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Petroleum Engineering Department

Stopping Lost Circulation in Dammam Formation, South Rumaila Field

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DECLARATION

I hereby declare that this project report is based on my original work except for citations and

quotations, which have been duly acknowledged.

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APPROVAL FOR SUBMISSION

I certify that this project report entitle " Lost Circulation mud problem in Dammam Formation
in southern Rumaila field , the prevention methods and treatment " was prepared by
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Abstract

Lost circulation is a challenging problem to be prevented or mitigated in the Dammam formation. Major progress is made to detect lost circulation and how to combat it. This paper describes the study of lost circulation events in more than 75 wells in South Rumaila field. Data are analyzed to determine the best ranges for key drilling parameters and provide the best remedial strategies, which have the greatest chance of mitigating or preventing this problem .Real field data (e.g. MW, ECD, Yp, RPM, SPM, and ROP) at the time of each event are recorded along with the lost circulation remedies attempted, and the outcome of those remedies. Practical field information from South Rumaila field and range of sources are reviewed and summarized to develop an integrated methodology and flowchart for handling lost circulation events in this zone. This paper will be extended work along with previous comprehensive statistical study and sensitivity analysis models about the Dammam formation. In addition, economic evaluation analysis is conducted for partial, severe, and complete losses to obtain the best field procedures .Proactive approaches are made prior entering the Dammam formation to prevent or mitigate the occurrence of the lost circulation. A broad statistical work, primitive mechanisms, typical drilling fluid properties, and recommended operational drilling parameters are estimated to use during drilling through this zone. Moreover, corrective actions are determined for each kind of the mud losses to provide efficient remedies, minimize non-productive time, and reduce cost.

Chapter one

1.1 Introduction

Lost circulation is a phenomenon in which the drilling fluid flows into one or more geological formations instead of returning back to the annulus and surface. As a result of this, the oil industry suffers a loss of over one billion dollars annually in rig time, materials, and other financial resources. Lost circulation is a common drilling problem especially in highly permeable formations, depleted reservoirs, and fractured or cavernous formations. The range of lost circulation problems begin in the shallow, unconsolidated formations and extend into the well-consolidated formations that are fractured by the hydrostatic head imposed by the drilling mud.

Lost circulation is a significant problem in the oil and gas industry. By industry estimates, more than 2 billion USD is spent to combat and mitigate this problem Although it may occur in any formation, some primary contributors to loss circulation are high permeability weakly consolidated formations, fracture calcium carbonate reservoirs and depleted aquifer zones.

Given sufficient experience in drilling a particular type of formation, it may be possible to avoid, or significantly minimize lost circulation events by controlling drilling fluid properties, rate of penetration, and other field parameters. However, this requires a high level of experience and study, which is generally not available. For this reason, the industry relies heavily on using methods of mitigating lost circulation events after they occur.

This study provides 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 Dammam formation.

The study summarizes mud loss and lost circulation information extracted from drilling data from the South Rumaila Field in Iraq. A lost circulation screening criteria are presented for the South Rumalia Field, based on the historical mud loss and lost circulation problems, materials used to mitigate the problems, and potential solutions found by this study.

1.2 Study area

South Rumaila Oil Field.

Discovered by the Iraq Petroleum Company in 1953, the Rumaila oil field spans a vast area of 1,600km² by extending frm north to south for approximately 80km and from west to east for 20km.

The main reservoir structures of the field are Zubair (Main Pay) formation, Upper Shale reservoir, and the Mishrif reservoir, which lies in the northern part of Rumaila.

Situated up to 4km-deep beneath the surface, the Rumaila reservoirs comprise sandstone and carbonate formations of Cretaceous age.

Commercial oil production at the Rumaila field was commenced towards the end of 1954 and grew steadily to peak at 1.75Mbopd in May 1979.

Figure 1: Location Map of Steady area

1.3 OBJECTIVES OF THE STUDY

The main aims of this work can be summarized as the following

- To provide a new classification for mud loss corrective and proactive methods used by the oil industry.
- To gather data of the key drilling parameters affecting lost circulation from many wells drilled in Iraq.
- To collect lost circulation treatment data based on the type of loss.
- To utilize machine learning and other statistical methods to create models that can predict mud loss for three formations in Basra city, Iraq (Dammam) prior to drilling. Then, provides recommendations of key drilling parameters that can mitigate the lost circulation problem.
- Since mud loss is affected by equivalent circulation density (ECD), and ECD can only be calculated while drilling using hydraulics, an empirical equation was created to estimate ECD prior to drilling the aforementioned formations. In addition, ECD is affected by the rate of penetration (ROP), which is also acquired while drilling. Thus, an empirical equation was created to estimate ROP prior to drilling.
- To perform a sensitivity analysis to understand the effect of each key drilling parameter on the lost circulation problem.
- To use data mining techniques to classify the mud loss treatments depending on the type of loss. Then, to come up with the best lost circulation treatment strategy for each type of loss.

Chapter two

2.1 Dammam Formation

Dammam formation is the first formation in South Rumaila field that is prone to mud losses. The top of this zone is found between 435 to 490 m, and all of the wells in the field must be drilled through this zone. The interval is composed of interbedded limestone and dolomite, which is generally 200 to 260 m thick. The top of the Dammam was eroded after burial and is karstified at depth. The karst features are believed to lead to the mud losses seen while drilling through this interval .
Figure 1 Shows borehole and well construction typical of a well drilled in the Dammam formation.

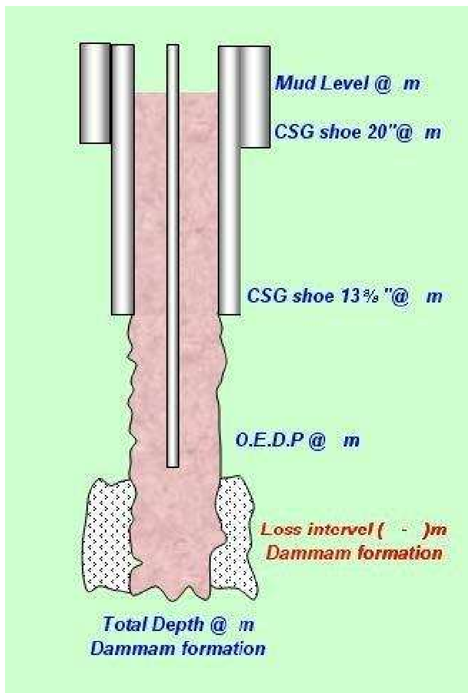

Figure 2—Lost Circulation Mud in Dammam Formatio

Lost circulation may occur in the Dammam formation during drilling the zone or completing the zone. Common field practices in drilling the Dammam include reducing drilling parameters like WOB, RPM, and SPM, and altering drilling mud properties while drilling this formation. In addition, a bit without nozzles is often used to avoid jet velocity against the borehole walls. It is also recommended to run in and pull out drill strings slowly to reduce pressure on the formation. It is also very important to break gel strength for drilling mud into the hole by using rotation before circulatig drilling fluid into the hole.

2.2 Methodology

Lost circulation events were identified for more than 75 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 tabulated for analyses.

This section presents samples of the wells data, including the number of wells analyzed for the Dammam formation. These data were analyzed to determine ranges for the key drilling parameters and mud properties that have the greatest chance of avoiding or mitigating lost circulation in this formation.

All these real data precisely collected from various daily drilling report (DDR), final reports, and technical reports. A broad statistical analysis has been made to determine which drilling mud properties and operational drilling parameters that have a pivotal influence on lost circulation.

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 impact on this problem .

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 is samples of daily drilling report (DDR) for this zone to get a coherent image about how all these real data were collected

Table 1—Well Data Events, Dammam Formation

Depth (m)	MW(gm/cc	YP	SPM	RPM	nozzles	Type of losses	Type of treatment	result
438-512	1.06	12	110	60	WON	No loss	No treatment	success
512-562	1.07	20	130	70	WON	Complete loss	H.V Mud	Fail
562-632	/	/	140	75	WON	Complete loss	Blind drilling	success
632	/	/	140	75	No bit	Complete loss	Cement plug	Fail
632	/	/	180	75	No bit	Complete loss	H.V Mud + Cement plug	success
632-668	1.05	14	100	55	WON	No loss	No treatment	success
668-704	1.05	14	105	55	WON	No loss	No treatment	success

Recommended key drilling parameters have been determined in this paper to prevent or mitigate lost circulation in the Dammam 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 2 shows the prices for lost circulation materials that are used in the economic evaluation .

Table 2—Cost of Lost Circulation Materials

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

2.3 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.

Ty6All those remedies/techniques that are applied prior to entering lost circulation zones to prevent the occurrence of losses can be defined as proactive methods. The main advantage of using these techniques are to increase the chances of avoiding or minimizing lost circulation in the Dammam formation. In this section, each preventive approach will be extensively demonstrated to get a clear image regarding these approaches.

2.3.1 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 2 will illustrate lost circulation mud cases and appropriate treatment

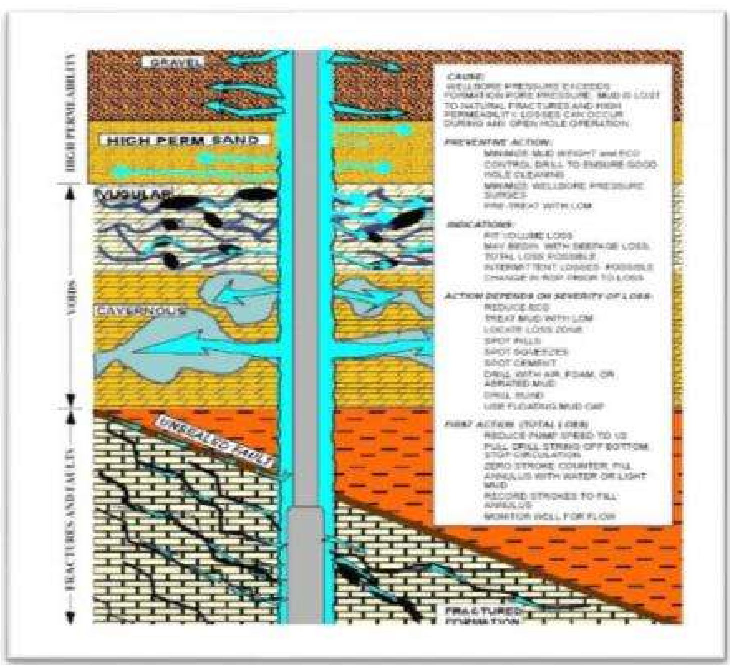

Figure 3—Lost Circulation Mud Cases and Appropriate Treatment (

2.3.2 Waiting Method:

1. Pull out drilling strings to casing shoe.
2. Waiting period between (4-8) hours.
3. Drilling strings will gradually run in hole.
4. Circulate drilling mud and rotate drilling string slowly.
5. Check mud levels in mud tanks system to make sure there are no mud losses.
6. Starting drilling operation at moderate speeds to seal formation apertures by engraved cutting.

2.3.3 Reduction of the Pump Rate:

This technique is used to restore or prevent partial losses. When the pump rate is reduced, the friction pressure in the annulus will be reduced. Thus, the extra pressure due to friction will be small.

2.3.4 Reduction of the Drilling Mud Weight:

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

2.3.5 Increasing of the Drilling Fluid Viscosity:

This mechanism often used during drilling shallow, unconsolidated, and high permeability formation (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.

2.3.6 By Using Bit Without Nozzles:

This will reduce the jet velocity due to nozzles.

- If drilling operations are under shutdown situation, it is best to rotate drilling strings about 15 minutes without mud circulation when drilling operations resume to break gel strength.
- Stabilizers should not be used during drilling depleted or weak formations.
- Lowering drill strings into wellbore slowly in front of unconsolidated zones.

Chapter Three

3.1 Recommended Key Drilling Parameters to Drill the Dammam Formation

On this study, the ranges of key drilling parameters to drill the Dammam formation are identified and summarized by reviewing historical data, integrated analysis, and comprehensive statistical study. As a proactive approach, each key drilling parameter is analyzed separately to estimate the best operational range that will prevent or mitigate mud losses.

➢ 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 3 will show pore pressure and fracture gradient for the Dammam

Table 3—Pore Pressure and Fracture Gradient for the Dammam (British Petroleum, 2013)

Formation	Depth, m	PP, (gm/cc)	FP, (gm/cc)	PP, (gm/cc) + Swap Margin	FP, (gm/cc) - Surge Margin
Dammam	500	1.045	1.08	1.06	1.07

Figure 4 shows a plot of volume loss versus mud weight for more than 75 wells drilled through Dammam formation. The data show a noticeable increase in losses when the mud weight exceeds 1.06 gm/cc. Therefore, from this plot, the optimal mud weight to drill the Dammam formation is 1.05 gm/cc to 1.06 gm/ cc. By using these values, the lost circulation can be avoided or mitigated.

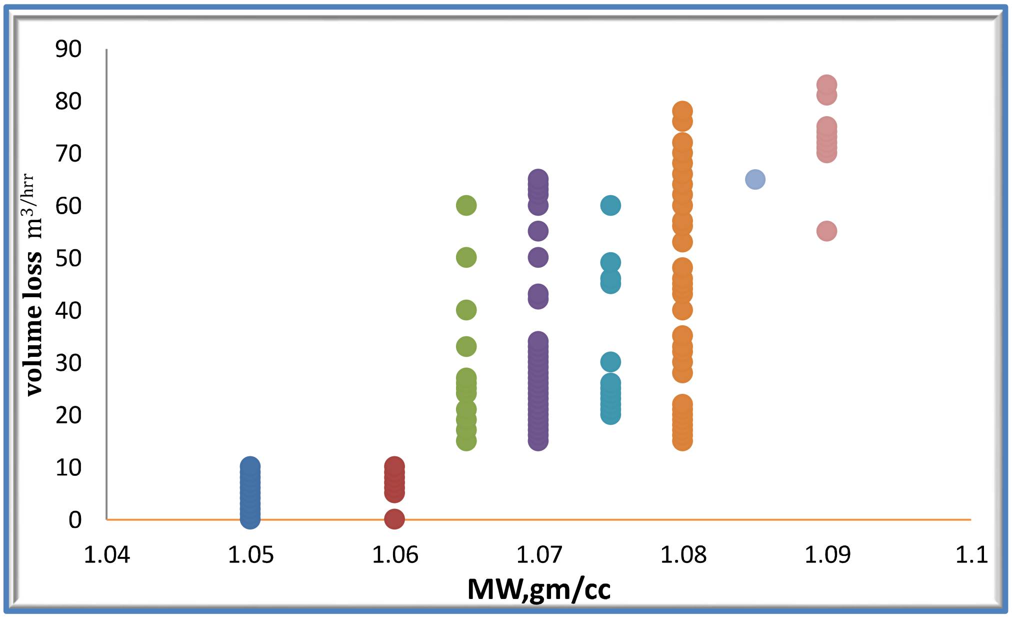

Figure 4—Mud Weight versus Volume Loss (Dammam Zone, more than 75 wells)

Equivalent Circulation Density (ECD):

This property is related with real downhole pressure (friction pressure) in 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.

Figure 5 shows a plot of lost circulation rate versus ECD for more than 75 wells drilled through the Dammam formation. The data show a noticeable increase in losses when the ECD exceeds 1.075 gm/cc. Therefore, from this plot, that the proper ECD to drill the Dammam formation is 1.06 gm/cc to 1.075 gm/ cc. By using these values, the lost circulation can be avoided or mitigated.

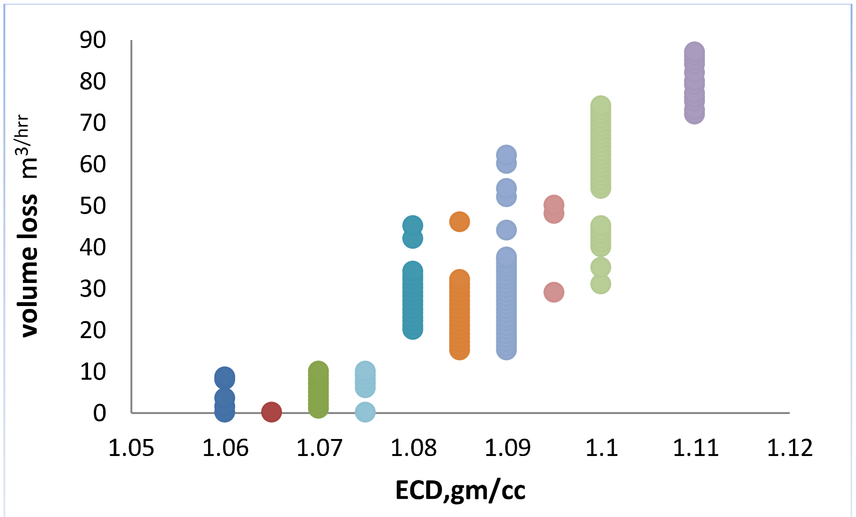

Figure 5—Equivalent Circulation Density (ECD) versus Volume Loss (Dammam Zone, more than 75 wells)

Yield Point (Yp):

Efficient hole cleaning is largely relying on yield point. This property is responsible for suspending and lifting cutting to the surface. During dynamic drilling operations, this property called yield point. However, during static drilling operations, it is called gel strength. Bentonite is one of the most important materials that provides a good yield point, and in the same time, there are many materials that are used to increase yield point like salt clay, PAC-HV, CMC-HV, and lime. Other chemicals can be used to control and decrease yield point. By increasing this property, ECD will be maximized. 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 volume loss versus yield point (Yp) for more than 75 wells drilled through the Dammam formation. The data show a noticeable increase in losses when the yield point exceeds 25 Ibf/100ft2 . Polymer mud was used for these wells. From this figure, the proper yield point (Yp) that should be used to drill the Dammam zone is from 20 Ibf/100ft2 to 25 Ibf/100ft2 . By using these values, efficient hole cleaning can be provided as well as minimizing the friction pressure in the annulus (which will decrease ECD).

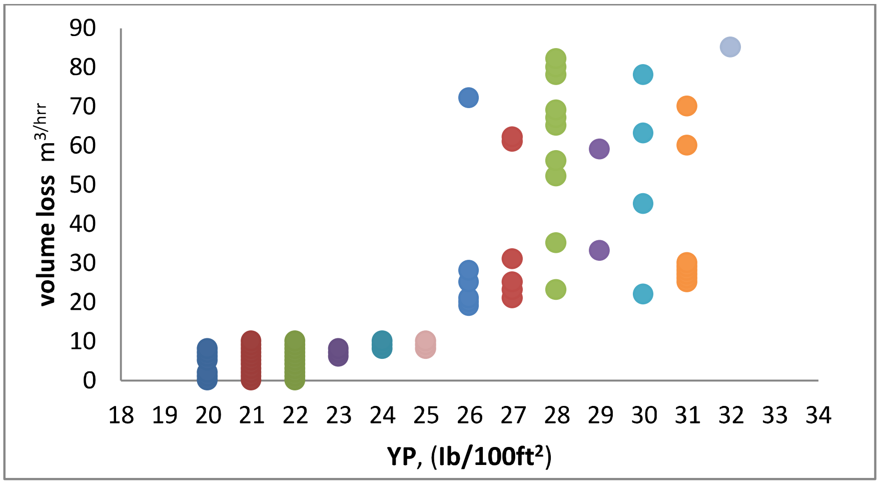

Figure 6—Yield Point (Yp) versus Volume Loss (Dammam, Polymer Mud, more than 75 Wells)

By using fresh water-bentonite mud (FWB-Mud) for THE Dammam zone, values of the yield point (Yp) will be different. In this type of the mud, bentonite is used to increase this property. Figure 7 shows the yield point (Yp) versus the volume loss in the Dammam formation

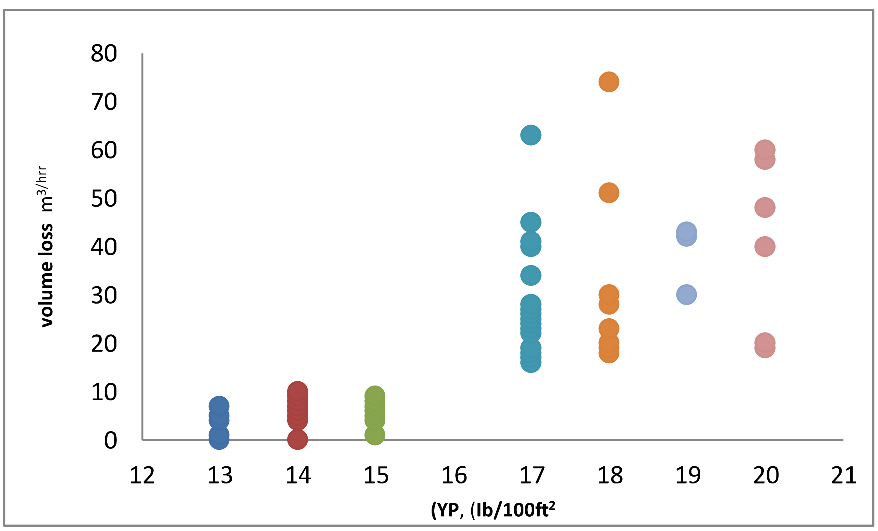

Figure 7—Yield Point (Yp) versus Volume Loss (Dammam Zone, FWB Mud, more than 75 Wells

From above figure 7, the proper yield point (Yp) that should be used to drill the Dammam zone is from 13 Ibf/100ft2 to 15 Ibf/100ft2 .

➢ 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 75 wells drilled through the Dammam formation. From this plot, the optimal plastic viscosity (PV) to drill the Dammam formation is 6 cp to 10 cp. By using these values, the lost circulation can be mitigated.

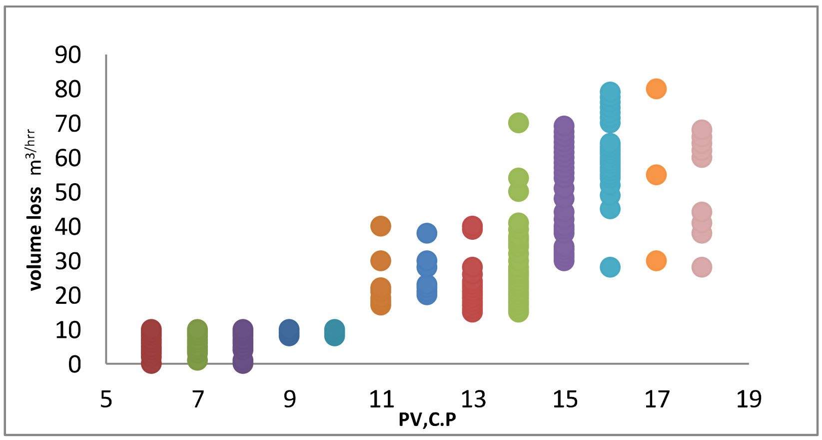

Figure 8—Plastic Viscosity versus Volume Loss (Dammam Zone, more than 75 Wells

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 75 wells drilled through the Dammam formation. Therefore, from this plot, the proper weight on bit to drill the Dammam formation is 5 Ton to 10 Ton.

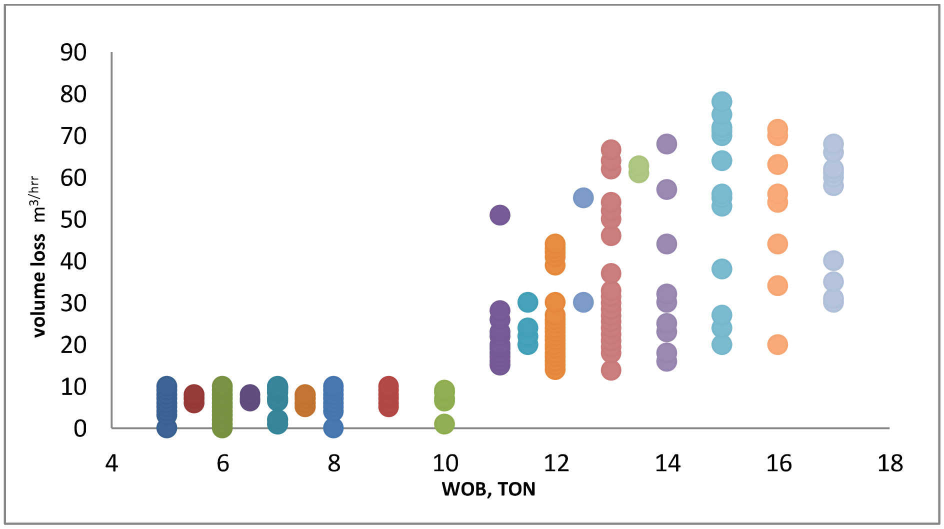

Figure 9—Weight on bit (WOB) versus Volume Loss (Dammam Zone, more than 75 Wells

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. Figure 10 and 11 shows plots of volume loss versus strokes per minute (SPM) and flow rate (Q) respectively for more than 75 wells drilled through the Dammam formation. The data show a noticeable increase in losses when the SPM and Q exceed 110 and 1936 (L/STK) respectively. From these figures, that the proper SPM and Q that should be used to drill the Dammam zone are from 100 SPM to 110 SPM and from 1760 L/STK to 1936 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.

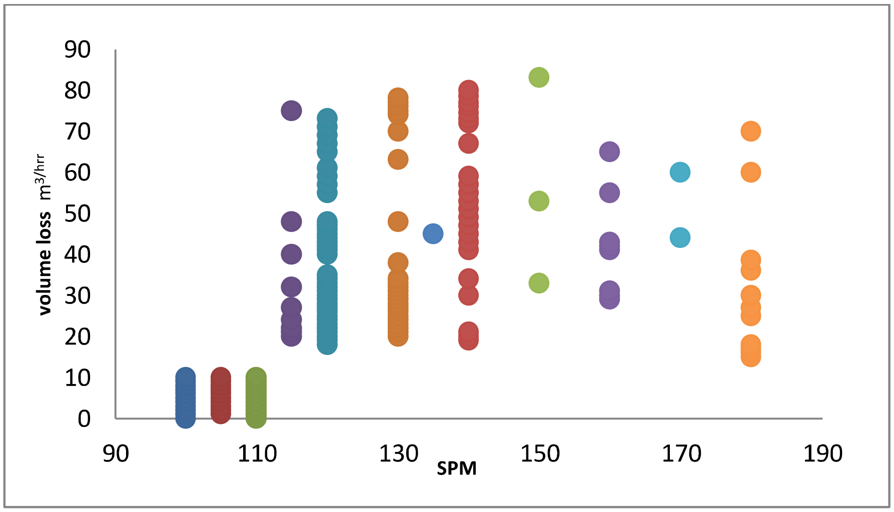

Figure 10—Stroke per Minute (SPM) versus Volume Loss (Dammam Zone, more than 75 Wells)

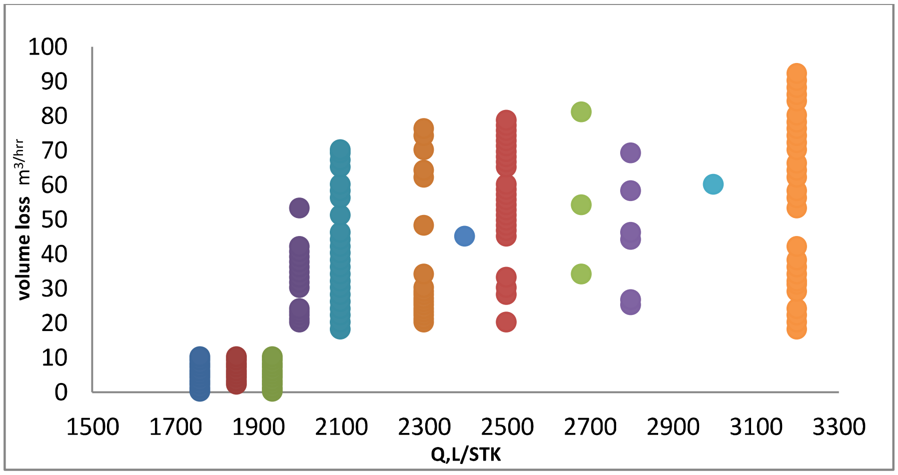

Figure 11—Flow rate (Q) versus Volume Loss (Dammam Zone, more than 75 Wells)

Revolutions per Minute (RPM):

This property is related to rotate drill string, bit, and penetration rate. Using high RPM will lead to have excessive cutting into the annulus, which 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 and volume loss for the Dammam formation.

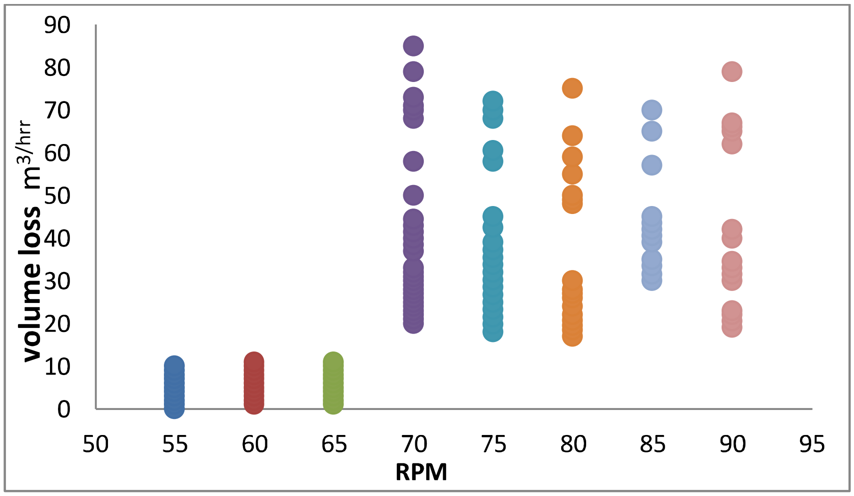

Figure 12—Revolutions per Minute (RPM) versus Losses Amount (Dammam Zone, more than 75 wells)

From above figure 11, the appropriate RPM that is advisable to us to drill the Dammam formation is from 55 RPM to 65 RPM. By using these ranges, a good penetration rate can be provided, decrease the amount of cutting, and minimize friction pressure into the annulus.

Rate of Penetration (ROP):

Excessive cutting and high ROP will lead to increase downhole pressure. In addition, ROP and mud weight have a linear relationship with ECD. 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 volume loss versus ROP for more than 75 wells drilled through the Dammam formation. The data show a noticeable increase in losses when the ROP exceeds 8. From this figure, the proper ROP that should be used to drill the Dammam formation is from 5 to 8 m/hr.

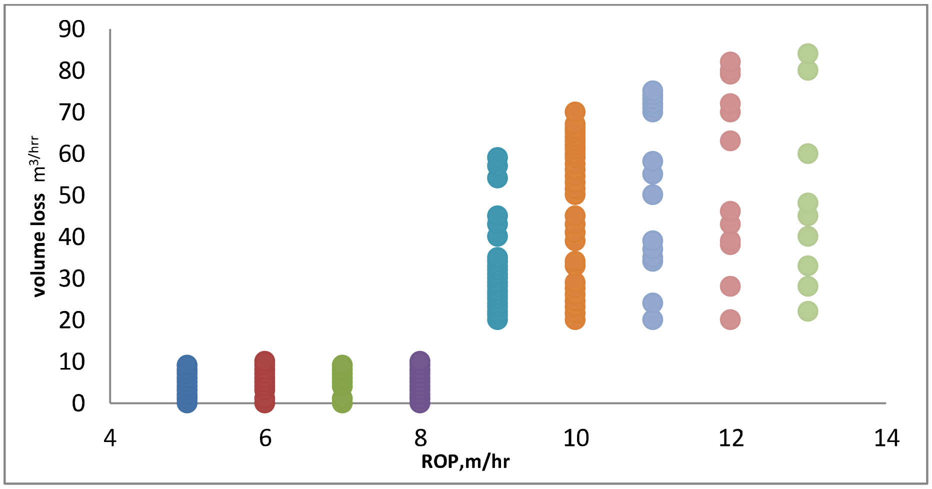

Figure 13—Rate of Penetration (ROP) versus Losses Amount (Dammam Zone, more than 75 wells)

Bit Without Nozzles (WON):

It is advisable to use bit without nozzles during drilling the Dammam 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 75 wells drilled through the Dammam 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 Dammam formation.

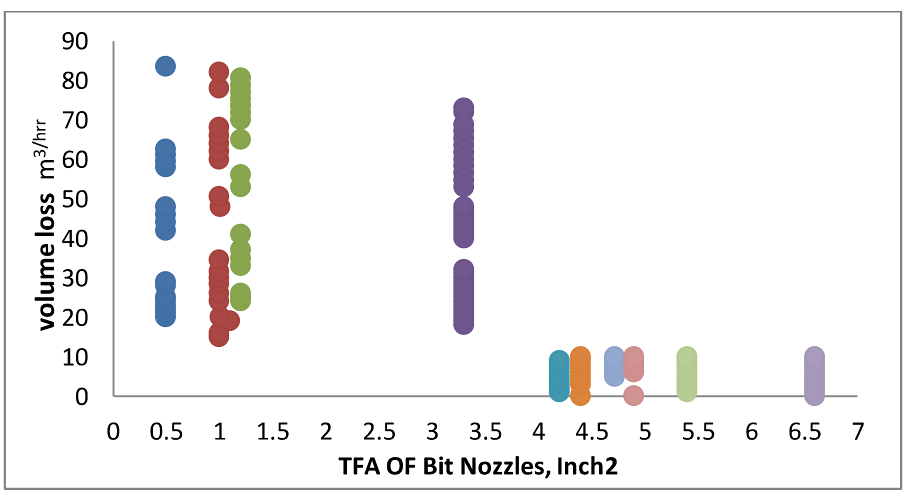

Figure 14—Total Flow Area of Bit Nozzles versus Losses Amount (Dammam Zone, more than 75 wells)

Table 4 shows recommended key drilling parameters to drill the Dammam formation. In some cases, under the same recommended parameters, the Dammam zone will suffer from severe mud loss problem or even complete losses. In these cases, the major reason to have these types of mud loss is using a high range of key drilling parameters before using recommended key drilling parameters. In different words, the lost circulation will initiate due to high ranges of the above parameters. If the recommended key drilling parameters are not utilized initially and the lost circulation problem is occurred, the key drilling parameters can't be used afterwards and the only option left is to use corrective treatments to mitigate or stop losses.

Table 4—Recommended Drilling Mud Properties and Operational Drilling Parameters for Dammam Formation

Property	Minimum Value	Maximum Value
Mud Weight (MW, gm/cc),	1.05	1.06
Equivalent Circulation Density (ECD), (gm/cc)	1.06	1.075
Yield Point (Yp), (lbf/100ft^2) (Polymer Mud)	20	25
Yield Point (Yp), (lbf/100ft^2) (FWB Mud)	13	15
Plastic Viscosity (PV), cp	6	10
Weight of Bit (WOB), Ton	5	10
Strokes per Minute (SPM)	100	110
Flow Rate (Q), L/STK	1760	1936
Revolutions per Minute (RPM)	55	65
Rate of Penetration (ROP, m/hr.)	5	8
Bit Nozzles	Without Nozzles	Without Nozzles

3.2 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 .

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 :

- 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 been used in the South Rumaila field (Dammam Formation) to stop or mitigate mud losses. Each type of the mud losses requires a specific treatment to stop or mitigate it. Therefore, it is necessary to detect which type of losses is experienced to prepare an optimal remedy for it. Selecting appropriate treatment by depending on the type of the lost circulation 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 losses .

3.3 Partial Losses Remedies

In this type of loss, part of drilling fluid will be lost into formation about (1-10 m3 /hrs.). This type of loss is the simplest one, and it is easy to control it. However, by ignoring this type of loss, it will aggravate to severe loss or complete loss. Therefore, it is very crucial to do required actions to stop this loss and to avoid unwanted consequences. 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 loss. Figure 14 shows the probability of success and failure for the recommended actions which should be used to treat partial losses.

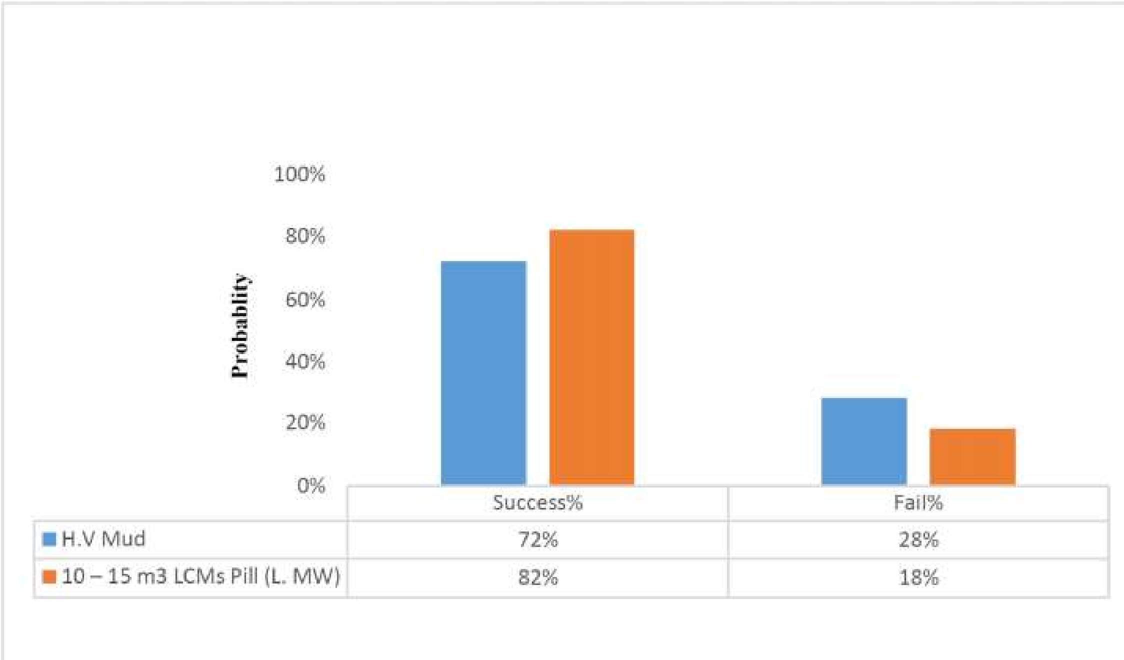

Figure 15—Recommended Remedies for Partial Losses (Dammam Zone, more than 75 wells)

Table 5 illustrates procedures of each action that use to regulate this type of the loss

Table 5—Partial Losses Treatments (Dammam Formation)

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 m³ LCMs Pill (Low MW) Product: Amount Mica Fine: 15 kg/m³ Mica Medium: 15 kg/m³ Nut Plug: 15 kg/m³ $CaCO_3$ Medium: 15 kg/m³ $CaCO_3$ Coarse: 15 kg/m³	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

3.3.1 High Viscosity Muds:

This treatment uses high viscosity drilling mud (Patch) with low mud weight. Usually, Bentonite, lime, or salt clay are used to increase viscosity. This pill is pumped in front of the thief zone in calculating sufficient quantities to plug losses zone, especially in partial losses. It is recommended after displacing this patch to interested zone to wait around (±2-3 hours).

3.4 Severe Losses Remedies

This type 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 it. In addition, by ignoring this type of the loss, it will aggravate to complete loss. Therefore, it is very necessary to do the required actions to combat this type of the loss and avoid a bad consequence. A comprehensive statistical study has been conducted to determine the optimal treatments to stop this type of losses. Figure 15 shows the probability of success and failure for the recommended actions which should be used to treat severe losses.

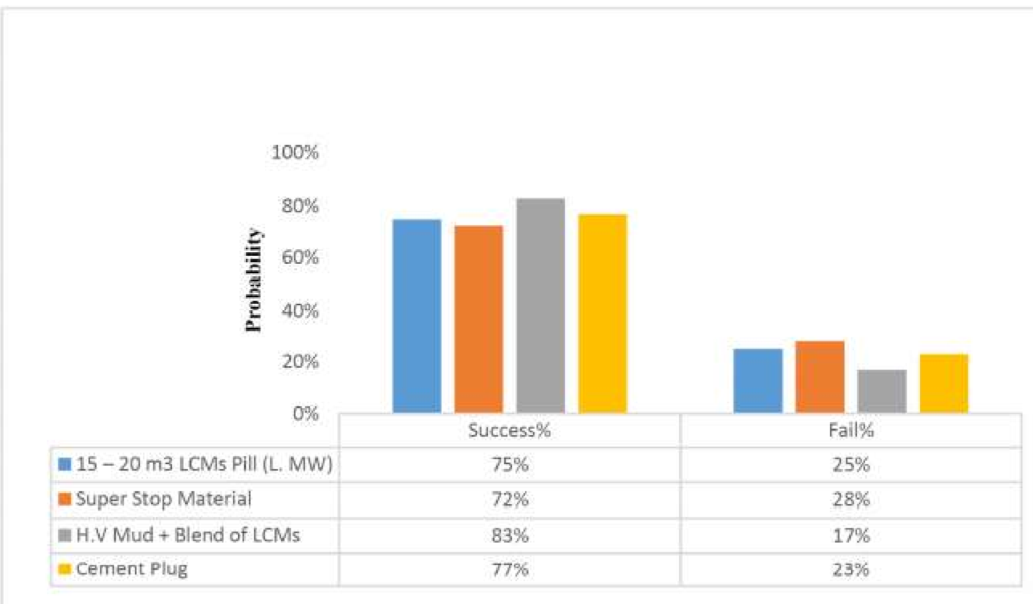

Figure 16—Recommended Remedies for Severe Losses (Dammam Zone, more than 75 wells)

Many treatments are used to control and mitigate this type of loss. Table 17 illustrates remedies that are used to regulate this type of the mud losses. Each treatment will be explained in details below to provide a clear image about how can apply them.

Table 6—Severe Losses Treatments (Dammam Formation)

Type of Losses	Type of the Treatment	Approach of the Treatment	Waiting
Severe Loss	15 – 20 m^3 LCMs Pill (Low MW) 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	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
	High Viscosity Drilling Mud (Low Density) + Blend of the LCMs	By creating plug to seal thief zone.	(4-6) hours
	Super Stop Material	• Mixing (4-5) bags (Weight of Bag 25 kg) of super stop material for each1m^3 water. • This treatment should be mixed in separate and clean tank. • It is very crucial to mix quickly 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.	(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

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

First, pill of the high-viscosity mud will be pumped in front of the thief zone. Blend of LCMs mix with low-density mud will be directly pumped after high viscosity patch to create an effective plug. It is very important to use low mud weight with blend of LCMs to avoid excessive ECD. This blend should be pumped in front of the losses zone, and it should wait around (± 4-6 hours) before resuming drilling processes. This remediation is often used for induced fractures in severe losses especially if there is not exact information regarding the width of fracture. That is why; this blend is used in various size distribution. Mixture of LCMs (fibrous, granular, flakes) are used to do this treatment. Lost circulation materials should be used in various volumes (coarse, medium, and fine) to have an effective remedy. Two ways are common to mix LCMs with high-viscosity mud. First method, by mixing a blend of commercially available LCMs including the following: by adding 5 kg/m3 of coarse volume, 5 kg/m3 of medium, and 5 kg/m3 of fine volume to total mud cycle. The second way, by mixing specific pill individually, by adding 15 kg/m3 of coarse volume and 15 kg/m3 of medium and 15 kg/m3 fine volume to the patch of high-viscosity mud. This blend should be pumped in front of the losses zone, and the waiting time should be around 4-6 hours (±) before resuming drilling operation. It is better to use squeeze pressure technique with this remedy.

3.5 Cement Plug:

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

3.5.1 Implementation Method of the Cement Plug:

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

• Lowering open end drill pipe (O.E.D.P) to the right place.

• Pumping high-viscosity mud or drilling mud with LCMs, and displace this in front of the interesting zone. It is better to wait around (±1-2 hours).

• Pumping the required cement volume into open end drill pipe (O.E.D.P).

• Displacing the plug-in front of losses zone. The volume of displacement is equivalent to the capacity of the open end drill pipe (O.E.D.P) subtracted the amount of cement which is left inside open end drill pipe (O.E.D.P) to lower freely.

• Pulling out some of the drill pipes strings which are equal to or more the head of the cement that is already remaining inside open end drill pipe (O.E.D.P).

• Pumping normal drilling fluid to clean open end drill pipe (O.E.D.P).

• Pulling out drill pipes strings to casing shoe.

• Waiting period around (± 18-20 hours) to harden cement plug.

3.6 Complete Losses

Remedies In this type of loss, mud cycle will completely be lost into the formation. This type of loss is the worst, and it is difficult to control it. In addition, this type of loss will maximize the expenses of the drilling operations and non-productive time (NPT). Therefore, it is very necessary to do required actions to combat or mitigate this kind of the losses to avoid unwanted consequences. Figure 16 illustrates the probability of success and failure for the recommended remedies which should be used to treat complete losses.

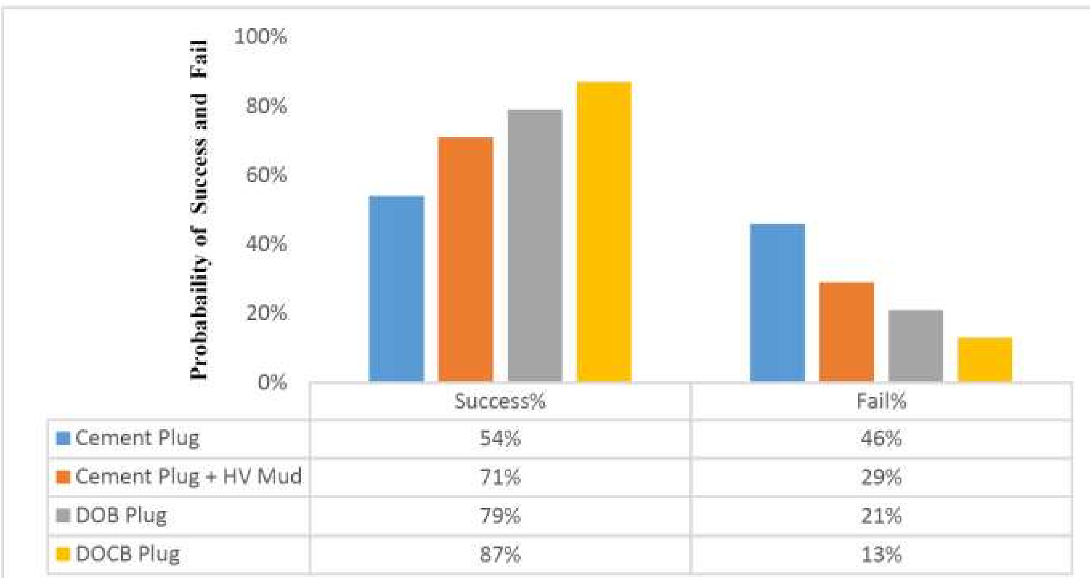

Figure 17—Recommended Remedies for Complete Losses (Dammam Zone, more than 75 wells)

Many treatments use to control and mitigate complete loss. Table 7 will illustrate remedies that should be used to regulate this kind of the losses, and table 8 will demonstrate the description and the executive steps for each of the remedial plug.

Table 7—Complete Losses Treatments (Dammam 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.	(18-20) 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.	(8-10) 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.	(10-12) hours

Table 8—The Executive Procedures for the Remedial Plugs (Complete Losses, Dammam zone)

Name of the Treatment	Description	Procedures
Cement plug + HV Mud	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.	1. Calculate the density of the cement. 2. Using open end drill pipe (O.E.D.P). 3. Pumping HV mud patch. 4. Pumping the required cement volume. 5. Displacing the plug-in front of losses zone by using normal drilling mud. 6. Avoidance contamination between plug and drilling fluid. 7. Pumping normal drilling fluid to clean open end drill pipe (O.E.D.P). 8. Pulling out drill pipes strings to casing shoe. 9. Waiting period around (± 18 - 20 hours) to harden cement plug.
DOB Squeeze (Diesel Oil Bentonite)	This remediation is very important and common. However, it is not easy to apply in the field. Some conditions are required for this treatment. Water should be removed from mixing tank and pumping pipes lines. In addition, it is much recommended to content loss zone on water to be effective treatment. Otherwise, this method is difficult to be successful.	Formula for 1 m^3 (Final) Oil base 0.70 m^3 Bentonite 800 kg 1. Using open end drill pipe (O.E.D.P). 2. Cleaning all mixing tanks and pumping pipes. 3. Two Pumps are required. 4. Initially, pumping clean water in front of the loss zone to guarantee bentonite hydration. 5. Squeezing process is required. 6. Displacing the plug-in front of losses zone by using normal drilling mud. 7. Avoidance contamination between plug and drilling fluid. 8. Pulling out drill pipes strings to casing shoe. 9. Waiting period around (± 8-10 hours) to harden cement plug.
DOBC Squeeze (Diesel Oil Bentonite Cement)	It is also very important and common. However, it is not easy to apply in the field. Some conditions are required for this treatment. Water should be removed from mixing tank and pumping pipes lines. In addition, it is much recommended to content loss zone on water to be effective treatment. Otherwise, this method is difficult to be successful.	Formula for 1 m^3 (Final) Oil base 0.72 m^3 Bentonite 450 kg Cement 450 kg The implementation principle of this treatment is the same technique for diesel oil bentonite plug.

3.7 Blind drilling:

on this method, the drilling operation is continuous but without any returns. In other words, there is drilling with lost circulation mud. This situation is very hazardous because there won't be any information about lithology of the formation. In addition, cutting will be accumulated around bit, which lead to stuck pipe problem. In this method, water will be used instead of drilling mud, so it is important to prepare sufficient quantities of clean water before use this technique, and it is necessary to prepare enough amounts of high viscosity mud and normal drilling fluid. The formation will be drilled by using water, and high-viscosity mud must be pumped after drilling one drill pipe to lift cutting above bit. These cutting will enter to the thief zone. Sometimes, one drill pipe is drilled by using just water, and another drill pipe will be drilled by using drilling mud. But in this case, the cost will be high due to drilling mud losses. Blind drilling will continue with pumping high viscosity after drilling each one drill pipe. In this method, it is prudent to monitor surface parameters for bit, and after completing formation drilling, it is necessary to circulate drilling mud into the hole to clean well from cutting.

The reasons for using the blind drilling technique:

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

Chapter four

4.1 Economic Evaluation

The economic evaluation is conducted for partial, severe, and complete losses. Table 20 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.

Treatment Name	Required Addition, kg/m^3	Cost, \$/m^3	Waiting Period, (hrs.)	NPT Cost, \$/1hr	Total Cost, (\$)	Success%	Failure%
H.V Mud Patch	100	31.7	2.5	1500	3781.7	72	28
Pill of LCM	Mica Fine (15), Mica Medium (15), Nut Plug (15), $CaCO_3$ Medium (15), $CaCO_3$ Coarse (15)	42.345	3.5	1500	5292.34	82	18

Table 20—Partial Losses Economic Calculations and Probabilities

Table 21 shows the economic calculations for the best severe losses treatments, the H.V Mud +Blend of LCM treatment has the highest probability of success for the severe losses.

Treatment Name	Required Addition, kg/m^3	Cost, \$/m^3	Waiting Period, (hrs.)	NPT Cost, \$/1hr	Total Cost, (\$)	Success%	Failure %
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	75	25
Super Stop Material	125	150	4.5	1500	6900	72	28
H.V Mud + Blend of LCM	Bentonite (100), Blend LCM (45)	72.2	5	1500	7572.2	83	17
Cement Plug	1029	327.22	18	1500	27327	77	23

Table 21—Severe Losses Economic Calculations and Probabilities

Economic evaluation and probabilities for the best complete losses treatments are shown in Table 22 , DOBC Plug treatment has the highest probability of success.

Treatment Name	Required Addition, kg/m³	Cost, $/m³	Waiting Period, (hrs.)	NPT Cost, $/1hr	Total Cost, ($)	Success%	Failure %
Cement Plug	1029	327	18	1500	27327	54	46
H.V Mud +Cement Plug	Bentonite (100), Cement (1029)	358.92	20	1500	30358.9	71	29
DOB Plug	Formula for 1 m³ Oil base 0.70 m³ Bentonite 800 kg	603.6	10	1500	15603.6	79	21
DOBC Plug	Formula for 1 m³ Oil base 0.72 m³ Bentonite 450 kg Cement 450 kg	645.75	12	1500	18645.7	87	13

Table 22—Complete Losses Economic Calculations and Probabilities

4.2 Recommended Lost Circulation Strategy to Dammam Formation

It is recognized that there is no single solution to lost circulation, and that most treatment and trial-anderror. 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 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 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 summarize the required treatments for each type of the lost circulation. Figure 17 is concluded by depending on data analysis for treatments that were used for the Dammam formation. More than 75 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 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 zone, 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 to develop an integrated methodology and flowchart for handling lost circulation events in the Dammam formation. Lost Circulation Strategy to Dammam Formation will be organized depending on the efficiency of the remedy (high probability of success) for several reasons:

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

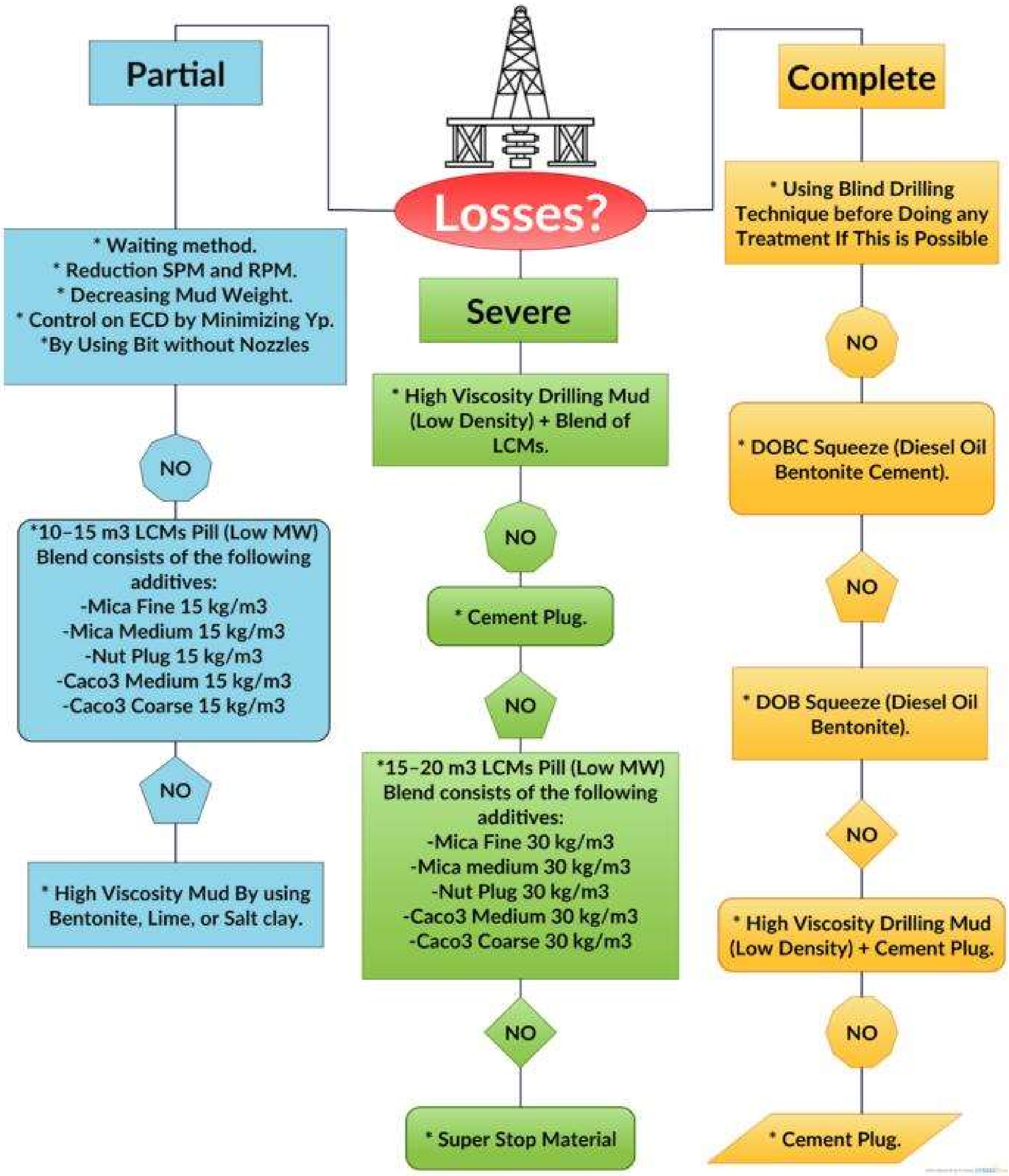

Figure 18—Treatment Strategy to Dammam Formation

4.3 Conclusion

This paper provides 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 many challenges in the 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:

- Key drilling parameters that should be used to drill the Dammam formation are identified and summarized in a table. Lost circulation can be mitigated or minimized when using these parameters
- One challenge in drilling wells in the South Rumaila field is the inconsistency of approaches to the lost circulation problem. Hence, a formalized methodology for responding to losses in the Dammam zone 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 Dammam 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 Dammam formation are summarized in a flow chart. This flow chart should be used to treat the mud losses in the Dammam formation depending on the type of 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 first treatment that should be used to treat partial losses is the waiting method. If it fails, then use the recommended treatments in the flow chart.
- The first treatment that should be used to treat severe losses is high viscosity mud and blend of LCM. If it fails, then use the recommended treatments in the flow chart.
- The best treatment to begin with for the complete losses is DOBC. 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.

- ❖ 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.

4.4 Acknowledgments

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

4.5 Nomenclature

APL Annular Pressure Loss

bbl/hr barrels per hour

BPC Basra Petroleum Company

cp centipoise

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/ft3 pounds per cubed feet in Inch

Kg/m3 Kilogram per cubed meter

LCMs Lost Circulation Materials

L/min Litter per minute

m meter

m3/hr cubed meter per hour

MW Mud Weight

NPT Non-productive Time

O.E.D.P Open End Drill Pressure

ppg pounds per gallon

PP Pore Pressure

Q Flow Rate

ROP Rate of Penetration

RPM Revolutions per Minute

SPM Stroke per Minute

TFA Total Flow Area

WOB Weight on Bit

WOC Waiting of Cement

WON Without Nozzles

Yp Yield Point Viscosity

$ Dollar

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Appendix

I.

volume losses	MW	volume losses	MW	volume losses	MW	volume losses	MW	volume losses	MW	volume losses	MW	volume losses	MW	volume losses	MW
0	1.05	0	1.06	15	1.065	15	1.07	20	1.075	15	1.08	65	1.085	55	1.09
1	1.05	5	1.06	17	1.065	16	1.07	21	1.075	16	1.08			70	1.09
2	1.05	6	1.06	19	1.065	17	1.07	22	1.075	17	1.08			71	1.09
3	1.05	7	1.06	21	1.065	18	1.07	23	1.075	18	1.08			72	1.09
4	1.05	8	1.06	24	1.065	19	1.07	24	1.075	19	1.08			73	1.09
5	1.05	9	1.06	25	1.065	20	1.07	25	1.075	20	1.08			74	1.09
6	1.05	10	1.06	26	1.065	21	1.07	26	1.075	21	1.08			75	1.09
7	1.05			27	1.065	22	1.07	30	1.075	22	1.08			81	1.09
8	1.05			33	1.065	23	1.07	45	1.075	28	1.08			83	1.09
9	1.05			35	1.65	24	1.07	46	1.075	30	1.08				
10	1.05			40	1.065	25	1.07	49	1.075	32	1.08				
				50	1.065	26	1.07	60	1.075	33	1.08				
				60	1.065	27	1.07			35	1.08				
						28	1.07			40	1.08				
						29	1.07			43	1.08				
						30	1.07			44	1.08				
						31	1.07			45	1.08				
						32	1.07			46	1.08				
						33	1.07			48	1.08				
						34	1.07			53	1.08				
						42	1.07			56	1.08				
						43	1.07			57	1.08				
						50	1.07			60	1.08				
						55	1.07			62	1.08				
						60	1.07			64	1.08				
						62	1.07			66	1.08				
						63	1.07			68	1.08				
						64	1.07			70	1.08				
						65	1.07			72	1.08				
										76	1.08				
										78	1.08				

II.

volume loss	ECD	volume loss	ECD	volume loss	ECD	volume loss	ECD	volume loss	ECD	volume loss	ECD	volume loss	ECD
0	1.06	0	1.065	1	1.07	0	1.075	20	1.08	15	1.085	15	1.09
1.5	1.06			2	1.07	6	1.075	21	1.08	16	1.085	16	1.09
3.5	1.06			3	1.07	7	1.075	22	1.08	17	1.085	17	1.09
8	1.06			4	1.07	8	1.075	23	1.08	18	1.085	18	1.09
8.5	1.06			5	1.07	9	1.075	24	1.08	19	1.085	19	1.09
				6	1.07	10	1.075	25	1.08	20	1.085	20	1.09
				7	1.07			26	1.08	21	1.085	21	1.09
				8	1.07			27	1.08	22	1.085	22	1.09
				9	1.07			28	1.08	23	1.085	23	1.09
				10	1.07			29	1.08	24	1.085	24	1.09
								30	1.08	25	1.085	25	1.09
								31	1.08	26	1.085	26	1.09
								32	1.08	27	1.085	27	1.09
								33	1.08	28	1.085	28	1.09
								34	1.08	29	1.085	29	1.09
								42	1.08	30	1.085	30	1.09
								45	1.08	31	1.085	31	1.09
volume loss	ECD	volume loss	ECD	volume loss	ECD					32	1.085	32	1.09
29	1.095	31	1.1	72	1.11					46	1.085	33	1.09
48	1.095	35	1.1	73	1.11							34	1.09
50	1.095	40	1.1	75	1.11							35	1.09
		41	1.1	76	1.11							36	1.09
		42	1.1	77	1.11							37	1.09
		43	1.1	79	1.11							37.5	1.09
		44	1.1	80	1.11							44	1.09
		45	1.1	82	1.11							52	1.09
		54	1.1	84	1.11							54	1.09
		55	1.1	85	1.11							60	1.09
		56	1.1	86	1.11							62	1.09
		57	1.1	87	1.11								
		58	1.1										
		59	1.1										
		70	1.1										

III.

	Yp	V	YP	V	YP	V	YP	V	YP	V	YP	V
0	20	0	21	0	22	6	23	8	24	8	25	19
1	20	1	21	1	22	7	23	9	24	9	25	20
2	20	2	21	2	22	8	23	10	24	10	25	21
5	20	3	21	3	22							25
6	20	4	21	4	22							28
7	20	5	21	5	22							72
8	20	6	21	6	22							
		7	21	7	22							
		8	21	8	22							
		9	21	9	22							
		10	21	10	22							
YP	V	YP	V	YP	V	YP	V	YP	V	YP	V	YP
26	21	27	23	28	33	29	22	30	25	31	85	32
26	23	27	35	28	59	29	45	30	26	31		
26	25	27	52	28			63	30	27	31		
26	31	27	56	28			78	30	28	31		
26	61	27	65	28					29	31		
26	62	27	67	28					30	31		
			69	28					60	31		
			78	28					70	31		
			80	28								
			82	28								

IV.

v	YP	V	YP	V	YP	V	YP
0	13	0	14	1	15	20	16
1	13	4	14	4	15	21	16
4	13	5	14	5	15	22	16
5	13	6	14	6	15	29	16
7	13	7	14	7	15	30	16
8		8	14	8	15	34	16
		9	14	9	15	43	16
		10	14			54	16
						59	16
V	YP	V	YP	V	YP	V	YP
16	17	18	18	30	19	19	20
17	17	19	18	42	19	20	20
18	17	20	18	43	19	40	20
19	17	23	18			48	20
22	17	28	18			58	20
23	17	30	18			60	20
24	17	51	18				
25	17	74	18				
26	17						
27	17						
28	17						
34	17						
40	17						
41	17						
45	17						
63	17						

V.

V	PV	V	PV	V	PV	V	PV	V	PV	V	PV	V	PV
0	6	1	7	0	8	8	9	8	10	17	11	20	12
2	6	3	7	1	8	9	9	9	10	18	11	21	12
3	6	4	7	4	8	10	9	10	10	19	11	22	12
4	6	5	7	5	8					21	11	23	12
5	6	6	7	6	8					22	11	28	12
6	6	7	7	7	8					30	11	30	12
7	6	8	7	8	8					40	11	38	12
8	6	9	7	9	8								
9	6	10	7	10	8								
10	6												
V	PV	V	PV	V	PV	V	PV	V	PV	V	PV		
15	13	15	14	30	15	28	16	30	17	28	18		
16	13	16	14	31	15	45	16	55	17	38	18		
17	13	17	14	32	15	49	16	80	17	41	18		
18	13	18	14	33	15	52	16			44	18		
19	13	19	14	34	15	54	16			60	18		
20	13	20	14	38	15	55	16			62	18		
21	13	21	14	39	15	56	16			64	18		
22	13	22	14	40	15	57	16			66	18		
23	13	23	14	42	15	58	16			68	18		
24	13	24	14	44	15	59	16						
26	13	25	14	48	15	60	16						
28	13	26	14	51	15	61	16						
39	13	27	14	54	15	62	16						
40	13	28	14	55.5	15	63	16						
		30	14	57	15	64	16						
		32	14	58.5	15	70	16						
		34	14	60	15	71.5	16						

VI.

V	WOB	V	WOB	V	WOB	V	WOB	V	WOB	V	WOB	V	WOB	V	WOB	V	WOB	V	WOB
0	5	6	5.5	0	6	6.5	6.5	1	7	5	7.5	0	8	5	9	1	10	15	11
3	5	7	5.5	1	6	7	6.5	2	7	6	7.5	4	8	6	9	6.5	10	16	11
4	5	8	5.5	2	6	8	6.5	6.5	7	7	7.5	5	8	7	9	7	10	17	11
5	5			3	6			7	7	8	7.5	6	8	8	9	8.5	10	18	11
6	5			4	6			8.5	7			7	8	9	9	9	10	19	11
7	5			5	6			9	7			8	8	10	9			20	11
8	5			6	6			9.5	7			9	8					22	11
9	5			7	6			9.75	7			10	8					23	11
10	5			8	6			10	7									26	11
				9	6													28	11
				10	6													51	11
V	WOB	V	WOB	V	WOB	V	WOB	V	WOB	V	WOB	V	WOB	V	WOB				
14	12	30	12.5	13.8	13	61	13.5	16	14	20	15	20	16	30	17				
15	12	55	12.5	17.9	13	62.7	13.5	18	14	24	15	34	16	31	17				
16	12			19.4	13			23	14	27	15	44	16	35	17				
17	12			20.9	13			25	14	38	15	54	16	40	17				
18	12			22.4	13			30	14	53	15	56	16	58	17				
19	12			23.9	13			32	14	55	15	63	16	60	17				
20	12			25.4	13			44	14	56	15	70	16	61	17				
21	12			26.9	13			57	14	64	15	71.5	16	62	17				
22	12			28.4	13			68	14	70	15			66	17				
23	12			29.9	13					71	15			68	17				
24	12			31.4	13					72	15								
25	12			32.9	13					75	15								
26	12			37	13					78	15								

VII.

V	SPM	V	SPM	V	SPM	V	SPM	V	SPM	V	SPM	V	SPM	V	SPM
0	100	1	105	0	110	20	115	18	120	20	130	45	135	19	140
1	100	2	105	1	110	21	115	19	120	21	130			20	140
2	100	3	105	2	110	22	115	20	120	22	130			21	140
3	100	4	105	3	110	24	115	21	120	23	130			30	140
4	100	5	105	4	110	27	115	22	120	24	130			34	140
5	100	6	105	5	110	32	115	23	120	25	130			41	140
6	100	7	105	6	110	40	115	24	120	26	130			43	140
7	100	8	105	7	110	48	115	25	120	27	130			45	140
8	100	9	105	8	110	75	115	26	120	28	130			47	140
9	100	10	105	9	110			27	120	29	130			49	140
10	100			10	110			28	120	30	130			51	140
								29	120	31	130			53	140
								30	120	32	130			55	140
								31	120	33	130			57	140
								32	120	34	130			59	140
								33	120	38	130			67	140
								34	120	48	130			72	140
								35	120	63	130			73	140
								40	120	70	130			74.5	140
V	SPM	V	SPM	V	SPM	V	SPM	41	120	74	130			76	140
33	150	29	160	44	170	15	180	42	120	75	130			77	140
53	150	30	160	60	170	16	180	43	120	76	130			78.5	140
83	150	31	160			17	180	44	120	77	130			80	140
		41	160			18	180	45	120	78	130				
		42	160			25	180	46	120						
		43	160			27	180	47	120						
		55	160			30	180	48	120						
		65	160			36	180	55	120						
						38.5	180	57	120						
						60	180	59	120						
						70	180	61	120						
								65	120						

								67	120						
								69	120						
								71	120						
								73	120						

VIII.

Q,L/STK	V	Q,L/STK	V	Q,L/STK	V	Q,L/STK	V	Q,L/STK
1849	0	1936	20	2000	18	2100	20	2300
1849	1	1936	21	2000	20	2100	21	2300
1849	2	1936	22	2000	22	2100	22	2300
1849	3	1936	23	2000	24	2100	23	2300
1849	4	1936	24	2000	26	2100	24	2300
1849	5	1936	30	2000	28	2100	25	2300
1849	6	1936	31.5	2000	30	2100	26	2300
1849	7	1936	33	2000	32	2100	27	2300
1849	8	1936	34.5	2000	34	2100	28	2300
	9	1936	36	2000	36	2100	29	2300
	10	1936	37.5	2000	38	2100	30	2300
			39	2000	40	2100	34	2300
			40.5	2000	42	2100	48	2300
			42	2000	44	2100	62	2300
			53	2000	46	2100	64	2300
					51	2100	70	2300
					56	2100	74	2300
					58	2100	76	2300
					60	2100		
					65	2100		
					67	2100		
					69	2100		

					70	2100		
Q,L/STK	V	Q,L/STK	V	Q,L/STK	V	Q,L/STK	V	Q,L/STK
2500	34	2680	25	2800	60	3000	18	3200
2500	54	2680	26.5	2800			20	3200
2500	81	2680	44	2800			22	3200
2500			46	2800			24	3200
2500			58	2800			29	3200
2500			69	2800			31	3200
2500							32	3200
2500							34	3200
2500							36	3200
2500							38	3200
2500							42	3200
2500							53	3200
2500							56	3200
2500							58	3200
2500							62	3200
2500							64	3200
2500							66	3200
2500							70	3200
2500							72	3200
2500							74	3200
2500							76	3200
2500							78	3200
2500							80	3200
2500							84	3200
2500							86	3200
2500							88	3200
							90	3200

IX.

V	RPM	V	RPM	V	RPM	V	RPM	V	RPM
0	55	1	60	1	65	20	70	18	75
1	55	2	60	2	65	21	70	19.75	75
2	55	3	60	3	65	22	70	21.5	75
3	55	4	60	4	65	23	70	23.25	75
4	55	5	60	5	65	24	70	25	75
5	55	6	60	6	65	25	70	26.75	75
6	55	7	60	7	65	26	70	28.5	75
7	55	8	60	8	65	27	70	30.25	75
8	55	9	60	9	65	28	70	32	75
9	55	10	60	10	65	29	70	33.75	75
10	55	11	60	11	65	30	70	35.5	75
						31	70	37.25	75
						32	70	39	75
						33	70	42.5	75
						37	70	45	75
V	RPM	V	RPM	V	RPM	38.5	70	58	75
17	80	30	85	19	90	40	70	60.5	75
18.5	80	31.5	85	20.5	90	41.5	70	68	75
19.5	80	33.5	85	22	90	43	70	70	75
20.75	80	35	85	23	90	44.5	70	72	75
22	80	39	85	30	90	50	70		
24	80	40.5	85	31.5	90	58	70		
26	80	42	85	33	90	68	70		
27	80	43.5	85	34.5	90	70	70		
28	80	45	85	40	90	71	70		
30	80	57	85	42	90	73	70		
48	80	65	85	62	90	79	70		
49	80	70	85	65	90	85	70		
50	80			66	90				
55	80			67	90				
59	80			79	90				
64	80								
75	80								

X.

V	ROP	V	ROP	V	ROP	V	ROP	V	ROP	V	ROP
0	5	0	6	0	7	0	8	20	9	20	10
1	5	1	6	1	7	1	8	21	9	21.5	10
2	5	3	6	4	7	2	8	22	9	23	10
3	5	4	6	5	7	3	8	23	9	24.5	10
4	5	5	6	6	7	4	8	24	9	26	10
5	5	6	6	7	7	5	8	25	9	27.5	10
6	5	7	6	8	7	6	8	26	9	29	10
7	5	8	6	9	7	7	8	27	9	33	10
8	5	9	6			8	8	28	9	34	10
9	5	10	6			9	8	29	9	39	10
						10	8	30	9	41	10
								31	9	43	10
								32	9	45	10
								33	9	50	10
								34	9	51.5	10
V	ROP	V	ROP	V	ROP			35	9	53	10
20	11	20	12	22	13			40	9	54.5	10
24	11	28	12	28	13			43	9	56	10
34	11	38	12	33	13			45	9	57.5	10
35	11	39	12	40	13			54	9	59	10
37	11	43	12	45	13			57	9	60	10
39	11	46	12	48	13			59	9	61	10
50	11	63	12	60	13					62	10
55	11	70	12	80	13					63	10
58	11	72	12	84	13					64	10
70	11	79	12							65	10
71	11	80	12							66	10
72	11	82	12							67	10
73	11									70	10
74	11										
75	11										

XI.

V	WON	V	WO	V	WON	V	WON	V	WON	V	WON	V	WON
20	0.5	15	1	24	1.2	18	3.3	1	4.2	0	4.4	5	4.72
21	0.5	16	1	25	1.2	19	3.3	2	4.2	3	4.4	6	4.72
22	0.5	19	1.1	26	1.2	20	3.3	3	4.2	4	4.4	7	4.72
23	0.5	20	1.01	33	1.2	21	3.3	4	4.2	5	4.4	8	4.72
24	0.5	24	1	35	1.2	22	3.3	5	4.2	6	4.4	9	4.72
25	0.5	26	1	37	1.2	23	3.3	6	4.2	7	4.4	10	4.72
28	0.5	28.5	1	41	1.2	24	3.3	7	4.2	8	4.4		
29	0.5	30	1	53	1.2	25	3.3	8	4.2	9	4.4		
42	0.5	31.5	1	56	1.2	26	3.3	9	4.2	10	4.4		
44	0.5	34.5	1	65	1.2	27	3.3						
46	0.5	48	1.01	70	1.2	28	3.3						
48	0.5	50.5	1	71.75	1.2	29	3.3						
58	0.5	60	1	73.5	1.2	30	3.3						
59.5	0.5	62	1	75.25	1.2	31	3.3						
61	0.5	64	1	77	1.2	32	3.3						
62.5	0.5	66	1	78.75	1.2	40	3.3						
83.5	0.5	68	1	80.5	1.2	41	3.3						
		78	1			42	3.3						
		82	1			43	3.3						
						44	3.3						
						45	3.3						
V	WON	V	WON	V	WON	46	3.3						
0	4.9	1	5.4	0	6.6	47	3.3						
6	4.9	2	5.4	1	6.6	48	3.3						
7	4.9	3	5.4	2	6.6	53	3.3						
8	4.9	4	5.4	3	6.6	54.75	3.3						
9	4.9	5	5.4	4	6.6	56.5	3.3						
10	4.9	6	5.4	5	6.6	58.25	3.3						
		7	5.4	6	6.6	60	3.3						
		8	5.4	7	6.6	61.75	3.3						
		9	5.4	8	6.6	63.5	3.3						
		10	5.4	9	6.6	65.25	3.3						
				10	6.6	67	3.3						
						68.75	3.3						
						72	3.3						
						73	3.3						