DYNAMIC FILTRATION TEST EXPERIMENT DESIGN

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ABSTRACT

Dynamic Filtration Test to Investigate the Effect of Preformed Particle Gels (PPGs) on Un-swept, Low-Permeable Zones/Areas. A filtration test is a simple means of evaluating formation damage. This work use schematically dynamic filtration test experiment design apparatus to carry out the various filtration test experiments. It uses different core samples, various brine concentration, and various gel types. The permeability of each sandstone core samples is calculated before and after the filtration test. Experiments are still being observed. The objective of this study is to find methods that minimized the damage caused by PPGs on un-swept, low-permeable zones/areas, thus improving PPG treatment efficiency. This approach will identify the best properties of the PPGs, which can neither penetrate conventional solid rocks nor form cakes on the rocks' surface.

INTRODUCTION

In the oil industry, the common practice of extracting oil from oil reservoirs occurs through water injection. This method has been shown as an effective method of oil extraction, even though it lacks efficiency. Water used in the process of water injection develops a high salinity, which in turn, places financial strain on the oil industry due to the costs associated with safely handling the water, and its reprocessing. Research suggests that Superabsorbent polymers (SAPs) are a viable solution to both problems, as polymers can be used to absorb water molecules and form a gel like substance; using them in regards to the correct environmental criteria could thereby facilitate the procedure of water injection in the oil industry. The two major factors that affect the effectiveness of polymers are temperature and pH levels. This study will demonstrate how the factors of temperature and pH are directly related to the swelling of polymers. It has been shown that the decrease in pH decreases the precipitation of the polymer, especially in dilute solutions. Furthermore, high temperatures can cause an even further precipitation in brine solution which contain divalent cations. This research will use dynamic filtration tests to determine whether swollen preformed particle gels (PPGs) affected unswept oil zones/areas. The objective of this study is to find methods that minimized the damage caused by PPGs on unswept, low-permeable zones/areas, thus improving PPG treatment efficiency. These results can help to identify of the best PPG types, particle sizes, and brine concentrations for specific reservoirs conditions and treatments. A filtration test is a simple means of evaluating formation damage. The oil industry currently uses two standard filtration tests both static and dynamic, to assess damage to core samples. The static test is suitable when testing for injection into the matrix rock; while the dynamic test assesses injection into a fracture. Filtration test experiments have been use in the past to study the damage of cores fully. However, no one has studied the effect of deformable swollen gel particles on low-permeability zones by using dynamic filtration test. There are 3 types of oil recovery. They are primary, secondary and tertiary. Primary recovery typically refers to the use of energy to inherent in a reservoir from gas under pressure or natural water drive. One of the processes is water flooding which can only recover 30% of the oil in a reservoir [4]. Excess water production has become a significant problem for oil field operations as reservoirs mature. This process is also expensive costing billions of dollars every year to remove excess water after the procedure. Furthermore, this procedure also causes corrosion and growth of certain bacteria which is hazardous to the environment [6]. Both primary and secondary types can extract up to 40% of the oil in a reservoir. Tertiary recovery, also known as Enhanced Oil Recovery, is the implantation of various techniques to increase the amount of crude oil that can be extracted from an oil field while minimizing the excess amounts of water. This process help to increase the oil extraction from an oil field by 30-60% [4]. The usage of preformed particle gels (PPGs) also known as water treatment is one of the Enhanced Oil Recovery methods that has been developed during the last decade of the oil industry. Some of the chemicals been used are gel systems using both polyacrylamides and different crosslink [1-3]. These particle gels have plenty characters which make them best to use in the oil field because there are ease to injection, salt acceptance, elastic properties and the ability to penetrate into the high permeable formation. Gel treatment method is cost effective and it also decrease water production and improve the homogeneity in mature oil field. These gels have been both used to suppress excess water production and improve oil productivity [5-6]. Published documents indicate that several particle gels were economically applied to reduce water production in mature oil fields. For example, preformed particle gels-PPGs have been applied in about 2,000 wells to reduce fluid channels in water floods and polymer floods in China [11-12]. Recently, Occidental Oil Company and Kinder-Morgan used similar product to control CO2 breakthrough for their CO2 flooding areas and promising results have been achieved. However, the achievement of the best water treatment mainly depends on whether chemical and mechanical methods can successfully correct the reservoir heterogeneity. In petroleum engineering, drilling fluids are specially formulated to be used during perforating operations to control fluid loss and minimize formation damage. To minimize formation damage, it is important to find methods that minimize the damage caused by PPGs on unswept, low-permeable zones/areas, thus improving PPG treatment efficiency and to determine what factors influence the blocking efficiency of the high permeable zones/areas without damaging the formation zones. This research will use dynamic filtration tests to determine whether swollen preformed particle gels (PPGs) affected unswept oil zones/areas. A filtration test is simple means evaluating formation damage. The oil industry currently uses two standard filtration tests. Both static and dynamic filtration tests are used to assess damage to core samples [8]. The former is suitable when testing for injection into the matrix rock; the latter assesses injection into a fracture. Filtration test experiments have been used in the past to study the damage of cores fully saturated with brine, oil, or residual oil while injecting suspended particles, oily water, or a combination of both into these cores. Static filtration test is used to study the effect of both weak and strong preformed particle gels on law permeable formation, respectively [13]. They determined that the best PPG treatments occurred when the PPG could simply penetrate the high permeable layers without damaging the low permeable formations [11]. However, no one has studied the effect of deformable swollen gel particles on low-permeability zones by using dynamic filtration test. Dynamic filtration is also used outside the oil industry, in procedures such as purifying water, processing foods and clarifying effluents [17]. During the dynamic filtration process, the slurry being filtered is being circulated over the filter cake, so that the cake is simultaneously eroded and deposited. The erosion rate depends on the shear rate of the fluid at the face of the cake. Two factors that affect dynamic equilibrium which are the amount of solid particles deposited and the erosion rate caused by the shear stresses generated by the fluid flow in the wellbore. The filtration rate tends to stabilize around a certain value at which mud cake thickness becomes constant. Dynamic filtration cause the permeate flux to decrease over time. This decrease results in increasing hydraulic resistance due to the accumulation of mud cake on the rock. As the mud cake thickens the permeate decreases until a steady state is reached [18]. In this study a dynamic filtration test will be used to determine if the Preformed Particle Gels (PPG) has an effect on the formation of the rock. In other words, this test will determine if the PPG damages or deforms the rock samples. Permeability, is one of the main factors that helps us to determine the effect of PPG on a rock. Permeability can be defined as the state or quality of a material or membrane that causes it to allow liquids or gases to pass through it. A change in the permeability of a rock after the dynamic filtration test will imply that the PPG influenced the rock. If the permeability of the rock after the test is different to the permeability of the rock before the test, it can be determined that the PPG in fact damaged or deformed the rock sample. The permeability in this case, depends on factors such as the flow rate, the viscosity of the brine, the length of the core sample, the diameter of the core sample and the pressure drop across the core sample. The Darcy Equation, which is used to calculate the permeability is as follows. Figure (1) represent both dynamic and static filtration test.

Dynamic Filtration

A filtration process in which the slurry being filtered is being circulated over the filter cake, so that the cake is simultaneously eroded and deposited

Static Filtration

A filtration process in which the slurry being filtered remains static. Filter cake continues to grow thicker as filtration continues.

<u>EXPERIMENTAL WORK</u>

Equipment and Apparatus:

Figure (2): Experimental model Syringe Pump: main apparatus used for dynamic filtration

A Teledyne Isco D-series pump is being used to pump the brine solution into the system at a constant lower pressure. The polymer pump is where the polymer will be inserted, it is designed that it’s easy to assemble and disassemble; this allows the use of different types of gels. The rock chamber is designed to meet the requirement in size of the rock sample to be used.   Valve 1 will be opened and value 2 will be closed to allow the brine to follow to the rock chamber. The brine will pass through the rock chamber into a tank. During this process the digital pressure gauge will show a reading. Secondly will close valve 1 and open valve 2 to allow the brine to go to the polymer pump. The pressure of the brine water will force the piston in the polymer pump to move downwards causing the gel to follow to the rock chamber.

Figure (3): Gel pack Schematic Mode represents the first gel pack model. This model was a long, acrylic round tube machined at McCoy Engineering machine shop. This tube has two end plates attached by caps. The inside diameter of the round tube measured 3 inches. The top cap had one hole connected to the pump through both the tubing and the fitting. This hole served as an inlet for the injection brine. The bottom cap had one hole as well through which brine was discharged.

Figure (4): Tube containing sandstone core sample represents a similar equipment design with no piston in it. This section determines the effect of gel penetration depth on the reduction of the core permeability. This model was used to carry the core sample which helps measure the effect of brine and PPG concentration on the sandstone core samples during the experiment.

Figure (5): Sodium chloride and Deionized Water used for brine solution. Brine concentrations significantly affects the PPGs gel swelling ratio. A high salinity brine results in both a lower swelling ratio and a higher swollen particle strength. Sodium chloride (NaCl) was used to prepare all brines. We used different brine concentrations prepared at room temperature to prepare the swollen PPGs gels.

Figure (6): Electronic Scale Balance and scientific stirrer: used to measure quantity of sodium chloride and preformed particle gels used for experiment.

Figures (7 and 8): Sandstone core samples Castlegate and Bernheimer. After each filtration test experiment the damage caused on the rock was removed by cutting slices off from the sandstone core surface before proceeding with the next step. This procedure is carried out with a sharp steel cutter which scratches the sandstone core surface until the core damage is no longer visible. The slicing of the core surface removes the damage on the core surface and would not affect he core permeability of the non-damaged area. The purpose of this cutting core surface was to determine the penetration of the PPG gel into the core and for proper utilization of core samples.

Figure (9): the PPG Solutions before and after mixture. A syringe pump with 300 psi injection pressure was used for PPGs gels. The load pressure caused by the piston reduced the core permeability core more while using higher permeability cores for all gels. The liquidblock 40k and HS fines produced serous core damage and more permeability reduction when higher permeability cores were used. More damage occurred when higher permeability cores were used because higher permeability cores had a larger pore throat (Absolute size of a pore throat is the radius of a circle drawn perpendicular to fluid flow and fitting within its narrowest point.) size which allowed PPGs to penetrate the core surface and form a cake easier than lower permeability cores. In today's field applications, the strong gel causes less formation damage to the unswept, low permeable zones/areas than the weak gels. In addition, the formation damage of unswept, low permeability, zones could be controlled by controlling the strength, type, and particle size of PPGs and brine concentration.

Polymers

SAP –LiquiBlock™ 40F

- Chemistry – Potassium salt of cross-linked polyacrylic acid
- The particle size range 1-200 microns
- Absorption (g/g) deionized water >200
- Moisture content (%) 5
- pH Value 5.5-6.0
- Apparent bulk density (g/l) 540
- ➢ Purchased from Emerging Technologies

SAP-LiquiBlock™ HS Fines

- Chemistry – Sodium salt of cross-linked polyacyclic acid
- The particle size range 1-140 microns
- Absorption (g/g) deionized water >180
- Moisture content (%) 7
- pH Value 6-7
- Apparent bulk density (g/l) 540
- ➢ Purchased from Emerging Technologies

SAP-LiquidBlock™ 2G-110

- Particle Size Distribution (microns) < 600
- Absorption (g/g) deionized water > 490
- Teabag Retention (g/g) 0.9% NaCl 40
- Apparent Bulk Density (g/l) 400
- Moisture (%) < 5
- Gel Time, Vortex Method (s) 3
- Swell Rate (mm/min) > 18
- Chemistry: Sodium salt of crosslinked polyacrylic acid
- Physical Form: White granules, free flowing
- Specific Gravity (Bulk Density) 0.62 – 0.74 g/ml
- Melting Point > 330 ºC
- Solubility in Water Swells in water
- Auto-Ignition Temperature > 400 ºC
- pH 6 - 8
- Purchased from Emerging Technologies

SAP-LiquidBlock™ AT-03S

- Particle Size Distribution (microns) 1 – 850
- Absorption (g/g) deionized water > 400
- Teabag Absorption (g/g) 0.9% NaCl 55 - 65
- Teabag Retention (g/g) 0.9% NaCl 40
- Apparent Bulk Density (g/l) 650 – 800
- Moisture (%) 10
- Gel Time, Vortex Method (s) 35 min - 70 max
- Residual Monomer (ppm) < 200
- Chemistry: Sodium salt of crosslinked polyacrylic acid
- Physical Form: White granules, free flowing
- Purchased from Emerging Technologies

PROJECT TASK

Procedure**:**

- Step 1 – finding the permeability before the treatment
- Step 2 – The polymer treatment
- Step 3 – Finding the permeability after the treatment

CALCULATION

Calculations of the following:

- Permeability (Permeability of sandstone rocks)

The linear Darcy equation was used to calculate the permeability (K) o f different sandstone samples as shown in Eq.

$$K = \frac{Q\mu L}{0.78d^2\Delta p} \qquad (1)$$

Where Q is the fluid flow rate, cm^3/s; μ is the brine viscosity, cP; L is the sandstone core length, cm; ∆p is the differential pressure, atm; d is the diameter of the sandstone core, cm; and the physical meaning of the constant 0.78 is π/4.

EXPERIMENTAL PROCEDURE

Figures (10) and Figure (11) shows the main experimental procedure on the Teledyne Isco D-series pump. The figure demonstrates the flow of brine and PPGs in the system.

Procedure for these experiments were as follow:

1. Sand stone core samples were first measured for permeability.
2. The rock sample is fitted in the core holder.
3. Brine is injected (using a syringe pump) through the sample. The pressure is monitored as it is needed to calculate the permeability.
4. Calculation of the permeability of the sample.
5. The swollen PPG is injected in the same manner, but the PPG is being constantly circulated (dynamic test).
6. Both the PPGs height and volume were measured; Permeability was measured before being compressed.
7. The piston on top of the particle gels inside the round tubes compresses the gel which was measured with different psi ranging from 50 – 250 psi.
8. The height, water loss and permeability was calculated for each load pressure.
9. Steps 2 and 3 are carried out again.
10. Compare results.

While running the test, Low pump pressure is used to avoid damaging the rock which will alter the results. After each filtration test experiment the damage caused on the rock was removed by cutting slices off from the sandstone core surface before proceeding with the next step. This procedure is carried out with a sharp steel cutter which scratches the sandstone core surface until the core damage is no longer visible. The slicing of the core surface removes the damage on the core surface and would not affect he core permeability of the non-damaged area. The purpose of this cutting core surface was to determine the penetration of the PPG gel into the core and for proper utilization of core samples

RESULTS & DISCUSSION

The results included the influence of PPGs, core permeability, and NaCl concentration on the damage to different sandstone core samples. The outcomes also contained the alteration of each core permeability after gel injection. Several PPGs such as At-03S, 40F, 2G-110, HS Fines were used to determine the influence of particle size on sandstone rock damage.

Different brines were chosen and used to investigate the influence of the NaCl concentrations on the core damage. Several completely swollen PPGs were prepared from At-03S, 40F, 2G-110, HS Fines PPGs and Different Brines. It was noted that the PPGs did not damage the low permeability cores of sandstone at different NaCl concentrations. Moreover, more core permeability reduction occurred when the NaCl concentration was lower for filtration tests before the gel was compressed by the piston.

In contrast the particle gel of liquid block damaged the sandstone cores and reduced their permeability. The Experimental results show that the highly concentrated gels with a low brine concentration are softer and more deformable than those with a high brine concentration.

Therefore, low brine concentration caused more sandstone core damage. Low concentration of PPGs gels damaged the formation more than the strong concentration of PPGs gels because the low concentration gel had less strength and compressed further than the high concentrated gel. We could observe some cake formed on the sandstone core surface when liquiblock 40k gel was used because the liquidblock 40k gel penetrated the low permeable formations and decreased their permeability's.

Through Table (1) to Table (8) and Figure (12) to Figure (19) : Shows results of different concentration of Brine and PPGs used on the sandstone samples.

The table shows the permeability obtained during the experiment. Initial permeability is the permeability before the PPG gel was applied and the final porosity is after the PPG was applied on the rock. The results showed a decrease in porosity for all the sandstone core samples we had. Castlegate had the largest decrease compared to Bentheimer. The 2G -110 gel had the most effect on the experiment for the castlegate rock which have the largest decrease in porosity. As shown from table the Brine concentration was increasing in the process we could also notice significant decreasing in porosity from one rock to another. From the table, we observe that with low concentration of PPG and brine there was a significant decrease in Bernheimer permeability. The PPGs did not propagate through sandstone cores and did not create a cake on the surface of the sandstone cores but when penetrated it forms cakes internally. The damage caused by PPGs was influenced by the PPGs size, the pressure being applied and the brine concentration. Filtration test results demonstrate that the strong PPGs gels did not damage low permeability cores. The PPGs damage on the core samples was also influenced by the rock permeability; more damage occurred when using sandstone core samples with high permeability of 290-320 mD.

Figure (8) Shows Damaged Bernheimer sandstone core caused by 25% of Liquid Block 40F
The sandstone core samples which was Bentheimer was affected in the experiment. We could observe some physical damage on the surface of the rock as well as some smooth features caused by the PPG. The samples were cracked opened where we could observe little formation of rock cake.

CONCLUSION

The sandstone core samples which were Castlegate and Bernheimer were affected in the experiment. The castlegate sandstone core has a Late cretaceous formation which is perm by N2 with a UCS of 2000-2500psi. The range of Permeability was from 800-1200mD with a porosity range of 27-29% We could observe some physical damage on the surface of the rock as well as some smooth features caused by the PPG. The samples were cracked opened where we could observe little formation of rock cakes. It however was not easy and a few challenges were faced during the given research period like pressure leaks in the system which was later resolved. The gel was compressed, reducing permeability as the load pressure increased. Results from this work could improve the selection of the best gel treatment methods for low permeable zones.

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Table (1): Bernheimer Sandstone Core Sample mixed with LiquidBlock 40 F

	Bernheimer Sandstone Core Sample				
Trial (1)	% LiquidBlock 40 F	% of Brine Solution	Pressure (PSI)	Permeability before Experiment	Permeability after Experiment
1	10	5	100	3500	3223.5
2	15	7	120	3500	3201.7
3	20	10	140	3500	3197.4
4	25	15	150	3500	3165.5
5	30	20	170	3500	3156.3
6	35	15	200	3500	3122.5

Table (2): Bernheimer Sandstone Core Sample mixed with LiquidBlock HS fines

	Bernheimer Sandstone Core Sample				
Trial (2)	% LiquidBlock HS fines	% of Brine Solution	Pressure (PSI)	Permeability before Experiment	Permeability after Experiment
1	30	10	120	3500	3360.4
2	15	7	140	3500	3346.3
3	20	5	150	3500	3275.5
4	25	10	160	3500	3542.4
5	10	5	170	3500	3212.2
6	35	15	190	3500	3245.4

Table (3): Bernheimer Sandstone Core Sample mixed with LiquidBlock 2G-110

	Bernheimer Sandstone Core Sample				
Trial (3)	% LiquidBlock 2G-110	% of Brine Solution	Pressure (PSI)	Permeability before Experiment	Permeability after Experiment
1	10	5	130	3500	3646.4
2	15	7	150	3500	3553.2
3	20	5	170	3500	3414.4
4	25	10	190	3500	3283.8
5	10	5	200	3500	3359.5
6	30	15	210	3500	3134.6

Table (4): Bernheimer Sandstone Core Sample mixed with LiquidBlock AT-03S

	Bernheimer Sandstone Core Sample				
Trial (4)	% LiquidBlock AT-03S	% of Brine Solution	Pressure (PSI)	Permeability before Experiment	Permeability after Experiment
1	20	10	150	3500	3423.5
2	15	7	160	3500	3301.7
3	25	10	180	3500	3397.4
4	10	5	190	3500	3265.5
5	30	20	200	3500	3256.3
6	35	15	220	3500	3122.5

Table (5): Castlegate Sandstone Core Sample mixed with LiquidBlock 40F

	Castlegate Sandstone Core Sample				
Trial (1)	% LiquidBlock 40 F	% of Brine Solution	Pressure (PSI)	Permeability before Experiment	Permeability after Experiment
1	10	3	100	2000	1223.5
2	15	10	120	2000	1201.7
3	20	15	140	2000	1197.4
4	25	20	150	2000	1165.5
5	30	25	170	2000	1156.3
6	35	20	200	2000	1122.5

Table (6): Castlegate Sandstone Core Sample mixed with LiquidBlock Fines

	Castlegate Sandstone Core Sample				
Trial (2)	% LiquidBlock HS fines	% of Brine Solution	Pressure (PSI)	Permeability before Experiment	Permeability after Experiment
1	10	5	120	2000	1838.3
2	15	7	140	2000	1729.5
3	20	10	150	2000	1638.4
4	25	15	160	2000	1520.6
5	10	5	170	2000	1514.5
6	35	20	190	2000	1494.5

Table (7): Castlegate Sandstone Core Sample mixed with LiquidBlock 2G-110

	Castlegate Sandstone Core Sample				
Trial (3)	% LiquidBlock 2G-110	% of Brine Solution	Pressure (PSI)	Permeability before Experiment	Permeability after Experiment
1	10	5	130	2000	1745.3
2	15	7	150	2000	1735.4
3	20	15	170	2000	1636.2
4	25	10	190	2000	1553.6
5	30	20	200	2000	1424.6
6	35	15	210	2000	1354.2

Table (8): Castlegate Sandstone Core Sample mixed with LiquidBlock AT-03S

	Castlegate Sandstone Core Sample				
Trial (4)	% LiquidBlock AT-03S	% of Brine Solution	Pressure (PSI)	Permeability before Experiment	Permeability after Experiment
1	20	15	150	2000	1360.4
2	15	7	160	2000	1346.3
3	10	3	180	2000	1275.5
4	20	10	190	2000	1542.4
5	30	15	200	2000	1212.2
6	35	20	220	2000	1245.4

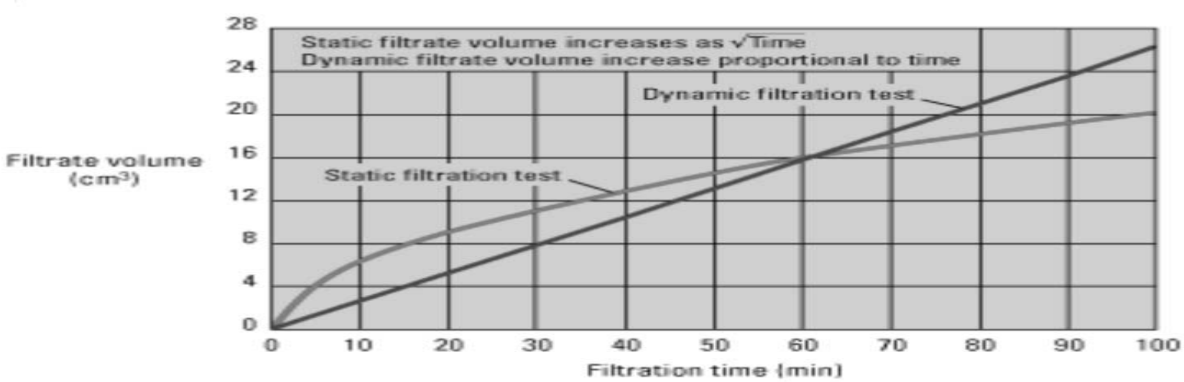

Figure (1) Represents Static and Dynamic Filtration

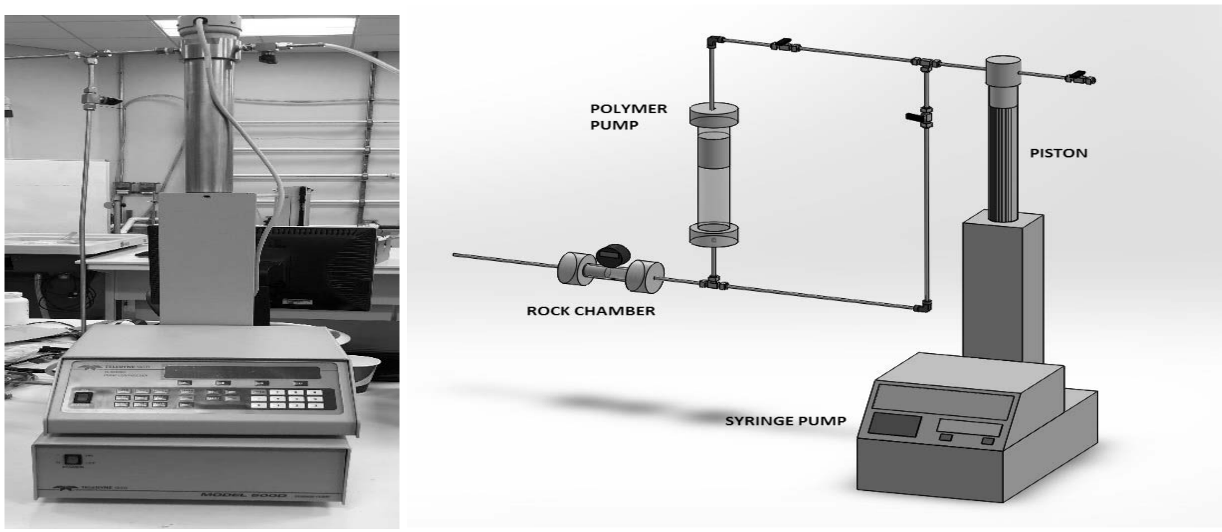

Figure (2): Experimental model Syringe Pump: main apparatus used for dynamic filtration

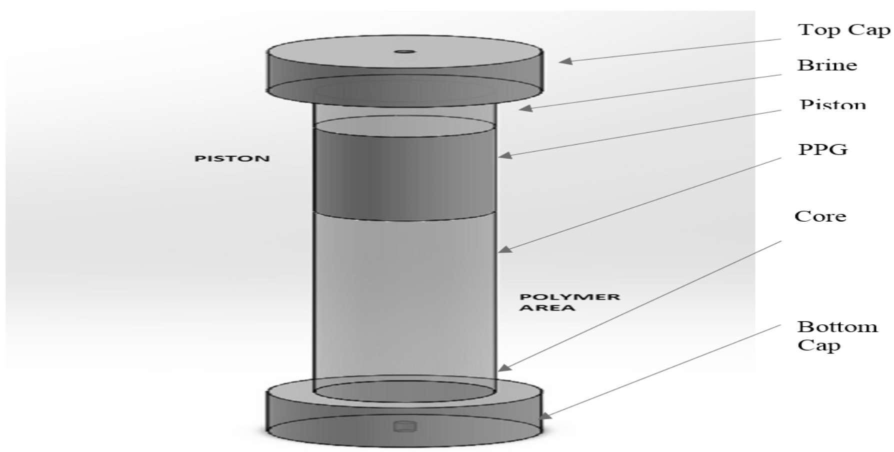

Figure (3): Gel pack Schematic Model

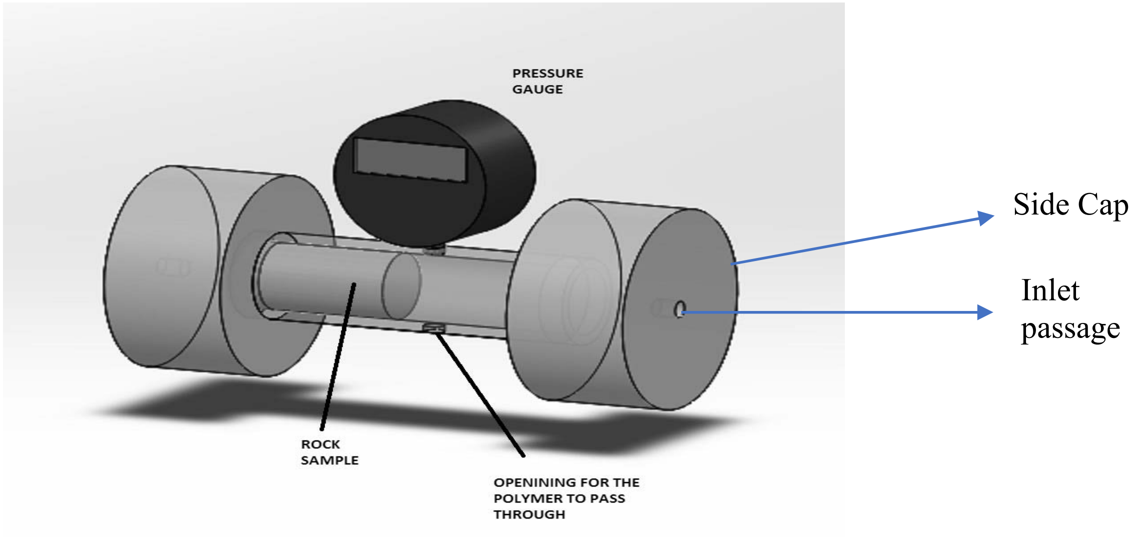

Figure (4) Tube containing sandstone core sample

Figure (5) Sodium chloride and Deionized Water: used for brine solution

Figure (6) Electronic Scale Balance and scientific stirrer used to measure and stir quantity of sodium chloride and preformed particle gels

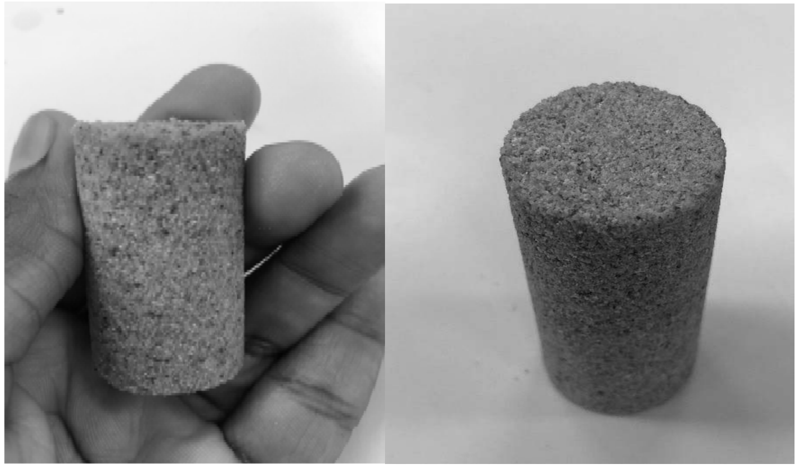

Figure (7) Sandstone core samples Castlegate and Bernheimer

Figure (8) Shows Damaged Bernheimer sandstone core caused by 25% of Liquid Block 40F

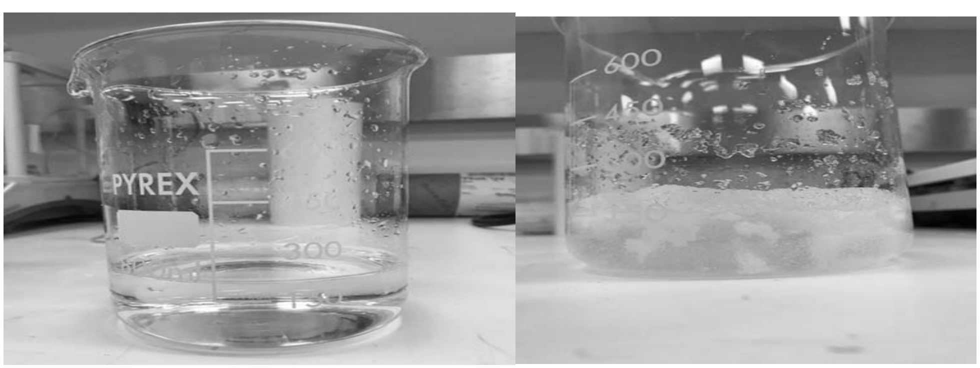

Figure (9) Shows the PPG Solutions before and after mixture

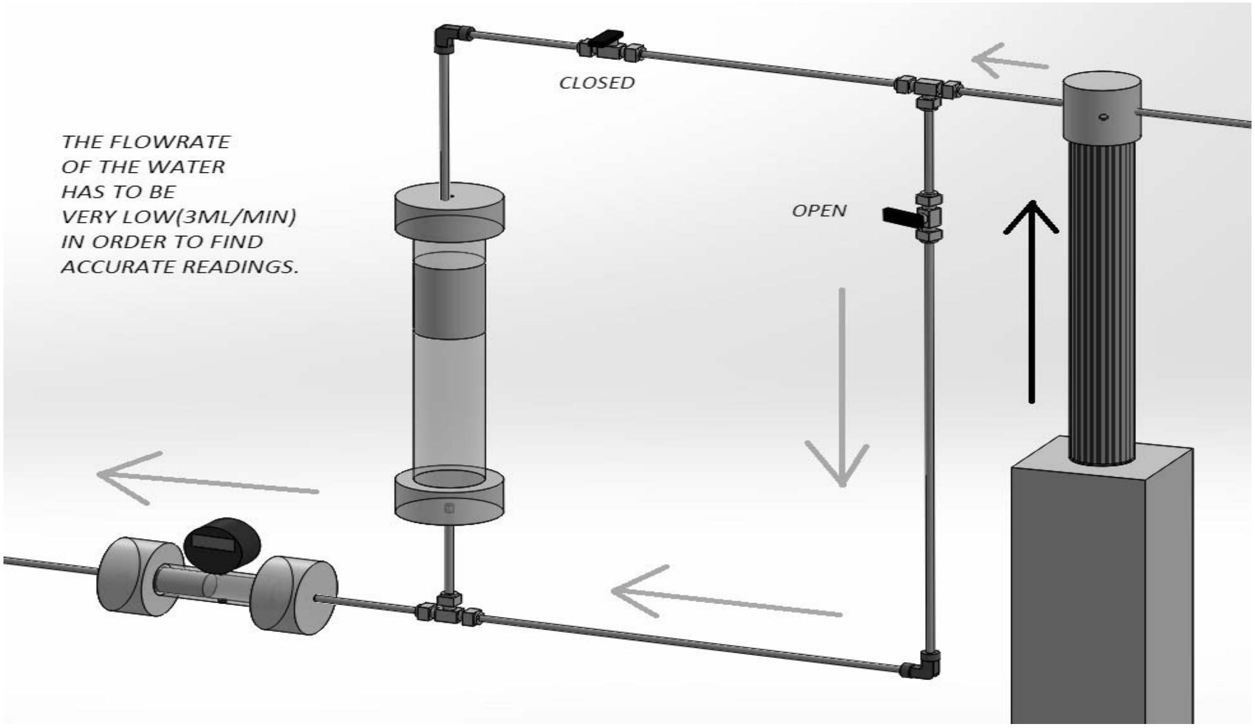

Figure (10) Flow of Brine in the system

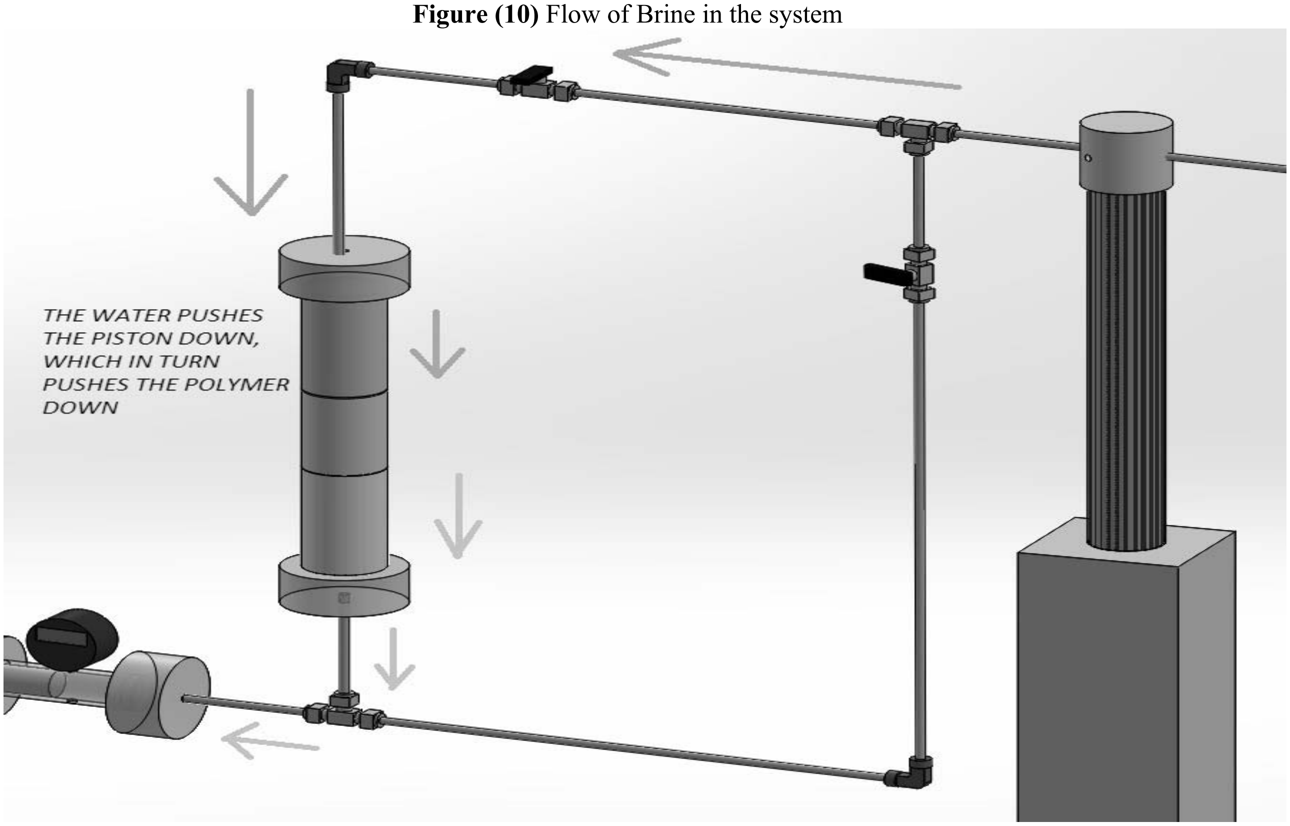

Figure (11) Flow of Polymer in the system

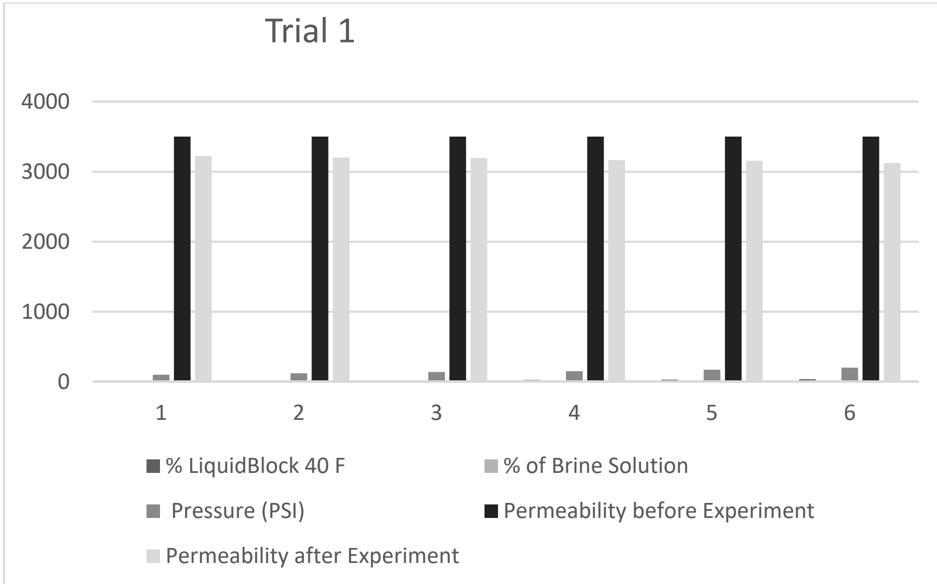

Figure (12): Bernheimer Sandstone Core Sample mixed with LiquidBlock 40 F

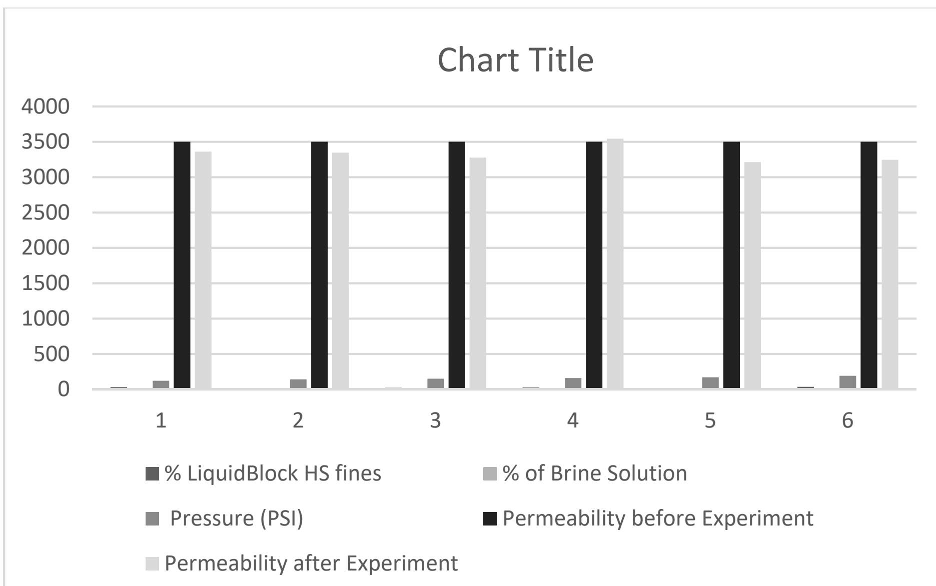

Figure (13): Bernheimer Sandstone Core Sample mixed with LiquidBlock HS Fines

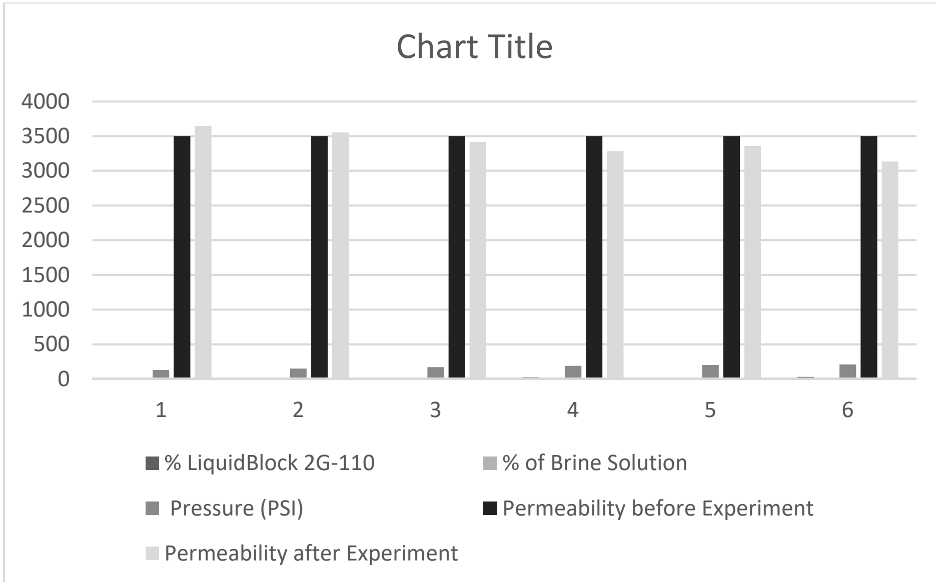

Figure (14): Bernheimer Sandstone Core Sample mixed with LiquidBlock 2G-110

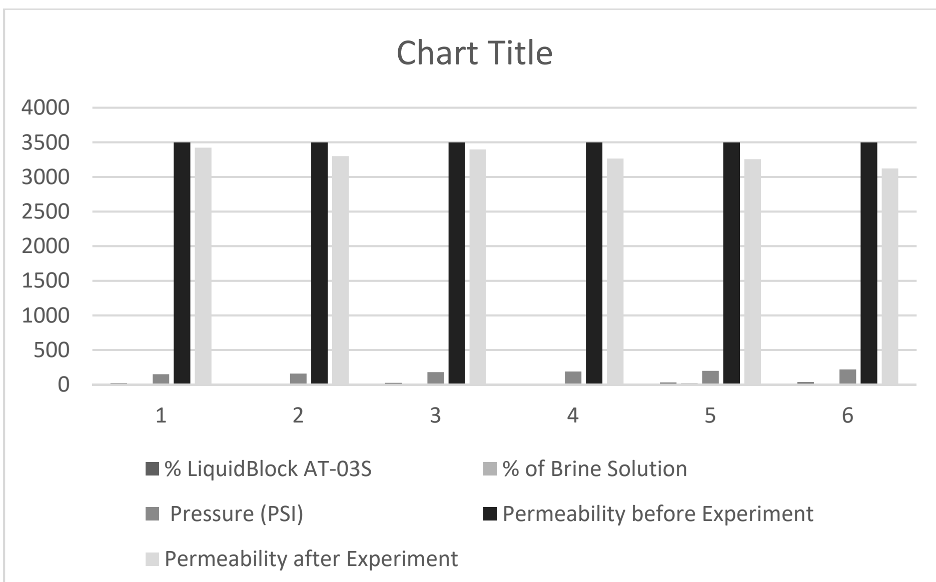

Figure (15): Bernheimer Sandstone Core Sample mixed with LiquidBlock AT-03S

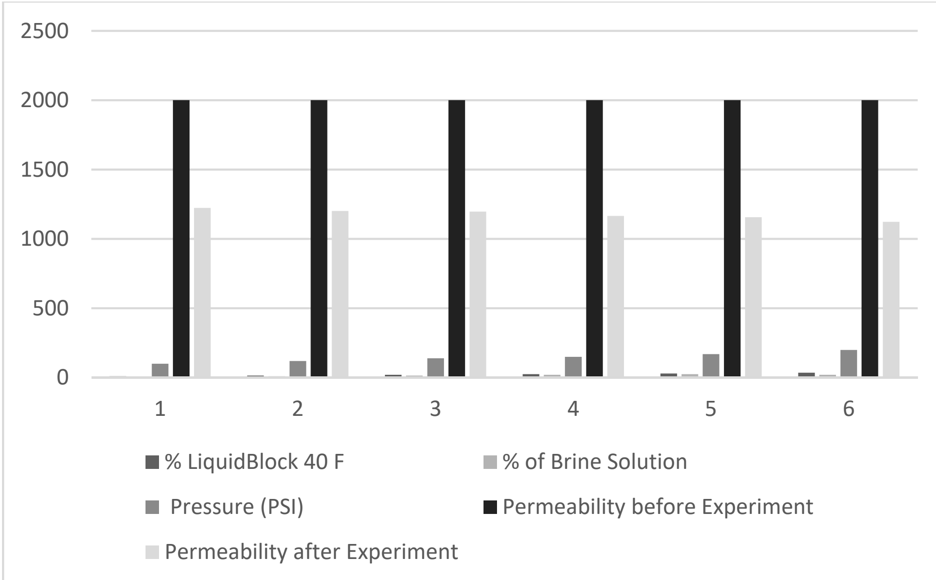

Figure (16): Castlegate Sandstone Core Sample mixed with LiquidBlock 40 F

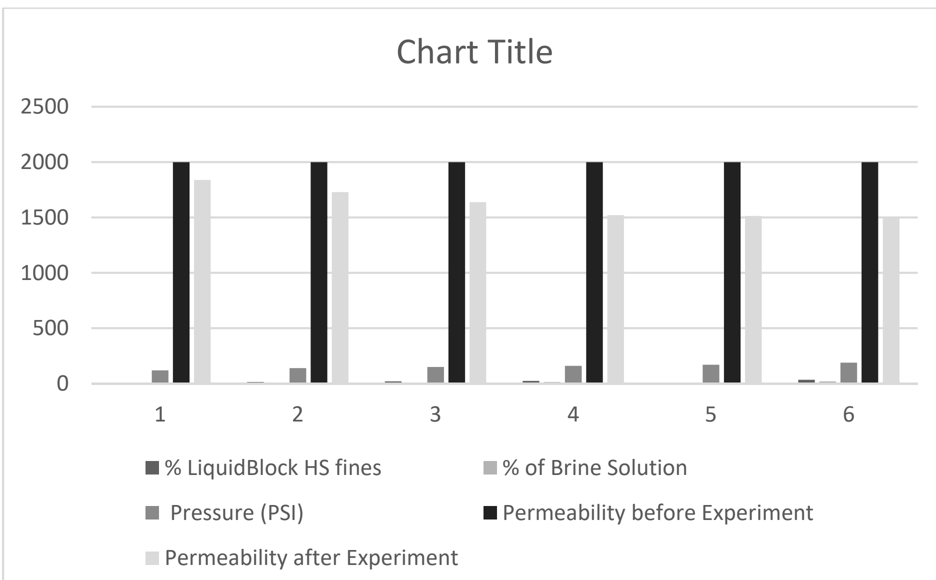

Figure (17): Castlegate Sandstone Core Sample mixed with LiquidBlock HS Fines

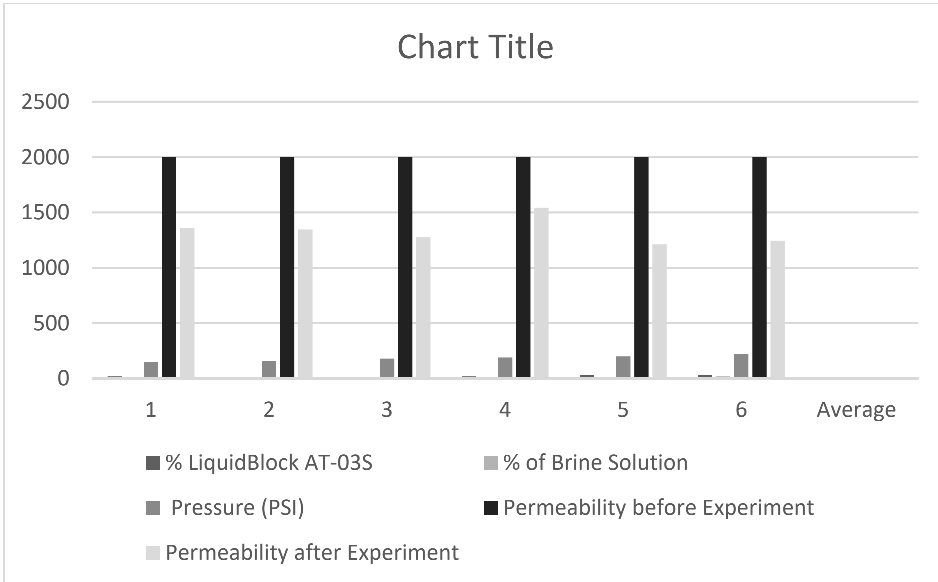

Figure (18): Castlegate Sandstone Core Sample mixed with LiquidBlock AT-03S

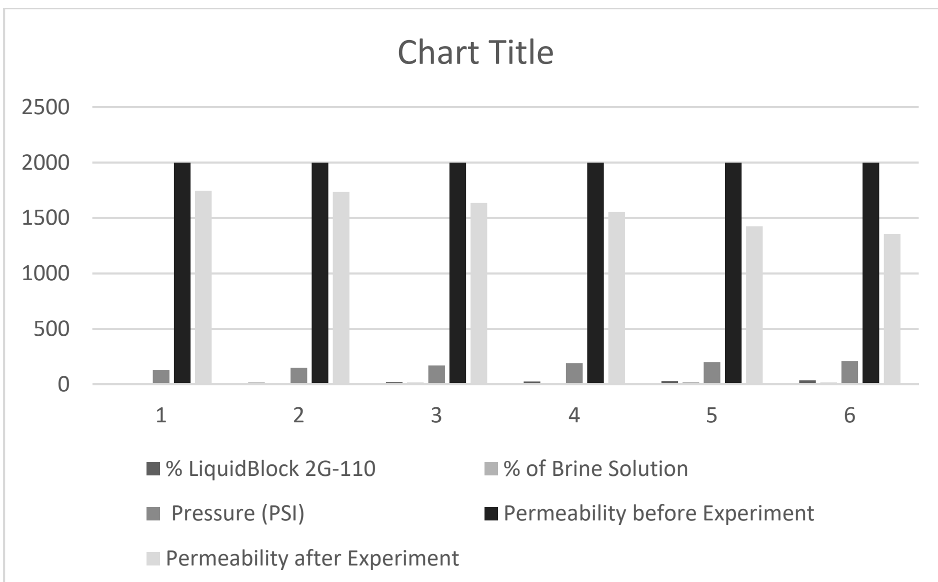

Figure (19): Castlegate Sandstone Core Sample mixed with LiquidBlock 2G-110