AADE-11-NTCE-19

Application of Fiber Laden Pill for Controlling Lost Circulation in Natural Fractures

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Abstract

Lost circulation in formations with natural fractures or vugs results in lost fluid accompanied with increased drilling non productive time (NPT) and cost. Voids within these systems can be large or small and may form an extensive network or remain confined to a localized area and these flow paths for drilling fluids are always open. With unrestricted flow path, large fracture opening size and huge interconnectivity, conventional particulate material based pills very seldom helps in controlling the losses. Conventional cementing system also fails because of the tendency of the slurry to continuously flow in to the formation. High filtrate loss slurry and hesitation squeeze procedure are suitable for sealing fractures or channels in permeable formations.

In this study, several combinations of ground marble and graphitic carbon were tested for controlling losses in a slot physically resembling a fracture. Complete filling of the slot with particles was observed; however it was always accompanied with higher fluid losses. Additions of 0.1 percent (Vol of LCM) of fibers to the particulate system lead to complete filling of the slot with controlled fluid loss. In other words, the fiber laden LCM pill was found to be forming an immobile mass within the slot by instantaneously getting de-fluidized. Natural and synthetic fibers with different aspect ratio and sizes were used for the testing. Impact of addition of high amounts of fibers on rheology of fluid was physically observed to be adverse. Experiments performed at elevated temperature showed no decrease in performance.

1. Introduction

With most of the world's easy-oil already produced and to keep up with the ever-increasing hydrocarbon demand, operators are forced to explore in deeper, hostile and much harsher drilling environments like HTHP, XHTHP, UHTHP, Deepwater, ERD, Depleted and Narrow Mud-Window wells. With this paradigm shift, the industry has inevitably inherited the complex problems associated with the above stated harsh drilling environments. Now the onus is on the service companies to keep up with operators demanding technological needs to tackle the issues associated with drilling the above stated wells.

One of the problems most widely discussed and that has garnered industry wide attention is Lost Circulation (LC), which is nothing but the complete loss of the drilling fluid in to the formation through natural or induced fractures[1]. Lost Circulation has always presented great challenges to the petroleum industry causing significant expenditure in cash and time in fighting the problem. Trouble costs include the loss of whole drilling fluid, wasted rig time and in worse cases it will lead to lost bore-holes, side tracked or by-passed wells, abandoned wells, relief wells and lost petroleum reserves[2]. A recently conducted SPE Forum series on Lost Circulation (Park City, Utah, USA 2010) itself exemplifies the industries' concern on this problem.

Application of Lost Circulation Materials (LCM) has been one of the widely used and understood techniques to arrest, mitigate and deal with lost circulation. Halliburton has been one of the pioneers in designing models, methods and materials that provide engineered solutions to lost circulation[2, 3]. Lost circulation materials like ground marble, resilient graphitic carbon, ground nut shells and cellulosic fibers are widely used across the petroleum industry. But again as endorsed and practiced by Halliburton[4] not all lost circulation materials are the same and can fit the purpose. It is the synergistic effect of the particles in combination that makes them work more efficiently[5, 6].

1A. Lost Circulation: Difference in Natural and Artificial Fractures Revisited:

It is a very well know phenomenon that there are usually two leak-off flow paths for lost circulation to occur, Natural and Artificial (induced). There is a significant difference in the pressure conditions and fracture sizes between the Natural and Artificial fractures[7]. Induced or artificial fractures are created by the pressure conditions within the wellbore. Induced fractures are created and lost circulation occurs when the wellbore pressure is sufficient enough to overcome the strength or fracturing pressure of the surrounding formation. The resulting fracture may open for a short time and then close again or remain open until some amount of lost circulation material is plugged inside and keeps the fracture propped. This type of induced fractures and lost circulation may be initiated while tripping, running a casing or tubing or due to simple circulation for cleaning and conditioning the hole. The loss rates rarely exceed the rig's pumping capabilities. It has been reported in several case studies and publications that this type of induced lost circulation event can be successfully dealt with the application of appropriate type of LCMs.

On the other hand, Natural Fractures are a set of complete different issues and needs to be dealt separately. Natural fractures, vugs and caverns are a result of natural geographical processes and are always open. The voids within these systems can be large or small, may run horizontally, vertically or both, and may form an extensive network or be confined to localized areas. Lost Circulation in these stratigraphies almost gets initiated instantaneously while drilling. When the openings are large enough to permit the unrestricted flow of whole mud, the subsequent loss returns are sudden and complete and the loss rate will generally exceed rig pumping capabilities. Due to the size of the openings and pressure differential, conventional lost circulation materials or methods might not be successful. Hence the endeavor in this work is to use novel LCM combinations and new testing methods for robust designing of the drilling fluid for arresting lost circulations in formations with large fractures.

Due to the recent advances in Coal Bed Methane drilling in coal seams[8], increased drilling activity has been seen in this type of formation. The coal seams are also characterized with many natural cleats, gaps and fractures that vary with coal maturity (**Figure 1).** An engineered solution, which is a combination of ground marble and resilient graphitic carbon was tested extensively in the lab prior to applying in the field successfully without any lost circulation issues for drilling through coal cleats. Keeping in view the above difference in natural fractures and some of the solutions applied, the present paper deals more with the application of LCM laden drilling fluid containing fibers as a potential viable alternative to previous solutions.

Figure 1: Coal formation with natural fractures

1B. Application of Fibers in Arresting Lost Circulations:

Fibers have been extensively used in construction industry as a way of reinforcing concrete to increase concrete toughness and stop crack propagation. Taking a clue from this, fibers have also found their application in the oil field mainly in the areas of cementing and stimulation [9]. Different types of fibers like nylon, polypropylene, etc have been successfully used in cement slurries in combination with particles to arrest loss of cement slurries in to the formation. Compared to just particles alone, fibers were proven to form a tough network structure along with particles and thus preventing cement losses in to the formations[10]. Fiber containing cement was also reported to be used in borehole-lining technique[11] where in the purpose of the fibers was to provide strength to the cement and also to arrest cement slurry losses. But on the other side, fibers also have their preferred application environment. That is they do not easily get dispersed in all types of fluid systems and may lead to un-invited problems like plugging of down-hole tools etc. There is also a critical concentration for the fibers at which they provide the desired functioning. For example, at very low concentrations too few fibers may interact with the available particles for forming the networks. And at very high concentration, then the pumping ability may be severely affected because of excessive viscosity development.

Based on the above discussion on different types of fractures and fiber application in controlling lost circulation, the present laboratory work is presented to gain the attention of the operating companies to make use of fibers in drilling fluids in combating lost circulations in naturally fractured, vugular type of formations.

2. Present Work:

The present work is about the use of fibers in combination with appropriate particulate LCM to plug slots that closely resemble large natural fractures. Tests were performed in Particle Plugging Apparatus (PPA) using the tapered slots on the drilling fluids containing fibers and appropriately selected lost circulation materials (LCM). The objective of the tests performed was to have

- A controlled fluid loss from the PPA;
- Complete filling of the slot with an LCM combination forming an immobile mass.

As part of this work, it is also being proposed that for better control of lost circulation in the case of large fractures it is always desirable for the fracture (slot) to be filled completely with LCM combinations.

2A. Methodology of the Experiments Performed:

Both aqueous and non-aqueous based drilling fluids were selected as the base fluids for performing the PPA experiments. The compositions of these fluids are shown in Table **1 and 2** respectively. The drilling fluids were hot rolled for a period of 16 hrs at a temperature of 150°F (aqueous fluid) and at 200°F (non-aqueous fluid). The rheology of these hot rolled fluids measured on FANN 35 SA at 120°F is reported in **Table 3.** The low shear yield point or Tau 0 of the fluids selected was also in the recommended range so as to prevent the un-wanted settling of lost circulation materials when added to the fluid while testing. Hence based on the above rheological data for the fluids it was satisfactory to carry out the planned tests on PPA.

In an earlier work[12], a new Tapered Slot (TS) was designed having a larger opening size that tapers down to a smaller size over a certain length, which more closely resembles a fracture. It was envisaged that this kind of slot can also represent specific type of fractures like natural fractures or vugular formations. The conceptual detail of the tapered slot is depicted in **Figure 2.**

Table 1: Formulation of Aqueous Drilling Fluid

Product	Conc. (ppb)
Barite	As required
Sodium Chloride	As required
Primary Viscosifier	1
Sodium Hydroxide	0.25
Fluid loss additive	0.15
Shale Stabilizer -1	0.5
Shale Stabilizer - 2	2
Shale Stabilizer - 3	5
Fluid loss additive/Viscosifier	5

Table 2: Formulation of Non- Aqueous Drilling Fluid

Product	Conc. (ppb)
Barite	As required
Base oil for 65:35 OWR	As required
Water+$CaCl_2$ (250,000 ppm)	As required
Emulsifier	8
Lime	1.5
Fluid loss additive	1.5
Viscosifier	3
Suspension agent	5
Calcium Carbonate	30
Low end rheology modifier	3
Drill solids	20

Table 3: Rheology data on FANN 35 at 120°F

RPM	Aqueous base fluid	Non-aqueous base fluid,
600	74	78
300	55	49
200	40	39
100	30	27
6	12	11
3	10	10
PV, cP	19	29
YP, lb/100ft^2	36	20
Tau 0, lb/100ft^2	7.12	9.18

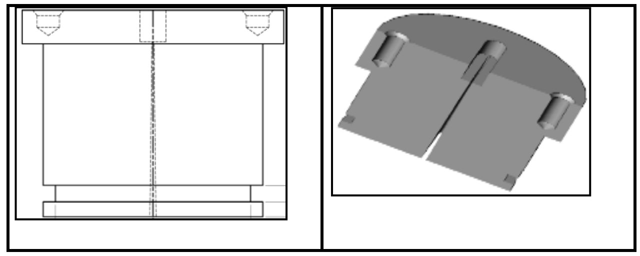


Figure 2: Conceptual design of the tapered slot

2B. Materials Used in the Tests:

Again based on the previous work[5], a combination of Ground Marble (GM) and Resilient Graphitic Carbon (RGC), which showed synergistically better performance, was used that form the particle part of the LCM. The concentration of the resilient graphitic carbon was kept at 20 percent by Vol in the overall LCM as per the discussions presented in the above cited work[5]. Viscose Cellulosic Fibers, Oil coated cellulosic fibers and Carbon fibers having fiber lengths in the range of 2000 to 3000 microns with an aspect ratio in the range of 2 to 50 were selected for the tests.

These fibers were added, along with ground marble and RGC, to the drilling fluid as per the concentrations shown in **Table 4.** From the table below it can also be noted that the concentration of fibers is around 0.1 percent by Vol in the overall LCM composition.

Table 4: Details of the Materials added to the Test Fluid, ppb

LCM	SG	Concentration in Test Fluid
Ground Marble, **GM**	2.7	30 - 60 ppb
Resilient Graphitic Carbon, **RGC**	1.75	8.2 ppb
Viscose Cellulosic Fiber	1.51	1.7 - 3.5 ppb
Oil coated Cellulosic Fibers	1.1	3 – 4 ppb
Carbon Fiber	2.12	0.5 ppb

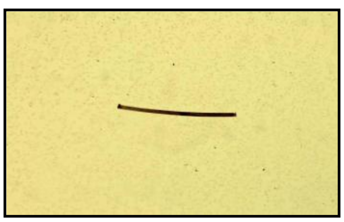
2C. Test Procedure:

Particle plugging apparatus (PPA) is the standard equipment used to evaluate the performance of the lost circulation material. The “performance of the LCM” is hereby defined as the ability to form an impermeable plug or bridge in the filtering media and arrest the fluid loss. The set up consists of a 500-ml volume cell that has a movable piston at the bottom. At the top, the cell has an assembly for perfectly sealing the filter media while testing. The cell is positioned with pressure applied from the bottom of the cell and the filtrate collected from the top. This prevents particles that settle during the static test from contributing to the performance of the LCM (as particles settle in the direction opposite to the filtration surface). The cell pressure is applied by a two stage hydraulic pump or using a nitrogen pressure line. Pressure is transferred to the drilling fluid through the floating piston in the cell. The filter media that is employed in the PPA tests as part of this work is the newly designed tapered slot. As stated in the earlier sections, the tapered slot physically resembles an actual fracture and can also be used to mimic a large type of natural or vugular fractures. All the tests were performed at 150°F and the reported results are also at this test temperature.

3. Results and Discussion:

3A. Properties of Fibers Tested.

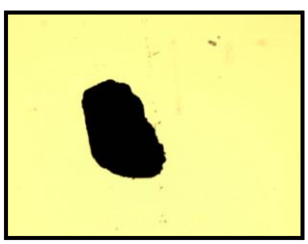
The fibers used in all the PPA testings were first analyzed under an Optical Microscope to capture the images and also to determine the fiber length and Aspect Ratios. The results are shown in **Figure 3** and **Table 5.** The typical lengths of the fibers used are in the range of 1500 – 3000 microns and Aspect Ratios in the range of 2 – 50.



Cellulosic Fiber - 1

Cellulosic Fiber - 2

Carbon Fiber



Oil Coated Fiber

Figure 3: Optical Microscopy Images of Fibers

Table 5: Properties of Fibers Tested

Fibers tested	SG	Fiber Length (μm)	Aspect Ratio
Viscose Cellulosic Fibers - 1	1.51	1570	~28
Viscose Cellulosic Fibers - 2	1.51	1900	~35
Oil coated Cellulosic Fibers	1.1	180	1.8
Carbon Fiber	2.12	3000	50

3B. PPA Test Results: Aqueous Based Fluids

Ground Marble and Resilient Graphitic Carbon Combinations:

In the initial stages of the work, tests were performed on the PPA only using the particulate combination of Ground Marble and Resilient Graphitic Carbon. Different sizes of Ground Marble and RGC were mixed in the concentration of 80:20 by Vol corresponding to a concentration of 50 ppb and 8.2 ppb, respectively, in the drilling fluid. In all the cases, it was observed that the mud loss was relatively high through the tapered slot, but fluid loss control was obtained in every case. The results of this particular combination in the drilling fluid are summarized in **Table 6.**

Table 6: GM and RGC Results

Test No	Combination	Conc. LCM	Conc. in fluid ppb	Mud loss (ml)
1	GM1200/RGC 400	80/20	50 /8.2	70
2	GM1200/RGC 1000	80/20	50 /8.2	90
3	GM600/RGC 1000	80/20	50 /8.2	80

Ground Marble and Fiber Combinations:

In the next stage, GM and Fibers were mixed and added to the test fluid in order to make cost-effective combinations. This is done by eliminating RGC from the combination. From the PPA test results, it was again noted that even this combination was not successful in arresting mud loss through the tapered slot. The results for this combination are summarized in **Table 7.** Probable reason for this uncontrolled fluid loss could be because of the fluid not having appropriate particle size distribution so as to form a formidable plug along with the fibers in the tapered slot. One observation that is worth mentioning is that the slot was completely filled with the GM and Fibers despite the fact that it did not help in controlling the mud losses.

Table 7: GM and Fiber Results

Test No	Combination	LCM Conc.	Conc. in fluid ppb	Mud loss (ml)
1	GM1200/ Viscose Cellulosic Fiber	95/5	60/1.8	No Control
2	GM1200/ Viscose Cellulosic Fiber	95/5	60/1.8	No Control
3	GM600/ Viscose Cellulosic Fiber	95/5	60/1.8	No Control

GM, RGC and Fiber Combination:

The tests in the later stages were performed on the tertiary combination of ground marble, resilient graphitic carbon and the fibers. The results of this combination are summarized in **Table 8.** From this table, it can be observed that using the fibers along with GM and RGC lead to a controlled mud loss along with complete filling of the tapered slot. The mud loss in case of GM1200/RGC400/Fibers was lower compared to the same combination with RGC 1000. This is due to the fact that RGC 400 with a smaller distribution of particle size compared to RGC 1000 is more efficient in combination with the GM1200, leading to quicker filling of the spaces available in the fiber mesh and hence leading to lower mud loss. The concentration of the oil coated fibers used in the above reported test result was also higher compared to the Viscose fibers used. This is because of the fact that the length and aspect ratio (1.8) of these oil coated fibers was far less than the viscose and carbon fibers and hence has to be used at higher concentrations.

Figure 4 below captures the scenarios where the combination of GM/RGC and Fibers lead to complete filling of the tapered slot. It was also observed that for this particular combination of particles and fibers, the slot was getting filled instantaneously with controlled fluid loss. Hence from this result it can be stated that for efficient control of lost circulation in the case of larger fractures may require an engineered combination of selective particles and fibers.

Table 8: GM, RGC and Fiber results

Test No.	Combination	LCM Conc.	Conc. in fluid ppb	Mud loss (ml)
1	GM1200/RGC400/V.Cellulosic Fiber -1	70/20/10	44 /8.2/3.5	10
2	GM1200/RGC400/V.Cellulosic Fiber -2	70/20/10	44/8.2/3.5	10
3	GM1200/RGC1000/V.Cellulosic Fiber -1	70/20/10	44/8.2/3.5	25
4	GM1200/RGC1000/ V.Cellulosic Fiber -2	70/20/10	44/8.2/3.5	40
5	GM1200/RGC400/ Carbon Fiber	79/20/1	49/8.2/0.5	15
6	GM1200/RGC1000/ Carbon Fiber	79/20/1	49/8.2/0.5	25
7	GM600/RGC1000/ Oil coated Fiber	65/20/15	41/8.2/4	25
8	GM1200/RGC1000/ Oil coated Fiber	65/20/15	41/8.2/4	40
9	GM1200/RGC400/ Oil coated Fiber	65/20/15	41 /8.2/4	10

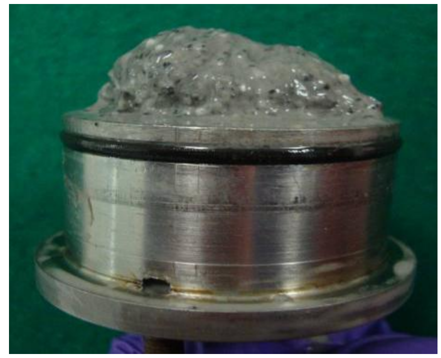


Figure 4: Tapered completely filled with GM/RGC and Fibers

Effect of Fiber concentration on drilling fluid viscosity:
Fibers tend to increase the viscosity of the base drilling fluid. The amount of the fibers and also the length of a particular fiber can impact the viscosity of the fiber laden drilling fluid. In the particular experiments that are reported above, different amount of fibers and their effect on viscosity was first observed. Based on the observations, the optimum concentration of 1.8 ppb in case of viscose fibers and 4 ppb in case of oil coated fibers was fixed that didn't have any significant effect on viscosity.

Figures 5 and 6 may represent physically how adverse the fluid rheology may become (may be un-pumpable) when fibers are used at high concentrations. One observation worth mentioning in this discussion is that, visually, the effect of addition of 15 percent by Vol (7.4 ppb) of Carbon fibers of 150 microns length did not have any significant effect on the mud viscosity. But addition of only 5 percent by Vol (2.5 ppb) of carbon fibers of length 3000 microns resulted in very thick mud. This demonstrated the impact of long fibers and its concentration on the drilling fluid viscosity.

It was difficult to measure the actual rheology or viscosity increase in the drilling fluid using any of the conventional tools like FANN 35 or Fann Yield Stress Adaptor (FYSA) [13] because the presence of the fibers in the fluid was leading to unstable dial readings on the above instruments. The reason for unstable dial reading in FANN 35 could be because of the fibers getting aligned with the shear flow on the bob. And in the case of FYSA, it could be because of the long length and aspect ratio of fibers plugging the paddles on the bob and sleeve of FYSA (**See Figure 7 below for the picture of FYSA)**.

The investigation in this area can be worth pursuing using other advanced rheological tools. This work is currently in progress and may be reported in follow up publications.

Figure 5: Aqueous drilling fluid with 0.5 ppb carbon fibers

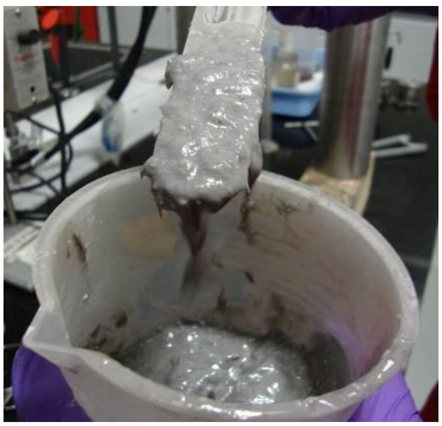


Figure 6: Aqueous drilling fluid with 2.5 ppb carbon fibers

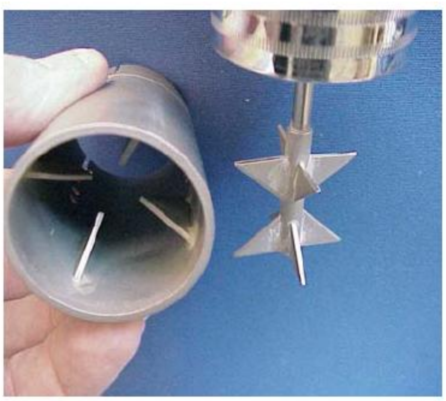


Figure 7: FYSA viscometer device

3C. PPA Test Results: Non-Aqueous Based Fluids

Ground Marble and Resilient Graphitic Carbon Combinations

The same combination of Ground Marble and RGC was also tested in a non-aqueous fluid system. The concentration with which the materials mixed were kept the same as used in the case of the aqueous drilling fluid. The PPA test performed with tapered slot in this case yielded uncontrolled mud loss. The results for this combination are shown in **Table 9.** Compared to the results of this same combination in aqueous base fluids, the mud loss was completely uncontrolled. As the LCM combination and the testing technique remained the same, the difference can be attributed to the change in base fluid system; that is to the non-aqueous fluid.

Table 9: GM and RGC results in NAF

Test No	Combination	Conc.	Mud loss (ml)
1	GM1200/RGC1000	80/20	No Control
2	GM600/RGC1000	80/20	No Control

GM, RGC and Fiber Combination:

Similar to the reported combination in section 3B, GM, RGC and Fibers were also tested in the non-aqueous fluid. Contrary to what was the best combination for the aqueous base fluids, in terms of complete filling of the slot and controlled mud loss, the losses were un-controlled in case of the non-aqueous base fluid. The results are reported in **Table 10.**

Except for the combination of GM1200/RGC400 and carbon fiber, where a controlled mud loss was observed, no other combination of GM/RGC and fibers yielded controlled mud loss.

Table 10: GM, RGC and Fiber results in NAF

Test No	Combination	Conc.	Mud loss (ml)
1	GM1200/RGC1000/Carbon Fiber	79/20/1	No Control
2	GM1200/RGC400/Carbon Fiber	79/20/1	35
3	GM600/RGC1000/Carbon Fiber	79/20/1	No control
4	GM1200/RGC1000/Viscose Cellulosic fiber	75/20/5	No Control
5	GM1200/RGC400/Viscose Cellulosic fiber	75/20/5	No Control

Other than attributing the difference in results to PSD combinations (GM1200 and RGC400) and the change in the base fluid, a justification for this type of result could not be totally explained or found in any literature. But then, as discussed in above part, the change in the base fluid system, that is the non-aqueous fluid could be the reason for this un-controlled mud loss.

The above results are in agreement with the DEA 13[14] study where it was reported that arresting lost circulation in the non-aqueous fluids have always been difficult. This is also in agreement with another one of the findings[15] where the inventors claimed to use an aqueous based LCM pill to arrest lost circulations when drilling with Non-Aqueous fluids. The composition of this LCM pill as reported in the patent application includes aqueous based drilling fluid, combinations of coarse or medium particles and fibers. The experiments performed and the conclusions from the current work are also in agreement with the above cited literature validating the theory with experiments. The reason for this different behavior of aqueous and non-aqueous fluid on the PPA tests is worth investigating and might lead to some answers for better control of mud losses in the case of non-aqueous drilling fluids.

Conclusions

- New testing techniques and LCM combinations are developed and presented that would lead to a better approach in testing materials for arresting lost circulations in case of large and natural fractures or vugs.
- A new Tapered Slot closely representing a fracture was designed and used for the specific test applications.
- Test results have shown that the binary combinations of Ground Marble and Resilient Graphitic Carbon, alone, were not successful in arresting the mud losses through the tapered slot. The slot was getting completely filled without quickly arresting the mud losses.
- Significantly, the combination of Ground Marble and Fibers (alone) were also unsuccessful in controlling the mud losses in the PPA tests.
- Addition of fibers to the combination of Ground Marble and Resilient Graphitic Carbon was found to be working successfully in quickly arresting the losses as well as filling the tapered slot completely. This combination leads to the formation of a solid immobile plug inside the slot.
- The mud losses were comparatively more in the case of a combination where the PSD was not as broad (smaller particle size distribution was less). That is the combinations with a broader PSD of particles were showing lower mud losses.
- Of the combinations tested, only one combination of GM/RGC and fiber provided controlled mud loss in the case of Non-Aqueous Fluids. This may be attributed to a change in the base fluid type and the difference in which the aqueous and non-aqueous fluids behave.
- The concentration of the shorter fibers (lower aspect ratio) required to arrest losses and fill the slot was higher compared to longer fibers (high aspect ratio). This exemplifies the significance of high aspect ratio materials to arrest lost circulations in large fractures.
- There is also a limit on the concentration of fibers that can be used in the fluids without any adverse effects on the viscosity and usability. This effect of fibers on the fluid viscosity is dependent on the amount of fibers and also on the length of a particular fiber.

Acknowledgments

The authors would like to thank the management of Halliburton for giving permission to publish this work. In addition the authors would also like to extend their thanks to Rob Murphy and Dr Matthew Miller for their critical review of the work presented. We also acknowledge our Analytical Services in Pune for their help in providing the Optical Microscopy images of various fibers. Thanks are also extended to Mr. Yogesh Choudhary for extensive proof reading of the manuscript.

Nomenclature

ERD = *Extended Reach Drilling*
GM = *Ground Marble*
HTHP = *High Temperature High Pressure*
LCM = *Lost Circulation Material*
NAF = *Non-Aqueous Fluids*
NPT = *Non Productive Time*
PPA = *Permeability Plugging Apparatus*
PV = *Plastic Viscosity*
RGC = *Resilient Graphitic Carbon*
TS = *Tapered Slot*
UHTHP = *Ultra High Temperature High Pressure*
Vol. = *Volume*
XHTHP = *Extreme High Temperature High Pressure*
YP = *Yield Point*

References

1. Messenger J.U, *Lost Circulation*, Pennwell Publishing Company, Tulsa, Oklahoma (1981).

2. Wang, H., Sweatman, R., Engelman, B., Deeg, W., Whitfill, D., Soliman, M., and Towler, B.F. *Best Practice in Understanding and Managing Lost Circulation Challenges*. SPE 95895, SPE/Annual Technical Conference and Exhibition, Dallas, 9-12 October 2005.

3. Whitfill D., Jamison D., Wang H., and Thaemlitz C., *New Design Models and Materials Provide Engineered Solutions to Lost Circulation*, SPE 101693, SPE Russian Oil and Gas Technical Conference and Exhibition, 3-6 October Moscow, Russia, 2006.

4. Whitfill D., and Hemphill T., *All Lost Circulation Materials and Systems are Not Created Equal,* SPE 84319, SPE/ Annual Technical Conference and Exhibition Denver, Colorado, 5-8 October 2003.

5. Kumar A., Savari S., Whitfill D., and Jamison D., *Wellbore Strengthening: The Less-Studied Properties of Lost-Circulation Materials*, SPE 133484, SPE/ Annual Technical Conference and Exhibition, Florence Italy, 19-22 September 2010.

6. Whitfill D., *Lost Circulation Material Selection, Particle Size Distribution and Fracture Modeling with Fracture Simulation Software,* SPE 115039, IADC/SPE Asia Pacific Drilling Technology Conference and Exhibition, Jakarta, Indonesia, 25-27 August 2008.

7. Canson B.E., *Lost Circulation Treatments for Naturally Fractured, Vugular or Cavernous formations,* SPE 13440, SPE/IADC Drilling Conference, New Orleans, Louisiana, 5-8 March, 1985.

8. Zeilinger S et al., *Utilizing an Engineered Particle Drilling Fluid to Overcome Coal Drilling Challenges,* SPE 128712, IADC/SPE Drilling Conference and Exhibition, New Orleans, Louisiana, 2-4 February, 2010.

9. Hassan I. H. et al, *Using a Novel Cement Fiber System to Control Lost Circulation: Case Histories from the Middle East and the Far East,* SPE 85324, SPE/IADC Middle East Drilling Technology Conference and Exhibition, Abu Dhabi, UAE, 20-22 October, 2003.

10. Tranquini N. et al, *Proven Synergistic Approach in Well Cementing Across Thief Zones: East Venezuela,* SPE 107501, SPE Latin American and Carribean Petroleum Engineering Conference, Buenos Aires, Argentina, 15-18 April 2007.

11. Van Vliet J. P. M. et al, *Development and Field Use of Fiber Containing Cement,* OTC 7889, 27th Annual OTC, Houston, 1-4 May 1995.

12. Savari S., Kumar A., Whitfill D. and Jamison D., *Engineered Insight into "Unexplored" Lost Circulation Material (LCM) Properties Corroborating Wellbore Strengthening Phenomenon*, 17th Oil Asia India Oil & Gas Review Summit & International Exhibition, Mumbai, India, 2010.

13. Olowolagba K. and Varadarajan V., *Applications and Rheology of Foamed Cement,* AADE-10-DF-HO-45, AADE Fluids Conference and Exhibition, Houston, Texas, USA, April 6 – 7, 2010.

14. DEA 13 - Investigation of Lost Circulation with Oil-based Muds (1985-1988).

15. Jaleh G, *Lost Circulation Material for Oilfield Use,* International Patent Application Number WO 2010/133301 A2.