

## Laboratory Apparatus Improves Simulation of Lost Circulation Conditions

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### Abstract

Lost circulation is a major recurring problem that costs drilling operators millions of US dollars per annum. Researchers have invested significant effort into understanding the properties of lost circulation materials (LCM). Understanding the proper application of these materials and their relative performance under wellbore conditions is essential to minimize lost circulation non-productive time (NPT). However, laboratory test equipment used to evaluate LCM formulations remains largely unchanged for over 20 years. Because well designs are becoming more challenging and reserves are more difficult to produce, new instrumentation is needed to better model lost circulation. For example, the use of porous and slotted disks is no longer an acceptable model for lost circulation in fractures or vugular carbonates.

This paper discusses the design and initial results of a new low-volume, laboratory-scale apparatus with multiple configurations to better model lost circulation conditions encountered while drilling through vugular and fractured zones. Several configurations comprise a tortuous path with varied cross-sectional geometries. Other possible configurations include a tapered slot, a zig-zag slot, a tapered hole or two helical pathways which intersect multiple times. The apparatus has a high working pressure and high pressure differentials can be used to test plugs formed by lost circulation materials.

### Background

The development and testing of lost circulation materials (LCM) in a laboratory is hampered by the scale of the tests that are possible, versus the scale of the application in the field. If actual fractures are initiated and propagated, as done in Drilling Engineering Association Project 13 in the mid-1980s, the 30-in x 30-in test blocks and equipment are on a "pilot scale" which is both expensive and difficult to manage.<sup>1,2</sup> If scaled down to 4-in diameter core, as was done in GPRI Project 2000 "Mitigating Lost Circulation in Synthetic-Base Fluids", the testing becomes more manageable, but remains very time consuming and expensive.<sup>3</sup>

Engineered solutions designed to improve wellbore strength and reduce drilling non-productive time (NPT) due to lost circulation are directed at wellbore stress management (WSM). This fully engineered approach should include means to help prevent lost circulation as well as stop losses.

Prevention of lost circulation by improving the wellbore strength can be accomplished by designing and applying borehole stress treatments that increase the hoop stress around the wellbore.<sup>4,5</sup>

Proprietary hydraulic design software can predict the equivalent circulating density (ECD) over an interval in one module, calculate the width of a fracture that may be initiated, and select and design a proper material and particle size distribution that can efficiently prop and plug that fracture in a second module.

Specialized combinations of materials can be quickly applied to a lost circulation incident since they are "one-sack" systems that can be maintained already mixed, or mixed and applied with the rig pumps through downhole tools and the bit.

Contingency chemical sealant treatment applications are systems designed to react with the drilling fluid itself to create highly viscous and cohesive sealants in the wellbore that are then displaced into the lost circulation fractures. Drilling-fluid-reactive systems are not dependent on temperature or pressure, thus removing a significant amount of placement uncertainty present with cross-linked systems, particularly those based on polymeric materials.

This combination of planning and application tools allows the operator to make decisions ahead of time during the "drilling the well on paper" phase as to which approach is the most economic: prevention or remediation.

### Current Test Methods

The design of new LCM appropriate for the more challenging wells being drilled today is hampered by the use of inadequate test media such as porous and slotted discs in Permeability Plugging Apparatus (PPA) cells. As shown in **Figure 1**, porous ceramic discs are most appropriate to determine ideal compositions to reduce loss rates in sandstone formations where seepage loss of drilling fluids is high. Slotted discs with parallel sides are most appropriate for natural fractures or fractures which are on the order of several feet in length. Tapered slots are most applicable for induced fractures which are less than 1 foot in length. Unfortunately, none of these test media are suitable for determining which LCM is appropriate for vugular carbonate formations. There is a need for better simulation of vugular carbonates because of the estimated amount of oil reserves found in this type of formation<sup>6</sup> and the lost circulation incidents associated with carbonate formations.

## New Apparatus Design

The first step in designing a new test apparatus is determining the appropriate size which can be used in the desired setting. In our case, we wanted to use the equipment in a laboratory setting while requiring a small volume of fluid, ideally less than a liter. We also desired to use as much existing equipment as possible such as a PPA cell and a PPA receiver. Limiting the size of the apparatus to the lab scale makes it impossible to simulate a cavern or even the large vugs seen in **Figure 2**.

**Figure 3** shows a scale of current size of laboratory equipment available today (right), and what may be the appropriate size for use in a laboratory setting (middle), compared to what may be appropriate in an operational setting (left). We determined that the largest opening we can safely test against is  $\frac{1}{2}$  inch (12.5 mm) diameter which is two times the diameter of existing test media and four times larger in area. Vugs larger than that may already be remediated using either cement, gunk squeeze, or other chemical sealants which have controlled and reliable gel or set times.

We considered various designs for the new test equipment such as a smaller version of the API recommended lost circulation test apparatus with smaller ball bearings. This apparatus, shown in **Figure 4**, contains a solid rod in the center of the test cell with  $\frac{1}{2}$  inch diameter ball bearings around this rod. This apparatus was rejected after it was determined that the pore throat size through the design was much smaller than  $\frac{1}{2}$  inch and that there were a large number of pathways through the apparatus. A second design considered in the planning stage is also shown in **Figure 4** and contains a tortuous path through a series of straight or tapered slots and ball bearings. This concept was also dropped after it was determined that the slot and pore throat sizes would be similar to that which already exists.

The first design of the test cell is shown in **Figure 5** and contains a tortuous path through the apparatus with plates containing  $\frac{1}{2}$  inch diameter holes connected by pathways which are 0.13 inch wide, giving a cross-sectional area of the pathway equal to the cross-sectional area of the hole in the plate. The holes are positioned such that the test fluid must follow the path shown by the red arrow in **Figure 5**. The overall test setup is shown in **Figure 6** and includes a standard PPA cell with a modified end cap connected via a  $\frac{5}{8}$  inch outside diameter curved tube to the bottom of the test cell. This allows the inside diameter of the tube to be the same as the diameter of the holes in test cell. An improved receiver is attached to the top of the test cell with tubing that is  $\frac{1}{4}$  inch inside diameter to allow large particulates to flow freely without plugging and causing a false positive test.

## Test Design and Results in the New Apparatus

The formulation of the base fluid used in this study is shown in **Table 1**. This fluid is a simple 12 lb/gal fluid with viscosity supplied by a hydrophobically modified natural polymer. This reduces or nearly eliminates the contribution of fine materials in the fluid, such as fluid loss control materials, to sealing the very small pore spaces between LCM or barite

particles. The fluid formulations with LCM were tested at room temperature and a maximum pressure of 1500 psi.

The LCM included “Engineered Composite Solutions” (ECS)<sup>7</sup> which are optimized combinations of nutshells and ground marble for ECS-1 and resilient graphitic carbon and cellulosic materials for ECS-2 in combination with superabsorbent polymer and precision cut fibers. The reservoir friendly materials included different shapes and sizes of ground marble and calcium carbonate in combination with an acid degradable superabsorbent material and fiber. The formulations are given in **Table 2**.

**Table 2** also shows the uncorrected fluid loss in milliliters needed to form an immovable plug and **Figure 7** shows pictures of the plugged  $\frac{1}{2}$  inch diameter hole in the bottom-most plate of the test apparatus. The pictures are from the tests using ECS-1 (left) and the reservoir friendly combination of materials (right). These plugs did not seal the LCM test cell without the addition of the superabsorbent polymer and the cut fibers. This is important to note considering that the ECS materials readily plug legacy slotted discs up to 0.1 inch (2540 mm) in width.<sup>7</sup> The plugs were compact, rigid, and tough indicating that they should withstand a pressure change of several hundred psi.

## Future Direction and Designs

Laboratory testing using this current cell setup is ongoing and the emphasis is on the use of chemical sealants or gunk-type reactions and their ability to hold pressure in the wellbore. Tests are also being conducted at temperatures above room temperature including 150 °F. Lab tests have also incorporated a second cell design as shown in **Figure 8**. This design continues to use the plates with the  $\frac{1}{2}$  inch holes, but the spacer between a majority of the plates is now 0.275 inches in width. This combination has proved to be more difficult to plug.

Another design for the test cell is shown in **Figure 9**. This design comprises two helical pathways that intersect at least twice. The diameter of the pathways is  $\frac{1}{2}$  inch and the bore of pathways could be smooth or textured.

## Conclusions

There is a need in the oil and gas industry to make laboratory tests which better simulate conditions encountered in the wellbore. This allows more efficient use of decision trees and materials to cure lost circulation in the more expensive drilling operations seen today. In summary:

- The test media currently used to develop and test LCM combinations is inadequate when simulating carbonate formations.
- Several designs were considered when determining an appropriate LCM test apparatus.
- The tested LCM cell design contains a series of holes and slots connected by a tortuous path.
- The new test cell described in this paper allows development of new compositions and combinations to be

investigated and helps refine decision making while in the planning stages of a well.

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**Table 2 LCM Formulations and Results (unless otherwise specified units in lb/bbl)**

| Formulation       | 1    | 2    | 3         |
|-------------------|------|------|-----------|
| ECS-1             | 80   |      | Reservoir |
| ECS-2             |      | 80   | Friendly  |
| Swelling Particle | 4    | 4    | Materials |
| 13 mm Fiber       | 0.5  | 0.5  |           |
| Fluid Loss, mL    | 35   | 30   | 43        |
| Pressure, psi     | 1500 | 1500 | 1500      |

### Tables

**Table 1 Fluid Formulation Used for Testing**

| Material                 | Amount |
|--------------------------|--------|
| Water, bbl               | 0.86   |
| Modified Polymer, lb/bbl | 1.5    |
| Barite, lb/bbl           | 201    |

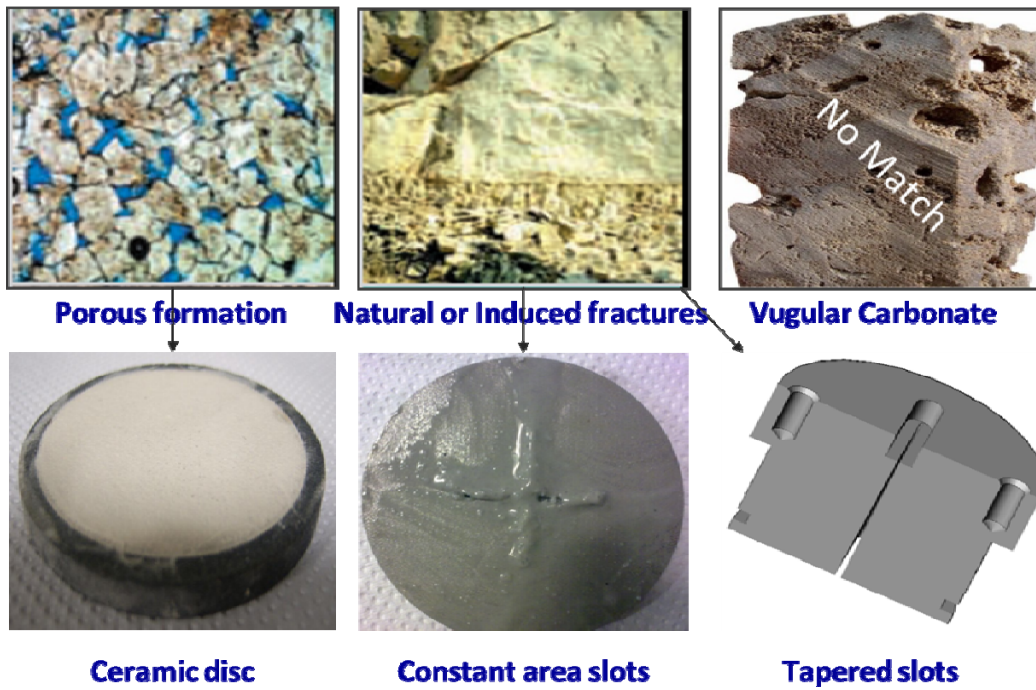
**Figures**

Figure 1 Test media with comparison to rock



Figure 2 Representations of carbonate caverns and vugs

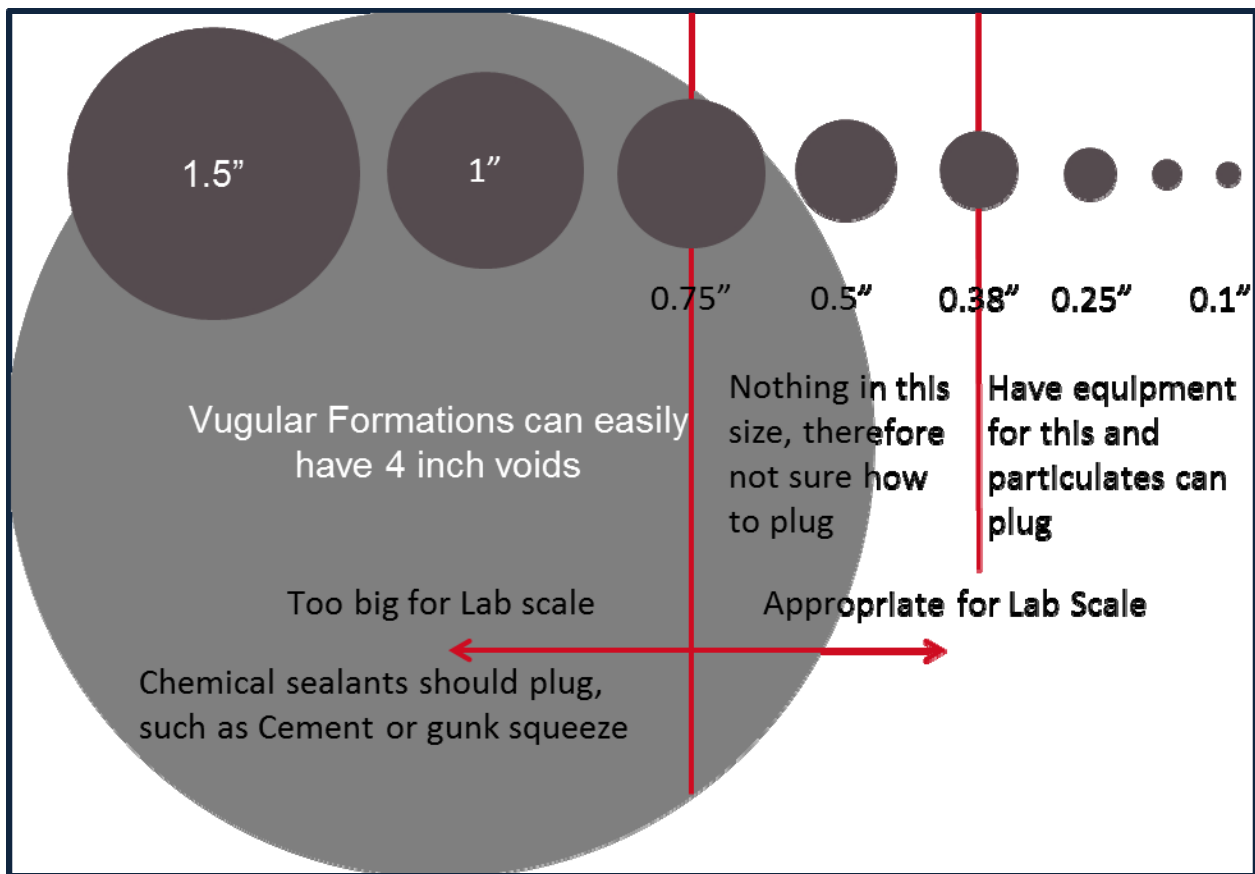


Figure 3 Laboratory scale of equipment compared to small vug

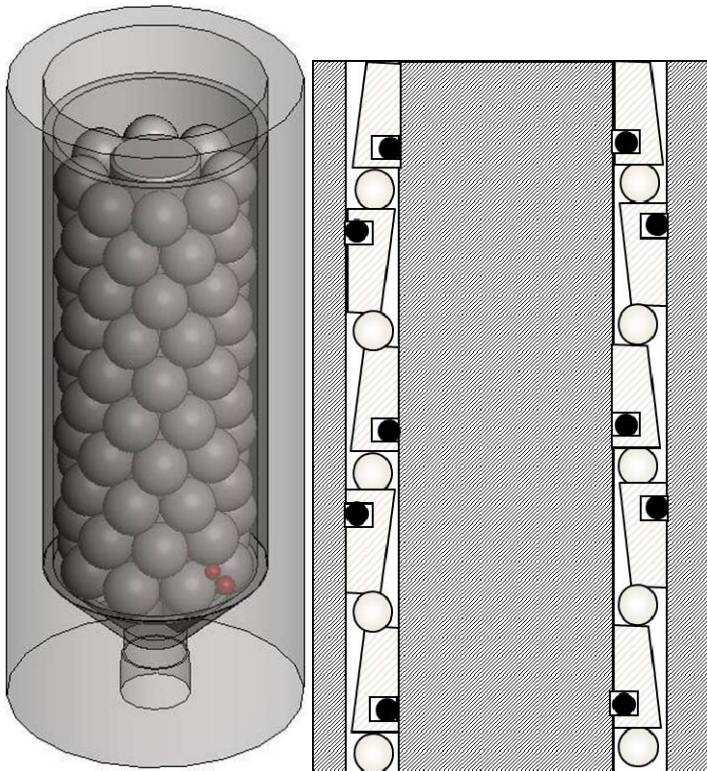
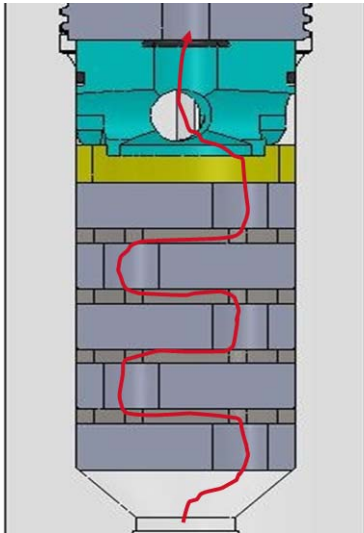
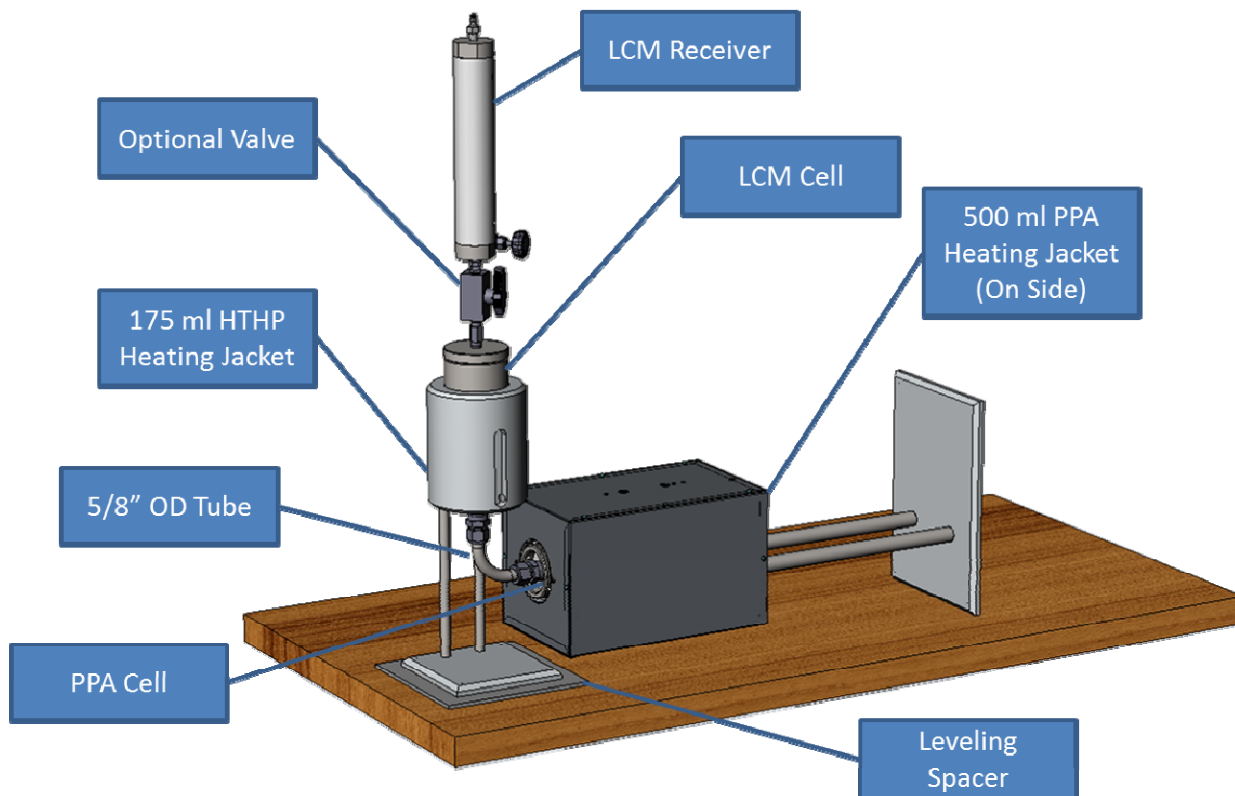


Figure 4 Designs of conceptual laboratory apparatuses



Flow Path in Vug Simulator  
Tortuous Path with 0.5 inch  
Holes and 0.13 inch  
space

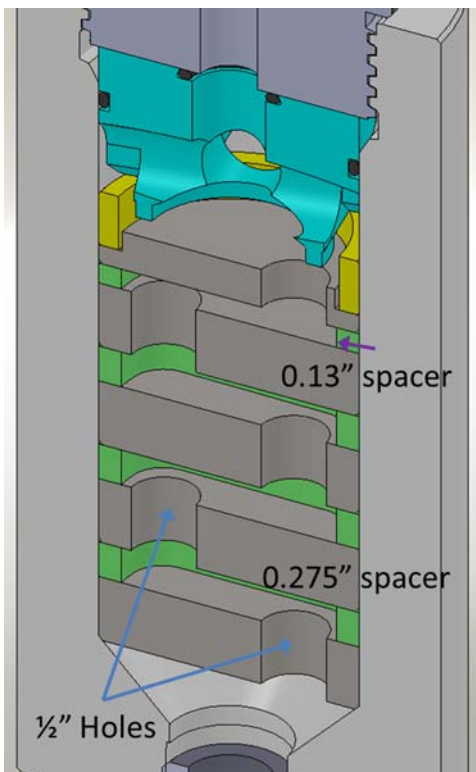
**Figure 5 Schematic of LCM cell with flow path**



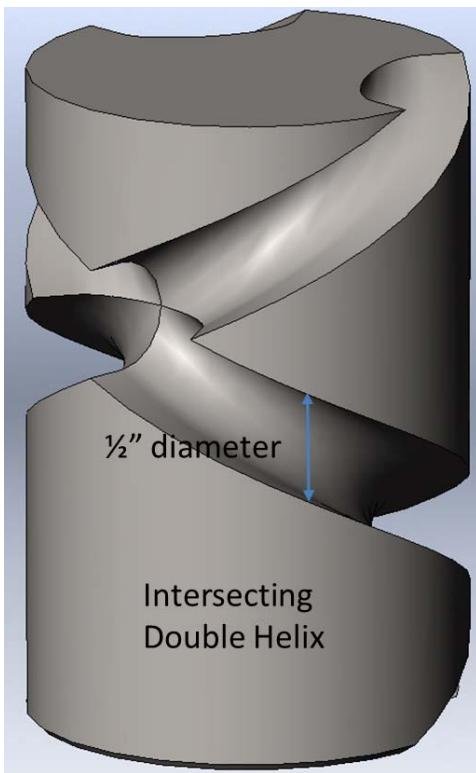
**Figure 6 Test setup showing connection from PPA cell to receiver**



**Figure 7 Disks with 1/2 inch holes plugged with ECS-1 combination (left) or reservoir friendly combination (right)**



**Figure 8 Next geometry used for future testing**



**Figure 9 Possible future geometry for LCM cell**