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A comprehensive analysis of lost circulation materials and treatments with applications in Basra's oil fields, Iraq: Guidelines and recommendations

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A COMPREHENSIVE ANALYSIS OF LOST CIRCULATION MATERIALS AND TREATMENTS WITH APPLICATIONS IN BASRA'S OIL FIELDS, IRAQ: GUIDELINES AND RECOMMENDATIONS

by

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This thesis consists of the following three articles, formatted in the style utilized by Missouri University of Science and Technology. Paper I, comprising pages 7 through 55, is submitted as a conference paper to the Society of Petroleum Engineering, under the title ‘‘Updated Classification of Lost Circulation Treatments and Materials with an Integrated Analysis’’. Paper II, comprising pages 56 through 118, is submitted as a conference paper to the American Association of Drilling Engineers, under the title ‘‘Comprehensive Review of Conventional Lost Circulation Treatments with an Integrated Analysis and Practical Guidelines in Basra’s Oil Fields, Iraq.’’ Paper III, comprising pages 119 through 142, is submitted as a conference paper to the American Association of Drilling Engineers, under the title ‘‘Cases Histories in Basra’s Oil Fields, Iraq: Evolving Advanced Techniques and Strategies to Stop or Reduce Lost Circulation.”

ABSTRACT

Lost circulation materials (LCM's) have been widely used to avoid or stop losses. Due to a large number of current available LCM's and their different applications, classification of LCM's is very important. The most recent LCM classification was published around 50 years ago, and this paper intends to fill this gap with an updated classification including conventional and new technologies. Lost circulation materials and treatments are re-classified into various categories based on their appearance, applications, chemical and physical properties.

Wells in Basra's oil fields are highly susceptible to lost circulation problems when drilling through the Dammam, Hartha, and Shuaiba formations. This paper discusses the most recent treatments, which are used in Basra's fields with integrated analysis and updated classification. In addition, the best lost circulation strategy of remedies will be presented to mitigate or stop this problem.

Sometimes it is difficult to regulate mud losses by using conventional lost circulation materials. Also, the cost of these materials are expensive, so it is important to find techniques and mechanism to live with some degree of losses. This work will also demonstrate methods that were used to ameliorate lost circulation without the use of lost circulation materials like liner hanger and casing-while-drilling, floating mud cap drilling, aerated mud, foam, air or mist with cases histories in Basra's fields.

This paper discusses the most recent developments in lost circulation materials and treatments, in addition to the presentation of a comprehensive summary of today's available LCM's, treatments and alternative approaches with their applications.

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1. INTRODUCTION

As the demand for petroleum resources increases, drilling of oil and gas wells is 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. Major progress has been made to understand this problem and how to combat it. However, most of the products and guidelines available for combating lost circulation are often biased towards advertisement for a particular service company. The purpose of this study is to develop practical guidelines that are general and not biased towards a particular service company product and which will also serve as a quick reference guide for lost circulation prevention and control at the well-site for drilling personnel.

Lost circulation is a common drilling problem especially in highly permeable formations, depleted reservoirs, and fractured or cavernous 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 (Moore, 1986). It can then be defined as the reduced or total absence of fluid flow up the formation-casing or casing-tubing annulus when fluid is pumped down the drill pipe or casing. The industry spends millions of dollars every year to combat lost circulation and its associated detrimental effects such as loss of rig time, stuck pipe, blow-outs, and less frequently, the abandonment of expensive wells. Two conditions are necessary for lost circulation to occur down hole: 1) the pressure in the well bore must exceed the pore pressure and 2) there must be a flow pathway for the losses to occur (Osisanya, 2011). Subsurface pathways that cause, or lead to, lost circulation can be broadly classified as follows:

- Induced or created fractures (fast tripping or underground blow-outs)
- Cavernous formations (crevices and channels)
- Unconsolidated or highly permeable formations
- Natural fractures present in the rock formations (including non-sealing faults)

The rate of losses is indicative of the lost pathways and can also give the treatment method to be used to combat the losses. The severity of lost circulation can be grouped into the following categories (South Oil Company, 2012):

- Seepage losses: up to 1 m^3/hr lost while circulating.
- Partial losses: 1 – 10 m^3/hr lost while circulating.
- Severe losses: more than 15 m^3/hr lost while circulating.
- Total losses: no fluid comes out of the annulus.

Wells in Basra's oil fields are highly susceptible to lost circulation problems when drilling through the Dammam, Hartha, and Shuaiba formations. Lost circulation events range from seepage to complete loss of borehole are a critical issue in fields development. This work discusses the most recent treatments, which are used in Basra's fields with integrated analysis and updated classification. In addition, the best-lost circulation remedies will be presented to mitigate or stop this problem. There is a wide range of lost circulation treatments available applied to control or eliminate lost circulation events. These systems can be divided into conventional systems, which include granular, fibrous and flaky materials that are mixed with the drilling fluids during either the drilling phase or with the cement slurries during the drilling and primary cementing phases. The other approach to controlling lost circulation is specialized cements, dilatant slurries, soft or hard reinforcing plugs, cross-linked polymers, and silicate systems that are also used during the drilling/cementing phases.

This study provides basic information on lost circulation, including an introduction to the problem, identifies a range of factors that affect lost circulation, and reviews historical work in lost circulation materials. The study summarizes mud loss and lost circulation information extracted from drilling data from Basra's oil fields in Iraq. A lost circulation screening criteria is presented for these fields, based on the historical mud loss and lost circulation problems, materials used to mitigate the problems, and potential solutions found by this study.

1.1 OBJECTIVES OF THE STUDY

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. In addition, The purpose of this research is to provide a comprehensive overview of lost circulation and to study a dataset of wells that have already been drilled in Basra's oil fields where lost circulation is a significant problem. The work will provide an integrated analysis regarding the loss problems in terms causes, treatments, and recommendations, and present general practical guidelines for mud properties to avoid or mitigate lost circulation in Basra’s oil fields.

The objectives of this study are as follows:

- To re-classify lost circulation materials and treatments into various categories based on their appearance, applications, chemical and physical properties.
- To summary and tabulate modern technologies for preventive treatments.
- To review lost circulation control methods that have been applied in Basra’s oil fields till date with a deep statistical study and integrated analysis.
- To classify lost circulation treatments based on the type of losses, cost, efficiency, and type of formation.
- To provide the successes and the failures of the methods presented above in fields applications.
- To develop practical guidelines that will serve as a reference material for lost circulation control at the well-site for drilling personnel.

1.2 RESEARCH METHODOLOGY

After reading more than 200 papers and case studies, the corrective and preventive treatments were summarized and tabulated. Based on the literature and real field data, an updated classification for lost circulation treatments is proposed based on losses type and application. In addition, the research methodology consisted of gathering information regarding drilling and lost circulation events for more than 800 wells in Basra’s oil fields, Iraq. These data were summarized and analyzed to determine screening criteria for the various lost circulation treatments. The research also employed a thorough literature review to identify relevant information that could be included in developing the screening guide.

It is recognized that there is no single solution to lost circulation and that most treatment proceed by trial-and-error. However, the screening guide presents a high-level 'go to' document with coherent guidelines, which engineers can utilize in making decisions regarding lost circulation treatments.

The objectives of this study will be achieved through the following methods:

- More than 200 technical journals, papers, textbooks, cases histories, real field data, and manuals that address the problem of lost circulation are carefully reviewed and summarized.
- Study various daily drilling reports, finals reports, technical reports, and lost circulation events over the years in Basra's oil fields.
- Summarize these real field data based on the various lost circulation control methods used over time, their success stories, and their failures in various Basra's oil fields.
- Develop practical guidelines and lost circulation strategy for Basra's oil fields based on comprehensive statistical work and integrated analysis.
- Provide workable guidelines and coherent recommendations to avoid the non-productive time and money wasting by repeating ineffective treatment and inaccurate implementations.

1.3 DATA UTILIZATION FOR LOST CIRCULATION PROBLEM ANALYSIS

The utilization of available data for lost circulation treatments analysis is discussed in the following subsections.

1.3.1 Extensive Literature Review. 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.

1.3.2 Well Logging Data. Well logging data is available for several wells drilled in the study fields. Well logging data were used to build a coherent image and a valuable information about lost circulation problem in the Dammam, Hartha, and Shuaiba formations.

1.3.3 Daily Drilling Reports. Daily drilling reports can be a helpful source to identify the lost circulation events and the type of the mud losses. In addition, it can be used to determine the type of the treatment and its applications.

1.3.4 Daily Mud Reports. Daily mud reports were utilized to identify the key drilling characteristics: MW, rheological properties, and sand percent. In addition, the report describes the formation's cuttings size and provides an indirect clue to the hole cleaning issues during drilling of wells.

1.3.5 Daily Mud Logging Reports. Daily mud logging reports were used to identify the high pore pressure zones. The size and shape of cuttings were used to verify the active wellbore-failure mechanism taking place in the field to make a critical decision about whether to increase mud weight or to hold it at the same level.

1.3.6 Primary Cementing Reports. A direct utilization of cementing reports is one of the sources for determining the plug treatments and their applications.

1.3.7 End-of-Well Report and Non-Productive Time Analyses. End-of-report and non-productive time analyses were used to construct economical and efficient treatments of the lost circulation strategy in Basra's oil field.

PAPER

I. UPDATED CLASSIFICATION OF LOST CIRCULATION TREATMENTS AND MATERIALS WITH AN INTEGRATED ANALYSIS

ABSTRACT

Mud losses are considered one of the major contributors to drilling non-productive time (NPT). Among the top ten drilling challenges facing the oil and gas industry today is the problem of lost circulation. Enormous effort has been undertaken to understand the mechanics of lost circulation control. Lost circulation control during well construction is more than just selecting the right lost circulation material (LCM) but requires a complete engineered approach. Some of the approaches involve borehole stability analysis, equivalent circulating density (ECD) modelling, leak-off flow-path geometry considerations, drilling fluid and LCM selection to help minimize effects on ECD, on-site monitoring using annular pressure while drilling (APWD), and timely application of LCM and treatments.

Lost circulation materials (LCM's) have been widely used to stop or mitigate losses. Due to a large number of current available LCM's and their different applications, classification and testing of LCM's are very important. Conventional LCM's are currently classified into different categories based on their appearance as fibrous, flaky, and granular or a blend of all three. The most recent LCM classification was published around 50 years ago, and this paper intends to fill this gap with an updated classification and their applications including conventional and new technologies. Lost circulation materials and treatments are re-classified into various categories based on their appearance, applications, chemical and physical properties.

This paper classifies the lost circulation materials and treatments as corrective and preventive approaches. The corrective treatments can be applied after the occurrence of the lost circulation; however, the preventive techniques can be applied before entering losses zones as a proactive action. The most recent developments in lost circulation materials and treatments are discussed, in addition to the presentation of a comprehensive summary of today's available LCM's, treatments and alternative approaches with their applications.

1. INTRODUCTION

Lost circulation is a phenomenon in which the drilling fluid flows into one or more geological formations instead of returning to the annulus and surface. Because of this, the oil industry suffers a loss of over one billion dollars annually in rig time, materials, and other financial resources (Aadnoy et. al, 2007). Lost circulation is a common drilling problem especially in highly permeable formations, depleted reservoirs, and fractured or cavernous 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 (Moore, 1986).

Lost circulation is a common drilling problem especially in highly permeable formations, depleted reservoirs, and fractured or cavernous formations as shown in figure 1.1 (Nayberg and Petty, 1986). The range of lost circulation problems begin in shallow, unconsolidated formations and extend into the well-consolidated formations that are fractured by the hydrostatic head imposed by the drilling mud (Moore, 1986). By industry estimates, more than 2 billion USD is spent to combat and mitigate this problem each year (Arshad et al., 2015). Two conditions are both necessary for lost circulation to occur down hole: 1) the pressure in the wellbore must exceed the pore pressure and 2) there must be a flow pathway for the losses to occur (Osisanya, 2002). Subsurface pathways that cause, or lead to, lost circulation can be broadly classified as follows:

- Induced or created fractures (fast tripping or underground blow-outs).
- Cavernous formations (crevices and channels).
- Unconsolidated or highly permeable formations.
- Natural fractures present in the rock formations (including non-sealing faults).

The rate of losses is indicative of the lost pathways and can also give the treatment method to be used to combat the losses. The severity of lost circulation can be grouped into the following categories (South Oil Company, 2012):

- Seepage losses: up to 1 m^3/hr lost while circulating.
- Partial losses: 1 – 10 m^3/hr lost while circulating.
- Severe losses: more than 15 m^3/hr lost while circulating.
- Total losses: no fluid comes out of the annulus.

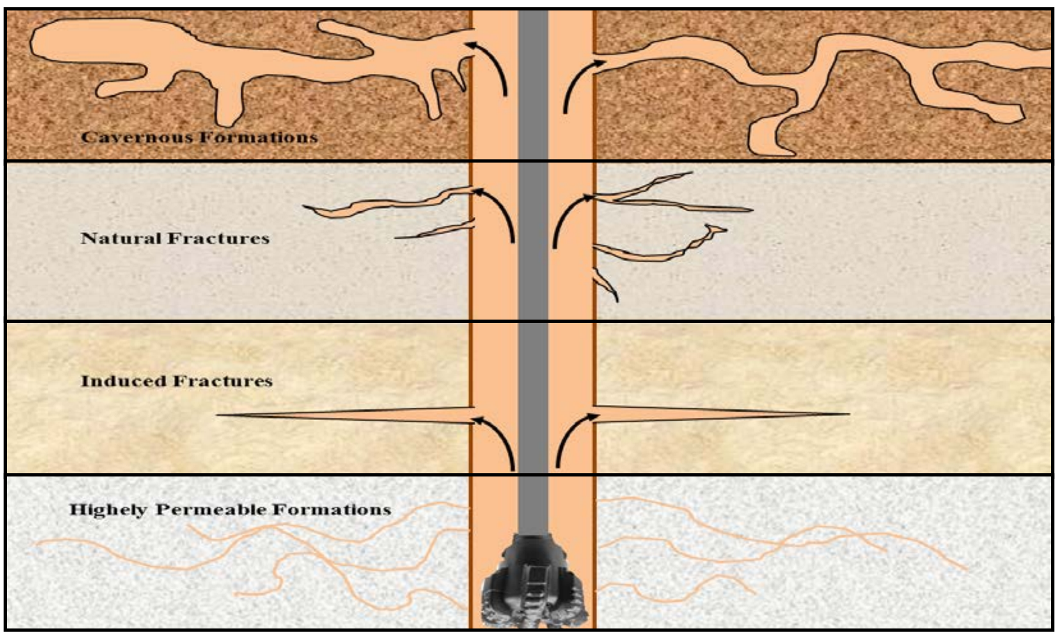

Figure 1.1: Candidate Formations for Losses Events (Nayberg and Petty, 1986)

One of the early efforts to cure losses or prevent them from happening by adding granular materials to the drilling fluid was introduced by M T. Chapman in 1890. Since then, lost circulation materials have been widely used to stop or mitigate drilling fluid losses into the formation. LCM’s are added continuously to the drilling fluid system or spotted as a concentrated LCM’s pill to seal naturally existing fractures or induced fractures that are produced while drilling.

2. METHODOLOGY

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. 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:

3.1 CORRECTIVE 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:

- To bridge across the face of fractures and vugs that already exist.
- To prevent the growth of any fractures that may be induced while drilling.

Table 3.1 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 3.2, 3.3, 3.4, 3.5 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. In addition, each material and treatment will be clarified in details in appendix A.

Table 3.1: 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	Formation's Problem
Granular	Seepage, Partial, and Severe	Permeable, Cavernous/Vugular, and Natural Fracture Formations
Flaky	Seepage, Partial, and Severe	Permeable, Cavernous/Vugular, and Natural Fracture Formations
Fibrous	Seepage, Partial, and Severe	Permeable, Cavernous/Vugular, and Natural Fracture Formations
Mixture of LCM's	Complete	Highly Natured Fractures, Interconnected Large Vugs, and to Widely Open Induced Fractures

Table 3.2: 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, FCL-CL 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, FCL-CL 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, FCL-CL 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 Mud, FCL-CL Mud	Any type of formation	(Pf >Pp)

Table 3.3: Updated LCM's and Treatments Classification with their Applications for Partial Losses

Name	Type of Losses	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 LCM's	(Severe≤ 20 m^3/hr.)	Medium Natural Fractures, Small or Medium Cavernous/Vugular Formations	(Pf >Pp)

Table 3.4: Updated LCM's and Treatments Classification with their Applications for Severe Losses

Name	Type of Losses	Formation's Problem	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 m^3/hr.	Highly Permeable Formations	(Pf>>Pp)
H.V Drilling Mud (Low Density) + Blend of LCMs	Severe > 20 m^3/hr.	Induced Fracture	(Pf>FG)
Cement Plug	Severe > 20 m^3/hr.	Induced Fracture	(Pf>FG)
High Filtration Spot Pills, High Filtration Mixtures (200-400 cc API)	Severe > 20 m^3/hr.	Highly Permeable Formations	(Pf >>Pp)
High Filtration Spot Pills, very high filtration mixtures (> 600cc API)	Severe > 20 m^3/hr.	Highly Permeable Formations and Large Cavernous/Vugular	(Pf>>Pp)
Precipitated Chemical Slurries, Silicate and Latex	Severe > 20 m3/hr.	Induced Fracture	(Pf>FG)

Table 3.5: Updated LCM's and Treatments Classification with their Applications for Complete Losses

Name	Type of Losses	Formation's Problem	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 Fractures, Interconnected Large Vugs, and to Widely Open Induced Fractures	(Pf>FG)
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)

3.2 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):

- Enhance the near-wellbore stress by increasing hoop stress, thus raising the threshold for fracture re-opening and growth.
- To increase the design range of the mud weight window.
- Increase the formation’s resistance to fracture propagation.

In this section. Table 3.6 will mention proactive approaches that have already been used to increase wellbore strengthening. Moreover, Appendix B will illustrate these techniques in details with some cases histories.

Table 3.6: Modern Technologies for Preventive Approaches (Wang et al. (2005), Riley et al. (2012), Hoelscher et al. (2012), Sharma et al. (2012), Nwaoji et al. (2013), Contreras (2014), Wang (2011), Sanders et al. (2010), Kumar et al. (2010))

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.

4. SUMMARY OF THE WORK

Lost circulation presents many challenges while drilling. To address these problems, several methods/techniques have evolved over the years. The objectives of this study are: 1) to review lost circulation control methods that have been applied in the drilling industry till date 2) to provide an updated classification of these materials and treatments with field applications and 3) to develop practical guidelines that will serve as a reference material for lost circulation control at the well-site for drilling personnel.

To achieve these study objectives, 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. A flowchart in figure 4.1 has also been developed that will serve as a quick reference guide for drilling personnel at the well-site. In addition, appendix C is a comprehensive summary that includes most of the available LCM’s which is very beneficial for operators and drilling engineers are tabulated in cross-referencing tables for each type of LCM’s.

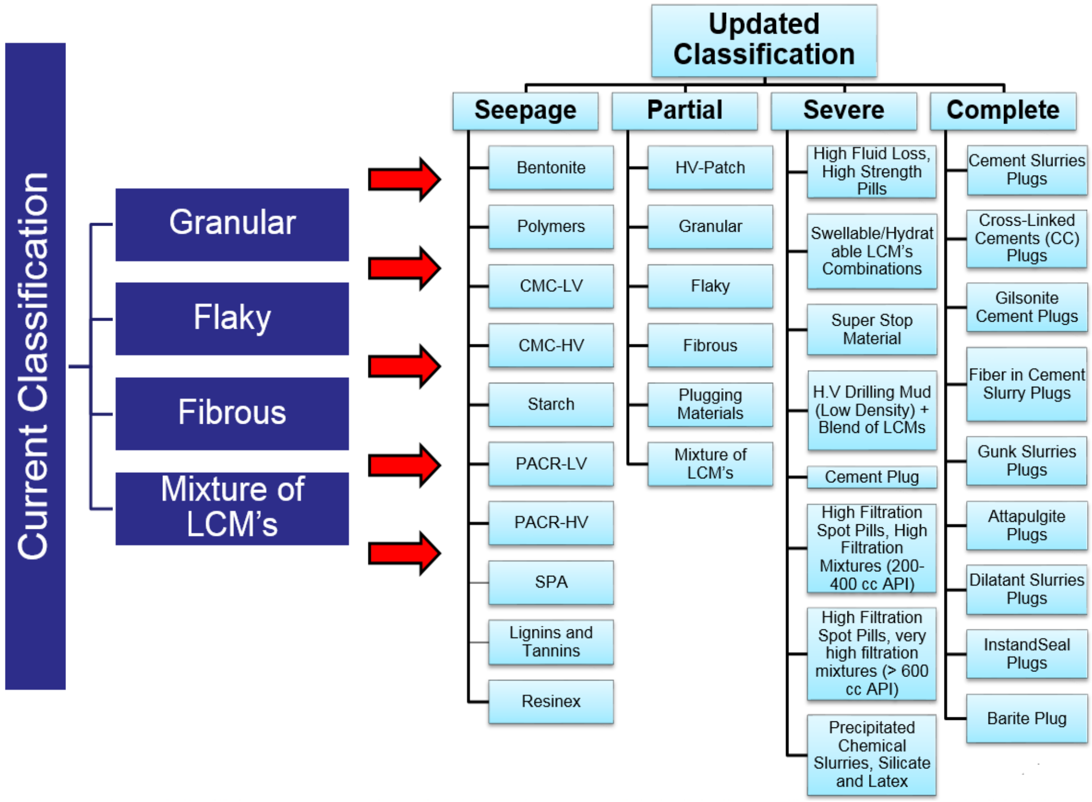

Figure 4.1: Current and an Updated Classification of the Lost Circulation Materials and Treatments

5. CONCLUSION

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 m^3/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 LCM's for preventive treatments applications.
- Industry collaboration to address and discuss this topic will benefit the entire drilling industry.

NOMENCLATURE

APWD	Annular Pressure While Drilling
$CaCO_3$	Calcium Carbonate
CC	Cross Linked Cement
CMC-LV	Carboxymethly Cellulose (Low Viscosity)
CMC-HV	Carboxymethly Cellulose (High Viscosity)
DOB	Diesel Oil Bentonite
DOBC	Diesel Oil Bentonite Cement
DVC	Deformable Viscous Cohesive
ECD	Equivalent Circulation Density
FCL	Ferro Chrome Lignosulfonate
FCL-CL	Ferro Chrome Lignosulfonate- Chrome Lignite
FP	Fracture Pressure
FG	Fracture Gradient
FWB	Fresh Water Bentonite
H.V	High Viscosity
Ib/bbl	pounds per barrel
Ib/ft^3	pounds per cubed feet
ID	Internal Diameter
in	Inch
LCMs	Lost Circulation Materials
m	meter
m^3/hr	cubed meter per hour

MCC	Magnesia Cross-Linked Cement
MW	Mud Weight
NPT	Non-productive Time
OBM	Oil Base Mud
PAC-LV	Low Viscosity Polyanionic Cellulose
PAC-HV	High Viscosity Polyanionic Cellulose
Pp	Pore Pressure
PSD	Particle Size Distribution
RGC	Resilient Graphitic Carbon
RCC	Regular Cross-Linked Cement
SPA	Sodium Polyacrylates
WBM	Water Base Mud
Yp	Yield Point Viscosity

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APPENDIX A
THE DETAILED PRODUCERS AND APPLICATION FOR THE LOST CIRCULATION MATERIALS AND TREATMENTS (CORRECTIVE METHODS)

1. MATERIALS AND TREATMENTS OF THE SEEPAGE LOSSES

- **Bentonite:**

The primary fluid-loss control agents for water-based muds are clay-type solids. Since these solids are colloidal in nature, they provide viscosity as well as filtration control. The ability of bentonite to reduce filtration can be attributed to:

1. Small particle size
2. Flat plate-like shape
3. Ability to hydrate and compress under pressure

Insufficient bentonite in a mud causes increased filtrate loss, particularly at increased temperature and pressure. Sodium montmorillonite clays are used mostly in freshwater mud systems; however, they are occasionally used in saltwater muds (Amoco Production Company Drilling Fluids Manual, 2007).

- **Polymers:**

Polymer fluids contain polymers which greatly diversify their application. These fluids contain polymers to viscosify, polymers to control filtration, polymers to deflocculate, polymers to provide high-temperature stabilization, etc. Polymer fluids generally contain only minor amounts of bentonite to build viscosity. Primary viscosification is provided by high molecular weight polymers such as PHPA, PAC, XC polymer, etc. Because these fluids contain only small quantities of bentonite or clay solids, they are less prone to rheological and filtration property fluctuations resulting from the effects of contaminants on the clay structure. Polymers fluids also reduce cuttings dispersion and stabilize the wellbore through encapsulation. The main target for this material is to regulate on seepage losses and increase yield point. Usually these fluids contain less than 5% by volume total low-gravity solids and can be divided into two general polymer mud categories (Amoco Production Company Drilling Fluids Manual, 2007):

1. Non-Dispersed Polymer Muds.
2. High-Temperature Deflocculated Polymer Muds.

- **Sodium Carboxymethylcellulosics (CMC):**

CMC is an organic colloid used for filtration control. This material is available in several grades, each varying in viscosity and filtration control qualities. The three grades are commonly called high-viscosity CMC, medium or regular-viscosity CMC, and low-viscosity CMC. The choice of CMC depends upon the properties desired for the drilling fluid. When viscosity increase and filtration control are both desired, high or medium CMC should be used. When no viscosity increase is needed and a decrease in filtrate loss is required, low-viscosity CMC is adequate. (Amoco Production Company Drilling Fluids Manual, 2007).

- **Starch:**

Most starch products are used in salt and saturated saltwater environments. Most of the starches used in the domestic oil industry are made from corn or potatoes. The starch grains are separated from the vegetable and specially processed so that they will rapidly and efficiently swell and gelatinize to reduce filtration loss. The sponge-like pegs also fit into the tiny openings left in the filter cake and lower fluid loss by a plugging action. Biocide is recommended when bacterial degradation is a concern (Amoco Production Company Drilling Fluids Manual, 2007).

- **Polyanionic Cellulosics (PAC):**

PAC materials are organic filtration control agents similar to CMC, but generally of higher purity and quality. This material can be used in both freshwater and saltwater environments. PACs are generally more calcium tolerant than are CMCs (Amoco Production Company Drilling Fluids Manual, 2007).

- **Sodium Polyacrylates (SPA):**

SPAs are polymers that are available in various ranges of molecular weight and offer high temperature stability. SPAs of low molecular weight are deflocculants for clays and are used to improve fluid loss. control by that mechanism. SPAs of very high molecular weight are effective for fluid loss control by increasing the viscosity of the filtrate and by plugging in the cake. They are sensitive to calcium ions, especially at high molecular weight. Derivatives of SPA which are less sensitive to ionic content are available as proprietary thinners and fluid loss additives. An example is the AMPS type polymers (Amoco Production Company Drilling Fluids Manual, 2007).

- **Lignins and Tannins:**

These include: sulfonated tannins, quebracho, lignosulfonates, lignites and lignite derivatives. The mechanisms by which they work is by thinning the clays (adsorbing on the positive edges of the clay platelets, which leads to repulsion among the platelets), plus plugging action of the particles themselves. These additives improve the distribution of solids within the drilling fluid by deflocculating solids such as bentonite and through the colloidal nature of the chemical, skewing the particle size distribution to lower valves (Amoco Production Company Drilling Fluids Manual, 2007).

- **Resinex:**

Resinex is formed by causticizing cellulose and reacting it with ethylene oxide which replaces one or more of the hydroxyl groups present on the cellulose molecule. Although Resinex is nonionic, it is still water soluble due to the hydroxy ethyl groups. Resinex imparts high viscosity to water or brines but exhibits no gel strengths. It is susceptible to degradation through shear or heat and has a maximum thermal stability of about 325°F.It is can be used under high pressure and high temperature to control seepage losses (Amoco Production Company Drilling Fluids Manual, 2007).

2. MATERIALS AND TREATMENTS OF THE PARTIAL LOSSES

- **High Viscosity Muds:**

This treatment is high viscosity drilling mud (Patch) with low mud weight. Usually, Bentonite, lime, or salt clay are used to increase viscosity. This pill is pumped in front of the thief zone in calculated and sufficient quantities to plug losses zone especially in partial losses. It is recommended after displacing this patch to interesting zone to wait around (±2-3 hours). Sometimes, the above remediation is used before lost circulation material or cement plug to guarantee zone plugging. The viscosity for this pill will be roughly 100 to 120 sec (Marsh funnel measurement) (South Oil Company, 2010).

- **Fibers:**

It is easy for fibrous materials to be deformable because these materials are long and slender particles. These materials have the ability to form" brush heap" like the a mat in pore openings. These materials are usually not effective treatment if they use individually. On the other hand, they work best in combination with other granular and flake materials. They can be classified to short and rather weak fibers such as ground paper, wood, cane, rice hulls, peanut hulls, leather, and tree bark, or longer and strong fibers such as flax, hemp, animal hair, cotton linters, nylon, and other fibers. Finely ground cellulose fibers are often used for seepage loss control and as a pretreatment in high permeability zones. These materials are effectively cost, and it is much recommended to use these materials in pills or patches in order to cure partial to severe losses. Most fibrous materials absorb large amounts of water and increase the viscosity (Baker Hughes, 1999).

- **Flakes:**

These types of materials have large planar surfaces and are very thin, and they have the possibility to form a “shingle-like” layer against pore openings. It is possible to use individually as effective treatment to combat seepage losses or partial losses, but at the same time, it is preferred to use flakes materials with fibrous and granular materials to produce blends. There are various types of materials like ground mica, plastic laminate, cellophane, and polyethylene plastic chips. Mica material has an advantage as an effective material for seepage losses and partial losses, and advantage of mica is that it does not absorb large amounts of free water or oil like cellophane material (Baker Hughes, 1999).

- **Granules:**

Granules are roundish shaped particles and rigid. They have the ability to form “bridging” agent that use to combat mud losses. These materials can be categorized to ground walnut shells, pecan shells, almond shells, plastic, and calcium carbonate. These materials are better than cellulose fibers regarding water absorption. In other words, they absorb less water than cellulose fibers. Other granular LCM materials frequently used in cement slurries are Gilsonite, ground coal, and calcinated shale. These materials can be used individually or with flakes, and fibers as a blend. Granules materials will be more effective if they use with flakes and fibers as a blend, and it is much recommended to use these materials in pills or patches in order to cure partial to severe losses (Baker Hughes, 1999).

- **Mixtures:**

These are combinations of granular, flaky and fibrous materials that will penetrate fractures, vugs, or extremely permeable formations and seal them off effectively. Table A.1 will show conventional lost circulation materials (LCM) (Baker Hughes, 1999).

Table A.1. Conventional Lost Circulation Materials (LCM) (White, 1956) and (Baker Hughes, 1999)

Type	Material
Fibrous	Ground paper, Wood fiber, Cane, Rice hulls, Peanut hulls, Leather, Tree bark, Flax, Hemp, Animal hair, Cotton linters, Nylon, Cellulose fibers, Raw cotton, Bagasse, Flax shive, Bark fiber, Textile fiber, Mineral fiber, Glass fiber, Peat moss, feathers, Beet pulp.
Granular	Ground walnut shells, Pecan shells, Almond shells, Plastic, Calcium carbonate, Perlite, Coarse bentonite, Ground plastic, Nut shells, Nut hulls, Ground tires, Asphalt, Wood, Coke.
Flake	Ground mica, Plastic laminate, Cellophane, Polyethylene plastic chips, Cork, Mica, Corn cobs, Cottonseed, hulls, Vermiculite.
Mixtures	Film, fiber and sawdust; Textile fiber and sawdust; Cellulose fiber and sawdust; Perlite and coarse bentonite.

3. MATERIALS AND TREATMENTS OF THE SEVERE LOSSES

- **High Fluid Loss, High Strength Pills (HFHS):**

HFHS pills allow the de-fluidization of the pumped slurry to take place while squeezing, as a result, a high solid plug will be formed. Recently, a number of HFHS treatments have been introduced commercially and they often come in a one sack product. HFHS treatments are typically a blend of different fibers where some of these fibers might be treated or coated to enhance their performance. An optimum HFHS treatment should apply for different losses scenarios, easy to pump through bottom hole assemblies and they should have a high shear-stress resistance. In order for such treatments to succeed, the fluid transporting these treatments should leak off into permeable formations resulting in a good seal. This type of treatments is difficult to apply in low permeability formations such as shale and might not perform as expected when using a non-aqueous drilling fluid. Applying this type of treatments will help to reduce both cost and time due to their simple application; they also have been successfully applied in the field (Al-Hameedi et al., 2016; Alsaba et al., 2014).

- **Swellable/Hydratable LCM's Combinations:**

Settable/Hydratable treatments are basically a blend of LCM's with a highly reactive material such as polymers. These treatments will be activated either by chemical reagents or whenever they contact drilling fluids or formation fluids; as a result, a plug will be formed within the losses zone. These types of treatments often require special placement procedures (Al-Hameedi et al., 2016; Alsaba et al., 2014).

- **High Viscosity Drilling Mud (Low Density) + Blend of the LCMs:**

First of all, pill of the high viscosity mud will be pumped in front of the thief zone. A blend of LCMs mix with low density mud will be directly pumped after high viscosity patch to create an effective plug. It is very important to use low mud weight with a blend of LCMs to avoid excessive equivalent circulation density (ECD). This blend should be pumped in front of the losses zone, and it has to wait around (± 4-6 hours) before resuming drilling processes (South Oil Company, 2010).

- **Super Stop Material:**

- Mixing (4-5) bags (Weight of Bag 25 kg) of super stop material for each 1 m^3 water.
- This treatment should be mixed in the separate and clean tank.
- It is very crucial to mix quickly in order to avoid treatment bulge in the surface tank.
- Displacing the remediation in front of the loss zone.
- Pulling out drill pipe strings above loss zone, and making mud circulation about (10 minutes) to enforce treatment to enter formation.
- Waiting around (±1-2 hours) (South Oil Company, 2010).

- **High filtration spot pills:**

High filtration drilling mud is used in order to seal loss zone. The principle of work for this treatment is by passing water into the formation, and solids content will form a seal in front of thief zone. Figure A.1 illustrates this treatment. There are three types of this method (Eni Company, 2010):

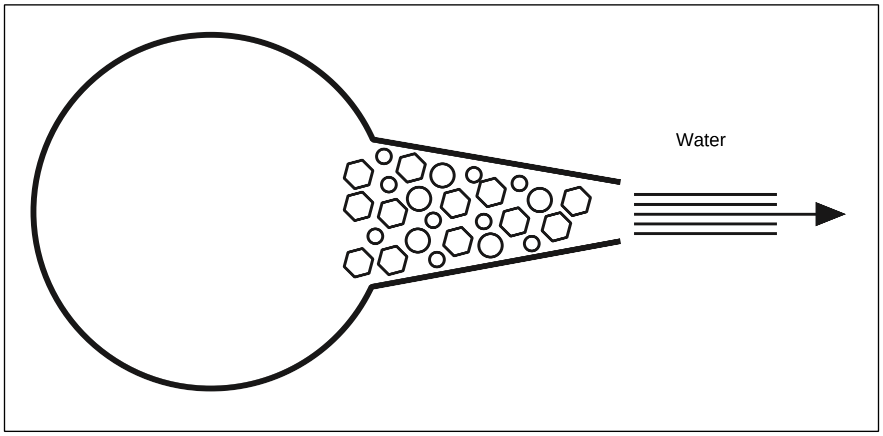


Figure A.1. High-fluid-loss-squeeze Technique for Lost Circulation (Eni Company, 2010)

Table A.2. High filtration mixtures (200-400 cc API), 1 m^3 (final) of high filtration mixtures

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

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

- **Precipitated Chemical Slurries, Silicate and Latex:**

Both sodium silicate solutions and commercial latex additives used for cementing can be made to precipitate and plug loss zones when pumped in combination with calcium chloride. The general scheme is to pump a calcium chloride pill followed by the silicate of latex slurry. When these two slurries mix in the open hole hopefully adjacent to the loss zone, they form a viscous plug which can slow and seal severe loss zones. While sodium silicate (like Halliburton's Flow Check) has been used for many years in combination with lost circulation while cementing, latex appears to have the potential for being significantly more effective. Latex reacts faster, forms a cohesive mass, and is applicable in oil-based muds. Oil-based mud also acts as an activator of latex so that mud contamination would not necessarily render the slurry ineffective (Baker Hughes, 1999).

4. MATERIALS AND TREATMENTS OF THE COMPLETE LOSSES

Table A.4 will illustrate remedies that use to regulate complete losses treatments

Table A.4. Complete Losses Treatments (South Oil Company, 2011)

Type of Losses	Type of the Treatment	Approach of the Treatment	Waiting
Complete Loss	Cement Plug	By pumping, cement slurry with specific density in front of thief zone, by using O.E.D.P to plug zone.	(18) hours
	High Viscosity Mud (Low Density) + Cement Plug	First, pumping high viscosity mud (low density), then pumping cement plug directly to create an efficient seal, by using O.E.D.P.	(18-20) hours
	Drilling Mud (Low Density) + Blend of the LCMs + Cement Plug	First, pumping drilling mud (low density) plus blend of the LCMs, then pumping cement plug directly to create an efficient seal, by 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 base + bentonite + cement to create a plug, by using O.E.D.P to seal zone with 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 A.5 will demonstrate the description and the executive steps for each of the remedial plug to get integrated image regarding procedures of the application.

Table A.5. The Executive Procedures for the remedial Plugs (South Oil Company, 2011)

Name of the Treatment	Description	Procedures
Cement Plug	This plug is very prominent and very prevalent in oil industry field. This treatment is used to combat complete losses, and it is rarely used in partial or severe losses. It is very necessary to do very accurate calculations regarding the weight of cement.	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 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 remediation is very important and common. However, it is not easy to apply in the field. Some conditions are required for this treatment. Water has to be removed from mixing tank and pumping pipes lines. In addition, it is much recommended to content loss zone on water in order to be effective treatment. Otherwise, this method is difficult to be successful.	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 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.

Table A.5. The Executive Procedures for the remedial Plugs (Cont'd)

Name of the Treatment	Description	Procedures
DOBC Squeeze (Diesel Oil Bentonite Cement)	It is also very important and common. However, it is not easy to apply in the field. Some conditions are required for this treatment. Water has to be removed from mixing tank and pumping pipes lines. In addition, it is much recommended to content loss zone on water in order to be effective treatment. Otherwise, this method is difficult to be successful.	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.
Barite Plug	This kind of the plug is used to regulate on the abnormal zone pressure. Sometimes, some wells suffer from kick or blowout problem, and in the same time, it is not possible to increase mud weight to dodge lost circulation in upper zones in the same hole. Hence, this barite plug is used to pump in front of the zone of interest	Composition of this plug • Water. • SAPP. • NaoH. • 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).

APPENDIX B
THE DETAILED PRODUCERS AND APPLICATION FOR THE LOST CIRCULATION MATERIALS AND TREATMENTS (PREVENTIVE METHODS)

1. **Nanoparticles:**

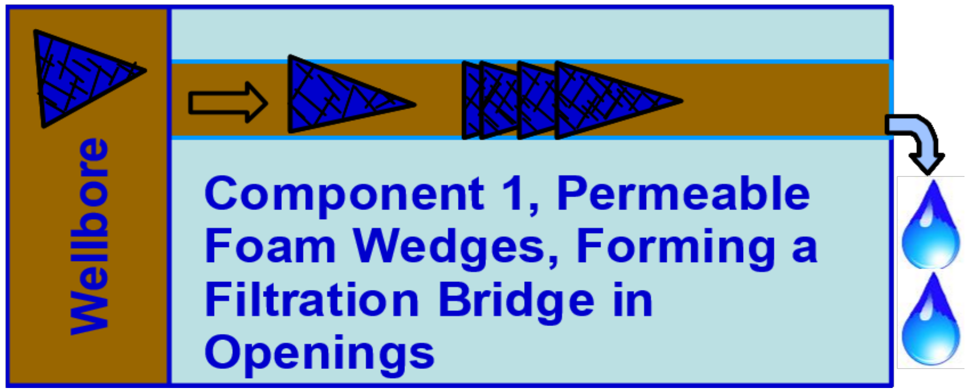
Currently applied nanoparticles include silica, iron hydroxide and calcium carbonate. These types of particles can be prepared by either ex-situ or in-situ procedures. Ex-situ stands for the preparation of nanoparticles that occurs into an aqueous solution that is later added to the mud. In-situ involves the addition of the precursors that form the nanoparticles directly to the mud. For practical field practices, authors recommend in-situ practices for avoiding a significant increase in water content of the mud into the circulation system. Other types of nanoparticles obtained from aluminum and titanium have been investigated for permeability reduction in presence of WBM. Carbon black nanoparticles with a specific gravity ranging from 1.9 to 2.1 have been used to reduce mud cake reduction to mitigate differential pipe sticking. Ballard and Massam investigated the use of barium sulfate nanoparticles as a weighting agent. Zinc nanoparticles application for lubricity improvement has been reported by Griffo and Keshavan when used as a drilling bit lubricator in the presence of other additives including silica gel (Al-Hameedi et al., 2016; Alsaba et al., 2014).

2. **Plug Forming Assurance Technology:**

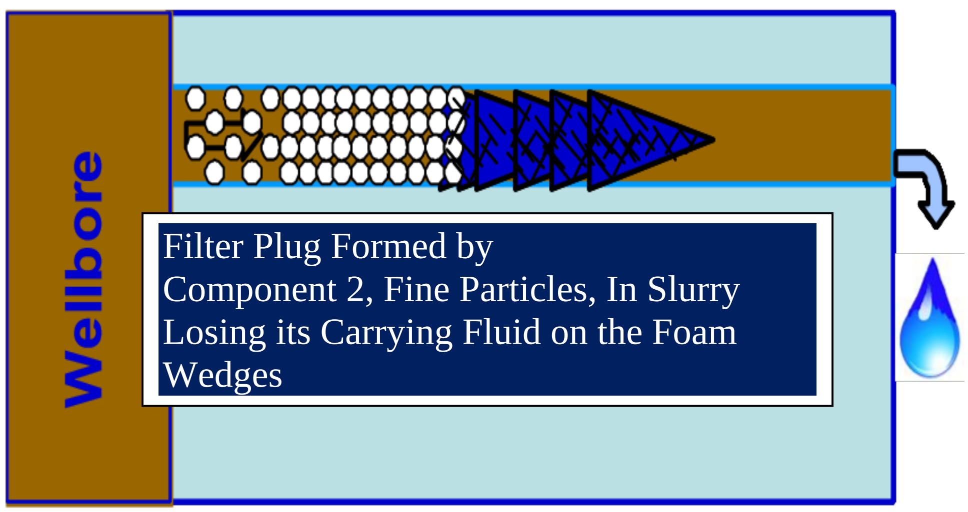
Existing fractures or vugs can have irregular shapes and widths. To address uncertainties in fracture size and shape, a new technology was developed. This technology is applied using two components: foam wedges and micron-sized particles. Foam wedges are described as small pieces of “foam rubber-like chunks” that are highly deformable. This characteristic allows the foam wedges to be compressed and forced into openings of different sizes and shapes. Once the openings are filled with the foam, they will form a highly permeable filtration bridge for the second component. The second component which consists of high fluid loss fine particles will form a plug within the filtration bridge, Foam wedges. Figure B.1 is described as small pieces of “foam rubber-like chunks” that are highly deformable, in addition, figure B.2 illustrates the main steps and the work principle of the plug forming assuring technology (Al-Hameedi et al., 2016; Alsaba et al., 2014).

Figure B.1: Wedge Foam (From Wang, 2011)

Step 1



Step 2



Step 3

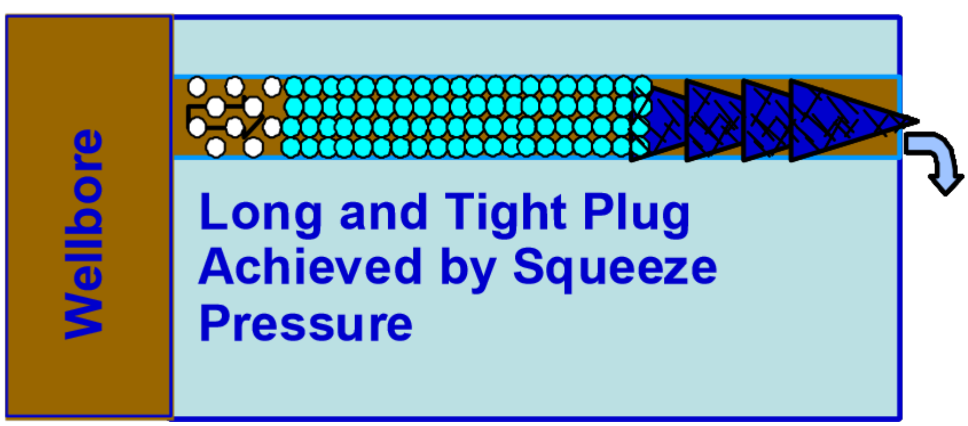


Figure B.2. Designed Working Mechanism for the PFA Technology (Wang, 2011)

3. Customized Combinations of LCM's:

Combining different LCM's types and sizes have proved its effectiveness in both lab tests and field trials due to the wide range of particle size distribution and the different physical properties of the combined LCM's. In general, the combination includes granular, fibrous and flaky LCM's. Various laboratory tests were conducted to investigate the effect of combining two types of LCM's (ground marble and resilient graphite) on their performance and it was observed that they performed better than when they were used alone. A wide range of LCM's combinations is available for different lost circulation scenarios. The combinations of LCM's are also optimized based on the particle size distribution that is capable of sealing a broad range of fracture sizes. In addition to the efficient performance of the combined LCM's, they usually come premixed and sacked thus saving rig time (Al-Hameedi et al., 2016; Alsaba et al., 2014).

4. 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. Because this material has several advantages which contribute to regulate on mud losses. In different words, resilient graphitic carbon (RGG) has many unique characteristics that can be exploited in controlling on lost circulation mud. RGC contribute to impart its excellent properties like resiliency and crush resistance to other LCM combinations. In addition, this material is appropriate to use in reservoir sections because it is completely inert; therefore, RGC does not cause damage for the productive zone. This paper is going to demonstrate the unique properties for RGC like resiliency, lubricity, resistance to attrition, and compatibility with downhole tools. As well, this paper includes field and laboratory data that illustrate that RGC is versatile material regarding lost circulation control and wellbore strengthening applications. The main objective of this study to exhibit the importance of LCM type, more importantly about the compressive and resilient LCM (Resilient Graphitic Carbon, RGC) and its significance in effective wellbore strengthening applications. The content of this paper can be classified into three points (Savari et al., 2012):

- Resiliency results of RGC and other LCM-RGC combinations.
- RGC for effective wellbore strengthening.
- RGC, non-magnetic and non-interactive with any downhole tools.
- Important characteristics for resilient graphitic carbon (RGC).

5. **Chemical grout:**

This treatment is chemical consolidation mechanism that has been proved as an 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. In different words, this technology has a prominent role on wellbore stability in fractured and unstable formations. Experimental works have already been proved that this remedy provides a good stability for wellbore wall. Obviously, there are pros and cons regarding using this technology (Soroush and Sampaio, 2006):

6. **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 the ability to maintain the seal and isolate the fracture tip from the wellbore pressure. It is recommended to provide differential pressure in order to dislodge the seal body and keep it immobile. As usually, each method has strong and weak points. Figure B.3 will illustrate the DVC system reacts with a water-based mud (Soroush and Sampaio, 2006):

- **Advantages**

- It does not rely on appropriate permeability zones.
- It is not required to know permeability.

- **Disadvantages**

- It is required to use a large amount of sealant has to travel along distance along wellbore to cover the unconsolidated zone.
- Limited squeeze pressure by other weak formations.

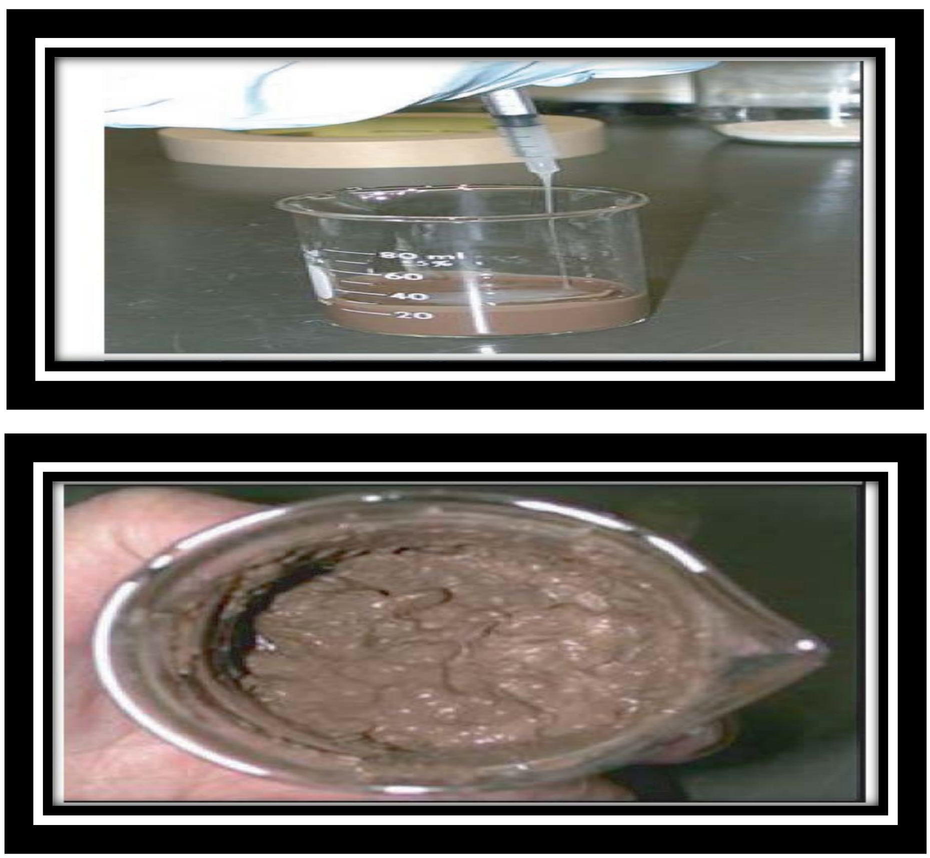


Figure B.3. The DVC System Reacts with a Water-Based Mud to Form a DVC Sealant.
(Wang et al., 2008)

7. **Resin treatment (Formation consolidation and chemical casing method):**

In this method, water dispersible resins are used in order 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. It is recommended to use drilling mud with pH between 6 and 10 with this method. As usually, each method has strong and weak points (Soroush and Sampaio, 2006):

- **Advantages**

- Wellbore strengthening approach and drilling operations can be done simultaneously.
- It is an efficient technique for both shales and sandstones.
- It does not have a big effect on drilling fluid properties.
- This method has the possibility to increase fracture gradient to 1200 psi.

- **Disadvantages**

- It is difficult to remove damage.
- It is not cost-effective.
- The leftovers cannot be reused or recycled.

8. **$CaCO_3$:**

Is one of the most valid and adaptable lost circulation materials that has already been used for wellbore strengthening issues. It is a granular occurring, ground rock. It is used to prepare pills with oil-based, synthetic-based, and water-based muds.

- It is readily available and can easily be added to LCM spot pills in high concentrations. It can be added in circulation as prevention.

- Granulometry is divided in Fine – Medium – Coarse categories, with particle sizes of 0.05 mm for the fine type, 0.1 mm for the medium, 3 mm for coarse and super coarse > 3 mm.
- The fine and medium types are used to control seepage and partial losses. The medium, coarse and super coarse types are used for partial and total losses in fracture formation and/or in micro fractures (Carbonates). This material can also be used in combination with other plugging materials (Al-Hameedi et al., 2016).

APPENDIX C
SUMMARY OF MATERIALS

a comprehensive summary that includes most of the available LCM's which is very beneficial for operators and drilling engineers are tabulated in cross-referencing tables for each type of LCM's (Appendix C). The tables list the generic name, trade name and the recommended application for each LCM. The majority of LCM's comes in different grades; fine, medium and course to suit different losses scenarios ranging from seepage to severe losses (Al-Hameedi et al., 2016; Alsaba et al., 2014; Halliburton and Manuel Molina 2105).

Table C.1: Examples of granular LCM's

Generic Name / Description	Trade Name	Provider
Ground/Sized walnut shells	WALL-NUT	Halliburton
	MIL-PLUG	Baker Hughes
	NewPlug	NEWPARK
	WALNUT HULLS	GEO Drilling Fluids
	NUTSHELL	Anchor Drilling Fluids
	MESUCO-PLUG	Messina Chemicals
Resilient, angular, dual-carbon based, sized graphite	STEELSEAL	Halliburton
	G-SEAL	MI SWACO
	C-SEAL	MI SWACO
	LC-LUBE	Baker Hughes
	NewSeal	NEWPARK
A proprietary natural loss prevention material (LPM)	SURE-SEAL	Drilling Specialties
	TORQUE-SEAL	Drilling Specialties
A blend of acid soluble particulates	EZ-PLUG	Halliburton
Sized-ground marble	BARACARB	Halliburton
	SAFE-CARB	MI SWACO
	NewCarb	NEWPARK
	FLOW-CARB	Baker Hughes
	MIL-CARB	Baker Hughes
	W. O. 30	Baker Hughes

Table C.2: Examples of flaky LCM's

Generic Name / Description	Trade Name	Provider
Cellophane	MILFLAKE	Baker Hughes
	MESUCOFLAKE	Messina Chemicals
Sized grade of Mica	MILMICA	Baker Hughes
	MESUCO-MICA	Messina Chemicals
Flaked Calcium Carbonate	SOLUFLAKE	Baker Hughes

Table C.3: Examples of fibrous LCM's

Generic Name / Description	Trade Name	Provider
Natural cellulose fiber	BAROFIBRE	Halliburton
	M-I-X II	MI SWACO
	VINSEAL	MI SWACO
	CHEK-LOSS	Baker Hughes
	MESUCO-FIBER	Messina Chemicals
	CyberSeal	NEWPARK
	FIBER SEAL	GEO Drilling Fluids
A proprietary microcellulosic fiber for use in water base muds	DYNARED	Drilling Specialties
A proprietary microcellulosic fiber for use in oil base muds	DYNA-SEAL	Drilling Specialties
Shredded cedar fibers.	M-I CEDAR FIBER	MI SWACO
	FIBER PLUG	Anchor Drilling Fluids
	PLUG-GIT	Halliburton
	MIL-CEDAR	Baker Hughes
Acid soluble extrusion spun mineral fiber	N-SEAL	Halliburton
	CAVI-SEAL-AS	Messina Chemicals
	MAGMA FIBER	GEO Drilling Fluids/ Anchor Drilling Fluids

Table C.4: Examples of LCM's Combinations

Generic Name / Description	Trade Name	Provider
A combination of different LCM types and wide range of particle sizes.	STOPPIT	Halliburton
	PRIMA SEAL	GEO Drilling Fluids
	STOP-FRAC S	Halliburton
	WELL-SEAL	Drilling Specialties
	BARO-SEAL	Halliburton
	STOP-FRAC D	Halliburton
	M-I SEAL	MI SWACO
	MIL-SEAL	Baker Hughes
	CHEM SEAL	Anchor Drilling Fluids
	KWIK-SEAL	Messina Chemicals
	MESUCO-SEAL	Messina Chemicals
A blend of acid soluble particulates.	EZ-PLUG	Halliburton
A proprietary particulate blend designed to be used with foam wedges.	QUIK-WEDGE	Sharp-Rock Technologies, Inc.
A proprietary particulate blend that includes modified natural materials and other additives.	STRESS-SHIELD	Sharp-Rock Technologies, Inc.

Table C.5: Examples of acid soluble LCM's

Generic Name / Description	Trade Name	Provider
A blend of acid soluble particulates	EZ-PLUG	Halliburton
A non-damaging, cross linkable water soluble polymer blended with selected sized cellulosic fibers.	N-SQUEEZE	Halliburton
Acid soluble extrusion spun mineral fiber	N-SEAL	Halliburton
	CAVI-SEAL-AS	Messina Chemicals
	MAGMA FIBER	GEO Drilling Fluids/ Anchor Drilling Fluids
Sized and treated salts	BARAPLUG	Halliburton
Acid Soluble Sized-Calcium Carbonate	BARACARB	Halliburton
	SAFE-CARB	MI SWACO
	NewCarb	NEWPARK
	FLOW-CARB	Baker Hughes
	MIL-CARB	Baker Hughes
	W. O. 30	Baker Hughes
Flaked calcium carbonate	SOLUFLAKE	Baker Hughes
Nontoxic fibrous powdered polysaccharide, biodegradable and acid soluble lost circulation material.	HOLE-SEAL-II	Messina Chemicals

Table C.6: Examples of High Fluid Loss LCM's Squeezes

Generic Name / Description	Trade Name	Provider
High fluid loss squeeze	GEO STOP LOSS	GEO Drilling Fluids
High-solids, high-fluidloss reactive lost circulation squeeze	DIASEL M	Drilling Specialties
A specially formulated high-solids high fluid loss squeeze.	DIAPLUG	Messina Chemicals
A proprietary blend of granular and fibrous materials.	X-Prima	NEWPARK
A blend of granular and fibrous materials.	NewBridge	NEWPARK
Micro-sized cellulosic fiber combined with a blend of organic polymers	ULTRA SEAL	GEO Drilling Fluids
A blend of fine particles to promote high fluid loss and other additives in addition to highly compressible and permeable foam rubber chunks.	WEDGE-SET	Sharp-Rock Technologies, Inc.
A combination of both resilient graphitic carbon and malleable components	DUO-SQUEEZE	Halliburton

Table C.7: Examples of Settable/Hydratable LCM's

Generic Name / Description	Trade Name	Provider
A combination of swelling polymer along with engineered combinations of resilient graphitic carbon and other materials	HYDRO-PLUG	Halliburton
Dry powdered/granular material with synthetic polymers, inorganic minerals, chemical reagents and stabilized organic filler.	SUPER-STOP	Messina Chemicals
A non-damaging, cross linkable water soluble polymer blended with selected sized cellulosic fibers.	N-SQUEEZE	Halliburton

Table C.8: Examples of Nanoparticles LCM's

Generic Name / Description	Trade Name	Provider
Iron Hydroxide NP	Iron Hydroxide NP	nFluids Inc.
Calcium Carbonate NP	Calcium Carbonate NP	nFluids Inc.

II. STATISTICAL ANALYSIS AND COMPREHENSIVE REVIEW OF CONVENTIONAL AND STATE-OF-ART LOST CIRCULATION TREATMENTS WITH PRACTICAL GUIDELINES FOR DRILLING IN BASRA'S OIL FIELDS, IRAQ

ABSTRACT

Wells in Basra's oil fields are highly susceptible to lost circulation problems when drilling through Dammam, Hartha, and Shuaiba formations. Lost circulation events range from seepage to complete loss of borehole are a critical issue in fields development. This paper discusses the most recent treatments, which are used in Basra's fields with integrated analysis and updated classification. In addition, the best lost circulation strategy of remedies will be presented to mitigate or stop this problem.

This study demonstrates the various lost circulation treatment materials and their application, which have already been used in Basra's oil fields (e.g. Rumaila, Zubair, Nahr Umar, and Allhis fields). The treatments are categorized into general groups to assist in describing the way they work and to differentiate their applications. Each lost circulation treatment is selected by based on the type of losses, cost, efficiency, and type of formation. In addition, Practical field information from a range of sources is reviewed and summarized to develop an integrated methodology and flowchart for handling lost circulation events in these fields.

Due to a large number of current available LCM's and their different applications, classification and reviewing of LCM's are very important. The central focus of this work is to find out the reasons associated with treatment's application that makes lost circulation treatments to be unsuccessful. Furthermore, this work will provide workable guidelines and coherent recommendations to avoid the non-productive time and money wasting by repeating ineffective treatment and inaccurate implementations. Given sufficient

experience in drilling a particular type of formation, it may be possible to avoid or significantly minimize, lost circulation events by controlling mud properties, drilling rate, or other field parameters. However, this requires a high level of experience and study, which is generally not available. For this reason, the industry relies heavily on using methods of mitigating lost circulation events after they occur. This study provides a unique compilation of information regarding traditional approaches and the latest approaches to lost circulation control. In addition, engineered solutions and practical solutions are developed, which will contribute to give clear image and coherent understanding about this complicated and costly problem in Basra's oil fields. Due to the lack of published studies for Basra's oil fields, this work can serve as a vigorous resource for drilling through these zones.

1. INTRODUCTION

The concept of lost circulation or lost returns can be defined as “the partial or total loss of circulating fluid from the wellbore to the formation. It is the loss of whole fluid, not simply filtrate, to the formation. Losses can result from either natural or induced causes and can range from a couple of barrels per hour to hundreds of barrels in minutes. Lost circulation is one of drilling’s biggest expenses in terms of rig time and safety. Uncontrolled lost circulation can result in a dangerous pressure control situation and loss of the well” (Baker Hughes, 1999). Lost circulation may also occur at any point in the drilling operation. If losses occur while drilling a long section of the well, the objective of the treatment will likely be to plug off or limit the losses to allow drilling ahead without casing and cementing. In other situations, the approach may be to limit the losses and cement the well.

Lost circulation incidents could lead to a series of unwanted consequences that could cost up to million dollars or more (Kumar and Savari, 2011). The severity of the consequences varies depending on the loss severity; it could start as just losing the drilling fluid and it could continue to a blowout. In general, lost circulation events are classified based on the losses rate (m^3/hr.). When the fluid loss rate is 0.5 -1 m^3/hr., the loss is classified as seepage loss which could happen in any type of formation. As the fluid loss rate increase from 1 to 10 m^3/hr., the losses are recognized as partial losses that could occur in gravels, small natural horizontal fractures, or induced vertical fractures. Once the loss rate increase to 15 m^3/hr. and above, the losses are considered to be severe losses. If there will essentially be no returns to the surface, the losses are recognized as complete losses that could occur to long open sections of gravel, large natural horizontal fractures, caverns, interconnected vugs and to widely opened induced fractures. Lost circulation events may occur in naturally fractured formations, cavernous formations, highly permeable formations or due to drilling induced fractures as shown in figure 1.1 (Nayberg and Petty, 1986).

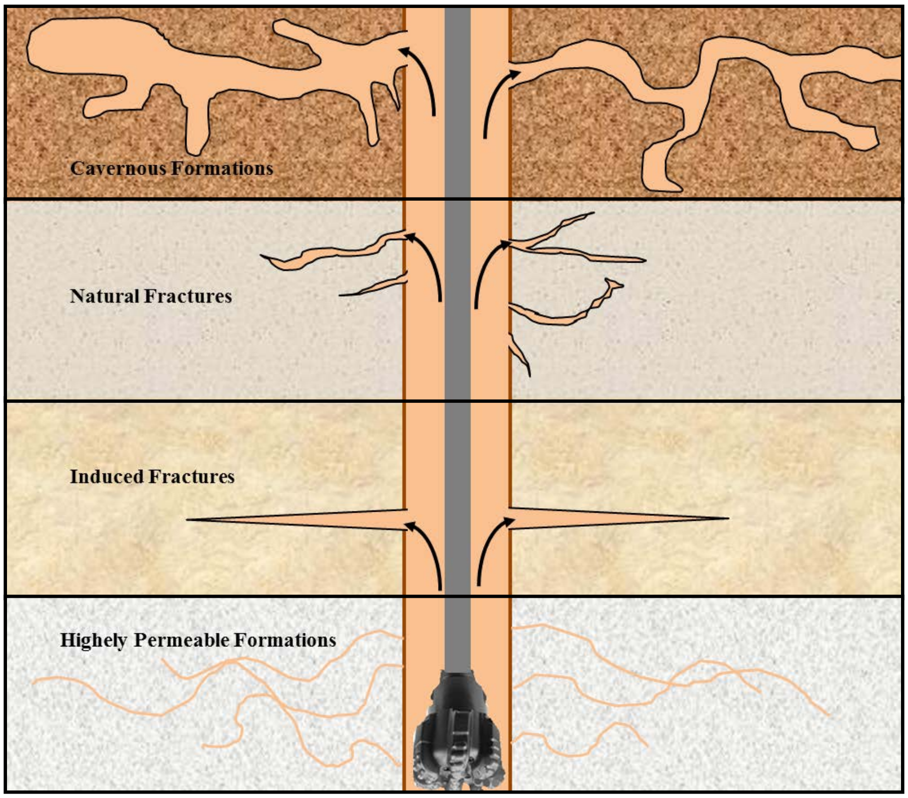


Figure 1.1: Candidate Formations for Losses Events (Nayberg and Petty, 1986)

There is a wide range of lost circulation treatments available applied to control or eliminate lost circulation events. These systems can be divided into conventional systems, which include granular, fibrous and flaky materials that are mixed with the drilling fluids during either the drilling phase or with the cement slurries during the drilling and primary cementing phases. The other approach to controlling lost circulation is specialized cement, dilatant slurries, soft or hard reinforcing plugs, cross-linked polymers, and silicate systems that are also used during the drilling/cementing phases.

This study provides basic information on lost circulation, including an introduction to the problem, identifies a range of factors that affect lost circulation, and reviews historical work in lost circulation materials. The study summarizes mud loss and lost circulation information extracted from drilling data from in Basra's oil fields in Iraq. A lost circulation screening criteria is presented in Basra's fields, based on the historical mud loss and lost circulation problems, materials used to mitigate the problems, and potential solutions found by this study.

2. METHODOLOGY

Data of more than 800 wells that were drilled in Basra's oil fields are reviewed, lost circulations treatments are extracted from Daily Drilling Reports (DDR), technical reports, and final drilling reports. First, the treatments were classified treatments for seepage, partial, severe, and complete losses. Treatments that are used less than 10 times are not included in this analysis. Then, the probability of success/failure is calculated for each treatment. Finally, a flow chart is conducted to summarize the treatments that should be used in case of experiencing seepage, partial, severe, and complete losses. Figure 2.1 summarizes the methodology of this paper.

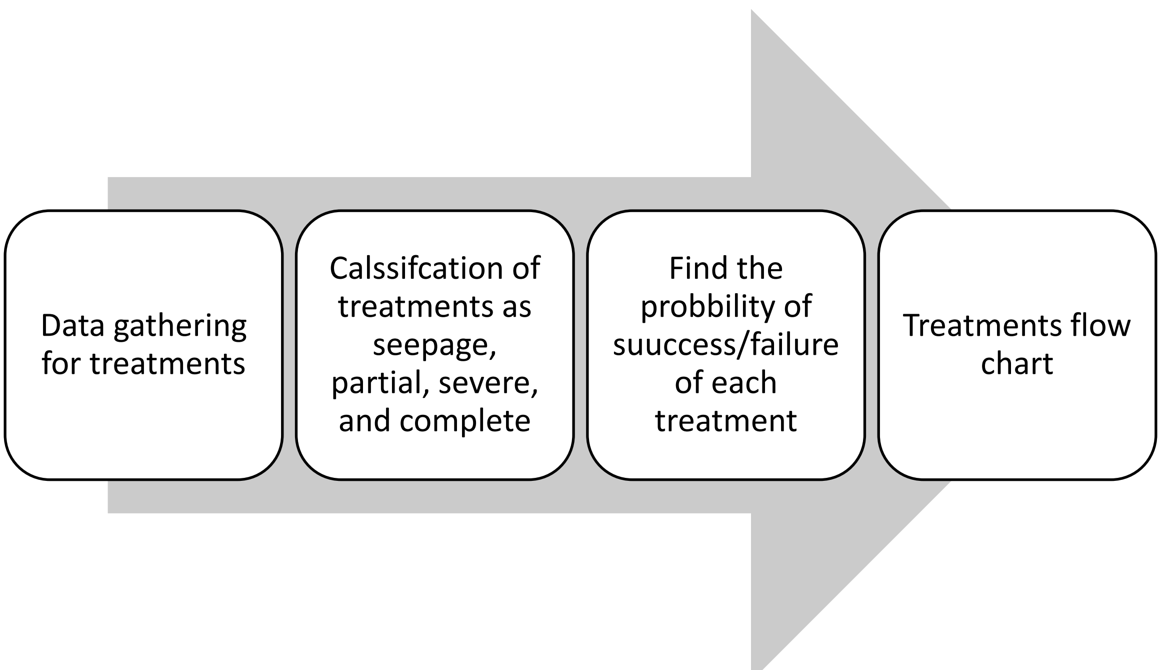


Figure 2.1: Methodology

3. FORMATIONS WHICH ARE PRONE FOR LOST CIRCULATION IN BASRA’S OIL FIELDS

Lost circulation mud is very common and very troublesome issue in Basra’s oil fields. This problem causes non-productive time, money wasting, and negative consequences on the drilling operations. In spite of several remedial measures and big efforts to avoid or mitigate this dilemma, mud losses issues are still one of the most severe problems encountered in drilling operations. Thief zones are one of the most challenging problems to be prevented or mitigated during the drilling phase into Basra’s oil fields. There are usually three formations which are prone to mud losses in this field (South Oil Company, 2011).

3.1 DAMMAM FORMATION

The Dammam formation is the first formation in Basra’s oil fields that is prone to mud losses. The top of this zone is found between 435 to 490 m, and all of the wells in the field must be drilled through this zone. The interval is composed of interbedded limestone and dolomite, which is generally 200 to 260 m thick. The top of the Dammam was eroded after burial and is karstified at depth. The karst features are believed to lead to the mud losses seen while drilling through this interval (Arshad, 2015). Figure 3.1 shows borehole and well construction typical of a well drilled in Basra’s oil fields at the time the well passes through the Dammam formation. 13-3/8” casing has been set, and most commonly a 12 ¼” bit is used to drill through the formation. A lost circulation event is shown near the bottom of the openhole in Figure 3.1, but may occur anywhere in the openhole section through the Dammam (South Oil Company, 2010).

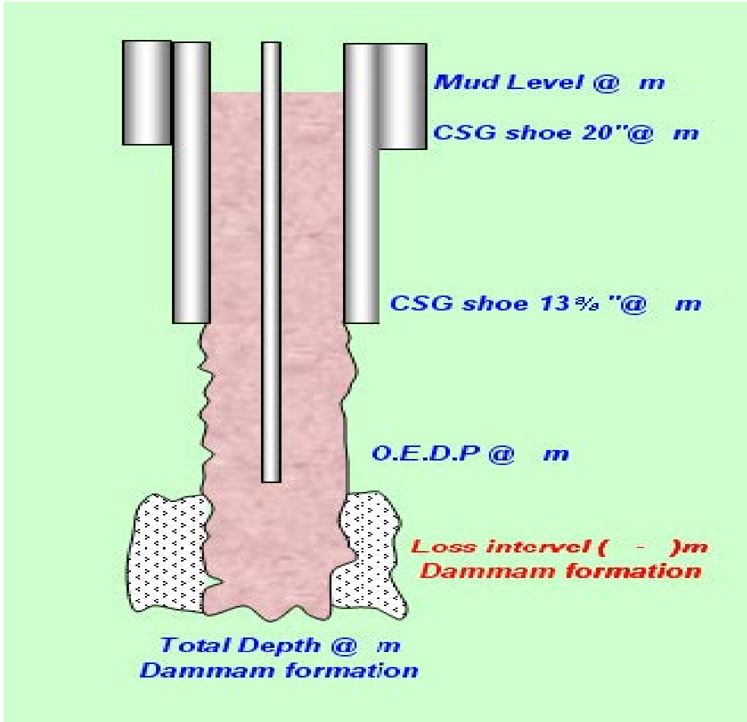


Figure 3.1: Lost Circulation Mud in the Dammam Formation

3.2 HARTHA FORMATION

The Hartha formation is the second zone that is usually prone to lost circulation problems. Mud losses in Hartha formation are more complicated than Dammam formation. This zone is deeper (formation top 1530 to 1640 m), and it is located below transitional zones like the Tayarat and Ummer-Radhuma zones which have abnormal pressures and H2S flow. Figure 4 shows the borehole and well construction typical of a well drilled in Basra’s oil fields at the time the well passes through the Hartha formation. 13-3/8” casing has been set, and most commonly a 12 ¼” bit is used to drill through the formation. The Dammam formation has been drilled and is exposed openhole while the Hartha is drilled. A lost circulation event is shown near the bottom of the openhole in Figure 3.2, but it is possible to have losses simultaneously the Dammam and the Hartha formations, or only losses in the Hartha as it is drilled (South Oil Company, 2010).

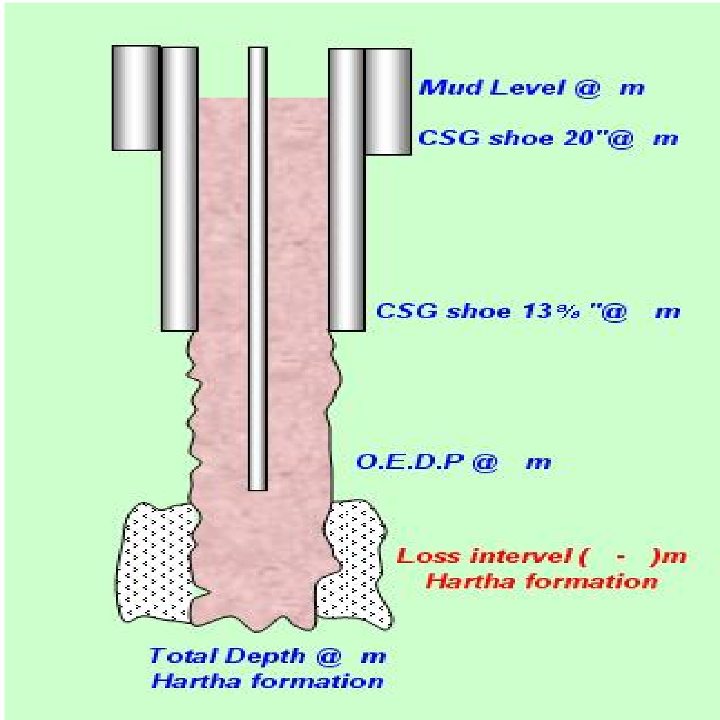


Figure 3.2: Lost Circulation in the Hartha Formation

3.3 SHUAIBA FORMATION

The Shuaiba formation occurs at approximately 2900 m and is a limestone with little to no visible porosity. However, the zone is highly susceptible to fracturing and lost circulation, which is more troublesome and even more complicated than lost circulation in the Dammam or the Hartha formations. Sometimes, mud losses in the Shuaiba formation lead to the abandonment of the drilling operation due to unsustainable non-productive time (NPT) and drilling cost. Mud losses in Shuaiba also cause severe wellbore stability problems. Figure 3.3 shows the borehole and well construction typical of a well drilled in Basra’s oil fields at the time the well passes through the Shuaiba formation. Both the 13-3/8” and 9-5/8” casing strings have been set. Commonly an 8 1/2” bit is used to drill through the formation.

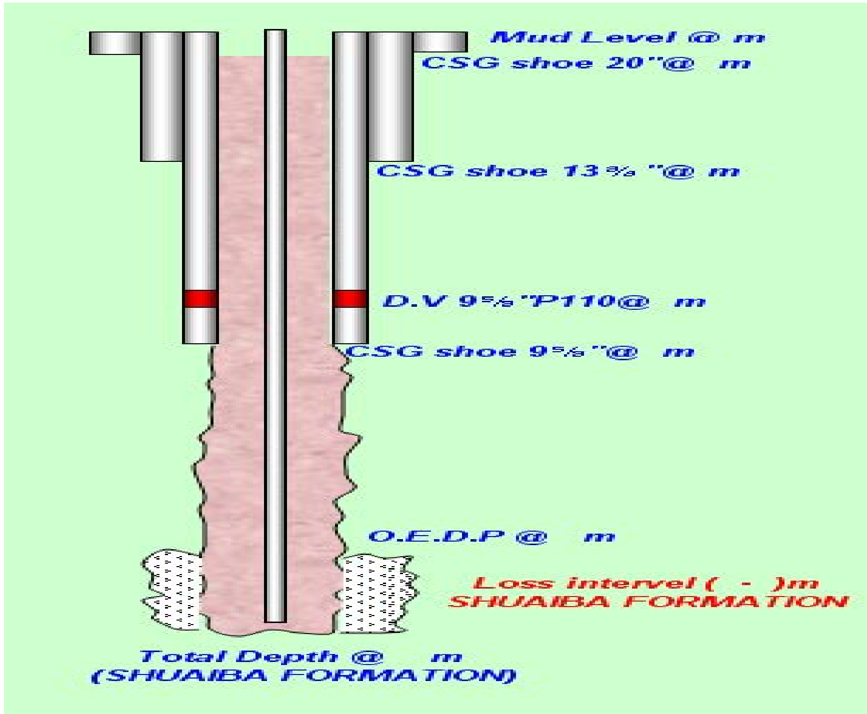


Figure 3.3: Lost Circulation Mud in the Shuaiba Formation

4. FACTORS IMPACTING MUD LOSSES

There are multiple reasons that cause to initiate lost circulation mud in Dammam, Hartha, and Shuaiba formations in Basra's oil fields in Iraq. Table 4.1 will demonstrate the major factors that cause this issue:

Table 4.1: Causes of Lost Circulation

Pressure Induced Fractures	**Natural Fractures/Permeability**
• Excessive mud weight. • Annulus friction pressure (ECD). • Wellbore pressure surges. • Imposed/trapped pressure. • Shut – in pressure. • Low formation pressure.	• High permeability formations. • Unconsolidated formation. • Fissures / fractures. • Unseal fault boundary. • Vugular / cavernous formation.

5. ADVERSE EFFECTS ON DRILLING OPERATIONS DUE TO MUD LOSSES

Either directly or indirectly, mud loss has an enormous negative impact on drilling operations. The concept of lost circulation can be described as “mud losses is one of the most troublesome and costly problems encountered while drilling a well. It can be characterized by a reduction in the rate of mud returns from the well compared to the rate at which it is pumped downhole during a lost circulation an appreciable part or entire volume of drilling fluid can be lost into the formation” (Pilehvari and Nyshadham, 2002). There are several negative effects due to lost circulation mud (South Oil Company, 2008). Table 5.1 will show the bad consequences due to lost circulation:

Table 5.1: Summary of Unwanted Consequences of the Mud Losses

Surface Hole	**Intermediate Hole**	**Production Hole**
• Loss of drive/conductor shoe. • Hole cleaning problems. • Hole bridge/collapse. • Stuck pipe. • Well control event. • Loss of well.	• Loss of fluid level monitoring. • Loss of formation evaluation. • Hole cleaning problems • Hole bridge/collapse • Extended well bore exposure time. • Stuck pipe • Well control event • Underground blowout • Additional casing string.	• Loss of fluid level monitoring. • Loss of formation evaluation. • Hole cleaning problems • Hole bridge/collapse • Extended well bore exposure time. • Stuck pipe • Well control event • Underground blowout • Additional casing string. • Production zone damage

6. LOSS SEVERITY CLASSIFICATIONS

Mud losses are categorized according to the total volume of fluid lost during the event. The volume of mud losses depends on a number of factors, including formation properties, drilling fluid properties, and formation breakdown pressure (Eni Company, 2010). The categories of losses are described as seepage, partial, severe, and complete losses, depending on the volumes of mud losses and thief zone (Nayberg & Petty, 1986). All the mud losses for wells in Dammam, Hartha, and Shuaiba formations in Basra's oil fields in Iraq are reported according to this classification system. Table 6.1 clarify the Classifications of Lost Circulation.

Table 6.1: Loss Severity Classifications

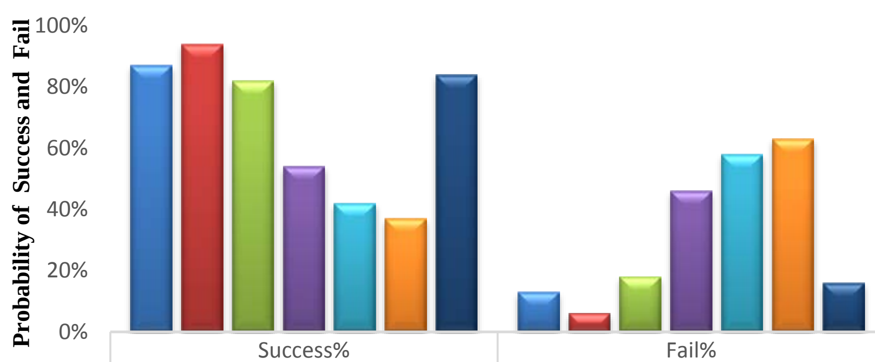
Seepage Loss	**Partial Loss**	**Severe Loss**	**Total Loss**
• These losses could occur in any type of formation due to differential pressure (over-balanced drilling). The other name for this type is filtration. The fluid loss rate is 0.5–1 m^3/hrs (3-6 bbls/hrs). • Gradual losses • Operation not interrupted • Possible warning of increased loss severity.	• This kind of the losses usually happens in gravel beds, small natural horizontal fractures and barely opened, induced vertical fractures. • The fluid loss rate is 1-10 m^3/hrs (7-70 bbls/hrs). • The immediate drop in fluid level when pumping is stopped. • Slow to regain returns after starting circulation. • The operation usually interrupted. • Remedial action required.	• This kind of the loss will be more than a partial loss, and normally about 15 m^3/hrs (95 or above bbls/hrs) or more. • It occurs in vugular or cavernous formations or induced fractures. • Operation suspended. • Remedial action required.	• Return flow stops immediately. • Pump pressure decrease. • String weight increase. • Operation suspended. • Remedial action required. • It occurs in large natural fractures, interconnected vugs and to widely open induced fractures.

7. LOST CIRCULATION TREATMENTS USED IN BASRA'S OIL FIELDS

Some proactive actions which should be taken in case of experiencing mud loss are a reduction of the pump pressure, reduction of the drilling mud density, waiting method, increasing the drilling fluid viscosity, and using bit without nozzles are not sufficient to avoid lost circulation material. Narrow mud weight window between pore pressure and fracture pressure lead to mud losses. Several remedies that have already been used in Basra's oil fields in Iraq to stop or mitigate mud losses. Plainly, each type of the mud losses is required specific treatment to stop it or mitigate. Therefore, it is necessary to detect which kind of losses that we should prepare an optimal remedy for it. By selecting appropriate treatment for the mud losses, that, in turn, will reflect positively on the drilling operations in terms combating the problem, saving time, and reducing expenses. In this section, remedies will be classified depending on the type of treatment (South Oil Company, 2010).

7.1 SEEPAGE LOSS REMEDIES

These losses could occur in any type of formation due to differential pressure (over-balanced drilling). The other name for this type is filtration. The fluid loss rate is 0.5–1 m^3/hrs (3-6 bbls/hrs). Figure 7.1 will show the probability of success and failure for the remedial materials which have been used to treat seepage losses in Basra's oil fields.

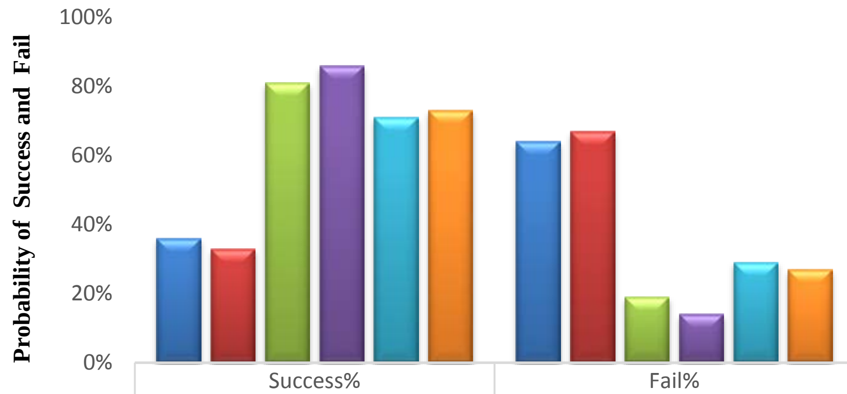


	Success%	Fail%
Bentonite	87%	13%
CMC-LV	94%	6%
CMC-HV	82%	18%
Starch	54%	46%
PACR-HV	42%	58%
PACR-LV	37%	63%
Resinex	84%	16%

Figure 7.1: Treatments for Seepage Losses in Basra’s Oil Fields

7.2 PARTIAL LOSSES REMEDIES

In this kind of loss, part of drilling fluid will be lost into formation about (1-10 m^3/hr). This type of loss is the simplest one, and it is easy to control on it. However, by ignoring this kind of the losses, it will aggravate to severe loss or complete loss. Therefore, it is very crucial to do required actions to stop this loss to avoid unwanted consequences. Several treatments use to control and mitigate this type of loss. Figure 7.2 will show the probability of success and failure for the remedial actions which have been used to treat partial losses in Basra’s oil fields. Table 7.1 will illustrate remedies that use to regulate this type of the loss.



	Success%	Fail%
Waiting Method	36%	64%
Reduction Key Drilling Parameters	33%	67%
H.V Mud	81%	19%
10 – 15 m3 LCMs Pill (L. MW)	86%	14%
Plugging Materials, Fine Mica	71%	29%
Plugging , Fine and Meduim CaCO3	73%	27%

Figure 7.2: Treatments for Partial Losses in Basra's Oil Fields

Table 7.1: Partial Losses Treatments in Basra's Oil Fields

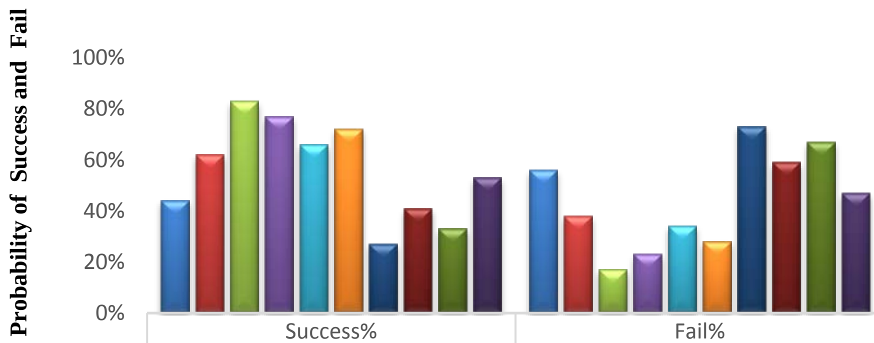
Type of Losses	Type of the Treatment	Approach to the Treatment	Waiting
Partial Loss	Waiting Method	• Pull out drilling strings to casing shoe. • Waiting period between (2-4) hours. • Drilling strings will gradually run in hole. • Circulation drilling mud and rotation drilling string slowly. • Check mud levels in mud tanks system to make sure there are no mud losses. • Starting drilling operation at moderate speeds to seal formation apertures by engraved cutting.	(2-4) hours
	Reduction Key Drilling Parameters	By reduction the pump pressure, MW, Yp, RPM, ROP, and bit without nozzles	No Waiting
	High Viscosity Patch	High viscosity drilling mud (Patch) with low mud weight. By using Bentonite, lime, or salt clay to increase viscosity.	(2-3) hours

Table 7.1: Partial Losses Treatments in Basra's Oil Fields (Cont'd)

<table>
<tr><th>Type of Losses</th><th colspan="2">Type of the Treatment</th><th>Approach to the Treatment</th><th>Waiting</th></tr>
<tr><td rowspan="9">Partial Loss</td><td colspan="2">10 – 15 m^3 LCMs Pill (Low MW)</td><td rowspan="7">These materials have the ability to form" brush heap" like the mat in pore openings, then creating a plug to seal thief zone. It is practically interesting to use this blend of LCM with low mud weight to avoid increasing in annular pressure losses (APL) and equivalent density (ECD).</td><td rowspan="7">(3-4) hours</td></tr>
<tr><td>Product</td><td>Amount</td></tr>
<tr><td>Mica Fine</td><td>15 kg/m^3</td></tr>
<tr><td>Mica Medium</td><td>15 kg/m^3</td></tr>
<tr><td>Nut Plug</td><td>15 kg/m^3</td></tr>
<tr><td>Caco3 Medium</td><td>15 kg/m^3</td></tr>
<tr><td>Caco3 Coarse</td><td>15 kg/m^3</td></tr>
<tr><td colspan="2">Plugging Materials, Fine Mica</td><td>Fine mica will be mixed with a low density of the drilling fluid.</td><td>(2-3) hours</td></tr>
<tr><td colspan="2">Plugging Materials, Fine and Medium $CaCO_3$</td><td>Fine and Medium $CaCO_3$ will be mixed with a low density of the drilling fluid.</td><td>(3-4) hours</td></tr>
</table>

7.3 SEVERE LOSSES REMEDIES

This kind of loss will be more than partial loss about (15 or above m^3/hr). This type of loss is risky, and it is not easy to control on it. In addition, by ignoring this kind of the losses, it will aggravate to complete loss. Therefore, it is very necessary to do required actions to combat this kind of the losses to avoid bad consequences. Many treatments use to control and mitigate this type of loss. Figure 7.3 will show the probability of success and failure for the remedial actions which have been used to treat severe losses. Table 7.2 will illustrate remedies that use to control this type of the loss in Basra's oil fields.



	Success%	Fail%
15 – 20 m3 LCMs Pill (L. MW)	44%	56%
Super Stop Material	62%	38%
H.V Mud + Blend of LCMs	83%	17%
Cement Plug	77%	23%
High Filtration Spot Pills, High Filtration Mixtures (200-400 cc API)	66%	34%
High Filtration Spot Pills, Very High Filtration Mixtures (> 600cc API)	72%	28%
Plugging Materials, Blend of Mica	27%	73%
Plugging Materials, Blend of Nut Plug	41%	59%
Plugging Materials, Blend Magma Fiber	33%	67%
Plugging Materials, Blend of CaCO3	53%	47%

Figure 7.3: Treatments for Severe Losses in Basra's Oil Fields

Table 7.2: Severe Losses Treatments in Basra's Oil Fields

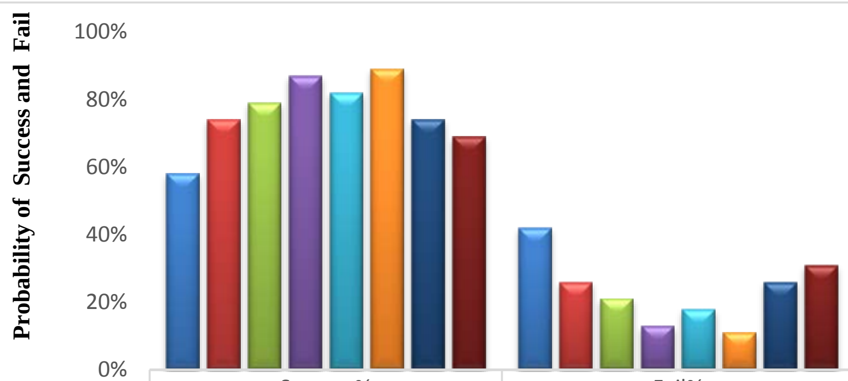
Type of Losses	Type of the Treatment		Approach to the Treatment	Waiting
Severe Loss	15 – 20 m^3 LCMs Pill (Low MW)		These materials have the ability to form" brush heap" like the mat in pore openings, then creating a plug to seal thief zone. It is practically interesting to use this blend of LCM with low mud weight to avoid increasing in annular pressure losses (APL) and equivalent density (ECD).	(3-4) hours
	Product	Amount		
	Mica Fine	30 kg/m^3		
	Mica Medium	30 kg/m^3		
	Nut Plug	30 kg/m^3		
	Caco3 Medium	30 kg/m^3		
	Caco3 Coarse	30 kg/m^3		
	H.V Drilling Mud (Low Density) + Blend LCMs		By creating a plug to seal thief zone.	(4-6) hours

Table 7.2: Severe Losses Treatments in Basra's Oil Fields (Cont'd)

Type of Losses	Type of the Treatment	Approach to the Treatment	Waiting
Severe Loss	Super Stop Material	• Mixing (4-5) bags (Weight of Bag 25 kg) of super stop material for each1 m^3water. • This treatment should be mixed separately and clean tank. • It is very crucial to mix quickly to avoid treatment bulge in the surface tank. • Displacing the remediation in front of the loss zone. • Pulling out drill pipe strings above loss zone, and making mud circulation about (10 minutes) to enforce treatment to enter formation.	(4 -5) hours
	Cement Plug	By pumping cement slurry with specific density in front of thief zone, by using O.E.D.P to plug	(18) hours
	High Filtration Spot Pills, High Filtration Mixtures (200-400 cc API)	High filtration drilling mud is used to seal loss zone. The principle of work for this treatment is by passing water into the formation, and solids content will form a seal in front of thief zone. Procedure formula for 1 m3 (final) of high filtration mixtures 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 %	(± 4-6 hours)
	High Filtration Spot Pills, very high filtration mixtures (> 600cc API)	Procedure formula for 1 m3 (final) of very high filtration mixtures Diatomite 30 % Lime 15% Attapulgite 0-4 %	(± 4-6 hours)

7.4 COMPLETE LOSSES REMEDIES

In this kind of loss, mud cycle will completely be lost into the formation. This type of loss is the worst one, and it is difficult to control on it. In addition, this kind of the problem will lead to maximizing the expenses of the drilling operations and non-productive time (NPT). Therefore, it is very necessary to do required actions to combat or mitigate this kind of the losses to avoid unwanted consequences. Figure 7.4 will illustrate the probability of success and failure for the recommended remedies which should use to treat complete losses. Table 7.3 will illustrate remedies that use to control this type of the loss in Basra's oil fields.



	Success%	Fail%
Cement Plug	58%	42%
Cement Plug + HV Mud	74%	26%
DOB Plug	79%	21%
DOCB Plug	87%	13%
Gilsonite cement	82%	18%
InstandSeal	89%	11%
Blend of Fibers in Cement	74%	26%
High Filtration Spot Pills, Very High Filtration Mixtures (> 600cc API)	69%	31%

Figure 7.4: Treatments for Complete Losses in Basra's Oil Fields

Table 7.3: Complete Losses Treatments in Basra’s Oil Fields

<table>
<tr><th>Type of Losses</th><th>Type of the Treatment</th><th>Approach to the Treatment</th><th>Waiting</th></tr>
<tr><td rowspan="6">Complete Loss</td><td>Cement Plug</td><td>By pumping, cement slurry with specific density in front of thief zone, by using O.E.D.P to plug zone.</td><td>(18) hours</td></tr>
<tr><td>High Viscosity Mud (Low Density) + Cement Plug</td><td>First, pumping high-viscosity mud (low density), then pumping cement plug directly to create an efficient seal, by using O.E.D.P.</td><td>(18-20) hours</td></tr>
<tr><td>DOB Squeeze (Diesel Oil Bentonite)</td><td>By mixing oil base + bentonite to create a plug, by using O.E.D.P to seal zone with squeeze technique.
Formula for 1 m^3 (Final)
Oil base 0.70 m^3
Bentonite 800 kg</td><td>(8-10) hours</td></tr>
<tr><td>DOBC Squeeze (Diesel Oil Bentonite Cement)</td><td>By mixing oil base + bentonite + cement to create a plug, by using O.E.D.P to seal zone with squeeze technique.
Formula for 1 m3 (Final)
Oil base 0.72 m3
Bentonite 450 kg
Cement 450 kg</td><td>(10-12) hours</td></tr>
<tr><td>Gilsonite cement</td><td>The principle of work for Gilsonite cement is exactly the same in the Gel-Cement plug. There is just on difference by using Gilsonite material instead of bentonite material. Gilsonite material is more effective than bentonite material.
Procedure
Slurry Composition
(Class G Cement)
<table>
<tr><th>Gilsonite %</th><th>water weight%</th><th>Slurry 100 kg</th><th>Density gm/cc</th></tr>
<tr><td>0</td><td>44</td><td>75.7</td><td>1.90</td></tr>
<tr><td>50</td><td>61</td><td>139.5</td><td>1.51</td></tr>
<tr><td>100</td><td>78</td><td>203.2</td><td>1.37</td></tr>
</table></td><td>(8) hours</td></tr>
<tr><td>Fibers in cement</td><td>This plug is prepared by mixing lost circulation material (Fiber) with cement in specific and homogenous proportions to restore and combat lost circulation mud.</td><td>(18) hours</td></tr>
</table>

Table 7.3: Complete Losses Treatments in Basra's Oil Fields (Cont'd)

Type of Losses	Type of the Treatment	Approach to the Treatment	Waiting
Complete Loss	InstandSeal	This treatment is one of the most important and more successful treatments that use to combat lost circulation material. It is emulsion that has a big ability to form high viscosity and high gel strength after arriving in front of the formation. This emulsion has already proved its success in high temperature. The most important feature in this emulsion is controlling the hardness time. In other words, it is possible to be a time of the hardness from few minutes to many hours. We can regulate on the hardness time for this treatment by increasing or decreasing the concentration of this emulsion and by controlling on pumping rate. It is possible to pump this emulsion by drill strings (Bit and other Accessories), and this will contribute to reduce non-productive time (NPT) and minimizing the cost of drilling. After pumping this emulsion to the wellbore, the hardness and gel strength will stay for many weeks under well conditions. It is much recommended to make prior preparation for this treatment before expected occurrence for mud losses.	(18) hours
	High Filtration Spot Pills, Very high filtration mixtures (> 600cc API)	Procedure formula for 1 m3 (final) of very high filtration mixtures Diatomite 30 % Lime 15% Attapulgite 0-4 % Granular LCM 1 – 2.5 % Fibrous LCM 1 %	(± 4-6 hours)

8. ANALYSIS AND RECOMMENDATIONS OF THE LOST CIRCULATION EVENTS IN BASRA'S OIL FIELDS

This section provides an analysis of the lost circulation events of an enormous number of drilled wells in Basra's oil fields. Real field data is minutely collected and analyzed to get an integrated analysis and a coherent image about mud losses in various oil fields. The best lost circulation strategy to Basra's oil fields is concluded and summarized depending on the gathering of lost circulation events, comprehensive statistical work, and the most important courses of the international oil companies to determine the successful remedies for each type of the mud losses. These treatments are classified by relying on lost circulation classifications to avoid unwanted consequences due to inappropriate actions, minimize non-productive time, and reduce cost. In addition, engineered solutions and practical guidelines are developed, which will contribute to understanding this complicated and costly problem in the Dammam, Hartha, and Shuaiba formations in Basra's oil fields.

8.1 PREPARATIONS BEFORE STARTING TO DRILL THESE FORMATIONS

Many preparations must be taken before drilling Dammam, Hartha, and Shuaiba formations, which are prone to lost circulation mud (South Oil Company, 2008).

- Prior preparation for work meeting which consists of a supervisor, mud engineer, log engineer, and geologist before drilling formations which are prone to mud losses to take all the necessary measures.
- Providing a sufficient amount of drilling mud for emergencies especially bentonite material.
- By supplying required precautions of various lost circulation materials.

- Determination accurate depth of the mud losses in these formations by strict monitoring and by depending on previous geological information and old documents.
- It is necessary to change drilling mud properties before entering these formations to avoid or mitigate sudden losses.
- Prior preparation for drilling fluid with low mud weight in anticipation for any increasing in the drilling mud density during drilling operations.
- Prior planning by mixing sufficient amount of the high-viscosity mud (Pill) to provide a quick remedy for partial losses.
- In case severe or complete losses occur, it is better to continue in drilling operations as much as possible. After that, pull out drilling strings from hole to casing shoe and use required remedies.
- It is recommended in some cases to use the wellbore strengthening technique especially during drilling Hartha and Shuaiba zones to avoid lost circulation mud due to narrow mud weight window. Because Hartha zone is located below high-pressure formation like Rus, Umm ER-Radhuma, and Tayarat; therefore, it is important to use the wellbore strengthening technique. In addition, Shuaiba formation is also located below high-pressure formation like Nahr Umr and Mishrif zones, so it is practically interesting to use the wellbore strengthening methods. The main advantage of using this approach 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, weak and depleted formations. In different

words, by using wellbore strengthening approach, the range of the mud weight window will increase.

8.2 OCCURRENCE INDICATORS TO LOST CIRCULATION

The results of an investigation conducted to diagnose occurrence indicators of lost circulation in Dammam, Hartha, and Shuaiba formations (South Oil Company, 2009).

1. A gradual decline in mud level in the drilling fluid tanks system. Sometimes, this gradual decline will aggravate to high drop which leads to losing returns from the wellbore in case complete loss.
2. The remarkable decline in the mud pumps pressure. Sometimes, this decline may be reached to zero in the complete losses situation.
3. High ROP.

8.3 IMPORTANCE OF THE LOCATION FOR OPEN END DRILL PIPE (OEDP)

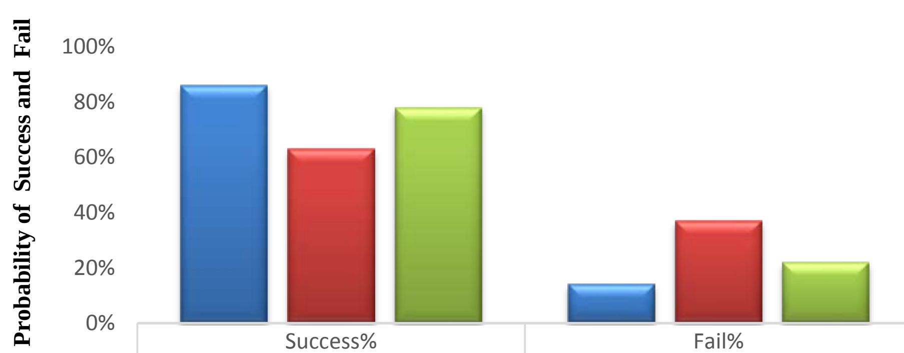
The location of the open-end drill pipe (OEDP) is one of the most important factors that assist to stop or mitigate lost circulation mud. Therefore, it is necessary to place OEDP in appropriate depth to avoid unwanted consequences. Hence, there are three locations OEDP (South Oil Company, 2010):

8.3.1 Bottom of the Loss Zone. This location usually selects to determine accurate depth for thief zone and try to seal loss zone at the same time. If the loss zone is small, and it is easy to control on it, it is prudent to be careful and use relatively low flow rate during displacement to avoid pressure increasing on the loss zone. This location of OEDP is usually used for high viscosity drilling mud and LCMs remedies.

8.3.2 Top of the Loss Zone. This location is effective and successful. It is very common, and it is used in the most remedies and plugs. This location of OEDP is often used in balanced plugs that depend on hydrostatic pressure calculations. It is much recommended to determine required height above the loss zone.

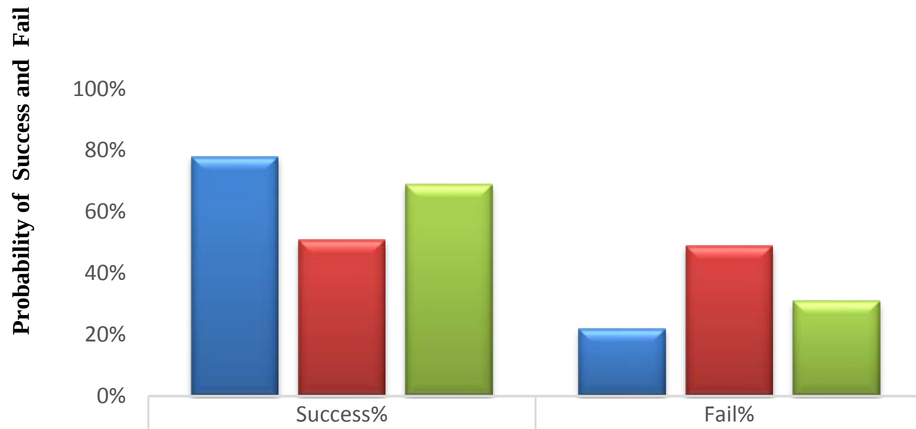
8.3.3 Middle of the Loss Zone. This location is not common, and it rarely selects to implement remedies and plugs. This location is hazardous, and it often leads to aggravating lost circulation mud in the loss zone by increasing pressure on the zone that in turn lead to break formation. This location is usually used for high viscosity drilling mud and LCMs remedies. It is not preferred to do cement plugs in this kind of location.

To examine which location is preferable in regard plugs remedies, a comprehensive statistical analysis is conducted for a tremendous number of plugs treatments, which have already been implemented in Dammam, Hartha, and Shuaiba formations in Basra's oil field. Figures 8.1, 8.2, and 8.3 will illustrate the results of the statistical analysis for Dammam, Hartha, and Shuaiba zones respectively.



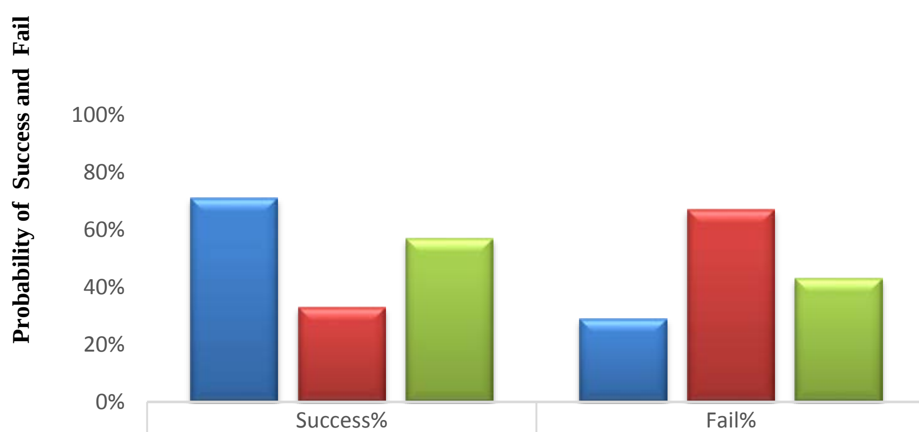
	Success%	Fail%
Top of the Loss Formation	86%	14%
Middle of the Loss Formation	63%	37%
Bottom of the Loss Formation	78%	22%

Figure 8.1: The Location of O.E.D.P, Dammam Formation in Basra's Oil Fields



	Success%	Fail%
Top of the Loss Formation	78%	22%
Middle of the Loss Formation	51%	49%
Bottom of the Loss Formation	69%	31%

Figure 8.2: The Location of O.E.D.P, Hartha Formation in Basra’s Oil Fields



	Success%	Fail%
Top of the Loss Formation	71%	29%
Middle of the Loss Formation	33%	67%
Bottom of the Loss Formation	57%	43%

Figure 8.3: The Location of O.E.D.P, Shuaiba Formation in Basra’s Oil Fields

8.4 REQUIRED CALCULATIONS OF THE CORRECTIVE REMEDIES

The success of the mud losses remedies is associated with necessary steps. Accurate calculations for the used treatment is one of the most important steps that contributes to combat or mitigate lost circulation mud effectively. In other words, it is practically interesting to do precise calculations to guarantee efficient treatment. Therefore, this section will include some important calculations, which are related to the remedies of the thief zone. The following information is required for the loss zone before an effective treatment could be implemented:

8.4.1 The Volume of the Displacement Fluid. Plainly, it is necessary to do accurate calculations for the required volume of the placement fluid because that will positively reflect on the treatment success. Placement fluid is used to displace various remedies in front of thief zone to seal it. This kind of the fluid will be used with partial, severe, and complete treatment. Normal drilling mud is usually used as placement fluid. Hence, it is prudent to detect the required volume of it. Equation 1 is used to calculate the displacement fluid.

$$Displacement\ Volume = (IDdrill\ pipe)2 \times 0.785 \times h \quad (1)$$

Where,

Displacement volume = Required volume of the drilling mud (m^3), which is needed to displace treatment in front of thief zone.

$ID_{Drill\ Pipe}$ = inside diameter of drill pipe (m).

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

8.4.2 The Volume of the Required Plug. Several plugs that use to stop or mitigate lost circulation mud. So, it is required to calculate the required volume of these plugs in front of the thief zone to get a positive result. Usually, more than the actual volume of the required plug which pumps as safety factor roughly (1-2 m^3). Equation 2 is used to calculate the required plugs or treatments.

$$Volume\ of\ Required\ Plug = (DOH)2 \times 0.785 \times h \qquad (2)$$

Where,

Plug Volume= is the required volume of the plug to cover the entire thief zone (m^3).

DOH = Diameter of open hole (m).

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

8.4.3 Estimating the Density of the Required Plug. It is necessary to do precise calculations to find the appropriate density of the required plug to avoid unwanted consequences. Some steps should take to obtain the density of the required plug.

- By detecting the static level column of the drilling mud above the loss zone.
- Subtracting the static level column of the drilling mud above the loss zone from total drilled depth to get the level of the mud.
- Using equation 3, we can get hydrostatic pressure.

$$HP= (\rho mud \times h)/10 \qquad (3)$$

Where,

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

ρmud = 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.

$$\rho plug = \frac{HP \times 10}{h} \qquad (4)$$

Where,

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

HP = Hydrostatic pressure that thief zone can resist it without unwanted consequences (Kg/cm^2).

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

8.4.4 Estimating Pressure in the Loss Zone. It is of a practical interest to determine the pressure of the loss zone. That pressure can be found from the following procedure by measuring the static fluid column above the loss zone (Baker Hughes, 1999).

- First, pull out the drill string to the top of the suspected thief zone.
- Attaching Length of wood is approximately (4 feet) to the rig's survey line.
- By running this Length of wood down the drill pipe to detect the static fluid level. (A sonic echo measuring device can also be used to locate the fluid level).
- Finally, Calculate the loss zone pressure from equation 5:

$$Ploss\ zone = \text{Dstatic fluid column} \times (MW) \times (0.052) \qquad (5)$$

Where,

P_{loss} zone = Loss zone pressure (psi).

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

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

8.4.5 Estimating Mud Weight in the Loss Zone during the Drilling Operations. During the drilling operation, it is recommended to estimate the mud weight of the drilling fluid. This estimation will mitigate lost circulation mud. the mud weight that should be used in the loss zone to reinforce formation can be calculated by using equation 6:

$$MW = \frac{Ploss\ zone}{D\times(0.052)} \qquad (6)$$

8.5 LOST CIRCULATION STRATEGY TO BASRA'S OIL FIELD

It is recognized that there is no single solution to lost circulation and that most treatment and trial-and-error. However, the screening guide presents a high-level 'go to' document with coherent guidelines, which engineers can utilize in making decisions regarding lost circulation treatments in Dammam, Hartha, and Shuaiba formations. The part also employed a thorough literature review to identify relevant information that could be included in developing the screening guide.

There is a wide range of lost circulation treatments available applied to control or eliminate lost circulation events. These systems can be divided into conventional systems, which include granular, fibrous and flaky materials that are mixed with the drilling fluids during either the drilling phase or with the cement slurries during the drilling and primary cementing phases. The other approach to controlling lost circulation is specialized cement, dilatant slurries, soft or hard reinforcing plugs, cross-linked polymers, and silicate systems that are also used during the drilling/cementing phases.This section will summarize the required treatments for each type of the lost circulation. Figure 8.4 is concluded based on data analysis for treatments that were used for Dammam, Hartha, and Shuaiba formations in Basra's oil fields. An enormous number of drilled wells in Basra's oil fields have been analyzed to find the successful remedies for each type of the losses, and these treatments are classified by relying on the mud losses classifications to get effective remedies, minimize cost, reduce non-productive time, and avoid unwanted consequences due to inappropriate actions. A lost circulation screening criteria is presented for these zones, based on the historical mud loss and lost circulation problems, materials used to mitigate the problems, and potential solutions found by this study. The flow chart in figure 8.4 should be used to treat mud losses in Basra's oil fields. The first treatment on the flow chart has the highest probability of success, the probability of success will decrease as moving down in the flow chart. Thus, use the first treatment in the table as the first action in case of mud losses, if it failed, then move to the next treatment and so on. In addition, Practical field information from a range of sources was reviewed and summarized to develop an integrated methodology and flowchart for handling lost circulation events in the Dammam, Hartha, and Shuaiba formations. Lost circulation strategy to these formations will be organized depending on the efficiency of the remedy (high probability of success) for several reasons:

- To maximize the guarantee of the treatment success.
- To avoid or reduce repetition of the treatments that use to stop lost circulation.
- To minimize NPT by using appropriate actions.
- To acquire more effectively cost. In different words, using corrective measures that are associated with high success percentage are more economic than applying remedial actions that have low success percentage.

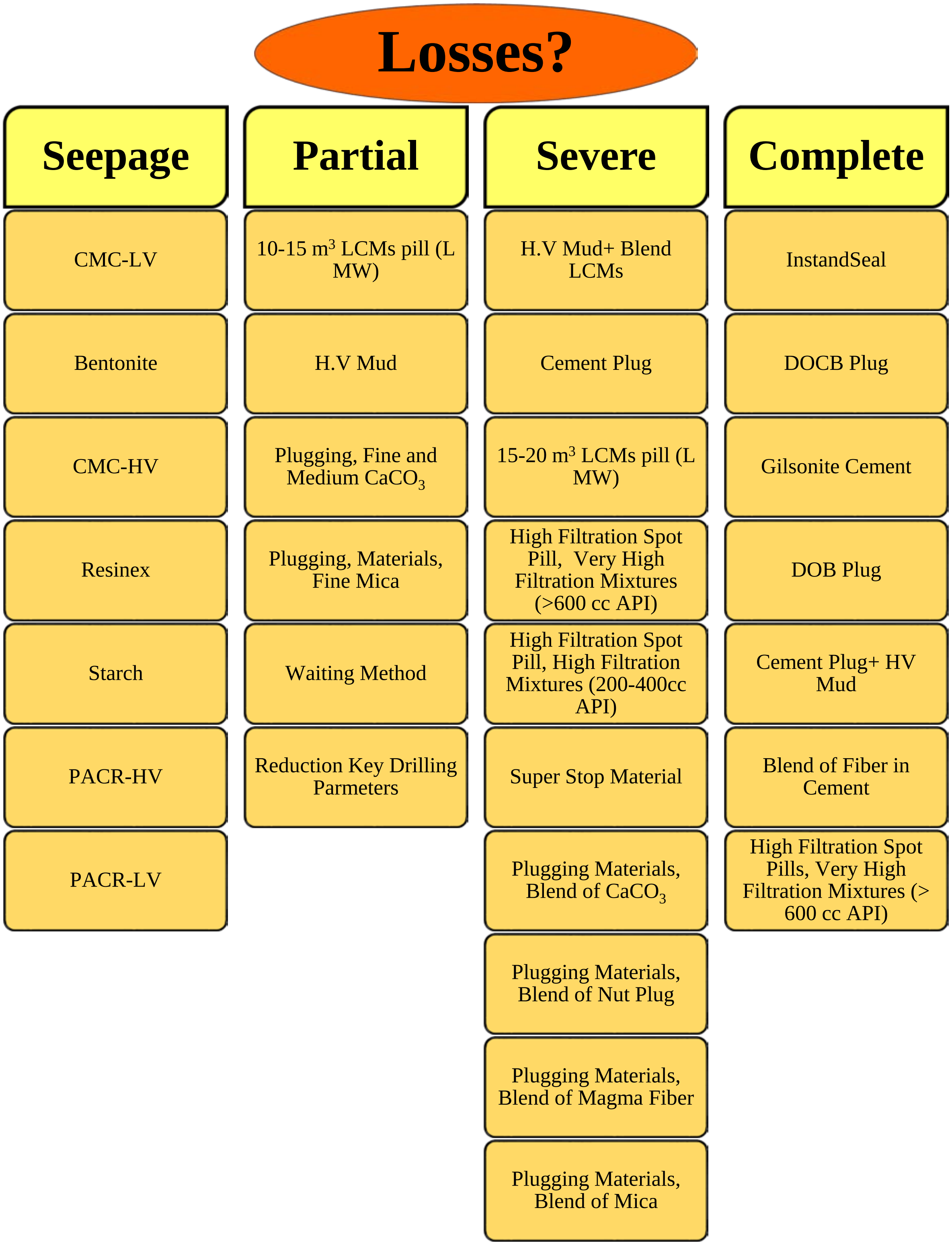


Figure 8.4: Treatment Strategy to Dammam, Hartha, Shuaiba in Basra’s Oil Field

8.6 REASONS FOR FAILURE TO CURE LOST CIRCULATION

The reasons for failure to cure lost circulation are:

1. The first step to combat lost circulation mud is the accurate identification of the loss zone. Sometimes, there is not exact information about the location of the thief zone that will lead to failing remediation. To avoid the non-productive time and money wasting by repeating ineffective treatment, it is very necessary to run one of the survey methods to know the precise location of the loss zone.
2. There is no sufficient study and integrated analysis for loss zone before treatment. In different words, remediation and techniques are not appropriate to the type and riskiness of lost circulation.
3. Failure to take the necessary measures quickly.
4. Old documents like daily reports and detailed applications are not kept on the same field. It is very crucial to save all techniques and mechanisms that have already been used for several wells as a reference for next methods.
5. Contamination the pill or plug with drilling mud which leads to reduce or prevent proper settings for treatment. So, some techniques and methods are affected negatively due to this contamination. Hence, it is necessary to apply balanced column methods to avoid this dilemma.
6. Bad application of the squeeze pressure method. In other words, by using high squeeze pressure for the treatment that will lead to create fractures and aggravate the problem. Hence, drilling mud pressure plus surface pressure should be lesser than fracture gradient pressure.

7. Gunk ratios to drilling mud are not appropriate. It is very important to apply the ratio of mud-to-gunk accurately to have sufficient viscosity and good strength for the plug to stop losses.
8. The lack of a crucial decision or hesitation to take appropriate remedies. Sometimes, application of the unsuccessful remedies leads to aggravating mud losses problem.
9. No information regarding the geometry of the fractures, vugs, and caves.
10. Calculations will not be accurate regarding the fluid displacement, the volume of the plug, pressure of the loss zone, and the required density of the treatment. Therefore, that will strongly reflect negatively on the effectiveness of the remedies.
11. No appropriate selection to type of the treatment. Selected remedies should be used by depending on the type of the loss mud to reduce expense and non-productive time.
12. The absence of the engineering approaches in the executive solutions.
13. Insufficient thickening time for plugs to harden.

8.7 PRACTICAL GUIDELINES TO STOP OR MITIGATE LOST CIRCULATION

It is important to do prior preparation for any contingency plans like sufficient materials of the drilling mud especially bentonite material, enough amounts LCMs, and adequate water source to control the drilling operations.

- It is much recommended to do the following actions before doing the required remedies:

  1. Determine the top and the bottom of the loss zone.

  2. Detect the type of the lithology.

  3. Diagnose the type of the losses.

  4. Estimate the pressure in the loss zone.

  5. Do precise calculations for the required treatments.

- It is practically interesting to drill the thief zone as much as possible by using blind drilling method and then do the required remedy.

- A quick economic evaluation is desirable before doing any action.

- It is necessary to reduce human error as much as possible by preparing optimal drilling program, monitoring to apply for this program during drilling operations, and avoiding mechanical issues. The following drilling practices have already been identified, which have a prominent role on the problem of the lost circulation mud:

  1. High pump pressure (high SPM) will lead to the generation of excessive equivalent circulation density (ECD). Therefore, it is preferable to use the lowest circulation rate that will clean the hole adequately.

  2. High rotation (high RPM) and high circulation rates directly after shutdown, it will cause more pressure on the loss zone. Hence, if drilling operations are under shutdown situation, it is the best to rotate drilling strings with low RPM about 15 minutes without mud circulation when drilling operations resume to break gel strength.

3. Running drill string into wellbore quickly will affect negatively on the weak formations. Therefore, it is desirable to lowering drill strings into wellbore slowly in front of unconsolidated zones.
4. Do strict surveillance to downhole annular pressure and make sure that the equivalent circulation density (ECD) within allowable limits.

- Formations which are prone to the mud losses, it is preferable to add sized LCM in the drilling mud before drilling these formation, because that will improve the strength of the weak formation, widen the fracture gradient, and prevent or mitigate induced fractures from propagating beyond their initiation stages.
- By depending on broad research, graphitic carbon and sized calcium carbonate are effective LCMs, and it is advisable to add to the drilling mud before drilling depleted and weak zone as wellbore strengthening approach.
- It is important to avoid high concentration of the coarse LCMs to avoid excessive equivalent circulation mud (ECD).
- Lost circulation materials (LCMs) have many various forms, and each of them has specific properties and cost. The performance of the lost circulation materials (LCMs) is basically relied on its particle size distribution (PSD), shape, size, and concentration.
- It is practically interesting to reduce yield point (Yp) and the solids content of the drilling mud within allowable limits to reduce gel strength and equivalent circulation density (ECD) befoe addition lost circulation materials (LCMs) to drilling mud.

- Economic aspect has a pivotal role whether to use wellbore strengthening approaches as proactive remedies or deal with the problem when/if the problem occurs.
- During handling losses, it is much recommended to get ready for well control issues.
- Proper selection for the type of the remedies to avoid the non-productive time and reduce expenses.
- It is very advisable to get integrated image about the geometry of the formations that are prone to mud losses by using image log or caliper log to do proper actions.
- It is essential to provide sufficient time to harden plugs into wellbore especially cement and barite plugs to enhance compressive strength for treatment and get good results.

9. CONCLUSION

Lost circulation presents many challenges while drilling. To address these problems, a number of methods/techniques have evolved over the years. The objectives of this study are: 1) to review lost circulation control methods that have been applied in Basra's oil fields till date 2) to provide the successes and the failures of these methods in field applications by conducting comprehensive statistical analysis and 3) to develop practical guidelines that will serve as a reference material for lost circulation control at the well-site for drilling personnel.

To achieve these study objectives, an enormous number of drilled wells in Basra's oil fields that address the problem of lost circulation were carefully reviewed and analyzed. The results of this study are practical guidelines that are not biased towards a particular service industry product but are general to the healing or mitigation of the problem of lost circulation while drilling. A flow chart has also been developed that will serve as a quick reference guide for drilling personnel at the well-site.

Based on this study, the following conclusions were made:

- One challenge in drilling wells in Basra's oil fields is the inconsistency of approaches to the lost circulation problem. Hence, a formalized methodology for responding to losses in Dammam, Hartha, and Shuaiba formations is developed and provided as means of assisting drilling personnel to work through the lost circulation problem in a systematic way.

- The OEDP should be placed in the top of the formation that is experiencing mud loss to have the highest probability of success and to avoid the unwanted consequences.
- The highest probability of success treatment should be used to treat the mud losses even if it is not the cheapest to avoid the repetition of treatments which reduces the NPT. Using a low-probability of success treatment may not be effective and the usage of multiple treatments may be required, even if it is cheaper than other treatment but the NPT will be higher which increases the cost.
- NPT is the most influence factor in the cost of mud treatments. Thus, any treatment that has a low probability of success should not be used as a first choice to treat mud losses.
- Successful control or treatment of lost circulation depends on several factors such as borehole temperature, pressure, depth, lithology, and size of the thief zone.
- There are no guaranteed methods for solving lost circulation problems entirely but many approaches can be used to prevent its occurrence, especially those that occur via induced fractures when drilling formations that are prone to losses.
- Practical guidelines have been developed that when used with the accompanying flow chart will serve as a quick reference guide to prevent and minimize the problem of lost circulation while drilling.

NOMENCLATURE

D	Depth
DDR	Daily Drilling Report
DOH	Diameter of Open Hole
ECD	Equivalent Circulation Density
FP	Fracture Pressure
Ft/min	foot per minute
FWB	Fresh Water Bentonite
gm/cc	gram per cubed centimeter
HP	Hydrostatic Pressure
H. V	High Viscosity
Ib/bbl	pounds per barrel
Ib/ft^3	pounds per cubed feet
in	Inch
Kg/m^3	Kilogram per cubed meter
LCMs	Lost Circulation Materials
L/min	Litter per minute
m	meter
m^3/hr	cubed meter per hour
MW	Mud Weight
NPT	Non-productive Time
O.E.D.P	Open End Drill Pressure
ppg	pounds per gallon

PP	Pore Pressure
Q	Flow Rate
ROP	Rate of Penetration
RPM	Revolutions per Minute
SPM	Stroke per Minute
TFA	Total Flow Area
WOB	Weight of Bit
WOC	Waiting of Cement
WON	Without Nozzles
Yp	Yield Point Viscosity
$	Dollar

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APPENDIX A
THE PROCEDURES OF PARTIAL LOSS TREATMENTS

METHODS OF AVOIDING LOST CIRCULATION

Controlled field methods may be used to inhibit or recover from lost circulation. These methods are fundamental techniques and simplistic mechanisms to avoid or combat mud losses (South Oil Company, 2007). These approaches include:

- **Waiting Method:**

1- Pull out drilling strings to casing shoe.

2- Waiting period between (4-8) hours.

3- Drilling strings will gradually run in hole.

4- Circulation drilling mud and rotation drilling string slowly.

5- Check mud levels in mud tanks system to make sure there is no mud losses.

6- Starting drilling operation at moderate speeds to seal formation apertures by engraved cutting.

- **Reduction of the Pump Pressure:** This technique usually uses when mud losses are partial losses. By reduction the pump pressure this will decrease extra pressure due to mud circulation.

- **Reduction of the Drilling Mud Density:** By decreasing mud weight within allowable limits to reduce hydrostatic pressure on the weak formations. Drilling fluid density is usually minimized by adding water or diesel oil.

- **Increasing of the Drilling Fluid Viscosity:** This mechanism often uses during drilling shallow, unconsolidated, and high permeability formation like (loose sand and gravel). It better to magnify viscosity (yield point and gel strength) to prevent mud losses by sealing high permeability. Drilling fluid viscosity is usually maximized by adding bentonite, lime, salt clay, or gypsum.

- **By Using Bit Without Nozzles:** The benefit from this issue to just reduce jet velocity due to nozzles.
- If drilling operations are under shutdown situation, it is the best to rotate drilling strings about 15 minutes without mud circulation when drilling operations resume to break gel strength.
- Stabilizers should not be used during drilling depleted or weak formations.
- Lowering drill strings into wellbore slowly in front of unconsolidated zones.

Some of these methods are shown in Figure A.1 along with the formations where they are best applied.

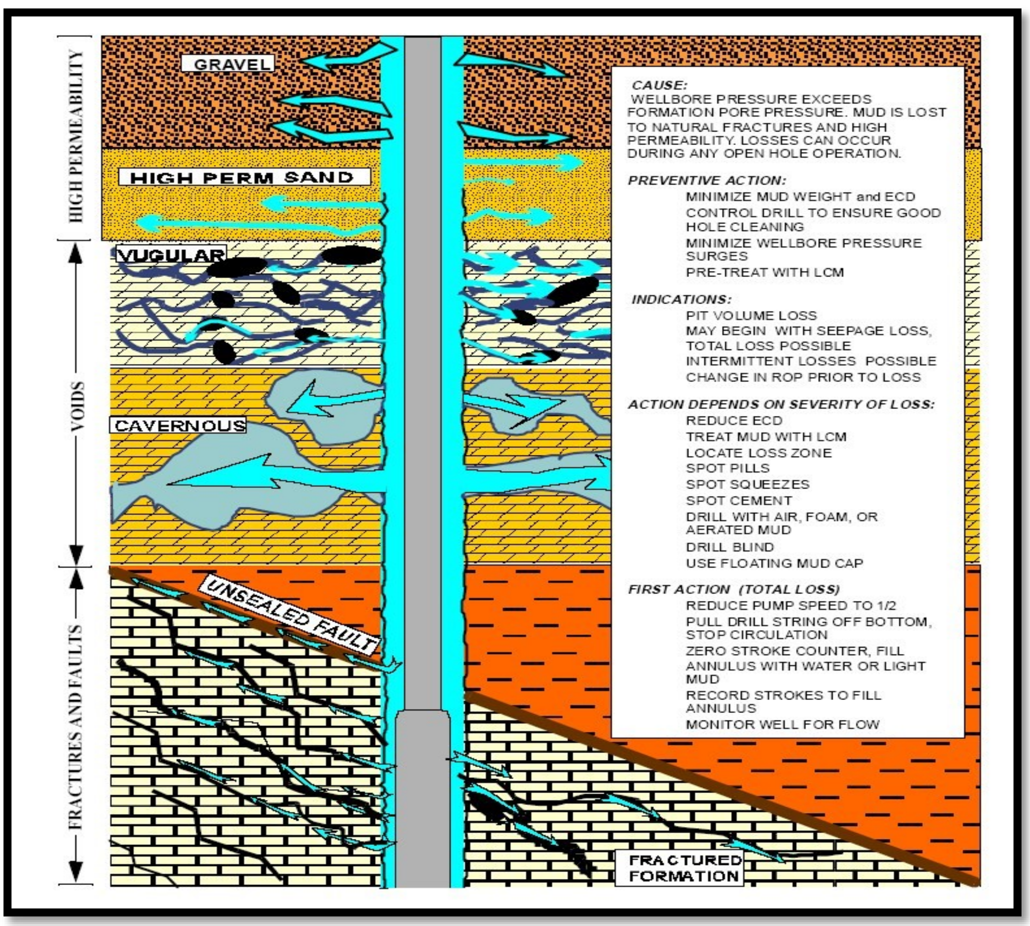

Figure A.1: Lost Circulation Mud Cases and Appropriate Treatment (Baker Hughes, 1999)

HIGH VISCOSITY MUDS

This treatment is high viscosity drilling mud (Patch) with low mud weight. Usually, Bentonite, lime, or salt clay are used to increase viscosity. This pill is pumped in front of the thief zone in calculated and sufficient quantities to plug losses zone, especially in partial losses. It is recommended after displacing this patch to interesting zone to wait around (±2-4 hours). Sometimes, the above remediation is used before lost circulation material or cement plug to guarantee zone plugging (South Oil Company, 2008).

PLUGGING MATERIAL WHILE CIRCULATION (LCM)

High filtration and high viscosity drilling mud (Low Mud Weight) is mixed with lost circulation material. LCMs should be added in accurate proportions and calculated quantities to get effective treatment. (2-4%) from mica and (2-3%) from granular are added to high filtration and high viscosity drilling mud (Low Mud Weight). This remediation is pumped in front of the thief zone, and it should wait around (±3-4 hours) after displacing this patch to interesting zone. There are specific lost circulation materials which use as plugging material while Circulation. LCMs that can be used are (Eni Company, 2010). Table A.1will show conventional lost circulation materials (LCM).

- **MICA:** is a silica-base lamellar material. It is used to prepare pills with oil-based, synthetic-based, and water-based muds. This material is common and effective because it has some positive points like:

- It is readily available and can easily be added to LCM pills, or in circulation as a preventer.
- Granulometry varies from fine- coarse, with particle sizes from 2-3 mm for fine up to 4-6 mm for coarse.

- Mainly used to control seepage and partial losses especially in highly permeable sandstone.

- **Nut plug:** Is a granular material with a vegetable base (nutshells). It is used to prepare pills with oil-based, synthetic-based, and water-based muds.
  - It is readily available and can easily be added to LCM pills.
  - Classified into three categories: Fine – Medium – Coarse with a particle size from 0.15 to 0.5 mm for the fine type; from 0.5 to 1.6 mm for medium; from 1.5 to 6 mm for coarse.
  - Used to control partial or total losses in fracture formation and/or in micro fractures. This material can also be used in combination with other plugging materials.

- **$CaCO_3$:** Is one of the most valid and adaptable lost circulation materials. It is a granular occurring, ground rock. It is used to prepare pills with oil-base, synthetic-based, and water-based muds.
  - It is readily available and can easily be added to LCM spot pills in high concentrations. It can be added in circulation as prevention.
  - Granulometry is divided in Fine – Medium – Coarse categories, with particle sizes of 0.05 mm for the fine type, 0.1 mm for the medium, 3 mm for coarse and super coarse > 3 mm.
  - The fine and medium types are used to control seepage and partial losses. The medium, coarse and super coarse types are used for partial and total losses in fracture formation and/or in micro fractures (Carbonates). This material can also be used in combination with other plugging materials.

- **Magma fiber:** Is a material acidizable with hydrogen chloride and could be in reservoirs. It is fibrous and very adaptable. It can be used as an additive for oil-based, synthetic-based and water-based muds.
  - It is non-damaging inert material that forms a good filter cake panel.
  - In concentration of 30 Ib/bbl, it is used to control total losses; it also can be used to spot pills or as mud additive for prevention. In concentration between 5 and 15 Ib/bbl it is used for seepage and partial losses.
  - It is used to plug highly permeable unconsolidated formation and all kinds of fractures.

Table A.1: Conventional Lost Circulation Materials (LCM) (White, 1956) and (Baker Hughes, 1999)

Type	Material
Fibrous	Ground paper, Wood fiber, Cane, Rice hulls, Peanut hulls, Leather, Tree bark, Flax, Hemp, Animal hair, Cotton linters, Nylon, Cellulose fibers, Raw cotton, Bagasse, Flax shive, Bark fiber, Textile fiber, Mineral fiber, Glass fiber, Peat moss, feathers, Beet pulp.
Granular	Ground walnut shells, Pecan shells, Almond shells, Plastic, Calcium carbonate, Perlite, Coarse bentonite, Ground plastic, Nut shells, Nut hulls, Ground tires, Asphalt, Wood, Coke.
Flake	Ground mica, Plastic laminate, Cellophane, Polyethylene plastic chips, Cork, Mica, Corn cobs, Cottonseed, hulls, Vermiculite.
Mixtures	Film, fiber and sawdust; Textile fiber and sawdust; Cellulose fiber and sawdust; Perlite and coarse bentonite.

APPENDIX B
THE PROCEDURES OF SEVERE LOSS TREATMENTS

LOST CIRCULATION MATERIALS BLEND (LCM BLEND)

This remediation is often used for induced fractures in severe or complete losses especially if there is not exact information regarding the width of fracture. That is why this blend is used in various size distribution. A mixture of LCMs (fibrous, granular, and flakes) is used to form this treatment. Lost circulation materials should be used in various volumes (coarse, medium, and fine) to get on effective remedies. Two ways are common to mix LCMs with high viscosity mud. The first one, by mixing a blend of commercially available LCMs including the following: by adding 5 kg/m^3 of coarse volume and 5 kg/m^3 of medium and fine volume to total mud cycle. The second one, by mixing specific pill individually, by adding 15 kg/m^3 of coarse volume and 15 kg/m^3 of medium and fine volume to the patch of high-viscosity mud. This blend should be pumped in front of the losses zone, and it should wait around (± 4-6 hours) before resuming drilling processes. It is better to use squeeze pressure technique with this kind of remedies. (South Oil Company, 2010).

HIGH VISCOSITY DRILLING MUD (LOW DENSITY) + BLEND OF THE LCMS:

First, pill of the high-viscosity mud will be pumped in front of the thief zone. A blend of LCMs mixed with low-density mud will be directly pumped after high viscosity patch to create an effective plug. It is very important to use low mud weight with a blend of LCMs to avoid excessive equivalent circulation density (ECD). This blend should be pumped in front of the losses zone, and it should wait around (± 4-6 hours) before resuming drilling processes (South Oil Company, 2009).

SUPER STOP MATERIAL

- Mixing (4-5) bags (Weight of Bag 25 kg) of super stop material for each 1 m^3 water.
- This treatment should be mixed in the separate and clean tank.
- It is very crucial to mix quickly to avoid treatment bulge in the surface tank.
- Displacing the remediation in front of the loss zone.
- Pulling out drill pipe strings above loss zone, and making mud circulation about (10 minutes) to enforce treatment to enter formation.
- Waiting around (±4-5 hours).

CEMENT PLUG

This plug is very prominent and very prevalent in oil industry field. This treatment is used to combat complete losses, and it is rarely used in partial or severe losses. In this kind of remedy, it is very necessary to do very accurate calculations regarding the weight of cement to avoid unwanted consequences, especially in the weak formation due to high cement slurry density. Also, it is much recommended for this plug to have high viscosity and high gel strength to seal losses zone. The time of the cement stiffness should be started after (45 min) from pumping cement to avoid cement hardness problems and to maintain cement properties at the same time. It is essential to do precise calculations regarding the required cement quantity preclude negative ramifications. As well as. It is very important to prevent contamination between cement plug and drilling fluid to keep on cement plug characteristics (South Oil Company, 2010).

Implementation Method of the Cement Plug:

- Knowing the level of drilling mud in the hole to do accurate calculations regarding the weight of cement plug and the required cement magnitude.

- Lowering open end drill pipe (O.E.D.P) to the right place.
- Pumping high-viscosity mud or drilling mud with LCMs, and displace this in front of the interesting zone. It is better to wait around (±1-2 hours).
- Pumping the required cement volume into open end drill pipe (O.E.D.P).
- Displacing the plug-in front of losses zone. The volume of displacement is equivalent to the capacity of the open end drill pipe (O.E.D.P) subtracted the amount of cement which is left inside open end drill pipe (O.E.D.P) to lower freely.
- Pulling out some of the drill pipes strings which are equal to or more the head of the cement that is already remaining inside open end drill pipe (O.E.D.P).
- Pumping normal drilling fluid to clean open end drill pipe (O.E.D.P).
- Pulling out drill pipes strings to casing shoe.
- Waiting period around (18 hours) to harden cement plug.

HIGH FILTRATION MIXTURES (200-400 CC API)

Procedure formula for 1 m3 (final) of high filtration mixtures

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 %

This treatment will be pumped in front of loss zone, and it is preferred to do squeezing during displacement under pressure (50-150 Psi). Waiting period should be around (± 4-6 hours) (Eni Company, 2010).

VERY HIGH FILTRATION MIXTURES (> 600CC API)

Procedure formula for 1 m^3 (final) of very high filtration mixtures

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

This treatment will be pumped in front of loss zone, and it is preferred to do squeezing during displacement under pressure (50-150 Psi). Waiting period should be around (± 4-6 hours) (Eni Company, 2010).

APPENDIX C
THE PROCEDURES OF COMPLETE LOSS TREATMENTS

DOB SQUEEZE (DIESEL OIL BENTONITE)

This remediation is very important and common. But at the same time, it is not easy to apply in the field. Some conditions are required for this treatment. Water should be removed from mixing tank and pumping pipes lines. Also, it is much recommended to content loss zone on the water to be an effective treatment. Otherwise, this method is difficult to be successful (South Oil Company, 2010).

Procedure

Formula for 1 m^3 (Final)

Oil base	0.70 m^3
Bentonite	800 kg

Steps of using:

- Cleaning all mixing tanks and pumping pipes lines which will be used to mix this remedy.
- Two pumps should be available. First on, to displace to open end drill pipe (O.E.D.P). The second one, to displace into annulus by using kill line.
- Pumping clean water in front of the loss zone to guarantee bentonite hydration. Water should be pumped before diesel oil bentonite plug.
- Prior preparation to a valve which is placed near to cement head to save on plug inside open end drill pipe (O.E.D.P) during waiting for remaining quantities. It is very difficult to mix this treatment at once due to its high viscosity, so this plug is mixed to two or three patches to obtain good results. Each patch is 3 m^3, and it is pumped into open end drill pipe (O.E.D.P). After that, the valve is closed, and it

should be prepared to second quantity in the same way until pumping all required magnitudes.

- It is prudent to pump around 1 m^3 after pumping all diesel oil bentonite plug.
- Switching the pumping pipes lines directly to displacement line to displace this treatment. Displacement process will be in three stage.
- The first stage is by starting in displacement by using cement head inside open end drill pipe (O.E.D.P) with one pump and normal flow rates (1 m^3/min) until this plug reached in front of thief zone.
- The second stage, Pipe ram is closed. The second pump is operated which is already tied with kill line into the annulus. Pumping operation will be inside open end drill pipe (O.E.D.P) and into annulus by using two pumps with 600 L/min regarding open end drill pipe (O.E.D.P) and 300 L/min regarding annulus. This stage is done after displacing half of diesel oil bentonite plug into loss zone.
- The third stage is displacing the remaining half of diesel oil bentonite plug into loss zone into loss zone, in the same way for the second stage, but in different placement rates. In other words, 300 L/min regarding open end drill pipe (O.E.D.P) and 150 L/min regarding annulus.
- Open pipe ram.
- Pulling out some of the drill pipes strings to allow for treatment to lower into the hole.
- Cleaning open end drill pipe (O.E.D.P) from remaining diesel oil bentonite plug.
- Pulling out drill pipes strings to casing shoe.
- Waiting period around (±8-10 hours).

- Sometimes, after pumping diesel oil bentonite plug. Directly, a cement plug is pumped.

DOBC SQUEEZE (DIESEL OIL BENTONITE CEMENT)

The implementation principle of this treatment is exactly the same technique for diesel oil bentonite plug. It is also very important and common. But at the same time, it is not easy to apply in the field. Some conditions are required for this treatment. Water should be removed from mixing tank and pumping pipes lines. Also, it is much recommended to content loss zone on the water to be an effective treatment. Otherwise, this method is difficult to be successful (South Oil Company, 2010).

Procedure

Formula for 1 m^3 (Final)

Oil base	0.72 m^3
Bentonite	450 kg
Cement	450 kg

GILSONITE CEMENT

The principle of work for Gilsonite cement is exactly the same in the Gel-Cement plug. There is just on difference by using Gilsonite material instead of bentonite material. Gilsonite material is more effective than bentonite material, and this plug is often used in cavernous formations (Eni Company, 2010).

Procedure

Slurry Composition

(Class G Cement)

Gilsonite %	water weight%	Y. Slurry L/100 kg	Density gm/cc
0	44	75.7	1.90
50	61	139.5	1.51
100	78	203.2	1.37

It has exactly the same execution procedure for cement plug. The waiting period is 8 hours.

FIBERS IN CEMENT

This plug is prepared by mixing lost circulation material (fiber) with cement in specific and homogenous proportions to restore and combat lost circulation mud. These plugs have already been implemented by Schlumberger Company in Indonesia (Duri Field), and it was very successful. The principle of work for this plug is by forming synaptic situation for cement with fiber in front of thief loss. In different words, it is very difficult to enter cement into the formation, and it guarantees to stay cement in front of loss zone. This plug works under any temperature, and the required lost circulation material which needs to mix with cement is 30 Ib/bbl, figure C.1 will show synaptic situation for cement with fiber in front of thief loss (Schlumberger, 1999).

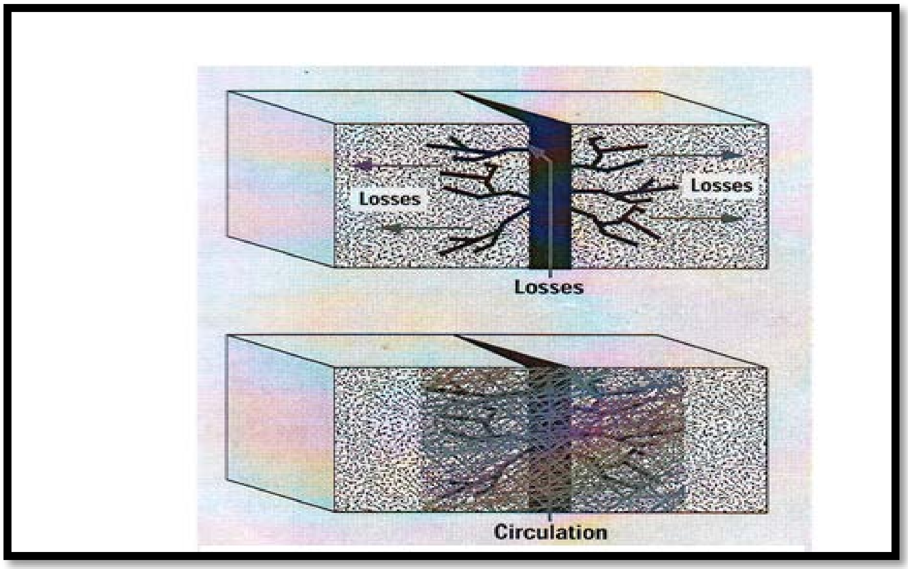

Figure C.1: Shows Synaptic Situation for Cement with Fiber in front of Thief Loss (Schlumberger, 1999)

INSTANDSEAL

This treatment is one of the most important and more successful treatments that used to combat lost circulation material. It is emulsion that has a big ability to form high viscosity and high gel strength after arriving in front of the formation. This emulsion has already proved its success in high temperature. The most important feature in this emulsion is controlling the hardness time. In other words, it is possible to have a time of the hardness from few minutes to many hours. We can regulate on the hardness time for this treatment by increasing or decreasing the concentration of this emulsion and by controlling on pumping rate. It is possible to pump this emulsion by drill strings (bit and other accessories), and this will contribute to reduce non-productive time (NPT) and minimizing the cost of drilling. After pumping this emulsion to the wellbore, the hardness and gel strength will stay for many weeks under well conditions. It is much recommended to make prior preparation for this treatment before expected occurrence for mud losses (Eni Company, 2010).

Advantages for this treatment:

- Low solid content.
- It is possible to pump this material by drill strings.
- Controlling on the hardness time from few minutes to many hours.
- It is possible to prepare this treatment before weeks.
- It is compatible with all types of the drilling mud.
- There is no need to use lost circulation materials.
- It is easy to break high gel strength by using weak acid.
- It contributes to reduce non-productive time (NPT) and minimizing cost of drilling.
- Very high efficiency to cure lost circulation mud.

Application of this treatment:

- It is used to stop severe and complete losses.
- It is possible to work in high temperature 190 F° (89 Cº).
- The Higher density that is allowable to use with this emulsion is 1.44 gm/cc.

This emulsion has two phases:

1. Aqueous phase: It has a high concentration of polymer.
2. Oil phase: It has particles with a hyperlink.

When this emulsion goes out from the bit and it lowers in front of loss zone, its particles interrelate with an aqueous phase that in turn lead to form high gel strength in high speed. The hardness time can be regulated in the surface, but after this emulsion enter formation, we cannot control the hardness time. Figure C.2 will illustrate this treatment.

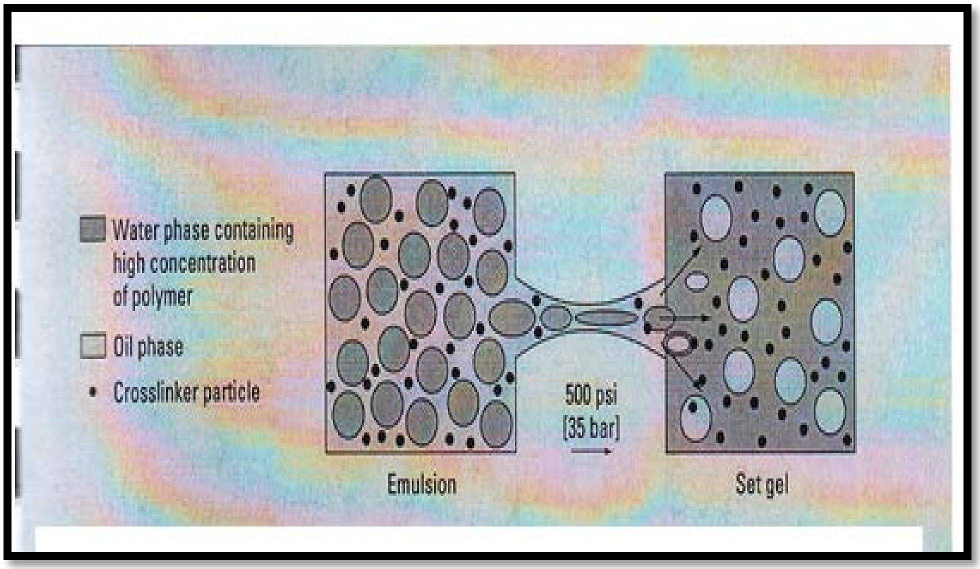

Figure C.2: Composition of the Emulsion and How It Harden (Eni Company, 2010)

This emulsion has already been used in the Middle East in Shuaiba formation. This zone is very critical. Shuaiba formation in one of the fields in the Middle East had mud losses around 400 bbl/hr, after pumping 75 bbl of emulsion (InstanSeal) in front of loss zone, the losses were reduced and drilling operation is resumed. Figure C.3 will clarify the hardness time of the remedy.

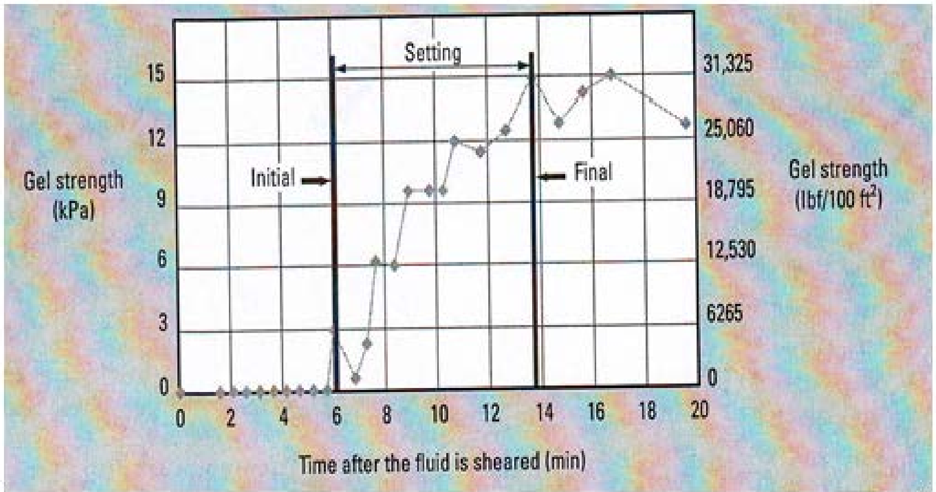

Figure C.3: Shows Synaptic Situation for Cement with Fiber in front of Thief Loss (Schlumberger, 1999)

III. CASES HISTORIES IN BASRA’S OIL FIELDS, IRAQ: EVOLVING ADVANCED TECHNIQUES AND STRATEGIES TO STOP OR MITIGATE LOST CIRCULATION

ABSTRACT

As the demand for petroleum resources increases, drilling of oil and gas wells are often carried out in challenging and hostile environments in Basra’s oil fields. Among the top drilling challenges facing drilling operations today is the problem of lost circulation. Major progress has been made to understand this issue and how to combat it. However, most of the products and guidelines available for stopping or mitigating lost circulation are often biased towards advertisement for a particular service company. Wells drilled in Basra’s oil fields are highly susceptible to lost circulation problems when drilling through the Dammam, Hartha, and Shuaiba formations. Lost circulation events range from seepage losses to complete loss of the borehole and are a critical issue in fields development.

In some situations, it is very difficult to regulate on mud losses by using conventional lost circulation materials (LCMs). As well as, the cost of these materials is expensive, so it is important to find techniques and mechanism to live with losses. In different words, the driller must “live with the losses”. This paper will demonstrate methods that have been used to ameliorate lost circulation without the use of lost circulation materials. However, it is much recommended to be very cautious when these techniques are applied because utilizing these methods involve risk to the drilling operation. Hence, it must be carefully and thoroughly planned to ensure the safest possible outcome. The drilling techniques/procedures that will describe in the subsequent paragraphs may be used to prevent or remedy lost circulation problems.

There is specific advanced technology that uses for this purpose like liner hunger and casing-while-drilling (CWD), floating mud cap drilling, aerated mud, foam, air or mist, and these methods can serve as long-term methods that will reduce the costly effects of lost circulation while drilling. There is a positive advantage for expandable tubulars which contribute to use a number of mud weights for different sections without losing hole size due to the telescoping effect of the casing. This paper illustrates some cases history, which has already been used in Basra’s oil fields to provide alternative techniques to stop or mitigate lost circulation. In addition, the most recent approaches will be presented to provide a coherent benefit and a clear image in regard various remedies.

1. INTRODUCTION

Lost circulation is a broad subject and several studies and measures have been introduced in the oil industry to combat it. Lost circulation is a common drilling problem especially in highly permeable formations, depleted reservoirs, and fractured or cavernous 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 (Moore, 1986).

Lost circulation can be defined as the reduced or total absence of fluid flow up the formation-casing or casing-tubing annulus when fluid is pumped down the drill pipe or casing. The industry spends millions of dollars every year to combat lost circulation and its associated detrimental effects such as loss of rig time, stuck pipe, blow-outs, and less frequently, the abandonment of expensive wells. Two conditions are both necessary for lost circulation to occur downhole: 1) the pressure in the wellbore must exceed the pore pressure and 2) here must be a flow pathway for the losses to occur (Osisanya, 2011). Subsurface pathways that cause, or lead to, lost circulation can be broadly classified as follows:

- Induced or created fractures (fast tripping or underground blow-outs).
- Cavernous formations (crevices and channels).
- Unconsolidated or highly permeable formations.
- Natural fractures present in the rock formations (including non-sealing faults).

Circulation may be lost even when fluid densities are within the customary safety-margin; less dense than the fracture density of the formation. Stopping circulation losses before they get out of control is crucial for safe and economically rewarding operations (Abbas et al. 2004). There is a wide range of lost circulation treatments available applied to control or eliminate lost circulation events. These systems can be divided into conventional systems, which include granular, fibrous and flaky materials that are mixed with the drilling fluids during either the drilling phase or with the cement slurries during the drilling and primary cementing phases. The other approach to control lost circulation is using drilling techniques/procedures, which is the central focus of this work. In addition, this paper will be an extended study of the comprehensive review of conventional lost circulation treatment with an integrated analysis and practical guidelines in Basra's oil fields, Iraq (Al-Hameedi et al., 2017).

2. USING DRILLING TECHNIQUES/PROCEDURES (LIVING WITH LOSSES)

In some situations, it is very difficult to regulate on mud losses by using conventional lost circulation materials (LCMs). As well as, the cost of these materials is expensive. Thus, it is important to find techniques and mechanism to live with losses. In different words, the driller must “live with the losses”. In this section, Methods that are used to treat mud losses without utilizing LCMs will be presented. However, it is much recommended to be very cautious when these techniques are applied because utilizing these methods involve risk to the drilling operation. Hence, it must be carefully and thoroughly planned to ensure the safest possible outcome. The drilling techniques/procedures that will describe in the subsequent paragraphs may be used to prevent or remedy lost circulation problems (South Oil Company, 2011) and (Baker Hughes, 1999).

2.1 BLIND DRILLING

This method means that drilling operation is continuous but without any returns. In other words, continuing the drilling operation even if there is no mud returned to the surface. This situation is very hazardous because the drilling crew will not know anything about lithology of the formation. In addition, cutting will be accumulated around the bit, which in turn, that lead to occur stuck pipe problem. In this method, water will be used instead of drilling mud, so it is important to prepare sufficient quantities of clean water before use this technique, and it is necessary to prepare enough amounts of high-viscosity mud and normal drilling fluid. The formation will be drilled by using water, and high-viscosity mud must be pumped after drilling one drill pipe to lift cutting above the bit. The cutting will enter to the thief zone. Sometimes, one drill pipe is drilled by using just water, and another drill pipe will be drilled by using drilling mud. But in this case, the cost will be high due to drilling mud losses. Blind drilling will continue with pumping high viscosity after drilling each one drill pipe. In this method, it is prudent to monitor surface parameters for the bit, and after completing formation drilling, it is necessary to circulate drilling mud into the hole to clean the well from cutting (South Oil Company, 2011).

The reasons for using the blind drilling technique:

- If loss zone is the last zone of the hole, and there is no ability to plug it. In this case, blind drilling is used to drill all formation and running casing after that.
- To reach competent formations, the blind drilling approach is recommended to use to exactly determine the depth of the thief zone. Hence, after implementing cement plug after blind drilling, the competent zone will fill with hard cement, so that will give an indication on the bottom of the loss zone.
- Sometimes, thief zone is the first in the hole, so there is usually no complications and implications if blind drilling technique is used.

Not always, blind drilling can be used in the Dammam formation, it is recommended to use this technique because it is a shallow depth and the first formation of the intermediate hole. Therefore, the risk of experiencing a kick or blowout is minimal. Figure 2.1 illustrates the probability of the success and failure for the Dammam formation in regard blind drilling method.

Figure 2.1: Blind Drilling, Dammam Formation in Basra's Oil Fields

Blind drilling method cannot be readily applied in the Hartha formation. Two zones, Umm ER Radhuma and Tayarat, located above the Hartha, contain H_2S. If mud density is reduced to control loss into the Hartha, then a kick may occur in these shallower zones. Table 2.1 summarizes the close tolerances of mud density for these formations, and figure 2.2 illustrates the probability of the success and failure for the Hartha in regard blind drilling method.

Table 2.1: Various Drilling Densities

Formation	Required Density, gm/cc
UMMER-RADHUMA	1.14 to 1.15
TAYARAT	1.14 to 1.15
HARTHA	1.12 to 1.13

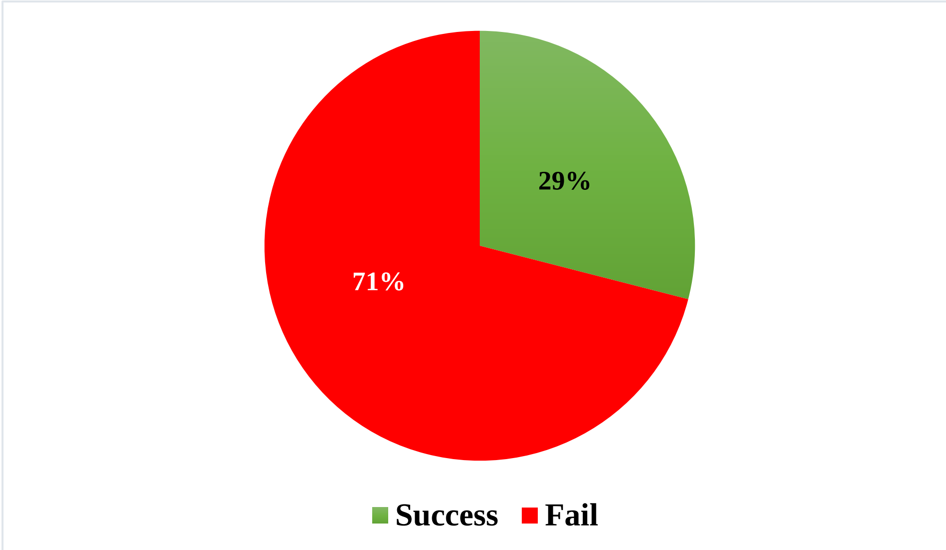

Figure 2.2: Blind Drilling, Hartha Formation in Basra's Oil Fields

It is crucial to consider that the Shuaiba formation is located below transitional zones like Mishrif, Mauddud, and Nahr Umr zones. These formations have abnormal pressures, so it is very prudent to consider this case to avoid collapse issues in formations like the Mishrif, Mauddud, and Nahr Umr. Hence, there is a big hazard when blind drilling used in the Shuaiba formation because there are abnormal formations which are located above this formation. Table 2.2 illustrates various required drilling densities for these formations. These zones will also be susceptible to a kick, should mud levels in the borehole fall due to lost circulation in the Shuaiba formation. In addition, figure 2.3 illustrates the probability of the success and failure for Shuaiba zone in regard blind drilling method.

Table 2.2: Different Drilling Densities

Formation	Required Density, gm/cc
Mishrif	1.17 to 1.18
Nahr Umr	1.17 to 1.18
Shuaiba	1.15 to 1.16

Figure 2.3: Blind Drilling, Shuaiba Formation in Basra's Oil Fields

2.2 AERATED MUD

There is two-phase flow in this kind of method, and two-phase flow is air and mud. The principle of work for aerated mud to decrease equivalent circulation density (ECD) to the 4 to 8 lb/gal range. In subnormally pressured intervals, this method is usually used to reduce massive mud losses that cannot be easily resolved. Equivalent circulation mud in this type of mud will slightly be higher than the pore pressure to avoid breakout failure and tensile failure. In this technique, there is equipment on the surface to separate the air and mud so that the mud can be processed through the surface system and recirculated. It is very important to use air drilling compressor and other equipment with this method like a rotating head and mist and air/mud separator. Some issues are associated with aerated mud such as severe corrosion rates, unsteady flow in large diameter holes, and erosion from turbulent flow.

There are several different methods used to achieve aerated mud:

- Down the drill pipe” aeration – injecting both air and mud into the standpipe.
- Using a parasite tubing string run outside the last casing string to inject the air and pumping mud as normal. The mud and air mix at the casing shoe and the aerated mud flows up the annulus.
- “Dual casing micro-annulus” aeration – where a temporary casing is hung inside the last cemented casing so that air is injected down the two casings annulus and flows into the mud at the inner casing shoe then back up the drill pipe to inner casing annulus as aerated mud.

The most common method that used to achieve aerated mud is by injection of both air and mud into the standpipe. For parasite aeration, it is easy to regulate on air and mud flows, the air pressure requirement is usually lower. On the other hand, extra cost and more time are required for parasite injection in terms tubing plus extra equipment for pressure control. As well as, in parasite aeration, equivalent circulation mud will not be low as can be obtained with standard aeration due to the restricted air volume capacity of the tubing and the depth of injection being higher. While dual casing micro-annulus aeration, the last cemented casing must be large sufficient to allow the temporary inner casing to be run. This may require a larger casing size and previous hole size (South Oil Company, 2011) and (Baker Hughes, 1999).

2.3 FOAM

In this method, air (or gas) with water and foaming surfactant slurry are used to form foam drilling. This method will reduce equivalent circulation density to the 0.24 to 0.48 gm/cc range that in turn will affect positively on wellbore stability. This method is applied in very low-pressure zones where massive lost circulation occurs and is difficult to cure. When drilling, the air and foamer slurry foam must be metered within a narrow range of ratios and requires a rotating head and extra mechanical equipment. There are two types of this mud. The first one is stable foam drilling, and other is stiff foam drilling. Stable foam uses mainly water and a surfactant (commonly called soap) to form a stable air-in-water foam mixture with the air while stiff foam drilling uses a mud-like formulation as the foamer slurry with bentonite and polymers to form a longer lasting foam. Stiff foam drilling is preferred to drill large holes more than stable foam drilling. Stiff foam drilling has sufficient air volumes to do the proper cleaning for large holes while stable foam drilling does not have enough air volumes to do the good cleaning for large holes. In general, foam has excellent hole cleaning features and uses less air volume as compared to air or mist drilling. On the other hand, high cost is associated with water and foamer chemical because the foamer slurry cannot be recovered and reused (South Oil Company, 2011) and (Baker Hughes, 1999).

2.4 AIR OR MIST

Equivalent circulation mud in this kind of mud will be the lowest from 0 to 0.24 gm/cc. The most application for this method is in dry formations where the well produces little liquid and massive lost circulation and networks of vugs or caverns are encountered. The requirements of this method are large capacity high-pressure air compressors, a rotating head, and other mechanical equipment. Air drilling is commonly referred to as “dust” drilling as the discharge from the well is dust. Mist drilling uses water and a small amount of 1% foamer solution injected to help remove small amounts of produced fluids from the well (Baker Hughes, 1999).

3. CASE HISTORIES (GENERAL CONSIDERATIONS)

Narrow mud weight windows represent a challenging environment to well designers. A narrow mud weight window forms when a high collapse pressure or formation pressure zone exists in the same drilling interval with a weak formation. This is usually seen in drilling depleted formations. The following case histories are from Basra's oil fields, which represent a big challenge due to lost circulation issues. Using drilling techniques/procedures applications are especially suitable for meeting this challenge. However, the application of the techniques technology may be different when the sequence of the high-pressure zone and the weak zone varies.

When the weak zone is at the top, the mud used to drill through it may be particulate free as long as the ECD is maintained below the fracture gradient. After drilling through the weak zone, a method should be used to determine how weak this zone really is. Due to the uncertainty of depletion, some formations may not be as weak as predicted. If this is the case, advanced methods are not needed. When the weak zone is below a high pore/collapse pressure zone, the mud weight should be higher than the low fracture strength when penetrating this weak formation. In this case, the mud must be treated with the designed particulates for strengthening while drilling. If this doesn't work, and lost circulation occurs. In this case, appropriate corrective methods should be used to stop or mitigate this problem. In some situations, it is very difficult to combat mud losses by using conventional remedial treatments. As well as, the cost of these materials is expensive, so it is important to find techniques and mechanism to live with losses. Therefore, in this section, we are going to illustrate methods that have been used to ameliorate lost circulation without the use of lost circulation materials. The following case histories are from Basra's oil fields to provide more understanding in regard alternative techniques to regulate or mitigate mud losses.

3.1 CASE 1. USING LINER HANGER TO STOP MUD LOSSES IN SHUAIBA FORMATION, WELL-306, SOUTH RUMAILA FIELD

Sometimes, lost circulation mud will not be cured by using remedial and preventive methods. Therefore, it is important to find techniques or mechanisms to ceases mud losses. There is s specific advanced technology that used for this purpose like expandable tubulars and casing-while-drilling (CWD), and these methods can serve as long-term methods that will reduce the costly effects of lost circulation while drilling (Davison et al., 2004). There is a positive advantage for expandable tubulars which contribute to use a number of mud weights for different sections without losing hole size due to the telescoping effect of the casing. Casing-while-drilling employs downhole and surface components to provide the ability to use normal oilfield casing as the drill string so that the well is simultaneously drilled and cased (Tessari et al., 1999). The casing is rotated from the surface with a top drive. Drilling fluid is circulated down the casing internal diameter (ID) and up the annulus between the casing the wellbore. The main target of this method is to reduce the non-productive time (NPT), cost, and the casing running times when severe and total fluid losses make conventional drilling practices difficult and expensive. Casing while drilling (CWD) technology has already been used for 306 well in South Rumaila field (South oil company, 2009). Lost circulation mud stopped after using this technique in this field. Casing while drilling (CWD) technology demonstrated to be an effective technical-economical solution to drill and cement production casing string (7 in, 8 1/2 in) in South Rumaila field. There are two kinds of the casing while drilling (CWD) technology: retrievable and non-retrievable systems. The non-retrievable system has been used to isolate the Shuaiba formation, this kind of casing is designed to leave the casing drill shoe (CDS) on the bottom if the last section of the well is being drilled to total depth (TD) or is to be drilled afterward to continue with the following hole sections. Figures 3.1 and 3.2 are pictures of part of the CWD assembly. There are some visions and ideas that has already deduced after applying casing while drilling (CWD) technology in 306 well in South Rumaila field, Shuaiba formation (South oil company, 2009):

- Unwanted consequences of the lost circulation mud like drilling and operation cost, tripping time to land conventional casing to bottom, and rig floor safety in comparison with traditional mechanisms will be reduced by using casing while drilling (CWD) technology.
- High-efficiency cleaning due to high annular velocity which in turn lead to avoid bit balling issue, drag problem, and stick pipe dilemma.
- Lost circulation zones have been clearly identified, even drilling without returns.
- Casing while drilling (CWD) technology helps to restore mud circulation to surface.

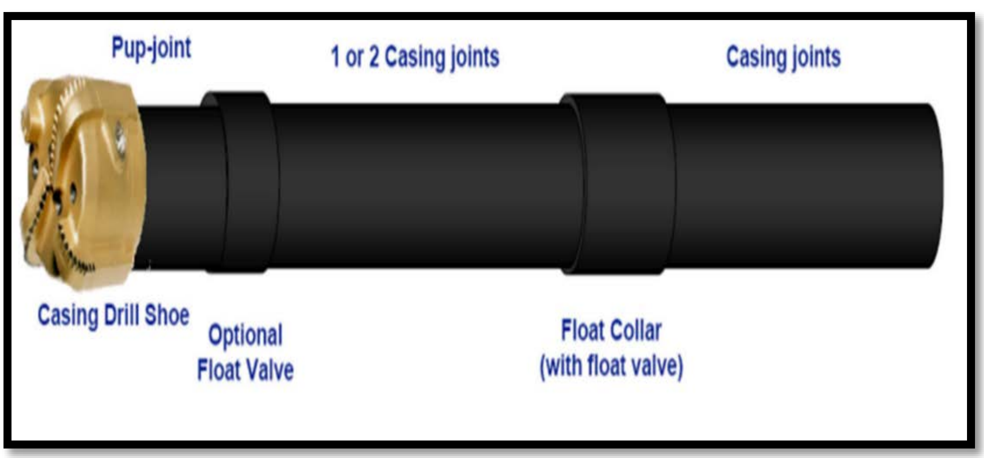

Figure 3.1: BHA Components of CWD Assembly (Gallardo et al., 2010)

Figure 3.2: Top Drive and Internal Casing Drive (Tessari et al., 2006)

The Shuaiba formation occurs at approximately 2900 m and is a limestone with little to no visible porosity. However, the zone is highly susceptible to fracturing and lost circulation, which is more troublesome and even more complicated than lost circulation in the Dammam or the Hartha formations. Sometimes, mud losses in the Shuaiba formation lead to the abandonment of the drilling operation due to unsustainable non-productive time (NPT) and drilling cost. Mud losses in the Shuaiba also cause severe wellbore stability problems. Figure 3.3 shows the borehole and well construction typical of a well drilled in the South Rumaila field at the time the well passes through the Shuaiba formation. Both the 13-3/8” and 9-5/8” casing strings have been set. Commonly an 8 1/2” bit is used to drill through the formation.

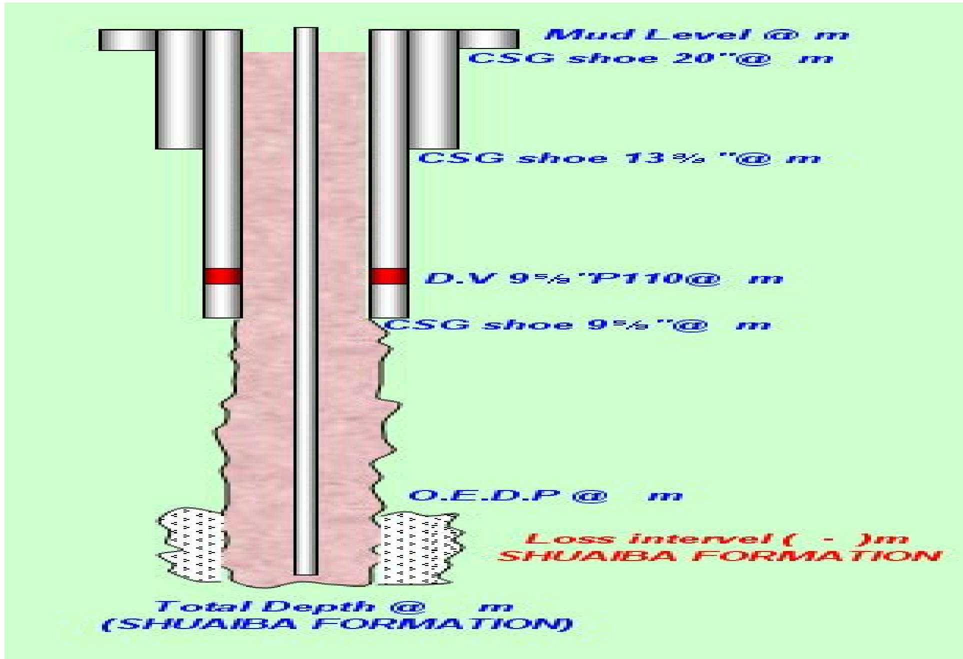

Figure 3.3: Lost Circulation Mud in the Shuaiba Formation

It is also very crucial to consider that the Shuaiba formation is located below transitional zones like Mishrif, Mauddud, and Nahr Umr zones. These formations have abnormal pressures, so it is very prudent to consider this case to avoid collapse issues in formations like the Mishrif, Mauddud, and Nahr Umr. As it summarized in this work (Table 2.2), which illustrates various required drilling densities for these formations. These zones will also be susceptible to a kick, should mud levels in the borehole fall due to lost circulation in the Shuaiba formation.

This case history occurred in well 306, Shuaiba formation, South Rumaila field. It had complete losses for three months, and various plugs treatment were used to stop or mitigate mud losses (e.g. High Viscosity Drilling Mud (Low Density) + Blend of the LCMs, Super Stop Material, Cement Plug, High Filtration Spot Pills, High Filtration Mixtures (200-400 cc API), very high filtration mixtures (>600cc API), High Viscosity Mud (Low Density) + Cement Plug, DOB Squeeze (Diesel Oil Bentonite), DOBC Squeeze

(Diesel Oil Bentonite Cement), Gilsonite cement, Fibers in cement, and InstandSeal). At that time, more than 60 conventional treatments and plugs have been used. However, lost circulation didn’t remedy, and it was so hazardous case on drilling operations. Several unwanted consequences were associated due to complete mud losses like collapse issues, very high cost, and non-productive time. For this reason, there were orientations to abandon this well. Then, a drilling expert named Kazem Awash suggested drilling the remaining of the Shuaib formation by using blind drilling till the bottom of the zone. Then, run casing string to isolate Shuaiba zone, and resume drilling till productive zone, which is Zubair formation. Casing string 7 inches has been run to stop lost circulation in Shuaiba formation. After isolating Shuaiba zone by using 7 inches casing string successfully, productive zone (Zubair Formation) was drilled by using 5 7/8" without any problems. Finally, casing string 4.5" has been run to Zubair zone with liner hunger at depth 2900 m. The major objective of liner hunger is to minimize the cost of the casing drilling (South oil company, 2009).

3.2 CASE 2. USING FLOATING MUD CAP DRILLING TO STOP MUD LOSSES IN DAMMAM FORMATION, 176 WELL, ZUBAIR FIELD

Usually, this technique is used during total mud loss and the intrusion of reservoir fluids into the wellbore. By using weighted drilling mud that is continuously pumped into the annulus, the well will be under control. Water is used instead of drilling fluid, and the water and drill cuttings are lost to the zone. Mud column pressure in the annulus will regulate on formation fluids. It is necessary to design appropriate mud weight which is preferred to be (~250 psi) higher than the formation pressure. In addition, it is important to maintain drilling density from time to time by using the addition of fresh mud to the annulus to avoid mud losses. Theoretically, in some levels, mud pressure will be equivalent to the formation pressure, that in turn, cause the mud to “float” against the formation pressure, just above the lost circulation zone. It is much recommended to maintain hydrostatic pressure to slightly be higher than the formation pressure to preclude unwanted consequences due to shear failure or tensile failure, Figure 3.4 will show floating mud cap drilling method (South Oil Company, 2011) and (Baker Hughes, 1999).

Mud cap drilling cannot take place without a large dedicated water supply. It is essential that pump rates that will clean the bit and annular velocities that will convey the cuttings into the loss zone be maintained. Slip velocity calculations for the cuttings can be performed. Generally, annular velocities above 120 ft/min will be required. The drilling circumstances have a big role on the procedures for executing the floating mud cap(South Oil Company, 2011) and (Baker Hughes, 1999).

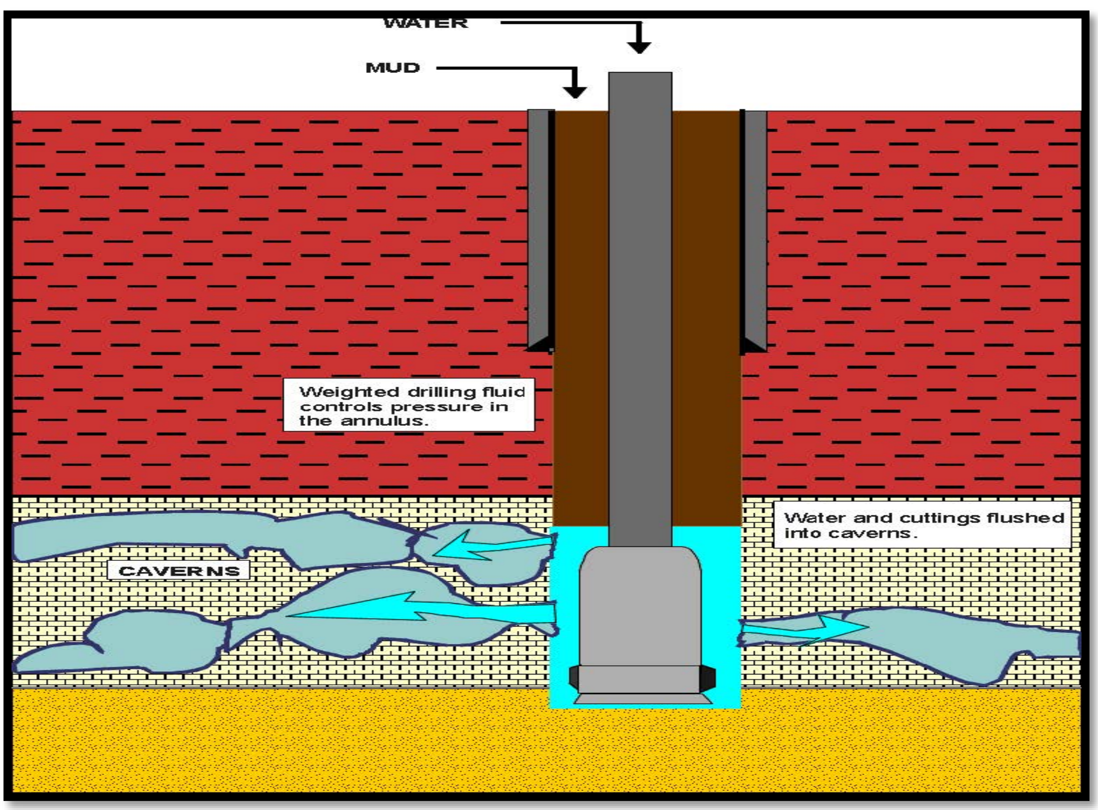

Figure 3.4: Floating Mud Cap Drilling Method (Baker Hughes, 1999)

The Dammam formation is the first formation in Basra's oil fields that is prone to mud losses. The top of this zone is found between 435 to 490 m, and all of the wells in the field must be drilled through this zone. The interval is composed of interbedded limestone and dolomite, which is generally 200 to 260 m thick. The top of the Dammam was eroded after burial and is karstified at depth. The karst features are believed to lead to the mud losses seen while drilling through this interval (Arshad, 2015). Figure 3.5 Shows borehole and well construction typical of a well drilled in Zubair field at the time the well passes through the Dammam formation. 13-3/8" casing has been set, and most commonly a 12 ¼" bit is used to drill through the formation. A lost circulation event is shown near the bottom of the openhole in Figure 8, but may occur anywhere in the openhole section through the Dammam (South Oil Company, 2010).

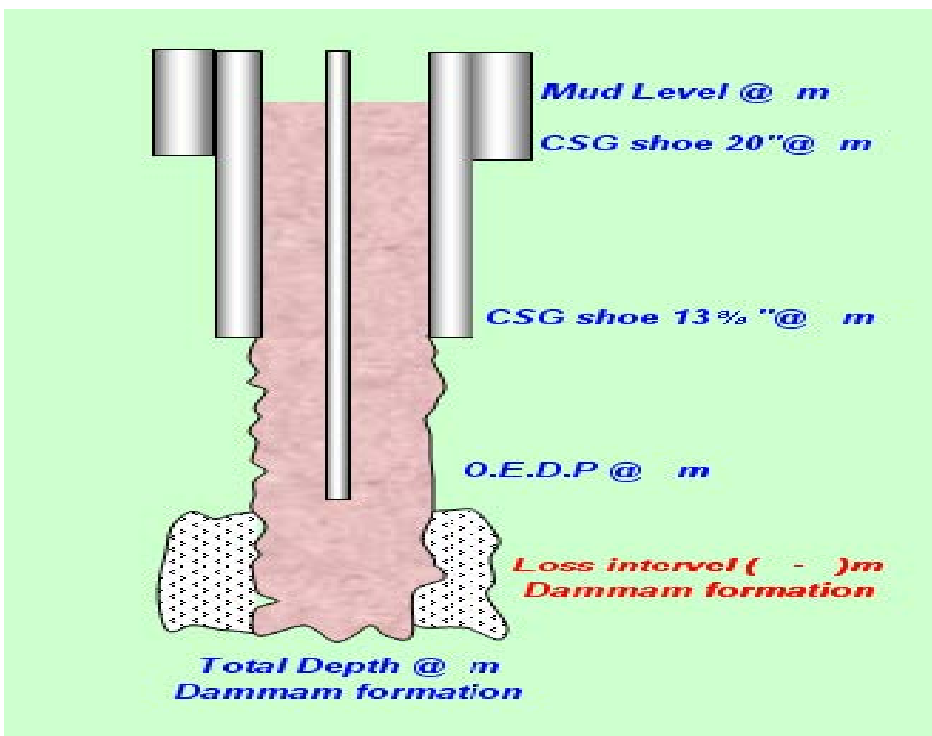

Figure 3.5: Lost Circulation Mud in the Dammam Formation

mud cap drilling has been used in the Dammam formation, well 176, Zubair field to stop lost circulation problem, which is a significant problem in this formation. It had complete losses, and various plugs treatment were used to regulate or mitigate mud losses (e.g. High Viscosity Drilling Mud (Low Density) + Blend of the LCMs, Super Stop Material, Cement Plug, High Viscosity Mud (Low Density) + Cement Plug, DOB Squeeze (Diesel Oil Bentonite), DOBC Squeeze (Diesel Oil Bentonite Cement), and Gilsonite cement). However, lost circulation didn't stop, and it was so severe case on drilling operations. Several unwanted consequences were associated due to complete mud losses like high cost and non-productive time. Then, floating mud cap drilling has been implemented, and it provided the best control to mud losses in the Dammam formation. After that, drilling operations has been resumed without problems.

4. CONCLUSION

This problem is very common, and most fields in the world suffer from mud losses during drilling operations. Hence, lost circulation is a challenging problem to be prevented or mitigated during drilling. Lost circulation treatments are widely applied to mitigate losses using a corrective approach or to prevent losses using preventive approaches, also known as “wellbore strengthening”. Therefore, it is essential to research and find alternative techniques to avoid or mitigate this troublesome problem because that will reflect positively on the oil industry especially the drilling operations in terms time and cost.

This paper summarizes the experience reached drilling wells using Casing while Drilling (CWD) technology in production section and floating mud cap drilling in the intermediate hole, which are affected by severe and total fluid losses in Basra’s oil fields. Total or severe fluid losses in intermediate and production sections turn conventional drilling into a non-cost-effective way to drill these sections in Basra’s oil fields. Additionally, the shear failure and associated logistic problems were mitigated through CWD technology in production hole. The experience gained while drilling these wells has led to a better understanding of the advantages of the process. It's most effective applications have been to reduce the cost and risks associated with wells which routinely experience lost circulation when drilled conventionally.

Based on this study, the following conclusions were made:

- Blind drilling can be used to combat mud losses in the Dammam formation; however, this method should be avoided in deeper formations such as the Hartha and Shuaiba formations because it will have a very low probability of success in the deeper formations.

- There are no guaranteed methods for solving lost circulation problems entirely but many approaches can be used to prevent its occurrence, especially those that occur via induced fractures when drilling formations that are prone to losses.
- It is crucial to find alternative approaches if conventional treatments don’t remedy lost circulation. In addition, a quick economic evaluation is desirable before doing any action.

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SECTION

2. CONCLUSION

Based on this study, the following conclusions were made:

- Successful control or treatment of lost circulation depends on several factors such as borehole temperature, pressure, lithology, type of losses, accurate calculations depth, and size of the thief zone.
- There are no guaranteed methods for solving lost circulation problems entirely, but a lot of approaches can be used to prevent its occurrence, especially those that occur via induced fractures when drilling formations that are prone to losses.
- Practical guidelines have been developed that when used with the accompanying flow chart will serve as a quick reference guide to prevent and minimize the problem of lost circulation while drilling in Basra’s oil fields.

VITA

Husam Hasan Alkinani was born in November 1992, in Baghdad, Iraq. He was in the top of his high school graduates and graduated with 3.7/4 GPA. Due to his excellent performance in high school, he received a fully funded scholarship from the prime ministry office of Iraq/ Higher Committee of Education Development in Iraq (HCED) to study engineering in the United States. He started as a freshman at Missouri University of Science and Technology in fall 2012. He received his bachelor's degree in Petroleum Engineering and a minor in Geology in December 2016 with 3.9/ 4 GPA. Then he started with Master's degree at Missouri University of Science and Technology directly after he finished his bachelor's degree. He received his Master's degree in Petroleum Engineering in December 2017.

His research interest focuses on drilling problem in southern Iraq, mud loss modeling, and neural network and machine learning with applications in Petroleum Engineering.