

Research Article

# Novel Engineered Fiber Based Wellbore Strengthening Material in Prevent and Control Real-Time Loss Circulation While Drilling in Bibi-Hakimeh Oil Field

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## Abstract

Loss circulation is one of the most time and cost consuming problems which occurs mostly in naturally fractured formation, induced fractures and also may happen through highly permeable formations and can causes many operational problems such as differential pipe sticking, drill string stuck in the wellbore, drilling fluid costs due to compensate of the lost fluid via the formation, well flow, blowout and etc. controlling severe to total lost circulation in naturally/induced fractured formations has always been challenging. While solving lost circulation after occurrence is critical, prevention is the best drilling practice for saving the operator time and money. One important component of the prevention plan is the design of wellbore strengthening treatments. The goal of these treatments is to increase the “hoop stress” in the near wellbore region, widen the mud weight window and enable wellbore pressure containment. To address this problem, novel fiber based wellbore strengthening material is designed as an engineered solution to improve wellbore wall tensile and compressive strength and reduce drilling non-productive time caused by lost circulation. By using newly fiber based wellbore strengthening material in drilling fluid composition during drilling operation, loss circulation would be prevented in more than 80% of loss zone layers and in case of encountering cavernous layers with large fracture widths it makes the operator easier to control the loss. In this paper a novel fiber based wellbore strengthening material named LIGNO-SEAL is introduced and successfully used to prevent and control loss in an onshore well with severe to complete loss situations in BIBI-HAKIMEH oil field in southern parts of Iran.

## Keywords

Loss Circulation, Differential Pipe Sticking, Induced Fractures, Hoop Stress, Wellbore Strengthening Material

## 1. Introduction

Loss circulation can causes many operational problems such as differential pipe sticking, drill string stuck in the wellbore, drilling fluid costs due to compensate of the lost fluid via the formation, well flow, blowout and etc. controlling severe to total lost circulation in naturally/induced fractured formations has always been challenging.

Loss circulation is one of the most time and cost consuming problems which occurs mostly in naturally fractured formation, induced fractures and also may happen through highly permeable formations. Drilling fluid loss circulation can take place during drilling operation and also drilling trips when pressure surges happen due to the lowering of drill-pipe

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**Received:** 13 November 2024; **Accepted:** 25 November 2024; **Published:** 13 December 2024



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or casing pipes into the hole. Loss circulation problems are not just confined to one special layer or formation. Loss may occur at any different layer of different depths where the total applied pressure against the formation goes beyond formation fracture pressure. In general, four types of formations are responsible for lost circulation occurrence according to [table 1](#) [1, 2].

**Table 1.** Different type of responsible formations for loss circulation occurrence.

Loss zone area classification

Natural/ Induced fractured formations

Vugular/ Cavernous formations

Highly permeable formations

Unconsolidated formations

Basically, lost circulation treatments can be divided into two categories: 1) those where the lost circulation is solved by the addition of solid materials to the drilling mud; and 2) those where the problem can only be solved by the use of a non-mud system. The decision to use what material has been shown to be dependent on the type of lost circulation zone and the severity of the losses, but in many cases a number of different materials are used, sometimes with, sometimes without, success [3-6].

Many articles have published over the years to describe loss circulation and its occurrence reasons and introduced different method and materials to cure and prevent drilling fluid loss during drilling, cementing and also well completion jobs.

Different prevention and remediation methods and material to control loss during different drilling stages in published literature is introduced to industry. Loss control materials includes using of nanoparticle based dispersion with a chemical activator to form a strong gel structure against the loss zone area [4], engineered fiber-based loss control pills [7, 8], usage of ultrasonic nanoparticles [9], application of wellbore strengthening material in control loss during drilling [10], expandable resin-based LCM by using expandable resins with a gas producing agent and surfactant in the LCM composition [11], fibrous organic cellulose for seepage mud losses [12] and modified innovative resins [13-15]. Although all of the mentioned materials have both some advantageous and disadvantageous according to the drilling operation complexity and limitations. Most of the proposed methods and material for loss circulation control are categorized in remediation method and are applicable after loss circulation occurrence.

While solving lost circulation after occurrence is critical, prevention is the best drilling practice for saving the operator time and money. By encountering loss zone areas in case of inexistence of wellbore strengthening material in drilling fluid composition inability of loss circulation prevention causes to

the loss of all hole mud volume and surface mud volumes to fill up the well in case of total loss condition. This led to the drilling operation waiting due to the lack of sufficient mud to continue drilling operation and the consequent NPT costs.

One important component of the prevention plan is the design of wellbore strengthening treatments. The goal of these treatments is to increase the “hoop stress” in the near wellbore region, widen the mud weight window and enable wellbore pressure containment. To address this problem, novel fiber based wellbore strengthening material is designed as an engineered solution to improve wellbore wall tensile and compressive strength and reduce drilling non-productive time caused by lost circulation.

Using wellbore strengthening material in mud system during drilling increases wellbore wall strength against the applied differential pressure especially in depleted reservoirs and offshore wells with narrow mud weight windows due to the low fracture gradient pressure. Loss prevention material enable the operator to deepen the drilling operation by increasing the mud weight window margin through providing mechanical stability against the applied DF hoop stress to the wellbore wall. The vacant fractures is now filled with wellbore strengthening material which can carry more differential pressure and LPM's act as a barrier in front of mud entrance inside the vugs and fractures.

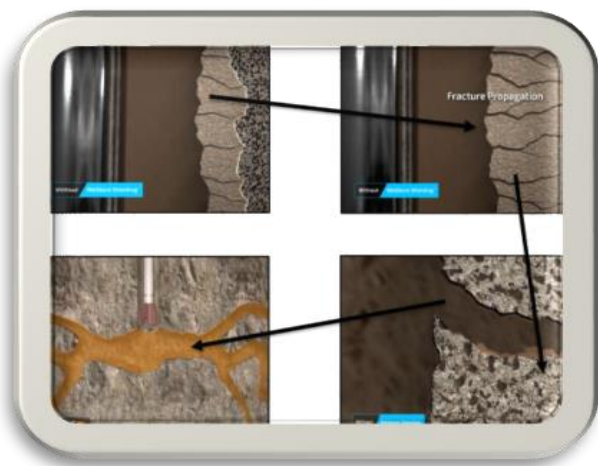
Also using this wellbore strengthening material eliminates the necessity of usage additional casing to reach the total target depth due to occurrence of severe loss circulations. So using LPM additives is vital for a successful drilling operation and endurance of operation especially in depleted reservoirs, high permeable zones, directional wells, etc.

This paper describes novel Fiber based wellbore strengthening material named LIGNO-SEAL developed by particle size distribution principle to prevent loss circulation before occurrence during drilling fractured and cavernous layers through increase wellbore wall mechanical stability against bottom-hole differential pressure fluctuations by dual performance mechanism which is bridging and sealing both pre-existing and induced fractures and create a thin layer of LPM cake across the wellbore wall during drilling operation..

## 2. Material and Methodology

By using newly fiber based wellbore strengthening material in DF composition, loss circulation would be prevented in more than 80% of loss zone layers and in case of encountering cavernous layers with large fracture widths it makes the operator easier to control the loss by decrease the loss rate from complete condition to partial loss condition. Ligno-seal creates a thin impermeable layer on the wellbore wall and plugs the pre-existing micro-fractures in addition of involuntary induced fractures due to wrong drilling mechanical parameters and excess mud weight. The newly based fiber wellbore strengthening material give the ability to the depleted reservoirs to withstand up to 700psi excessive differential pressure

by increasing formation fracture gradient pressure through providing additional mechanical stability.



**Figure 1.** Propagation and widening the pre-existing fracture in absence of using Ligno-seal.

In this paper a novel fiber based wellbore strengthening material named LIGNO-SEAL is introduced and successfully used to prevent and control loss in an onshore well with severe to complete loss situations in BIBI-HAKIMEH oil field in southern parts of Iran according to the well history before using of this additive.

LIGNO-SEAL (LS) is proprietary blend of natural and modified cellulose based fibers designed to provide Non-Invasive properties to any kind of drilling fluid system. LIGNO-SEAL is designed to use in active mud system to minimize fluid invasive and stabilize wellbore wall by providing mechanical stability by carrying applied stress inside the well. LS seals micro fractures/pores of formation effectively so eliminates the chances of Stuck-pipe and solid invasion to which makes it ideal product to use in reservoir zone. LS removes the chance of the initiation and propagation of the existing and so on both voluntary and involuntary induced fractures through making strong mat type bonding structure along the pores and provide sufficient sustaining against differential pressures during drilling till the total target depth. LIGNO-SEAL is designed to minimize fluid invasion and stabilize the wellbore. LS seals micro fractures/pores of the formation effectively and eliminates the chances of stuck-pipe. In absence of Ligno-Seal fracture propagation and complete loss occurs by mechanism explained in Fig 1. As shown in [figure 1](#), the presence of existing micro-fractures inside the formation allows Mud-Filtrate to penetrate inside formation due to differential pressure of Mud density. This leads to propagate the fracture further inside the formation and by further exceeding of the invaded fluid pressure through the pores, the propagation of the fractures goes longer and widened.

For this main reason usage of Ligno-Seal in drilling fluid

composition is a necessity for drilling operation endurance to the total target depth. Effect of Ligno-Seal in sealing pre-existing Micro-Fractures is shown in [figure 2](#).



**Figure 2.** Performance of lingo-seal in sealing and preventing of fractures propagation.

Besides providing mechanical stability of the formation through the non-invasive characteristic of the mud which provided by the LPM additives, being inert to both the mud type and the drilled formation to prevent downhole chemical reactions and degradation of the mud particle additives and formation swelling in shale layers is vitally important to wellbore strengthening materials. According the different lab tests and different field test using in more than 10 wells with different type of muds and formations, LS is completely inert to both mud and formation type.

The novel Fiber based wellbore strengthening material LIGNO-SEAL developed to prevent loss circulation before occurrence during drilling fractured and cavernous layers through increase wellbore wall mechanical stability against bottom-hole differential pressure fluctuations by dual performance mechanism which is bridging and sealing both pre-existing and induced fractures and create a thin layer of LPM cake across the wellbore wall during drilling operation. Ligno-seal design is based on particle size distribution principle methods, in order to provide a wide range of particles with different sizes to cover wide range of existing micro-fractures with variable sizes in the under drilled formation. Hence LS consists of two categories of particles with macro and micro sizes in its composition.

The purpose of the micro particles in LS composition is entering and bridging micro cracks and block the pre-existing micro fractures by providing a safe and strong bonding inside the openings of the fractures and increase the fracture propagation pressure of both the existing and induced fractures. This procedure maintained by deepening the well depth and entering new layers with different type of existing fractures.

After securing the fractures throat in bridging step of loss prevention, the most important factor of maintaining the static condition of the well is the ability of the used LPM materials to withstand against the downhole differential pressure to prevent swiping of the wellbore strengthening material from inside the fractures. The macro-sized particles in the LS

composition create a thin and impermeable layer through a strong sticky bonding along the entire wellbore wall length which stabilizes and maintains the blockage of the blocked fractures and cracks against the variable downhole differential pressures and guarantee a safe drilling endurance to the total target depth. LS can withstand up to 3000psi differential pressure consequently make it possible to drill extreme wells with different pressure zones without worrying of Loss circulation. Fig 3 shows the particle size distribution of the LS composition.



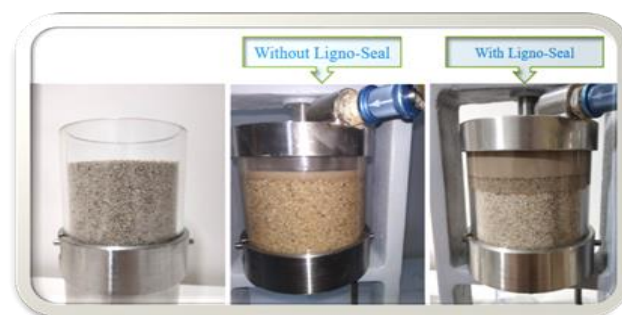
**Figure 3.** Particle size distribution of the lingo-seal composition.

A sand invasion test is (Figure 4) performed to show the efficiency of LS presence in mud system composition to prevent mud invasion through the porous medium of the rocks by bridging and sealing the existing pores and sealing the bridges by creating a thin layer of lingo-seal cake along the pores. A maximum pressure of 500psi has applied to ensure LS wellbore strengthening material through the existing sand pores and their sealment. By performing this test at first stage without adding LS wellbore strengthening material to the mud composition and increase the applied pressure to 100 psi, it observed that almost 90% of the cell mud invaded and lost into the sand pores. At second stage and by adding LS into mud composition and increase its concentration during 5 stages from 4 to 12ppb, observed mud filtrate invading decreases to 3mm at 12ppb concentration through the sand pores which is shown in table 2. According to the results of this test (figure 5), by increasing the concentration of LS in mud system, the fluid invasion depth inside the porous san bed decreases. Performing daily rig site invasion test can help to predict the accurate remained wellbore strengthening material in mud composition and also predict the existence of fractured layers n the under drilled formations. Any significant increasement in mud invasion depth gives sign of decreasing LS concentration in mud system and its applicability and efficiency in preventing loss by infiltrate and blockage through formation pores and fractures. So then by increase the LS concentration, progressive drilling endurance would be

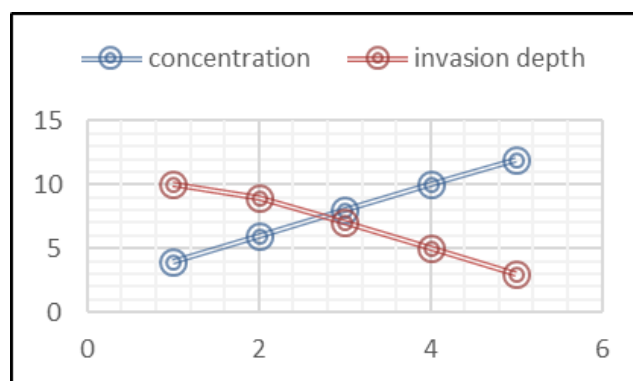
guaranteed to the total target depth without any loss challenges.

**Table 2.** Relation between LS concentration in mud system and fluid invasion depth.

Concentration	Fluid invasion Depth
4 ppb	10 mm
6 ppb	9 mm
8 ppb	7 mm
10 ppb	5 mm
12 ppb	3 mm



**Figure 4.** Sand invasion test to show LS efficiency in seal sand bed pores and throats.



**Figure 5.** Fluid invasion depth versus LS concentration in drilling fluid system.

The effectiveness of lingo-seal wellbore strengthening material is as a result of optimized particle size distribution, combination, mud compatibility, particle strength and high elasticity specification. Besides the major mechanism of lingo-seal as a wellbore strengthening material to provide and increase wellbore wall mechanical stability against bottom-hole differential pressure fluctuations and seal pre-existing and induced fractures during drilling operation it



also can increase hole cleaning efficiency by encapsulating drilled cuttings. After sealing the pre-existing fractures and thin LPM layer creation on wellbore wall cracks opening, the remained LS in mud composition collaborate in drilled conduction to surface solid control facilities by encapsulating multiple cutting and make an integrated multi-cutting capsules through LS components sticky bonding specialty. Ligno-seal encapsulate several cutting into one integrate larger diameter particle to prevent remaining drilled cutting beneath the bit and cutting re-drilling in case of mud inability in hole cleaning operation. This can be so effective especially in highly deviated wells to prevent creation of cutting beds in low side of the hole and the consequent operation problems such as drill-string stuck inside the well. Cutting capsulation by using LS on surface shakers during drilling operation is shown in figure 6.



**Figure 6.** Ligno-seal drill cutting capsulation during drilling operation.

Drilling 12 1/4" of well BH-194 in BIBI-HAKIMEH oil field to the target depth of 1382 meters was in progress. According to table-3, by encountering to 1056 depth, the well involved into complete loss and due to the severity of the loss conditions and the lack of mud return and inefficiency of the conventional loss control pills, drilling operation was in waiting due to the loss of the total circulation volume of drilling fluid and the continuous required time to compensate the lost mud volume. This caused a significant decrease in the daily drilling rate so that it takes 8 days to the drilling operator to drill 1056 to 1245 intervals for 8 days by pumping continuous large amounts of LCM pills with average rate of 0.98 m/h. By encountering to 1245m, drilling operation stopped due to the inability to control total loss circulation and well flowed due to the in-existence of and fluid hydrostatic well pressure to control formation pore pressure. It takes 9 days to both kill the continuous flow of the well and cure the loss and the drilling depth was constant at the same depth of 1245 meters during this period of time. The drilling operation continued from the depth of 1245 to the target depth of 1382 meters. Due to the continuous conditions of complete loss, well flow and multiple tools stuck inside the well, it takes 31 days to complete the 12 1/4" hole section from 1056 meters to the target depth of 1382 meters with average rate of 0.43m/h. by pulling out of the hole, drill string got stuck and during the fishing job, total length of 150 meters of the string remained inside the well. Finally, decision was made to set cement plug and sidetrack the well. The total volume of formation fluid loss during this period was 35,909 bbl. Finally, after repeated attempts to cementing the well and sidetracking operations, the well got side tracked and drilling the new well started from 1038m by using fiber based lingo-seal wellbore strengthening material. Result of drilling well BH-194 SD1 by using LS in the same intervals is shown in table 4.

### 3. Case History

**Table 3.** Well BH-194 drilling and loss history (Main hole before sidetracking).

Date	Depth (m)	Rate of loss (bph)	LCM PILL		Total volume loss
			vol	#ppb	
11-Aug	1056	complete loss	40	40	818
12-Aug	1062	80-100	40	40	558
	1074	complete loss	40	40	
	1077	complete loss	40	40	
13-Aug	1090	complete loss	40	40	1255
	1109	complete loss	40	40	
	1110	complete loss	40	40	
14-Aug	1139	complete loss	40	40	592

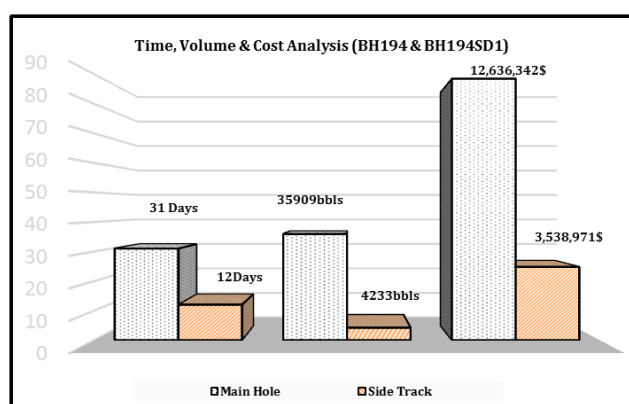
Date	Depth (m)	Rate of loss (bph)	LCM PILL		Total volume loss
			vol	#ppb	
	1140	complete loss	40	40	
	1145	complete loss	70	40	
15-Aug	1185	Oct-60	3 stage	40	360
16-Aug	1195	Aug-60	periodic	40	37
	1200	complete loss	50	40	
17-Aug	1238	0-120	periodic	40	562
	1239	complete loss	60	40	
18-Aug	1239	0-60	periodic	40	2789
	1245	complete loss	70	40	
19-Aug	1245	flow and complete loss	120	50	1100
	1245	complete loss	70	40	
22-Aug	1245	no return	50	50	2200
	1245	no return	40	50	
24-Aug	1245	no return and flow	100	20	2181
25-Aug	1245	no return and flow	150	50	807
	1245	no return and flow	100	50	
26-Aug	1246	100 - 250			1890
27-Aug	1252-1254.6	loss and flow			1791
28-Aug	1257	15-Oct	periodic	Hi-vis	928
3-Sep	1377	loss and stuck (50-70)	periodic	Hi-vis	1058
4-Sep	1382	loss, flow and stuck (80-100)	periodic	Hi-vis	2123
5-Sep	1382	loss, flow and stuck (80-120)	periodic	Hi-vis	2885
6-Sep	1382	loss, flow and stuck (100-120)	periodic	Hi-vis	1649
7-Sep	1382	loss, flow and stuck (100-120)	periodic	Hi-vis	1504
8-Sep	1382	loss, flow and stuck (100-120)	250	55	2565
9-Sep	1382	loss, flow and stuck (100-110)	150	55	1946
10-Sep	1382.5	loss, flow and stuck (150)	100	Hi-vis	2486
12-Sep	1382.5	loss, flow and stuck	170	50	1825
31 days	Total Mud Losses(bbl.)				35,909

**Table 4.** Well BH-194 drilling and loss history (Main hole before sidetracking).

Date	Depth (m)	Rate of loss (bph)	Ligno-seal		Total volume loss
			vol	#ppb	
12-Oct	1034-1036	2 - 8	TCV	7	89
13-Oct	1063	10 - 16	TCV	20	292

Date	Depth (m)	Rate of loss (bph)	Ligno-seal		Total volume loss
			vol	#ppb	
14-Oct	1096.3	6 - 10	TCV	20	247
15-Oct	1111	4 - 6	TCV	12	143
16-Oct	1135	3 - 5	TCV	11	145
17-Oct	1150	4	TCV	12	126
19-Oct	1178	2 - 4	TCV	10	120
20-Oct	1245	10 - 20	TCV	20	259

As it is shown in [table 4](#), the 1034 to 1245m intervals drilled in just 8 days and total formation loss was 1421bbl in this 8 day LS usage in drilling fluid composition which is 34488bbl less than the previous well prior of using LS in drilling program causes in saving 96% of drilling fluid cost and volume which was lost to the formation in the previous hole. [Figure 7](#) shows time, volume and cost analysis of 12 ¼" hole section drilling results for well BH-194 prior and after using LS wellbore strengthening material in drilling fluid composition.



**Figure 7.** Time, Volume and cost analysis of well BH-194 prior and after usage of LS.

## 4. Conclusion

Loss circulation is one of the most time and cost consuming problems which occurs mostly in naturally fractured formation, induced fractures and also may happen through highly permeable formations and can causes many operational problems such as differential pipe sticking, drill string stuck in the wellbore, drilling fluid costs due to compensate of the lost fluid via the formation, well flow, blowout and etc. Many articles have published over the years to describe loss circulation and its occurrence reasons and introduced different method and materials to cure and prevent drilling fluid loss

during drilling, cementing and also well completion jobs. Although all of the mentioned materials have both some advantageous and disadvantageous according to the drilling operation complexity and limitations. Most of the proposed methods and material for loss circulation control are categorized in remediation method and are applicable after loss circulation occurrence. While solving lost circulation after occurrence is critical, prevention is the best drilling practice for saving the operator time and money. A novel Fiber based wellbore strengthening material named LIGNO-SEAL developed by particle size distribution principle to prevent loss circulation before occurrence during drilling fractured and cavernous layers by dual performance mechanism which is bridging and sealing both pre-existing and induced fractures and create a thin layer of LPM cake across the wellbore wall during drilling operation. LIGNO-SEAL (LS) is proprietary blend of natural and modified cellulose based fibbers designed to provide Non-Invasive properties to any kind of drilling fluid system. LIGNO-SEAL is designed to use in active mud system to minimize fluid invasive and stabilize wellbore wall by providing mechanical stability by carrying applied stress inside the well. LS seals micro fractures/pores of formation effectively so eliminates the chances of Stuck-pipe and solid invasion to which makes it ideal product to use in reservoir zone. Ligno-seal also can increase hole cleaning efficiency by encapsulating drilled cuttings. After sealing the pre-existing fractures and thin LPM layer creation on wellbore wall cracks opening, the remained LS in mud composition collaborate in drilled conduction to surface solid control facilities by encapsulating multiple cutting and make an integrated multi-cutting capsules through LS components sticky bonding specialty. LS has successfully used for drilling 12 ¼" section for loss prevention in well BH-194SD1 which complete loss circulation caused to drilling operation failure in the previous drilled hole. Using lingo-seal causes 96% of saving the volume and cost related to the drilling fluid during drilling operation of well BH-194SD1. Usage of the novel fiber based wellbore strengthening material due to the unique mat-type structure performance in prevent and control loss circulation in naturally and induced micro-fractured for-

mations is mandatory for enhance drilling performance by decreasing drilling operations time and cost and prepare safe drilling program to the final target depth.

## Abbreviations

LPM	Loss Prevention Material
NPT	Non Productive Time
LS	Ligno-seal
TCV	Total Circulating Volume

## Author Contributions

Majid Nasirzadeh Heris is the sole author. The author read and approved the final manuscript.

## Funding

This work is supported by Sazeh Farnam Kish Company.

## Data Availability Statement

The data supporting the outcome of this research work has been reported in this manuscript.

## Conflicts of Interest

The authors declare no conflicts of interest.

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## Biography



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## Research Field

**Majid Nasirzadeh Heris:** Drilling Fluid industry, Wellbore Strengthening Material, Petroleum Engineering, Drilling Performance Optimization