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Common Misconceptions Regarding Lost Circulation Treatments

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Abstract

Lost circulation remains a challenge in mature, depleted fields as well as exploratory prospects. While the challenge is the same, the underlying causes of lost circulation and the known background information is different, thus, the process of selecting the best lost circulation material (LCM) or treatment design is different.

Under the best conditions, there is a variety of information that must be assimilated and understood to design the best lost circulation treatment. Any misunderstandings in evaluating that data can lead to less than optimal decisions.

This paper highlights some of the typical beliefs that influence lost circulation treatment designs and attempts to clarify misconceptions surrounding the most common issues.

When lost circulation decisions are based on valid techniques and well-understood concepts, the chance for success of the applied solutions increases, thereby improving the economics and efficiency of the well and drilling operation.

Introduction

Lost circulation of whole mud into the formation has economic impacts that go beyond the initial cost of the lost mud – which can be very costly for some fluids – and the lost circulation treatment. The bigger impact of lost circulation involves increased risk in controlling wellbore pressures, cost for non-productive time (NPT), and the many hidden costs of reduced production if the fluid/treatment was not optimized for the specific reservoir and completion type.

There is more than one way to treat fluid losses with the first solution being prevention, followed by a hierarchy of potential physical, mechanical and chemical solutions that have to be evaluated and ranked based on effectiveness, risks and cost.

Designing the best treatment program with appropriate lost circulation material (LCM) is further challenged by collecting and understanding the critical information needed to evaluate the lost circulation treatment options.

Eliminating the misconceptions regarding lost circulation treatments will clarify many of the steps needed to design an effective lost circulation strategy.

Common Beliefs and Misconceptions About Lost Circulation

Typical assumptions, beliefs, misunderstandings, and misconceptions about lost circulation treatments are centered around the following categories:

- Identifying the knowledge keepers
- LCM size vs grade
- LCM shape
- LCM material source
- The applicability of one solution to all problems
- Downhole tool limitations with regards to concentration and type of LCM
- Maintenance treatments
- Particle size selection
- Pore pressure depletion and its effect on fracture gradient
- LCM acid-solubility requirements

Identifying the Knowledge Keepers

Lost circulation is a multi-dimensional phenomenon. Its prevention and treatment requires knowledge of LCM properties, fluid properties (drilling, completion or cementing fluids), experience in the specific solution recommended, geology, geo-mechanics, drilling and drilling tools. Even the amount of information known about a well or area varies widely from mature fields with an abundance of rock property data to exploratory areas with scant data available.

For the reasons above, it is hard to assume that anyone can be an expert in all of the knowledge areas involved. This is why overcoming a lost-circulation challenge is usually a result of cooperation between a number of people from different backgrounds including the operator, service companies and even rig contractors.

Ivan and Bruton (2003) developed a lost circulation assessment and planning process that covers the main activities and knowledge sources required for a successful LCM solution. The key data that the operator can provide include image logs, pore pressures and fracture gradients, rock mechanics logs (including Young's modulus, Poisson's ratio, fracture initiation pressure), and offset well data. The geology and geo-mechanics team can help more with loss-zone characterization including identifying the most probable loss zone and loss mechanism.

The service companies can provide data on their LCM, limitations and the appropriate deployment technique. They can also provide an escalation plan (or decision tree) that covers different scenarios and loss rates in different loss zones. They can also run hydraulics simulations to make sure the equivalent circulating density (ECD) remains below the fracture gradient and the equivalent static density (ESD) remains above the pore pressure.

Rig contractors provide data on volumes they can handle, pump pressure limitations, and other data that becomes part of the LCM solution. They monitor volumes in and out of the well closely for losses or flows.

The best lost-circulation specialist is the one who knows to gather information from other experts on the well.

LCM Size vs Grade

For the uninitiated, the mixture of size and grade information given about LCM size and grade feels like comparing apples and oranges. Most LCM is marketed by grade while the technical information provided is a mixture of charts that present the size information in a single digit designation of the grade or a graph that presents the grade as a volume percent or cumulative percentage over the range of sizes.

This confusion can be clarified by understanding the nomenclature and how it is used.

- PSD – Particle Size Distribution
- d_{50} – the median size or middle point where half the particles are above in size and half are below in size.
- d_{10} – the point at which 10% of the particles are that size or less
- d_{90} - the point at which 90% of the particles are that size or less

Don't be misled by LCM grade. LCM is frequently described by the terms – fine, medium or coarse – indicating a relative grade. However, in the mind of the user, it can be misunderstood to imply size. LCM grades are a relative term and *only* true for the same source of LCM. Thus, Nut Shell fine has a smaller PSD than a coarser grade of Nut Shell, but not necessarily finer than medium or coarse Calcium Carbonate. Table 1 compares the d_{50} for two common LCM types. As you can see the grade sizes are only in comparing that specific type of material and assumptions about sizes of other LCM types cannot be assumed.

Table 1 – Comparison of d_{50} (µm) Sizes for Different Grades of Two LCM Types

Product/Size Grade	Fine	Medium	Coarse
Calcium Carbonate	50	150	400
Nut Shells	500	1100	1200

The particle size distribution can also be presented in graphical formats showing either the simple distribution by volume at each size (Fig. 1) or as a cumulative curve. The graphical format in Fig. 1 provides more information on the modality of the PSD. Modality is the number of peaks in a PSD curve showing concentrations at different particle sizes. Products can be mono-modal, bi-modal or multi-modal with each style of product having specific applications.

Generally speaking, an LCM with a narrow PSD (narrow variation between d_{10} and d_{90}) is used to design a solution when enough data on the loss zone is available to target very specific size fractures. On the other hand, an LCM with a wide PSD (wide variation between d_{10} and d_{90}) would be selected when less information is available about the loss zone.

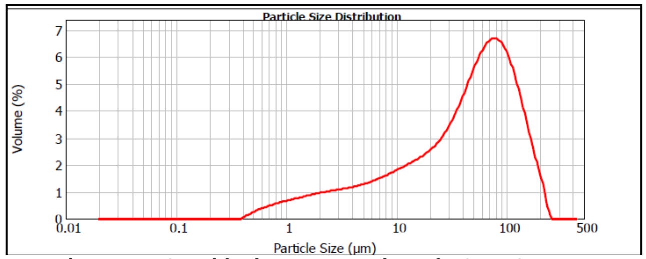

Figure 1 – Graphical representation of LCM PSD.

LCM Shape

LCM shape is rarely evaluated. It is typically assumed to be spherical for simplification of calculations as a sphere can be described by one number – its diameter. Image analysis, a new particle size measurement approach, shows that most particles are not spherical. The degree of sphericity, circularity or aspect ratio can be used to differentiate between spherical and non-spherical particles where an aspect ratio of 1 indicates a sphere. Figure 2 shows the aspect ratio and PSD of common LCM.

While shape characteristics are important in particle characterization and LCM solutions development as identified by Kumar et al (2013), currently, available bridging and plugging theories still use the assumption that LCM particles are spherical.

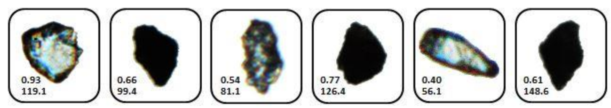

Figure 2. Aspect ratio and PSD values of common LCM. Aspect ratio is the top number and PSD, in µm, is the bottom number of each LCM box.

The term "fiber", when referring to shape, indicates materials that have significantly different aspect ratios. Typical oilfield fibers can go up to several mm in length with a small micro-meter (µm) diameter. The term "fiber" can also be used to indicate source of the LCM which adds to misunderstandings and confusion.

LCM Source

While particle size distribution is arguably the most important specification for LCM; the source of the LCM plays a key role in maintaining size and shear degradation resistance. The term "source" can be used to indicate the type of material or the variation within the type of material.

Sources vary from natural to synthetic materials and may also vary within the same type based on source. An example of different sources can be found in the difference between calcium carbonate and graphite. An example of a variation within the same type is metamorphic calcium carbonate having superior mechanical properties to sedimentary calcium carbonate.

The term “fiber” is sometimes loosely utilized to describe the source such as cellulose fibers which are actually granular in shape, having an aspect ratio close to 1. This frequently caused confusion as the term “fiber” is used to describe shape with a high aspect ratio as defined by Alsaba el al (2014) as long, slender and flexible type of LCM.

The Applicability of One Solution to All Problems

Loss zone characterization is arguably the most important part of finding the appropriate lost circulation solution; however, this step is typically overlooked.

Solutions for losses in shale formations vary significantly from those required for sandstones, and those required for sandstones vary from those required for carbonate formations. Shale formations are virtually impermeable which significantly reduces the performance of any high-fluid-loss pills.

Solutions for shallow sections generally have a different set of criteria to meet than deeper sections from temperature and pressure requirements.

Solutions for natural losses can vary from those used for induced losses in terms of size and concentration.

Table 2 shows the ranking for some solutions that can be equally successful across a variety of scenarios and others that can perform well on one fracture size and poorly on another fracture size.

Table 2 - Ranking of Various LCM Solutions Based on Fracture Size

Formulations Ranking	Tapered Slot Size (mm)		
	2 – 4	1 – 2	0.5 – 1
1	Crosslink Polymer Pill	Crosslink Polymer Pill	1-mm Fiber Blend
2	Fibrous Pill/Granular/High-Fluid-Loss LCM Blend	1-mm Fiber Blend	Fibrous Pill/Granular/High-Fluid-Loss LCM Blend
3	Coarse Fiber Blend	Fibrous Pill/Granular/High-Fluid-Loss LCM Blend	Crosslink Polymer Pill
4	Swellable LCM Blend	Swellable LCM Blend	Swellable LCM Blend
5	High-Fluid-Loss Pill	High-Fluid-Loss Pill	High-Fluid-Loss Pill
6	1-mm Fiber Blend	Coarse Fiber Blend	Coarse Fiber Blend

Although this table covers only a small number of the potential sizes required and potential solutions, it is clear that one solution is not optimal across all lost circulation situations.

Downhole Tool Limitations

A wide variety of downhole tools exists today to help drill faster and more efficiently under different downhole conditions. The existing numbers of different tools, LCM material type, size, concentration, blends and mud weights makes it impossible to pre-screen every combination possible for compatibility.

Therefore, a good practice would be to test what would be a worse-case scenario recognizing that in most applications, smaller LCM products used in lower concentrations should not have an impact on tool performance . The test is usually conducted in a flow loop configured to handle sufficient volume of the drilling fluid to circulate and activate the tools with the expected concentration of LCM. Fig. 3 shows the schematic for such a flow-loop test.

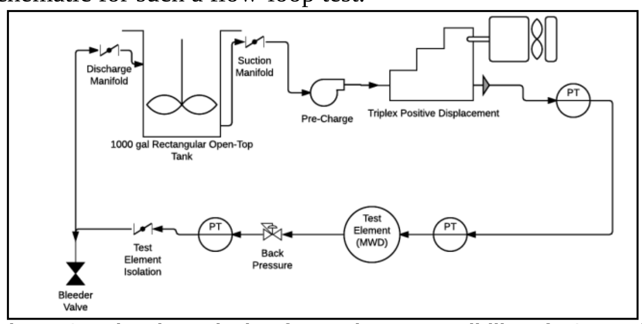

Figure 3 – Flow loop design for testing compatibility of LCM and downhole tools.

Another good practice is to know the screen gauge used in the tools so that the LCM treatment design is optimized to pass through the tool, but yet seal the loss zone.

There are also a few fail-safe mechanisms that can be used such as drill-pipe filters and anti-jamming techniques.

Generally speaking, most granular material up to a certain size range will pass through the tools. However, it is it is more difficult to predict blended products and many fiber products will eventually plug the tool.

Maintenance Treatments

Particle attrition is one of the main reasons why engineered LCM solutions or lost material preventive (LMP) efforts fail to seal the formation over time. Table 3 shows the degradation from shear in just 30 minutes for three common types of LCM. It is clear the degradation from shear is both real and varies depending on the type of LCM as demonstrated by Scott el al (2012).

Table 3 – Shear Degradation of LCM

Material Type	d_{50} Value (µm)			
	0 Shear	10-Min Shear	20-Min Shear	30-Min Shear
Graphitic Material	690.8	560.7	401.5	373.7
Calcium Carbonate	656.4	191.9	125.8	33.5
Nut Shells	679.8	479.5	453.3	456.6

While the conventional wisdom suggests using a coarser size grade to maintain the PSD presence of a finer grade of the same product being used; several other factors come in play. A study conducted by the author shows that in certain cases, such as calcium carbonate, using a coarser grade leads to faster degradation resulting in an even finer blend in a short time span (Fig. 4).

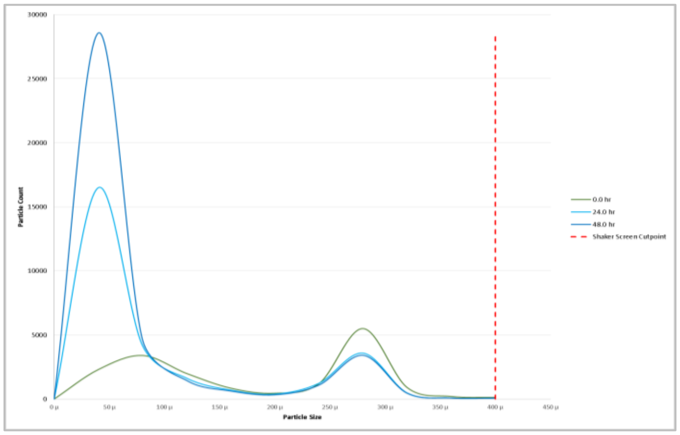

Figure 4 – Degradation of LCM over Time.

Valsecchi (2013) attributes LCM particle degradation to three factors: interaction of LCM solids with the drilling fluid, interaction of LCM solids with the solid boundaries and the interaction of LCM solids with other LCM solids. His work shows that large particles have a higher probability of collision with other particles and therefore are exposed to a more intense process of degradation than smaller particles. This supports the results obtained by the author in independent studies.

Particle Size Selection

Choosing the right particle size is one of the most fundamental design criteria for LCM solutions, yet it remains one of the most controversial issues.

The first hurdle is to characterize the fracture aperture (fracture width) or pore size that must be plugged. Some approaches calculate the fracture aperture before drilling using geo-mechanic equations and some approaches derive the fracture width after the losses have occurred from the loss rates. The majority of the industry uses the first technique as it is the more proactive approach.

Once the fracture aperture or pore size has been determined, the next decision is the choice of particle size to properly plug the leak. Various values including d_{50}, d_{90} and d_{75} have all been touted to be the "right value" to be matched to the fracture width by different authors from a list summarized by Kumar et al (2010).

While much work has been validated by lab data, there is only minimum field data is available to support one view over another.

Pore Pressure Depletion and Fracture Gradient

Pore pressure dictates the mud density required to maintain overbalance and avoid well control situations. The amount of overbalance can be dictated by a government agency, well design, or operators' best practices. The higher the mud density, the higher the equivalent circulating density (ECD) will be and the closer to the fracture gradient limit. While ECD can be closely maintained while drilling; ECD spikes are harder to predict and control when initiating circulation after connections or following long static periods.

The assumption that the fracture gradient depletes the same amount as the pore pressure can lead to miscalculations. Alberty and McLean (2001) stated "the predicted effect of reservoir depletion on the fracture gradient is much less if based on the shale intervals than if based on the sands."

LCM Acid Solubility Requirements

In order to minimize formation damage, a typical requirement for LCM to be used in a reservoir is that is must be acid soluble or water soluble. The reason underlying this requirement is that assumption that solubility of the LCM will assist in cleanup and prevent production impairment.

The acid solubility requirement by itself can be misleading as some LCM products, while soluble in acid, produce other precipitates that can be detrimental to reservoir productivity. A better approach is to check that the by-product of the acid reaction is also acid or water soluble. It is also recommended to test the solubility at typical downhole temperatures to have more accurate expectations for treatment downhole as shown in Table 4.

Table 4 – Effect of Temperature on Acid Solubility

Product A	Result (wt%)
Acid Soluble Fraction (15% HCl, 15 minutes at 22°C)	12.9
Acid Soluble Fraction (15% HCl, 2 hours at 80°C)	41.9

New technology has increased the variety of potential solutions from acid-soluble particulates to gels to cement. New approaches include degradable materials that degrade with time and/or temperature as discussed by Droger et al (2014).

Conclusions

Dealing with lost circulation has major economic impacts that go far beyond the cost of lost fluid and remedial treatment to encompass even the future productivity of the well. Understanding the common assumptions and removing misconceptions about lost circulation will lead to better treatment decisions.

Acknowledgments

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Nomenclature

ECD = *Equivalent circulating density*
ESD = *Equivalent static density*
LCM = *Lost circulation material*
LMP = *Lost material prevention*
PSD = *Particle size distribution*
Modality = *The number of peaks in a PSD graph*
NPT = *Non-productive time*

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