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Review of Lost Circulation Materials and Treatments with an Updated Classification

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Abstract

Drilling fluid losses are considered one of the major contributors to drilling non-productive time (NPT). Lost circulation materials (LCM's) have been widely used to avoid or stop losses. Due to the large number of current available LCM's and their different applications, classification and testing of LCM's is very important. Conventional LCM's are currently classified into different categories based on their appearance as fibrous, flaky, and granular or a blend of all three. The most recent LCM classification was published around 50 years ago and this paper intends to fill this gap with an updated classification including conventional and new technologies. We propose to re-classify LCM's into 7 categories based on their appearance and application as: granular, flaky, fibrous, LCM's mixture, acid/water soluble, high fluid loss squeeze, swellable/hydratable combinations, and nanoparticles.

Particle plugging apparatus (PPA) and HPHT fluid loss apparatus in conjunction with slotted/tapered discs are used to evaluate LCM performance for corrective treatments. Until now, no single standardized testing method or interpretation that evaluates LCM's performance when preventive treatments are applied in order to increase the fracture gradient has been developed. The difficulty in standardizing the testing methods is due to the disagreement about wellbore strengthening mechanism.

This paper discusses the most recent developments in lost circulation materials such as plugging assurance technology and nano-technology, in addition to the presentation of a comprehensive summary of today's available LCM's.

Introduction

With the significant increase in oil demand, a huge number of conventional hydrocarbon resources are being depleted. As a result, more challenging drilling operations are required. When drilling challenging wells, such as extended reach wells or deep water wells, the operational mud weight window narrows. The lower limit is increased due to higher collapse pressure in deviated well while the upper limit, controlled by the fracturing gradient, is reduced due to higher equivalent circulation density (ECD) in extended reach wells, damaged wellbores, and lower overburden gradient or as a result of wellbore deviation. This decrease in the operational mud window can lead to common problems such as lost circulation.

Lost circulation incidents could lead to a series of unwanted consequences that could cost up to million dollars or more [1]. The severity of the consequences varies depending on the loss severity; it could start as just losing the drilling fluid and it could continue to a blowout. In general, lost circulation events are classified based on the losses rate (bbl/hr.). When the fluid loss rate is 1-10 bbls/hr., the loss is classified as seepage loss which could happen in any type of formation. As the fluid loss rate increase from 10 to 500 bbls/hr., the losses are recognized as partial losses that could occur in gravels, small natural horizontal fractures, or induced vertical fractures. Once the loss rate increase to 500 bbls/hr. and above, the losses are considered to be complete losses [2]. Lost circulation events may occur in naturally fractured formations, cavernous formations, highly permeable formations or due to drilling induced fractures (Fig.1).

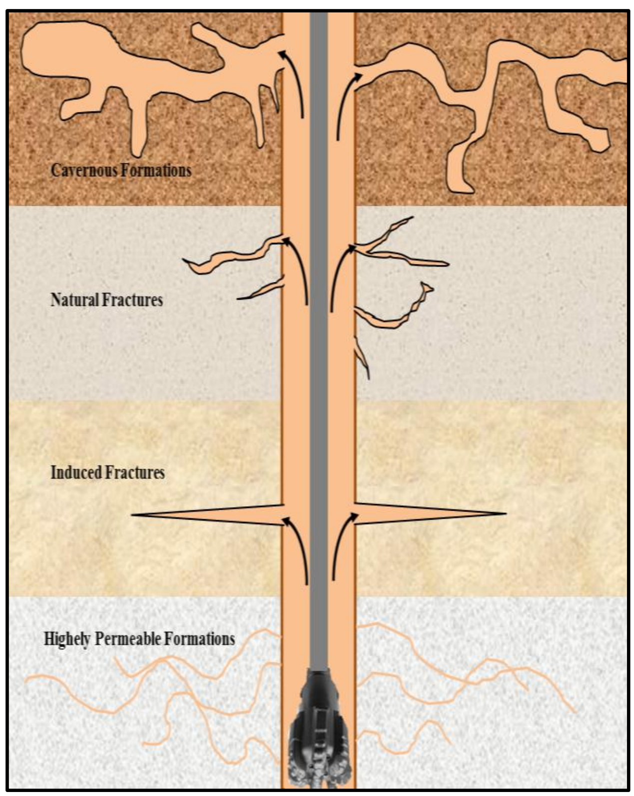

Figure 1: Candidate formations for Losses Events

One of the early efforts to cure losses or prevent them from happening by adding granular materials to the drilling fluid, was introduced by M T. Chapman in 1890 [3]. Since then, lost circulation materials have been widely used to stop or mitigate drilling fluid losses into the formation. LCM's are added continuously to the drilling fluid system or spotted as a concentrated LCM's pill in order to seal naturally existing fractures or induced fractures that are produced while drilling.

Lost Circulation Treatment: Corrective vs. Preventative

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

Corrective Methods

This approach treatment can be defined as any method that is applied after the occurrence of the losses [1]. In this approach, lost circulation treatments are either added continuously to the drilling fluid or spotted as a concentrated pill in order to mitigate the losses. There is a wide range of corrective lost circulation treatments depending on the type of losses or the type formation being treated. For seepage and partial losses, LCM blends are added to the mud in various concentrations. The addition of LCM's into the mud will help reducing seepage and partial loss, but when severe losses are encountered; other treatments are required to solve the problems. For severe losses, settable pills such as cement plugs, gunk, deformable or soft plugs are often used to gain circulation. Deformable, viscous and cohesive plugs (DVC) are claimed to be effective due to their physical properties such as the cohesion which helps in creating an impermeable seal thus preventing the drilling fluids from leaking into the fractures [4]. These types of treatments require special placement and mixing procedures that need to be taken into consideration. For depleted or highly permeable formations, high fluid-loss high solid-content squeeze pills are used to mitigate the losses when encountered [4].

Preventive Methods

These can be defined as those treatments/solutions which are applied prior entering lost circulation zones in order to prevent the occurrence of losses. The overall objective of this method is to strengthen the wellbore [6]. The concept of wellbore strengthening can be defined as "a set of techniques used to efficiently plug and seal induced fractures while drilling to deliberately enhance the fracture gradient and widen the operational window" [7]. This approach depends on propping or sealing the fractures using LCM's [8]. Based on a linear elastic fracture mechanics model, the stress cage model was presented by Alberty and Mclean [9]. This model suggests an increase in the hoop stresses around the wellbore where the LCM's sets at the fracture mouth and form a seal. Fracture Closure Stress (FCS) model [10] was introduced by Dupriest to explain how LCM's could increase the fracture gradient (FG) when added to drilling fluids as a remedial solution for loss circulation. FCS is defined as "the normal stress on the fracture plane keeping the fracture faces in contact". The increase in FCS is achieved by widening the fracture and sealing the fracture tip thus, compressing the adjacent rock which will result in changing the near wellbore hoop stresses. The Elastic-Plastic Fracture model [11] presented by Aadnoy and Belayneh explains how the FG could be increased above the theoretical Kirsch model value. This model suggests that the fracturing resistance could be improved as a result of the mud cake plastic deformation that builds up at the fracture mouth.

New Lost Circulation Treatments Technologies

Due to the importance of LCM's in mitigating or preventing losses, improving their ability to control losses could led to a significant impact on reducing both NPT and drilling risks. With the increase in the drilling complexity, the industry is developing new technologies that are effective in preventing/mitigating lost circulation events. These new technologies include the use of newly developed materials and optimized combinations of conventional LCM's.

Nanoparticles Technology

Nanoparticles were recently introduced to be used in drilling fluids. Nanoparticles can be described as solid particles with a size ranging from 1 to 100 nm or about a magnitude smaller than bentonite. Due to the small pore throat size in shale formations which makes it harder to form an impermeable filter cake, nanoparticles were found successful in forming a tough, dense filter cake and sealing micro cracks in shale resulting in a significant impact on wellbore stability [12]. Forming such a filter cake will reduce fluid losses into the formation and as a result, the wellbore will be stabilized [13]. The performance of treated silica nanoparticles was also inspected on Marcellus and Mancos shales and it showed an effective plugging of the shale pores. The reduction in shale permeability is an alternative way of reducing the fluid loss into the shales which cannot be achieved by conventional filter cake buildup [14]. Another application of silica nanoparticles in the Marcellus and Mancos shales used the Shale Membrane Tester (SMT) operated by the University of Texas and a service company in presence of water-based mud (WBM). The experimental setup includes placing a well-preserved shale core into a cell under differential pressure applied to both sides of the sample. This test was aimed to test the feasibility of using WBM in the drilling of shales, which typically is a common cause of well-instability due to shale swelling by fluid adsorption. A concentration of 10 wt. % of nanoparticles was shown to reduce permeability in shale membranes. However, after a variety of screening tests the concentration of nanoparticles was reduced down to 3 wt. % giving a permeability reduction of around 98% [15]. Further evaluation of Silica nanoparticles was conducted to investigate their permeability reduction capability for a larger variety of shales [16]. Iron hydroxide and calcium carbonate nanoparticles at low concentrations have also been investigated for wellbore strengthening purposes [17, 18]. Nwaoji et al. [17] showed that these types of nanoparticles can be implemented into WBM to strengthen the wellbore and thereby ensuring its stability. Contreras [18] presented the impact that nanoparticles have on OBM in wellbore strengthening and its implications in reducing the number of casing strings in a well. Further developments of nanoparticle-based drilling fluids are currently conducted and its success is anticipated.

Plug Forming Assurance Technology

Existing fractures or vugs can have irregular shapes and widths. To address uncertainties in fracture size and shape, a new technology was developed [19]. This technology is applied using two components: foam wedges and micron-sized particles. Foam wedges (Fig.2) are described as small pieces of "foam rubber-like chunks" that are highly deformable. This characteristic allows the foam wedges to be compressed and forced into openings of different sizes and shapes. Once the openings are filled with the foam, they will form a highly permeable filtration bridge for the second component. The second component which consists of high fluid loss fine particles will form a plug within the filtration bridge.

Figure 2: Wedge Foam (From Wang, 2011 [19])

High Fluid Loss, High Strength Pills (HFHS)

HFHS pills allow the de-fluidization of the pumped slurry to take place while squeezing, as a result, a high solid plug will be formed [20]. Recently, a number of HFHS treatments have been introduced commercially and they often come in a one sack product. HFHS treatments are typically a blend of different fibers where some of these fibers might be treated or coated to enhance their performance. An optimum HFHS treatment should apply for different losses scenarios, easy to pump through bottom hole assemblies and they should have a high shear-stress resistance [21]. In order for such treatments to succeed, the fluid transporting these treatments should leak off into permeable formations resulting in a good seal. This type of treatments is difficult to apply in low permeability formations such as shale and might not perform as expected when using a non-aqueous drilling fluid [4]. Applying this type of treatments will help reducing both cost and time due to their simple application; they also have been successfully applied in the field [22].

Customized Combinations of LCM's

Combining different LCM's types and sizes has proved its effectiveness in both lab tests and field trials due to the wide range of particle size distribution and the different physical properties of the combined LCM's. In general, the combination includes granular, fibrous and flaky LCM's. Various laboratory tests were conducted to investigate the effect of combining two types of LCM's (ground marble and resilient graphite) on their performance and it was observed that they performed better than when they were used alone [23]. A wide range of LCM's combinations is available for different lost circulation scenarios. The combinations of LCM's are also optimized based on the particle size distribution that is capable of sealing a broad range of fracture sizes. In addition to the efficient performance of the combined LCM's, they usually come premixed and sacked thus saving rig time.

LCM's Classifications

LCM's classification is an important factor in the decision making processes to prevent/cure lost circulation events. Conventional LCM's can be classified based on their appearance as fibrous, flaky, and granular or a blend of all three [24]. LCM's have different physical and chemical properties and therefore a proper LCM selection is a key factor for a successful lost circulation treatment.

Howard et al. [25] classified LCM's based on their physical properties into four groups: fibrous, granular, lamellated and dehydratable. Robert J White [3] modified the previous classification by replacing the dehydratable category with mixture of LCM category.

The need to re-classify LCM's into different categories is necessary due to the large number of up to date available LCM's and their different application. This paper intends to gather available LCM's currently used in drilling operations in order to serve as a reference manuscript.

Updated LCM's Classification

Due to the different properties of LCM's and how these properties contribute to their various applications, the proposed classification in this paper is based on both the physical, chemical properties, and their application. The physical properties include the appearance and the size of these particles while the chemical properties include material solubility in acids, swellability, and reactivity with other chemicals to activate the blend. LCM's are re-classified into 7 categories: granular, flaky, fibrous, LCM's mixture, acid soluble, high fluid loss LCM's squeezes (HFLS), swellable/hydratable LCM's, and nanoparticles.

Granular

Granular materials are defined as additives that are capable of forming a seal at the formation face or within the fracture to prevent the losses into the formation [2, 25]. They are available in a wide particle size distribution. Due to their rigidity, this type of materials is used often for wellbore strengthening applications. Granular materials have higher crushing resistance than other types and some of them could be classified as granular and at the same time acid soluble such as calcium carbonate. Granular materials include graphite, nut shells (Fig.3), sized calcium carbonate, glisonite, course bentonite, asphalt, and perlite (See Table A.1).

Flaky

Flaky materials are defined as "A type of LCM that is thin and flat in shape, with a large surface area" [26] (Fig.4). This type may or may not have any degree of stiffness and they are capable of forming mat over the permeable formation face [2, 25]. Flaky materials include cellophane, mica, cottonseed hulls, vermiculite, corn cobs, and flaked calcium carbonate (See Table A.2).

Figure 3: Graphite (Left), Nut Shells (Right)

Figure 4: Mica (Left), Cellophane (Right)

Fibrous

Fibrous materials can be defined as "A type of LCM that is long, slender and flexible and occurs in various sizes and lengths of fiber" [26]. This type of materials may have a little degree of stiffness and will form a ''mat-like'' bridge when used to reduce the losses into fractures or vugular formations [25]. The ability to form a "mat-like" bridge serves as a filtration medium for smaller particles in the drilling fluids to deposit and form a seal [2]. Fibrous materials comes in a wide range of grades/sizes and some types of fibrous material are acid soluble such as Magma fiber. Fibrous materials are often used in both WBM and OBM but some of these materials have some limitations when used in OBM. Fibrous materials include cellulose fibers, nylon fibers, mineral fibers, saw dust, and shredded paper (See Table A.3).

Mixture of LCM's

It was observed that mixing two or more LCM's together will yield a better performance in mitigating losses due to the different properties and particle sizes of the mixed LCM's [1, 2, 6, 35]. A variety of engineered LCM's blends are available for different lost circulation scenarios. These blends contain optimized types and particle size distribution that have been evaluated in various lab tests to prove their ability in sealing wide range of fracture sizes. However, improper particle size distribution of the blended LCM's could results in a poor performance [3] (See Table A.4).

Acid Soluble/ Water Soluble

Conventional LCM's have the disadvantage of damaging the formation when used in the reservoir section; as a result the development of non-damaging LCM's has risen [27]. Acid/water soluble LCM's are considered as non-damaging LCM's that could be used to cure losses encountered in reservoir sections. Acid soluble materials include calcium carbonate (Fig.5) and mineral fibers. Water soluble LCM's include sized salts (See Table A.5).

Figure 5: Calcium Carbonate

High Fluid Loss LCM's Squeeze

This type of LCM's combination is often used to cure sever losses when encountering fractured or highly permeable formations. The filtration process will form a plug that seals the losses zone. These treatments often require special procedures in order to squeeze them into the losses zone and it is usually performed as a "hesitation squeeze" [28] (See Table A.6).

Swellable/Hydratable LCM's Combinations

Settable/Hydratable treatments are basically a blend of LCM's with a highly reactive material such as polymers. These treatments will be activated either by chemical reagents or whenever they contact drilling fluids or formation fluids; as a result, a plug will be formed within the losses zone. These types of treatments often require special placement procedures [28] (See Table A.7).

Nanoparticles

Current applied nanoparticles include silica, iron hydroxide and calcium carbonate [29]. These types of particles can be prepared by either ex-situ or in-situ procedures. Ex-situ stands for the preparation of nanoparticles that occurs into an aqueous solution that is later added to the mud. In-situ involves the addition of the precursors that forms the nanoparticles directly to the mud. For practical field practices, authors recommend in-situ practices for avoiding a significant increase in water content of the mud into the circulation system. Other types of nanoparticles obtained from aluminum and titanium have been investigated for permeability reduction in presence of WBM [30]. Carbon black nanoparticles with a specific gravity ranging from 1.9 to 2.1 have been used to reduce mud cake reduction to mitigate differential pipe sticking [31]. Ballard and Massam [32] investigated the use of barium sulfate nanoparticles as a weighting agent. Zinc nanoparticles application for lubricity improvement has been reported by Griffo and Keshavan [33] when used as a drilling bit lubricator in the presence of other additives including silica gel (See Table A.8).

LCM's Laboratory Evaluation

Laboratory evaluation of LCM's is a crucial step to investigate their feasibility and durability prior field applications. As mentioned above, LCM's treatments could be applied as either a preventive or a corrective method and therefore, their laboratory evaluation should be standardized based on their application.

Corrective Treatments Tests

Particle plugging apparatus (PPA) and HPHT fluid loss apparatus are often used as standard tests to evaluate the ability of the added LCM's to seal either slotted/tapered discs that simulate natural/induced fractures or ceramic discs that simulate a porous formation. The drilling fluids containing LCM's is forced to pass through these discs under high pressures and temperatures. The performance of the tested LCM's is evaluated by both the total fluid loss within 30 minutes and the time it takes to form a tight seal. In addition, particle size distribution (PSD) analysis has been used to ensure a proper particle size selection that would yield an effective treatment based on the pore size or the estimated fracture width [22]. Different PSD models are used to optimize the selection of LCM's such as Abram's median particle-size rule, the Vickers method, and the ideal packing theory. However, each method has its own limitation that makes it inadequate under some conditions. For instance, the lack of information about the pore/fracture size could result in a poor optimization [1]. In general, there is an agreement in the industry on how LCM's can be tested for corrective methods application.

Preventive Treatments Tests

The evaluation of LCM's performance for their performance in wellbore strengthening applications is not well established. PPA is sometimes used to evaluate the selected LCM's where low fluid loss is desirable, however; the amount of fluid lost is a not a good measure of how LCM's will affect fracture gradient due to the fact that these tests are run under constant pressure and at the same time, these slotted/tapered discs doesn't really simulate the filtration process through permeable formation.

Several laboratory testing have been introduced in the literature in order to understand the mechanism of wellbore strengthening. However, each of these laboratory investigations focuses on one aspect of wellbore strengthening and neglects the others. So far, these tests could be divided into 3 connected categories based on the measured/evaluated parameter. The first category focuses on measuring the amount of increase in fracturing, propagation, and re-opening pressures. The second focuses on evaluating LCM's sealing efficiency and the integrity of the formed seal. The third puts emphasis on measuring the physical properties of LCM's as well as optimizing the particle size distribution for preventive treatments.

The DEA-13 fracturing experiments [34] were one of the early efforts that looked at the parameters affecting both the propagation and re-opening pressures in a model wellbore drilled in large rock blocks. These experiments revealed the significance of adding solids into drilling fluids on propagation and re-opening pressures. In the late 1990's, the effectiveness of LCM's in enhancing the fracture pressure was investigated by the GPRI joint industry project (JIP) using hollow rock cores, in order to replicate the DEA-13 fracturing experiments on a smaller scale [35].

Due to the importance of LCM's fracture sealing efficiency for wellbore strengthening, different testing devices were developed to measure this parameter. A testing apparatus was developed to simulate fractures in impermeable formations in order to understand the mechanism of fracture sealing using LCM's [35-37]. The fracture faces were simulated by an opposed piston that uses two matched uneven aluminum platens, and the fracture width is adjustable. A similar testing apparatus was also developed but for permeable zones [38, 39]. An extensive laboratory work to investigate the parameters affecting wellbore strengthening was presented by Mostafavi et al. [40]. The sealing efficiency of different LCM's was measured using PPA. Hydraulic fracturing experiments using cement cores with a model wellbore were later conducted to evaluate the effect of LCM's in strengthening the wellbore. The testing results analysis showed the significance of LCM's mechanical properties, PSD, and the concentration used. Salehi [41] also conducted a set of hydraulic fracturing experiments using hollow cylinder rock cores to investigate the strengthening effect.

The increase in the fracture gradient is strongly believed to be affected by the physical properties of LCM's such as the size, strength, resiliency, and the crushing resistance. Despite the fact that most of these physical properties are measurable, there is no standardized method that evaluates the fracture gradient enhancement based on their physical properties. This is because of the controversial thoughts about the role of LCM's physical properties in wellbore strengthening techniques. On one hand, some wellbore strengthening models suggest that the material size and strength are not important. On the other hand, some other models emphasize on both while the remaining highlight the size and neglect the strength. Table 1 summarizes wellbore strengthening models and the role of LCM's size and strength [41]. The difficulty in standardizing the testing methods is obviously due to the disagreement about wellbore strengthening mechanism.

Table 1: Summary of Wellbore Strengthening Models

Wellbore Strengthening Model	**Material Size**	**Material Strength**	**Authors**
Fracture Pressure Inhibitor	Important	Selected Strength	Fuh et al. [42]
Stress Cage	Important		Alberty and McLean [9]
Fracture Closure Stress (FCS)	Not Important		Dupriest [10]
Stress Cage	Important		Wang [43]
Fracture Healing	Important		Aadnoy and Belayneh [44]
Fracture Propagation Resistance (FPR)	Important	Not Important	Van Oort et al. [35]

Even though a lot of tests and methods were conducted and developed to evaluate the performance of LCM's and their effects for wellbore strengthening application, no single test is used as a standard industry practice. And this variance is due to the fact that the mechanism of wellbore strengthening is still not well understood. Therefore, the development of a set of standardized tests in conjunction with a meaningful analysis of the laboratory results that would predict fracture gradient enhancement for different LCM's is needed. Industry collaboration to address this topic will benefit the entire drilling industry.

The authors believe that the strengthening effect could be predicted by correlating the measured values of LCM's sealing efficiency with the measured values of fracture gradient enhancement from hydraulic fracturing experiments.

Summary of Available LCM's

A large number of LCM's are commercially available through a wide range of specialized drilling fluids services companies [44-53]. With this striking number of different LCM's, a comprehensive summary that includes most of the available LCM's which is very beneficial for operators and drilling engineers are tabulated in cross-referencing tables for each type of LCM's (Appendix A). The tables list the generic name, trade name and the recommended application for each LCM. Majority of LCM's comes in different grades; fine, medium and course to suit different losses scenarios ranging from seepage to severe losses.

Conclusions and Remarks

This paper construct a new LCM's classification that can serve as a reference for operators, service companies and drilling industry in general to properly classify the materials used to control/mitigate lost circulations. The authors do believe in the importance of standardizing the LCM's classification with the aim of creating a unique technical way to refer them in each specific application during drilling operations and well planning. LCM's were re-classified into 7 categories based on their appearance and application as; granular, flaky, fibrous, LCM's mixture, acid/water soluble, high fluid loss squeeze, swellable/hydratable combinations, and nanoparticles.

However, it was difficult to establish a classification based on either the size or the strength of materials due to the lack of information regarding the strength of different LCM's and how the strength could be affecting the treatment performance.

This paper describes each LCM type including its commercial names for the 7 categories. New lost circulation technologies are presented focusing on the versatility of the applications of nanoparticles used to mitigate lost circulation either by plugging very low permeability formations or by serving as a wellbore strengthening agent.

For corrective treatments, particle plugging apparatus (PPA) and HPHT fluid loss apparatus in conjunction with slotted/tapered discs are used to evaluate LCM performance. However there are no standardized tests or interpretation methods that evaluate LCM's performance when preventive treatments are applied. The difficulty in standardizing the testing methods is due to the disagreement about the wellbore strengthening mechanism.

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Appendix A

Table A.1: Examples of granular LCM's

Granular LCM's			
Generic Name / Description	**Trade Name**	**Provider**	**Application**
Ground/Sized walnut shells	WALL-NUT	Halliburton	Used as concentrated pills or high filtration squeeze. It is used to cure seepage, partial and total loss based on the selected grade.
	MIL-PLUG	Baker Hughes	
	NewPlug	NEWPARK	
	WALNUT HULLS	GEO Drilling Fluids	
	NUTSHELL	Anchor Drilling Fluids	
	MESUCO-PLUG	Messina Chemicals	
Resilient, angular, dual-carbon based, sized graphite	STEELSEAL	Halliburton	Can be used as a background treatment or as a concentrated pill depending on the losses rate. Used as wellbore strengthening material.
	G-SEAL	MI SWACO	
	C-SEAL	MI SWACO	
	LC-LUBE	Baker Hughes	
	NewSeal	NEWPARK	
A proprietary natural loss prevention material (LPM)	SURE-SEAL	Drilling Specialties	Can be used as a preventive treatment or as a concentrated pill.
	TORQUE-SEAL	Drilling Specialties	
A blend of acid soluble particulates	EZ-PLUG	Halliburton	Can be used as a background treatment, for seepage losses or sever losses
Sized-ground marble	BARACARB	Halliburton	Used as a bridging agent for lost circulation problems. Used as wellbore strengthening material.
	SAFE-CARB	MI SWACO	
	NewCarb	NEWPARK	
	FLOW-CARB	Baker Hughes	
	MIL-CARB	Baker Hughes	
	W. O. 30	Baker Hughes	Used for sever losses.

Table A.2: Examples of flaky LCM's

Flaky			
Generic Name / Description	**Trade Name**	**Provider**	**Application**
Cellophane	MILFLAKE	Baker Hughes	Used in conjunction with other LCM's depending on the severity of the losses.
	MESUCO-FLAKE	Messina Chemicals	
Sized grade of Mica	MILMICA	Baker Hughes	Used as preventive measures for seepage losses.
	MESUCO-MICA	Messina Chemicals	
Flaked Calcium Carbonate	SOLUFLAKE	Baker Hughes	Used for seepage or sever losses based on the selected grade.

Table A.3: Examples of fibrous LCM's

Fibrous			
Generic Name / Description	**Trade Name**	**Provider**	**Application**
Natural cellulose fiber	BAROFIBRE	Halliburton	Can be used as a preventive treatment or concentrated pills to cure seepage to sever losses based on the selected grade.
	M-I-X II	MI SWACO	
	VINSEAL	MI SWACO	
	CHEK-LOSS	Baker Hughes	
	MESUCO-FIBER	Messina Chemicals	
	CyberSeal	NEWPARK	
	FIBER SEAL	GEO Drilling Fluids	
A proprietary micro-cellulosic fiber for use in water base muds	DYNARED	Drilling Specialties	Used as normal treatment to cure seepage losses or as a concentrated pill for loss circulation.
A proprietary micro-cellulosic fiber for use in oil base muds	DYNA-SEAL	Drilling Specialties	
Shredded cedar fibers.	M-I CEDAR FIBER	MI SWACO	Can be used as a preventive treatment, concentrated pill or high fluid-loss squeezes.
	FIBER PLUG	Anchor Drilling Fluids	
	PLUG-GIT	Halliburton	
	MIL-CEDAR	Baker Hughes	
Acid soluble extrusion spun mineral fiber	N-SEAL	Halliburton	Can be used as a background treatment or as a concentrated pill
	CAVI-SEAL-AS	Messina Chemicals	
	MAGMA FIBER	GEO Drilling Fluids/ Anchor Drilling Fluids	

Table A.4: Examples of LCM's Combinations

LCM's Combinations			
Generic Name / Description	**Trade Name**	**Provider**	**Application**
A combination of different LCM types and wide range of particle sizes.	STOPPIT	Halliburton	Used as a concentrated pill.
	PRIMA SEAL	GEO Drilling Fluids	
	STOP-FRAC S	Halliburton	
	WELL-SEAL	Drilling Specialties	Used to cure minor to sever losses based on the selected grade.
	BARO-SEAL	Halliburton	Can be used as a preventive treatment or concentrated pills to cure seepage to sever losses based on the selected grade.
	STOP-FRAC D	Halliburton	
	M-I SEAL	MI SWACO	
	MIL-SEAL	Baker Hughes	
	CHEM SEAL	Anchor Drilling Fluids	
	KWIK-SEAL	Messina Chemicals	
	MESUCO-SEAL	Messina Chemicals	
A blend of acid soluble particulates.	EZ-PLUG	Halliburton	Can be used as a background treatment, for seepage losses or sever losses.
A proprietary particulate blend designed to be used with foam wedges.	QUIK-WEDGE	Sharp-Rock Technologies, Inc.	Can be used as a pre-treatment or as a concentrated pill.
A proprietary particulate blends that includes modified natural materials and other additives.	STRESS-SHIELD	Sharp-Rock Technologies, Inc.	Can be used as a pre-treatment or as a concentrated pill

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

Acid Soluble/ Biodegradable/Water Soluble			
Generic Name / Description	**Trade Name**	**Provider**	**Application**
A blend of acid soluble particulates	EZ-PLUG	Halliburton	Can be used as a background treatment, for seepage losses or sever losses
A non-damaging, cross linkable water soluble polymer blended with selected sized cellulosic fibers.	N-SQUEEZE	Halliburton	Used as a settable squeeze for sever losses
Acid soluble extrusion spun mineral fiber	N-SEAL	Halliburton	Can be used as a background treatment or as a concentrated pill
	CAVI-SEAL-AS	Messina Chemicals	
	MAGMA FIBER	GEO Drilling Fluids/ Anchor Drilling Fluids	
Sized and treated salts	BARAPLUG	Halliburton	Use as a temporary seal in high permeability formations
Acid Soluble Sized-Calcium Carbonate	BARACARB	Halliburton	Used as a bridging agent for lost circulation problems
	SAFE-CARB	MI SWACO	
	NewCarb	NEWPARK	
	FLOW-CARB	Baker Hughes	
	MIL-CARB	Baker Hughes	
	W. O. 30	Baker Hughes	Used for sever losses.
Flaked calcium carbonate	SOLUFLAKE	Baker Hughes	Used for seepage or sever losses based on the selected grade.
Nontoxic fibrous powdered polysaccharide, biodegradable and acid soluble lost circulation material.	HOLE-SEAL-II	Messina Chemicals	Can be used as a pretreatment or as a concentrated pill.

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

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

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

Settable/Hydratable LCM's Combinations			
Generic Name / Description	**Trade Name**	**Provider**	**Application**
A combination of swelling polymer along with engineered combinations of resilient graphitic carbon and other materials	HYDRO-PLUG	Halliburton	Used as a hydratable pill to plug vugular, fractured, and cavernous formations.
Dry powdered/granular material with synthetic polymers, inorganic minerals, chemical reagents and stabilized organic filler.	SUPER-STOP	Messina Chemicals	Used as a swellable pill for sever losses.
A non-damaging, cross linkable water soluble polymer blended with selected sized cellulosic fibers.	N-SQUEEZE	Halliburton	Used as a settable squeeze for sever losses.

Table A.8: Examples of Nanoparticles LCM's

Nanoparticles			
Generic Name / Description	**Trade Name**	**Provider**	**Application**
Iron Hydroxide NP	Iron Hydroxide NP	nFluids Inc.	Used as a background treatment to seal micro fractures and wellbore strengthening applications.
Calcium Carbonate NP	Calcium Carbonate NP	nFluids Inc.	