A customisable approach

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Lost circulation is a major cause of nonproductive time (NPT) in oil well construction and poses financial and health, safety, and environmental (HSE) risks. In extreme cases, it could lead to total well loss and abandonment. Such outcomes are rare due to advances in treatment technologies and increased industry experience.

Other consequences may include:

- Loss of large volumes of drilling fluid to the formation.
- Hole instability and poor wellbore cleaning while drilling or cementing.
- Increased risk of stuck pipe, downhole tool loss, and fishing operations.
- Sidetracks if fishing operations are unsuccessful.
- Annular plugging and early cement job termination.
- Failure to achieve the planned top of cement (TOC).
- Compromised zonal isolation and costly remedial work.
- Safety or environmental incidents caused by well control situations.

These outcomes can result in NPT, unplanned contingency operations, and increased well costs.

Repeated lost circulation material (LCM) treatments increase expenses, which makes it essential to design effective solutions from the start. Effective treatments start with a clear grasp of the lost circulation problem.

High-permeability formations require particulate-type solutions to reduce permeability at the formation face. In contrast, fractured formations may warrant larger bridging materials or chemically reactive solutions, such as thixotropic cement. This type of cement creates a high-gel-strength barrier to seal thief zones. Even within the same loss mechanisms, such as fractured formations, it is important to understand the formation characteristics to help optimise the treatment and improve the chances of success.

For this reason, Halliburton developed a science-based and methodical approach that uses geological analysis, material science, and fluid mechanics to customise bridging LCM packages. This approach accounts for pore throat size, porosity, estimated fracture size, local LCM material properties, and the density and rheological profile of the carrying fluid. The goal is to design a mixture of multiple bridging materials with complementary physical properties that plug the formation and cure the lost circulation event.

From uncertainty to accuracy: advanced modelling for effective lost circulation treatment

While legacy regions may have established treatments, there is room to improve their effectiveness and reduce costs. As drilling extends deeper, into older and depleted reservoirs where lost circulation is more prevalent, operators often lack sufficient experience to manage the losses. In addition, new exploration areas lack proven treatment methods. In these scenarios, a science-based and methodical approach is essential. It outperforms outdated legacy tables and lost circulation decision trees, minimises trial and error, and reduces NPT.

When Halliburton treats lost circulation events with bridging materials, three key design criteria are applied:

- Select an LCM concentration that plugs the fracture.
- Determine the maximum pumpable concentration that avoids plugging downhole restrictions.
- Choose fluid properties that best transport the LCM package.

These considerations are crucial when cementing, where the risk of plugging downhole tools is greater than while drilling.

The approach involves two key steps. First, engineers run a computer simulation that uses digital twin models. The primary model predicts the required LCM materials and concentrations to plug the target geometry. The algorithm considers wellbore hydraulics, loss zone dynamics, and filter cake modelling. It uses a hydraulics engine model that simulates downhole conditions and fluid dynamics to predict slurry behaviour under various temperatures and pressures in actual cement operations. The model also estimates loss zone geometry through a hydraulic match that applies pre-job circulation data, well geometry, loss type, rate, and location. This defines key loss zone characteristics, which are then used to predict loss rates, volumes, and pressures as different fluid trains pass through the loss zone throughout the cement job. With the integration of downhole hydraulics and loss zone dynamics, the model estimates the loss conduit geometry (if unknown) and identifies the optimal LCM blend and fluid properties to plug the fracture.

The second model evaluates the maximum safe concentration of the proposed LCM package that can pass through downhole restrictions, such as float

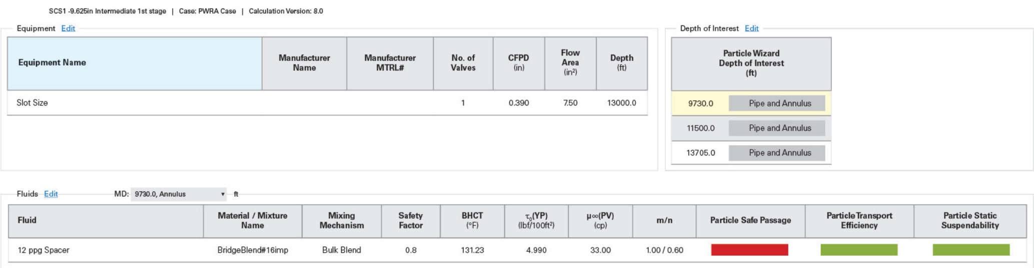

Figure 1. *Computer modelling evaluates the LCM package and concentration for the ability to seal a given geometry.*

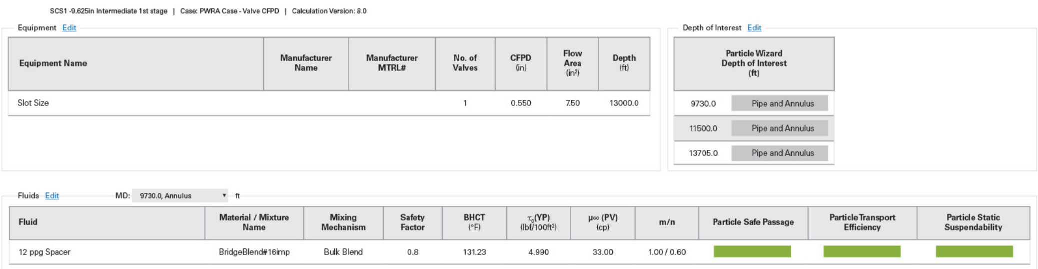

Figure 2. *Computer modelling assesses the LCM package and concentration for its ability to pass through a given geometry and the carrying fluid's capacity to transport it.*

equipment or liner hanger clearances. The model evaluates particle safe passage, transport efficiency, and static suspendability.

Cement specialists use both software models throughout the job design and customisation phase to balance the most effective LCM/fluids package with one that will clear critical downhole dimensions.

After the LCM package is designed with digital twin models, it is then tested in the lab with a plugging apparatus to confirm its effectiveness to seal the target geometry.

Accelerate design of service

This science-based and methodical approach facilitates the development of customised LCM packages tailored to specific issues that utilise local available materials. These include organic or biodegradable materials for environmentally sensitive locations, acid-soluble packages to reduce the risk of formation damage, and thermally stable formulations for geothermal and high-pressure, high-temperature (HPHT) applications. In ultra-high temperature applications, this design approach helps control lost circulation and improve cement mechanical properties, such as tensile strength and elasticity. This dual-function capability is valuable in unstable, depleted, or fractured formations where formation creep is a concern.

Cement specialists can also tailor the LCM specific gravity with precision to match a wide range of fluid densities – from low-density spacers to high-density cement systems. This approach helps ensure compatibility and supports proper placement within a broad range of well conditions without settlement or flotation under static conditions.

This approach also allows designs that incorporate local materials to help ensure a quick turnaround and reduce supply chain delays. In the event of a material shortage, materials are replaced with alternatives without a compromise to performance. This accelerates the design of service and reduces NPT.

In addition, this approach serves as a valuable risk assessment tool. It predicts the concentration limits of LCM through specific tool dimensions to help prevent service quality incidents, such as pressure-out events, while cementing. This reduces the risk of premature cement job termination, remedial work, and NPT.

Success in the field: total losses cured in vuggy, karstified dolomite formation

Introduced in 2022, this science-based and methodical approach to lost circulation has delivered impressive results in hundreds of global applications and cured lost circulation during both drilling and cementing. A recent success in the Middle East exemplifies the benefit of this approach.

The Dammam formation in southern Iraq is a karstified dolomite that presents a unique set of lost circulation challenges. Up to 90% of wells in the area experience significant total lost circulation attributed to geological characteristics, such as caverns, vugs, and large fractures. Operators and service companies have exhausted options to address losses in this formation with conventional LCMs and thixotropic cement systems. Conventional solutions required an average of five cement plug treatments supplemented with LCMs, and several days to drill through the section.

Figure 3. *Physical lab tests confirm the LCM package and concentration's ability to seal the expected geometry.*

Halliburton executed a customised design approach to tailor a lost circulation treatment that consisted of a blend of fibres, resilient angular particles, and coarse materials. The package was designed with digital twin models that considered geological formation characteristics, and physical lab tests verified the solution. In the field, the LCM package was batch mixed into the cement slurry and placed down an open-ended drill pipe. The losses were treated with a single plug compared to the usual three to six plugs required in previous wells. This saved the operator an average of 34 h of rig time and allowed them to drill to total depth, run casing, and complete the primary cement job with minimal losses. This design approach is now the operator's preferred method to cure losses in the area.

Customised approach improves lost circulation in well construction

Lost circulation throughout well construction can diminish drilling efficiency, increase costs, and could potentially affect HSE performance. Identification of the loss source is key to the appropriate treatment selection. When bridging materials are required, a science-based and methodical approach to lost circulation package design is crucial.

This approach helps improve treatment success rates and reduces operational risks, costs, and environmental impact. It transforms uncertainty into precision through advanced modelling, real-time data utilisation, and tailored material selection to deliver reliable solutions even in difficult geological formations. The approach gives operators confidence in Halliburton's ability to deliver effective, field-proven solutions for lost circulation. As drilling advances into deeper and more complex formations, this method sets the standard for efficient operations that maximise customer asset value.