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Insights into Mud Losses Mitigation in the Rumaila Field, Iraq

Al-Hameedi AT, Alkinani HH, Norman SD, Flori RE, Hilgedick SA

Department of Geoscience and Geological Engineering and Petroleum Engineering, Missouri University of Science and Technology, USA

Abstract

Lost circulation is a complicated problem to be banned or combatted during the drilling operations. Mud losses remedies are extensively used to stop or mitigate losses using remedial methods or to prevent mud losses using proactive measures. Lost circulation presents a lot of big challenges during drilling. To address these problems, a number of methods/techniques have evolved over the years. The Rumaila field in Iraq is one of the largest oilfields in the world. Wells drilled in this field are highly susceptible to lost circulation problems when drilling through the Hartha formation. Lost circulation events range from seepage losses to complete loss of the borehole and are a critical issue in field development. This paper describes a study of the lost circulation events for more than 300 wells drilled in the Rumaila field. Lost circulation events were extracted from daily drilling reports, final drilling reports, and technical reports. Key drilling parameters (e.g. ROP, SPM, RPM, WOB, bit type) and mud properties (e.g. mud weight, yield point, gel strength) at the time of each event were recorded along with the lost circulation remedies attempted, and the outcome of those remedies. These data have been analyzed to determine the best ranges of the key drilling parameters that have the greatest chance of mitigating lost circulation in the Hartha formation.

Practical field information from the Rumaila field and range of sources have been reviewed and summarized to develop an integrated methodology and flowchart for handling lost circulation events in this formation. In a related development, this paper will be extended work along with previous comprehensive statistical study and sensitivity analysis models about the Hartha formation to obtain the best field procedures for avoiding or minimizing lost circulation events in the Hartha formation. Proactive approaches have been made prior entering the Hartha formation to prevent or mitigate the occurrence of lost circulation. A unique statistical work, primitive mechanisms, typical drilling fluid properties and recommended operational drilling parameters have been evaluated to use during drilling the Hartha formation. In addition, corrective actions have been determined for each kind of the mud losses to provide effective remedies, minimize non-productive time, and reduce cost.

Lost circulation strategy to the Hartha formation has been summarized depending on statistical work and economic analysis evaluation to determine the most successful remedies for each type of the losses. These treatments are classified by relying on the mud losses classifications in order to avoid unwanted consequences due to inappropriate actions. This study provides a typical compilation of information regarding traditional approaches and the latest approaches to lost circulation control. In addition, the work attempts to provide useful guidelines or references for both situations in terms preventive measures, remedial methods, and analytical economic study.

Keywords: Lost circulation; Engineered solutions; Statistical analysis; Rumaila field; Iraq

Abbreviations: APL: Annular Pressure Loss; bbl/hr: barrels per hour; BPC: Basra Petroleum Company; BPC: British Petroleum Company; D: Depth; DDR: Daily Drilling Report; DOH: Diameter of Open Hole; ECD: Equivalent Circulation Density; FCL: Ferro Chrome Lignosulfonate; 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; WBM: Water Base Mud; WOB: Weight of Bit; WOC: Waiting of Cement; WON: Without Nozzles; Yp: Yield Point Viscosity; $: Dollar

Introduction

Drilling fluid losses and problems associated with lost circulation while drilling represent a major expense in drilling oil and gas wells. By industry estimates, more than 2 billion USD is spent annually to combat and mitigate lost circulation [1].

The Rumaila field in Iraq is one of the largest oilfields in the world. Wells drilled in this field are highly susceptible to lost circulation problems when drilling through the Hartha formation. Lost circulation events range from seepage losses to complete loss of the borehole and are a critical issue in field development. Figure 1 shows the Rumaila field location. 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 Dammam formation. This zone is deeper

*Corresponding author: Al-Hameedi AT, Department of Geoscience and Geological Engineering and Petroleum Engineering, Missouri University of Science and Technology, USA, Tel: +1-832-908-2858; E-mail: ata2q3@mst.edu

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(formation top 1660 m), and it is located below transitional zones like Tayarat and Ummer-Radhuma zones which have abnormal pressures and H_2S flow. Figure 2 shows the borehole and well construction typical of a well drilled in the Rumaila field 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 open hole while the Hartha formation is drilled. A lost circulation event is shown near the bottom of the open hole in Figure 2, but it is possible to have losses simultaneously the Dammam and Hartha formations, or only losses in Hartha as it is drilled. Field methods used to drill Hartha are similar to those noted for Dammam, i.e., reduced WOB, RPM, SPM; adjusting mud properties; slow are careful removal or insertion of drill pipe to avoid surging, and breaking gel strength with rotation [2].

Treating the drilling fluid with conventional LCM as background treatments or concentrated pills is a common industry practice to mitigate seepage or partial losses. Other solutions that require more time for preparation and placement are used when severe or complete losses are encountered such as cement [3-6], chemically activated cross-linked pills (CACP) [7,8], cross-linked cement (Mata and Veiga 2004), deformable-viscous-cohesive systems (DVC) [9,10], nanocomposite gel [11], gunk squeezes and concentrated sand slurries [12,13].

Figure 1: Rumaila field (www.drillingcontractor.org, The Rumaila field .

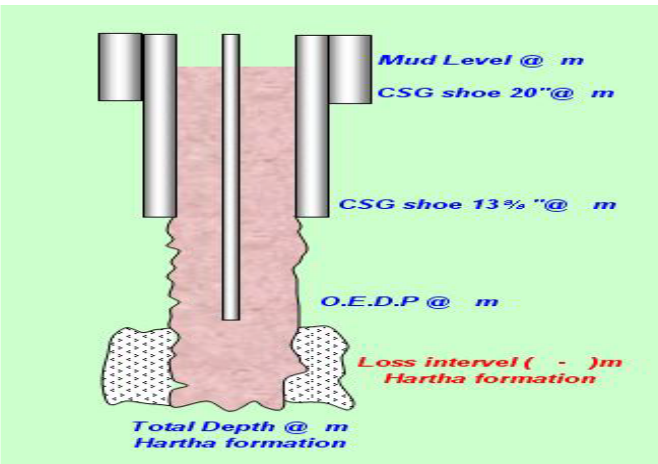

Figure 2: Lost circulation mud in the Hartha formation.

Different testing methods are used to evaluate the performance of LCM treatments, based on the fluid loss volume at a constant pressure, such as the particle plugging apparatus (PPA) or the high-pressure-high-temperature (HPHT) fluid loss in conjunction with slotted/tapered discs or ceramic discs [14,15]. Other testing equipment has been developed to evaluate the sealing efficiency of LCM treatments in sealing permeable/impermeable fractured formations [16-18]. Both particle size distribution (PSD) and total LCM concentration were found to have a significant effect on the sealing efficiency.

This study provides basic information on lost circulation, including an introduction to the problem, identifies a range of factors that affect lost circulation, provide proactive techniques, appropriate corrective actions, and economic evaluation analysis to lost circulation in the Hartha formation. The study summarizes mud loss and lost circulation information extracted from drilling data from the Rumaila field in Iraq. A lost circulation screening criteria are presented for the Rumaila field, based on the historical mud loss and lost circulation problems, materials used to mitigate the problems, and potential solutions found by this study.

Methodology

Lost circulation events were identified for more than 300 wells discussed in this comprehensive statistical study, according to the formation and depth. Drilling parameters which are known to have the greatest impact and the lowest influence on lost circulation, and readily adjusted during the drilling operations were tabled for analyses. This section presents samples of the wells data, including the number of wells analyzed for the Hartha formation. These data have been analyzed to determine the best ranges for the key drilling parameters and mud properties that have the greatest chance of avoiding or mitigating lost circulation in this formation. Actually, all these real data precisely collected from various daily drilling report (DDR), final reports, and technical reports. A broad statistical work has been made in order to determine which drilling mud properties and operational drilling parameters that have a pivotal influence on lost circulation [2]. This extensive study shows that all mud weight (MW), equivalent circulation density (ECD), yield point (Yp) have a direct impact on lost circulation whereas SPM, RPM, ROP, WOB and bit nozzles directly or indirectly effect on this problem [2]. Real data were minutely collected to find out the minimum and maximum range of the related parameters to avoid or mitigate lost circulation. Tables 1 and 2 are samples of daily drilling report (DDR) for this zone to get a coherent image about how all these real data were collected (Tables 1 and 2).

Recommended key drilling parameters have been determined in this paper to prevent or mitigate lost circulation in the Hartha formation. This is done based on reviewing data of key drilling parameters. In addition, mud losses treatments events are examined, and statistical analysis is conducted for these remedies. The probability of each treatment is calculated by adding the number of times they were used successfully divided by the total number of attempts. An economic evaluation is performed for the same data based on the cost of each material and the NPT, the rig cost is estimated to be 36000 $/day. Table 3 shows the prices for lost circulation materials that are used in the economic evaluation [19]. Thus, the lost circulation strategy has been developed by depending on statistical work and economic analysis to efficiently remedy in terms stopping mud losses, minimizing non-

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D, (m)	MW, (gm/cc)	YP	SPM	RPM	Nozzles	Type of losses	Type of Treatment	Result
1674 - 1734	1.12	14	120	60	3*14/32	No Loss	No Treatment	Success
1734 - 1790	1.12	15	110	60	3*14/32	No Loss	No Treatment	Success
1790 - 1821	1.12	14	120	60	3*14/32	No Loss	No Treatment	Success

Table 1: Well data 1 events, the Hartha formation.

D, (m)	MW, (gm/cc)	YP	SPM	RPM	Nozzles	Type of losses	Type of Treatment	Result
1670 - 1740	1.13	17	140	60	3*14/32	Partial Losses	H.V Mud	Success
1740 - 1790	1.13	14	110	60	3*14/32	No Loss	No Treatment	Success
1795	1.14	16	150	70	WON	Severe Loss	Blend LCM	Success

Table 2: Well data 2 events, the Hartha formation.

productive time, and reducing cost. This treatment strategy has been classified by relying on the kind of mud loss. 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 Hartha formation (Table 3).

Material Name	Price for each $/Ton	Price for each $/kg
Bentonite	317	0.317
Mica Fine	500	0.5
Mica Medium	700	0.7
Nut Plug	960	0.96
$CaCO_3$ Medium	313	0.313
$CaCO_3$ Coarse	350	0.35
Super Stop Material	1200	1.2
Blend of LCM	900	0.9
Cement	318	0.318
Diesel Oil	500	0.5

Table 3: Cost of lost circulation materials.

Preventive measures (Proactive approaches)

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 [9]. All those remedies/techniques that are applied prior entering lost circulation zones in order to prevent the occurrence of losses can be defined as proactive methods. The main advantage of using these techniques are to increase the chances of avoiding or minimizing lost circulation in the Hartha formation. In this section, each preventive way will be extensively demonstrated to get a clear image regarding these approaches.

Primitive methods to prevent or restore lost circulation mud

There are some applications which use to inhibit or restore lost circulation mud. Plainly, all these methods are fundamental techniques and primitive mechanisms to avoid or combat mud losses. Figure 3 will illustrate lost circulation mud cases and appropriate treatment.

Waiting method:

• Pull out drilling strings to casing shoe.

• Waiting period between (4-8) 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 in order 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 that leads to decrease extra pressure due to mud circulation.

Reduction of the drilling mud weight: By decreasing mud weight within allowable limits in order 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 likes (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 in order 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.

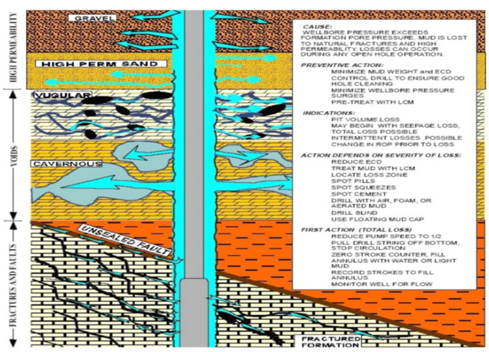

Figure 3: Lost circulation mud cases and appropriate treatment [26].

Recommended key drilling parameters to drill the Hartha Formation: By doing data review, integrated analysis, and comprehensive statistical work for plenty of the wells (More than 300 wells) in order to find out optimal drilling mud properties and proper operational drilling parameters to avoid or mitigate lost circulation mud in this formation as a proactive approach. In this study, several wells data have been examined to detect the typical range of the

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required parameters. Each of the property will be analyzed to figure out the influence of this property on the lost circulation.

Mud weight: This parameter has a pivotal role in lost circulation. By increasing mud weight, hydrostatic pressure will be increased. In the same vein, equivalent circulation density will be maximized. Therefore, excessive mud weight will initiate or aggravate lost circulation problem. Hence, this property should be designed between pore pressure and fracture gradient to avoid unwanted consequences, and it is advisable to do strict surveillance during drilling operations. It is completely normal to change mud weight during drilling by depending on well conditions. In other words, the drilling crew should not adhere completely to the drilling program because it is possible to change mud weight based on the drilling situation. Table 4 will show pore pressure and fracture gradient for the Hartha [20,21] (Table 4).

Formation	Depth, m	PP, (gm/cc)	FP, (gm/cc)	PP, (gm/cc) + Swap Margin	FP, (gm/cc) - Surge Margin
Hartha	1660	1.11	1.15	1.12	1.14

Table 4: Pore and fracture gradient for Hartha (British Petroleum, 2013).

Figure 4 illustrate a plot of lost circulation rate versus mud weight for more than 300 wells drilled through the Hartha formation. The data show a noticeable increase in losses when the mud weight exceeds 1.13 gm/cc. From this Plot, we can deduce that the optimal drilling density to drill the Hartha formation is 1.12 gm/cc to 1.13 gm/cc. By using these values, we can avoid or mitigate lost circulation as much as possible.

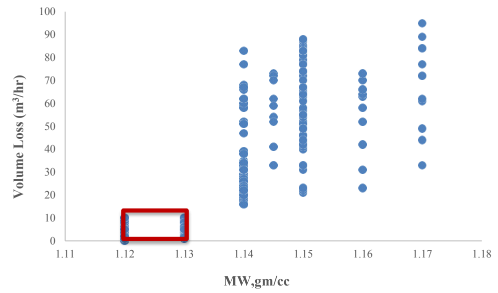

Figure 4: Mud weight versus volume loss (Hartha Formation, 300 wells).

Equivalent circulation density (ECD): This property is related with real downhole pressure (Friction Pressure) into the annulus. Therefore, it is recommended to monitor this parameter during drilling operations. This property has a linear relationship with yield point, mud weight, flow rate, and rate of penetration. By doing gathering data for various wells that have been drilled to determine the optimal equivalent circulation density (ECD) which contribute to avoid or mitigate lost circulation issue in the thief zones.

Figure 5 shows a plot of lost circulation rate versus equivalent circulation density (ECD) for more than 300 wells drilled through the Hartha formation. The data show a noticeable increase in losses when the ECD exceeds 1.15 gm/cc. From this Plot, we can note that proper equivalent circulation density to drill the Hartha formation is 1.13 gm/cc to 1.15 gm/cc. By using these values, we can avoid or mitigate lost circulation as much as possible.

Yield point (Yp): Efficient hole cleaning is largely relying on yield point. In other words, this property is responsible for suspending and lifting cutting to the surface. During drilling operations, this property calls yield point, and during static drilling operations, calls gel strength. Bentonite is one of the most important materials that provides a good yield point, and in the same time, there are other materials like salt clay,

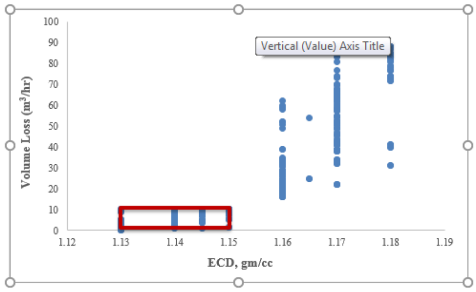

Figure 5: Equivalent Circulation Density (ECD) versus volume loss (Hartha Formation, 300 wells).

PAC-HV, CMC-HV, and lime. There are some chemical materials, which use to control and decrease this property. By increasing this property, equivalent circulation density (ECD) will also maximize. Therefore, it is advisable to maintain this property within upper and lower bound limits. In addition, this parameter is completely depending on the type of drilling mud.

Figure 6 demonstrates a plot of lost circulation rate versus yield point (Yp) for more than 150 wells drilled through the Hartha formation. The data show a noticeable increase in losses when the yield point exceeds 24 Ibf/ft^2. Polymer mud was used for these wells. From this plot, we can diagnose that proper yield point (Yp) that should be used to drill the Hartha zone is from 20 Ibf/ft^2 to 24 Ibf/ft^2. By using these values, we can provide efficient hole cleaning, decrease equivalent circulation density (ECD), and minimize losses pressure (Friction Pressure) into annulus.

By using Ferro Chrome Lignosulfonate mud (FCL-Mud) for the Hartha zone, values of the yield point (Yp) will be different. In this type of the mud, we will largely depend on bentonite material to increase this property. Figure 7 will illustrate the different range of the yield point (Yp) due to different type of the mud for the Hartha formation. From Figure 7, we can conclude that proper yield point (Yp) that should be used to drill the Hartha zone is from 13 Ibf/ft^2 to 15 Ibf/ft^2. By using these values, we can provide efficient hole cleaning and decrease equivalent circulation density (ECD) and losses pressure (Friction Pressure) into annulus.

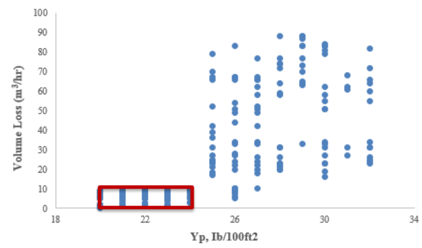

Figure 6: Yield point (Yp) versus volume loss (Hartha formation, Polymer Mud, 150 wells).

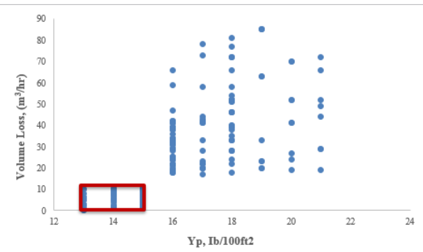

Figure 7: Yield point (Yp) versus volume loss (Hartha formation, FCL Mud, 150 wells).

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Plastic Viscosity (PV): This parameter is related to effective drilling density. It considers the second component of the drilling fluid viscosity. In addition, this property is represented the friction forces between molecules of the drilling mud. This parameter has directly or indirectly role on lost circulation issue. In other words, by increasing plastic viscosity, the ECD will be increased. Thus, it is recommended to use a proper range of this parameter. Figure 8 shows a plot of volume loss versus plastic viscosity (PV) for more than 300 wells drilled through the the Hartha formation. From this plot, the optimal plastic viscosity (PV) to drill the Hartha formation is 9 cp to 14 cp. By using these values, the lost circulation can be mitigated.

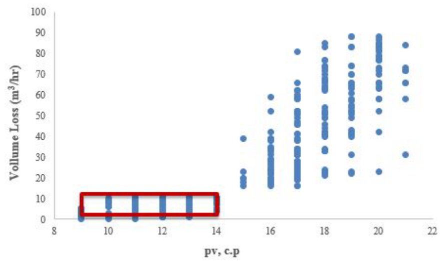

Figure 8: Plastic viscosity versus volume loss (Hartha formation, more than 300 wells).

Weight on Bit (WOB): It has a significant impact on rate of penetration. By increasing weight on bit, rate of penetration (ROP) will be maximized; therefore, effective mud weight will be increased. Hence, weight on bit has directly or indirectly influence on mud loss. Thus, it is practically interest to use a good range of this parameter to avoid unwanted consequences. Figure 9 shows a plot of volume loss versus weight on bit (WOB) for more than 300 wells drilled through the Hartha formation. Therefore, from this plot, the proper weight on bit to drill the Hartha formation is 7 Ton to 13 Ton.

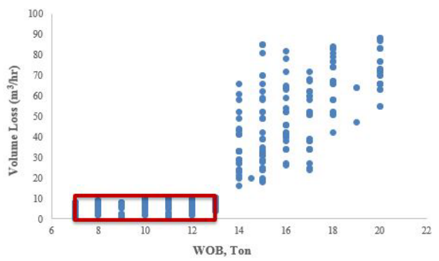

Figure 9: Weight on bit (WOB) versus volume loss (Hartha formation, more than 300 wells).

Strokes per Minute (SPM) & Flow Rate (Q): Both parameters are related to mud pump pressure. They are responsible for drilling mud cycle from mud system to wellbore by using mud pumps. In addition, these properties are associated with effective wellbore cleaning into the annulus. Both of them have either directly or indirectly role on lost circulation issue. In other words, by using high mud pump pressure, extra annulus pressure will be exerted on the thief zone. Hence, it is recommended to use a proper range of these parameters.

Figures 10 and 11 shows plots of volume loss versus strokes per minute (SPM) and flow rate (Q) respectively for more than 300 wells drilled through the Hartha formation. The data show a noticeable increase in losses when the SPM and Q exceed 120 and 2112 (L/STK) respectively. From these figures, that the proper SPM and Q that should be used to drill the Hartha zone are from 100 SPM to 120 SPM and from 1760 L/STK to 2112 L/STK respectively. By using these ranges, efficient hole cleaning as well as the reduction of the fractional pressure in the annulus can be reached.

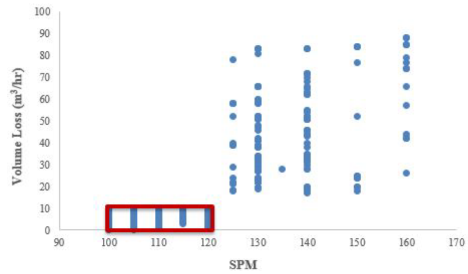

Figure 10: Stroke per minute (SPM) versus volume loss (Hartha formation, more than 300 wells).

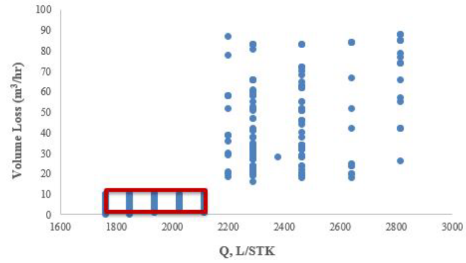

Figure 11: Flow rate (Q) versus volume loss (Hartha formation, more than 300 wells).

Revolutions per minute (RPM): This property is related to rotate drill string, bit, and penetration rate. That means by using high RPM that will lead to have excessive cutting into the annulus, which in turn, it will increase downhole pressure and narrow annulus. Therefore, it is crucial to use RPM parameter within upper and lower bound limits to avoid unwanted consequences. Figure 12 will clarify the relationship between revolutions per minute (RPM) and the loss amount for the Hartha formation. From Figure 12, we can deduce that appropriate revolutions per minute (RPM) that is advisable to us to drill the Hartha formation is from 60 RPM to 70 RPM. By using these ranges, we can provide a good penetration rate, decrease cutting amounts, and minimize friction pressure into annulus.

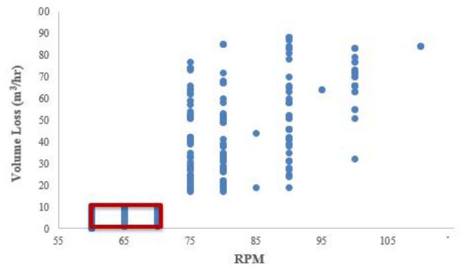

Figure 12: Revolutions per minute (rpm) versus volume loss (Hartha formation, 300 wells).

Rate of Penetration (ROP): Excessive cutting and high rate penetration will lead to increase downhole pressure. In addition, Rate of penetration and drilling fluid density have a linear relationship to maximize equivalent circulation density. ROP has a linear relationship with WOB, SPM, and RPM. Therefore, it is prudent to use appropriate ranges of this property to avoid increasing annular pressure losses (APL) and equivalent circulation density (ECD).

Figure 13 shows a plot of lost circulation rate versus rate of penetration (ROP) for more than 300 wells drilled through the Hartha formation. The data show a noticeable increase in losses when the ROP exceeds 9. From this figure, we can conclude that proper rate versus rate of penetration (ROP) that should be used to drill the Hartha formation is from 4 to 9.

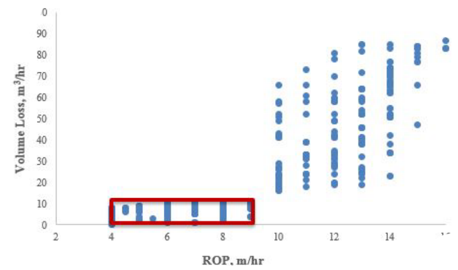

Figure 13: Rate of penetration (rop) versus volume loss (Hartha formation, 300 wells).

Bit without nozzles (WON): It is advisable to use bit without nozzles during drilling the Hartha formation for several reasons like to reduce jet velocity on the formation, minimize non-productive time (NPT), to use any type of lost circulation mud (LCMs), and to avoid nozzles plugging. In the same time, by doing a broad research for various drilled wells, it showed there is no side effect due to bit without nozzles during drilling weak zones. Therefore, it is practically interesting to use bit without nozzles (WON). Figure 14 will clarify the relationship between total flow area of bit nozzles and volume loss for more than 300 wells drilled through the Hartha formation. From this figure, it is easy to see that the use of bit without nozzles will have the lowest mud losses. Therefore, it is recommended to use bit without nozzles when drilling the Hartha formation.

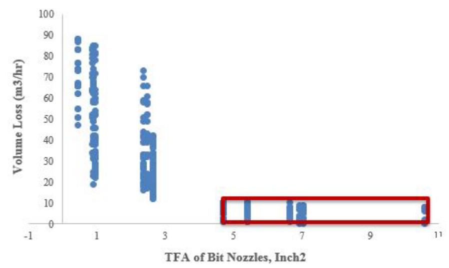

Figure 14: Total flow area of bit nozzles versus volume loss (Hartha formation, more than 300 wells).

Hence, after doing the analysis for various drilled wells in Rumaila field (The Hartha Formation), it is recommended to use the following values of drilling mud properties and operational drilling parameters to avoid or mitigate lost circulation issue during drilling operations. Table 5 shows recommended parameters to drill the Hartha formation. In some cases, under the same recommended parameters, the Hartha formation will suffer from severe losses circulation problem or even complete losses. In these cases, the major reason to have these types of the mud losses is initially using a high range of the drilling properties and operational drilling parameters. In different words, the lost circulation will initiate due to high ranges of the above parameters. After problem occurred even if low ranges of these parameters are used, the problem will continue and we need to do the required treatments to mitigate or stop mud losses.

Property	Minimum Value	Maximum Value
Mud Weight (MW, gm/cc),	1.12	1.13
Equivalent Circulation Density (ECD), (gm/cc)	1.13	1.15
Yield Point (Yp), (Ibf/100ft^2) (Polymer Mud)	20	24
Yield Point (Yp), (Ibf/100ft^2) (FWB Mud)	13	15
Plastic Viscosity (PV), cp	9	14
Weight of Bit (WOB), Ton	7	13
Strokes per Minute (SPM)	100	120
Flow Rate (Q), L/STK	1760	2112
Revolutions per Minute (RPM)	60	70
Rate of Penetration (ROP, m/hr.)	5	9
Bit Nozzles	Without Nozzles	Without Nozzles

Table 5: Recommended drilling mud properties and operational drilling parameters for the Hartha formation.

Corrective methods (Remedial treatments)

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 [22]. Each one of lost circulation material is selected by depending on the type of losses, cost, and type of formation. Lost circulation materials are used to achieve two goals [23]:

- 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.

Several remedies that have already been used in Rumaila field (The Hartha Formation) to stop or mitigate mud losses. Actually, each kind of the mud losses is required specific treatment to stop it or mitigate it. Therefore, it is necessary to detect which kind of losses that we have in order to prepare an optimal remedy for it. By selecting appropriate treatment by depending on the type of the lost circulation, that 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 the losses [21].

Partial losses remedies

In this kind of loss, part of drilling fluid will be lost into formation about (1-10 m^3/hrs.). 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 be aggravated to severe loss or complete loss. Therefore, it is very crucial to do required actions to stop this loss and avoid unwanted consequences. Actually, several treatments have been used to control and mitigate this type of loss. A comprehensive statistical study has been conducted to determine the optimal treatments to stop this type of losses. Figure 15 will show statistical study and success percentage of the recommended actions which should use to treat the partial losses [24-26].

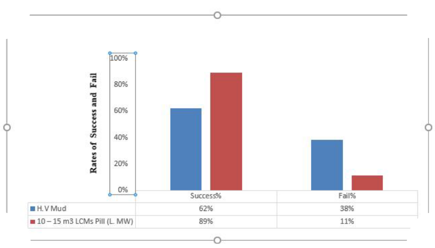

Figure 15: The Recommended remedies for the partial losses (Hartha formation, 300 wells).

Type of Losses	Type of the Treatment	Approach of the Treatment	Waiting
Partial Loss	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 ability to form" brush heap" like mat in pore openings, then creating plug to seal thief zone. It is practically interest 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		

Table 6: Partial losses treatments (Hartha formation).

Severe losses remedies

This kind of loss will be more than partial loss about (15 or above m^3/hrs.). 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 be aggravated to complete loss. Therefore, it is very necessary to do required actions to combat this kind of the losses and avoid bad consequences. A comprehensive statistical study has been conducted to determine the optimal treatments to stop this type of the mud losses. Figure 16 will show statistical study and success percentage of the recommended actions which should use to treat severe losses.

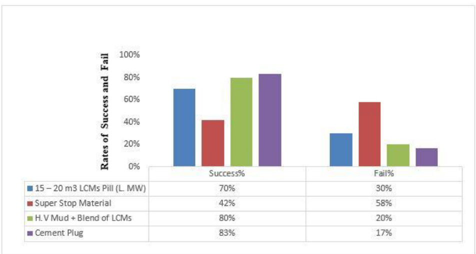

Figure 16: The recommended remedies for the severe losses (Hartha formation, 300 wells).

Actually, many treatments use to control and mitigate this type of loss. Tables 6 and 7 illustrate remedies that use to regulate this type of the mud losses. Each of the treatment will be explained in details below in order to get integrated image about how can apply them [27-30].

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 maximize the expenses of the drilling operations and non-productive time (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 17 will illustrate statistical study and success percentage of the recommended remedies which should use to treat complete losses.

Actually, many treatments use to control and mitigate complete loss. Table 8 will illustrate remedies that should use to regulate this kind of the losses, and Table 9 will demonstrate the description and the executive steps for each of the remedial plug to get integrated image regarding procedures of the application.

Type of Losses	Type of the Treatment		Approach of the Treatment	Waiting
Severe Loss	15 – 20 m^3 LCMs Pill (Low MW		These materials have ability to form" brush heap" like mat in pore openings, then creating 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		
	$CaCO_3$ Medium	30 kg/m^3		
	$CaCO_3$ Coarse	30 kg/m^3		
	High Viscosity Drilling Mud (Low Density) + Blend of the LCMs		By creating plug to seal thief zone.	(4-6) hours
Type of Losses	**Type of the Treatment**		**Approach of the Treatment**	**Waiting**
Severe Loss	Super Stop Material		Mixing (4-5) bags (Weight of Bag 25 kg) of super stop material for each 1 m^3 water.	(4 -5) hours
			This treatment should be mixed in separate and clean tank.	
			It is very crucial to mix quickly in order to avoid treatment bulge in 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.	
	Cement Plug		By pumping cement slurry with specific density in front of thief zone, by using O.E.D.P to plug	(18) hours

Table 7: Severe losses treatments (Hartha formation).

Type of Losses	Type of the Treatment	Approach of the Treatment	Waiting
Complete Loss	Blind Drilling Technique	Using water instead of drilling mud to drill as much as possible from thief zone before doing any actions.	No Waiting
	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 efficient seal, by using O.E.D.P.	(20) hours
	DOB Squeeze (Diesel Oil Bentonite)	By mixing oil base + bentonite to create plug, by using O.E.D.P to seal zone with squeeze technique.	(0) hours
	DOBC Squeeze (Diesel Oil Bentonite Cement)	By mixing oil base + bentonite + cement to create plug, by using O.E.D.P to seal zone with squeeze technique.	(12) hours

Table 8: Complete losses treatments (Hartha Formation).

Economic evaluation

The economic evaluation is conducted for partial, severe, and complete losses. Table 10 shows the results of the economic evaluation for the best partial losses treatments with their probabilities, Pill of LCM treatment has a higher probability of success than the H.V Mud Patch treatment. Table 11 shows the economic calculations for the best severe losses treatments, the cement plug treatment has the highest probability of success for the severe losses.

Economic evaluation and probabilities for the best complete losses treatments are shown in Table 12, DOB Plug treatment has the highest probability of success. Treatments are summarized, and the best approaches are deduced by depending on statistical analysis and economic evaluation for treatments that were used for the Hartha formation. Treatments are classified by relying on the mud losses classifications in order to get effective remedies, minimize cost, reduce non-productive time, and avoid unwanted consequences due to inappropriate actions.

Recommended lost circulation strategy to the Hartha Formation

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 Hartha formation. 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

<table>
<tr><th>Name of the Treatment</th><th>Description</th><th colspan="2">Procedures</th></tr>
<tr><td rowspan="9">Cement plug + HV Mud</td><td rowspan="9">This plug is very prominent and very prevalent in oil industry field. This treatment is used to combat complete losses. It is very necessary to do very accurate calculations regarding the weight of cement.</td><td colspan="2">Calculate the density of the cement.</td></tr>
<tr><td colspan="2">Using open end drill pipe (O.E.D.P).</td></tr>
<tr><td colspan="2">Pumping HV mud patch.</td></tr>
<tr><td colspan="2">Pumping the required cement volume.</td></tr>
<tr><td colspan="2">Displacing the plug in front of losses zone by using normal drilling mud.</td></tr>
<tr><td colspan="2">Avoidance contamination between plug and drilling fluid.</td></tr>
<tr><td colspan="2">Pumping normal drilling fluid in order to clean open end drill pipe (O.E.D.P).</td></tr>
<tr><td colspan="2">Pulling out drill pipes strings to casing shoe.</td></tr>
<tr><td colspan="2">Waiting period around (18 - 20 hours) in order to harden cement plug.</td></tr>
<tr><td rowspan="12">DOB Squeeze (Diesel Oil Bentonite)</td><td rowspan="12">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.</td><td colspan="2">Formula for 1 m³ (Final)</td></tr>
<tr><td>Oil base</td><td>0.70 m³</td></tr>
<tr><td>Bentonite</td><td>800 kg</td></tr>
<tr><td colspan="2">Using open end drill pipe (O.E.D.P).</td></tr>
<tr><td colspan="2">Cleaning all mixing tanks and pumping pipes.</td></tr>
<tr><td colspan="2">Two Pumps are required.</td></tr>
<tr><td colspan="2">Initially, pumping clean water in front of the loss zone to guarantee bentonite hydration.</td></tr>
<tr><td colspan="2">Squeezing process is required.</td></tr>
<tr><td colspan="2">Displacing the plug in front of losses zone by using normal drilling mud.</td></tr>
<tr><td colspan="2">Avoidance contamination between plug and drilling fluid.</td></tr>
<tr><td colspan="2">Pulling out drill pipes strings to casing shoe.</td></tr>
<tr><td colspan="2">Waiting period around (10 hours) in order to harden cement plug.</td></tr>
<tr><td rowspan="5">DOBC Squeeze (Diesel) Oil Bentonite (Cement)</td><td rowspan="5">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.</td><td colspan="2">Formula for 1 m³ (Final)</td></tr>
<tr><td>Oil base</td><td>0.72 m³</td></tr>
<tr><td>Bentonite</td><td>450 kg</td></tr>
<tr><td>Cement</td><td>450 kg</td></tr>
<tr><td colspan="2">The implementation principle of this treatment is exactly the same technique for diesel oil bentonite plug.</td></tr>
</table>

Table 9: The executive procedures for the remedial plugs (Complete losses, Hartha formation).

Treatment Name	Required Addition, kg/m³	Cost, $/m³	Waiting Period, (hrs)	NPT Cost, $/1 hr	Total Cost, ($)	Success %	Fail %
H.V Mud Patch	100	31.7	2.5	1500	3781.7	62	38
Pill of LCM	Mica Fine (15), Mica Medium (15), Nut Plug (15), Caco3 Medium (15), $CaCO_3$ Coarse (15)	42.345	3.5	1500	5292.345	89	11

Table 10: Partial losses economic calculations and probabilities.

Treatment Name	Required Addition, kg/m³	Cost, $/m³	Waiting Period, (hrs)	NPT Cost, $/1hr	Total Cost, ($)	Success %	Fail %
Pill of LCM	Mica Fine (30), Mica Medium (30), Nut Plug (30), $CaCO_3$ Medium (30), $CaCO_3$ Coarse (30)	84.69	3.5	1500	5334.69	70	30
Super Stop Material	125	150	4.5	1500	6900	42	58
H.V Mud + Blend of LCM	Bentonite (100), Blend LCM (45)	72.2	5	1500	7572.2	80	20
Cement Plug	1103	350.60	18	1500	27351	83	17

Table 11: Severe losses economic calculations and probabilities.

Treatment Name	Required Addition, kg/m³		Cost, $/m³	Waiting Period, (hrs)	NPT Cost, $/1 hr	Total Cost, ($)	Success %	Fail %
Cement Plug	1102.5		351	18	1500	27351	47	53
H.V. Mud +Cement Plug	Bentonite (100)		382.30	20	1500	30382.30	64	36
	Cement (1029)							
DOB Plug	Formula for 1 m³		603.6	10	1500	15603.6	80	20
	Oil base	0.70 m³						
	Bentonite	800 kg						
DOBC Plug	**Formula for 1 m³**		645.75	12	1500	18645.75	78	22
	Oil base	0.72 m³						
	Bentonite	450 kg						
	Cement	450 kg						

Table 12: Complete losses economic calculations and probabilities.

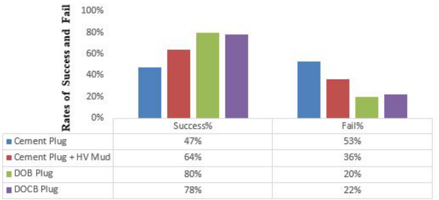

Figure 17: The recommended remedies for the complete losses (Hartha formation, 300 wells).

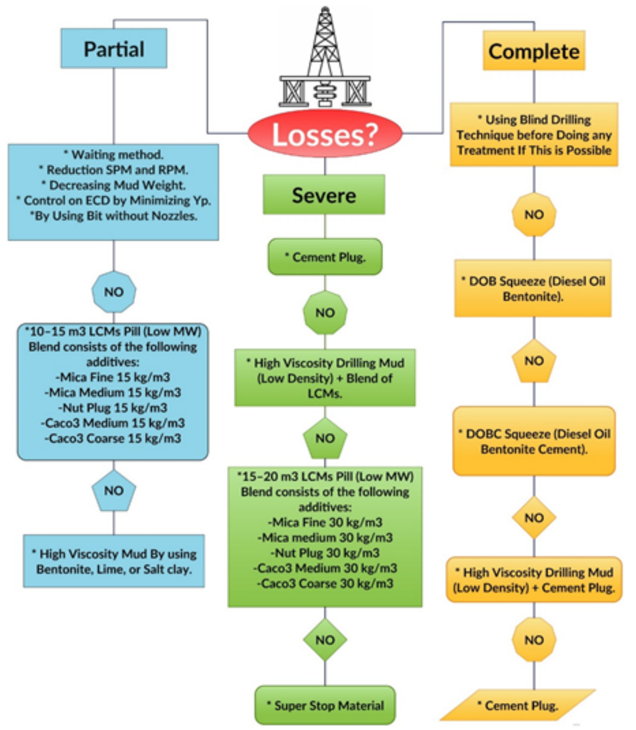

Figure 18: Treatment strategy to Hartha formation.

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 section will be summarized the required treatments for each type of the lost circulation. Figure 18 is concluded by depending on data analysis for treatments that were used for the Hartha formation. More than 300 wells have been analyzed to figure out successful remedies for each type of the losses, and these treatments are classified by relying on the mud losses classifications in order 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 this formation, based on the historical mud loss and lost circulation problems, materials used to mitigate the problems, and potential solutions found by this study. In addition, practical field information from a range of sources were reviewed and summarized o develop an integrated methodology and flowchart for handling lost circulation events in the Hartha formation. Lost circulation strategy to the Hartha formation will be organized depending on the efficiency of the remedy (high success percentage) for several reasons like:

• To maximize the guarantee of the treatment success.

• To avoid or reduce repetition of the treatments that use to stop lost circulation.

• To minimize Non-Productive time 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.

Conclusions and Recommendations

This paper has provided a detailed study of lost circulation, including a brief review of fundamentals of lost circulation, analyzing real field data, discussion of methods of mitigating losses, and an introduction to newer methods of loss control used in industry. Lost circulation presents a lot of challenges while drilling operations. To address these problems, a number of methods/techniques have evolved over the years. Lost circulation solutions may be applied before or after the occurrence of the problem. The solutions are therefore grouped into preventive and remedial respectively.

Based on this study, the following conclusions were made:

• Based on reviewing drilling reports, it is possible to extract lost circulation event data and determine drilling fluid properties and operational drilling parameters that can mitigate mud losses while drilling through the Hartha formation.

• The optimal parameters summarized in this work (Tables 5) are all within the range of parameters currently used to drill wells for thief zone in Rumaila field and it should be feasible to restrict the properties to these values and still successfully drill through the Hartha zone.

• One challenge in drilling wells in the Rumaila field is the inconsistency of approaches to the lost circulation problem. Hence, a formalized methodology for responding to losses in the Hartha formation is developed and provided as means of assisting drilling personnel to work through the lost circulation problem in a systematic way.

• Lost circulation problem in the Hartha formation should be prevented in the first place rather than controlling it; therefore, a keen observation and a backup strategy should be employed in the field to mitigate this problem.

• Treatments for partial, severe, and complete losses for the Hartha formation are summarized in a flow chart. This flow chart should be used to treat the mud losses in the Hartha formation depending on the type of the mud losses.

• 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.

• The best treatment to begin with for the complete losses is DOB. This treatment is not easy to be performed in the field. Thus, mud crew should be trained to perform this treatment correctly and to maximize the success of the treatment.

• NPT is the most influence factor in the cost of the mud losses treatments. Thus, any treatment that has a low probability of success should not be used as a first choice to treat mud losses.

• It is not easy to find guaranteed methods which entirely control or solve lost circulation problems. However, there are some techniques and approaches can be used to prevent its occurrence.

• Engineering guidelines and practical solutions 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.

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