

A Comprehensive Analysis of Lost Circulation Materials and Treatments with Applications in Basra's Oil Fields, Iraq: Guidelines and Recommendations

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Abstract

Lost circulation events in the Basra oil fields of Iraq were statistically analyzed to determine treatment effectiveness. Data from over 800 wells were gathered from various sources and reports; the treatments were classified by scenario – seepage, partial, severe, and complete losses – as well as cost, efficiency, and formation types. Statistical analysis was used to rank the effectiveness in different scenarios and recommend the best treatment for each type of losses.

Traditionally, lost circulation in the Basra area has been treated in a multitude of ways without consistent methodology. This analysis identifies and ranks the most effective treatments to create a “best” method/product recommendation and a flowchart suggesting additional measures in treating losses to optimize success and reduce overall cost and NPT.

This paper presents the best treatment for each scenario – seepage, partial loss, severe losses and complete losses – both for product selection and engineering. For instance, analysis of the data indicates the best location of the open-end drill pipe during lost circulation treatments is at the top of the formation that is experiencing mud loss to provide the highest probability of success and to avoid unwanted consequences. In addition, engineered solutions and practical techniques have been developed, which will contribute to give a clear image and a coherent understanding in regard this complicated and costly problem in the Basra oil fields of Iraq.

The result of this data analysis provides a path forward for the Basra area lost circulation events and suggests probable methods that can be used in similar formations globally. Additionally, the methodology can be adapted in studying other types of formations and drilling challenges.

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”¹. 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 more². 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 (m³/hr.). When the fluid loss rate is 0.5 -1 m³/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 m³/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 m³/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.

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.

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 1 summarizes the methodology of this paper.

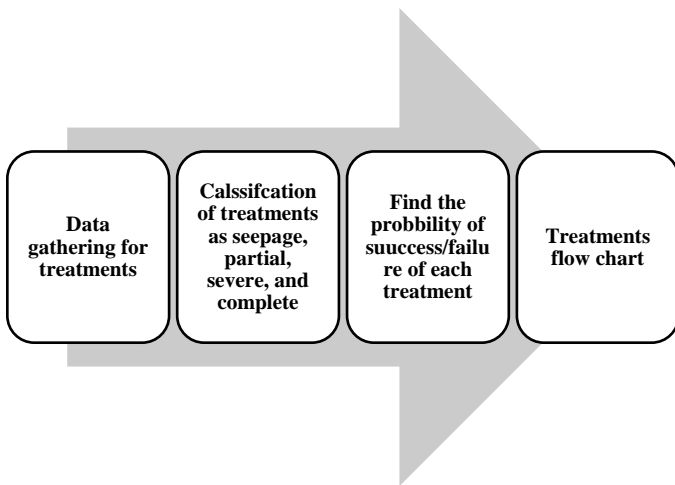


Figure 1. Methodology

Formations which are Prone to Lost Circulation in Basra's Oil Fields

Lost circulation 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 field³.

The 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 interval⁴. Figure 2 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 1/4" bit is used to drill through the formation. A lost circulation event is shown near the bottom of the openhole in figure 2, but may occur anywhere in the openhole section through the Dammam formation³.

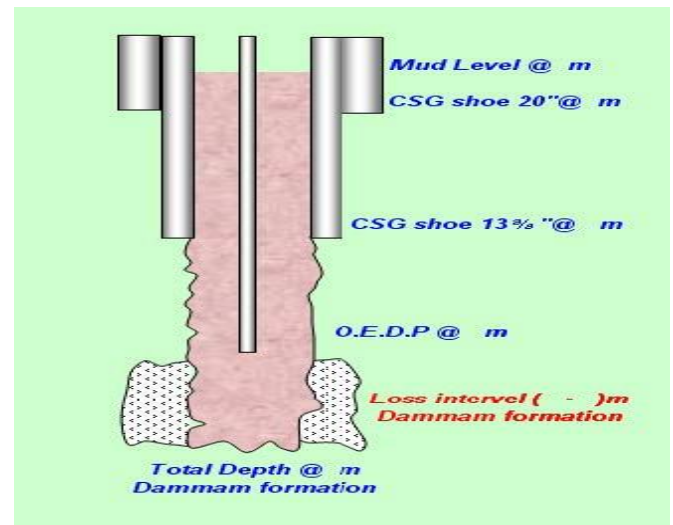


Figure 2. Lost Circulation in the Dammam Formation

The Hartha Formation

The Hartha formation is the second zone that is usually prone to lost circulation problems. Mud losses in the Hartha formation are more complicated than the 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 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 Hartha formation. 13-3/8" casing has been set, and most commonly a 12 1/4" 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, but it is possible to have losses simultaneously in the Dammam and the Hartha formations, or only losses in Hartha as it is drilled³.

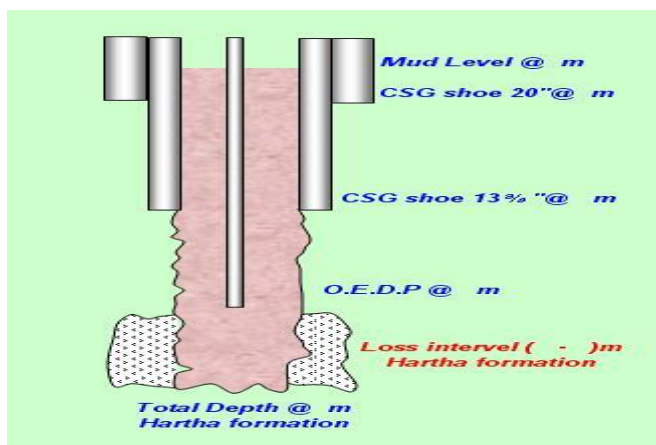


Figure 3. Lost Circulation in the Hartha Formation

The 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 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 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 3.

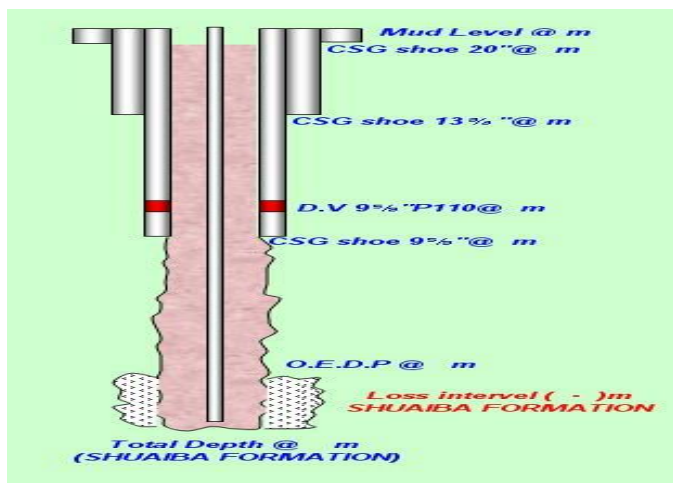


Figure 4. Lost Circulation in the Shuaiba Formation

Factors Impacting Mud Losses

There are multiple reasons that cause to initiate lost circulation in the Dammam, Hartha, and Shuaiba formations in Basra's oil fields in Iraq. Table 1 will demonstrate the major factors that cause this issue.

Table 1. Causes of Lost Circulation

Pressure-Induced Fractures	Natural Fractures/Permeability
<ul style="list-style-type: none"> Excessive mud weight. Annulus friction pressure (ECD). Wellbore pressure surges. Imposed/trapped pressure. Shut-in pressure. Low formation pressure. 	<ul style="list-style-type: none"> High permeability formations. Unconsolidated formation. Fissures /fractures. Unseal fault boundary. Vugular /cavernous formation.

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"⁵. There are several negative effects due to lost circulation mud³. Table 2 will show the bad consequences due to lost circulation:

Table 2: Summary of Unwanted Consequences of the Mud Losses

Intermediate Hole	Production Hole
<ul style="list-style-type: none"> Loss of fluid level monitoring. Loss of formation evaluation. Hole cleaning problems Hole bridge/collapse Extended wellbore exposure time. Stuck pipe Well control event Underground blowout Additional casing string. 	<ul style="list-style-type: none"> Loss of fluid level monitoring. Loss of formation evaluation. Hole cleaning problems Hole bridge/collapse Extended wellbore exposure time. Stuck pipe Well control event Underground blowout Additional casing string. Production zone damage

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 problem.

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 ³.

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 m³/hrs (3–6 bbls/hrs). Figure A.1 (Appendix A) 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.

Partial Losses Remedies

In this kind of loss, part of drilling fluid will be lost into formation (about 1–10 m³/hr). This type of loss is the simplest one, and it is easy to control 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 A.2 (Appendix A) 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 A.1 (Appendix A) will illustrate remedies that use to regulate this type of the loss.

Severe Losses Remedies

This kind of loss will be more than partial loss (about 15 or above m³/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 necessary to do the 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 A.3 (Appendix A) will show the probability of success and failure for the remedial actions which have been used to treat severe losses. Table A.2 (Appendix A) will illustrate remedies that use to control this type of the loss in Basra's oil fields.

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 NPT. Therefore, it is very necessary to do the required actions to combat or mitigate this kind of the losses to avoid unwanted consequences. Figure A.4 (Appendix A) will illustrate the probability of success and failure for the recommended remedies which should use to treat complete losses. Table A.3 (Appendix A) will illustrate remedies that use to control this type of the loss in Basra's oil fields.

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 mud losses. These treatments are classified by relying on lost circulation types 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.

Preparations before Starting to Drill These Formations

Many preparations must be taken before drilling the Dammam, Hartha, and Shuaiba formations, which are prone to lost circulation mud ³.

- 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 of an increase 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 the Hartha and Shuaiba zones to avoid lost circulation

mud due to narrow mud weight window. Because the 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, the 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.

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 OEDP³:

Bottom of the Loss Zone

This location is usually selected to determine the 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, 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.

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.

Middle of the Loss Zone

This location is not common, and it is rarely selected 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 the Dammam, Hartha, and Shuaiba formations in Basra's oil field. Figures 5, 6, and 7 will illustrate the results of the statistical analysis for the Dammam, Hartha, and Shuaiba zones respectively. The results of all three formation show that the best location to place the OEDP is at the top of the loss zone.

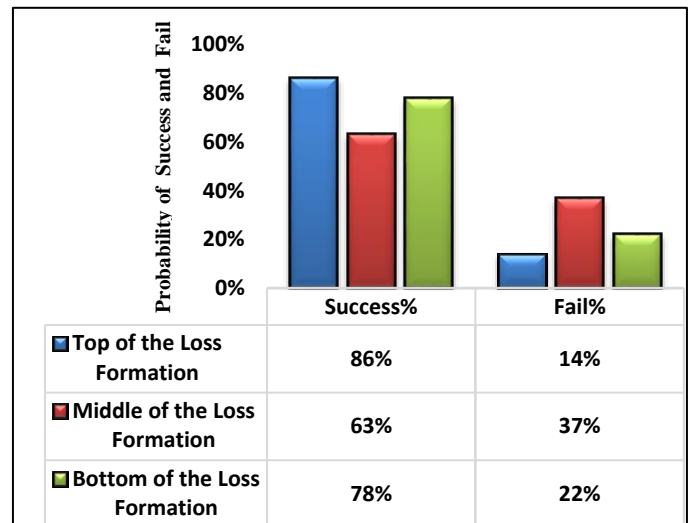


Figure 5. The Location of OEDP, Dammam Formation in Basra's Fields

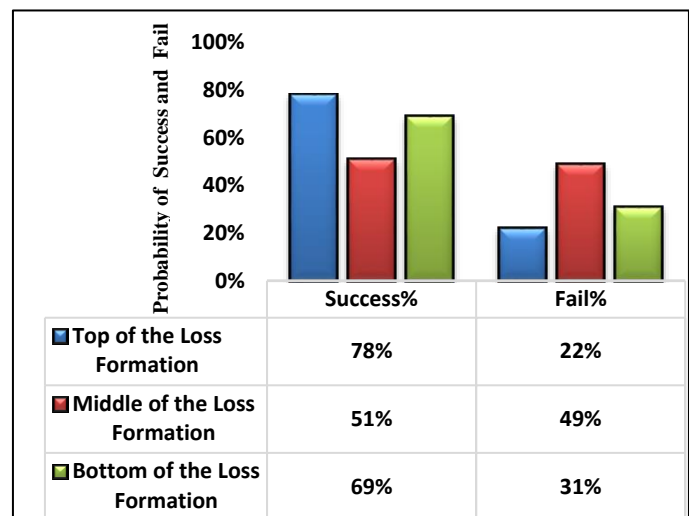


Figure 6. The Location of OEDP, Hartha Formation in Basra's Fields

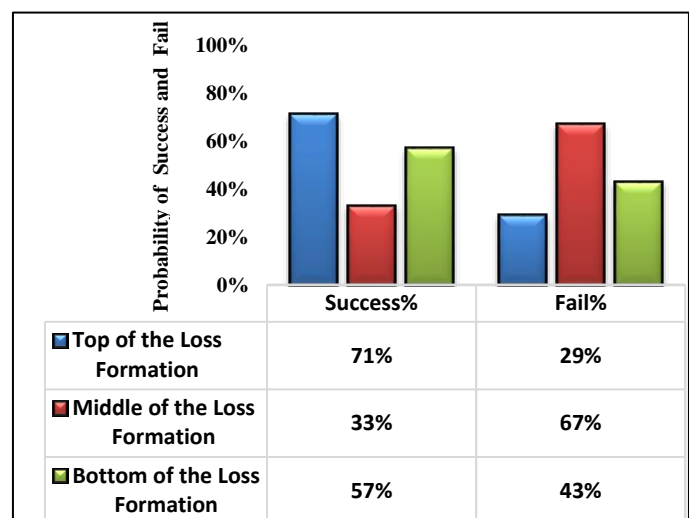


Figure 7. The Location of OEDP, Shuaiba Formation in Basra's Field

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 contribute 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:

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.

$$\text{Displacement Volume} = ID_{\text{pipe}}^2 \times 0.785 \times h \dots (\text{Eq. 1})$$

Where,

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

ID_{pipe}: Inside diameter of drill pipe (m).

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

The Volume of the Required Plug

Several plugs that use to stop or mitigate lost circulation mud. Thus, 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 is pumped as safety factor roughly (1-2 m^3). Equation 2 is used to calculate the required plugs or treatments.

$$\text{Volume of Plug} = D_{\text{OH}}^2 \times 0.785 \times h \dots (\text{Eq. 2})$$

Where,

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

D_{OH}: Diameter of open hole (m).

H: height of interval of the thief zone (m).

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.

$$HP = \frac{\rho_{\text{mud}} \times h}{10} \dots (\text{Eq. 3})$$

Where,

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

ρ_{mud} : 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.

$$\rho_{\text{plug}} = \frac{HP \times 10}{h} \dots (\text{Eq. 4})$$

Where,

ρ_{plug} : 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).

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 the 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 A.5 (Appendix A) is concluded based on data analysis for treatments that were used for the 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 types 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 flowchart in figure A.5 should be used to treat mud losses in Basra's oil fields. The first treatment on the flowchart has the highest probability of success, the probability of success will decrease as moving down in the flowchart. 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 and probability of success of the remedy such that the most efficient and the highest probability of success treatment will be utilized first for several reasons:

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

Reasons for Failure to Cure Lost Circulation

The reasons for failure to cure lost circulation are:

- The first step to combat lost circulation mud is the accurate identification of the loss zone. Sometimes, there is no 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.
- 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.
- Failure to take the necessary measures quickly.
- Old documents like daily reports and detailed applications are not kept on the same field. It is very crucial to saving all techniques and mechanisms that have already been used for several wells as a reference for next methods.
- Contamination the pill or plug with drilling mud which leads to reduce or prevent proper settings for treatment. Thus, some techniques and methods are affected negatively due to this

contamination. Hence, it is necessary to apply balanced column methods to avoid this dilemma.

- 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.
- 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.
- The lack of a crucial decision or hesitation to take appropriate remedies. Sometimes, application of the unsuccessful remedies leads to aggravating mud losses problem.
- No information regarding the geometry of the fractures, vugs, and caves.
- 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.
- 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.
- The absence of the engineering approaches in the executive solutions.
- Insufficient thickening time for plugs to harden.

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 in 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 breaking 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 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 formations, 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 ECD.
 - Lost circulation materials (LCMs) have many various forms, and each of them has specific properties and cost. The performance of the LCM basically relies on its particle size distribution (PSD), shape, size, and concentration.
 - It is practically interesting to reduce yield point (Y_p) and the solids content of the drilling mud within allowable limits to reduce gel strength and ECD before addition 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 of the type of the remedies to avoid the non-productive time and reduce expenses.

- It is very advisable to have an 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.

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 the 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 at 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 use 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 influential 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.

Acknowledgments

The authors would like to thank South Oil Company from Iraq and British Petroleum Company for providing us various real field data.

Nomenclature

D	Depth
DDR	Daily Drilling Report
DOH	Diameter of Open Hole
ECD	Equivalent Circulation Density
FWB	Fresh Water Bentonite
gm/cc	gram per cubed centimeter
H. V	High Viscosity
lb/bbl	pounds per barrel
lb/ft ³	pounds per cubed feet
Kg/m ³	Kilogram per cubed meter
LCMs	Lost Circulation Materials
L/min	Litter per minute
m ³ /hr	cubed meter per hour
MW	Mud Weight
NPT	Non-productive Time
OEDP	Open End Drill Pressure
ppg	pounds per gallon
ROP	Rate of Penetration
RPM	Revolutions per Minute
SPM	Stroke per Minute
TFA	Total Flow Area
WOB	Weight on Bit
WOC	Waiting of Cement
WON	Without Nozzles
Yp	Yield Point Viscosity

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Appendix A

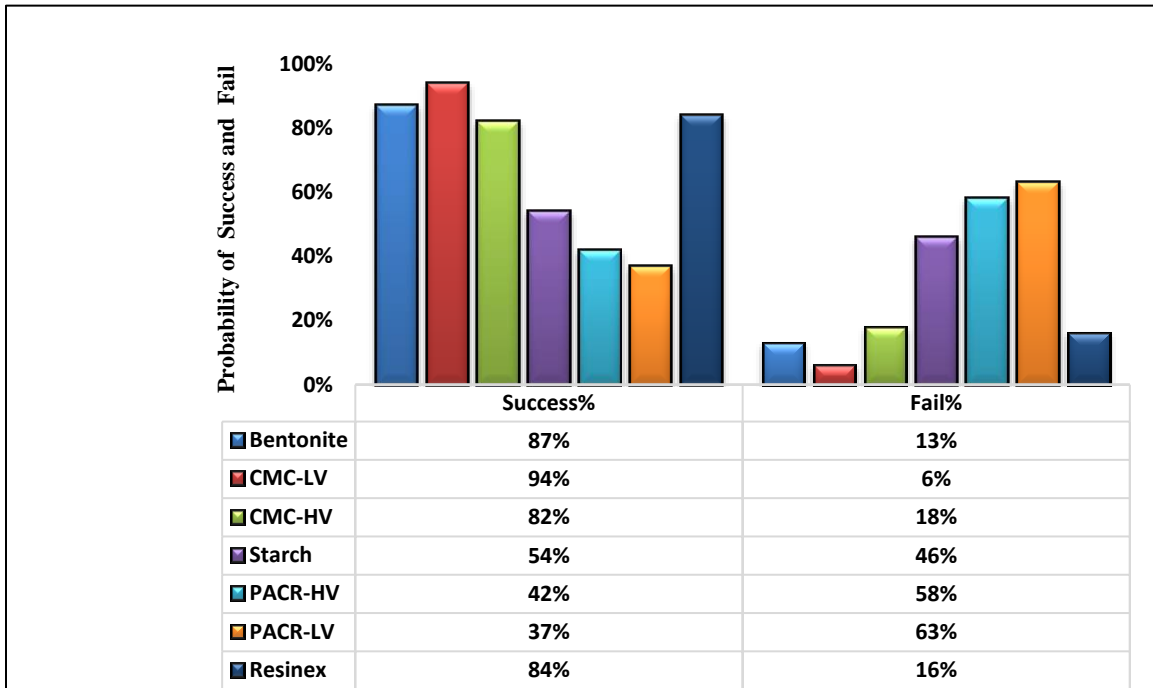


Figure A.1: Treatments for the Seepage Losses in Basra's Oil Fields

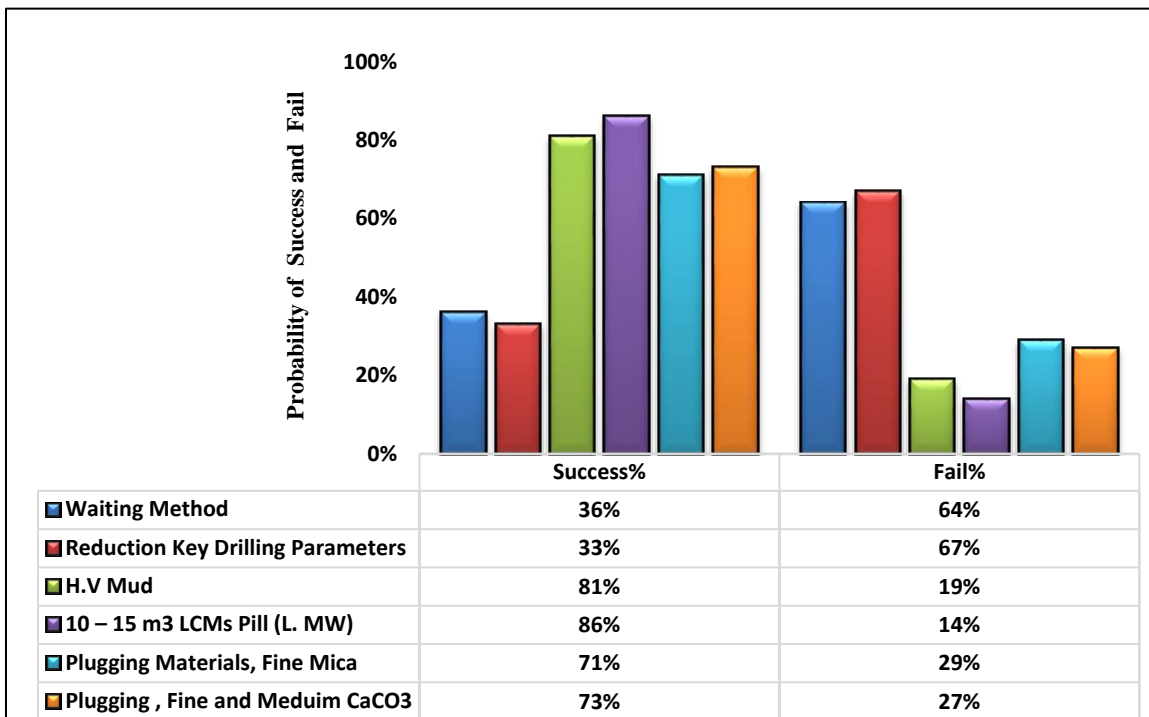


Figure A.2: Treatments for the Partial Losses in Basra's Oil Fields

Table A.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	<ul style="list-style-type: none"> • Pull out drilling strings to casing shoe. • Waiting period between (2-4) hours. • Drilling strings will gradually run into 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	
	10 – 15 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	15 kg/m ³		
	Mica Medium	15 kg/m ³		
	Nut Plug	15 kg/m ³		
CaCO ₃ Medium	15 kg/m ³			
CaCO ₃ Coarse	15 kg/m ³			
Plugging Materials, Fine Mica	Fine mica will be mixed with a low density of the drilling fluid.	(2-3) hours		
Plugging Materials, Fine and Medium CaCO ₃	Fine and Medium CaCO ₃ will be mixed with a low density of the drilling fluid.	(3-4) hours		

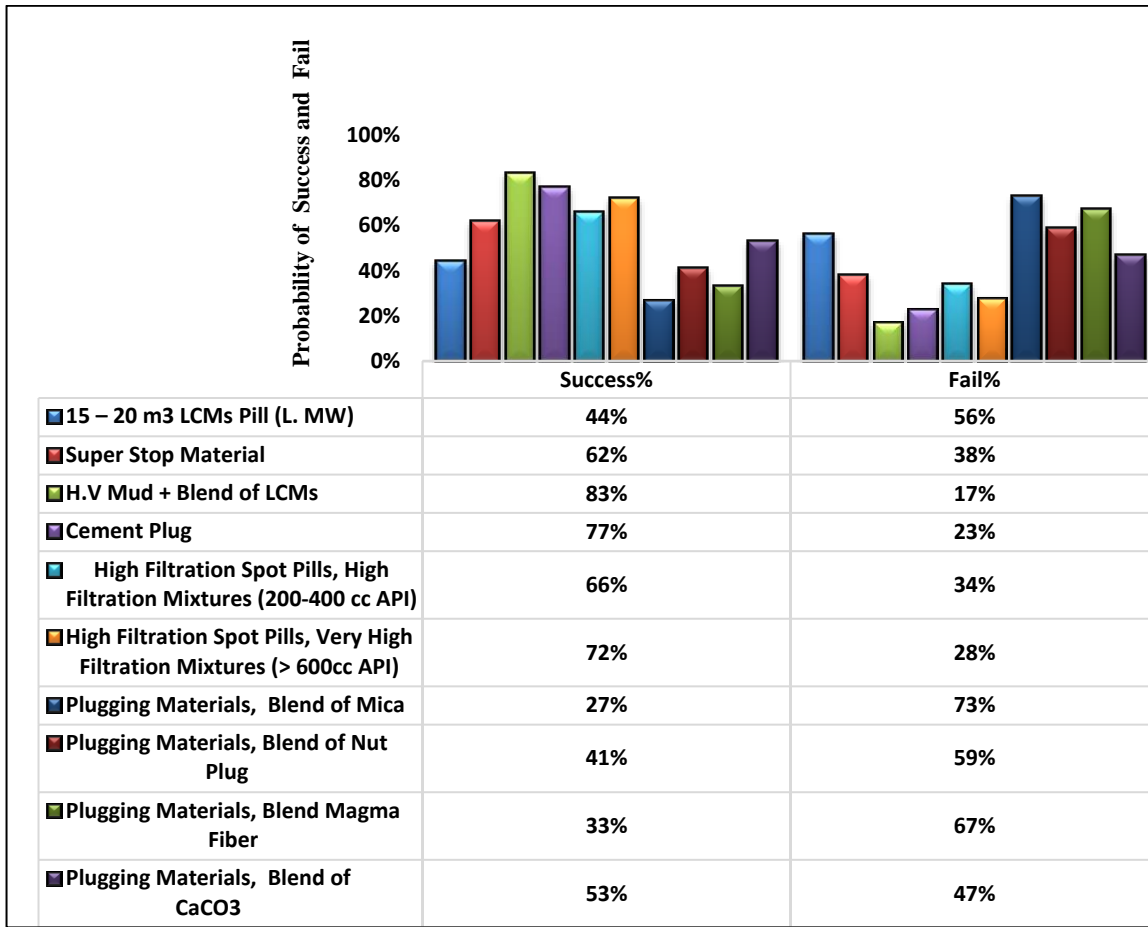


Figure A.3: Treatments for the Severe Losses in Basra’s Oil Fields

Table A.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 A.2: The 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	<ul style="list-style-type: none"> • Mixing (4-5) bags (Weight of Bag 25 kg) of super stop material for each 1 m³ water. • 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)	<p>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.</p> <p>Procedure formula for 1 m³ (final) of high filtration mixtures</p> <table style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 60%;">Attapulgate</td> <td style="text-align: right;">3 - 6 %</td> </tr> <tr> <td>Bentonite</td> <td style="text-align: right;">1.5 - 6 %</td> </tr> <tr> <td>Lime</td> <td style="text-align: right;">0.15 %</td> </tr> <tr> <td>Diatomite</td> <td style="text-align: right;">15 %</td> </tr> <tr> <td>Mica</td> <td style="text-align: right;">1 – 1.5 %</td> </tr> <tr> <td>Granular LCM</td> <td style="text-align: right;">1.5 – 2.5 %</td> </tr> <tr> <td>Fibrous LCM</td> <td style="text-align: right;">0.3 – 1 %</td> </tr> </table>	Attapulgate	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)
	Attapulgate	3 - 6 %															
Bentonite	1.5 - 6 %																
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Granular LCM	1.5 – 2.5 %																
Fibrous LCM	0.3 – 1 %																
High Filtration Spot Pills, very high filtration mixtures (> 600cc API)	<p>Procedure formula for 1 m³ (final) of very high filtration mixtures</p> <table style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 60%;">Diatomite</td> <td style="text-align: right;">30 %</td> </tr> <tr> <td>Lime</td> <td style="text-align: right;">15%</td> </tr> <tr> <td>Attapulgate</td> <td style="text-align: right;">0-4 %</td> </tr> </table>	Diatomite	30 %	Lime	15%	Attapulgate	0-4 %	(± 4-6 hours)									
Diatomite	30 %																
Lime	15%																
Attapulgate	0-4 %																

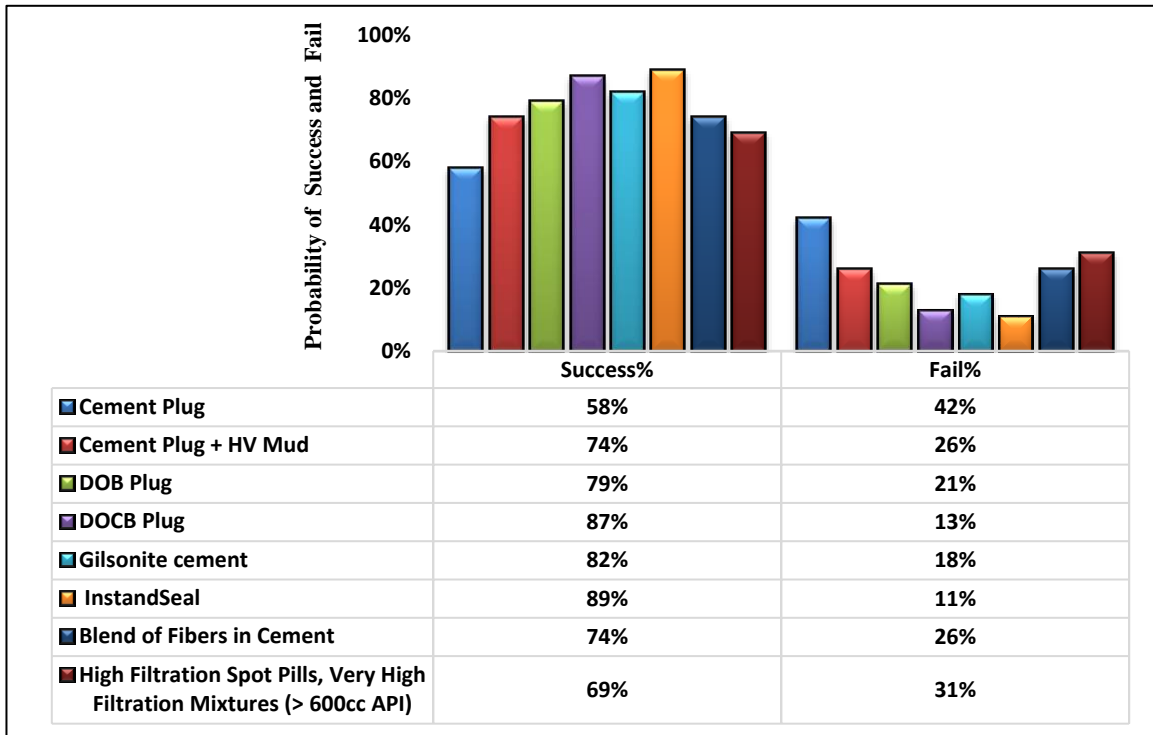


Figure A.4: Treatments for the Complete Losses in Basra’s Oil Fields

Table A.3: The Complete Losses Treatments in Basra’s Oil Fields

Type of Losses	Type of the Treatment	Approach to 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											
	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. Formula for 1 m ³ (Final) Oil base 0.70 m ³ Bentonite 800 kg	(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. Formula for 1 m ³ (Final) Oil base 0.72 m ³ Bentonite 450 kg Cement 450 kg	(10-12) hours											
	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. Procedure Slurry Composition (Class G Cement)	(8) hours											
	<table border="1"> <thead> <tr> <th>Gilsonite %</th> <th>water weight %</th> <th>Slurry / 100 kg</th> <th>Density gm/cc</th> </tr> </thead> <tbody> <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> </tbody> </table>	Gilsonite %		water weight %	Slurry / 100 kg	Density gm/cc	0	44	75.7	1.90	50	61	139.5	1.51
Gilsonite %	water weight %	Slurry / 100 kg		Density gm/cc										
0	44	75.7	1.90											
50	61	139.5	1.51											

Table A.3: The Complete Losses Treatments in Basra's Oil Fields (Cont'd)

Type of Losses	Type of the Treatment	Approach to the Treatment	Waiting
Complete Loss	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.	(18) hours
	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 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
	High Filtration Spot Pills, Very high filtration mixtures (> 600cc API)	Procedure formula for 1 m ³ (final) of very high filtration mixtures Diatomite 30 % Lime 15% Attapulgate 0-4 % Granular LCM 1 – 2.5 % Fibrous LCM 1 %	(± 4-6 hours)

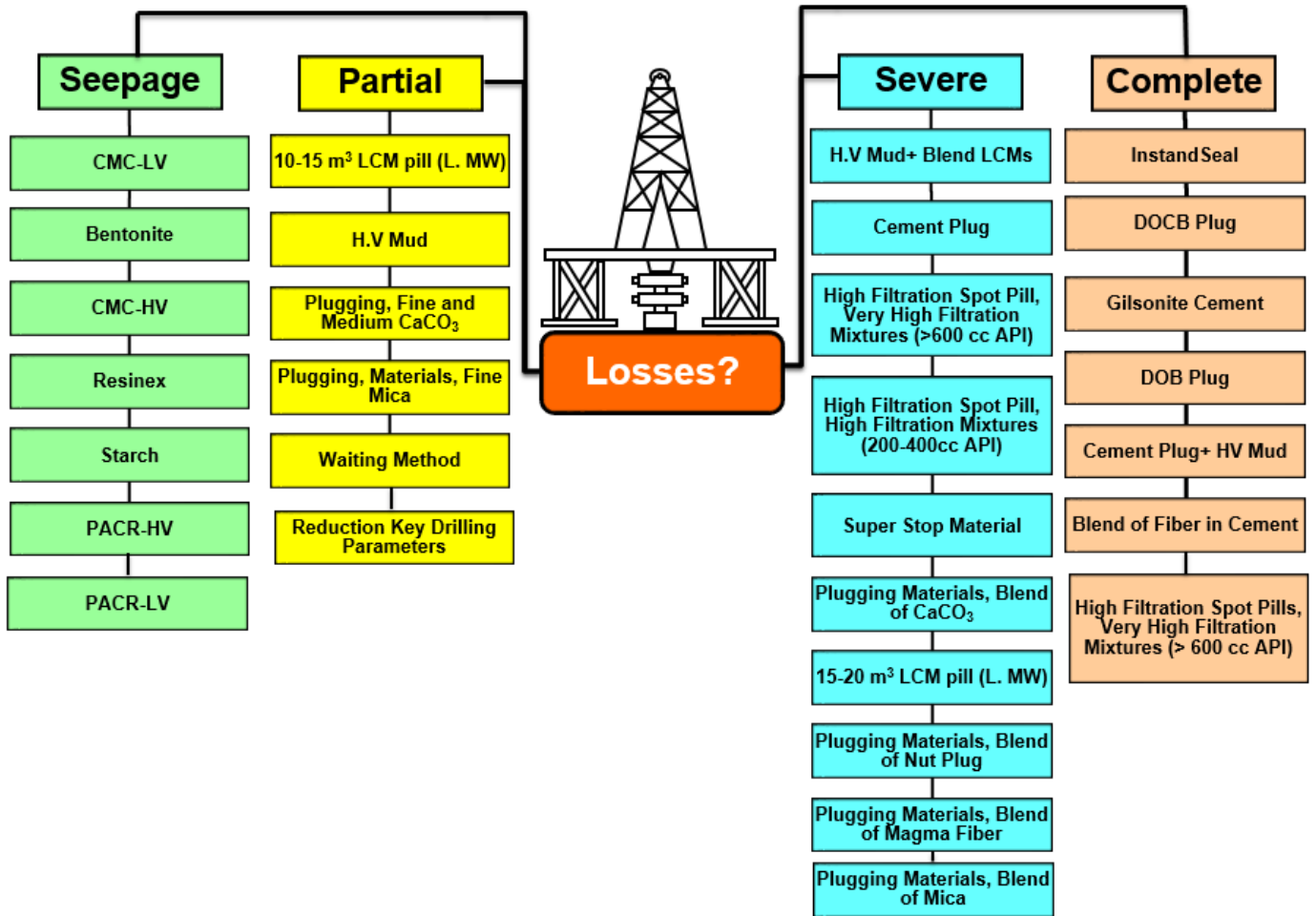


Figure A.5: The Treatment Strategy for the Dammam, Hartha, and Shuaiba in Basra's Oil Fields