allowing for the various dimensions of the pipe in the drill string. Concerning the blocks, the springs are free to rotate, meaning that angular momentum could not be taken up by the springs. The wellbore is vertical, where positive z is downwards, and a one-5-dimensional coordinate system is introduced. From the first spring, which is the first block (Hovda, 2018).

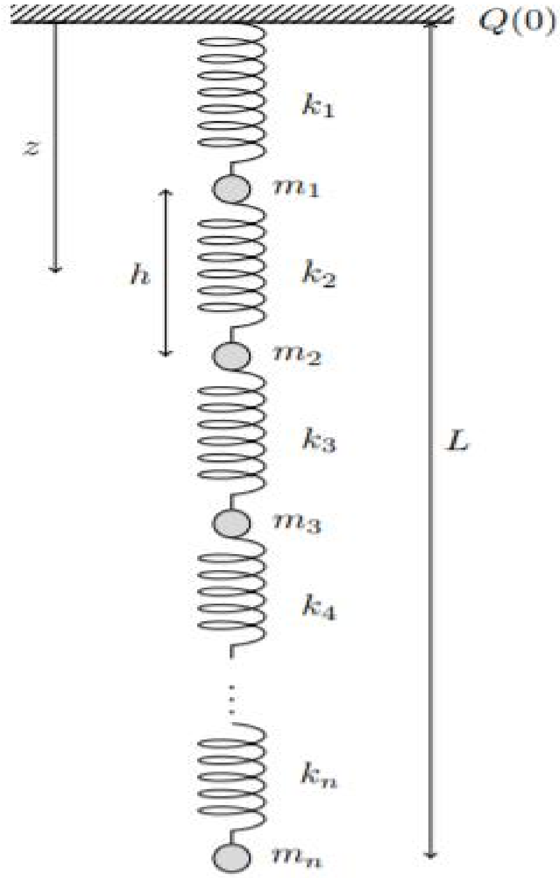

Fig. 4.4 Schematic view of the model of the drill string. The drill string is considered as a set of n blocks (mi) that are connected to n springs with spring constants ki. (Hovda, 2018)

The first block hangs from the first spring which is attached to a point named "block position" This point has the Q(t) coordinates and the selection of the coordinate system origin so that Q(0) = 0. Note, the pipe inside the hole will supply Q (t). Qi(t), where t is time, denotes the co-ordinate of each block. The Qi(t) coordinate is ih, in the inaccurate case where all springs are not in compression and not in tension. By Qi(t) = ih+qi(t) we define qi(t). Therefore, the physical condition of the drill string at any moment is uniquely defined by the generalized coordinates qi(t) and Q (t). Then we can write the second law of Newton for each element by:

$$
\begin{aligned}
-m_1\ddot{q}_1 + m_1 g BF_1 - k_1(q_1 - Q) + k_2(q_2 - q_1) + R_1 = 0 \\
-m_i\ddot{q}_i + m_i g BF_i - k_i(q_i - q_{i-1}) + k_{i+1}(q_{i+1} - q_i) + R_i = 0 \quad \text{for } 2 \le i \le n-1 \\
-m_n\ddot{q}_n + m_n g BF_n - k_n(q_n - q_{n-1}) + R_n = 0,
\end{aligned}
\tag{4-4}
$$

Where:

mi = is the mass of block i.

ki = is the constant of the spring above the block i.

g = means the gravity constant.

BF = the buoyancy factors.

Hint except for the elements only the pipe diameter changes, for example, the first and last the BHA elements, the total BFi are equal to one. All the forces from the drilling fluid are marked Ri, except for the buoyancy forces.

A semi-analytical model is created for axial drill string motions, where motion is easily the top analytical expression and movement convolution of anywhere in the drill string. In the same way, the swab and surge pressure are designed. This model's simplicity makes it usable in combination with on-site measurements for real-time implementation. The model also offers important physical intuition about the issue. The effect of extra mass has the repeated effect. The added impact of mass depends on how much the hole is tight. easy expressions are also given for the related amplification and resonant frequencies and. It will stretch itself when the drill string is free hanging with no force of driving. The inverse of the stable position is the stiffness matrix, multiplied by a weight distribution vector and another vector due to the constant flow velocity. On the drill string, forces of hydrostatic pressure act and handled by buoyancy factors. The damping term is due to the solution of a steady-state when the drill string is moving steadily. The damping term because of the basset forces when the drill string is accelerated. It is obvious when these forces having a substantial effect on the downhole pressure, depending on the movement's frequency. Surprisingly, there is such a large impact on the pressure from the added mass effect. In tight holes, extreme swab and surge pressures require large accelerations. The results demonstrate that, when the extra mass is independent of the viscosity, the swab and surge pressure is not viscosity dependent. t proposing that the technique can be used to determine the running in and running out speeds. furthermore, in deep and narrow holes, it is shown that one should consider resonance. Due to surface heave measurement for the Newtonian fluids, this model is used to anticipate downhole pressure variations. To avoid severe surges and swab pressure, this data is used to determine the acceptable weather conditions. Noting that the industry appreciates experiments to verify the model is very important. It is possible to use the model to describe the motion of the drill string in the case of non-Newtonian fluids (Hovda, 2018).

4.5 Surge and Swab Pressures in Horizontal and Inclined Wells

Several studies were performed to study the effects related to swab and surge pressure. Early studies reported that due to high tripping speeds, the issue of wellbore-like formation fracture lost circulation, kick, etc. was related to the pressure variations in the wellbore. A few other studies tried to clarify the causes and swab and surge pressure magnitude until 1960. Few quantitative methods were developed for the prediction of swab and surge pressure. Some of these studies for turbulent flow and laminar flow regimes accounted for the pressure differences due to viscous drag and stationary pipe walls for Newtonian fluids. Another study introduced the concept of Bingham plastic fluids' moving inner pipe and accounted for both the viscous drag and the inertial effects to account for variations in wellbore pressure.

Burckhardt (1960) introduced a technique semi-empirical to estimate surge pressure for Bingham plastic fluids and Schuh (1964) introduced an approximate model for Power-law fluids. Later the models introduced in previous studies were utilized to develop a computer program to investigate the various parameters' effect on swab and surge pressure. As per Clark and Fontenot (1974), the estimation from these models was in good agreement with the results of the field. Some studies have been undertaken in the past two decades to develop unsteady or transient state models that contribute to the pressure fluctuations that occur at the beginning and end of tripping operations during drill string acceleration. Effects of dynamics like compressibility of fluid and wellbore, fluid inertia, and axial elasticity of the tripping pipe were accounted for in more recent studies and comparative studies indicate that steady-state models are relatively conservative in anticipating surge pressures as the dynamic effects are not accounted for by these models. With time, these models were further improved to include effects such as temperature-dependent water and oil-based mud fluid rheology, well deviation, and eccentricity. The latest study by Hussain and Sharif (2009) showed that surge pressure decreased when increasing the degree of eccentricity and with the increase in bed thickness for a partially blocked eccentric annulus with a cutting bed. The drill string is located on the low side of the wellbore in inclined or horizontal wells, allowing the annulus to be eccentric. This changes the annular geometry and cannot be directly applied to the analysis of the flow in eccentricity annulus, generally used cylindrical coordinates for concentric annulus. This further complicates mathematical modeling, and it is difficult to acquire analytical solutions. There is very limited literature relating to swab and surge pressure. However, few studies have previously been investigated to name a few. Haciislamoglu & Langlinais (1991) analyzed the role of eccentricity on surge pressures as closed-end casing in a vertical hole. The analysis was depending on the reduction-ratio of the friction pressure, R, defined as the ratio of the eccentric annulus pressure gradient to the concentric annulus. A reduction of 35 % in surge pressure in an eccentric annulus as shown in the study. Of the limited theoretical and field study, all deduce that in an eccentric annulus, surge pressures decrease. Theoretical Formulation A dimensional analysis was carried out using present numerical results for concentric annulus to develop a simple regression model (Crespo 2011) for yield-power-law fluids (Herschel-Bulkley fluids) to predict swab and surge pressure for the close-ended pipe case. A new model for fully eccentric annuli has been developed, following this approach. For Newtonian, power-law, and Bingham plastic fluids as well, the model predictions are also true. Using the friction factor, the surge pressure is evaluated as:

$$\frac{\Delta P_S}{L} = \frac{2\rho V_p^2 f}{H} \tag{4-5}$$

where ρ is fluid density and L is wellbore length. Vp is the speed of the trip. The H= 0.5 (d_h- d_p) average annular clearance. The relationship between the generalized Reynolds number and friction factor is indicated methodically to identify the equation of pipe flow. So, the friction factor is calculated by:

$$f = \frac{a}{\mathrm{Re}^*} \tag{4-6}$$

The generalized Reynolds number expression is given by:

$$Re^* = \frac{\rho V_p^2}{\tau_0 + k(A + B/n)^n (\frac{Vp}{H})^n} \quad (4\text{-}7)$$

where A and B are geometric parameters functions of the diameter ratio K = dp/dh. The fluid consistency is denoted by k. The fluid behavior index and yield stresses are n and τ_o, respectively. The geometric parameters are given as:

$$A = 0.12 \times e^{2.82\overline{K}} + 0.0024 \times e^{9.29\overline{K}}$$

$$B = 0.28 \times e^{1.7\overline{K}} + 1.65 \times 10^{-5} \times e^{14.5\overline{K}} \quad (4\text{-}8)$$

The value of "a" is illustrated below and is a function of diameter ratio K

and fluid rheology:

$$a = 0.0066 * n^{-0.13} \times \left(\frac{\overline{K}}{0.75}\right)^{0.0469} + 2^{0.0437} \quad (4\text{-}10)$$

Swab and surge pressure is a function of many parameters that can influence the hydraulic wellbore due to variations in downhole pressure. These parameters include the type of fluid, the profile of the viscosity, tripping velocities, the ratio of diameter, and the degree of annular eccentricity. Various fluids have various flow behaviors, and their flow properties are defined by their rheological parameters, which can greatly impact bottom hole pressure. Some other factor that contributes to differences in bottom hole pressure and is highly reliant on wellbore geometry, that is, diameter ratio or annular clearance is the tripping speeds. The swab and surge effects are minimal at low speeds, and as the speed of tripping increases, they increase substantially. For the same fluid with essentially the same characteristic of flow. In the inclined and horizontal wells, the drill pipe eccentricity affects the surge and swab pressure. in a concentric annulus, the differential pressure loss is higher than in an eccentric annulus, the pipe can be moved faster than expected by the concentric models and is still safe to operate. Not taking eccentricity into account can lead to the under-estimation of the speed of tripping and can add time and cost to the non-productive rig. The comparison of results clearly shows that in an eccentric annulus, the surge pressure decreases to around 40 % for the same fluid with the same flow characteristics (Srivastav et al., 2012)

Conclusion

1. The BHA diameter appears to be more relevant to swab and surge than the BHA length. The most important variable for surge and swab pressures is annular clearance.
2. Around the drill bit, most of the pressure changes occur, and the surge and swab pressures are heavily dependent on the BHA and bit diameter.
3. The only manipulative parameter concerning control surge and swab pressure is the tripping speed. For certain critical situations, this has been built into a graphical view.
4. The properties of fluid, speeds of tripping, and annular clearance have important effects on the pressures of the surge and swab.
5. The concentric annulus-based models over-predict the surge and swab pressure and require pipe eccentricity correction.
6. The prediction of surge pressure for an eccentric and concentric model can be noted as the boundary limits for the anticipated surge pressures the pipe does not retain the concentric or fully eccentric geometry throughout in real field condition due to pipe lateral motion, resulting in surge pressure variations to limits between these.
7. The generated pressure surges are generally significantly affected by fluid rheological parameters, tripping speeds, and diameter ratios.
8. For thinning fluids under high shear, a little reduction in surge pressure can increase the safe limit of tripping speed.
9. Of the current models, the Herschel-Buckley fluid behavior model offers the most accurate estimates of drilling fluid behavior.
10. The speed of drilling operations, such as tripping or running the drill string, is of high significance to pressure change in laminar flow. The change in pressure is based on the length and diameter of the bottom hole assembly or the drill string. A high increase in pressure change occurs when the flow Behavior Index (n) gets less than 0,5. an increasing pressure change with a decreasing power law constant (K).
11. For the calculation of the pressure change, the mud and drill string velocity is of great importance in a turbulent flow. With increased velocity, the pressure change improves exponentially. The length of the section indicates a linear change in pressure and the

change in pressure depends on the annular space as well. A higher friction factor leads to higher pressure.

12. It is essential to manage the velocity and diameter of the drill string or BHA to decrease the pressure changes.
13. The displaced fluid induces annular flow with a steady velocity profile during the tripping operation, which is more sensitive than other fluid parameters to the fluid behavior index (fluid consistency index and yield stress).
14. The length and size of drill collar, mud weight, rheology are predetermined factors that have been carefully selected and maintained at the desired level during the operation of drilling and tripping to prevent blowout or loss of circulation issues. Only to a limited degree can these be varied.
15. The plastic viscosity and yield point of the fluid both have small effects on the ECD and should be considered in the estimates.
16. It is not possible to neglect or simplify the detailed components and the BHA dimensions to obtain precise ECD values.

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