

MALAWI UNIVERSITY OF SCIENCE AND TECHNOLOGY

DEPARTMENT OF EARTH SCIENCE

ASSESSMENT OF LOST CIRCULATION DURING DRILLING OF WELLS

Yunus Mzima

[PRE/014/19]

Thyolo, Malawi

Dissertation submitted to Ndata School of Climate and Earth Sciences of the Malawi University of Science and Technology in partial fulfillment of the requirements for Bachelor of Science Degree in Petroleum Resources (oil and gas)

10th November, 2023

DISSERTATION APPROVED BY:

SUPERVISOR:

Mr. R. Mvula Signature: 

ASSESSOR:

Signature: _____

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ABSTRACT

The problem of lost circulation poses significant challenges to drilling operations, leading to Non-productive time (NPT) and increased costs. In order to effectively control lost circulation during drilling well construction, a holistic engineered approach is required, extending beyond the selection of appropriate lost circulation materials (LCMs). This research. This research project aims to assess and understand the mechanics of lost circulation while providing an updated classification of LCMs and their applications. The methodology involves various elements, including borehole stability analysis, equivalent circulating density (ECD) modeling, leak-of flow-path geometry considerations, and drilling fluid and LCM selection to minimize the effects on ECD. On-site monitoring using annular pressure while drilling (APWD) and timely application of LCMs and treatments are also crucial aspects. Conventional LCMs have traditionally been categorized based on their appearances as fibrous, flaky, or granular, or a combination of these. However, the existing classification system is outdated, dating back several decades. This project seeks to fill this gap by providing an updated classification system that encompasses both conventional and new technologies. The classification will consider the LCMs appearance, applications, chemical and physical properties, and categorize them as either corrective or preventive approaches. Corrective treatments can be applied after the occurrence of lost circulation, while preventive techniques are deployed proactively before encountering lost circulation zones. Furthermore, this research project highlights the latest developments in LCMs and treatments, presenting a comprehensive summary of the currently available LCMs, alternative approaches, and their respective applications. By examining and evaluating the effectiveness of these materials and treatments, the aim is to provide valuable insights into their practical implementation and performance during drilling operations.

ACKNOWLEDGEMENT

I would like to express my deep gratitude and appreciation to all those who have contributed to the completion of this dissertation.

First and foremost, I am immensely thankful to my supervisor, Mr. R. Mvula, for this unwavering support, guidance, and invaluable insight throughout the research process. His mentorship has been instrumental in shaping this dissertation.

I am indebted to the Ndata School of Climate and Earth Science, basically Earth science department members for their encouragement and expertise. Their constructive feedback and intellectual discussions have enriched my understanding of the subject matter.

I would like to extend my heartfelt thanks to my family of Mrs. Mzima including my brothers and sisters for their unwavering belief in my abilities and their constant encouragement. Their love and support have been my pillars of strength.

I would also like to thank Islamic Zakaat Fund (IZF), for funding my education throughout my education journey without their support, I couldn`t reach this far in my education.

My sincere appreciation goes to my friends and colleagues who provided moral support during this academic journey. Their encouragement kept me motivated during challenging times.

I am also grateful to the participants of this study whose willingness to share their experiences and insights made this research possible.

Finally, I want to acknowledge the invaluable resources and facilities provided by Malawi University of Science and Technology. These resources have been crucial in conducting my research effectively.

This dissertation would not have been possible without the collective support and encouragement of all these individuals and institutions. Thank you for being a part of this significant milestone in my academic journey.

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1. CHAPTER 1: GENERAL INTRODUCTION

1.1. Background Information

As the demand for petroleum resources increases, drilling of oil and gas wells are often carried out in challenging and hostile environments. Among the top ten drilling challenges facing the oil and gas industry today is the problem of lost circulation (Alkinani, 2017). Lost circulation or lost returns are the partial or total loss of mud to subsurface formations. It occurs when the openings in the formation allow the mud flow into the formation, resulting in losses ranging from 0.16m^3/hr (1bbl/hr) to a complete loss of returns (Matanovic, 2013).

Lost circulation is a common drilling problem especially in highly permeable formations, depleted reservoirs and fractured or carvanous formations. The range of lost circulation problems begin in the shallow, unconsolidated formations and extend into the well-consolidated formations that are fractured by the hydrostatic head imposed by the drilling mud (Alkinani, 2017).

Losses can also occur in natural fractures and faults present in the formation. Lost circulation can range from partial to total depending on the rate fluid flows into the formation (Eikemo, 2023). These losses can cause non-productive time, increase cost, and cause well control incidents. When losses occur, they can be cured by reducing the drilling fluid density, adding LCM to the drilling fluid, and/or pumping LCM pills (Eikemo, 2023).

In recent years, the average annual loss time caused by lost circulation encountered by the China National Petroleum Corporation (CNPC) was over 4000 days, accounting for more than two-thirds of the total complex loss time of drilling accidents, with an annual direct economic loss of over 5 billion yuan. Imperfection in the plugging material and drilling fluid technology is the fundamental cause of these economic losses, due to the lost circulation. Thereby the development of a new technology is key to reducing the economic losses caused by lost circulation (Yang, et al., 2022).

In the Gulf of Mexico, the lost circulation problem has given rise to an expenditure of an additional 1 billion dollars each year, and 10–20% of the total cost of drilling high-temperature and high-pressure wells has been expended on drilling fluid losses according to the U.S. Department of Energy. The most common treatment for this problem is to introduce granular lost circulation material (LCM) into the drilling fluid system to plug fractures (Feng et al., 2018).

In the Middle East and Africa two recent case studies were made on lost circulation, the first one was on wells drilled in the western desert have traditionally experienced severe to total losses while drilling fractured dolomite. Frequently, such events have been difficult to cure by conventional means. The only solution has been multiple applications of cement plugs to heal the losses. This case study describes a well with dynamic losses of more than 150 bbl/hr that were healed by spotting one pill through the circulating substances across the thief zone. The losses were successfully cured, allowing the operator to continue drilling. The second case was, while drilling in sandstone, the well experienced total losses, which presented an immediate challenge to maintain hydrostatic pressure. The operator responded by pumping several conventional pills loaded with a broad particle size range of fibers, granules and polymers. These pills were unsuccessful at healing the losses, so the operator opted to deploy the new technology LCM. The losses were cured successfully with a single application (Addagalla, et al., 2020).

The consequences of leaving lost circulation problem unattended may lead to other wellbore instability problems, such as differential sticking, poor hole cleaning, well control issues, and pack offs. This problem has persisted in the oil, gas, and geothermal industries. Mud losses to the formation often worsen as the depth increases, causing the wellbore to be increasingly unstable, affecting wellbore cleaning and reducing the rate of penetration (ROP). Most lost circulation incidents occur at the wellbore surface, then can extend deep into the formation. Lost circulation also occurs during geothermal drilling because geothermal wells are mainly drilled in volcanic and hard formations, with natural fracture apertures often greater than 1000 microns. This factor and harsh

drilling environments from under-pressurization in fractured and altered material zones make lost circulation more common in geothermal wells than in oil wells (Fatemah K Saleh et al, 2020).

A study in Iceland revealed lost circulation to be the primary cause of wellbore instability in 75% of the wells in the Hengill Geothermal Area (Sveinbjornsson & Thorhallsson, 2014).

1.2. Problem Statement

Lost circulation is the uncontrolled flow of drilling fluid into the formation hence it is "lost" or the well goes on "losses". Losses can occur when the drilling fluid exceeds the fracture pressure of the formation thus creating fractures or invading the pore space in the formation. Losses can also occur in natural fractures and faults present in the formation (Eikemo, 2023).

While Malawi is currently in the exploratory stage of oil and gas production, there is a growing hope that the country will be able to produce its own oil and gas resources in the future. However, lost circulation during drilling operations is a common challenge encountered in oil-producing countries (Elizondo et al, 2023). Although lost circulation issues have yet to occur in Malawi, it is essential to proactively address this problem to ensure efficient and cost-effective drilling processes when oil and gas production becomes a reality in the country. Therefore, there is a need to research and understand the potential causes, frequency, severity and potential solutions for lost circulation during well drilling operations to facilitate effective planning and preparation for future oil and gas exploration activities in the country.

1.3. Main Objectives

The main objective of this research project is to assess lost circulation during the drilling of wells. The specific objectives are:

- To review lost circulation control methods applied in the drilling industry till date
- To provide an updated classification of these materials and treatments with field applications
- To develop practical guidelines that will serve as a reference material for lost circulation control at the well-site for drilling personnel

1.4. Research Questions

What are the commonly used lost circulation control methods in the drilling industry, how can these lost circulation materials be categorized based on their appearance, applications, chemical, and physical properties, and What are considerations and

parameters that drilling personnel should evaluate when selecting lost circulation control methods?

1.5. Significance of Study

The research project on assessment of lost circulation in drilling operations holds significant importance for the drilling industry and its stakeholders. The study seeks to address the challenges associated with lost circulation, which can cause non-productive time, increased costs, and potential wellbore instability. By achieving the objectives outlined, this research project will provide valuable insight and practical guidelines for drilling personnel and contribute to the overall optimization of drilling operations.

2. CHAPTER 2: LITERATURE REVIEW

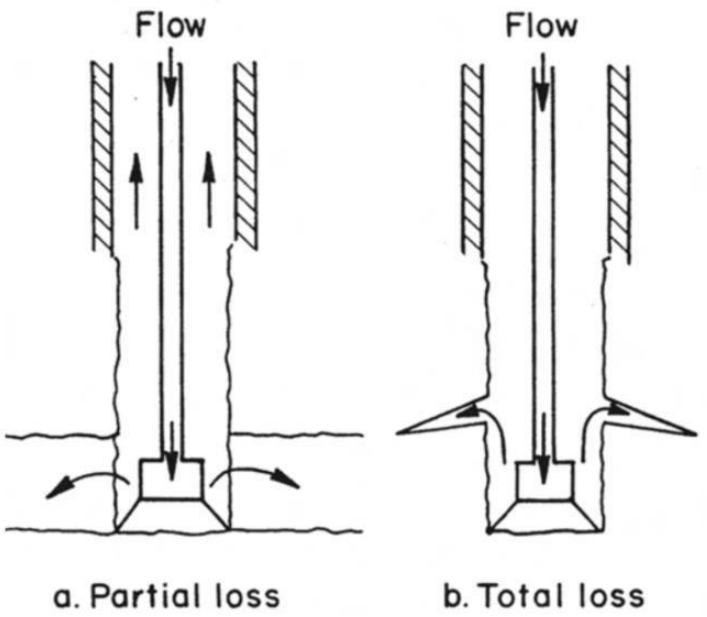
This chapter introduces the essential functions of the drilling fluid and how improper drilling conditions can lead to mud losses and, thus, lost circulation. A comprehensive study of the causes, challenges, impacts and assessment methods of lost circulation is presented. An extensive review of lost circulation materials (LCMs) used in this study, the limitations and challenges in developing and testing lost circulation materials for high-temperature environment are highlighted.

2.1. Review of drilling mud and lost circulation

Drilling mud is the fluid system that comprises a volume of fluid pumped with unique mud pumps from the surface, through the drill string, and out the nozzles of the drill bit; this mud goes up the annulus in the wellbore and back to the surface, for removing solids and maintenance treatment. The drilling mud is the only component that remains in contact with the wellbore throughout the process. The drilling mud is designed to perform the following functions: Cooling and lubricate drilling bit, Clean the wellbore by transporting the drilled cuttings (rock fragments) from the bottom to the surface, where it is mechanically removed, balances formation pressure in the wellbore to minimize well control problems, prevents and minimizes damage to productive formations, transmit hydraulic horsepower to the drill bit, and assist in drilling mud telemetry (Sharma et al, 2021).

Critical properties must be optimized and monitored during the drilling process for the drilling mud to perform its desired functions. The main properties of the drilling mud are: density, rheological properties, including viscosity, gel strength, and yield stress, fluid loss and filtration properties, mud stability at high temperatures and pressure (Aljadi, 2014). The cost of the drilling mud can average 10% of the total drilling cost; however, the performance of the drilling mud can affect the overall drilling cost in multiple ways. A well designed and well-maintained drilling mud can help achieve cost savings throughout the drilling process by enhancing the rate of penetration (ROP) (Sharma et al, 2021). If the drilling mud is poorly designed or maintained, it could lead to improper drilling conditions and potentially lost circulation.

As defined in the background, lost circulation or lost returns is the partial or total loss of mud to subsurface formations. It occurs when the openings in the formation allow the mud flow into the formation, resulting in losses ranging from 0.16m^3/hr (1bbl/hr) to a complete loss of returns (Matanovic, 2013).



Rock formations that are naturally fractured, cavernous, and have high permeability are potential zones for lost circulation. Additionally, improper drilling factors and conditions can lead to induced fractures, creating lost circulation zones. Factors that lead to induced fractures in formations include excessive downhole wellbore pressure and setting intermediate casing too high in transition zones. Excessive wellbore pressures are usually caused by high annular-friction pressure loss, high flow rates, and tripping in too swiftly, resulting in high surge pressure (Olubode et al, 2022).

2.2. Challenges/impact of lost circulation

This section highlights the key difficulties faced by drilling engineers and service providers in combating lost circulation and also highlights the consequences of lost circulation on wellbore integrity, drilling efficiency, and overall project economics.

One of the primary challenges is the presence of heterogeneous formations. Geological formations often consist of various types of rocks, including porous, fractured, or

carvenous formations. When drilling through these formations, the drilling fluid may encounter zones with high permeability or large voids, leading to fluid loss (Zhang et al, 2021).

High-pressure zones; some formations may contain high pressure zones, such as over-pressured zones or hydrocarbon reservoirs. If the drilling mud pressure is not properly managed, it can exceed the formation`s fracture gradient, causing fractures to open and the mud to escape into the formation (Mitchell et al, 2011).

The other challenge is the wellbore instability, the loss of drilling fluid can cause wellbore instability. When the fluid is lost into a permeable formation, it can lead to the collapse of the wellbore, resulting in reduced hole size or even complete wellbore blockage. This can make it difficult to continue drilling operations and may require remedial actions to regain wellbore stability (Alkinani, 2017). Lost circulation can also have significant financial implications for drilling operations. The cost of drilling fluids and associated additives can be substantial, and the loss of these fluids can result in increased expenses. Additionally, the downtime required to address lost circulation issues can lead to project delays and increased operational costs (Mirabbasi et al, 2022).

Lost circulation also has environmental consequences. The drilling fluids escaping into the formation may contain additives or chemicals that can impact the surrounding environment, including groundwater contamination or damage to ecosystems. Proper containment and mitigation measures are necessary to minimize these environmental risks (Mazlin Idress et al, 2019). Lost circulation complicates well control operations. If the drilling fluids is lost into a formation, the hydrostatic pressure in the wellbore decreases, potentially allowing formation fluids (e.g., oil and gas, or high-pressure water) to flow into the wellbore. This can lead to kicks or blowouts, which pose significant safety risks and immediate attention and remedial measures is required (Feng et al, 2017).

2.3. Lost circulation assessment methods

This section aims to provide a comprehensive overview of various lost circulation assessment methods reported in the literature. The review covers both conventional and advanced techniques, highlighting their strength, limitations, and potential applications.

Pump pressure analysis, this is the conventional technique that involves monitoring the surface pump pressure during drilling operations. Changes in pump pressure can indicate lost circulation events, such as sudden drops or fluctuations. However, this method is limited in providing precise information about the location and magnitude of the loss (Jianyi Zhang et al, 2021). The power-law fluid model is adopted to describe rheological properties of drilling fluid. In order to prevent blowout from occurring in the drilling process, the maximum allowable mud pressure at different reaming stages is calculated by numerical method under condition of complicated geological structure, the borehole pressure must be greater than minimum required mud pressure which is achieved hydrodynamic calculation method, only meet this condition can it transport the cuttings to the ground surface. Moreover, the pressure loss in the drill string, including loss in drill rod and loss through bit nozzles, is also calculated by newly derived equations. Finally, combining with practical engineering field data, the appropriate range of pumping pressure at different reaming stages is obtained through the calculation results of three types of pressure, which can help engineers minimize the occurrence of accidents and enhance the drilling efficiency (Hui Su et al, 2018).

Another conventional technique is the flow check analysis, the flow check analysis entails temporarily stopping drilling operations and observing fluid flow rates at the surface. A sudden drop or cessation of fluid flow indicates lost circulation. This method is straightforward and commonly practiced but offers limited information regarding the specific location of the loss (Taira et al, 2020). Mud loss calculations involve estimating the volume of lost drilling fluid based on the change in mud volume in the active circulation system. This method provides a quantitative assessment of lost circulation events, but it may not accurately determine the location or cause of the loss (Aljadi, 2014). It is widely used globally due to its simplicity.

Downhole pressure measurement; this is the advanced assessment method that involves deploying pressure gauges or sensors in the wellbore to monitor pressure changes during drilling. This method provides valuable insights into the location and severity of lost circulation events. It is utilized in various countries and requires specialized tools and expertise (Mitchell et al, 2011). Acoustic and Seismic methods, is another advanced assessment method that utilize downhole measurements of acoustic or seismic waves to identify fractures, voids, or damaged zones contributing to lost circulation. These techniques provide detailed information about subsurface conditions and are employed in drilling operations globally (Zhi Geng et al, 2019).

Drilling optimization techniques utilize real-time drilling data, such as rate of penetration, torque, and drag, to detect changes associated with lost circulation. These methods leverage machine learning algorithms or expert systems to analyze the data and provide early warning indicators of potential lost circulation events (Lavrov et al, 2016).

In conclusion, this literature review provides a comprehensive overview of the assessment techniques employed in the evaluation of lost circulation during well drilling operations. The review emphasizes the importance of accurate diagnosis and understanding the causes of lost circulation to implement effective remedial measures. The findings of this review can guide future research efforts in developing innovative approaches for lost circulation assessment and management, ultimately enhancing drilling efficiency and reducing associated costs and risks.

3. CHAPTER 3: METHODOLOGY

3.1. Research design

To achieve the study objectives of this research, a selected number of technical journals, papers, textbooks, cases histories, real fields data, and manuals that address the problem of lost circulation were carefully reviewed and summarized. The results of this study are practical guidelines that are not biased towards a particular service industry product but are general to the mitigation of the problem of lost circulation while drilling.

This section outline methods used in combating lost circulation problems during drilling of wells. qualitative data was collected and analyzed. The data analysis was performed us and interpret the collected information. The data consists of the secondary data sources only which were gathered from existing records, reports, and relevant literature, by utilizing Excel`s features, such as sorting functions, the collected data was organized to identify patterns, trends, and relationships. This allowed for a comprehensive analysis and understanding of the data, enabling insights and conclusions to be drawn regarding operations, including the potential impact on lost circulation.

The aim of this work is to update the classification of lost circulation treatment and materials. The current lost circulation materials are classified into four categories; granular, flaky, fibrous, and mixture of LCM's. The current classification is based on the physical properties only and it is 50 years old, thus a new classification is required to follow the developments in the industry. This paper was developed mostly based on the literature with real field data from Basra's oil fields. More than 200 technical journals, papers, textbooks, cases histories, real fields data, and manuals that address the problem of lost circulation are carefully reviewed and summarized. Lost circulation materials and treatments are extracted from the literature. The results from the lab are compared to what was applied on many oil fields including 800 wells drilled in Basra's oil fields. A new classification for lost circulation treatments and materials is developed. Unlike the current classification, the new classification is based on the appearance, applications, chemical, and physical properties. In addition, the lost circulation materials and treatments are re-classified into two major categories, proactive and corrective methods.

The proactive are applied prior to entering the losses zone. However, the corrective is applied after the occurrence of lost circulation. Finally, all materials and treatments for the proactive and corrective methods are summarized in tables with their executive procedures.

3.2. Lost circulation treatment: corrective vs preventative

The way that lost circulation treatments are applied could be classified based on the time when these treatments were implemented. It can be either before (preventive) or after (corrective) the occurrence of the lost circulation event:

4. CHAPTER 4: RESULTS AND DISCUSSION

Collective methods

This section demonstrates the various lost circulation treatment materials and their application. The treatments are categorized into general groups to assist in describing the way they work and to differentiate their applications. A wide range of bridging or plugging materials is available for reducing lost circulation or restoring circulation while drilling or cementing a well. Each lost circulation material is selected by depending on timing, type of losses, cost, phase drilling, mud type, and type of formation. Lost circulation materials and treatments are used to achieve two goals:

1. To bridge across the face of fractures and vugs that already exist.

2. To prevent the growth of any fractures that may be induced while drilling.

Table 1 will be demonstrated the conventional LCM's, which are currently classified into different categories based on their appearance as fibrous, flaky, and granular or a blend of all three. However, Table 2 to 5 will be illustrated the lost circulation materials and treatments, which are re-classified into various categories based on their appearance, applications, chemical and physical properties.

Table 1. Current LCM's and Treatments Classification with their Applications (Howard and Scott, 1951; Nayberg and Petty in 1986; Ali et al., 1994; Pilehvari and Nyshadham, 2002; Jiao and Sharma, 1995)

Name	Type of losses	Formations problem
Granular	Seepage, Partial and Severe	Permeable, carvenous/vugular,, and natural fracture formations
Flaky	Seepage, Partial and Severe	Permeable, carvenous/vugular,, and natural fracture formations

Fibrous	Seepage, Partial and Severe	Permeable, carvenous/vugular,, and natural fracture formations
Mixture of LCM`s	Seepage, Partial and Severe	Highly natured fractures, interconnected large vugs, and to widely open induced fractures

Table 2. Updated LCM's and Treatments Classification with their Applications for Seepage Losses

Name	Type of Losses	Type of Mud	Formation`s Problem	Drilling Phase
Bentonite	Seepage	FWBM, OBM, FCL Mud, FCLCL Mud	Any type of formation	(Pf>Pp)
Polymers	Seepage	KCL Mud, Polymer Mud, Lime Mud	Any type of formation	(Pf>Pp)
CMC-LV	Seepage	FWBM, OBM, FCL Mud, FCLCL Mud	Any type of formation	(Pf>Pp)
CMC-HV	Seepage	FWBM, FCL Mud, FCL-CL Mud	Any type of formation	(Pf>Pp)
Starch	Seepage	SWBM, KCL Mud, Lime Mud, Lime Mud	Any type of formation	(Pf>Pp)
PACR-LV	Seepage	FWBM, Polymer Mud, KCL Mud, Lime Mud	Any type of formation	(Pf>Pp)
PACR-HV	Seepage	FWBM, Polymer Mud, KCL Mud, Lime Mud	Any type of formation	(Pf>Pp)
SPA	Seepage	FWBM, OBM, FCL Mud, FCLCL Mud	Any type of formation	(Pf>Pp)
Lignins and Tannins	Seepage	FCL Mud, FCL-CL Mud	Any type of formation	(Pf>Pp)
Resinex	Seepage	OBM, KCL Mud, FCL	Any type of	(Pf>Pp)

		Mud, FCL-CL Mud	formation	

Table 3. Updated LCM's and Treatments Classification with their Applications for Partial Losses

Name	Type of loss	Formation`s Problem	Drilling Phase
High Viscosity Patch	Partial	Gravels, Small Natural Fractures, and Permeable Formations	(Pf≥Pp)
Granular	Partial	Gravels, Small Natural Fractures, and Permeable Formations	(Pf≥Pp)
Flaky	Partial	Gravels, Small Natural Fractures, and Permeable Formations	(Pf≥Pp)
Fibrous	Partial	Gravels, Small Natural Fractures, and Permeable Formations	(Pf≥Pp)
Plugging Materials	Partial	Gravels, Small Natural Fractures, and Permeable Formations	(Pf≥Pp)
Mixture of LCMs	(Severe≤20m^3/hr)	Medium Natural Fractures, Small or Medium Cavernous/Vugular Formations	(Pf>Pp)

Table 4. Updated LCM's and Treatments Classification with their Applications for Severe Losses

Name	Type of Losses	Formation`s Problems	Drilling phase
High Fluid Loss, High Strength Pills	Severe > 20 m3/hr	Fractured or highly permeable formations	(Pf>>Pp)
Swellable/Hydratable LCM's Combinations	Severe > 20 m3/hr	Large Cavernous/Vugular and Large Nature Formations	Pf>>Pp)
Super Stop Material	Severe > 20 m3/hr	Highly Permeable Formation	Pf>>Pp)
H.V Drilling Mud (Low Density) + Blend of LCMs	Severe > 20 m3/hr	Induced Fracture	(Pf>FG)
Cement Plug	Severe > 20 m3/hr	Induced Fracture	(Pf>FG)
High Filtration Spot Pills, High Filtration Mixtures (200-400 cc API)	Severe > 20 m3/hr	Highly Permeable Formations	Pf>>Pp)
High Filtration Spot Pills, very high filtration mixtures (> 600cc API)	Severe > 20 m3/hr	Highly Permeable Formations and Large Cavernous/Vugula	Pf>>Pp)
Precipitated Chemical Slurries, Silicate and Latex	Severe > 20 m3/hr	Induced Fracture	Pf>FG)

Table 5. Updated LCM's and Treatments Classification with their Applications for Complete Losses

Name	Type of Losses	Formations Problems	Drilling Phase
Cement Slurries Plugs	Complete	Highly Natured Fractures, Interconnected Large Vugs, and to Widely Open Induced Fractures	(Pf>FG)
Cross-Linked Cements (CC) Plugs	Complete	Highly Natured Fractures, Interconnected Large Vugs, and to Widely Open Induced Fractures	(Pf>FG)
Gilsonite Cement Plugs	Complete	Highly Natured Fractures, Interconnected Large Vugs, and to Widely Open Induced Fractures	(Pf>FG)
Fiber in Cement Slurry Plugs	Complete	Highly Natured Fractures, Interconnected Large Vugs, and to Widely Open Induced Fractures	(Pf>FG)
Gunk Slurries Plugs	Complete	Highly Natured	(Pf>FG)

		Fractures, Interconnected Large Vugs, and to Widely Open Induced Fractures	
Attapulgite Plugs	Complete	Highly Natured Fractures, Interconnected Large Vugs, and to Widely Open Induced Fractures	(Pf>FG)
Dilatant Slurries Plugs	Complete	Highly Natured Fractures, Interconnected Large Vugs, and to Widely Open Induced Fractures	(Pf>FG)
InstandSeal Plugs	Complete	Highly Natured Fractures, Interconnected Large Vugs, and to Widely Open Induced Fractures	(Pf>FG)
Barite Plug	Complete	Highly Natured Fractures, Interconnected Large Vugs, and to Widely Open Induced Fractures	(Pf>FG)

PREVENTIVE METHODS

Conventional lost circulation materials (LCMs), including pills, squeezes, pretreatments and drilling techniques often reach their limit in effectiveness and become unsuccessful when drilling deeper hole sections where some formations are depleted, structurally weak, or naturally fractured and faulted (Wang et al., 2005). All those remedies/techniques that are applied prior to entering lost circulation zones to prevent the occurrence of losses can be defined as proactive methods. The overall objective of this method is to strengthen the wellbore (Withfill, 2008). The concept of wellbore strengthening can be defined as "a set of techniques used to efficiently plug and seal induced fractures while drilling to deliberately enhance the fracture gradient and widen the operational window" (Salehi and Nygaard, 2012). This approach depends on propping or sealing the fractures using LCM's (Salehi and Nygaard, 2012). The main advantage of using wellbore strengthening is to increase the fracture gradient of the formation and the hoop stress. This provides an opportunity to use higher mud weight windows for drilling, especially, weaker and depleted formations. In different words, by using wellbore strengthening approach, the range of the mud weight window will increase. Wellbore strengthening methods generally use in order to get the following targets (van Oort et al., 2009):

1. Enhance the near-wellbore stress by increasing hoop stress, thus raising the threshold for fracture re-opening and growth.

2. To increase the design range of the mud weight window.

3. Increase the formation's resistance to fracture propagation.

In this section. Table 6 will mention proactive approaches that have already been used to increase wellbore strengthening.

Table 6. Modern Technologies for Preventive Approaches

Name	Description
Nanoparticles	• Solid particles (1-100 nm) • Seals micro fractures • Permeability reduction in shale • Wellbore Strengthening application
Plug Forming Assurance	• Developed to address fracture size and shape uncertainties • Uses 2 components; deformable foam wedges and fine particles
Customized Combinations	• Will have a wide range of PSD and different physical properties • Combining 2 or more LCM's will improve the overall performance • Often optimized as a function of PSD
Resilient Graphitic Carbon (RGC)	High performance material as proactive treatment and wellbore strengthening: Resilient graphitic carbon (RGC) is one of the most successful materials in preventing lost circulation mud.
Chemical Grout	This treatment is chemical consolidation mechanism that has been proved as effective way in underground openings for many years. This method is usually used inhibit water influx into well and to increase rock strength as wellbore strengthening approach.
Deformable, Viscous, And Cohesive Systems (DVC)	This method is usually used for strengthening the zone. DVC sealant may

	deform under pressure or stress. Deformation of this seal has ability to maintain the seal and isolate the fracture tip from the wellbore pressure.
Resin treatment (Formation consolidation and chemical casing method)	In this method, water dispersible resins are used to increase rock strength and support weak zones. There are various kinds of resins that have already used like epoxies, phenolic, and furans to control for wellbore stability.
CaCO3	It is readily available and can easily be added to LCM spot pills in high concentrations. It can be added in circulation as prevention. It is one of the most successful materials in preventing lost circulation mud

A flowchart has also been developed that will serve as a quick reference guide for drilling personnel at the well-site.

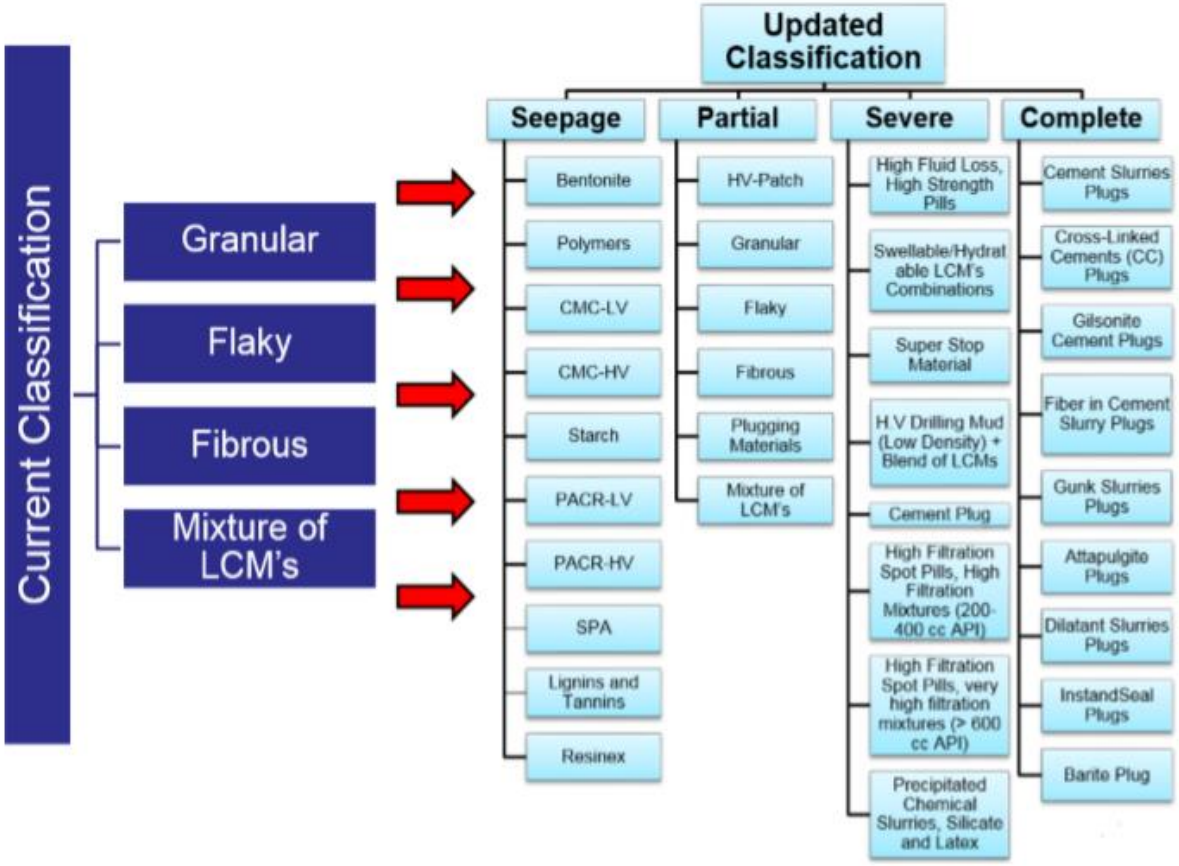


Figure 2. Current and an Updated Classification of the Lost Circulation Materials and Treatments

5. CONCLUSIONS ND RECOMMENDATIONS

Conclusions

This paper constructs a new LCM's classification that can serve as a reference and guideline for operators, service companies, and drilling industry in general to properly classify the materials used to control, mitigate or avoid lost circulations. Lost circulation materials and treatments are re-classified into various categories based on their appearance, applications, chemical and physical properties. The authors believe in the significance of classification the lost circulation materials and treatments based on timing, type of losses, cost, phase drilling, mud type, and type of formation. Lost circulation materials and treatments are categorized with the target of creating a unique technical approach to help the drilling personnel mitigating or stopping lost circulation. Based on this study, the following conclusions were made: Granular, flaky, and fibrous are used for partial losses only. Mixture of them can be used for severe losses ≤ 20 m3/hr. Lost circulation materials and treatments are re-classified into various categories based on their appearance, applications, chemical and physical properties. Modern technologies for preventive treatments are summarized and tabulated. There is a large gap in evaluating LCMs for preventive treatments applications. Industry collaboration to address and discuss this topic will benefit the entire drilling industry.

Recommendations

Based on the conclusions drawn from this study, the following recommendations can be made to enhance the classification and application of lost circulation materials and treatments:

1. Further research should be conducted to evaluate the effectiveness of different LCMs for preventive treatments, as there is currently a significant gap in knowledge regarding their application in this context.
2. Operators, services companies, and the drilling industry as a whole should collaborate and engage in discussions to address the challenges and advancements

related to lost circulation control. This collaboration can help in sharing best practices, exchanging knowledge and expertise, and ultimately benefiting the entire industry.

3. Operators should consider implementing the new LCMs classification proposed in this paper as a reference and guideline for choosing the appropriate materials for controlling, mitigating, or avoiding lost circulation. The classification takes into account factors such as timing, type of losses, cost, phase drilling, mud type and type of formation, providing a more comprehensive and targeted approach.
4. Emphasis should be placed on utilizing a combination of granular, flaky, and fibrous materials for partial losses only. For severe losses up to 20 m^3/hr, a mixture of these materials can be considered.
5. Molden technologies and innovative approaches for preventive treatments should be explored and adopted where applicable. The paper provides a summary and tabulation of these technologies, and operators should assess their feasibility and potential benefits for their drilling operations.

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