Eurasian J. Sci. Eng., 2023, 9(2), 140-153
https://doi.org/10.23918/eajse.v9i2p11

Published by Tishk International University
Available at: https://eajse.tiu.edu.iq/

RESEARCH ARTICLE Open Access

PERFORMANCE EVALUATION OF THE NEW NATURAL AND ENVIRONMENTALLY FRIENDLY MATERIAL FOR LOST CIRCULATION CONTROL AT HIGH PRESSURE AND HIGHT TEMPERATURE

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Article History
Received: 25.02.2023
Revised: 01.04.2023
Accepted: 10.04.2023
Communicated by: Dr. Orhan Tug
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Abstract:
Lost circulation refers to the loss of a part or whole drilling fluid into the formation and is considered as one of the most challenges in drilling operations. It could be occurred either naturally in highly fractured formations or induced by excessive overbalance pressure which leads to crack and rupture the formations being drilling and thereby inducing the loss of the mud into them. There are a number of treatments for lost circulation and perhaps the using of lost circulation materials (LCMs) is one of the common treatments. LCM is any material that used as an additive in the drilling fluid to seal and plug the openings in the formations. LCM manufacturers are continually introducing hundreds of materials every year. Recently, many research and studies had been done and continue for developing and investigating natural LCMs as alternatives for the conventional LCMs. In this study, a pomegranate peel (PP) has been developed and evaluated to be used as a natural LCM. The main two advantages of the PP LCM over the conventional LCM are its cost and naturally friendly properties. A series of filtration tests has been conducted on various sizes and concentrations of PP in order to investigate the effects of the size and percent of the additive on lost control characteristics. Moreover, for the purpose of comparison, a number of filtration tests has been conducted for similar sizes and precents of one of the most used LCM, carbonate calcium. It has been observed that the filtrate rate for the reference mud was 32 ml/30 min. While, the optimum reduction of 81% of the filtrate has been gained by addition of 15 ppb of the fine sized (less than 75 microns) PP. Meanwhile, only 47% of the lost being control through the addition of 20 ppb of the fine sized carbonate calcium.

Keywords: *Lost Circulation; LCM, Natural; Environment; Pomegranate Peel*

1. Introduction

Lost circulation is defined as the losses of a portion or all the drilling mud into the formations while drilling and completion processes. This problem is not new for the drilling engineers but the prevention and/or treatment attempts are still a challenge [1]. It costs the companies from two sides; the cost of the lost material and chemicals and the cost of the non-productive time (NPT) for treating the problem [2, 3]. Furthermore, the development and usage of additive materials for controlling the problem costs also [4]. Although a lot of lost control materials have been developed by different LCM manufacturers but each of the developed LCM has some limitations [3]. Ivan et al., [5] have stated that the cost of treatment by LCM reaches $200 million/year. Additionally, Lecolier et al. [6] claimed that the lost circulation problem costs 20% to 40% of the drilling operation costs. Another concern of the lost circulation is that if it is not treated quickly it may lead to other problems such as pipe sticking, well control and formation damage problems [7]. Lost Circulation could be occurred in four types of formations; unconsolidated formations, vugs or caves, natural fractured formations and induced fractures as shown in figure 1 [8]. Alhaidari [3] has classified the lost circulation into four categories based on the rate of lost in an hour as shown in table 1, they are; seepage losses which refers to losses of 1-10 bbl/hr.; partial losses which means losing 10-100 bbl/hr.; the third class is called sever losses when the losses rate exceeds 500 bbls/hr. and the last class is named total losses in the case of no returns of the fluid.

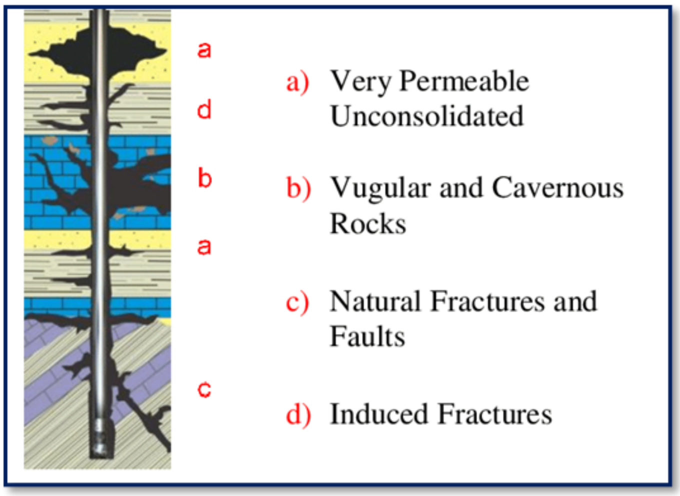

Figure 1: Potential geological formations for loss of circulation [8]

Table 1: Loss severity classification [3]

Loss type	Amount of loss (in bbl/hr)
Seepage loss	1-10
Partial loss	10-100
Sever loss	>500
Complete (Total) loss	no returns

Lost circulation materials (LCMs) could be defined as any materials that are added to the mud in order to plug or seal the openings within the formations. Alkinani [9] stated that there are a variety of LCMs available and their tests and categorization are critical. Jaf et al., [10]) have classified the LCMs into two groups; conventional LCMs and natural LCMs and they have summarized the most common used LCMs from each group in tables 2 and 3. The conventional LCMs are categorized into; granular, flaky, fibrous or a blend of them as shown in figure 2 [11].

Despite of their successful uses in many cases, Alsaba et al., [12] claimed the main three drawbacks of the conventional LCMs as; first they are incapable of plugging large fractures, second, their failure in high pressure high temperature conditions and lastly their insolubility may lead to formation damage problem in the reservoir zones. Therefore, the invention of the alternatives, natural LCMs, became necessary. Additionally, the natural LCMs overcomes the conventional ones in terms of the environmentally friendly and cost also. The drilling industry has begun to transform from the conventional LCMs to the natural ones by implementing laws mandated by regional and global

Environmental Protection Agencies [13]. The development and evaluation of a number of natural LCMs have started many years ago and the research and studies still continued to develop additional natural LCMs, the most common natural LCMs used are summarized in table 3. The objective of this research is to evaluate the effectiveness of a new developed natural LCM, pomegranate peel, in controlling the mud filtration.

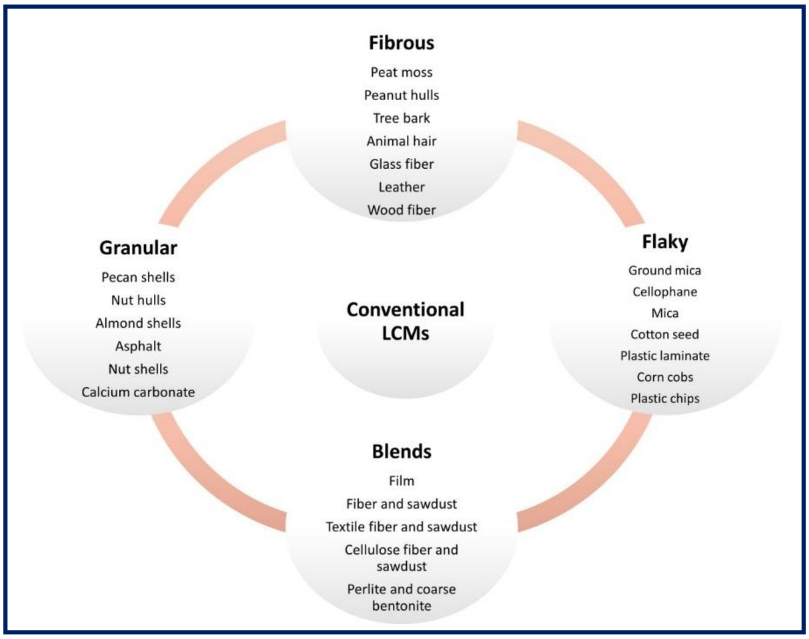

Figure 2: Types of conventional LCMs [11]

Table 2: Common conventional LCM used [10]

Material	Classification	Reference
Sawdust	Fibrous	Howard and Scott [14]
Prairie hay	Fibrous	Howard and Scott [14]
Bark	Fibrous	Howard and Scott [14]
Shredded wood	Fibrous	Howard and Scott [14]
Cellophane	Flaky	Howard and Scott [14]
Limestone	Granular	Howard and Scott [14]
Sulfur	Granular	Howard and Scott [14]
Plastic	Granular	Howard and Scott [14]
Nut shell	Granular	Howard and Scott [14]
Cotton seed hulls	Granular	Howard and Scott [14]
Thermoset rubber	Granular	Loeppke et al., [15]
Coal	Granular	Loeppke et al., [15]
Expanded aggregate	Granular	Loeppke et al., [15]
Gilsonite	Granular	Loeppke et al., [15]
Black walnut	Granular	Loeppke et al., [15]
Activated cross-linked pill	Pill	Caughron et al., [16]
Settable treatment pill	Pill	Aston et al., [17]
Resilient graphitic carbon	Granular	Savari et al., [18]
Shape memory polymer	Swellable	Mansour et al., [11]

Mica	Flaky	Ezeakacha and Salehi, [19]
Calcium carbonate	Flaky	Ezeakacha and Salehi, [19]
XC Polymer NPs	Granular	Salam et al., [20]
Magnesium oxysulfate cement	Cement	Cui et al., [21]

Table 3: Common natural LCM used [10]

Natural/Biodegradable Material	Reference
Ground cocoa bean shells	Green, [22]
Black walnut	Loeppke et al., [15]
Rice fractions (hulls, tips, straw, and bran)	Burts, [23]
Rice fractions (hulls, tips, straw and bran)	Burts, [24]
Cotton seed hull	Cremeans and Cremeans, [25]
Coconut coir	MacQuoid and Skodack, [26]
Fibers	Ghassemzadeh, [27]
Apple skin fibers	Ghazali et al., [28]
Rice husk	A.Razzaq and Kzar, [29]
Crushed palm date seeds	Al-Awad and Fattah, [30]
Wheat straw	Almahdawi et al., [31]
Banana peels	Akmal et al., [32]
Sugarcane bagasse	Akmal et al., [32]
Broad bean peel powder	Awl et al., [33]

2. Materials and Methods

2.1 Pomegranate Peel (PP)

The peels of pomegranate were collected during the winter of 2021. The pomegranate peel (PP) then being dried in sun light and then being powdered by griding as shown in figure 3. Moreover, in order to determine the effect of LCM particle size distribution, dried PP were divided into three different sizes, fine, medium and coarse through the use of (API RP 13C) standard mesh sieves. The particle and mesh sizes for each LCM grade are shown in table 4.

Figure 3: Preparation of different sizes of PP powder

Table 4: API-RP-13C standard mesh and micron sizes

LCM Grade	Microns	Mesh Sizes
Fine	< 75	> 200
Medium	75 - 250	60 – 200
Coarse	250 - 1000	18 – 60

2.2 Calcium Carbonate ($CaCO_3$)

In order to compare the evaluation results of the developed LCM, pomegranate peel, it has been decided to make same laboratory experiment to the most common conventional LCM used in northern Iraqi filed. After a survey among several companies in the region, it has been observed that they are mostly used the $CaCO_3$ LCM. Therefore, different sizes of the $CaCO_3$ LCM have been collected, as shown in figure 4, from Pulsar Petroleum company thankfully.

Figure 4: Fine, medium and coarse sized of $CaCO_3$ LCM

2.3 Preparation of Reference Mud (RM)

A water-based mud with composition shown in table 5 and properties shown in table 6 has been prepared according to the API-SPEC-13A-2010 standards.

Table 5: Composition of the reference mud (RM)

Materials	Bentonite (gm)	Water (mL)	NaOH (gm)
Concentration	80	1400	2

Table 6: Reference mud properties

Property	Quantity	Unit
Density	8.61	ppg
Plastic Viscosity	4	cp
Yield Point	15.1	Ib/100 ft^2
Gel Strength (10 sec.)	9.3	Ib/100 ft^2
Gel Strength (10 min.)	11.1	Ib/100 ft^2
PH	12	---

2.4 Preparation of Mud with $CaCO_3$

Various sizes and concentration of the collected $CaCO_3$ were added into the reference mud and the filtration tests for each size and concentration have been conducted. As mentioned earlier, these steps have been done for the purpose of comparison of the effectiveness of the developed LCM with $CaCO_3$ LCM. The concentration of the adding LCM was on the basis of pounds of the LCM material per each barrel of the mud (ppb), started from the addition of 5 ppb to 25 ppb with increment of 5 ppb.

2.5 Preparation of Mud with PP

As for the mud with $CaCO_3$, similar sizes and concentrations of the prepared pomegranate peel (PP) were added into the reference mud and the filtration tests have been conducted individually for each added size and concentration to evaluate the filtration control effectiveness of the developed PP LCM and to find out the optimum percent and size of it.

2.6 Rheological Properties Measurement

Before conducting the filtration tests, the laboratory apparatus (mud balance, Fann Viscometer, PH meter and a mixer) have been used to measure the rheological properties of the mud with various percents and concentration of both $CaCO_3$ and pomegranate peel LCMs. The plastic viscosity and yield point were determined using equations 1 and 2 respectively.

(1) $$PV = \emptyset_{600} - \emptyset_{300}$$
(2) $$YP = \emptyset_{300} - PV$$

Where the dial reading at 600 rpm is Ø600, and the dial reading at 300 rpm is Ø300.

2.7 Filtration Measurement

The point that distingue this study from the previous studies is that the most of the previous studies have used the standard API filter press apparatus, which cannot apply more than 100 psi pressure and has no heating part, for measuring the filtration properties of the fluids. While in this study a dynamic high pressure high temperature HPHT filter press as shown in figure 5 has been used instead. A differential pressure of 500 psi and temperature of 50 °C have been applied, these are the real conditions of the most reservoirs in the northern Iraqi fields.

Figure 5: Dynamic HPHT filter press apparatus

3. Results

3.1 Rheological Properties Results

The conducted rheological tests results are shown in tables 7 and 8.

Table 7: Rheological properties of the reference mud with various sizes and concentrations of $CaCO_3$

Drilling Fluid		Properties					
		Density ppg	PH	PV cp	YP Ib/100ft^2	Initial Gel Strength Ib/100ft^2	Final Gel Strength Ib/100ft^2
No $CaCO_3$	RM	8.61	12	4	15	9	11
Fine $CaCO_3$	RM + 5 ppb	8.7	12	4.5	13	10	11
	RM + 10 ppb	8.8	11.9	6	14	12	17
	RM + 15 ppb	8.85	11.8	6.5	15	13	20
	RM + 20 ppb	8.95	11.8	7	17	13	22
	RM + 25 ppb	9	11.6	8	19	15	25
	RM + 30 ppb	9.1	11.3	9	20	18	28
Medium $CaCO_3$	RM + 5 ppb	8.7	11	6	13	11	21
	RM + 10 ppb	8.75	11.1	7	21	22	25
	RM + 15 ppb	8.8	11.2	7.7	23	26	30
Coarse $CaCO_3$	RM + 5 ppb	8.7	11.6	5	22	14	16
	RM + 10 ppb	8.77	11.7	5	30	17	19
	RM + 15 ppb	8.8	11.9	5.1	33	19	20
RM+5ppb F+5ppb M+5ppb C		8.85	11.7	8	30	20	33

Table 8: Rheological properties of the reference mud with various sizes and concentrations of PP

Drilling Fluid		Properties					
		Density ppg	PH	PVcp	YP Ib/100ft^2	Initial Gel Strength Ib/100ft^2	Final Gel Strength Ib/100ft^2
No PP	RM	8.61	12	4	15	9	11
Fine PP	RM + 5 ppb	8.59	9.5	11	5	3	12
	RM + 10 ppb	8.55	7.5	11	9	8	13
	RM + 15 ppb	8.50	7.4	15	11	8	13
	RM + 20 ppb	8.48	6.9	16	15	11	15
	RM + 25 ppb	8.45	6.7	23	21	7	13
Medium PP	RM + 5 ppb	8.6	8.1	4	10	5	14
	RM + 10 ppb	8.58	7.3	5	13	6	15
	RM + 15 ppb	8.55	7	7	15	8	15
	RM + 20 ppb	8.45	6.8	8	18	11	17
	RM + 25 ppb	8.38	6.4	10	22	15	18
Coarse PP	RM + 5 ppb	8.61	8.2	6	4	6	11
	RM + 10 ppb	8.6	6.9	6	4	6	11
	RM + 15 ppb	8.58	6.6	6	8	8	12
	RM + 20 ppb	8.55	6.4	5	9	9	12
	RM + 25 ppb	8.53	6.3	5	10	7	11
RM+5ppb F+5ppb M+5ppb C		8.5	8.8	6	7	8	12

3.2 Filtration Test Results

The filtration tests result of the RM, RM with various sizes and percents of $CaCO_3$ and RM with various sizes and concentrations of PP are shown in tables 9-12.

Table 9: fluid losses rate of the reference mud with fine sized of $CaCO_3$

Filtrate (ml.)							
Drilling mud	RM	RM + Fine $CaCO_3$					
Time (min.)	0 ppb $CaCO_3$	5 ppb $CaCO_3$	10 ppb $CaCO_3$	15 ppb $CaCO_3$	20 ppb $CaCO_3$	25 ppb $CaCO_3$	30 ppb $CaCO_3$
5	12.3	9.6	7.5	7.1	6.6	7	8.1
10	17.1	14.5	11.2	10.4	9.4	9.8	11.8
15	21.7	18.2	14.5	12.3	11.6	12	14.9
20	25.5	21.2	17.2	14.4	13.2	14.1	17.6
25	28.5	25	19.5	16.4	14.6	15.7	19.9
30	32	27.5	21.7	17.7	16.9	17.7	22.2

Table 10: fluid losses rate of the reference mud with medium, coarse and blend sizes of $CaCO_3$

Filtrate (ml.)								
Drilling mud	RM	RM + Medium $CaCO_3$			RM + Coarse $CaCO_3$			RM + 5F + 5M + 5C ppb $CaCO_3$
Time min.	0 ppb $CaCO_3$	5 ppb $CaCO_3$	10 ppb $CaCO_3$	15 ppb $CaCO_3$	5 ppb $CaCO_3$	10 ppb $CaCO_3$	15 ppb $CaCO_3$	
5	12.3	7.9	8.1	8.2	8.8	8.8	8.9	6.5
10	17.1	10.6	10.8	11.1	12.5	12.9	14	9.7
15	21.7	12.5	13	13.2	15.5	16	18.2	12.2
20	25.5	14.2	14.9	15	18.7	18.8	22.7	14.4
25	28.5	15.8	16.5	16.8	20.5	20.8	26.1	16.1
30	32	17.1	17.9	18.3	23	23.3	29.2	17.7

Table 11: fluid losses rate of the reference mud with fine sized of PP

Filtrate (ml.)						
Drilling mud	RM	RM + Fine PP				
Time (min.)	0 ppb PP	5 ppb PP	10 ppb PP	15 ppb PP	20 ppb PP	25 ppb PP
5	12.3	3	2.6	2.3	2.1	1.8
10	17.1	4.8	3.7	3.4	3	2.4
15	21.7	5.8	5	4.2	3.6	3
20	25.5	7.2	5.8	4.9	4.4	3.7
25	28.5	8.3	6.4	5.5	4.9	4
30	32	9	7	6	5.3	4.3

Table 12: fluid losses rate of the reference mud with medium, coarse and blend sizes of PP

Filtrate (ml.)											
Drilling mud	RM + Medium PP					RM + Coarse PP					RM + 5F + 5M + 5C ppb PP
Time min.	5 ppb PP	10 ppb PP	15 ppb PP	20 ppb PP	25 ppb PP	5 ppb PP	10 ppb PP	15 ppb PP	20 ppb PP	25 ppb PP	
5	4.4	4.3	4.2	3.9	3.8	4.5	4.3	4.1	3.9	3.8	3.8
10	6.5	6.4	5.8	5.6	5.4	6.5	6.3	6	5.8	5.3	5.4
15	8	7.7	7	6.6	6.2	8.3	8.1	7.9	6.8	6.4	6.5
20	9.2	8.7	7.9	7.4	6.8	9.5	9.2	8.9	7.7	7.2	7.4
25	10.2	9.3	8.4	8	7.4	10.8	10.3	9.8	8.5	8.2	8.3
30	10.9	10.1	9	8.6	7.9	11.8	11.6	10.8	9.4	8.9	9

4. Discussion

As shown in table 9, the filtration rate for the reference mud (without additives) was 32 ml/30 min. and as could be seen from figures 6-8, the optimum achieved reduction in the filtration rate with the use of $CaCO_3$ was 16.9 ml/30 min, 47% filtration reduction. This achievement had been established with the addition of 20 ppb of the fine sized $CaCO_3$ LCM. On the other hands, it could be observed from figures 9-11 that a better filtration reduction has been achieved by the addition of the PP compared to the $CaCO_3$ addition. Particularly, the best filtration reduction was gained with adding 15 ppb of the fine sizes of the PP which reduced the filtration rate by 81%, reduced from 32 ml to only 6 ml/30 minutes. Despite that the filtration reduction is higher with the additions of 20 ppb and 25 ppb of the fine sized PP, but they caused the mud pH to be less than 7 pH which is not recommended as per API standards. Therefore, the optimum concentration and size were fine and 15 ppb of the PP is the decision. The result of this study has been compared with the filtration reduction rate in previous studies on other natural LCMs that cited in table 3. Fig. It could be observed that for equivalent LCM size and concentration, the highest filtration reduction rate is being achieved in this study among the previous studies as shown in figure 12.

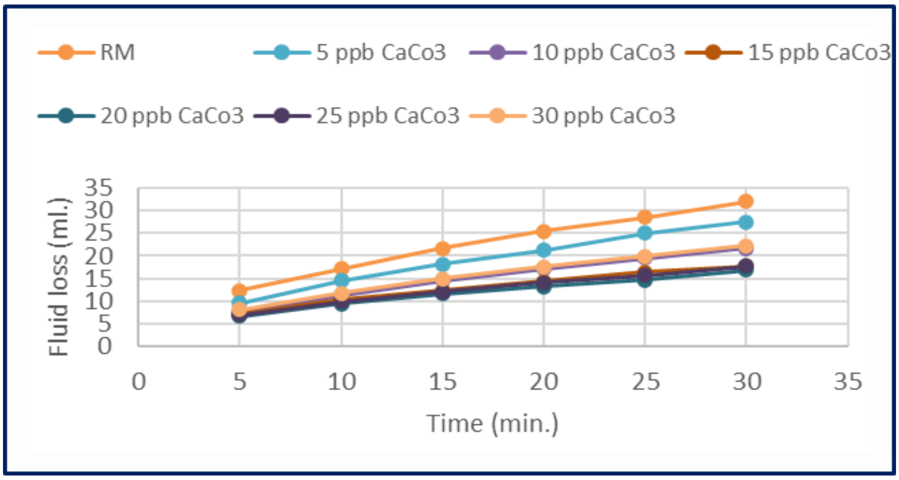

Figure 6: Effect of fine sized $CaCO_3$ on fluid losses

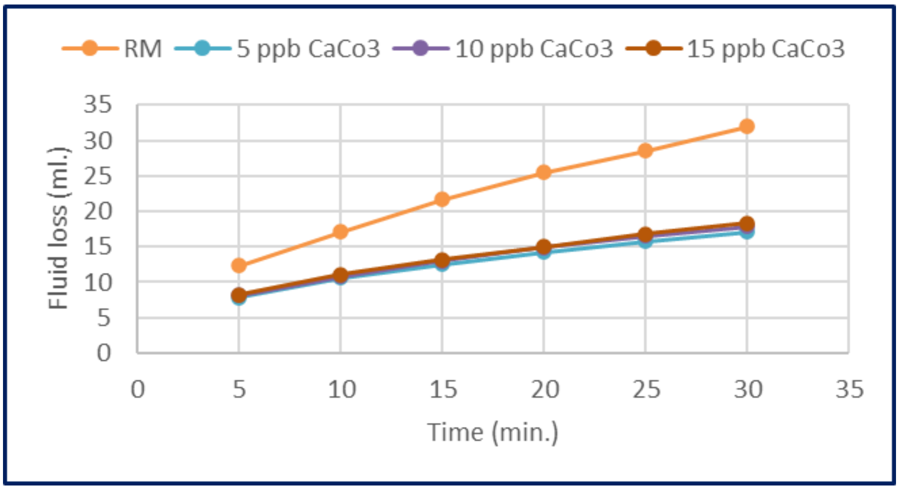

Figure 7: Effect of medium sized CaCO3 on fluid losses

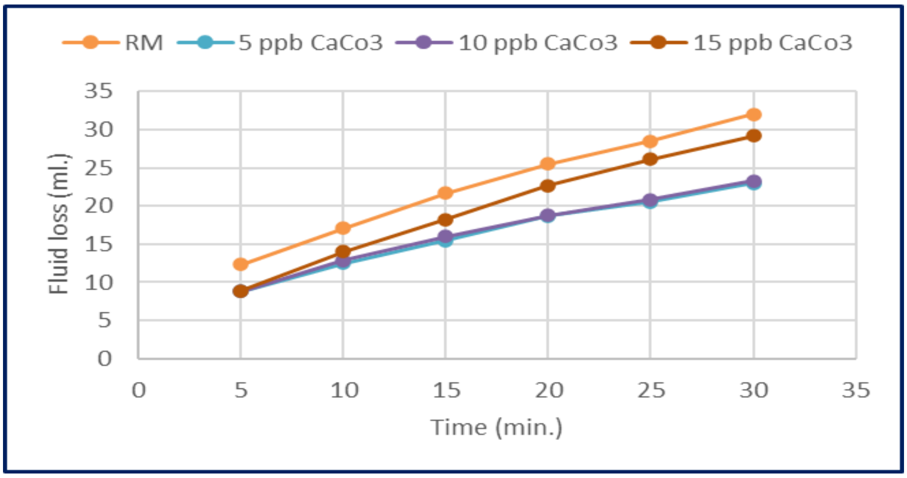

Figure 8: Effect of coarse sized CaCO3 on fluid losses

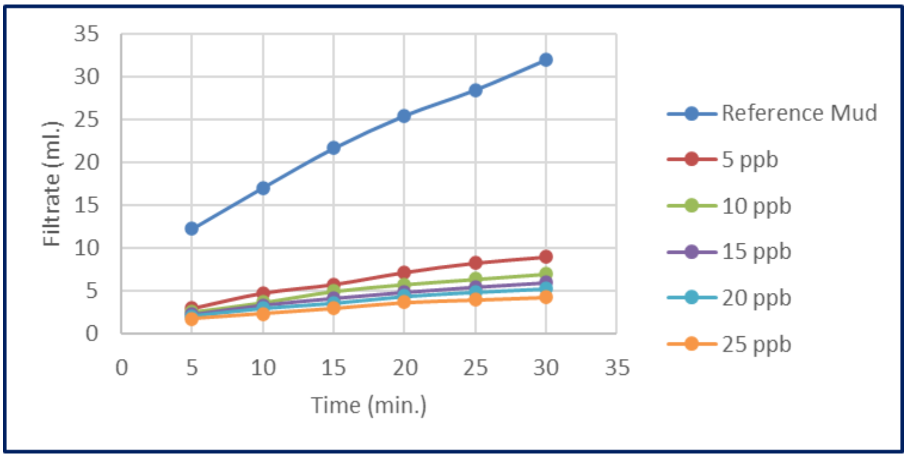

Figure 9: Effect of fine sized of PP on fluid losses

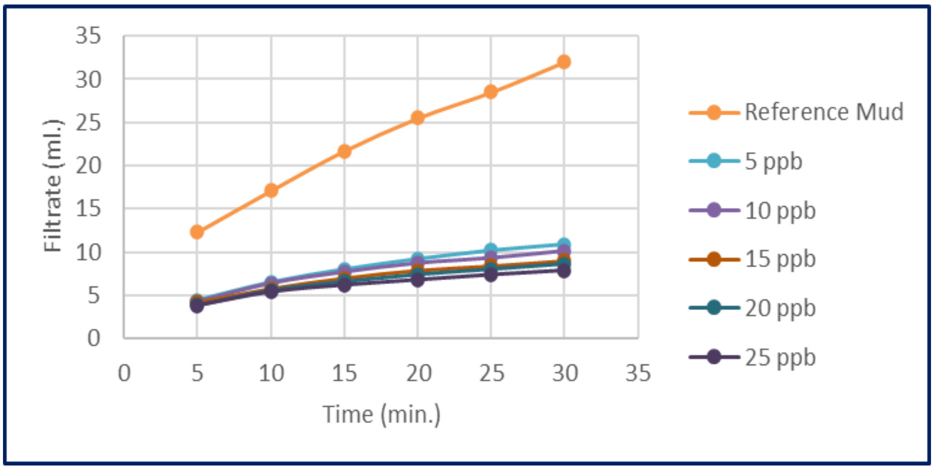

Figure 10: Effect of medium sized of PP on fluid losses

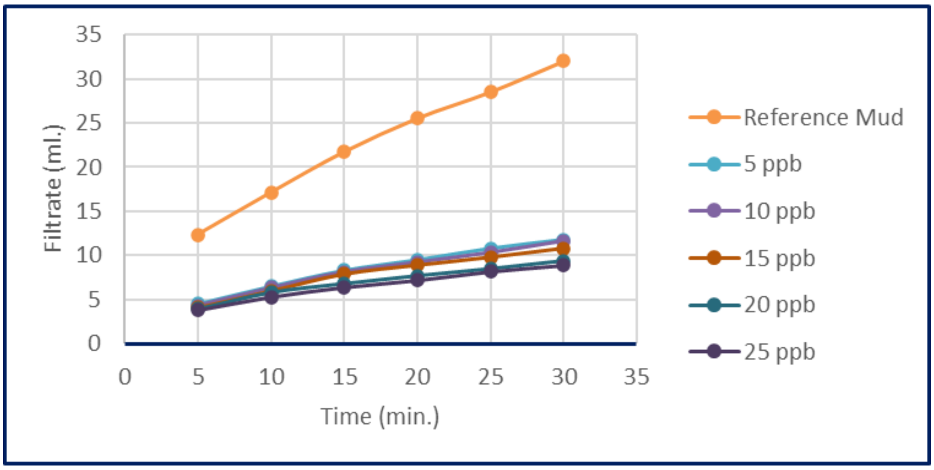

Figure 11: Effect of coarse sized of PP on fluid losses

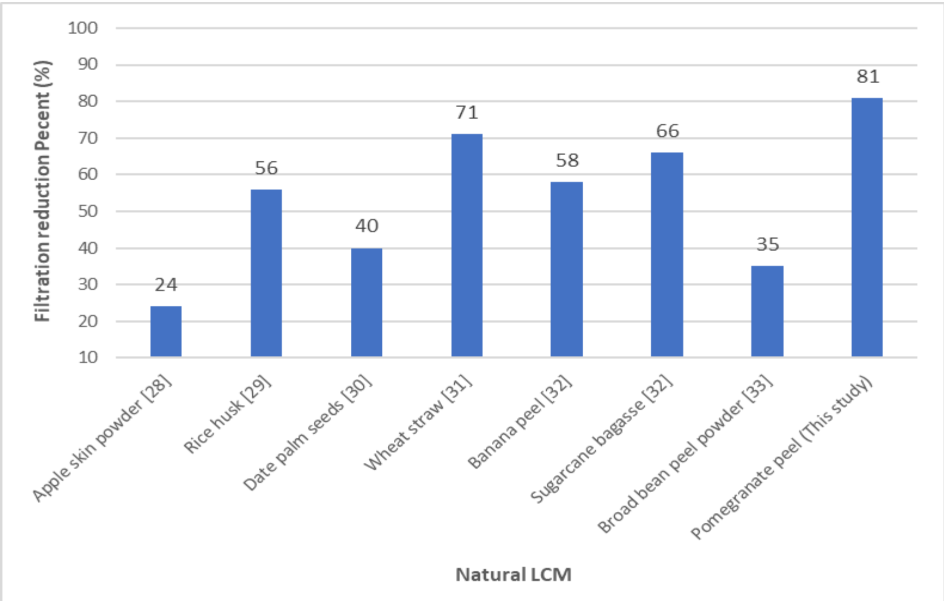

Figure 12: Filtration control rate with PP in comparison with other studies natural LCMs

5. Conclusion

The objective of this work was to study the effectiveness of the pomegranate peel (PP) as a natural LCM in a comparison with the most common conventional used LCM, $CaCO_3$. A series of high-pressure high temperature filtration tests have been conducted for the reference mud, mud with various sizes and concentrations of $CaCO_3$ and mud with different sizes and percents of PP. The tests results showed that the maximum filtration reduction was about 47% with the addition of 20 ppb of the fine sized $CaCO_3$. Meanwhile, a filtration reduction of 81% has been achieved by adding only 15 ppb of the PP. This achievement has verified the success of the developed natural LCM also that the PP overcomes the $CaCO_3$ in terms of environment and cost.

6. Author's Contribution

We confirm that the manuscript has been read and approved by all named authors. We also confirm that each author has the same contribution to the paper. We further confirm that the order of authors listed in the manuscript has been approved by all authors.

7. Conflict of Interest

There is no conflict of interest for this paper.

8. Acknowledgment

We would like to thank the staff of the Koya University/Petroleum Engineering Department for enabling us to use their excellent drilling fluids laboratory. We would also like to thank Mr. Shvan Ahmed, the manager of (Pulsar Petroleum) Company for enabling us to visit their company to observe their daily operation and for providing us the LCM materials as well.

References

[1] Shibeeb M, Alwasiti A, Al_Zubaidi N. The effect of nano materials on lost circulation control of Azkand Formation in Khabaz Oil Field. Journal of Engineering. 2020 Mar 23; 26(4): 80-93. https://doi.org/10.31026/j.eng.2020.04.06

[2] Alkinani HH, Al-Hameedi AT, Flori RE, Dunn-Norman S, Hilgedick SA, Alsaba MT. Updated classification of lost circulation treatments and materials with an integrated analysis and their applications. InSPE Western Regional Meeting 2018 Apr 22. OnePetro. https://doi.org/10.2118/190118-MS

[3] Alhaidari SA. Lost circulation management: new engineering approaches and techniques for better bridging and sealing the fracture [PhD Thesis]. Colorado School of Mines; 2020. https://hdl.handle.net/11124/174153

[4] Datwani A. Review of lost circulation mechanisms with the focus on loss to natural and drilling induced fractures [M.Sc. Thesis]. Dalhousie University, Halifax, Nova Scotia; 2012.

[5] Ivan C, Bruton J, Bloys B. How can we best manage lost circulation. InProceedings of the AADE 2003 National Technology Conference "Practical Solutions for Drilling Challenges", Houston, TX, USA 2003 Apr (pp. 1-3).

[6] Lecolier E, Herzhaft B, Rousseau L, Neau L, Quillien B, Kieffer J. Development of a nanocomposite gel for lost circulation treatment. InSPE European formation damage conference 2005 May 25. OnePetro. https://doi.org/10.2118/94686-MS

[7] Mostafavi Toroqi SV. Experimental analysis and mechanistic modeling of wellbore strengthening [PhD Thesis]. University of Galgary; 2012. http://hdl.handle.net/11023/300

[8] Antelo WL, Hernandez FT, Moreno RB. Review of rheological model to predict the loss of circulation in fractured formation. In; 2019 National Meeting or the Construction of Oil and Gas Wells., 2019, August 19-22; Serra Negra.

[9] Alkinani H H. A Comprehensive Analysis of Lost Circulation Materials and Treatments with Applications in Basra's Oil Fields, Iraq: Guidelines and Recommendations [M.Sc. Thesis]. Missouri University of Science and Technology; 2017.

[10] Jaf PT, Razzaq AA, Ali JA. The state-of-the-art review on the lost circulation phenomenon, its mechanisms, and the application of nano and natural LCM in the water-based drilling fluid. Arabian Journal of Geosciences. 2023 Jan; 16(1): 32. https://doi.org/10.1007/s12517-022-11104-3

[11] Mansour A, Dahi Taleghani A, Salehi S, Li G, Ezeakacha C. Smart lost circulation materials for productive zones. Journal of Petroleum Exploration and Production Technology. 2019; 9(1): 281-296. https://doi.org/10.1007/s13202-018-0458-z

[12] Alsaba M, Nygaard R, Saasen A, Nes OM. Lost circulation materials capability of sealing wide fractures. InSPE Deepwater Drilling and Completions Conference 2014 Sep 10. OnePetro. https://doi.org/10.2118/170285-MS

[13] Ismail A, Rashid HM, Gholami R, Raza A. Characterization based machine learning modeling for the prediction of the rheological properties of water-based drilling mud: an experimental study on grass as an environmental friendly additive. Journal of Petroleum Exploration and Production Technology. 2022 Jun 1: 1-9. https://doi.org/10.1007/s13202-021-01425-6

[14] Howard GC, Scott Jr PP. An analysis and the control of lost circulation. Journal of Petroleum Technology. 1951 Jun 1; 3(06): 171-82. https://doi.org/10.2118/951171-G

[15] Loeppke GE, Glowka DA, Wright EK. Design and evaluation of lost-circulation materials for severe environments. Journal of Petroleum Technology. 1990 Mar 1; 42(03): 328-37. https://doi.org/10.2118/18022-PA

[16] Caughron DE, Renfrow DK, Bruton JR, Ivan CD, Broussard PN, Bratton TR, Standifird WB. Unique crosslinking pill in tandem with fracture prediction model cures circulation losses in deepwater Gulf of Mexico. InIADC/SPE drilling conference 2002 Feb 26. OnePetro. https://doi.org/10.2118/74518-MS

[17] Aston MS, Alberty MW, Duncum SD, Bruton JR, Friedheim JE, Sanders MW. A new treatment for wellbore strengthening in shale. In; 2007 SPE annual technical conference and exhibition. 2007, November 11-14; Anaheim. https://doi.org/10.2118/110713-MS

[18] Savari S, Whitfill DL, Kumar A. Resilient lost circulation material (LCM): A significant factor in effective wellbore strengthening. InSPE deepwater drilling and completions conference 2012 Jun 20. OnePetro. https://doi.org/10.2118/153154-MS

[19] Ezeakacha CP, Salehi S. Experimental and statistical investigation of drilling fluids loss in porous media–part 1. Journal of Natural Gas Science and Engineering. 2018 Mar 1; 51: 104-15. https://doi.org/10.1016/j.jngse.2017.12.024

[20] Salam M, Al-Zubaidi NS, Al-Wasiti AA. Enhancement in lubricating, rheological, and filtration properties of unweighted water-based mud using XC polymer NPs. Journal of Engineering. 2019 Jan 31; 25(2): 96-115. https://doi.org/10.31026/j.eng.2019.02.07

[21] Cui KX, Jiang GC, Yang LL, Deng ZQ, Zhou L. Preparation and properties of magnesium oxysulfate cement and its application as lost circulation materials. Petroleum Science. 2021 Oct 1; 18(5): 1492-506. https://doi.org/10.1016/j.petsci.2021.08.002

[22] Green PC. U.S. Patent No. 4,474,665. Washington, DC: U.S. Patent and Trademark Office. 1984.

[23] Burts BD. U.S. Patent No. 5,118,664. Washington, DC: U.S. Patent and Trademark Office 1992.

[24] Burts BD. U.S. Patent No. 5,599,776. Washington, DC: U.S. Patent and Trademark Office. 1997.

[25] Cremeans KS, Cremeans JG. US pat. no. 6630429, Washington, DC. US Patent and Trademark Office. 2003.

[26] MacQuoid M, Skodack D. U.S. Patent Application No. 10/626,503. 2004.

[27] Ghassemzadeh J. U.S. Patent No. 7,923,413. Washington, DC: U.S. Patent and Trademark Office. 2011.

[28] Ghazali NA, Yusof MY, Azizi A, Mohd TA, Alias N, Sauki A, Yahya E. Lost circulation material characteristics of apple skin powder in drilling mud. InAdvanced Materials Research 2015 (Vol. 1119, pp. 564-568). Trans Tech Publications Ltd. https://doi.org/10.4028/www.scientific.net/AMR.1119.564

[29] Razzaq AA, Kzar WA. Reducing lost circulation problem by using rice material. Journal of Engineering. 2016 Jun 1; 22(6): 149-57.

[30] Alawad MN, Fattah KA. Superior fracture-seal material using crushed date palm seeds for oil and gas well drilling operations. Journal of King Saud University-Engineering Sciences. 2019 Jan 1; 31(1): 97-103. https://doi.org/10.1016/j.jksues.2017.01.003

[31] Almahdawi FH, Alrazzaq AA. Experimental Investigation of Local Thinners (Wheat Straw and Pomegranate Peel Powder) in Water-Based Drilling Fluid. Solid State Technology. 2020 Jul 30; 63(1): 730-43.

[32] Akmal IA, Jamaludin SK, Sauki A, Hassan H, Ilham WM. Potential of banana peels and sugarcane bagasse as lost circulation material additives in drilling mud application. InAIP Conference Proceedings 2021 Feb 26 (Vol. 2332, No. 1). AIP Publishing. https://doi.org/10.1063/5.0042902

[33] Awl M, Mahmood B, Mohammed P, Mohammed H, Hamad A, Abdulqadir A, Abdalqadir M. Performance Evaluation of the New Environmentally Friendly Additive for Enhanced Fluid Loss and Rheological Properties of Drilling Fluid, Journal of Chemical and Petroleum Engineering. 2023; 57(1): 189-202.