Design and Evaluation of Wellbore Strengthening Materials for Fractured Depleted Carbonate Reservoirs

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ABSTRACT

The lost circulation is a primary consideration while drilling through fractured carbonate formations. Uncontrolled lost circulation may result in high nonproductive drilling time and cost, stuck pipe, side-tracks, blowouts and occasionally, the abandonment of expensive wells depending upon the severity of the loss. Additionally, drill solids entering the reservoir as a result of lost circulation may plug the pore throats, leading to a significant decrease in production.

In the industry, there are two approaches to struggle with lost circulation; to mitigate (control and stop) losses after they occur, or alternatively strengthen the loss zones to prevent losses. Preventive methods, known as wellbore strengthening methods, aim to both alter stresses around wellbore and minimize fluid loss. They are effective not only on natural fractures but also induced fractures which occurs during drilling.

The objective of this study is to determine the optimum concentration and particle size distribution for fractured reservoir zones. A polymer-based reservoir drill-in fluid supported by wellbore strengthening materials (WSM) was used in this study. Sized ground marble (GM) was chosen as a WSM because of its hydrochloric acid solubility and reservoir non-damaging nature. Sized GM was used as a WSM in different concentrations and in different particle sizes range. The experiments were conducted by using Permeability Plugging Apparatus (PPA). Fractured formations were simulated by using metal slotted disks with fracture width of 400, 800 and 1200 microns. Tests were conducted at room temperature. During the study, a total of 269 tests were run to investigate the effect of different particle size distribution, concentration, and fracture width. The results have been compared according to the maximum sealing time required to reach predetermined pressure (2000 psi) and fluid lost volumes, therefore, optimum compositions have been determined.

1. INTRODUCTION

Small fractures are found in almost all formations, whereas highly conductive natural fractures are present mostly in chalks and limestone reservoirs where significant losses occur. In Turkey, highly fractured carbonate reservoirs are encountered frequently and may lead to lost circulation while drilling. Uncontrolled lost circulation may result in high nonproductive drilling time and cost, stuck pipe, side-tracks, blowouts and occasionally, the abandonment of expensive wells depending upon the severity of the loss. Additionally, drill solids entering the reservoir as a result of lost circulation may plug the pore throats, leading to a significant decrease in production.

Natural fractures could be the micro-fractured sized or large opening size with high interconnected channels. In natural fractures, there is no barrier to stop the flow into the formation because of the large opening size. Therefore, totally from hundreds to thousands of barrels of drilling fluid might be lost.

The methods applied to deal with lost circulation can be categorized into two groups: mitigating methods and preventive methods. In general, mitigating methods applied to stop and control losses after they occur. On the other hand, preventive methods aim strengthen the loss zone to prevent losses. Indeed, it has been proved that it is easier and more effective to prevent the occurrence of losses than attempts to control and stop them once they started (Cook et al. 2011)

The wellbore strengthening techniques have been extensively used preventive methods in the drilling industry to prevent or mitigate drilling fluid loss. Wellbore strengthening attempts to bridge, plug, or seal wellbore fractures with lost circulation materials (LCMs) such as resilient graphitic carbon, cellulosic fibers, ground nutshell and marble to arrest the propagation of lost circulation in fracture(s). The pressure-bearing capacity of the wellbore can be enhanced by one or a combination of the following mechanisms in wellbore strengthening treatments.

- Bridge a fracture near its mouth to increase the local compressive hoop stress around the wellbore and enhance fracture opening resistance. [Aston, Alberty, McLean, de Jong & Armagost (2004), Song& Rojas (2006)]
- Widen and prop a fracture to enhance the fracture closure stress that acts on closing the fracture. [van Oort, Friedheim, Pierce, and Lee, (2011)].
- Form a filter cake in the fracture to isolate the fracture tip from wellbore pressure and enhance resistance to fracture propagation. [Morita, Black, and Fuh, (1996), Morita, Fuh, and Black, (1996), Morita and Fuh (2012), Fuh, Morita, Boyd, McGoffin, (1992)]

While drilling of highly depleted fractured carbonate reservoirs, drilling with conventional water-based and oil-based systems might be difficult and losses can be occurred due to high overbalance. In these environments, sometimes systems with lower densities such as aerated mud, stable foam, and mist or air may be used. However, for drilling with these drilling fluids, it needs to set-up expensive surface equipment. By means of the usage of wellbore strengthening materials in conventional oil or water-based systems, these highly depleted environments can be drilled without needed systems with lower densities.

The intention of the study is to conduct an experimental investigation on determining optimum concentration and particle size distribution (PSD), which enables to drill of fractured reservoirs. In accordance with this purpose, the wells in Turkey is examined as a first step. According to the statistics obtained from the website of the General Directorate of Mining and Petroleum Affairs, there is no well that is currently producing oil or gas deeper than 4200 meters. Also, the deepest geothermal well in Turkey is SY-23 located in Alaşehir, Manisa. The depth of this well is 4312 meters (Ülgen, Damcı & Gülmez, 2018) as of January,2019. Since there is no deeper well than 4400 meters in Turkey, the fractured and depleted reservoirs at depth of 4400 meters had been chosen as a target of this study. 2000 psi overbalance had determined as aimed pressure to increase the usage of conventional oil or water-based systems supported with wellbore strengthening materials to eliminate the usage of systems with lower densities. By means of this, the formations can be drilled with 2.66 lb/gal of differential pressure gradient. In general, the densities of conventional water-based drilling systems may change between 8.50 lb/gal and 9.34 lb/gal. By using wellbore strengthening materials, environments with pore pressure ranging from 5.84 lb/gal to 6.65 lb/gal can be drilled. These densities could change according to the number of used materials.

A polymer-based reservoir drill-in fluid supported by wellbore strengthening materials (WSM) was used in this study. Sized ground marble was chosen as a WSM because of its hydrochloric acid solubility and reservoir non-damaging nature.

In this study, experiments conducted to find the effect of particle size distribution, concentration and the fracture size on sealing. Also, it is aimed to define optimum composition which seals the predetermined openings.

2. TEST PROCEDURE

The polymer-based drill-in fluid which is specially designed for drilling through the reservoirs used in this study. This system includes only additives essential for filtration control and cuttings carrying. The drill-in fluid used in this study was formulated using modified starch, XCD, biocide, and ground marble. The concentration of polymers used as shown below.

Table 1 - Composition of Drill-in Fluid.

Additive	Function	Concentration
M.Starch	Fluid loss reducer	7 lb/bbl
XCD	Suspending agent	2 lb/bbl
Biocide	Bactericide	0.5%

The size distribution of ground marble was determined by dry sieve analysis. During determination of sieve sizes used, available manufacturer's product range are taken into consideration. Therefore, the production of specially designed ground marble for this study by the manufacturer and the availability of materials were ensured.

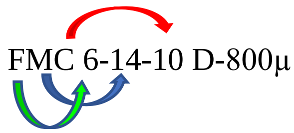
The particle size distribution of ground marble used in this study is presented in Table 2.

Table 2 - Particle Size Distribution of Ground Marble

	Particle Size
Coarse	850 µm – 1180 µm
Medium	250 µm – 850 µm
Fine	< 250 µm

The objective of this study is to determine the optimum concentration and particle size distribution for fractured reservoir zones. Sized ground marble was used as a WSM in different concentrations and in different particle sizes range. Each test was named according to including WSM concentration (or ground marble concentration) from each particle size range. For example, FMC 6-14-10 indicates the concentration of used each WSM concentration. The first number indicates that the concentration of fine size particles. For instance, FMC 6-14-10, shown in Table 3, includes 6 lb/bbl fine-sized ground marble. The second number is used for the concentration of medium-sized particles. FMC 6-14-10 has 14 lb/bbl medium-sized ground marble. The third number presents the concentration of coarse size particles. FMC 6-14-10 composition includes 10 lb/bbl coarse sized particles.

Table 3 – Detonation of WSM-laden samples



The experiments were conducted by using Permeability Plugging Apparatus (PPA) of which some parts modified. Fractured formations were simulated by using metal slotted disks with fracture width of 400, 800 and 1200 microns. Tests were conducted at room temperature (about 20 to 25 degrees Celcius). During the study, the following procedure was followed:

2.1 Procedure

1. 7 ppb Modified starch in 350 cc tap water is aged dynamically during overnight to become totally soluble and homogenized.
2. Added 2 ppb XCD polymer and mixed in the mixer (Hamilton Beach brand) at 19770 rpm for 15 minutes to become totally soluble and homogenized.
3. Reduced the volume of drill-in fluid according to calculated volume increase of Wellbore Strengthening Material (WSM) sample to get 350 cm3 drill-in fluid embedded with WSM
4. Added WSM particles and mixed only one (1) more minute. It needs to mix only one (1) minute to avoid from gridding effect.
5. Samples are taken for sealing capability tests. Drop defoamer into it to eliminate gas trapped in the mud.
6. Pour 350 ml of sample into the cell.
7. Place a slot into the cell and connect the top cap. Place the cell into the PPA.
8. Start pumping of hydraulic oil. (STAGE-I is initiated). By pumping hydraulic oil, the piston in the cell pushes fluid to pass through the slotted disc. Eventually, this disc is plugged and the P on the gauge starts to increase. By continuing the pumping of oil, P in the cell is increased.
9. When the bridge starts to form, pressure on the gauge starts to increase. When it reaches the lowest recordable pressure (100 psi) (see Figure 1), record the initial mud loss which indicates mud loss prior to sealing, i.e. mud loss up to 100 psi. (STAGE-I is finalized)
10. Continue to increase pumping with the rate of 10 psi/sec until pressure reaches 2000 psi. During this process, whole pressure falls are recorded. (STAGE-II is initiated)
11. When the pressure reaches 2000 psi, make sure that seal could withstand under 2000 psi without pressure falling.
    - If sudden pressure fall is observed, continue to recording pressure falls and pumping with the rate of 10 psi/sec increment.
    - If there is no sudden pressure fall, record mud loss values as mud loss in Stage II. (STAGE-II is finalized)

Mud loss in Stage II indicates mud loss volume between 100 psi and 2000 psi. It shows that whole mud loss which occurs during all pressure increments and falls.

12. To see whether the seal can hold 2000 psi without break, wait 5 minutes and continue to record pressure and volume change (STAGE-III is initiated). Mud loss in Stage III shows mud loss for 5 minutes.
13. After 5 min, the test is finished (STAGE-III is finished). Disassemble the cell and remove the slot.

Total mud loss volume is calculated by summation of mud loss in Stage I, Stage II and Stage III. NOTE: Although the aim of this study is to determine optimum composition which seals the fracture quickly with lower mud loss, it is also necessary to define the failing point. If mud loss value exceeds 125 ml, the test is stopped and recorded as "failed". According to the producer of the test set-up, if most of the sample is removed from the cell, pressuring piston could damage the top of the cell and may cause a pressure release.

Figure 1 – Pressure Pump Gauge

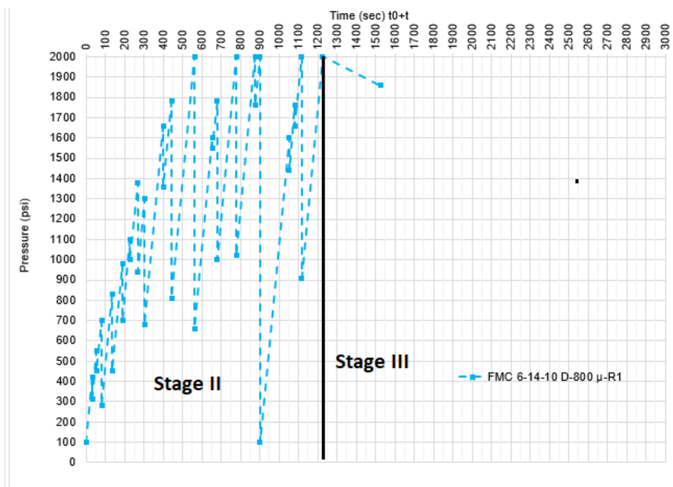


Figure 2 - Representation of Pressure Sealing Test Graphs

Table 4 - Examples of Mud Loss and Total Sealing Time Tables

Code	Mud Loss (ml)				Total Sealing Time (sec)
	Stage I	Stage II	Stage III	Total	
FMC 6-14-10 D-800μ	9.8	29.8	1.4	41	1526

*D-800μ indicates that test was done on the fracture which has the width of 800 μ.

3. RESULTS AND DISCUSSION

Based on the data obtained from several sealing capability tests of drill-in fluids with different sized ground marble samples with different concentrations, both particle size distribution and concentration effect on both sealing time and seal integrity were evaluated according to total sealing time and mud loss volume.

These test results will be categorized firstly according to the fracture width on which tests conducted. Then, the effect of PSD on sealing will be evaluated for each fracture width separately and the optimum composition will be also determined in these sections. After that, the effect of concentration on sealing will be examined for each fracture width. Finally, the effect of fracture width on sealing will be evaluated.

All results of total sealing time have been evaluated according to the following success criterion.

- Compositions must seal the fracture and resist to 2000 psi overbalance.

All results should meet the success condition. If the result of one test for the same sample did not meet these conditions, it could be said that this composition is not appropriate to use.

Although the results meet the success criteria, the repeatability of tests is also important. To provide this, the recommended range for each sample is presented. Since in use of standard deviation which is commonly used in statistics can cause that close data to stay out from deviation range whereas the results diverge highly from each other could be taken place in deviation range, in this study ±10% of mean is accepted as a recommended range. During the determination of this range, after the mean of three tests determined for each sample, 10% of it is calculated. By subtracting this value from mean, the lower limit of the recommended range is defined. By summing 10% of mean up to mean, the upper limit is determined. If the total sealing time of these three tests with the same composition is not in this recommended range, the repeatability of tests could be seen as questionable.

Although mud losses are not a primary indicator in comparison of samples, it could be used as secondary parameters to determine the optimum composition.

3.1 Effect of PSD of Ground Marble on Sealing 400 µm Fracture Width

Each particle size range was tested individually on the 400-µm fracture width. 30 lb/bbl from each particle size range was taken and tested. According to the results obtained, fine-sized particles (FMC 30-0-0) and medium-sized particles (FMC 0-30-0) could not form a bridge on this slot when they were used alone. Although coarse-sized particle (FMC 0-0-30) could seal the fracture, it could not withstand higher pressure differentials when it was used individually. Once mud loss value went over 125 ml, the tests were finished and recorded as “failed” as mentioned before.

However, the fracture sealed and withstand 2000 psi overbalance when it was used from each particle size range equally. Once 10 lb/bbl fine-sized, 10 lb/bbl medium-sized and 10 lb/bbl coarse-sized particles (FMC 10-10-10) were used, the bridge could be formed and aimed pressure was reached quickly. After the bridge was formed, the pressure value reached 2000 psi in 527.3 ± 3.5 sec averagely. Observed total mud loss value was 4.2 ± 0.5 ml and all tests are in the recommended range. Even these results could be used to show the importance of the use of different particle size ranges.

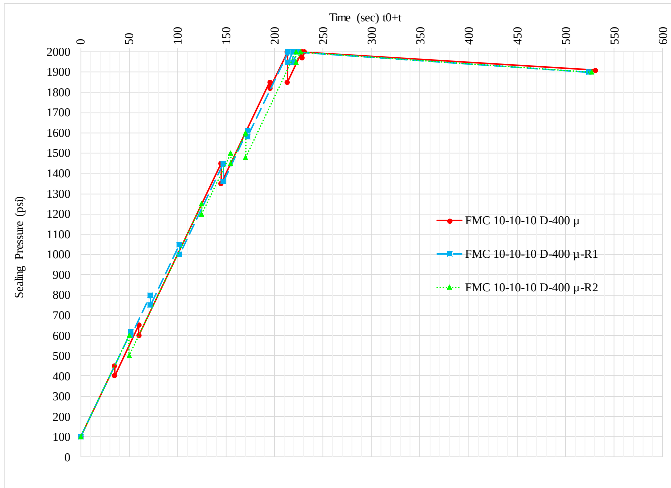


Figure 3 - Pressure vs Time curve for FMC 10-10-10 on sealing 400-micron fracture width

Since the aim of this study is to determine optimum WSM material composition which seals the fracture in this study, it was decided to check the importance of each particle range in sealing efficiency on 400-micron fracture width at lower concentrations. During these tests, it was observed that even the same composition is used on the plugging the same slots, the repeat tests could result in different sealing time as shown in Figure 4 and mud loss values due to pressure falls and their different damage on the bridge.

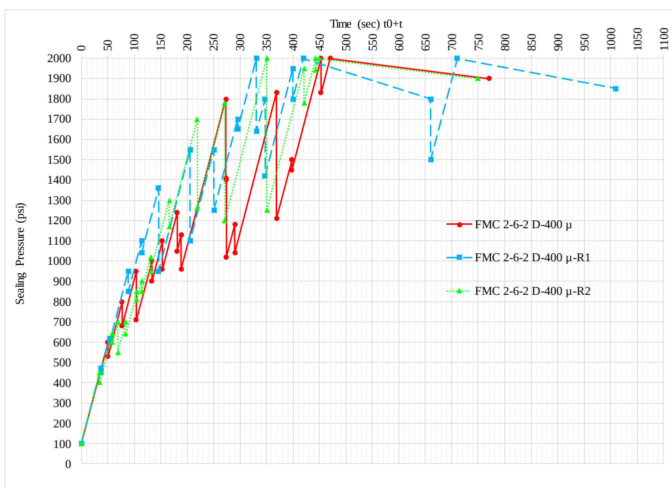


Figure 4 – Pressure vs Time curve for FMC 2-6-2 on 400-µ fracture width

Also, thanks to the proper selection of PSD, using the total concentration of 4 ppb WSM, 400 µm fracture width could be sealed as could be seen in Figure 5. However, repeat tests with this composition might give different results since two of these tests stayed out from the recommended range. However, this composition might be preferred by some operators on the conditions in which fluid loss amount and the sealing time of fractures are negligible.

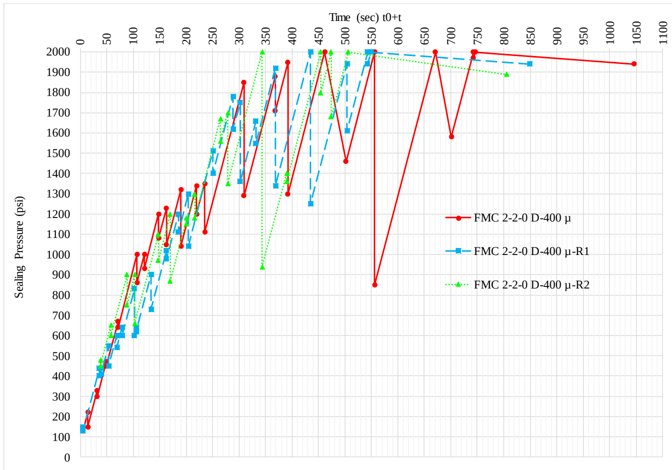


Figure 5 - Pressure vs Time curve for FMC 2-2-0 on 400-µ fracture width

During these tests, it was observed that

- ✓ If the concentration of fine-sized particles decreases, the total sealing time and mud loss increase aggressively.
- ✓ The decrease in the concentration of coarse size particles does not affect total sealing time and mud loss values significantly.
- ✓ In the absence of fine size particles, the bridge might not be sealed.

According to results obtained from these tests, the best compositions that sealed the fracture quickly with lower mud losses could be seen in the following table 5.

Table 5 - Comparison of Best Results for Sealing of 400 µm fracture width

Composition	Total Sealing Time (sec)			Total Mud Loss (ml)		
	Mean	Std Dev	Worst Case	Mean	Std Dev	Worst Case
FMC 10-10-10	527.3	3.5	531	4.2	0.4	4.8
FMC 10-8-10	526.7	13.5	540	5.1	1.5	6.6
FMC 10-10-8	517.7	19.1	538	4.7	1	5.8
FMC 10-10-6	527.7	10.4	536	4.5	0.5	5
FMC 10-10-4	517	14	531	4.3	0.3	4.5
FMC 8-6-2	533	17.1	547	6	0.8	6.7

Although mud loss values of 8-6-2 composition is a bit higher than others, it sealed the fracture nearly the same time with others and its concentration is lower. That's why it could be chosen as optimum concentration.

3.2 Effect of Concentration of Ground Marble on Sealing 400 µm Fracture Width

To show the effect of concentration, FMC 8-6-2 had been selected. By keeping the ratio between the particle size ranges the same, the effect of concentration on sealing 400-µm fracture width was observed.

Table 6 - The effect of concentration on sealing 400-micron fracture width

Composition	Success / Fail	Total Sealing Time (sec)		Total Mud Loss (ml)		Recommended or not
		Mean	Std Dev	Mean	Std Dev	
FMC 4-3-1	S	646.3	28.9	15.6	6.3	R
FMC 8-6-2	S	533	17.1	6	0.8	R
FMC 12-9-3	S	506.7	4.2	4.4	0.4	R
FMC 16-12-4	S	500.7	10.5	3	0.5	R

Table 6 shows that the number and severity of pressure fall decreased, and fracture could be sealed more quickly with lower mud losses by increasing concentration.

3.3 Effect of PSD of Ground Marble on Sealing 800 µm Fracture Width

Each particle size range was firstly tested individually on the 800-µm fracture width. 30 lb/bbl from each particle size range was taken and tested. The same results were obtained also on this fracture width. While fine-sized particles (FMC 30-0-0) and medium-sized particles (FMC 0-30-0) could not form a bridge on this slot when they were used alone, coarse-sized particles (FMC 0-0-30) could succeed to form a bridge on the aperture. However, the bridge could not withstand higher pressure differentials when it was used individually and once mud loss value went over 125 ml, the tests were finished and recorded as "failed". Therefore, it was concluded that each particle size range was not able to seal the fracture when they were used alone. In other words, one size range was not enough to plug and seal it.

Then, FMC 10-10-10 was used, the bridge could be formed and aimed pressure was reached. Observed total sealing time and total mud loss value was 1130.3 ± 56.3 sec and 25.7 ± 1.5 ml, respectively. Due to more pressure falls observed, other compositions with different particle size distribution at the same concentration (30 lb/bbl) were tested.

Firstly, the concentration of fine size range was kept the same, the concentration of coarse-sized and medium-sized particles was changed. It was found that,

- ✓ In the absence of coarse size particles, the bridge could not withstand higher pressure differentials.
- ✓ Once the concentration of medium size and coarse sized particles are close to each other, a more durable bridge could be formed.

Then, the concentration of medium size particles was kept the same and the concentration of coarse sized and fine-sized particles was changed. It was found the same results. Besides them,

- ✓ In the absence of fine-sized particles, the bridge might not be sealed.

If the concentration of coarse size particles was kept the same and the concentration of medium and fine-sized particles changed, the results were obtained.

During the tests with lower concentrations, the same results were obtained.

The best results on sealing of 800-µm fracture width can be arrayed like these.

Table 7 - Comparison of Successful Results on Sealing of 800-µm Fracture Width

Composition	Total Sealing Time (sec)			Total Mud Loss (ml)		
	Mean	Std Dev	Worst Case	Mean	Std Dev	Worst Case
FMC 10-10-10	1130.3	56.3	1193	25.7	1.5	26.8
FMC 8-10-10	1051.7	247.1	1327	26.3	5.8	33
FMC 10-6-14*	928	177.4	1112	21.6	4.9	27
FMC 6-10-14	890.3	53.4	947	23.6	2.2	25.2
FMC 6-14-10*	1119.3	352.5	1523	29.2	10.2	41

*The repeatability of these tests are questionable.

Although the repeatability of FMC 10-6-14 was questionable, the results were pretty good. When looking at the worst value of total sealing time, it was better than most of the tests. Therefore, FMC 10-6-14*, FMC 10-10-10 and FMC 6-10-14 compositions can be applied to seal 800-micron fracture width. FMC 6-10-14 could be seen the best composition among these compositions since the worst mud loss volume was observed with this composition, besides lower total sealing time. Although in this composition, concentration of coarse particles is high, since the maximum particle size is 1180 µ, it can be applied during drilling with downhole tools.

3.4 Effect of Concentration of Ground Marble on Sealing 800 µm Fracture Width

To show the effect of concentration, concentration of FMC 10-10-10 composition was increased.

Table 8 - Effect of Concentration on Sealing (1)

Composition	Total Sealing Time (sec)			Total Mud Loss (ml)		
	Mean	Std Dev	Worst Case	Mean	Std Dev	Worst Case
FMC 10-10-10	1130.3	56.3	1193	25.7	1.5	26.8
FMC 15-15-15*	1051.7	151.8	1184	19.7	1.7	21.1
FMC 20-20-20*	858.7	225.1	1116	14.3	6	21.1

*The repeatability of these tests is questionable

In this set of tests, increasing concentration leads to a decrease in total sealing time and mud loss.

Then, the concentration of FMC 6-10-14 composition increased. It was expected that an increase in the concentration of WSM led to a decrease in the total sealing time and a decrease in mud losses. However, in these tests, due to seal breaks and pressure falls, total sealing times increased with increasing concentration as can be seen in Table 9. This exception showed that particle alignment and distribution in the bridge is also important. Sometimes increase in concentration might not be end up with decreasing total sealing time due to this. On the other hand, the mean of mud loss values decreased with increasing concentration. However, the worst values indicated different results. Especially in the second test (FMC 9-15-21), mud loss values increased significantly. This might be due to particle alignment on the face of the fracture.

Table 9 - Effect of Concentration on Sealing (2)

Composition	Total Sealing Time (sec)			Total Mud Loss (ml)		
	Mean	Std Dev	Worst Case	Mean	Std Dev	Worst Case
FMC 6-10-14	890.3	53.4	947	23.6	2.2	25.2
FMC 9-15-21*	1064	236.2	1064	22.2	6.5	29.4
FMC 12-20-28*	973.7	135.4	1103	18.8	3.9	21.6

*The repeatability of these tests are questionable.

3.5 Effect of PSD of Ground Marble on Sealing 1200 µm Fracture Width

30 lb/bbl particle from each particle size range was tested on 1200-µm fracture width. None of these particles could form a bridge on the fracture alone even at 100 psi. Once mud loss went over 125 ml, tests were finished and recorded as “failed”.

Then, the FMC 10-10-10 composition was tested on the same fracture width. Although, the fracture was plugged by this composition at lower pressures. However, many seal breaks observed at higher pressure differentials. After the upper limit passed over, the tests were finished and recorded as “failed”. After this composition was failed, different particle size distributions were tested on the same slot. None of these compositions reached aimed pressure. However, different PSDs reached different maximum sealing pressures. During these tests, it is observed that

- ✓ In the absence of coarse sized particles, the bridge could not be formed.
- ✓ Increasing concentration of coarse sized particles leads to higher pressure differentials.

Then, the total concentration of the best results increased to 60 ppb. Higher sealing pressures observed. However, the aimed pressure could not be reached. Therefore, it can be concluded that ground marble may not be effective to plug 1200-µm fracture width when it is used alone.

After these tests, higher concentrations were tested on the same fracture width to see whether 1200-µm fracture width could be plugged with these particle size ranges or not. It was observed that FMC 15-30-45 (total WSM conc. of 90 lb/bbl), FMC20-40-60 (total WSM conc. of 120 lb/bbl) and FMC 25-50-75 (total concentration of 150 lb/bbl) compositions sealed the fracture. However, these concentrations are too high for continuous application in the mud. Therefore, it was not suitable for wellbore strengthening mechanisms. However, 1200-µm fracture width might be sealed with Lost Circulation Pill application by using higher concentrations of these particle size ranges.

3.6 Effect of Concentration of Ground Marble on Sealing 1200 µm Fracture Width

Besides tests were done before, the concentration of FMC 10-10-10 composition increased to show the effect of concentration on sealing. The results can be seen in Table 10. During all tests, increasing concentration increases maximum sealing pressures. Additionally, bridges could become more durable with increasing concentration.

Table 10 - Effect of Concentration on Sealing 1200-µm Fracture Width

Composition	Maximum Sealing Pressures (psi)		
	Test #1	Test #2	Test #3
FMC 10-10-10	1340	1100	1240
FMC 16-16-16	1540	1400	1800
FMC 20-20-20	1780	1940	1980

3.7 Effect of Fracture Width on Sealing

The same composition tested on different fracture widths to see the effect of fracture width. FMC 10-10-10 composition has been chosen. As can be seen in Table 11, increasing fracture width size affected seal integrity negatively. As the fracture width increases, it gets difficult to form a bridge and resist higher pressure differentials.

Table 11 - Total Sealing Time and Total Mud Loss Values for FMC 10-10-10 composition on different fracture width

Fracture Width Size (µm)	Total Sealing Time (sec)			Total Mud Loss (ml)		
	Mean	Std Dev	Worst-Case	Mean	Std Dev	Worst Case
400	527.3	3.5	531	4.2	0.5	4.8
800	1130.3	56.3	1193	25.7	1.5	26.8
1200	FAIL	FAIL	FAIL	>125	-	-

4. CONCLUSION

This study was done to investigate the Effect of Particle Size Distribution range, concentration and fracture width on sealing performance in Ground Marble laden drill-in fluids. Following conclusions are drawn as a result of experimental work:

1. Ground Marble particles can be used as wellbore strengthening materials to seal 400-µm and 800-µm fracture width and formed bridges resisted to 2000 psi.
2. The used particle size range of ground marble in this study may not be effective to plug the 1200-µm when used alone in wellbore strengthening applications under 2000 psi overbalance.
3. Particle Size Distribution has a major effect to seal the fracture regardless of the aperture.
4. The required maximum particle size might be determined according to the anticipated fracture width.
5. In general, concentration influences total sealing time and mud loss values inversely proportional.
6. Pressure falls and damage on the bridge caused by them are highly effective on the results. Even the same composition is tested repeatedly, with different sealing time and mud loss values observed depending on the severity of pressure falls.
7. Fracture size affects the stability of the seal inversely proportional. As the fracture width grows larger, sealing the fracture is getting harder.

5. ACKNOWLEDGEMENT

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6. NOMENCLATURE

GM: *Ground Marble*
LCM: *Lost Circulation Material*
PPA: *Permeability Plugging Apparatus*
PSD: *Particle Size Distribution*
WSM: *Wellbore Strengthening Material*

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