EFFECTIVE STRATEGIES FOR ADDRESSING LOST CIRCULATION CHALLENGES DURING DRILLING OPERATIONS

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CERTIFICATION

This is to certify that this project titled "effective strategies for addressing lost circulation challenges during drilling operations" was carried out by **IYERE EMMANUEL ONOKE** of the department of petroleum engineering, faculty of engineering, university of benin, in partial fulfilment of the requirement for the award of Bachelor Of Engineering (B.ENG) In Petroleum Engineering.

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DEDICATION

This project is dedicated to Almighty God for his mercy, grace love and infinite love. To my dad, late MR GILBERT ISUMA, my mum, MRS JUSTINA IYERE for her love and consistent prayers , my uncle, MR SYLVANUS OGUNDARE and my aunty, LADY M.A. EIGBE for their encouragement and support .

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ABSTRACT

The oil and gas industry is confronted with various drilling challenges as the global demand for these recourses continues to surge. One of the most significant issues faced in the industry is lost circulation, which arises when drilling fluids escapes into the formation and does not return to the surface, resulting in substancial financial losses.

While there has been considerable progress made in comprehending the problem of lost circulation and developing recommendations and developing recommendations and products to tackle it, continued research and innovation are still necessary to address this problem effectively.

A small selection of technical journals, papers, textbooks, and manuals that address the issue of lost circulation were thoroughly examined and summarized in order to meet the study's goals. The study's practical recommendations are unbiased against any specific provider.

CHAPTER 1

1.0 INTRODUCTION

1.1 BACKGROUND OF STUDY

Loss circulation refers to the uncontrolled flow of Wellbore fluids into the formation, leading to partial or total losses of drilling fluids. These losses can result in a reduced mud column inside the Wellbore, posing significant well control challenges. Loss circulation is a major contributor to drilling issues, causing hole instability problems and differential sticking. The time spent attempting to regain drilling fluid circulation or manage and circulate kicks can result in substantial non-productive time (NPT) in rig hours, leading to increased drilling costs. Non-Productive Time refers to any time when the drilling rate stops or when operations deviate from the original plan. A statistical study by Rehm et al. (2013) indicated that over 10 years, more than 12% of NPT in the Gulf of Mexico was attributed to lost circulation, and about 18% resulted from kicks and Wellbore instabilities. Other studies suggest that loss circulations can raise drilling costs by $70 to $100 per foot.

Preventing loss circulation is more cost-effective and simpler than dealing with its consequences. In the absence of abnormal pressure zones and natural fractures, enhancing the rheological properties of drilling fluids can prevent fluid loss. Drilling with optimized mud properties improves hole cleaning, avoiding high equivalent circulation density (ECD) and fluid losses. A common practice is to maintain mud hydro static pressure or bottom hole pressure (BHP) sufficiently above collapse pressure and below fracture gradient to prevent fracturing the Wellbore. Low formation fracture gradient reduces the pressure at which the formation breaks, narrowing the drilling operational window. Wellbore strengthening techniques widen this operational window, minimizing the risk of loss circulation and reducing the need for additional casing strings. Wellbore strengthening offers various applications and benefits, including accessing challenging reserves like depleted zones with varying fracture gradients, deep-water drilling, and formations with a narrow operational window. It addresses loss in depleted formations caused by using denser mud to support higher pressure zones, improves well control, and reduces NPT. Lavrov (2017) emphasizes the industry-recommended practice of sealing fractures during drilling and before cementing to prevent cement slurry loss. Tight operational windows are common in mature depleted fields, deep-water formations, naturally fractured formations, and deviated wells. Figure 1 illustrates various drilling conditions where Wellbore strengthening techniques can be applied to reduce NPT and mitigate drilling problems associated with lost circulation.

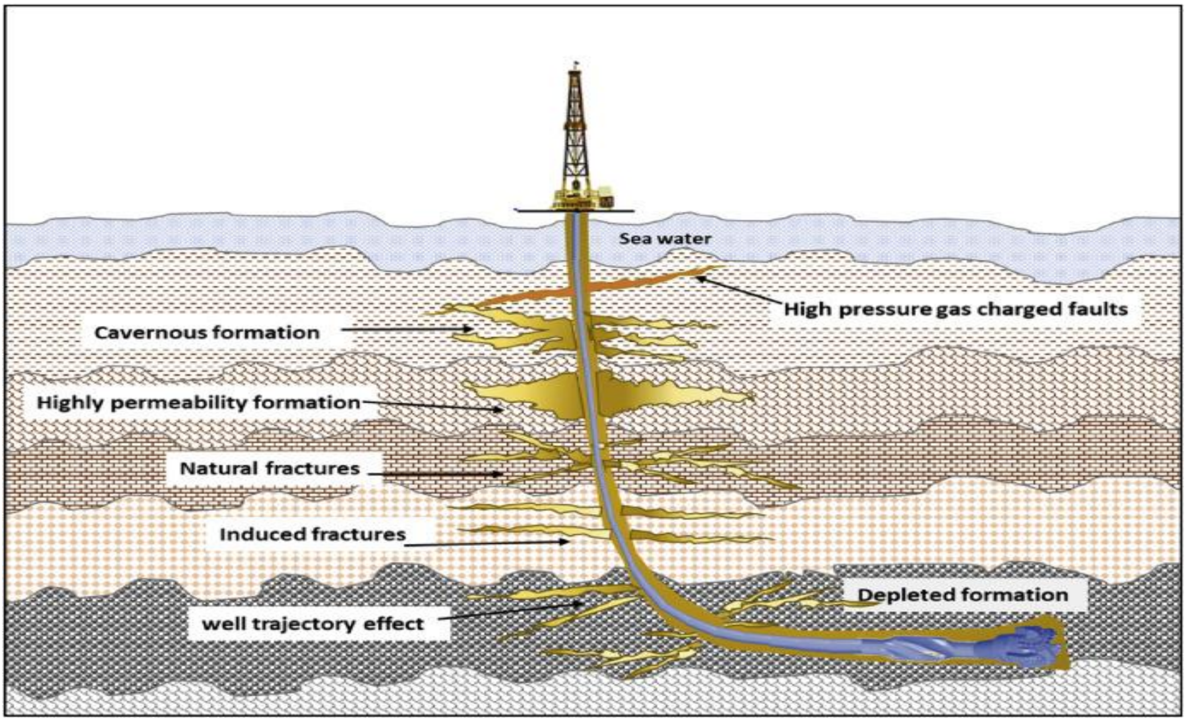

Fig.1. Drilling conditions where Wellbore strengthening techniques can be applied to reduce NPT and mitigate drilling problems associated with lost circulation.

1.2 STATEMENT OF THE PROBLEM

The oil and gas industry faces a significant challenge during drilling operations, which is the issue of lost circulation. This problem arises when drilling fluid escapes into permeable formations, leading to reduced hydrostatic pressure and hindered drilling progress. Various factors such as fractures, vugs, faults, or highly permeable zones in the formation can contribute to this phenomenon.

Lost circulation events result in primary issues that are critical to the success of the project. Firstly, they incur costly downtime and increased drilling expenses that require additional materials, equipment, and manpower to address the problem. Secondly, the interruption of drilling operations due to lost circulation can lead to significant delays in well completion timelines, adversely affecting project schedules and overall productivity. Thirdly, excessive lost circulation can compromise the mechanical stability of the wellbore, leading to challenges such as differential sticking, formation collapse, and wellbore collapse, posing risks to personnel safety and well integrity. Fourthly, lost circulation can have environmental implications, including contamination of subsurface formations, groundwater resources, and surface ecosystems. Lastly, addressing lost circulation requires the implementation of effective mitigation strategies tailored to specific well conditions, which may involve technical challenges and uncertainties. Therefore, it is of paramount importance to explore and develop effective strategies for mitigating lost circulation challenges during drilling operations to enhance drilling efficiency, minimize costs, ensure wellbore stability, and mitigate environmental impacts.

1.3 AIM AND OBJECTIVES

1.3.1 AIM

This study aims to provide a comprehensive understanding of lost circulation challenges and equip stakeholders with the knowledge and tools needed to effectively mitigate these challenges during drilling operations.

1.3.2 OBJECTIVES

1. To Review and compare conventional and innovative methods for controlling lost circulation during drilling.
2. To Identify and evaluate the effectiveness of various approaches such as wellbore strengthening, bridging agents, lost circulation materials (LCMs), managed pressure drilling (MPD), and cementing in addressing lost circulation.
3. To Develop practical recommendations and guidelines for selecting and implementing appropriate lost circulation mitigation strategies based on specific well conditions and operational requirements.
4. To provide a detailed analysis of the above methods, their successes, and failures in the field applications. The analysis will be based on the very detailed review of relevant literature, including academic research papers and industry reports.
5. To provide guidelines to control lost circulation at the well site. They'll include implementation procedures, equipment, materials, and special geological and operational considerations..

1.4 SCOPE OF STUDY

The study aims to cover various aspects related to lost circulation encountered during drilling operations, with a focus on understanding the phenomenon, exploring mitigation strategies, and providing practical recommendations for implementation.

The scope of the study includes:

1. Understanding Lost Circulation
2. Review of Mitigation Strategies
3. Case Studies and Best Practices
4. Recommendations and Guidelines
5. Cost-Benefit Analysis
6. Environmental Impact Assessment

1.5 SIGNIFICANCE OF THE STUDY

This topic is highly relevant to petroleum engineering as lost circulation can have significant impacts on drilling operations and overall well performance. Petroleum engineers are responsible for designing and optimizing drilling operations, and addressing lost circulation is a critical aspect of the process. By studying and implementing effective strategies to mitigate lost circulation challenges, Petroleum engineers can improve drilling efficiency, reduce costs and minimize potential risks associated with lost circulation.

CHAPTER 2

Literature review

Lost circulation is a common issue faced during drilling operations. To combat this, various studies and methods have been developed over the years. One common method used to prevent lost circulation in shallow, unconsolidated formations is to thicken the mud by adding flocculating agents such as lime or cement to freshwater muds. Another technique used to combat lost circulation is to drill without fluid returning to the surface while drilling below-surface casing in normal-pressure formations where natural fractures are common. However, this technique requires a large volume of water and close supervision. Current research on lost circulation has focused on developing Lost Circulation Materials (LCMs), particularly chemical formulations that have been proven to be more effective. Shear-thickening Fluid (STF) is a multi-component system created by Hamburger et al. (1983) of Exxon Production Research Company to combat severe lost circulation in ten different wells. STF comprises liquid oil, an oil-soluble surfactant, and aqueous-phase droplets containing dissolved polymer. As it passes through the drill-bit nozzles, the resulting high shear rates cause the fluid to thicken irreversibly into a high-strength viscous paste. In addition, researchers have studied the use of conventional LCMs (granules, flakes, and fibers) with a new high-performance material, composed of thermoset rubber, in controlling mud loss in simulated fractured formations using both water-based and oil-based muds. From field applications, it has been found that the use of thermoset rubber was very effective in controlling severe mud losses in fractured formations. Expanded Aggregates (EAs) have also been researched as an effective solution for lost circulation problems. EAs are vitrified mineral-based materials that have high compressive strengths, do not change mud rheological properties, and have rapid lost return resolution properties. Internally activated silicate solution has also been studied to combat lost circulation. Laboratory tests have indicated that this solution has a low viscosity initially, but its viscosity increases rapidly to form a gel after a specific time, depending on its design and temperature. This gel is coherent, strong, and does not produce free water as a function of time. They also found out that the gel formed by this solution could withstand differential pressures greater than 1500 psi per foot of plugged formation when using a high-pressure experimental setup to plug cores of different permeabilities and different saturation fluids. Specially formulated squeeze materials (reactive pills) have also been studied as LCMs. These include lost circulation material squeeze systems (LCMSS) and Chemically Activated Cross-linked Pills (CACP). The latter produces a substance described as rubbery, spongy, and ductile when set, and the setting time is controllable by using either a retarder or an activator based on the thief formation or bottom hole temperature. However, laboratory tests and field trials suggest that these pills are not biologically or chemically degradable and hence must be used with caution near pay zones. Finally, mud-reactive-chemical-squeeze (MRCS) systems and processes have been studied for use in subsalt zones to cure losses. This technology is successful in the subsalt zone because the solidification of the mud and the formation of a permeable filter cake are essential to the success of this method.

2.1 THE BASICS OF LOST CIRCULATION CONTROL

Good understanding has been worked out with regard to lost circulation control mechanics. The lost circulation control during the well construction is much beyond just the selection of appropriate lost circulation material (LCM) but a complete engineered approach. Some of the common approaches include borehole stability analysis, ECD modeling, leak-off flow-path geometry, drilling fluid, and LCM selection to minimize effects on ECD, on-site monitoring using annular pressure while drilling (APWD), and connection flow monitoring techniques, apart from timely application of LCM and treatments. This section provides in-depth explanations about some of the lost circulation controls.

2.2 LOST CIRCULATION MATERIAL (LCM) SELECTION

This would be crucial in most drilling operations in order to eliminate fluid losses and drill further. An LCM should respond, therefore, by blocking the fracture and providing a bridge in good time for the formation of a sealing. At times, the seal could be temporary, and in some, a permanent seal. Permanent sealing is usually applied where there is a need to block off thieving zones in non-producing intervals, while temporary sealing is for the need to block off a loss zone within pay intervals. Previous studies have proved that there are some products that perform better than others when used as lost circulation material. This then classifies LCMs into a common category along with their physical and chemical characteristics that group them. These are:

1. Conventional Lost Circulation Materials; (Fibers, Flakes, Granules)

2. High Fluid Loss Squeezes; (Diatomaceous earth or clay blends)

3. Gunk Slurries; (Diesel oil bentonite)

4. Precipitated Chemical Slurries; (Silicate and Latex)

5. Resin Coated Sand

6. Cross Linked Polymer Slurries

7. Cements

8. Barite Plugs

9. Dilatant slurries

2.2.1 Conventional lost circulation materials

Conventional LCMs come under granular LCM, flake LCM, fibrous LCM, or any mixture of the three. The granular LCMs cause two bridging: one at the formation face and the other within the matrix. The latter sealing is preferred, since it forms a more permanent bridge within the formation, such that pipe movements in the wellbore can never dislodge the granular particles. For the granular LCMs to function in an efficient manner, their efficiency is premised on the particles' size, where larger ones will first bridge across or within a void, and the smaller particles can bridge openings between. Fibrous materials work well for controlling losses in porous and highly permeable formations since they mat over the pore openings of the formation. The reduction in sizes of openings to the formation allows for rapid deposition of a filter cake by the colloidal particles in the mud. Flake LCMs are also designed to form a mat on the formation face, which gives the best results as fibrous when used to treat losses in highly permeable formations. When actual field conditions are represented in laboratories to show the field representative sample, blends are manufactured and supplied to the field as a combination of granular, flake, and fibrous materials.

2.2.2 High Fluid Loss Squeezes

These LCMs experience rapid water loss, resulting in the accumulation of thick residual solids in the loss zone. This approach is particularly effective in halting the extension of fractures, be they natural or induced, as the deposited solids hinder pressure transmission to the fracture tips. The primary high fluid loss agents are DiaSeal (diatomaceous earth) and Attapulgite/Calcium Carbonate

2.2.3 Gunk Slurries

Gunk slurries involve the combination of two or more fluids that, upon contact with the wellbore or loss zone, create a viscous plug, sealing the area. For partial losses, Mud-Diesel-Oil-Bentonite (M-DOB) plugs yield better results. These plugs break down over time, pose challenges in long open hole intervals, and are difficult to control in severe loss situations. They lack compressive strength. Other options like Reverse-Diesel-Oil-Bentonite (R-DOB) are suitable for oil-based muds.

2.2.4 Precipitated Chemical Slurries

Silicate solutions and commercial latex additives, used in cementing, can precipitate when pumped in conjunction with calcium chloride. The recommended procedure involves pumping a calcium chloride pill followed by a silicate or latex slurry, forming a viscous plug when mixed in the open hole near the loss zone.

2.2.5 Chemically Activated Cross-linked Pills (CACP)

Cross-linking involves connecting two independent polymer chains using crosslinking agents. CACPs are advantageous in stopping losses in water, oil, or synthetic-based drilling muds. However, a notable limitation is their non-biodegradability in the wellbore, necessitating caution near pay zones.

2.2.6 Cement Slurries

Special cement formulations, such as magnesium-based and thixotropic cements, are more commonly used. Portland cements serve as LCMs only after other methods prove unsuccessful or are chosen based on experience. Particle size distributions in the 30 to 100micron range in Portland cements generally avoid permeability matrix penetration near producing zones. To mitigate formation damage, cement recipes incorporating acid-soluble additives are considered viable alternatives.

2.2.7 Dilatant Slurries

These LCMs are made up of both water soluble and insoluble polymers and solids of a certain size. Shear-thickening fluid (STF), created in 1983 by Exxon Production Research Company, serves as an illustration. These fluids are ideal for preventing losses in any loss zone because they have the capacity to thicken irreversibly when they travel through the high-shear zones of the drill bit.

Five important points can be distilled from the theories and observations gathered during years of combating decreased circulation.

1. In both low and high differential pressure situations, a lost circulation material should be equally effective at sealing cracks or vugs in hard formations as well as unconsolidated formations.

2. It ought to create a strong seal at both high and low differential pressures.

3. The ultimate shear strength of the plug should be low enough to guarantee removal by washing or jetting, but high enough to sustain a fluid column (low side-track danger).

4. When drilling, drill pipe trips, and casing runs occur, the plugging seal must endure both positive (surge) and negative (swab) pressures.

5. It should function in water-, synthetic-, or oil-based mud systems and have a manageable/controllable set time.

2.3 BOREHOLE STABILITY ANALYSIS

It's critical to comprehend the underlying ideas behind this procedure in order to prevent and remediate losses caused by borehole stability problems.

2.3.1 Identification of Fractures and Fractures

One of the main issues with drilling in fractured rocks is lost circulation. Drilling fluid losses to a formation might occur via naturally occurring fractures or fractures that have been created by drilling activities. If the crack was already there, it might be continuously open, in which case losses to the formation might only happen at mud pressures higher than the formation pressure. When the mud weight—which is necessary for well control and to keep the wellbore stable—exceeds the formation's fracture resistance pressure, induced fractures take place. A crucial first step in solving the lost returns issue is determining the kind of fracture causing the losses. Examples of induced and natural fractures are shown in Figures 2.1 and 2.2, respectively.

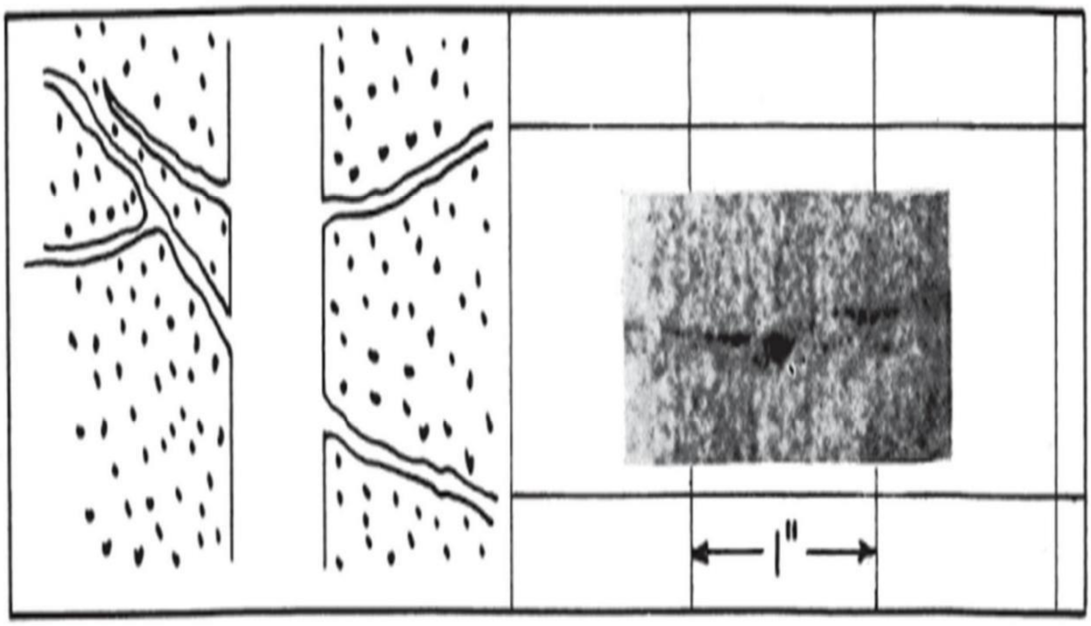

Fig. 2.1 – Natural or Intrinsic Fractures (After Howard and Scott, 1951).

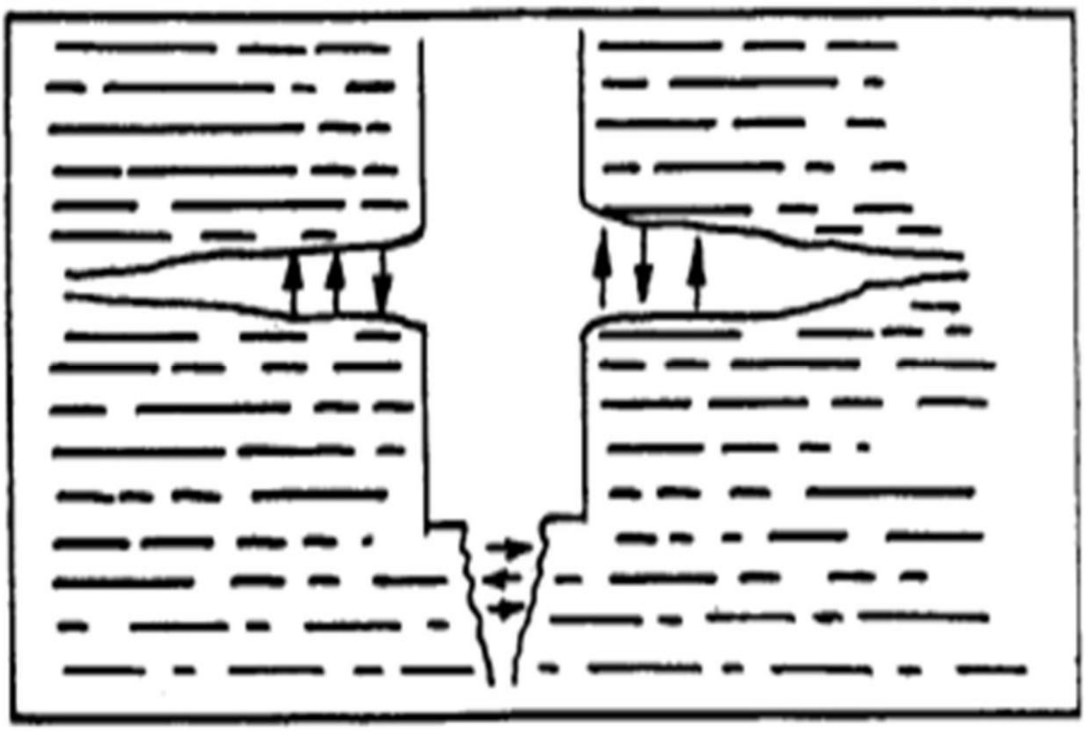

Fig 2.2 – Induced Fractures (After Howard and Scott, 1951).

Wellbore images obtained by acoustic, electrical, and optical methods can be used to identify and differentiate between induced and natural cracks. Both the presence and kind of a fracture can be determined by directly measuring the mud loss flow rates and the downhole annular pressure during drilling (APWD). The rate at which fluid enters and exits the wellbore can be precisely measured by high resolution flow meters. The fracture characteristics can be interpreted using the characteristic response of the rate of losses. A helpful method for determining the kind of lost circulating zone is to utilize a plot of variation for the levels of mud pits.

A qualitative response of mud losses to variations in mud pit level over time is depicted in Figure 2.3.

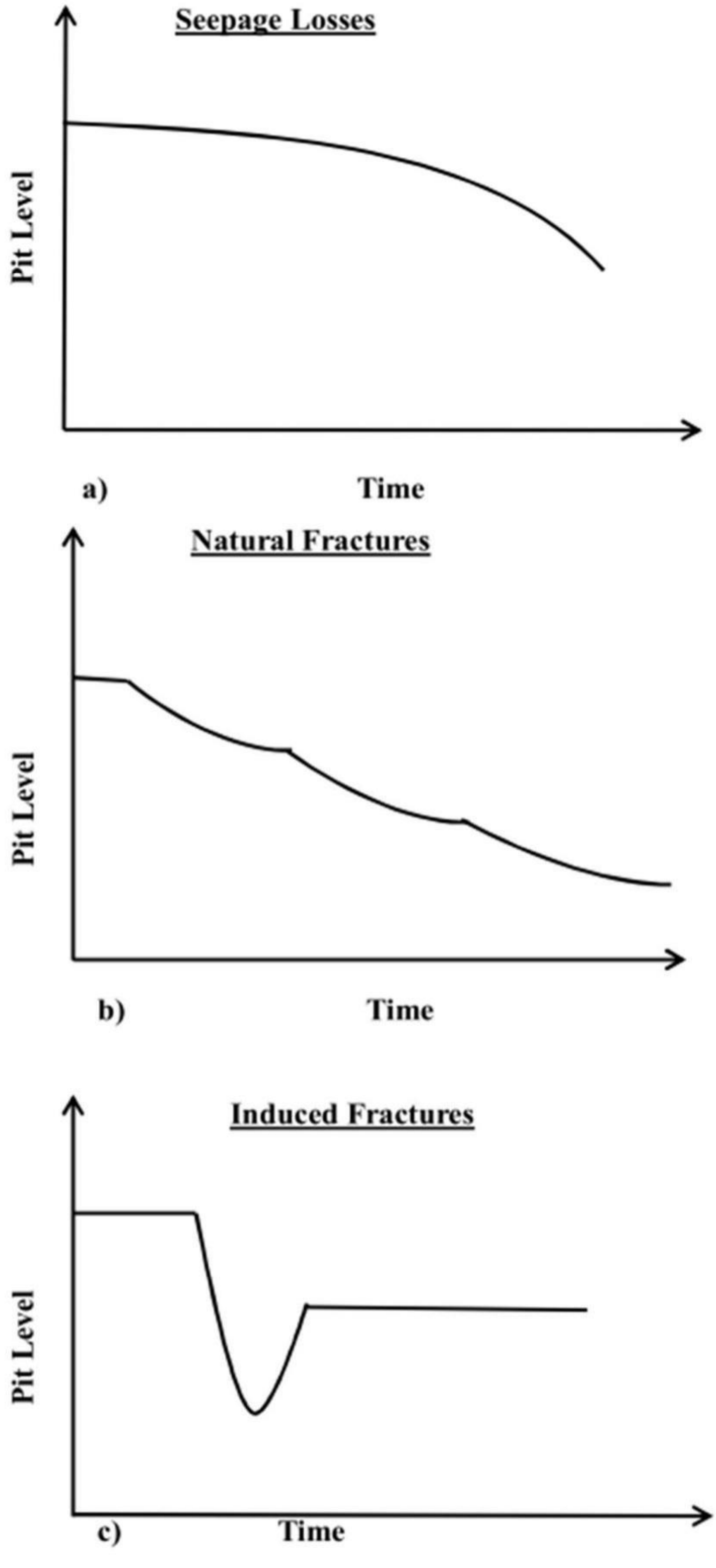

Fig. 2.3 – Losses from Pit Level (After Majidi et al. 2011)

While losses from spontaneous fractures are first rapid and then decrease over time, losses through pores start out slowly and increase over time. It is crucial to remember that there are other reasons why mud can leak during drilling operations besides cracks, and care needs to be taken when determining these reasons. Dyke et al. (1995) have identified the following causes of varying mudtank levels during drilling:

1. Matrix permeability causes downhole losses.
2. Losses into natural and artificial fissures in the downhole.
3. Variation in volume due to pressure and temperature influences.
4. Mud losses on surfaces.
5. The expansion and collapse of holes.
6. Shift in the lithology of bottom holes

A summary of several key distinguishing characteristics between naturally occurring and artificially produced fractures is provided in Table 2.1.

NATURAL FRACTURES	INDUCED FRACTURES
May occur in any type of formation	May happen in any kind of rock, although formations like shale that have weak planes as a defining feature would be anticipated to experience it.
Mud in trenches gradually sinking indicates loss. Drilling farther may reveal further cracks, which might result in a total loss of returns.	Usually, losses are abrupt and come with total loss of returns. The formation of induced fractures is facilitated by mud weights greater than 10.5 ppg.
	Loss may follow any sudden surge in pressure.
	Suspected caused fractures should be considered when lost circulation happens but not in neighboring wells.

Table 2.1: Features for Fracture Identification (Based on Howard and Scott, 1951).

2.3.2 Fracturing Mechanics

Usually, induced fractures happen where formations are the weakest. According to Howard and Scott (1951), pressure and surfaces that the pressure may act upon are necessary for the creation of fractures. The resulting forces must be large enough and applied in a way that will divide the forms. The fractures that are formed will either be vertical or horizontal, depending on depth. Horizontal pancake fractures often occur at depths of 2,500 feet or less because to a smaller vertical load (overburden) than horizontal stresses. Because the overburden is larger than the horizontal strains at depths more than 3,500 feet, vertical cracks are produced. A wellbore's typical stress distribution is seen in Figure 2.4.

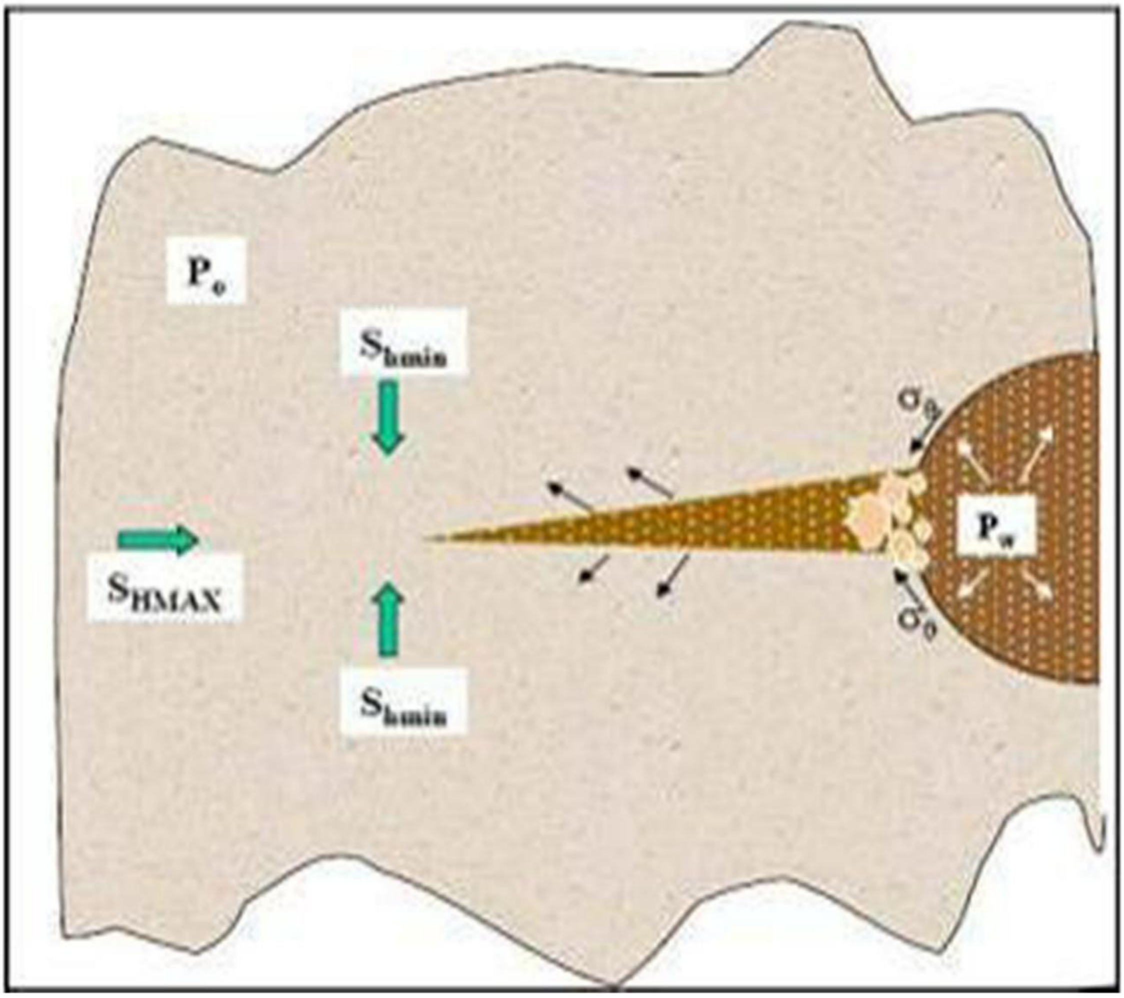

Fig. 2.4 – Stress Distribution in a wellbore (After Kumar et al. 2011)

Where,

P_w = Wellbore Pressure;

P_o = Pore Pressure;

S_{hmin} = Minimum Horizontal Stress;

S_{HMAX} = Maximum Horizontal Stress; and

σs= Effective Tangential (Hoop) Stress

2.4 Equivalent Circulation Density Management (ECD)

Drilling programs aim to reduce high ECDs that cause induced fractures by managing downhole pressures. Mud characteristics including density, viscosity, and fluid loss can be adjusted to provide the desired control. The fluid's hydrostatic pressure in the wellbore and the friction pressure generated while the fluid is being cycled are combined to produce the ECD.

$$\boldsymbol{ECD = \frac{\Delta P_F}{0.052\ x\ TVD}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2.1)}$$

Where, $\Delta P_F = P_{hydrostatic} + P_{friction}$;

ΔP_F = Total Annular Frictional Pressure loss.

$P_{hydrostatic}$ = Hydrostatic Pressure;

$P_{friction}$ = Annular Friction Pressure;

and TVD = True Vertical Depth.

ECD, or equivalent circulatory density, depends on the following factors:

1. Annular space: The ECDs will be larger the smaller the annular area.

2. Fluid rheology: ECDs will rise with increasing viscosities.

3. Pump rate: ECDs increase at increasing rates.

An essential first step in preventing lost returns during drilling operations is understanding the fracture gradient in the area. This goes beyond adjusting the mud's characteristics or regulating the production of excessive ECDs.

A leak-off test is used to determine the fracture gradient (LOT). The equivalent mud weight (LOT) offers a secure way to calculate the pressure (equivalent mud weight) that a wellbore can bear before breaking and losing returns.In this test, pressure is applied to the borehole just below the casing shoe until fluid starts to seep into the formation, indicating the creation of a fracture. As seen in Figure 2.5, the leak-off pressure (LOP) is the first departure from a linear pressure-volume curve.

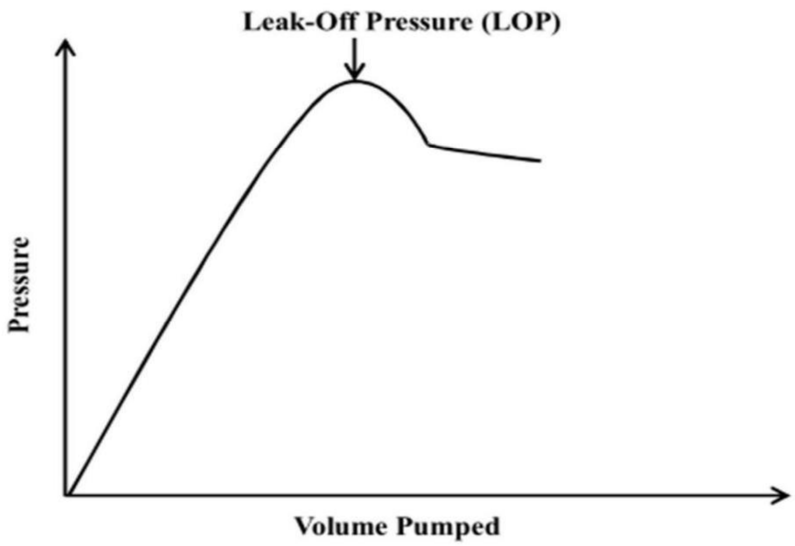

Fig. 2.5 – Leak-Off Test (After Carlton and Chenevert, 1974)

A less complex formation integrity test (FIT) is frequently used in its place if the local fracture gradient is adequately established at a certain casing shoe depth. To test cement integrity, FIT is carried out by pressurizing the formation to a preset pressure without breaking the formation. Fracture gradients in other wells are predicted by combining LOTs to provide local and regional depth trends. Nevertheless, using LOTs to create a fracture gradient curve has the following drawbacks.

1. In the absence of a distinct or obvious deflection or deviation point, individual tests may be challenging to interpret.

2. Test data is frequently manually entered at a coarse sampling rate, making it impossible to examine the raw data.

3. The drilling team's enthusiasm to move forward with the drilling may potentially add some bias towards higher interpretations.

4. Because leak-off pressures (LOPs) from a collection of nearby wells are frequently dispersed, there is a great deal of leeway in the interpretation of local trends.

The drawbacks of LOT can be addressed using an extended leak-off test (XLOT), which bears significant resemblance to the first phases of a lost circulation event. The primary purpose of XLOT's design was to determine the lowest in-situ stress, or fracture closure pressure, or FCT. On the other hand, it may be utilized to record more fracture occurrences, which will be an important resource for creating drilling plans to counter lost circulation. Among the extra occurrences that XLOT recorded are:

1. Pressure to Initiate Fracture: FIP.

2. Pressure used to reopen fractures: FRP.

3. Fracture Closure Pressure, or FCP.

4. Initial Shut-in Pressure, or ISIP.

5. Pressure for Fracture Propagation: FPP

The expense of breaching the near-well barrier and the advantage of understanding the stress and FPP that lay behind that barrier should both be considered when deciding whether to do an XLOT at the casing shoe. The volume of rock, typically 1-

2hole diameters within the formation, whose stress condition is impacted by the borehole's presence is known as the near-well barrier.

An example of an XLOT from the Norne field offshore Norway is shown in Figure 2.6.

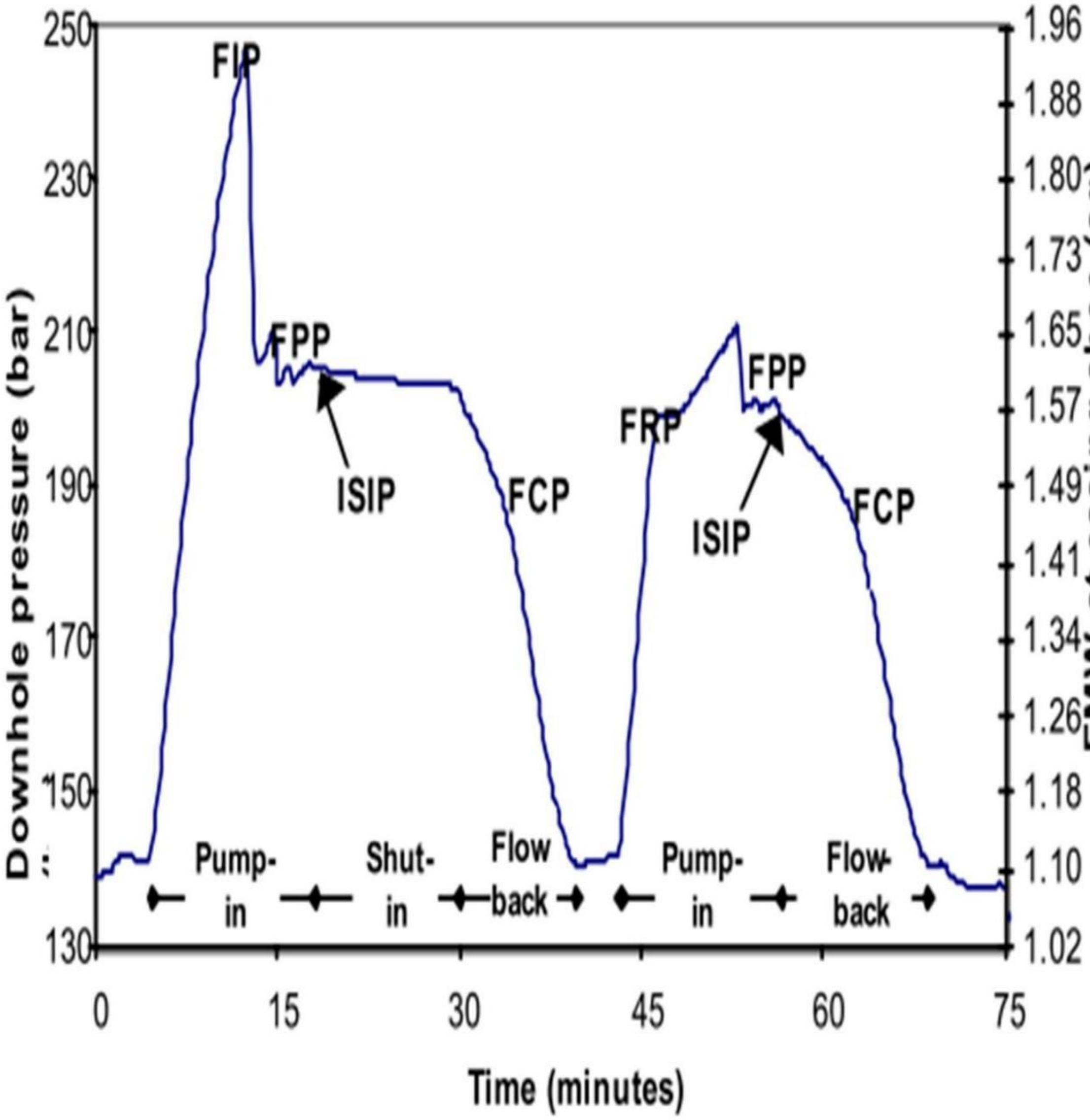

Fig. 2.6 – Extended Leak-off Test (After Okland et al. 2002)

CHAPTER 3

A REVIEW OF LOST TECHNIQUES AND METHODS FOR CIRCULATION CONTROL

Solutions for lost circulation can be used either before or after the issue arises (Wang et al. 2009). As a result, the remedies are divided into remedial and preventative categories. Some of the lost circulation control strategies employed by the petroleum sector are highlighted in this chapter.

1.1 USING MATERIALS FOR LOST CIRCULATION (LCMs)

When drilling or cementing a well, a variety of bridging or plugging materials are available to minimize lost circulation or restore it (Nayberg and Petty, 1986). The cost and availability of LCM in a particular drilling location determine which one to utilize in a specific scenario. LCMs are made to achieve two objectives:

1. To build a bridge across preexisting fractures and vugs.

2. To stop any cracks from growing that could be caused by drilling.

The following categories can be used to broadly categorize lost circulation materials:

1. Granular: depending on the particle size distribution (PSD), these LCMs create bridges at the formation face and throughout the formation matrix to provide an effective seal.

2. Fibrous: To reduce mud loss in cracks and vugular formations, these LCM groups are utilized in drilling muds.

3. Flakes: To reduce mud loss or provide an effective seal over several permeable formations, flaky kinds of LCMs are employed to plug and bridge a variety of porous formations.

4. Mixtures: they are compositions of fibrous, granular, and flaky materials that may

successfully seal off cracks, vugs, and other highly permeable formations.

5. Encapsulated fluid-absorbing particles: they are very absorbent substances that, when exposed to water, condense into a spongy mass..

TYPE	MATERIAL
FIBROUS	consist of raw cotton, bagasse, flax shive, wood fiber, bark fiber, textile fiber, mineral fiber, leather, glass fiber, peat moss, feathers, beet pulp, and other similar materials that possess a fibrous texture.
GRANULAR	composed of perlite, coarse bentonite, ground plastic, nut shells, nut hulls, ground tires, asphalt, wood, coke, and other materials that are granular in texture
FLAKE	composed of cellophane, cork, mica, corn cobs, cottonseed hulls, vermiculite, and other similar materials that have a flake-like texture.
MIXTURE	composed of two or more different materials combined together. Examples include film, fiber and sawdust; textile fiber and sawdust; cellulose fiber and sawdust; perlite and coarse bentonite, and other similar materials.

Table 3.1 lists a few LCMs that are often utilized

3.2 WELLBORE STRENGTHENING

Lost circulation materials (LCMs) are frequently used in drilling, including pills, squeezes, pretreatments, and drilling techniques. However, these conventional LCMs become less effective when drilling deeper hole sections, particularly in formations that are depleted, structurally weak, or naturally fractured and faulted. This limits their usefulness, and to solve this problem, a new lost circulation solution called wellbore strengthening has been developed. The process of propping and plugging fractures with LCMs induced in the formation is referred to as wellbore strengthening. The use of wellbore strengthening improves the fracture gradient of the formation, allowing higher mud weight windows for drilling, especially in weaker and depleted formations. The primary aim of wellbore strengthening is to improve the fracture gradient of the formation, rather than strengthening the rock matrix.

However, In oil and gas drilling, there are ways to enhance the strength of rock matrix in permeable and depleted formations. One such method is the stress cage approach, which involves creating an additional hoop stress or "stress cage" in the area surrounding the wellbore. This is done by creating fractures of specific sizes near the wellbore and filling them with specially sized lost circulation materials (LCMs) in a frac-and-pack operation. The packed LCMs generate an additional tangential stress or hoop stress in the near-wellbore zone, which helps to increase the threshold for fracturing and fracture propagation. The stress cage approach can be applied while drilling into the weak zone to obtain an instantaneous strengthening effect. To ensure the effectiveness of this approach, it is important to use log analysis to identify the location of the fracture and determine its ge-ometry, particularly its width. Once the width is known, a mixture of particulate materials can be determined to seal the fracture. This approach is one of several methods used to strengthen wellbores. By increasing the hoop stress in the near-wellbore zone, the stress cage approach can help prevent fractures from propagating further into the formation, thereby improving wellbore stability and reducing the risk of wellbore failure.

The order of importance for the characteristics that influence the performance of particulate materials in wellbore strengthening process was provided by Freidheim et al. (2008). These characteristics include:

1. Particle size

2. Particle size distribution

3. Concentration

4. Shape (periodicity/aspect ratio)

5. Others such as surface texture, compressive strength, bulk density, and resiliency.

Some examples of particulate materials that are used for wellbore strengthening are ground marble ($CaCO_3$) and sized resilient graphitic carbon. Images of these materials are shown in figures 3.1 and 3.2.

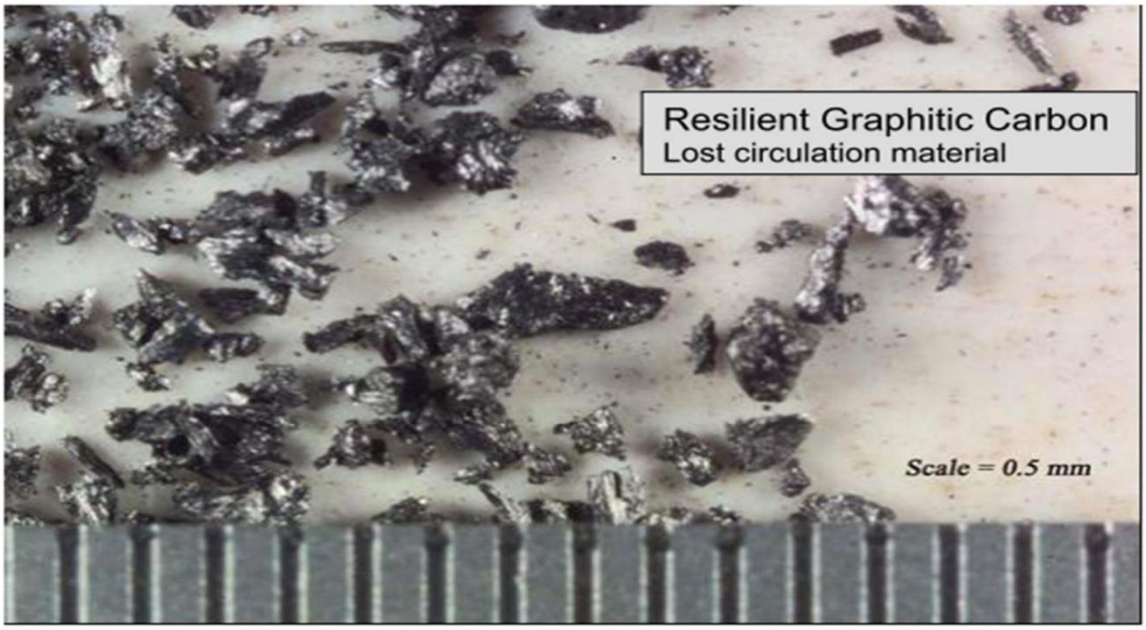

Fig. 3.1 – Particulate LCM for Wellbore Strengthening (After Wang et al. 2009

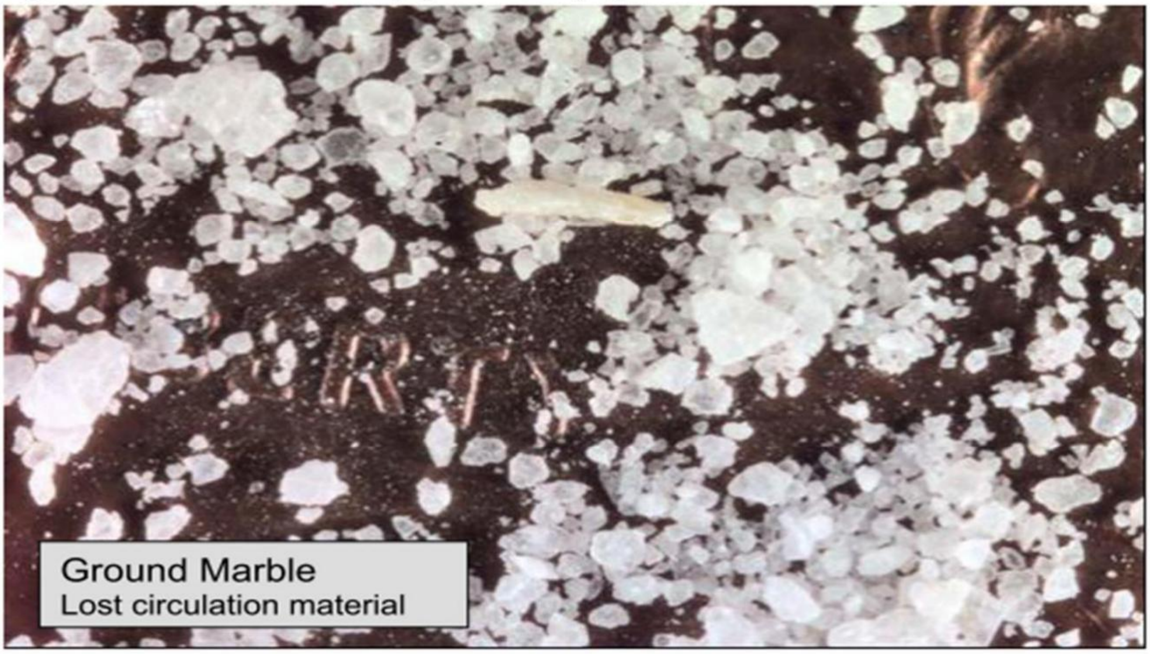

Fig. 3.2 – Particulate LCM for Wellbore Strengthening (After Wang et al. 2009)

3.3 MATERIALS AND TREATMENTS OF THE SEVERE LOSSES

3.3.1 High Fluid Loss, High Strength Pills (HFHS):

HFHS pills can effectively de-fluidize pumped slurry and create high solid plugs by squeezing. A combination of different fibers, some of which are coated or treated to enhance their performance, are now readily available in a one-sack product. The ideal HFHS treatment should perform well in various loss scenarios, be easy to pump through bottom hole assemblies, and have high resistance to shear stress. For successful implementation, the fluid carrying these treatments should leak off into permeable formations, creating a strong seal. While HFHS treatments may not be as effective in low permeability formations like shale or when using non-aqueous drilling fluid, they have already demonstrated success in reducing both cost and time due to their simple application. Researchers (Al-Hameedi et al., 2016; Alsaba et al., 2014) have studied and confirmed the effectiveness of these treatments in the field.

3.3.2 **Combinations of Swellable/Hydratable LCMs:**

In essence, settable/hydratable therapies combine LCMs with a highly reactive substance, like polymers. A plug will form inside the losses zone when these treatments are triggered, either by chemical reagents or by coming into touch with drilling or formation fluids. Special installation methods are frequently necessary for these kinds of treatments (Al-Hameedi et al., 2016; Alsaba et al., 2014).

3.3.3 **Low Density High Viscosity Drilling Mud + LCM Blend:**

The high viscosity mud pill will first be pumped in front of the theft zone. To construct an effective plug, low density mud mixed with a blend of LCMs will be pumped directly after the high viscosity patch. For a blend of LCMs, it is crucial to use low mud weight in order to prevent high equivalent circulation density (ECD). Pumping this blend in front of the losses zone is recommended, and drilling operations must wait approximately (± 4-6 hours) before continuing (South Oil Company, 2010).

3.3.4 **Material Super Stop:**

-Mixing four to five bags of super stop material (weighing 25 kg each) for every one m3 of water.

- The separate, clean tank is where this treatment should be mixed.

-Mixing rapidly is essential to preventing treatment bulge in the surface tank.

-Moving the cleanup to the front of the area of loss.

-Drill pipe strings above the loss zone being pulled out, and mud being circulated for approximately ten minutes to force treatment to enter formation.

-Waiting for approximately one to two hours (South Oil Company, 2010).

3.3.5 High filtration spot pills:

To seal the loss zone, high filtration drilling mud is utilized. The treatment's basic method is to introduce water into the formation, where the solids content will create a seal in front of the theft zone. This treatment is demonstrated in Figure 3.3. This approach comes in three varieties (Eni Company, 2010):

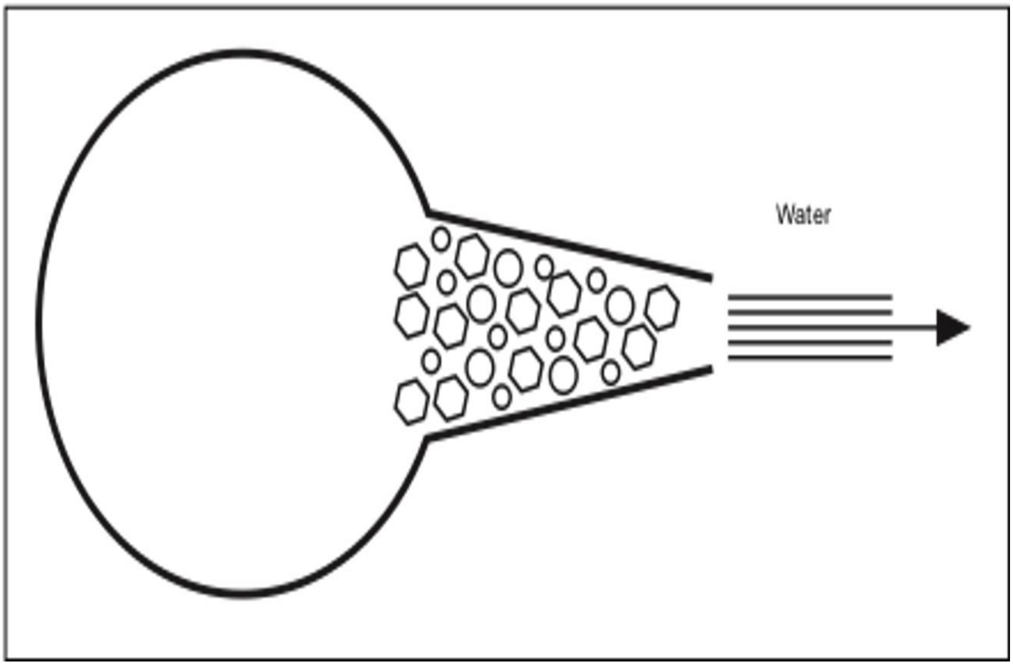

Figure 3.3. High-fluid-loss-squeeze Technique for Lost Circulation (Eni Company, 2010)

Table 3.2. High filtration mixtures (200-400 cc API), 1 m3 (final) of high filtration mixtures

ELEMENT	AMOUNT
Attapulgite	3 - 6 %
Bentonite	1.5 - 6 %
Lime	0.15 %
Diatomite	15 %
Mica	1 – 1.5 %
Granular LCM	1.5 – 2.5 %
Fibrous LCM	0.3 – 1 %

Table 3.3. Very high filtration mixtures (> 600cc API), 1 m^3 (final) of very high filtration mixtures

ELEMENT	AMOUNT
Diatomite	30 %
Lime	15%
Attapulgite	0-4 %
Granular	1 – 2.5 %
LCM	1 %
Fibrous LCM	1 %

3.4 MATERIALS AND TREATMENTS OF THE COMPLETE LOSSES

Table 3.4 provides remedies for regulating complete loss treatments

Type of Losses	Type of the Treatment	Approach of the Treatment	Waiting Period
Complete Loss	Cement Plug	To block the thief zone, pump cement slurry with a specific density and use O.E.D.P.	(18) hours
	High Viscosity Mud (Low Density) + Cement Plug	Initially, the process involves pumping mud with high viscosity (low density), followed by the direct pumping of a cement plug to establish an effective seal using O.E.D.P.	(18-20) hours
	Drilling Mud (Low Density) + Blend of the LCMs + Cement Plug	To create an efficient seal, we need to pump drilling mud (low density) along with a blend of LCMs and follow it up by directly pumping a cement plug using O.E.D.P.	(18-20) hours
	DOB Squeeze (Diesel Oil Bentonite)	By mixing oil base + bentonite to create a plug, by using O.E.D.P to seal zone with squeeze technique.	(8-10) hours

	DOBC Squeeze (Diesel Oil Bentonite Cement)	By mixing oil-based mud with bentonite and cement, a plug can be created. The zone can then be sealed using the O.E.D.P squeeze technique.	(10-12) hours
	Barite Plug	This barite plug is used to pump in front of the zone of interest by using barite material and other materials.	(3) hours

Table 3.4. Very high filtration mixtures (South Oil Company, 2011)

Table 3.5 will demonstrate the description and the executive steps for each of the remedial plug to get integrated image regarding procedures of the application.

Name of the Treatment	**Description**	**Procedures**
Cement Plug	This type of plug is commonly used in the oil industry to fix complete losses, but is rarely used for partial	1. Calculate the density of the cement. 2. Using open end drill pipe (O.E.D.P). 3. Pumping the required cement volume. 4. Displacing the plug in front of losses zone by using normal

	or severe losses. Accurate calculations are essential when determining the weight of cement to use for this treatment.	drilling mud. 5. Avoidance contamination between plug and drilling fluid. 6. Pumping normal drilling fluid in order to clean open end drill pipe (O.E.D.P). 7. Pulling out drill pipes strings to casing shoe. 8. Waiting period around (± 18-20 hours) in order to harden cement plug.
DOB Squeeze (Diesel Oil Bentonite)	This correction is widespread and highly significant. Applying it in the field is challenging, though. This treatment is contingent upon a few requirements. Pumping pipes and the mixing	Formula for 1 m^3 (Final) Oil base 0.70 m^3 Bentonite 800 kg 1. Using open end drill pipe (O.E.D.P). 2. Cleaning all mixing tanks and pumping pipes. 3. Two Pumps are required. 4. Initially, pumping clean water in front of the loss zone to guarantee bentonite hydration. 5. Squeezing process is required. 6. Displacing the plug in front

	tank must be cleared of water. In addition, for treatment to be effective, it is highly advised to content the loss zone with water. If not, it is tough to achieve success with this strategy.	of losses zone by using normal drilling mud. 7. Avoidance contamination between plug and drilling fluid. 8. Pulling out drill pipes strings to casing shoe. 9. Waiting period around (± 8-10 hours) in order to harden cement plug.
DOBC Squeeze (Diesel Oil Bentonite Cement)	It is a very common and important method, but it is not easy to implement in the field. Certain conditions must be met before this treatment	Formula for 1 m^3 (Final) Oil base 0.72 m^3 Bentonite 450 kg Cement 450 kg The implementation principle of this treatment is exactly the same technique for diesel oil bentonite plug.

	can be applied. The mixing tank and pumping pipelines must be free of water, and it is highly recommended to remove any water in the content loss zone to ensure the effectiveness of the treatment. Without meeting these requirements, this treatment method is unlikely to succeed.	
Barite Plug	The anomalous zone pressure is controlled with the help of this	Composition of this plug • Water. • SAPP. • NaoH.

	type of plug. When a well experiences a kick-out or blowout issue, this barite plug is utilized to pump in front of the interest zone.	• FCL. • Barite Implementation Method of the Barite Plug: 1. Identification of the height of zone 2. Selecting the appropriate density of this plug. 3. Using bit with nozzles to avoid nozzles plugging. 4. Displacing this barite plug by using normal drilling mud. 5. Avoidance contamination between plug and drilling fluid. 6. Pulling out drilling pipes strings above blowout zone and continue in rotation only to deposit barite plug into formation. 7. Waiting period about (3 hours).

3.4 Table 3.5. The Executive Procedures for the remedial Plugs (South Oil Company, 2011)

3.5 APPLYING ADVANCED DRILLING TECHNIQUES

Remedial and preventive measures may not always be enough to cure decreased circulation loss. Thus, it's critical to identify methods or processes that stop mud losses. Expandable tubulars and casing-while-drilling (CWD) are two examples of specific advanced technology utilized for this purpose. These techniques can be employed as long-term solutions to lessen the expensive impacts of lost circulation during drilling (Davison et al., 2004). Because of the telescoping action of the casing, expandable tubulars have the benefit of allowing the use of multiple mud weights for different sections without compromising hole size. Using downhole and surface components, casing-while-drilling allows regular oilfield casing to be used as the drill string, allowing the well to be cased and drilled at the same time (Tessari et al., 1999). Using a top drive, the case is turned away from the surface. Drilling fluid travels up the annulus between the casing and the wellbore and down the internal diameter (ID) of the casing. This method's primary goal is to cut down on nonproductive time (NPT), costs, and casing running periods when significant fluid losses make traditional drilling techniques challenging and costly. In the South Rumaila field, 306 wells have already been drilled using casing while drilling (CWD) technique (South oil company, 2009). This approach stopped lost circulation mud in this field.In the South Rumaila field, casing while drilling (CWD) technique proved to be a successful technical and economical way to drill and produce cement using casing strings (7 in., 8 1/2 in.). Casing while drilling (CWD) technology comes in two varieties: retrievable and non-retrievable systems. In order to isolate the Shuaiba formation, the non-retrievable system was employed. This type of casing is made to leave the casing drill shoe (CDS) on the bottom in the event that the well's final section is drilled to total depth (TD) or is to be drilled later in order to proceed with the subsequent hole sections. Images of the CWD assembly are shown in Figures 3.1 and 3.2. Using casing while drilling

(CWD) technique in 306 wells in the South Rumaila field, Shuaiba formation, has already led to the following conclusions and concepts (South oil company, 2009):

- By employing casing while drilling (CWD) technology, undesirable effects of the lost circulation mud such as drilling and operation cost, tripping time to land conventional casing to bottom, and rig floor safety in comparison with traditional mechanisms will be decreased.

- The high annular velocity leads to excellent hole cleaning efficiency and prevents bit balling, drag, and stick pipe issues.

- It also makes it easy to identify lost circulation zones and even drill without returns.

- Drilling while casing (CWD) technology aids in bringing the mud's circulation back to the surface.

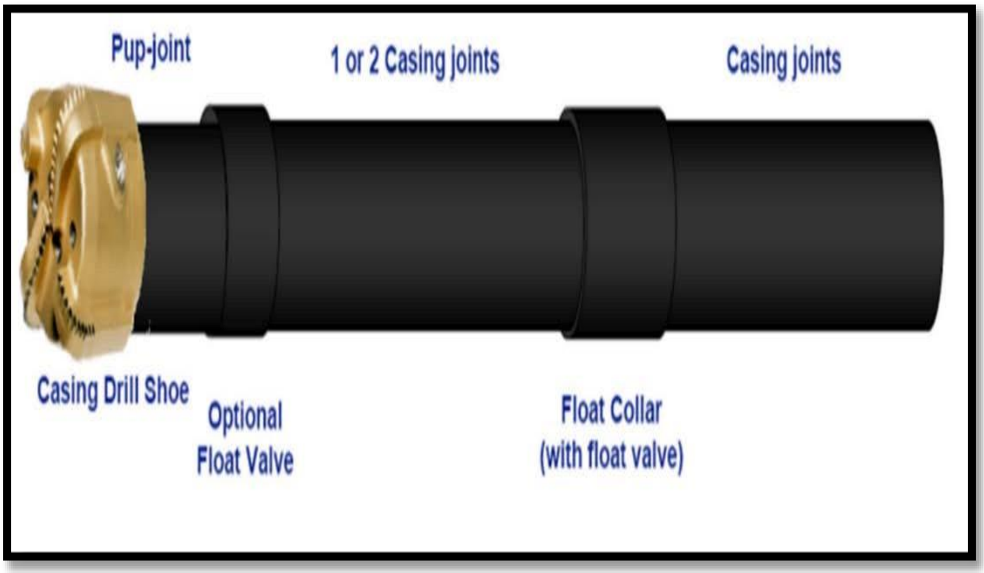

Figure 3.4 BHA Components of CWD Assembly (Gallardo et al., 2010)

Figure 3.5: Top Drive and Internal Casing Drive (Tessari et al., 2006)

3.6 REQUIRED CALCULATIONS FOR THE CORRECTIVE REMEDIES

To effectively combat or mitigate lost circulation mud, it is crucial to take necessary steps. Accurate calculations play a vital role in the success of mud losses remedies. Precise calculations ensure efficient treatment and guarantee positive results. This section covers some important calculations related to the remedies of the thief zone, which will help in achieving the desired outcomes. To ensure success in treating the loss zone, we need to gather some essential information.

3.6.1 The Volume of Displacement Fluid.

Accurate calculations are necessary to determine the right volume of placement fluid to displace various remedies in front of the thief zone, which will ensure effective sealing. The placement fluid is essential in partial, severe, and complete treatments, and we typically use normal drilling mud as the placement fluid. It's important to calculate the required volume of the fluid using Equation 1 for optimal results. By doing so, we'll be able to implement an effective treatment plan and achieve positive outcomes.

Displacement volume = $(\text{ID drill pipe})^2 \text{x } 0.785 \text{ x h}$ …………………(1)

Where Displacement volume = required volume of drilling mud (bbl/ft), which is needed to displace treating fluid in front of thief zone.

ID Drill Pipe = inside diameter of drill pipe (inch).

h= Depth to the top of plug or treatment in front of the thief zone (m).

3.6.2 The required plug's volume.

Numerous plugs that were intended to minimize or stop lost circulation mud. To have a good outcome, it is therefore necessary to determine the volume of these plugs that must be placed in front of the thief zone. Typically, greater than the required plug's real volume, which pumps as a safety factor of about 1-2 m3. The necessary plugs or treatments are determined using equation 2.

Volume of Required Plug = $(\text{DOH})^2 \times 0.785 \times \text{h}$………………………………(2)

Whereas

Plug Volume= is the amount of plug that must be used to completely enclose the thieving zone (bbl/ft).

Open hole diameter (in/ft) = DOH.

h is the height in meters of the thieving zone interval.

3.6.3 Calculating the Needed Plug's Density.

To prevent unintended outcomes, exact calculations must be performed to determine the proper density of the necessary plug. To determine the necessary plug's density, a few steps must be taken.

- find its static level column above the loss zone
- subtract it from the total drilled depth to find the mud level.
- We can calculate the hydrostatic pressure using equation 3.

HP= (pmud ×h)/10……………………………………………..(3)

Where.

HP = Hydrostatic pressure that thief zone can resist it without unwanted consequences (Kg/cm2).

pmud = Mud Weight (gm/cc)

h= the static level column of the drilling mud above the loss zone (m).

- By using hydrostatic pressure and equation 4, we can get the required density of the plug that does not affect negatively on the thief zone.

pplug = (HPx10)/h…………………………………………………..(4)

Where,

mud = Density of the required plug (gm/cc).

HE = Hydrostatic pressure that thiet zone can resist it without unwanted consequences (Kg/em?).

h = the height of the thief zone (m).

3.6.4 Calculating the Loss Zone Pressure.

Determining the pressure within the loss zone is a useful task. By measuring the static fluid column above the loss zone, the following approach can be used to determine that pressure (Baker Hughes, 1999).

- The drill string should be pulled out to the top of the suspected thief zone first.
- The wood's approximate length (4 feet) is attached to the rig's survey line.
- To find the static fluid level, run this length of wood down the drill pipe.
- Lastly, use equation 5 to calculate the loss zone pressure.

Pressure loss zone = D(static fluid column) × (MW) × (0.052) …………………..(5)

Where,

Pressure loss Zone = Loss zone pressure (psi).

Dstatic fluid column = is the static fluid column above the loss zone (feet)

MW = is the mud weight (Ib/gal).

3.6.5 Calculating the Mud Weight in the Loss Zone for Drilling Activities.

It is advised to estimate the mud weight of the drilling fluid throughout the drilling process. This estimate will lessen mud lost in circulation. Equation 6 can be used to determine the appropriate mud weight to be applied in the loss zone to strengthen formation:

CHAPTER 4

4.0 ANALYSIS OF RESULTS AND DISCUSSIONS

4.1 Guidelines for preventing lost circulation during drilling.

It is crucial to prepare ahead of time for any contingency plans, such as having enough LCMs, enough bentonite material for the drilling mud, and a sufficient supply of water to regulate the drilling operations.

It is strongly advised that you take the following steps prior to performing the necessary remedies:

1. Establish the upper and lower boundaries of the loss zone.
2. Determine the lithology type.
3. Determine the kind of losses.
4. Calculate the pressure within the area of loss.
5. Perform accurate computations for the necessary interventions.

- Using the blind drilling approach to drill as much of the thieving zone as feasible and then performing the necessary cure is practically interesting.
- It is best to conduct a speedy economic analysis before taking any action.
- An ideal drilling program must be prepared, monitored throughout drilling operations to be applied, and mechanical problems must be avoided in order to minimize human mistake as much as feasible. Drilling techniques that have been found to have a significant impact on the lost circulation mud issue include the following:

1. High SPM or pump pressure will cause an excessive amount of equivalent circulation density (ECD). Consequently, it is best to utilize the lowest circulation rate that will sufficiently clean the hole.
2. Immediately following shutdown, high rotation (high RPM) and high circulation rates will increase the pressure on the loss zone. In order to break gel strength, it is therefore best to rotate drilling strings at a low RPM for approximately 15 minutes without mud circulation when drilling activities resume.
3. Rapidly inserting the drill string into the wellbore will have a detrimental effect on the weak formations. Consequently, it is preferable to gradually lower drill strings into the wellbore before unconsolidated zones.
4. Maintain close monitoring of the downhole annular pressure and ensure that the equivalent circulation density (ECD) stays within permitted bounds.

- It is advisable to incorporate sized light-colored cement (LCM) into the drilling mud prior to drilling formations that are prone to mud losses. This will enhance the weak formation's strength, expand the fracture gradient, and stop or lessen induced fractures from spreading past their initial stages.
- Based on extensive research, it has been determined that sized calcium carbonate and graphitic carbon are effective LCMs, and doing so is recommended as a wellbore strengthening strategy before drilling depleted and weak zones.
- To prevent too much equivalent circulation mud (ECD), it's crucial to avoid high concentrations of coarse LCMs.
- There are numerous different types of lost circulation materials (LCMs), and each one has unique characteristics and prices. Particle size distribution (PSD), shape,

size, and concentration are the main factors that determine how well loss circulation materials (LCMs) operate.

- Before adding loss circulation materials (LCMs) to drilling mud, it is practically interesting to reduce the yield point (Yp) and the solids content of the mud within permissible limits in order to minimize gel strength and equivalent circulation density (ECD).
- Whether to address the issue when/if it arises or to apply wellbore strengthening techniques as preventative measures depends critically on the state of the economy.
- It is very advised to prepare for well-control concerns when handling losses.
- It is extremely essential to gain an integrated image of the geometry of the formations that are prone to mud losses by using image logs or caliper logs to take correct actions.
- Appropriate selection of the remedies to avoid the non-productive time and reduce expenses.
- To improve compressive strength for treatment and achieve desired outcomes, it is crucial to provide plugs—especially cement and barite plugs—enough time to harden into wellbore.

4.1.1 Finding the Loss Area

When drilling through a low-pressure and naturally fractured formation, a sudden and significant loss of returns accompanied by an increase in drilling torque and relative drilling roughness usually indicates that the loss zone is at the bottom. This is a reliable indication if no previous incident of lost circulation had occurred. Similarly, drilling through vugs, channels, and caverns can result in the drill-string advancing to a certain depth without any weight.

Since rock strength generally increases with depth, an induced fracture is usually closer to the previous casing shoe than the total depth. To locate the loss zone accurately, a temperature survey is used. The circulation of drilling fluids alters the static geothermal gradient in a borehole because of the injection of cooler mud.

To determine the normal temperature gradient in the well under static conditions, a base temperature log is run. Then, a volume of mud, equal to 1000 – 1500 feet of open hole, is pumped into the hole from the surface, and a second temperature log is run. The two logs are compared to determine the location of the loss zone. On the second log, a cooler gradient is observed from the surface to the point of mud exit into the loss zone. However, below the loss zone, a higher temperature gradient should be observed on both logs. A temperature survey is an effective way to locate a loss zone, as shown in Figure 4.1.

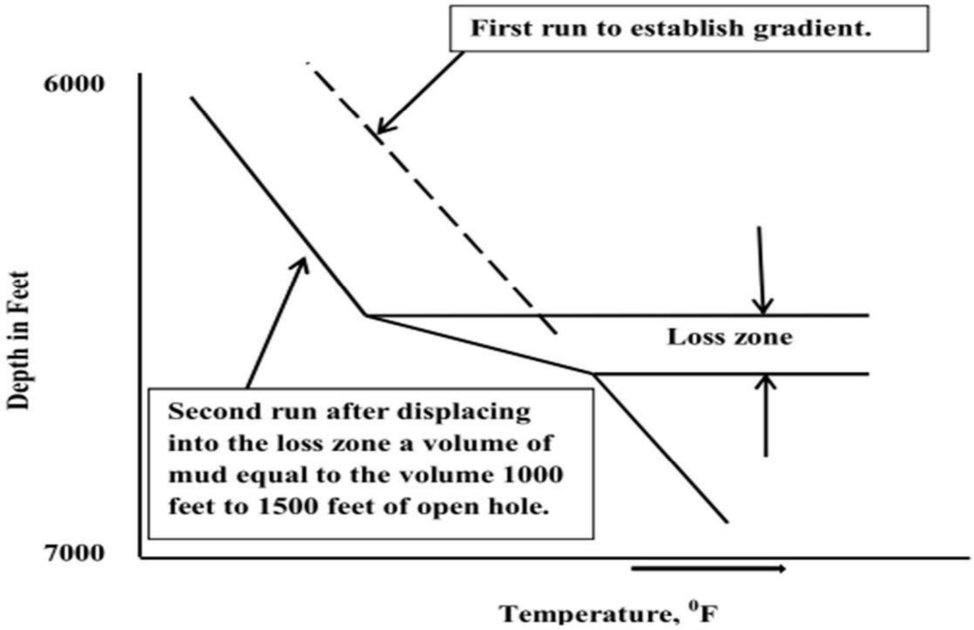

Fig. 4.1 Temperature Survey (After Canson, 1985).

Radioactive logs, noise logs, and mechanical devices (flowmeters) can also be used to locate the loss zone (Canson, 1985). The above methods are useful when the loss zone is off the bottom of the well. When the loss zone is at the bottom of the well, it is advisable to drill through the loss interval until the top and bottom of the loss interval can be established.

4.1.2 Determining the Loss Zone Pressure

When there is a complete loss of returns, this information is quite helpful. Without this knowledge, treatment outcomes may be unsatisfactory since the flow of treatment material into the loss zone is left up to trial and error (Canson, 1985). Understanding the static fluid level in the wellbore is necessary in order to estimate this pressure. There are several ways to estimate the static fluid level in the well; two of the strategies that are employed are counting pump strokes to fill the annulus and utilizing echo meter readings (Gray and Darley, 1980). According to Ferron et al. (2011), another technique is as follows:

Using soft clay, a ball with a diameter of one inch is produced. The release of the ball over the wellbore initiates the stopwatch, which is stopped when the ball reaches the wellbore's static fluid level. When releasing the ball, it is best to avoid hitting the wellbore's walls because this will delay the ball's arrival at the fluid level. The distance to the top of the fluid level in the wellbore can be determined from figure 4.2 by following the vertical axis until it reaches the curve. The pressure inside the loss zone can be calculated using the following straightforward calculation based on the estimated distance and the depth of the loss zone:

$$P_{loss\ zone} = D_{static\ fluid\ column} \times MW \times 0.052 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4.1)$$

Where,

$P_{loss\ zone}$ is the pressure in the loss zone (psi);

$D_{static\ fluid\ column}$ is the static fluid column above the loss zone (feet); and MW is the mud weight (lb/gal).

Fig. 4.2 – Approximate Distance to Top of Fluid Level in Wellbore (After Ferron et al. 2011)

4.1.3 Methods for Finding Cross-flows in the Loss Area

Activation of oxygen is one technique used to identify cross-flows (Sweatman et al. 2004). It is possible to identify downhole water flows using oxygen activation logging instruments like pulse-neutron spectroscopy (PNS) and pulse-neutron capture (PNC). The following reaction takes place when oxygen is exposed to neutrons that have energy higher than 10 Mev:

16 O + n = 16 N* + P ……………………………………………………(4.2)

The nitrogen is left in an excited state, and it takes 7.35 seconds for it to beta-decay back to oxygen. The logging tool detects oxygen activation by using the gamma ray that the oxygen instantly emits. Water must have a fluid velocity greater than the logging tool's speed in order to be identified.

4.2 LOSSES FROM SEEPAGE

When the rate of loss falls between 1 and 10 barrels per hour, an incident involving lost circulation might be categorized as seepage loss. They can be found in any kind of formation. Seepage loss may be regarded as a loss, or it may be caused by several circumstances arising from the drilling activities. Drilling into competent formations at fast drilling rates, for instance, may cause losses that are estimated but are not real. Perceived seepage losses can have a number of factors (Ferron et al. 2011). Drilling fluid retained on drill particles that have been withdrawn from the hole;

- Normal displacement of drilling mud with drilled solids; a specific volume of drilling fluid is required to fill the new hole being drilled.
- The maximum amount of drilling fluid that can be kept on drill solids that have been removed from the system is one barrel for every barrel of removed drilled cuttings.

Thus, before beginning any therapy, it is crucial to evaluate the seepage loss in light of the aforementioned considerations. Separating perceived losses from actual losses can be accomplished by monitoring the total volume of mud lost over time and using floating sensors or acoustic reflectors to monitor the mud level in the mud pit (Beda and Carugo, 2001).

4.2.1 Causes, Effects, and Control of Seepage Loss

Very porous rocks have seepage losses. Drilling fluid is continuously lost through the pore throats and into the rock. Seepage loss is often defined as a loss rate of 10 to 30 barrels per hour. This low rate of mud loss could possibly be caused by other factors. Drilling fluid that is retained on drilled solids is one of the causes. The trapped fluid is eliminated together with the drilled solids since they are taken out of the system at the surface. If the drilling rate is high and the shale sakers are not effectively extracting the fluid from the cuttings, the effect will be more noticeable. In this instance, the volume lost might be so great as to suggest seepage losses. The expansion of holes in unconsolidated formations could be another cause. This could provide the false impression that the hole is leaking more fluid than is indicated by the computed volume. To determine the true cause, the situation needs to be assessed. Corrective measures can be implemented as soon as the cause of the loss has been determined.

The decision to initiate or forego seepage loss control depends on the stage of drilling operations, the severity of losses, and the type of drilling fluid. For instance, if the hole is being drilled with inexpensive water-based mud, the loss rate is low, and the hole section is approaching the casing point, the operator may decide not to take any action to control losses.

4.2.2 High seepage losses may have a number of negative effects, some of which are covered below.

1. Cost: Although seepage loss is often slower, mud compounds may eventually be lost to the formation in significant quantities. The total cost of seepage losses may be high if sensitive zones are drilled using Oil Base Mud (OBM) or Synthetic Oil Base Mud (SBM).

2. Formation Damage: Seepage losses in a reservoir formation could allow drilling fluid to infiltrate into the rock's pore spaces, causing damage to the area close to the wellbore that would be detrimental to the well's productivity. It may also make it harder to analyze logs. 3

3. Stuck Pipe: The goal of the optimal mud design is to cover the wellbore walls with a thin, impermeable filter cake. A thick, porous filter cake is typically deposited by high seepage loss, which causes downhole issues A low-quality filter cake may cause tight hole conditions and increased drag. The mud must be treated by wiper trips and several circulations, which raises the well's overall cost. Thick filter cakes have the potential to jam the drill string mechanically or differentially, increasing the cost and recovery time of the well.

4. Hole expansion: In unconsolidated sand deposits, hole expansion may result from high seepage loss. The matrix on the borehole walls collapses as a result of the pressure penetration, losing the differential pressure across the sand grains and causing the hole to grow.

4.2.3 Controlling Seepage Losses

"Blocking" and "Filtration Control" materials are used in tandem to control seepage losses. Since neither of them can effectively regulate the flow of fluid into the pore throats on its own, the mud system requires both of them.

1. **Blocking Material:** Drilled solids and barytes are the primary blocking material in the mud system which are lodged into the pore throats under the differential pressure and partially block the opening, reducing the rate of flow of drilling fluid into the formation. Blocking materials need to be of a certain size to create effective blockage. Seepage loss occurs when the pore throats of the formation are large enough to allow

the flow of drilling fluid. Hence, the primary requirement to stem the loss is to reduce this opening. Once the opening is sufficiently reduced, it can be plugged in easily. Finer obstructing particles accumulate until the gap is between one and five microns, after the larger particles have blocked the pore mouths.

2. **Filtration Control Material**: The filtration loss persists even after drilled solids and barytes are used to seal the pore mouths. In the Water Base Mud (WBM), materials like "Bentonite" and "Polymers" are employed as filtration control material. These materials effectively plug smaller holes, hence halting seepage loss entirely. The blocking materials must effectively block the formation's face and sufficiently close the gap in order for the filtration control material, which is coated on top of the blocking material layer, to function as an effective seal. Therefore, a mix of filtration control material and blocking material is needed to achieve control of seepage losses.

The Non-Aqueous Fluids (NAF) have a separate filtration loss control mechanism. Water particles are present in the dispersed phase of NAFs. These scattered water particles aid in filtration loss management because of their high surface tension, which prevents them from simply passing through the narrower gap left by the blocking material.

3. **Optimized Particle Dimensions:** This method aims to determine, compute, and blend the necessary mud system particle sizes to successfully seal off the wellbore's pore throats. If the blocking particles are too big, they will bounce off the wall and be circulated out of the well rather than becoming trapped in the pore throats; if they are too small, they will pass through the pore throat opening. The minimum particle size needed to obstruct pore throats is the subject of multiple theories. Particles can obstruct pore throats 2.5 to 3 times larger than their actual size, according to a widely accepted field approximation, as seen below.

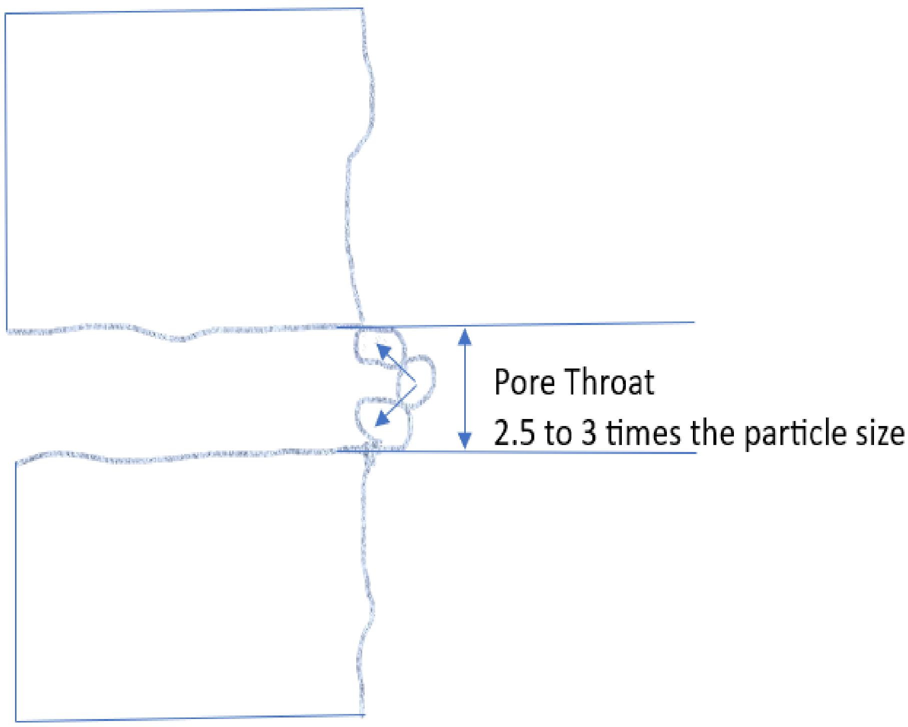

Fig. 4.3 The one-third blocking rule

Another name for this is the "one-third blocking rule." The particles reduce the gap by forming a bridge as they attempt to lodge into the pore mouths under differential pressure. Because of the narrowing of the gap, there is still some fluid movement via the pore throat. Smaller particles build up to fill in and narrow these spaces even more. Based on the aforementioned estimate, the majority of organizations advise using a "Optimized Particle Size Distribution" strategy, which involves blending various micron particles.

Pore throat measurements in actuality are rarely accessible. To obtain precise measurements on core plugs, a comprehensive series of air permeability examinations and mercury injection procedures are required. Since no two particles or pore throats are exactly the same size in reality, the blocking particle size can be chosen using an estimate of the pore throat diameter expressed in microns. Information on formation permeability is easily accessible and can be acquired from the geologist or reservoir engineer.

Even though there are comprehensive formulas and charts available for precisely calculating the pore throat diameter for certain permeability and porosity values, a reasonable approximation can be made using the formation's permeability by applying the following general rule of thumb:

Pore-Throat Diameter in Microns = Permeability Squared in Milli-Darcy

For example:

If the permeability of a formation is 1.5 Darcy = 1,500 milli-Darcy

The Pore-Throat diameter $\simeq$ 38 microns

Hence the approximate size of the required blocking particle = 38/3 $\simeq$ 13 microns

Controlling seepage losses in high mud weight drilling is easier and comparatively less expensive than in lower mud weight drilling because barite is employed as a weighting ingredient in most mud systems. Barite's particle size distribution serves as a blocking substance. A API The D50 of barite is around 15–20 microns, and its particle size distribution ranges from 0.5 to 100 microns. Particle diameter D50 represents the ratio of 50% larger to smaller particles.

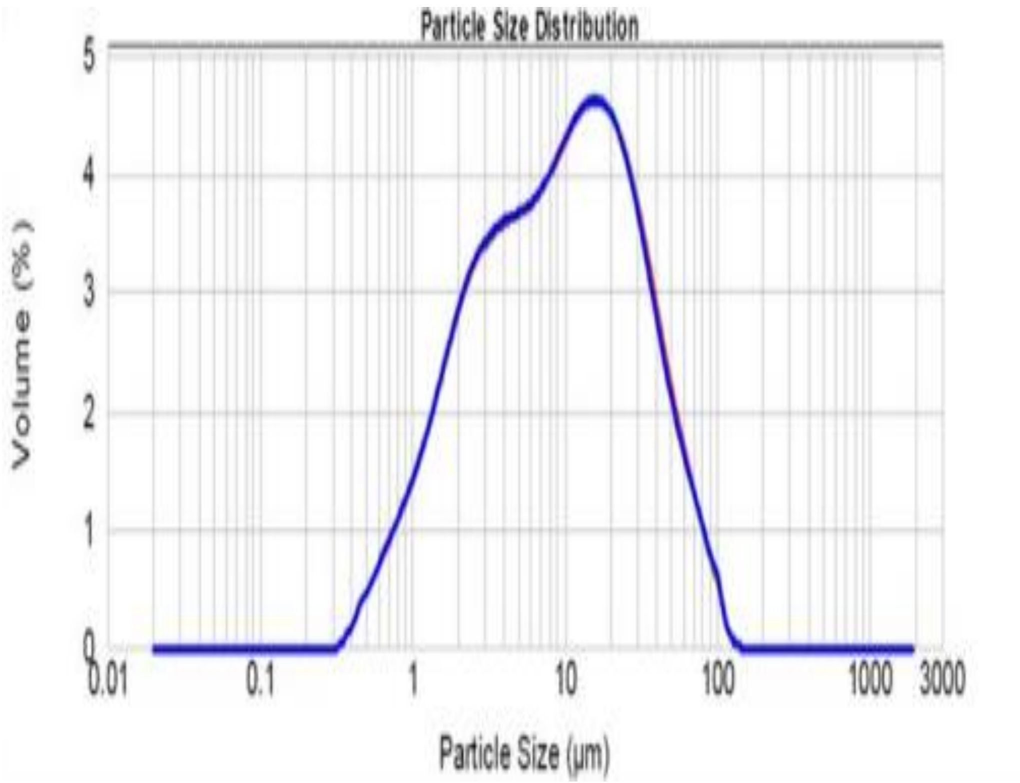

Fig. 4.4 - Particle size distribution

To effectively block pore throats in a low-mud weight scenario, the fluid system will need to be supplemented with diverse particle sizes. For low-weight mud systems, a drill and "seal pill" with extra blocking material in the base fluid is a preferable tactic. Very fine $CaCO_3$ (5–10 microns) combined with a tiny bit of Asphaltene helps build an efficient base cake in low permeability sands. A more coarse-grained blocking substance is required if the permeability is multi-darcy. Because $CaCO_3$ is soluble in acid and can be eliminated by acid washing the well when it is completed, it can be used as a good bridging material for reservoir development, helping to lessen the "Skin" effect.

Table 4.1 – Seepage Loss Quick Reference Guide to Pretreat Active Mud System with LCMs

LCMs		MUD WEIGHTS (lb/gal)				COMMENTS
		7.0 to 12.5	12.5 to 15.0	15.1 to 17.0	17.1 +	
GRAPHITIC CARBON (FINE)	LCM CONCENTRATION (lb/bbl)	5-10	5-10	5-10	5-10	Add recommended amounts to active mud system.
$CaCO_3$ (FINE)		5-10	5-10	5-10	5-10	
TOTAL LCM CONC. (lb/bbl)		10-20	10-20	10-20	5-10	

4.3 PARTIAL LOSSES

Partial losses can happen when the severity of the loss ranges between 10-500 bbl/hr. These kinds of losses are common in gravels, small horizontal fractures that occur naturally, and very slightly opened vertical fractures that are induced (Nayberg, 1987). To prevent and cure partial losses in all the formations mentioned above, LCMs can be used in the mud. However, it is crucial to follow the guidelines discussed in the previous sections to select the optimum PSD of these bridging materials. Ferron et al. (2011) have provided guidelines in Table 4.2 on the amounts of LCMs that should be added to the active mud system to prevent and cure partial losses.

Table 4.2 – Partial Loss Quick Reference Guide to Pretreat Active Mud System with LCMs

LCMs		MUD WEIGHTS (lb/gal)				COMMENTS
		7.0 to 12.5	12.5 to 15.0	15.1 to 17.0	17.1 +	Pump sweeps as needed. Do not over treat as this can lead to a build-up of solids which will increase ECDs.
Micro-Fiber (Fine)	LCM CONC. (lb/bbl)	10	10	10	10	
Micro-Fiber (Medium)		10	10	10	10	
Micro-Fiber (Coarse)		10	10	10	10	
$CaCO_3$ (Fine)		10	10	10	10	
$CaCO_3$ (Coarse)		10	10	10	10	
Total Lcm Conc. (Lb/Bbl)		30-50	30-50	30-50	30	

4.4 SEVERE AND TOTAL LOSSES

If the mud losses exceed 500 bbl/hr, they are considered severe. When there is no fluid returning through the annulus, it is classified as total losses. These kinds of losses occur in lengthy, open sections of gravels, large, natural horizontal fractures, caverns, interconnected vugs, and widely-opened induced fractures, as stated by Nayberg in 1987. It is extremely hard to deal with losses into large caverns, which occur only at very shallow depths. In some cases, a cure may not be possible, and other actions may be required, as mentioned by Ferron et al. in 2011. Some of the actions that may be taken include drilling blind or drilling with aerated mud.

4.5 LOST CIRCULATION DECISION TREE

A lost circulation decision tree is a tool used in the oil and gas industry to help drilling engineers and operators make decisions when faced with lost circulation issues. It is a flowchart that outlines a series of steps and procedures to follow in order to mitigate the problem. These decision trees are typically customized for each field and well interval, based on offset well data, and are unique to each drilling mud company. It's important to note that using a decision tree developed for one field or company may not be effective in other fields or companies. An example of a lost circulation decision tree for one of the drilling mud companies is provided below.

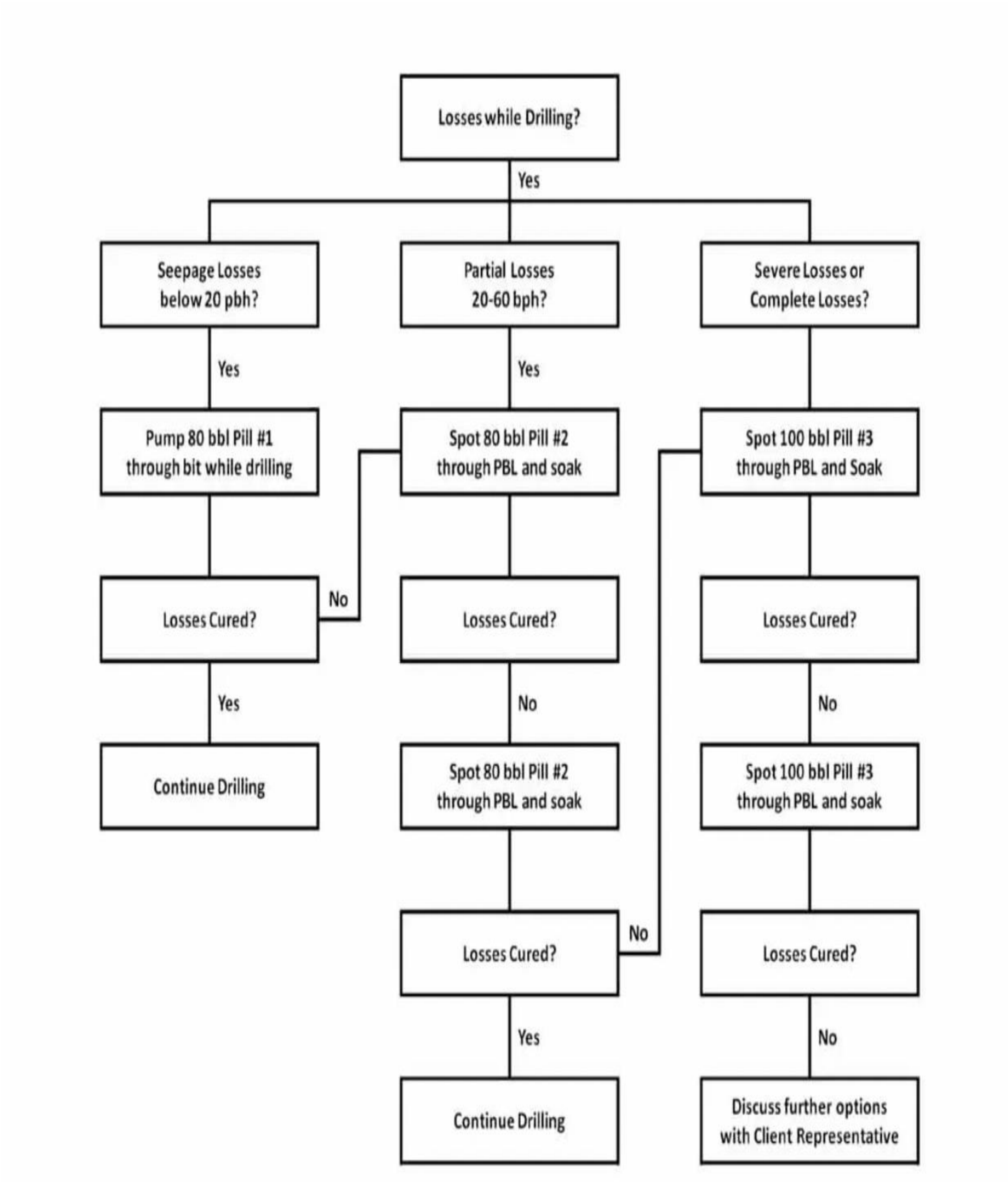

Figure 4.5 : A typical loss circulation decision tree

4.6: LOST CIRCULATION CONTROL FLOW CHART

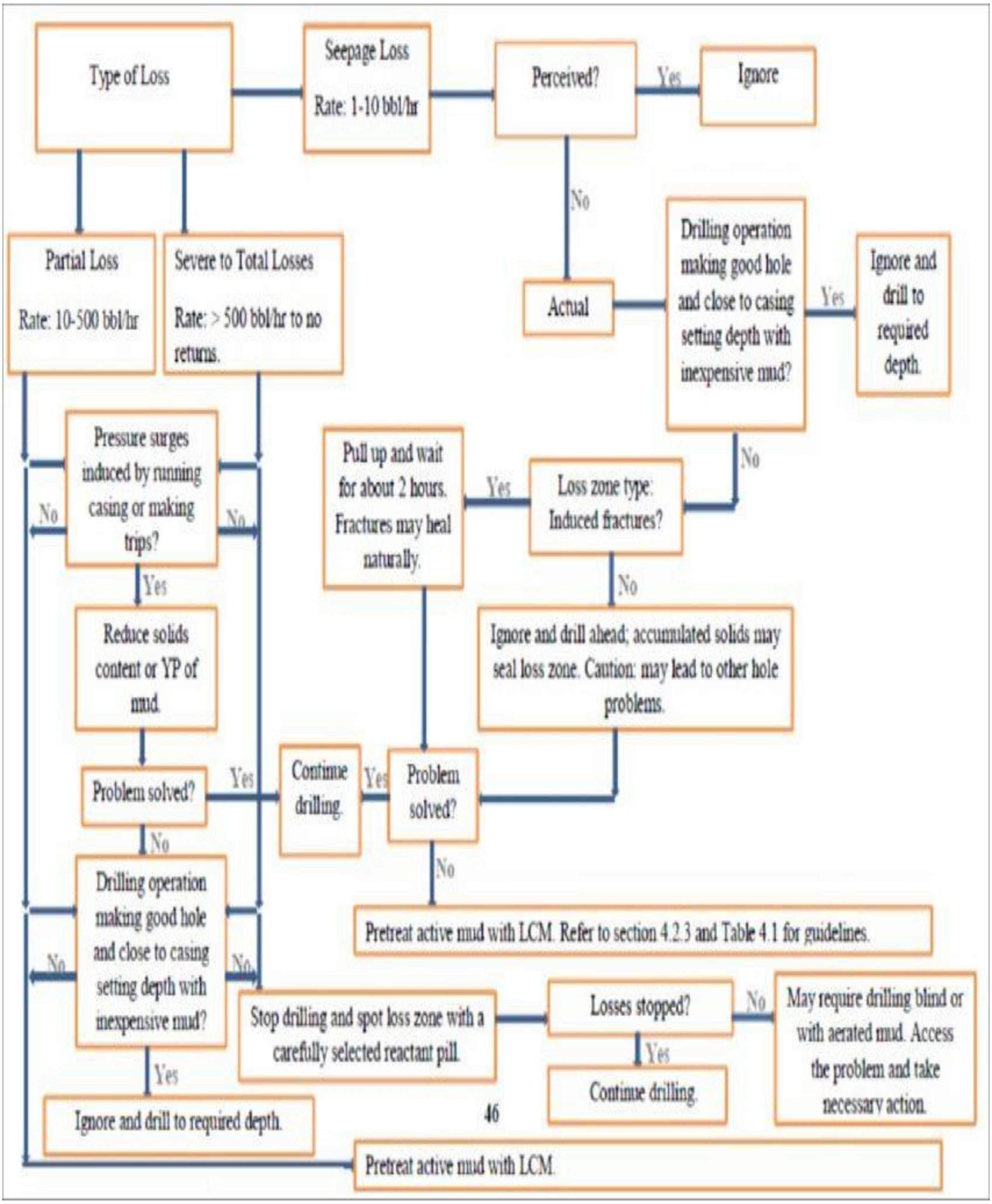

Fig. 4.6 Lost circulation and control flow chart

CHAPTER 5

CONCLUSIONS, AND RECOMMENDATIONS

5.1 CONCLUSIONS

The study's findings led to the following conclusions:

1. many strategies can be used to prevent lost circulation from occurring, particularly when drilling formations that are prone to losses;
2. Effective control or treatment of lost circulation depends on several factors, including borehole temperature, pressure, depth, and size of the thief zone;
3. Practical guidelines have been developed that, when used in conjunction with the accompanying flow chart, will serve as a quick reference guide to prevent and minimize the problem of lost circulation during drilling.

5.2 RECOMENDATION

In light of forthcoming research in this field, the following suggestions should be taken into account:

1. When choosing lost circulation materials (LCMs) for lost circulation control, it is possible to take reservoir productivity into account.

2. Due to the broad nature of lost circulation control, a study focusing on a specific formation type such as depleted reservoirs—may be carried out to gain a deeper knowledge of control strategies.

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