Application of Modified Bentonite by Using Polymer for Conformance Study

by

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Bandar Seri Iskandar

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Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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…………………………….

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September 2014

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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(Meysam Rashedi)

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ABSTRACT

Nowadays, one of the most common problems that production engineers are facing is water production. Due to lower viscosity of water in compare to oil, water flows easier in porous medium and probes its way in to production. One of the methods to deal with this problem is to use blocking agents. Blocking agents function can vary from restricting water's movement by decreasing permeability of rock to completely sealing off the water path. Many different products have been used as blocking agents including gels, polymers and foams. Hypothesis of this study is based on this fact that bentonite can swell and block the porous and subsequently reduce permeability of desired area. Objectives of this study are to examine modified bentonite's potential as a blocking agent through examining its' swelling ability in different situations in terms of salinity, ph and temperature and compare its properties with conventional bentonite. Results proved bentonite's swelling capacity is a function of all mentioned parameters. pH displayed its' optimum performance on pH around 7 and 12. In these two pH points bentonite can swell to its maximum capacity. Salinity however had negative effect on swelling. Salinity can minimize the swelling capacity up to 2.4 of its initial volume. Temperature on the other hand start effecting swelling ability around 60 ℃. temperatures below 60 ℃ didn't affect the swelling at all. For temperatures more than 60℃, each 10℃ increase in temperature resulted in 4% increase in swelled volume of mud.

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND STUDY

Nowadays one of the most important issues during production in heterogeneous reservoirs is unbalanced production from different paths in wellbore. This is more due to selective behavior of well in favor of permeable parts of wellbore. In long term it can cause water coning and water cut, consequently this will lead to inefficiency and shorter life of well (Lake, 1989). Many research and studies have been done till now to overcome this problem. Different approaches have been used. Some studies focused more on increasing permeability of tight section of wellbore using methods like acidizing, or fracturing. Meanwhile other studies focused on reducing the permeability of permeable zone in order to balance the production. This approach mostly involves using blocking agents to tighten the permeable areas. Ultimately this leads to restriction of water movement in permeable areas.

Trying to open a way for tight section reservoir is only effective when there is no water cut yet. When water starts to probe a gap into oil production the only solution would be blocking the path way. Many studies concentrated on using gel treatment to tighten the permeable zones (Seright, 1995). In gas zones engineers try to use high pressure foam injection. However based on Johannes (2013) mixture of bentonite and polyacrylamide in mud can allow it to expand up to 40 times of its initial volume. This allows bentonite to become high potential blocking agent.

1.2 PROBLEM STATEMENT

The problem is behavior of heterogeneous reservoirs in wellbore. Wellbore intend to produce selectively from permeable zones. This has caused aquifers to enter production in many cases. Methods being used including gel treatment and foam injection are effective and reasonable. However it is more convenient to develop a more feasible and easier method using frequently used materials such as bentonite. In fact the main aim of this project is to facilitate current treatments with new method and improve sweep efficiency in tight zones.

1.3 OBJECTIVES

The objectives of this study are as follow:

1. To examine properties of bentonite for possible pore block agent.

2. To find optimum conditions in which bentonite can show the best performance.

3. To compare performance of enhanced bentonite with conventional bentonite.

1.4 SCOPE OF STUDY

In this study the focus is to use fine grain bentonite which is modified by coating it with polymer to improve the characteristics of bentonite as blocking agent. As modification continues rheological, swelling ability and other features of bentonite will be recorded for obtaining the maximum performance.

Results to be gathered will all be based on lab experiments. Only few results from other blocking methods might be brought from other sources for comparison purposes.

CHAPTER 2

LITERATURE REVIEW

2.1 BENTONITE

Bentonite is used to be called “Soap mineral” till the time Wilbur. Knight found the largest bentonite deposit in Benton shale near river rock. Bentonite is a mineral with several uses such as drilling mud, binder and for purification. This is due to its unique characteristics compare to other clays. Small amount of bentonite, as low as 60 grams can create enough suspension to carry the cuttings out of borehole(Thompson, 2009). Another property of bentonite is its swelling ability which can expand up to 12 times of its original volume (Judith E. Thompson, 2009; Azar, 2007). One of its uses is in drilling field where its high swelling ability made it one of the most frequently used additives. There are other features which make it ideal for drilling industry. Based on CETCO Oil Service by very small amount of bentonite a very viscous solution can be made. Not only this, but bentonite solution can create mud cake on walls which are at very low permeability. This help drillers to lose drilling fluid at very low rate and not damaging other layers. Based on same source bentonite solution sustains for a long time. Unlike many solutions which require constant stirring to keep the solvents suspended, bentonite can sustain in the solution for a reasonable time. The other reason is impermeability toward gasses which makes it very safe solution for drilling. There is one last important feature which is its price and availability. Bentonite is being formed by volcanic ashes exposed to water and it makes it very frequent on earth surface.

2.1.1 Types of Bentonite

Bentonite exists in many different grades.There are different types of bentonites which are classified based on their dominant element. These elements include “Na”, “K”,”Ca”, and”Al”. Out of these types, sodium bentonite is the most frequently used bentonite in drilling industry. This is due to excellent absorbing feature which allows it to expand as many times as it is in dry condition. On the other hand calcium bentonite is a good ion absorber. Based on Azar (2007) one of the problems drillers face is mud contamination by ions including “Magnesium”, “Carbonate”, “Bicarbonate “ and “sulfide”. These ions can be removed by calcium bentonite.

2.1.2 Properties of Bentonite

Bentonite can create high viscosity solution with very low amount (CETCO.com, n.d.; Azar, 2007). This cause bentonite to create high viscous solution with very low solid percentage. Compare to other types of bentonite, sodium bentonite makes viscous solution with less concentration. Based on CETCO sodium bentonite can create 60 centipoises solution with only 7.5% solid in solution. While for calcium bentonite to create this viscosity solid percentage has to reach 32.5. Another property which makes it suitable for drilling industry is its colloidal property. It is also a good self sealant which allows it to perform without noticeable invasion. It means less water loss during drilling operation.

2.1.3 Limitation of Conventional Bentonite

Despite all these features bentonite has proved to be with limits facing some circumstances. Bentonite performs well in certain range of temperature, concentration, pressure and environment.

Salinity Effect of Solution on Swelling Ability of Bentonite

For example NaCl with concentration of 4 mol/dm^3 leads the swelling feature to drop to its minimum (Shirazi, 2011). Based on the same author all different types of bentonites ranging 1.33 g/cm^3 to 1.90 g/cm^3 have same swelling rate ratio of 1 when there is no NaCl in the solution. Bentonite densities refer to their swelled water. The heaviest sample (1.9 g/cm^3)sample is the driest bentonite. By adding first few amounts however swelling ability of all bentonites drop significantly. Lighter bentonites tend to show more drop compare to heavier. For instance bentonite weights 1.33 g/cm^3 reaches swelling ability of 0 when it is exposed to saturation of 4 mol/dm^3 NaCl. Decreasing trend also must be kept on mind. Based on their result slight increase in NaCl concentration causes huge drop in swelling ability of bentonite.

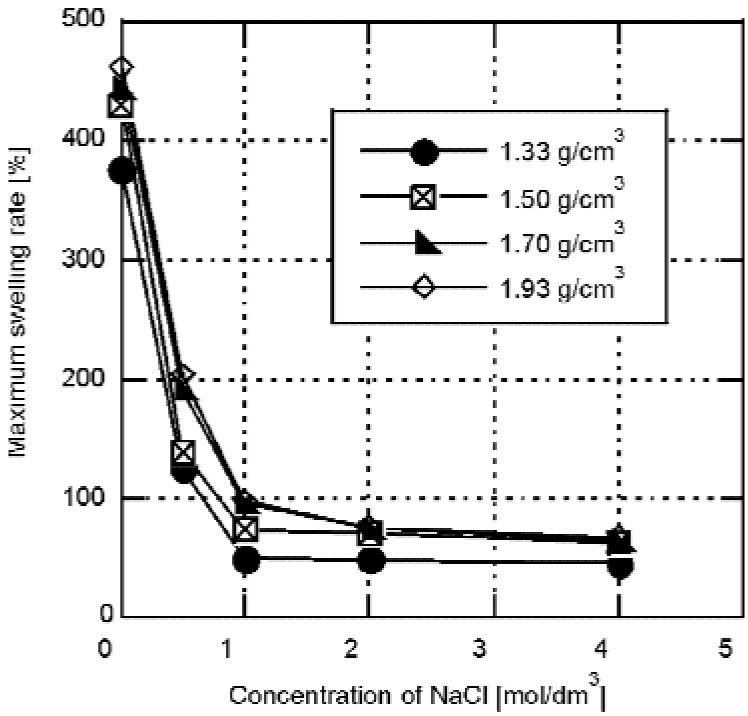

FIGURE 2.1 Max swelling rate vs NaCl concentration

Pressure Effect on Swelling Ability of Bentonite

On the other hand pressure plays very important role in boosting swelling capacity in presence of NaCl. As the experiment was conducted by Shirazi(2011) slight pressure increase up to 0.16 Kpa for 1.33 g/dm^3 bentonite would lead to 25% increase in swelling rate ratio. Similar results are applicable for other densities as well. Therefore in borehole where the pressure reaches 6000 Psia we can expect bentonite to perform very well.

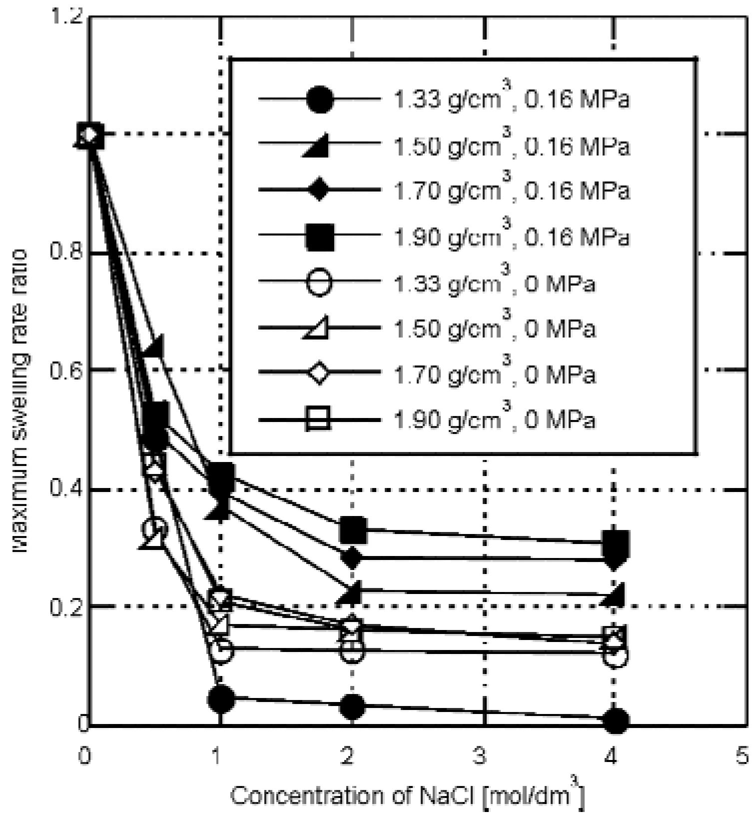

FIGURE 3.2 Swelling rate of bentonite under different pressures

Bentonite's Water Saturation Effect on Swelling Rate

On the other part of study conducted by Shirazi(2011) he has gone through checking the swelling rate of bentonite. There were two different parameters to control which were bentonite density and NaCl concentration. Based on results NaCl concentration did not have considerable effect on swelling rate of bentonite. All different types of mud could reach their maximum swelled volume together. On the density part results shows that lighter bentonites in term of density suddenly stop swelling when they reach their maximum capacity. Unlike low density bentonites, heavier bentonites start to reduce swelling rate as they approach their swelling limit.

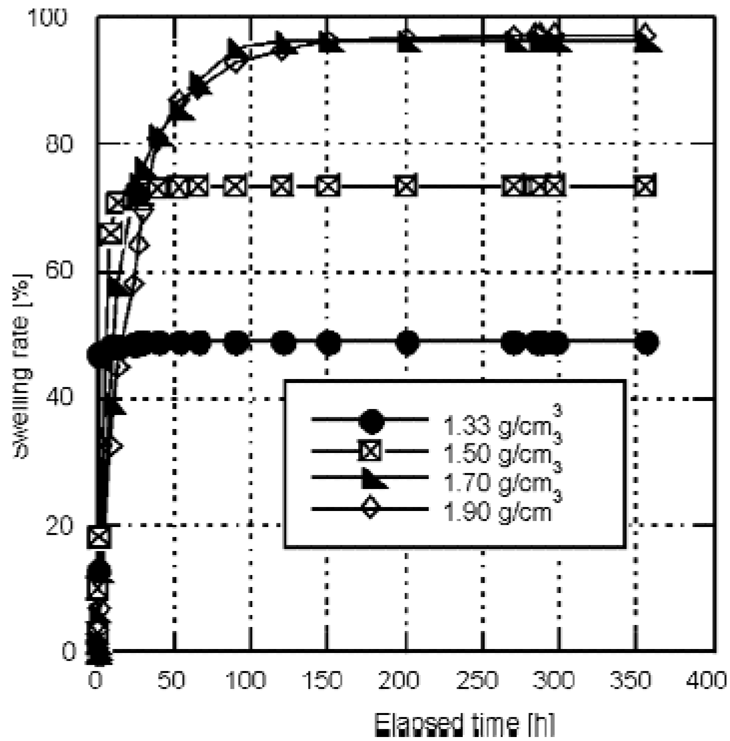

FIGURE 2.3 Swelling rate of bentonite with different densities

Bentonite's Swelling Rate

One of the most important part of his study, he has examined swelling ability by elapse of time. As it can be seen in following graph, bentonite keeps its swelling ability even after 100 hours being dumped in water. This can be a clear indication for bentonite's potential as a blocking agent. This means if we succeed in sending bentonite into porous earlier than 100 hours, there will be a great chance for bentonite to expand and restrict fluid movement in porous medium.

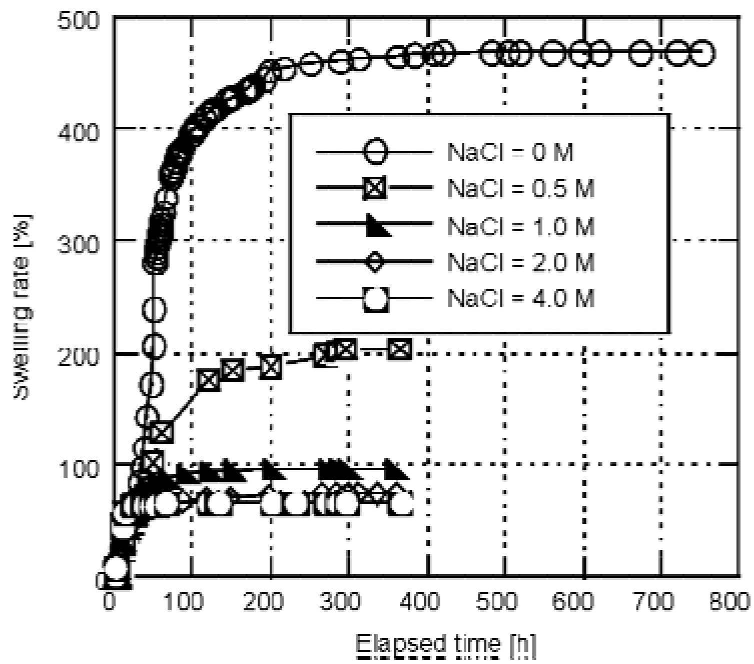

FIGURE 2.4 Swelling rate of bentonite in different concentration of NaCl

2.1.4 Structure of Bentonite

Bentonite grain has layered structure with thickness around 10 angstrom. Bentonite usually exists in form of flakes ranging from 0.01 micrometers to 10 microometers. This layered structure of bentonite is responsible for its ability to absorb large quantity of water. As it can be seen in following picture, water molecules and cathions can be absorbed into between these layers and causes bentonite to inflate. Bentonite has negative charges in surface which gives it ability to expand and absorb any polar fluids in large amount.

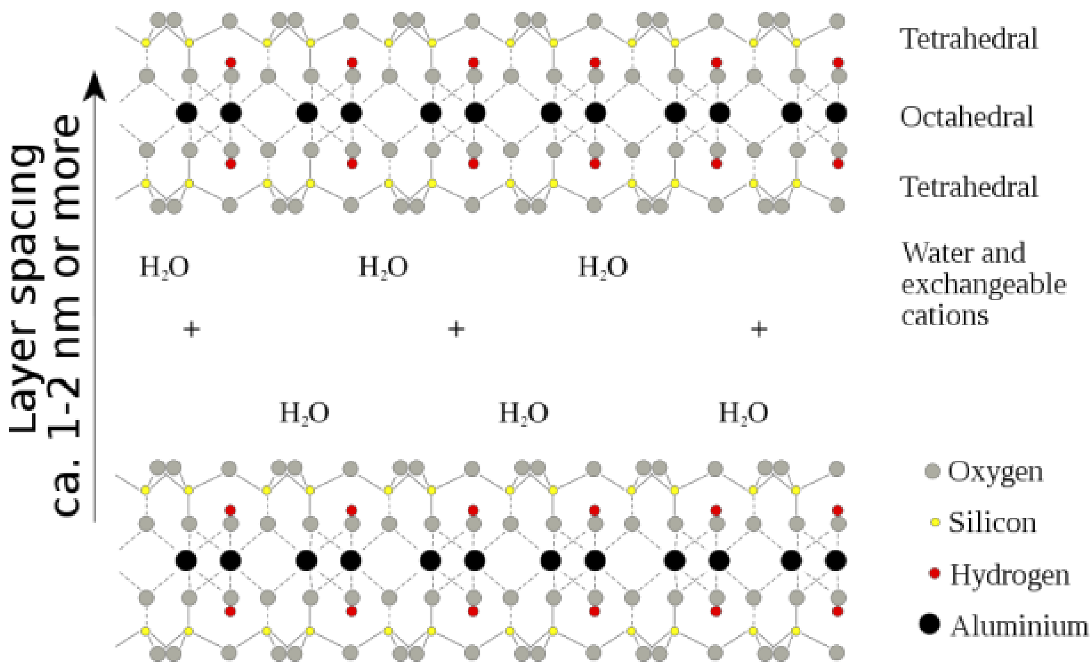

FIGURE 2.5 Bentonite’s structure in water

2.1.4 Effect of Grain Size on Properties of Bentonite

Based on research done on effect of bentonite’s particle size on its properties (Abdue, 2011), some properties of bentonite have high dependency on grain size. While properties such as swelling rate and capacity remains the same, rheological aspects of mud is being affected. Apparent viscosity is among the highest features of mud to be changed. In coarser grain samples grains tend to attach to each other and create colloid. This causes apparent viscosity of mud to increase.

2.2POLYMERS EFFECT ON BENTONITES PERFORMANCE

On the other research (Ghassem Alaskari, 2007) rheological effect of bentonite mud treated with two different polymer as additives has been examined. These two polymers are XC polymer and CMC polymer. Based on this research, salinity, pH and temperature modification has been examined on rheological and filtration performance of the drilling mud. pH increase shows to increase plastic viscosity. Intense plastic viscosity increase appears especially after 10.8.

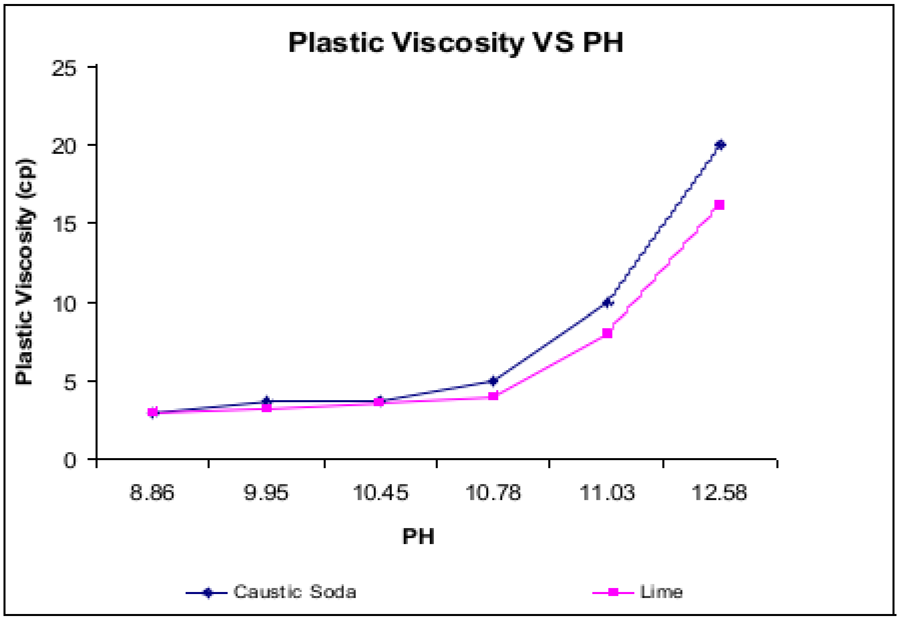

FIGURE 2.6 pH effects on Plastic viscosity in presence of lime and caustic soda

Plastic viscosity remains around 3cp till viscosity of 10.8. When pH is increased 11.5 viscosities reaches 12 cp. This trend is also applicable for yielding strength as well. Yield strength increment pace increases from 10.8. This all can be concluded that high pH will enhance rheological property of the mud. On the other hand salinity showed a negative effect on mud performance by reducing its swelling ability. Author has mentioned that a good attention requires for drilling with bentonite to avoid encountering salty formations. For temperature side, the results have been seen negatively as high temperature caused filtrate volume on wall to be decreased.

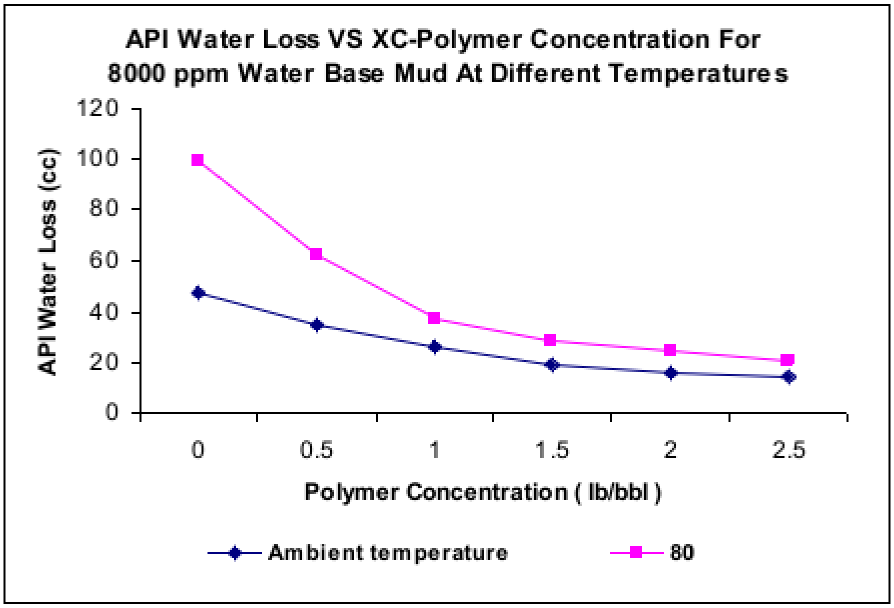

FIGURE 2.7 Polymer concentration effect on water loss

However this means that particles may have penetrated deep into formation. This result can be interpreted as positive point as the purpose of study is to reduce preamble formations. Nevertheless, temperature causes polymers to lose their performance and effectiveness.

As it was clear in mentioned experiments and researches bentonite mud reacts different under different pH, pressure, temperature and salinities. This limitation not only limits bentonite to small ranges of operation, it also increases the potential of failure in operations. For this reason researchers are more focusing on modifying bentonite by different methods such as heat treatment, ion exchange and polymer coating to enhance its features for better results. During treatments bentonite's features must be monitored to find and keep it on optimum performance.

2.3OPTIMUM CONDITION FOR HIGHEST PERCENTAGES OF SWELLING BEHAVIOR

On research done by Sansuri (2010) optimum percentage of bentonite and crosslinker polymer were investigated. Based on this research optimum percentage of bentonite in presence of N,N-methylenediacrylamide polymer was 1% wt. experiment with higher concentrations of bentonite showed decrease in overall swelling ability of bentonite. Even though higher amount of bentonite led to higher volume of swelled bentonite however this resulted in decrease in absorbing ability of bentonite.

2.4POLYMERS EFFECT ON BENTONITE'S RHEOLOGICAL BEHAVIOUR

In this research done by Heinz (2004) polymers were classified in two categories of positive charge and negative charge. By conducting different experiments, it was found that positive charges polymers have the lowest effect on rheological behavior of bentonite solutions. For example the following graphs show effect of positive and negative charge polymers on yielding points. Other experiments were also conducted to see effects of polymers on other properties of bentonite including gel strength and apparent viscosity. The results confirmed that negative charge polymers had significant effect on rheological properties of bentonite. These effects varied in scale and direction of effect.

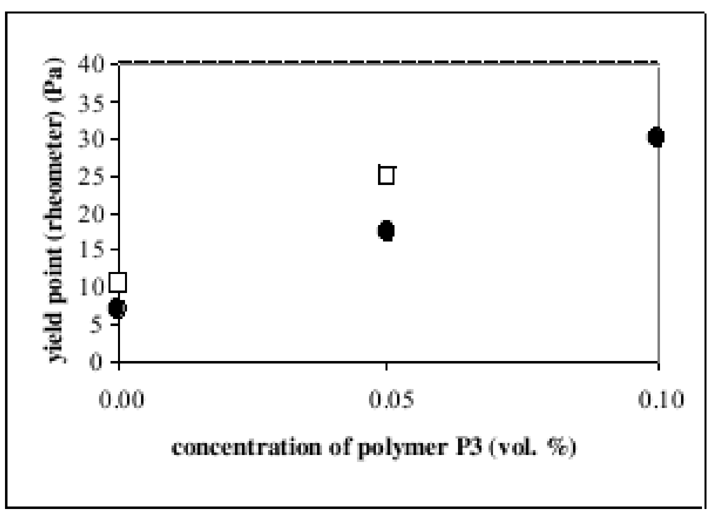

FIGURE 2.8 Polymer concentration effect on yield point

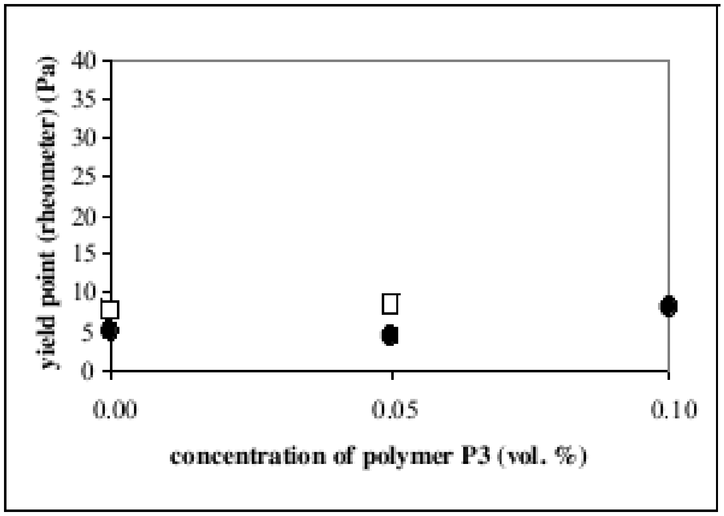

FIGURE 2.9 Polymer effect on yield point

2.4COMPARISON BETWEEN DIFFERENT BLOCKING AGENTS

In continue there will be a review on other blocking agents and their benefits and weaknesses. These agents include gels, particulates, precipitates, microorganisms, foams and emulsions. Based on conditions of reservoir different methods respond differently. On a study conducted on different blocking agents and their effectiveness. Seright took different variants to compare the result. These variants including injection pressure of agent, concentration of blocking agent, as well as nature of reservoir porous medium. The results support foam as blocking agent. He mentioned better results can be obtained for using it in unconsolidated reservoirs as well as non fractured ones. Blocking pressure tends to show slight deviation as injection pressure increases verses blocking pressure. This deviation however is negligible comparing to the results. This however shows that injection pressure plays very important role in effectiveness of blocking agent. This information further is endorsed by another study. Both authors (Hanssen 1993; Seright1995) by studying different cases could prove relationship between injection pressure and the effectiveness of treatment.

Another study (Pan, 2006) slag blocking agent has been tested for its performance. In this test silicon is used as core in slag. This study was conducted for operations with high temperature wells when they inject steam into the well. Therefore a great attention was paid for heat sustainability of the agent. Beside that wells studied had been exposed to high amount of steam injection which had caused water to appear in production. In some stages they received injection steam as well. This could be mean that the case is more about damaged wells. The main focus of study was more on suspension stability, injection characteristic, initial setting time, thickening process and setting strength. This in other word means playing with other parameters to get the optimum condition. Results confirmed its effectiveness when the produced liquid increased from 10.27 ton/day to 20.16 ton/day as well as reduction in water production from 94% to 75.5%.

2.4POLYMERS CHARACTERISTICS

Based on RSCC (RSCC Aerospace & Defense) big chain molecules like polymers can be linked to other molecule using different methods. Managing to make a cross linking bonds between adjacent chains can increase its stability against heat and other patterns (Chen, 2000). Practically it means to make more connections between two molecules. Recent researches by Jagadish and Vishalakshi (2012) shows that gel cross link with N-N'-methylenebisacrylamide (MBA) can show at least 5 times of swelling ability that might a gels with two cross linker have. Since in this study it's convenient for blocking agent to expand more and more, it is decided to use N-N'-methylenebisacrylamide cross linker.

2.5POLYMERIZATION

By definition (Jenkins, 1996) polymerization is a process in which monomer molecules react to create long chains polymer or 3D networks. Polymerization has different forms and types which can be categorized through different systems. For polymerization of bentonite there are several elements must present during the reactions which are initiator, cross linker and Acrylic Acid.

2.5.1 Initiator

Based on (Imai, 1991) initiator is source of any chemical that can react with monomers to create intermediate compound capable linking with other monomers to large polymers. The most commonly used initiators release free radicals (atoms with odd number of free electron which makes them reactive). The most well known initiators are including peroxides and aliphatic azo compounds. In another research (Hosseinzadeh, 2011) ammonium persulfate proved a reliable initiator in coating bentonite with polymer. In the same research effect of initiator concentration on swelling capacity of bentonite was investigated. Study showed there is an optimum concentration in which swelling capacity of bentonite can be maximized.

2.5.2 Cross linkers

By definition (Gent, 2001) cross-link is a link that connects two polymer chains together. They can be both covalent and ionic. Cross linking is usually practices to enhance physical properties polymer. Cross linking usually results in higher tolerance facing heat and pressure. To coat bentonite methylenebisacrylamide has shown acceptable performance in based on experiment done by Hosseinzadeh (2011). Methylenebisacrylamide due to its positive charge nature completely neutralize the negative charge in bentonite.

CHAPTER 3

METHODOLOGY

3.1 FLOW CHART

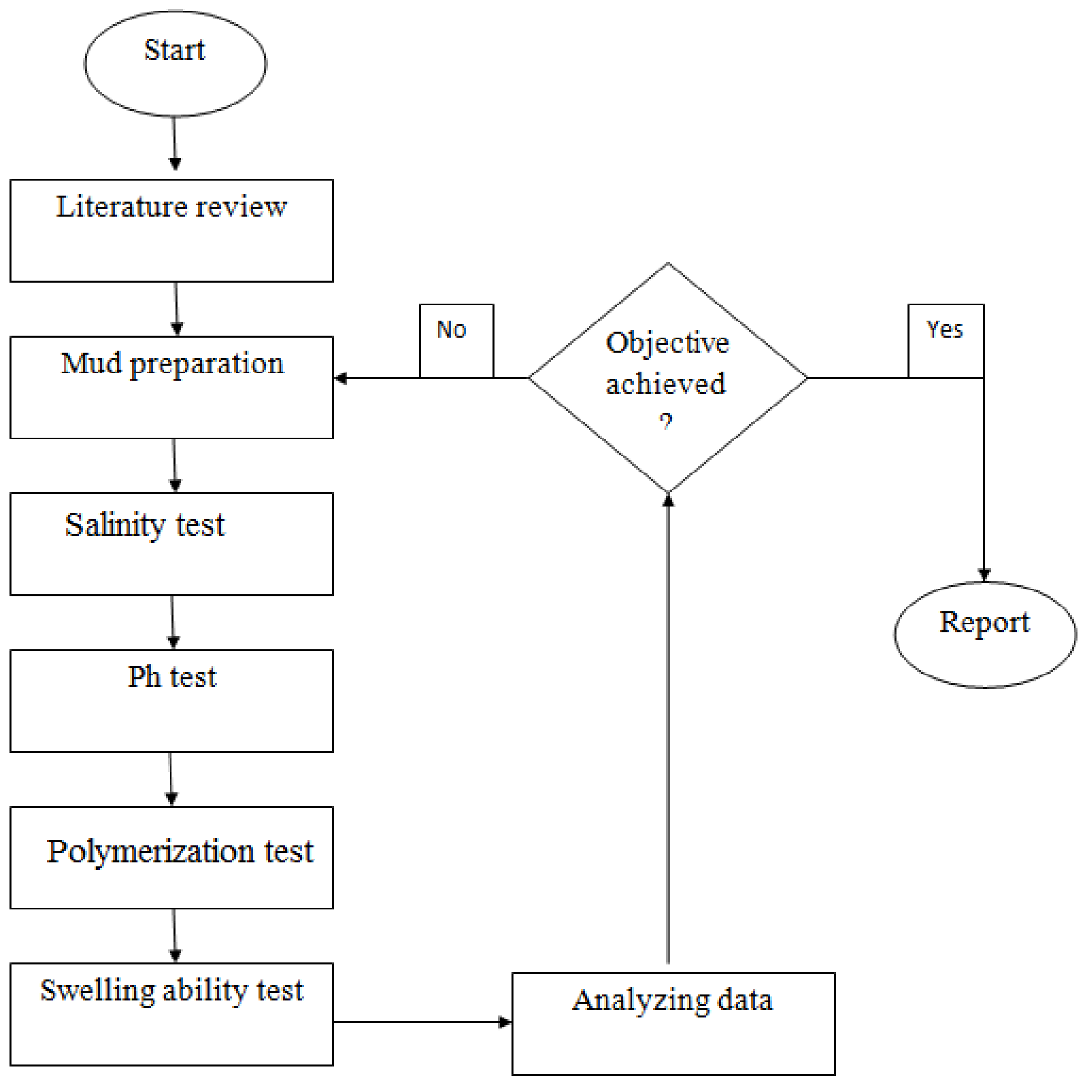

FIGURE 3.1flow chart

3.1.1 Flow Chart Break Down

- Start: Project begins
- Literature review: Relevant articles, book, and papers are being studied in order to gain a comprehensive knowledge about the problem and possible approaches. Relevant subjects are as follow:
  - Bentonite and its properties
  - Bentonite modifying methods
  - Blocking agents
  - Polymers and properties
- Mud preparation: Different types of polymers and surfactants with different concentration must be added to bentonite solution.
- Salinity test: Bentonite’s swelling capacity must be examined in different concentrations of cations.
- pH test: For each sample effect of pH test must be checked to find the optimum condition for modifying agents.
- Polymerization: coating bentonite with polymer must be done to find the optimum concentrations for initiator and MBA.
- Swelling ability test: Swelling ability of bentonite changes by modifications and different conditions. Swelling ability of mud must be checked with presence of calcium and magnesium ions.

3.3 EXPERIMENT METHODOLOGY

3.3.1 Proposed Experiment Procedure

Bentonite's swelling index vs salinity

To measure bentonite's swelling rate in different concentrations of cation high concentration (20% w/w) of KCl, must be prepared. 80 grams of KCl must be added to 320 ml of distilled water. Another solution with same procedure must be prepared for NaCl again.

Next by using balance 0.3 grams of KCl must be dumped into a container. After that distilled water has to be added to container till the solution reach 120 grams. Next, using a 100 ml measuring cylinder 100 ml of the solution has to be transferred to measuring cylinder. Solution in measuring cylinder is 100 ml of 0.05% w/w KCl. To prepare solution with different concentrations follow the same procedure with following weights. The tables for different concentrations are being provided in appendix.

TABLE 3.1 additive's weight for KCl samples

Solution	Weight of KCl to be dumped into container (g)	Weight of NaCl to be dumped into container (g)
KCl 0.05% w/w, NaCl 0 % w/w	0.3	0
KCl 0.5% w/w, NaCl 0 % w/w	3	0
KCl 1% w/w, NaCl 0 % w/w	6	0
KCl 1.5% w/w, NaCl 0 % w/w	9	0
KCl 2% w/w, NaCl 0 % w/w	12	0
KCl 2.5% w/w, NaCl 0 % w/w	15	0
KCl 3% w/w, NaCl 0 % w/w	18	0

When the seven samples are ready, 2 grams of bentonite must be added to each sample. These 2 grams must be added bit by bit. After each time enough time must be given to bentonite to swell and settle in measuring cylinder. After transferring all bentonite into cylinders, samples must remain for 24 hours for reading the volume. The whole procedure done for KCl must be repeated with $MgCl_2$ and $CaCl_2$.

Bentonite's Swelling Rate vs pH

To measure bentonite's swelling rate in different pH, 10 samples of solutions with different pH must be prepared. The followings are procedure to prepare solutions with pH of 2, 4, 5, 7, 8, 9, 10, 11, 12 and 13. The same set of samples also should be prepared in presence of 0.5 and 1 % w/w NaCl.

For pH=2, 10 ml of HCl 1 mol/lit should be dumped in beaker and then it should be filled till 1 lit by distilled water. 100 ml of this solution has to be displaced to measuring cylinder for nest step. To prepare other sets of samples refer to the following table. The second column of table refers to volume of prepared solution with ph of 2 which must be transferred to measuring cylinders.

TABLE 3.2 additive's weight for pH test for acidic solutions

PH	Volume of solution to be transferred (ml)
2	100
4	1
5	0.1

After transferring specified amounts of solutions to measuring cylinders, they must be filled with distilled water up to 100 ml.

For solution with ph equal to 7, 100 ml of distilled water can be added to measuring cylinder.

For alkaline solutions NaOH must be used. First 1 liter of ph=13 using NaOH has to be prepared. To do so, 5.844 g of NaOH must be dumped into a beaker and by using distilled water it must be raised up to 1 liter. Using magnetic stirrer the solution has to be mixed properly. Afterward 100 ml of the solution must be transferred to measuring cylinder.

Then using remaining prepared solution other samples can be prepared. Referring to the following table volume of solution needed to prepare the rest of samples can be found.

TABLE 3.3 additive’s weight for pH test for alkaline solutions

pH	Volume of solution to be transferred (ml)
13	100
12	10
11	1
10	0.1
9	0.01
8	0.001

After transferring required volumes of solution to measuring cylinders, levels of solutions can be raised to 100ml using distilled water.

Similar sets of samples for both acidic and alkaline with same pHs must be prepared. This time in addition to additive for pH, similar steps for salinity tests must be taken to create same sets of samples with salinities of NaCl 0.5% w/w and NaCl 1% w/w.

Next, pre weighted 2grams bentonites must be added bit by bit to the measuring cylinders. This should be in a way that bentonite’s grains get enough time to swell before dropping the next bit.

Bentonite’s Swelling Rate vs temperature

Similar to salinity experiment using distilled water 5 measuring cylinder must be filled and then 2 grams of bentonite have to be added in similar manner to each measuring cylinder. Then, samples have to be placed in following temperatures: 25, 50, 55, 70 and 80℃.

After 24 hours reading must be done in order to measure its swelling.

Polymerized Bentonite’s Swelling rate

An Initially 1.7 gram of Polymer which is equal to 0.1 mol polymer were added to 100 ml of water and was stirred by magnetic stirrer for 20 minutes to dissolve in water properly. During solving the polymer the temperature should be set on 60℃. After polymer has to be dissolved completely in solution, amount of 0.05 gram of initiator *ammonium persulfate* which is equal to X mol has to be added bit by bit to the dissolved polymer. During this dumping temperature should be increased up to 80 ℃. amount of 0.08 gram of MBA which is equal to 0.02 mol also was added respectively. Then a prepared 10grams of bentonite which was added to distilled water before has to be dumped into the solution. Then the solution must be transferred to oven to be dehydrated properly. When it is completely dried they should be turned to powder and then be divided to 2 grams sets. Then they must be added to solutions with 0.05, 0.5, 1, 1.5, 2, 2.5, 3 w/w solutions with the same procedure as mentioned for salinity test. Then after 24 hours sweilling rate of modified bentonite should be measured.

3.4 PROJECT ACTIVITIES

As this project involves lab experiments there are number of skills which must be learnt prior to conducting the experiments. These skills include ability to work with rheological test kit and other ordinary skills such as measuring pH and temperature and working with lab's apertures.

3.5 KEY MILESTONE

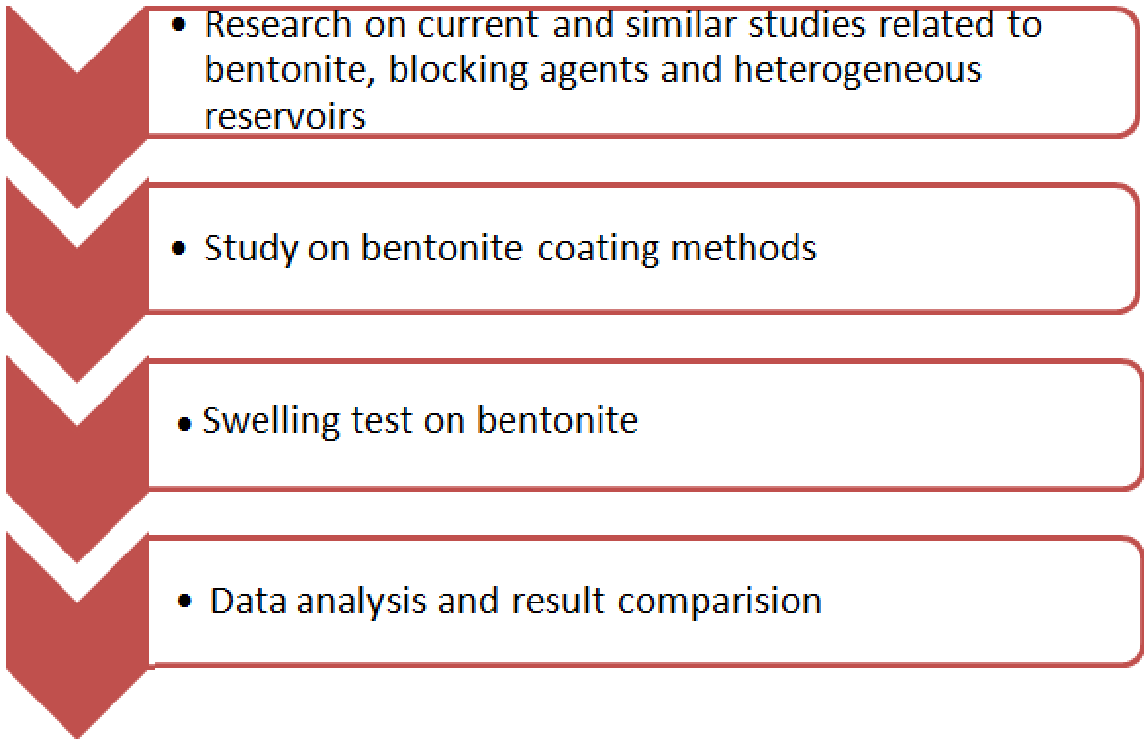

FIGURE 3.2 key milestone

3.6 TIMELINE

Table1_FYP1_Gannt chart

TABLE 3.4Gannt chart FYP1

Task / Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Topic Selection & Allocation - Propose new topic related to Internship project - Meet Super Visor														
Preliminary Research Work - Data Gathering - Literature review														
Extended Proposal Submission - Submission of Extended proposal to SV														
Proposal Defence - Preparation for presentation - Proposal defence														
Data review & literature review - Study daily studies on blocking agents, rheological features bentonite and treated bentonite														
Interim Report draft submission														
Interim Report Submission														

Proposal defense

Report Submissions

TABLE 2.5 Gannt chart FYP2

Task / Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Raw Data Study - Swelling ability of bentonite index - Swelling ability of modified bentonite														
Literature review - Read articles about: o Effect of polymer on swelling ability of bentonite o Effect of surfactant on swelling ability of bentonite														
Submission of Progress Report							●							
Data analysis - Discuss ways to optimize modified bentonite's properties														
Pre-SEDEX										●				
Submission of Draft Final Report											●			
Submission of Dissertation												●		
Submission of Technical Paper												●		
Viva													●	
Submission of Project Dissertation (Hard Bound)														●

● **University Dates**

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 KCL'S EFFECT IN PRESENCE OF NACL ON BENTONITE

In swelling test, different concentrations of ions were added to solution to observe their effect on swelling ability of bentonite. NaCl however was selected as constant salt in all samples as the most common composition exist in reservoir waters. For first study potassium ion (K+) was selected. For the first trial swelling test was conducted on K+ ion alone while concentration of NaCl was kept 0. Seven different concentrations including 0.05 % w/w, 0. 5 % w/w, 1 % w/w, 1. 5 % w/w, 2 % w/w, 2. 5 % w/w and 3 % w/w were selected and results are shown in the following graph.

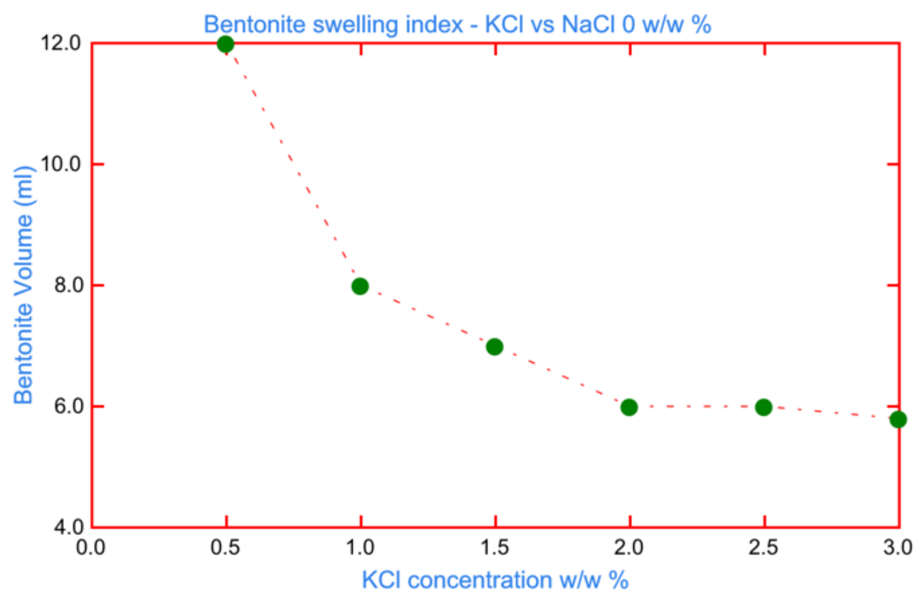

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FIGURE 4.1 KCl effect on bentonite's swelling ability while NaCl is 0%

As it can be observed on the graph in low concentration of KCl (0. 5 % w/w) bentonite swells up to 12 ml which is relatively high swelling ability. As it moves to higher concentrations swelling ability drops. Slope of graph indicates swelling ability is very sensitive in very low concentrations. This means small changes in KCl concentration results in high volume change. As it moves to higher concentrations the difference in swelling ability is difficult be observed. In last three samples the difference in volume is only 0.25 ml while difference in concentration is about 1.5% w/w.

For the next trial all measuring cylinders were filled by the same KCl concentrations with this exception that this time they all contained 0.5% w/w of NaCl.

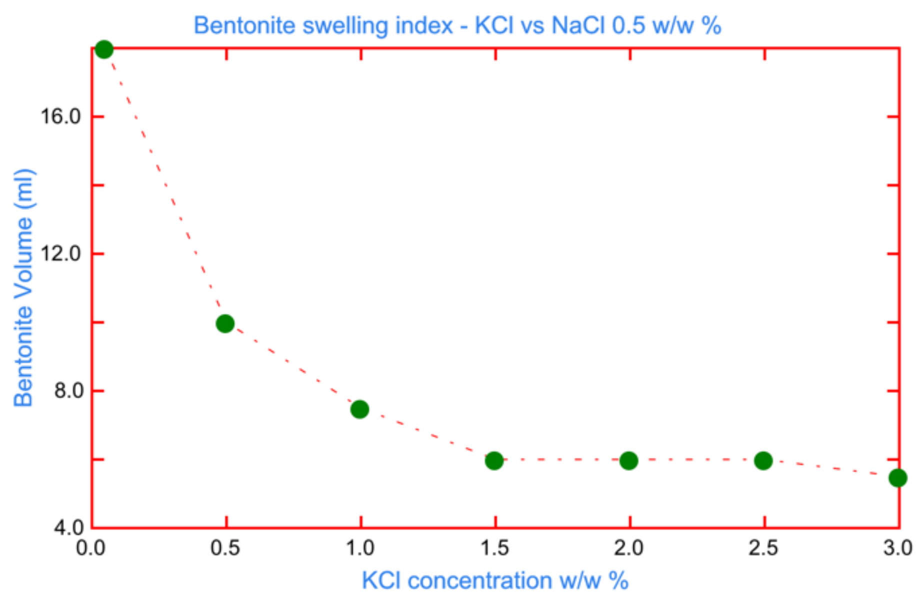

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FIGURE 4.2 KCl effect on bentonite's swelling ability while NaCl is 0.5%

This amount of NaCl affects the swelling behavior of bentonite from beginning. Amount of 0.05 % w/w KCl in presence of 0.5% NaCl reduces swelling rate to 18 ml. for next sample the swelling rate reaches 10ml. this volume compare to its equivalent in first set is being dropped by 2ml. the whole 7 samples keep swelling rate below its equivalent in first set which NaCl concentration were 0. Despite of this difference the whole curve keeps its trend with a sharp slope at the beginning and smoother slope as concentration increases. In this set however the curve starts from lower inflation volume and reaches its stable swelling rate at concentration of 1.5 %w/w. even though at concentration of 3% w/w drops to 5.75 but it takes increase of 1.5% w/w in KCl concentration to create this 0.25ml difference.

The next examined set was 1%w/w NaCl solution which had results as it was predicted. Initial swelling rate started at lower point compare to its predecessor. It started with 13.75 ml. like previous graph the curve keeps its trend which is starting with sharp slope and ending with smoother slope at the end.

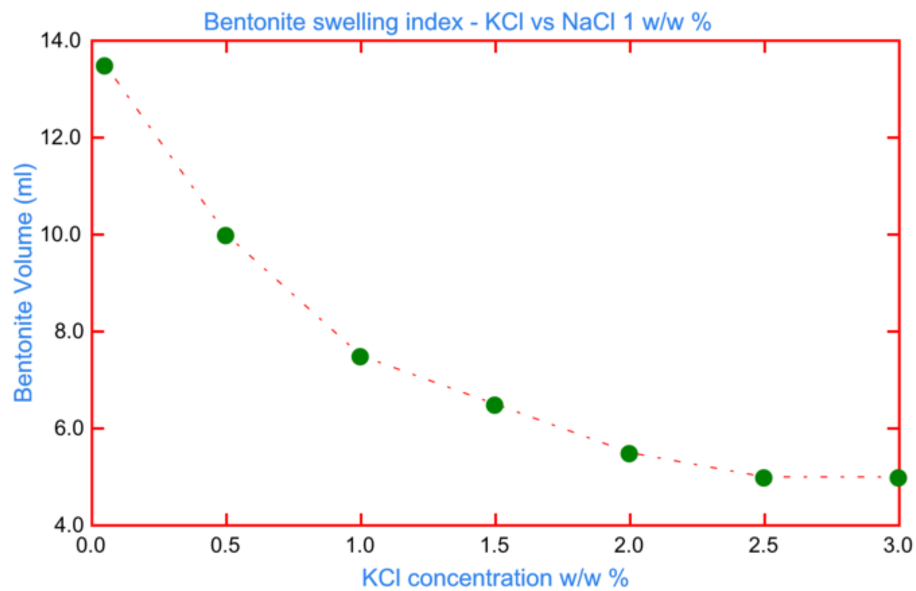

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FIGURE 4.3 KCl effect on bentonite's swelling ability while NaCl is 1%

Even though initial points in each set start with noticeable difference in swelling rates but the final points end up with small differences.

After third set, graphs lose their curvy shape and become closer to straight lines but overall features of curves were similar. As it can be viewed in following graph the sharp slope at the beginning is replaced by a smoother line.

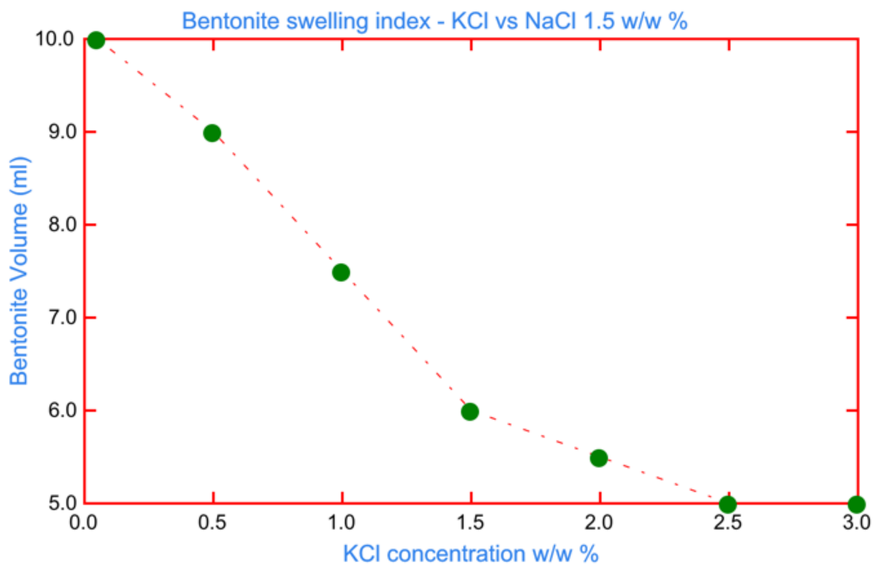

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FIGURE 4.4 KCl effect on bentonite's swelling ability while NaCl is 1.5%

The following graphs are showing the remaining sets of experiment with the same expected results

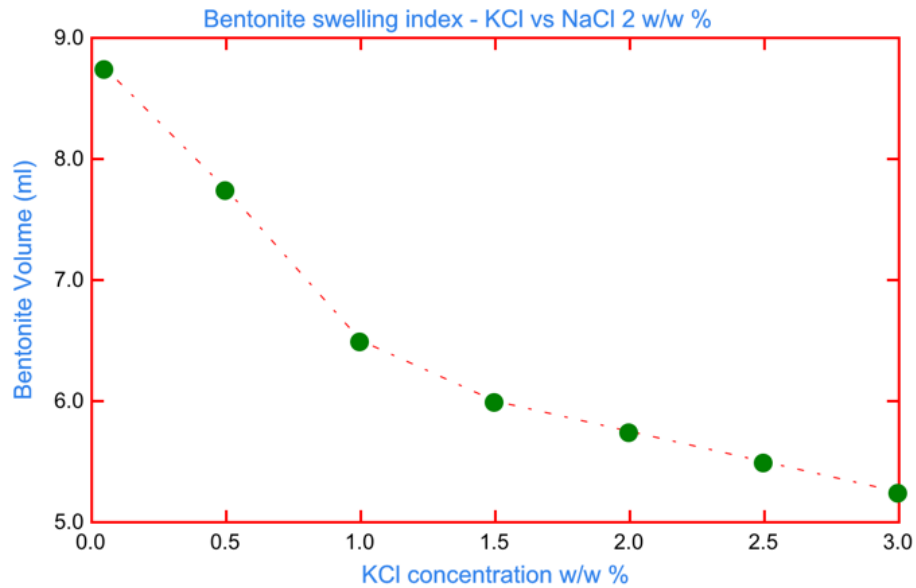

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FIGURE 4.5 KCl effect on bentonite's swelling ability while NaCl is 2%

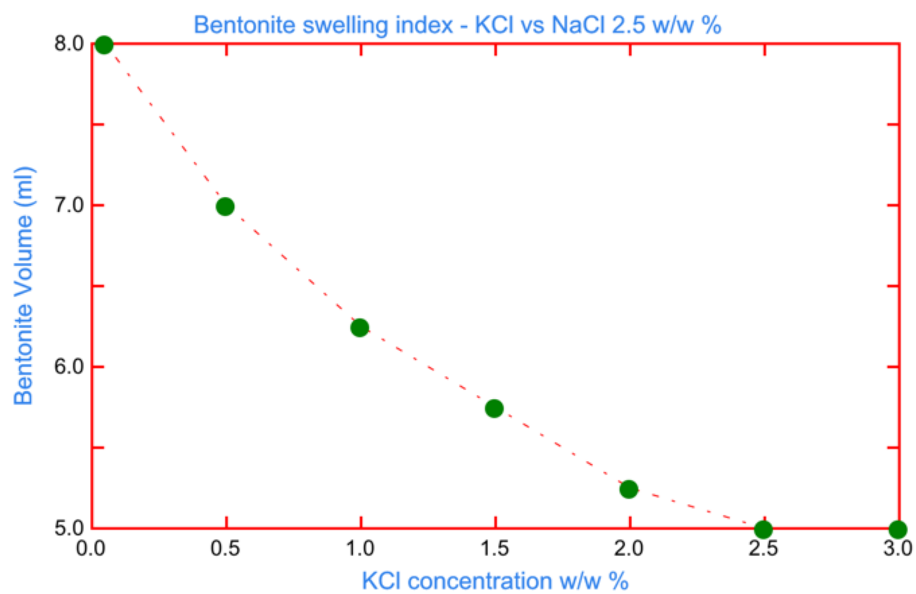

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FIGURE 4.6 KCl effect on bentonite's swelling ability while NaCl is 2.5%

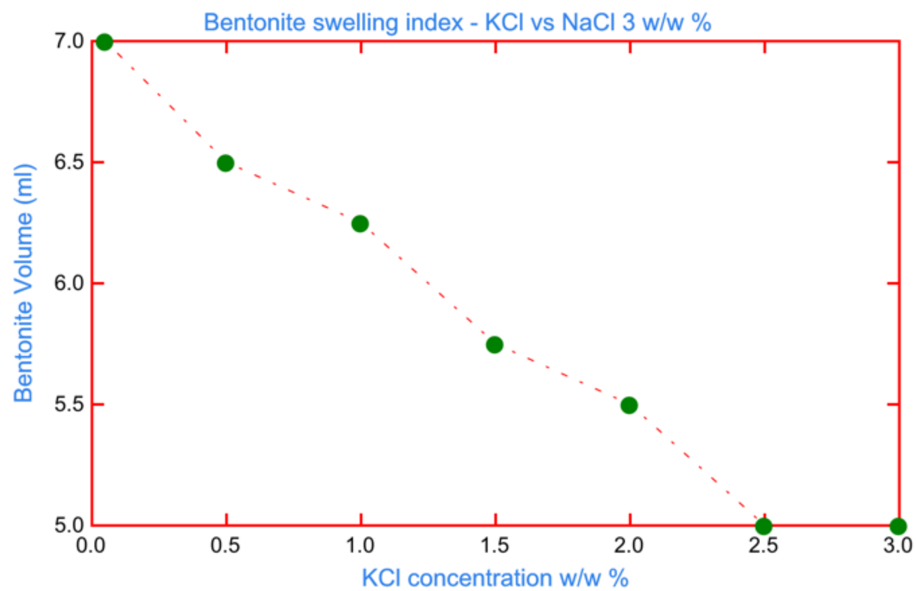

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FIGURE 4.7 KCl effect on bentonite's swelling ability while NaCl is 3%

In 3% w/w KCl solution the curvy shape of graph has been disappeared and it becomes a straight line. This behavior also can be seen in 3.5% KCl set.

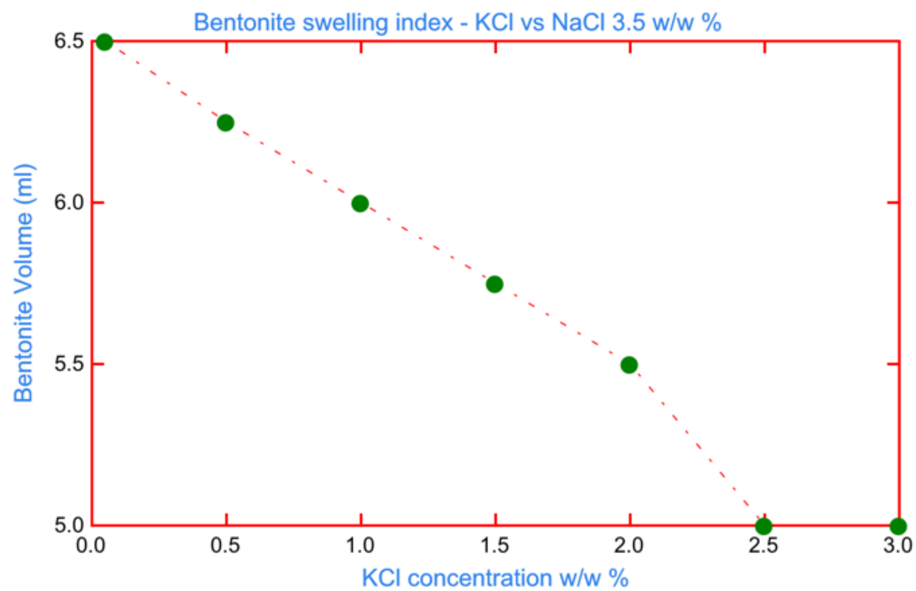

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FIGURE 4.8 KCl effect on bentonite's swelling ability while NaCl is 3.5%

To have a clearer picture of all above graphs and compare swelling rates of each set the following graph was produced.

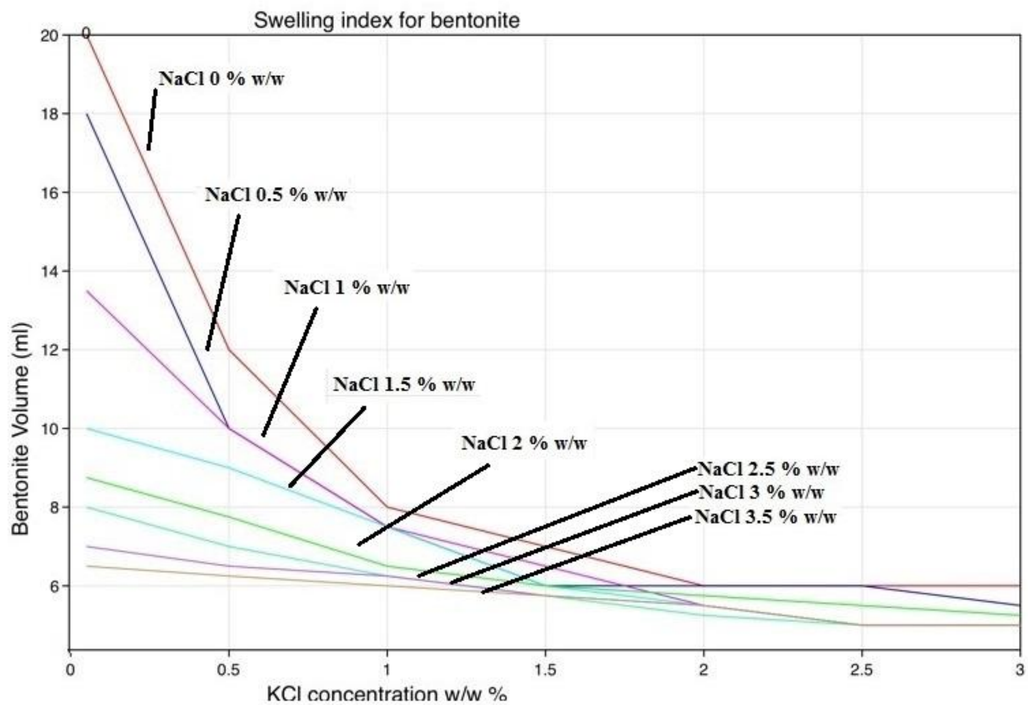

FIGURE 4.9 Comparison graph between different concentrations of NaCl

As it can be observed in this cumulative graph the whole samples roughly follow a systematic order. Every sample set with higher concentration of NaCl lies below the lower concentrated solutions. On the other side of graph it can be seen that all curves narrow around 6 ml. these all graphs indicate that swelling rate of bentonite is highly dependent on salinity of solutions. This sensitivity is high at low concentrations.

4.2 MGCL2'S EFFECT IN PRESENCE OF NACL ON BENTONITE

Similar to previous experiment, another set of solution sample consisting of different concentrations of $MgCl_2$ and $NaCl$. Separate results in form of graphs are provided in Appendix.

To compare the results properly cumulative graph was prepared accordingly similar to KCl. As it can be seen in this graph, similar trend compare to KCl can be observed. For $MgCl_2$, however bentonite reaches its minimum swelling capacity much earlier than KCl. For $MgCl_2$ at weight percentage of 1 % w/w or more, capacity is being pushed to almost 6 ml only. Considering initial volume of 2.5 ml for 2 grams of bentonite, it gives swelling rate of 2.4.

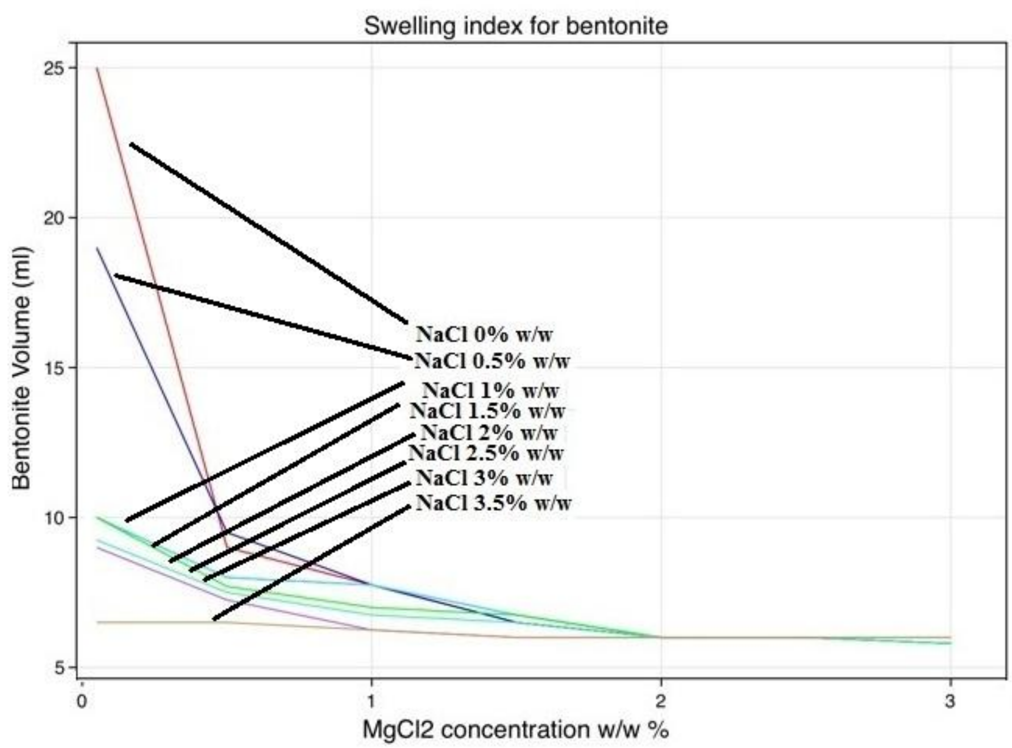

FIGURE 4.10 Comparison graph between different concentrations of MgCl2

4.3 CACL2'S EFFECT IN PRESENCE OF NACL ON BENTONITE

Similar to previous experiment, another set of solution sample consisting of different concentrations of $CaCl_2$ and $NaCl$. Separate results in form of graphs are provided in Appendix.

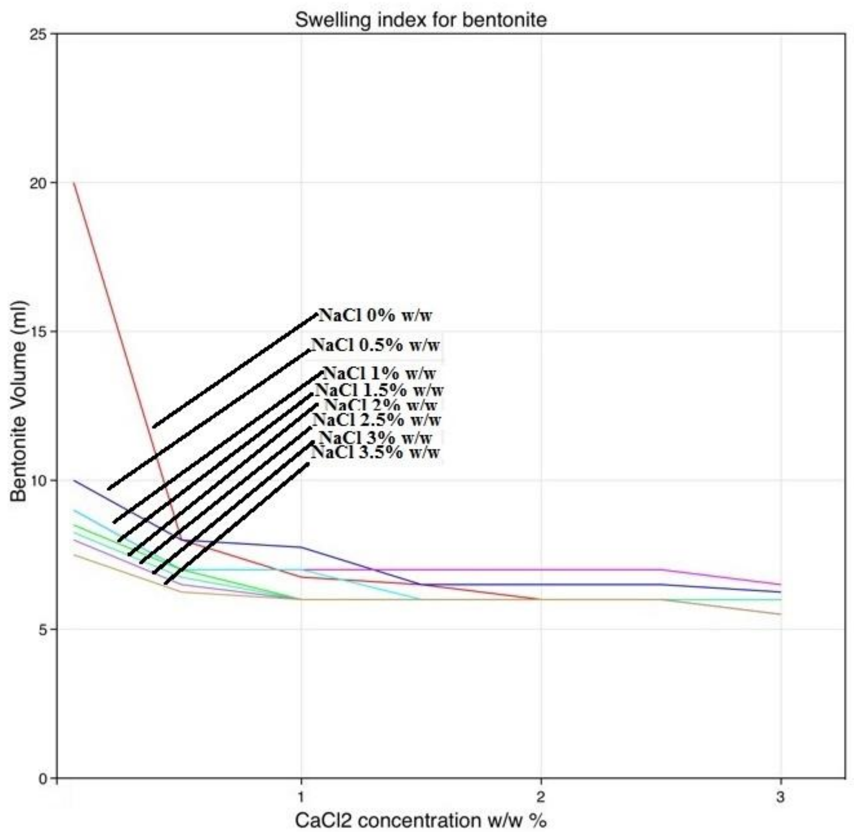

FIGURE 4.11 Comparison graph between different concentrations of CaCl2

Compare to two other cations Ca^{+2} show stronger effect on swelling behavior of bentonite. As it can be seen in the graph, except for 0.05 % w/w $CaCl_2$, 0 % w/w $NaCl$ which swells up to 20 ml of water, the rest of samples barely can swell up to 10 ml. For Ca^{+2} minimum swelling of 2.4 is being achieved with concentration of 0.05 % w/w.

4.4 PH EFFECT IN PRESENCE OF NACL ON BENTONITE

Results acquired from experiment shows swelling capacity of bentonite are highly dependent on pH level of solution. As it can be seen in the following graph all sets of samples roughly follow the same trend. Experiment proved acidic fluids can't affect swelling capacity of bentonite very much. In very extreme acidic solution (pH<4) however smoothly begins to affect it. Bentonite reaches one of its local maximums at pH=7 where there is neutral water. By increasing pH of neutral water the capacity begins to decrease until it reaches its minimum in 8<pH<10. The second climax can be reached in pH=12. As it can be observed in the graph for solution with NaCl 0 % w/w bentonite swells up to 25 ml. afterward increasing alkalinity of the solution has negative effect on swelling ability of bentonite. As it can be seen in the graph, for NaCl 0% w/w in pH higher than 12 swelling ability reduce to 12 ml.

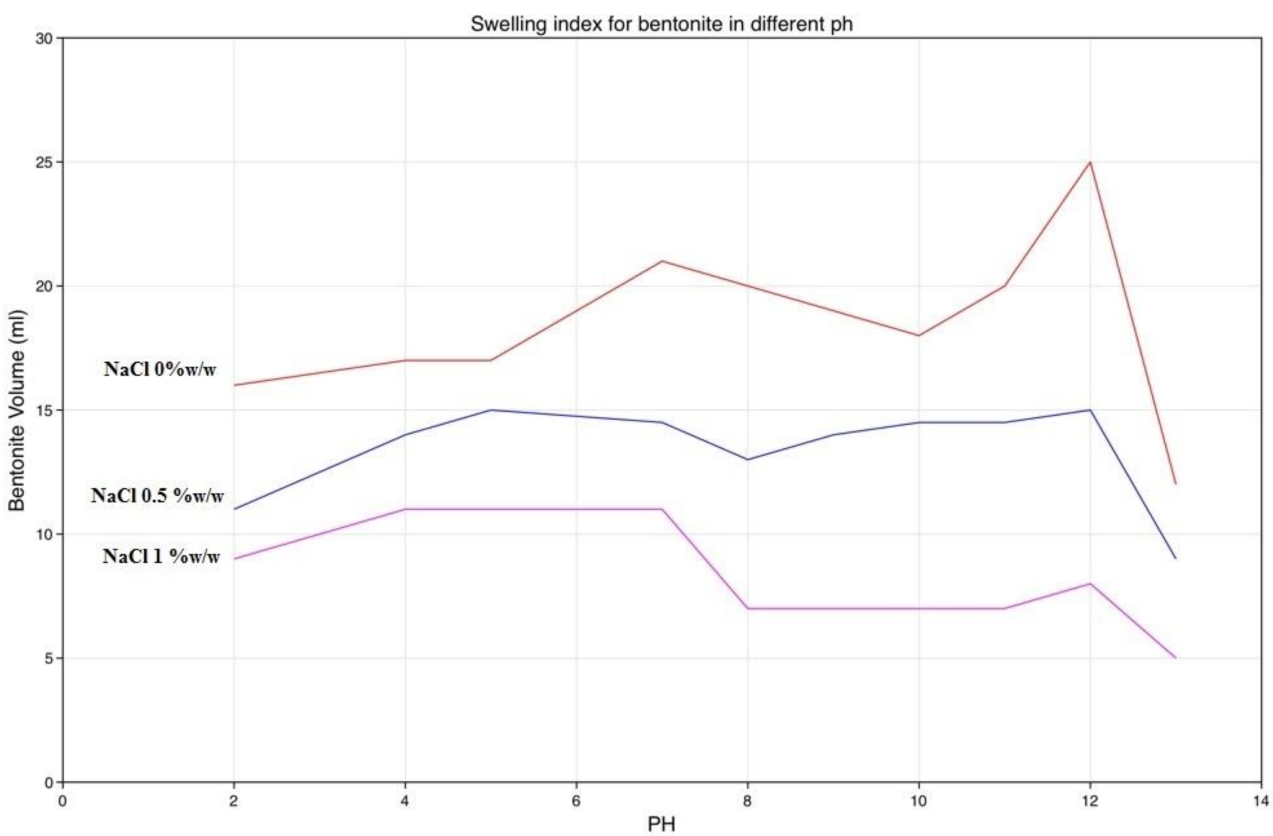

FIGURE 4.12 Swelling index vs pH

4.5 TEMPRATURE EFFECT IN PRESENCE OF NACL ON BENTONITE

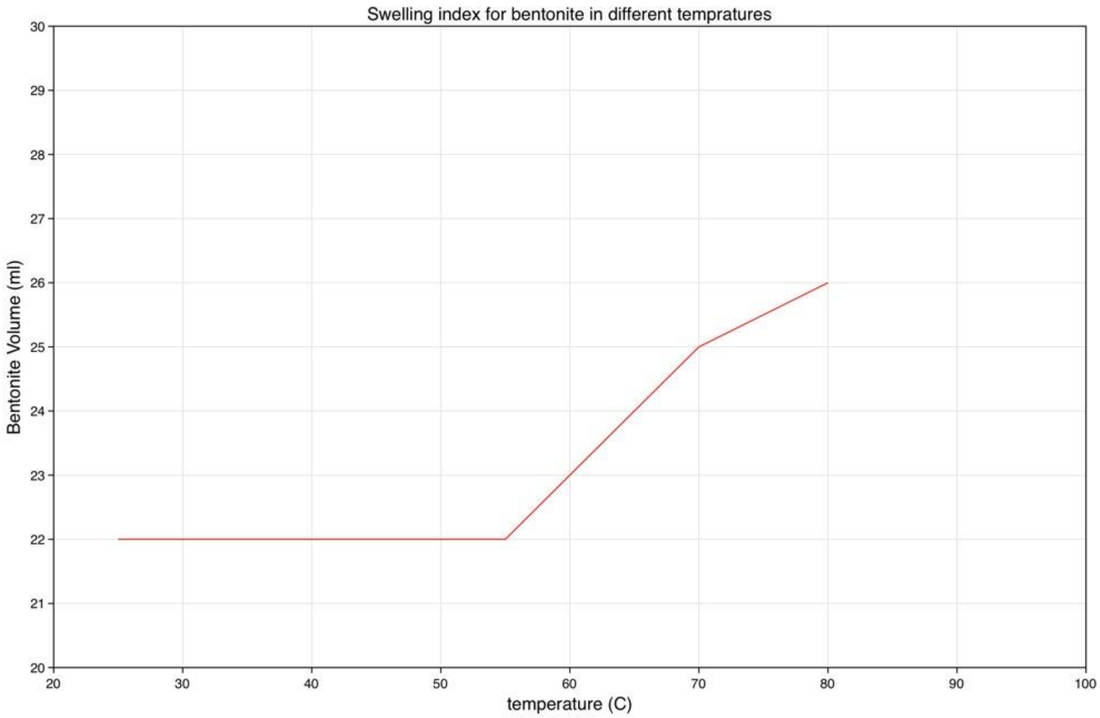

FIGURE 4.13 Swelling index vs Temperature

Based on results obtained from experiment with temperature as variable, it is clear that temperature has positive effect on swelling capability of bentonite. in low temperatures (25℃ to 55℃) temperature shows no or little effect, but when it increases more than that it begins to show its effects. By omparison it can be said that from 60 ℃ onward for each 10C increase in temperature, it results in 15% increase in volume.

4.6 POLYMERIZATION EFFECT ON SWELLING RATE OF BENTONITE

Based on results which were acquired from polymerization test, polymerization has significant effect on swelling ability of bentonite. As it can be observed in the following graph in low concentrations of KCl polymer has negative effect on swelling ability of bentonite. Based on the graph in concentration of 0.05 % w/w KCl conventional bentonite can swell up to 18 ml while for modified bentonite it reduces to 14 ml. this decrease continues until it concentration of 1% w/w KCl. At this point both types of bentonite's reach their limits however this time swelling ability of modified bentonite is higher at 7 ml. this shows at high concentrations of salts modified bentonite performs better. In fact this can be interpreted as a positive result because it is unlikely to find a reservoir aquifer with low salinity.

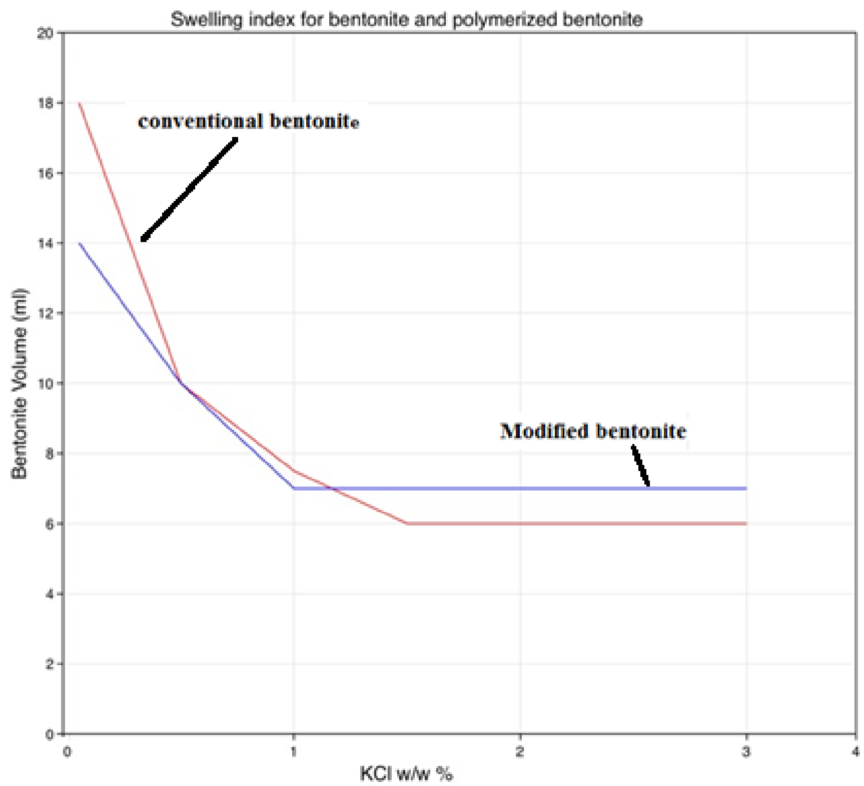

FIGURE 4.14 Swelling index of conventional bentonite vs modified bentonite

CHAPTER 5

SUMMARY OF PROJECT PROGRESS AND FUTURE WORK

After gathering and analyzing relevant data, general form bentonite's reactions to different conditions have been clarified. Now it is apparent that bentonite can swell even after 100 hours of being exposed to water. This fact allows bentonite to be used for long distance targets. Despite of this fact that salinity level affects swelling capacity of bentonite, but in high concentrations swelling rate stabilizes. Moreover temperature showed to have positive effect on bentonite's swelling ability. In high temperatures bentonite's swelling ability increases. pH also is another parameter that can affect swelling rate of bentonite. Two optimum points around pH=12 and pH=7 show to have maximum swelling capacities in pH range. This means injecting fluid can be designed in a way that can reach optimum pH when it reaches the target point. Modified bentonite with polymer also proved to swell more than conventional bentonite in high concentration salty solutions. This proved the modified bentonite has potential to be used as blocking agent.

Other studies show every blocking agent behaves different based on type of reservoir's situation (Seright, 1995). Some agents tend to perform better in unconsolidated reservoirs, while other agents such as foams perform better in presence of probing gas. Based on this fact, it is recommended for future studies to check the results under different reservoir situations. Core flooding experiment also can simulate real reservoir condition in lab. It is highly recommended for future works to optimize bentonite mud in core flooding experiment to assure its effectiveness.

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APPENDIX 1

TABLE A.1.1 additive's weight for KCl samples NaCl 0.5%w/w

Solution	Weight of KCl to be dumped into container (g)	Weight of NaCl to be dumped into container (g)
KCl 0.05% w/w, NaCl 0.5 % w/w	0.3	3
KCl 0.5% w/w, NaCl 0.5 % w/w	3	3
KCl 1% w/w, NaCl 0.5 % w/w	6	3
KCl 1.5% w/w, NaCl 0.5 % w/w	9	3
KCl 2% w/w, NaCl 0.5 % w/w	12	3
KCl 2.5% w/w, NaCl 0.5 % w/w	15	3
KCl 3% w/w, NaCl 0.5 % w/w	18	3

TABLE A.1.2 additive's weight for KCl samples NaCl 1% w/w

Solution	Weight of KCl to be dumped into container (g)	Weight of NaCl to be dumped into container (g)
KCl 0.05% w/w, NaCl 1 % w/w	0.3	6
KCl 0.5% w/w, NaCl 1 % w/w	3	6
KCl 1% w/w, NaCl 1 % w/w	6	6
KCl 1.5% w/w, NaCl 1 % w/w	9	6
KCl 2% w/w, NaCl 1 % w/w	12	6
KCl 2.5% w/w, NaCl 1 % w/w	15	6
KCl 3% w/w, NaCl 1 % w/w	18	6

TABLE A.1.3 additive's weight for KCl samples NaCl 1.5% w/w

Solution	Weight of KCl to be dumped into container (g)	Weight of NaCl to be dumped into container (g)
KCl 0.05% w/w, NaCl 1.5 % w/w	0.3	9
KCl 0.5% w/w, NaCl 1.5 % w/w	3	9
KCl 1% w/w, NaCl 1.5 % w/w	6	9
KCl 1.5% w/w, NaCl 1.5 % w/w	9	9
KCl 2% w/w, NaCl 1.5 % w/w	12	9
KCl 2.5% w/w, NaCl 1.5 % w/w	15	9
KCl 3% w/w, NaCl 1.5 % w/w	18	9

TABLE A.1.4 additive's weight for KCl samples NaCl 2% w/w

Solution	Weight of KCl to be dumped into container (g)	Weight of NaCl to be dumped into container (g)
KCl 0.05% w/w, NaCl 2 % w/w	0.3	12
KCl 0.5% w/w, NaCl 2 % w/w	3	12
KCl 1% w/w, NaCl 2 % w/w	6	12
KCl 1.5% w/w, NaCl 2 % w/w	9	12
KCl 2% w/w, NaCl 2 % w/w	12	12
KCl 2.5% w/w, NaCl 2 % w/w	15	12
KCl 3% w/w, NaCl 2 % w/w	18	12

TABLE A.1.5 additive's weight for KCl samples NaCl 2.5% w/w

Solution	Weight of KCl to be dumped into container (g)	Weight of NaCl to be dumped into container (g)
KCl 0.05% w/w, NaCl 2.5 % w/w	0.3	15
KCl 0.5% w/w, NaCl 2.5 % w/w	3	15
KCl 1% w/w, NaCl 2.5 % w/w	6	15
KCl 1.5% w/w, NaCl 2.5 % w/w	9	15
KCl 2% w/w, NaCl 2.5 % w/w	12	15
KCl 2.5% w/w, NaCl 2.5 % w/w	15	15
KCl 3% w/w, NaCl 2.5 % w/w	18	15

TABLE A.1.6 additive's weight for KCl samples NaCl 3%w/w

Solution	Weight of KCl to be dumped into container (g)	Weight of NaCl to be dumped into container (g)
KCl 0.05% w/w, NaCl 3 % w/w	0.3	18
KCl 0.5% w/w, NaCl 3 % w/w	3	18
KCl 1% w/w, NaCl 3 % w/w	6	18
KCl 1.5% w/w, NaCl 3 % w/w	9	18
KCl 2% w/w, NaCl 3 % w/w	12	18
KCl 2.5% w/w, NaCl 3 % w/w	15	18
KCl 3% w/w, NaCl 3 % w/w	18	18

TABLE A.1.7 additive's weight for KCl samples 3.5% w/w

Solution	Weight of KCl to be dumped into container (g)	Weight of NaCl to be dumped into container (g)
KCl 0.05% w/w, NaCl 3.5 % w/w	0.3	21
KCl 0.5% w/w, NaCl 3.5 % w/w	3	21
KCl 1% w/w, NaCl 3.5 % w/w	6	21
KCl 1.5% w/w, NaCl 3.5 % w/w	9	21
KCl 2% w/w, NaCl 3.5 % w/w	12	21
KCl 2.5% w/w, NaCl 3.5 % w/w	15	21
KCl 3% w/w, NaCl 3.5 % w/w	18	21

APPENDIX 2

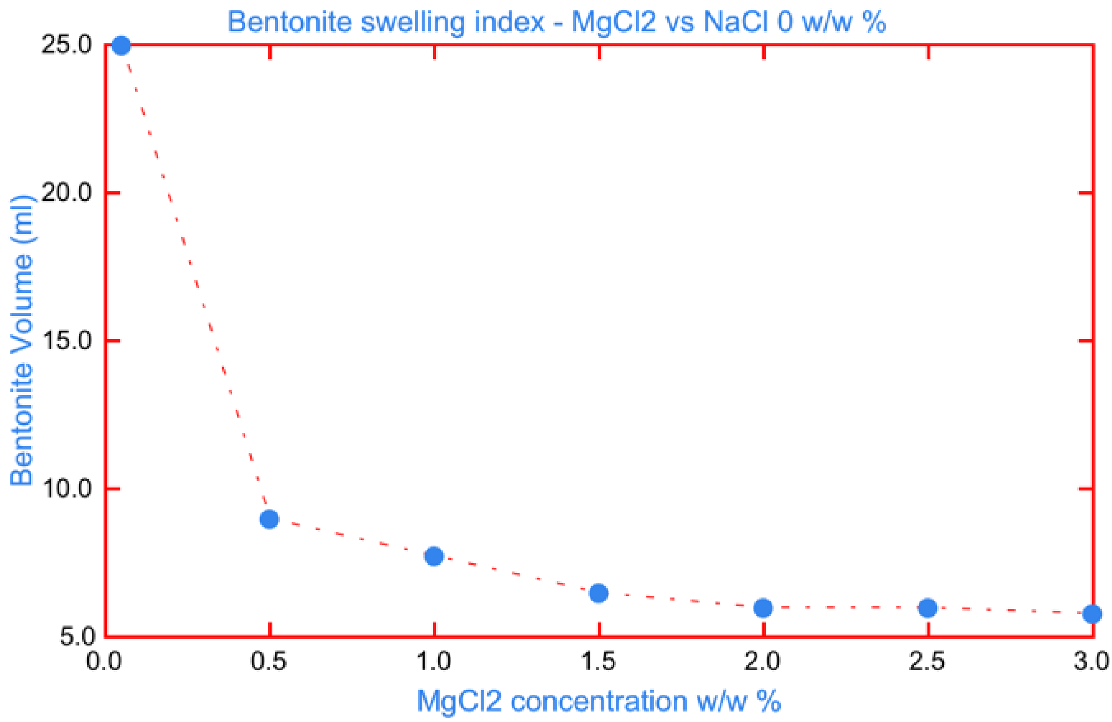

FIGURE A.2.1 MgCl effect on bentonite's swelling ability while NaCl is 0%

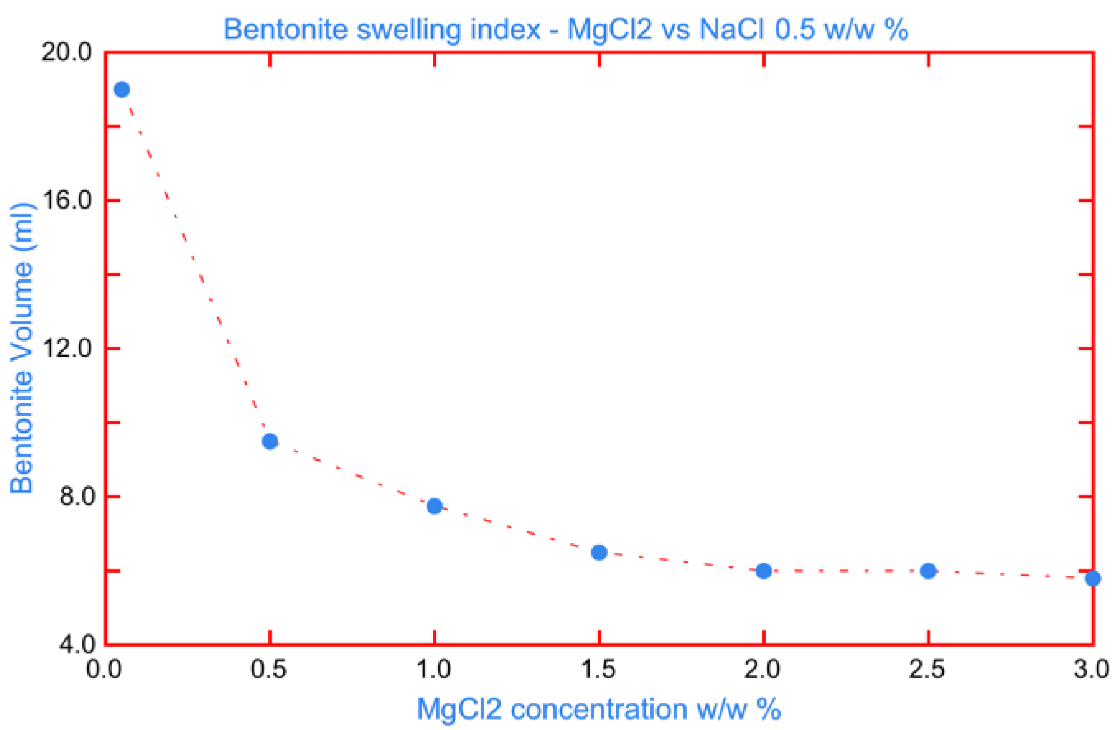

FIGURE A.2.2 MgCl effect on bentonite's swelling ability while NaCl is 0.5%

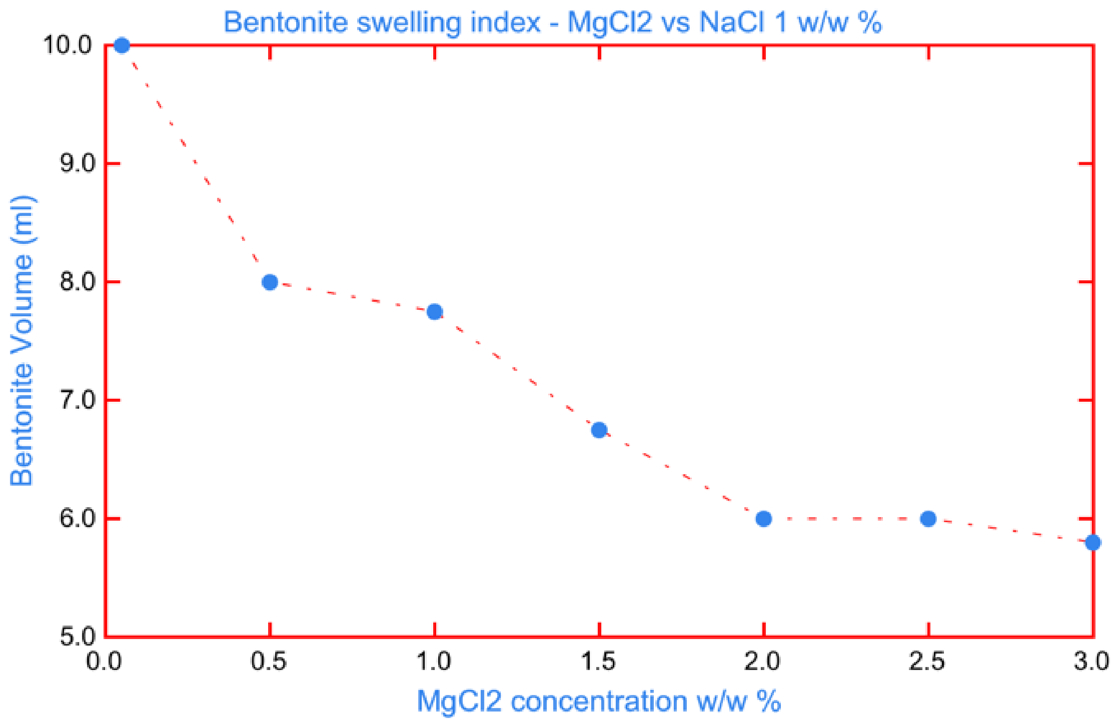

FIGURE A.2.3 MgCl effect on bentonite's swelling ability while NaCl is 1%

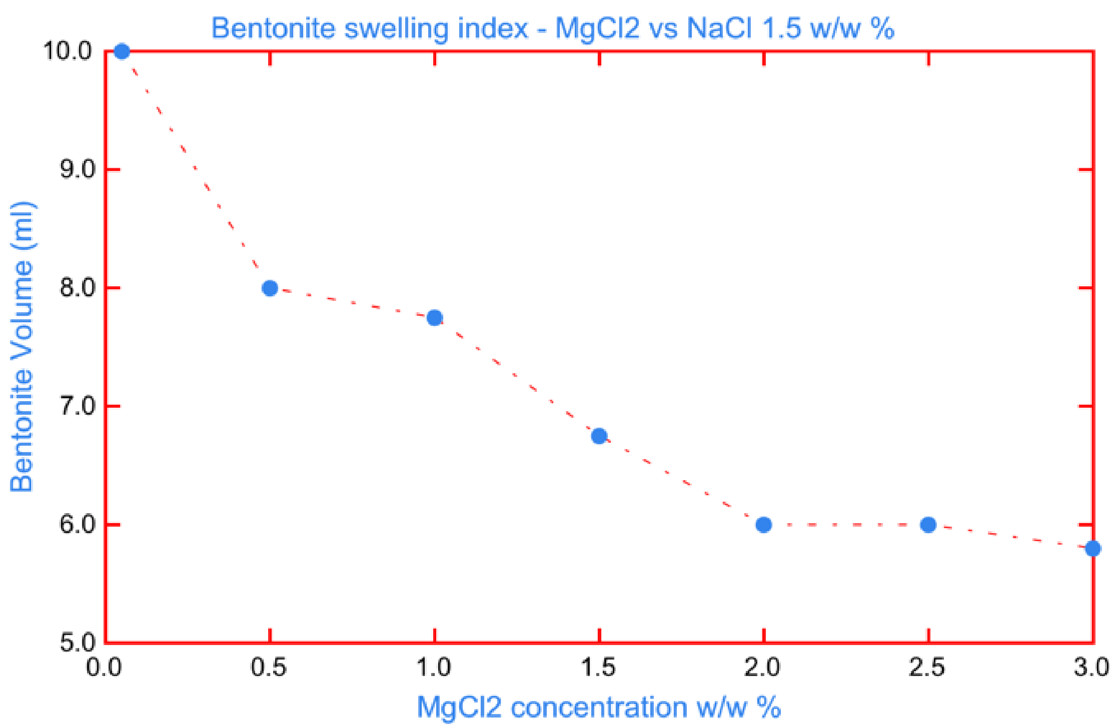

FIGURE A.2.4 MgCl effect on bentonite's swelling ability while NaCl is 1.5%

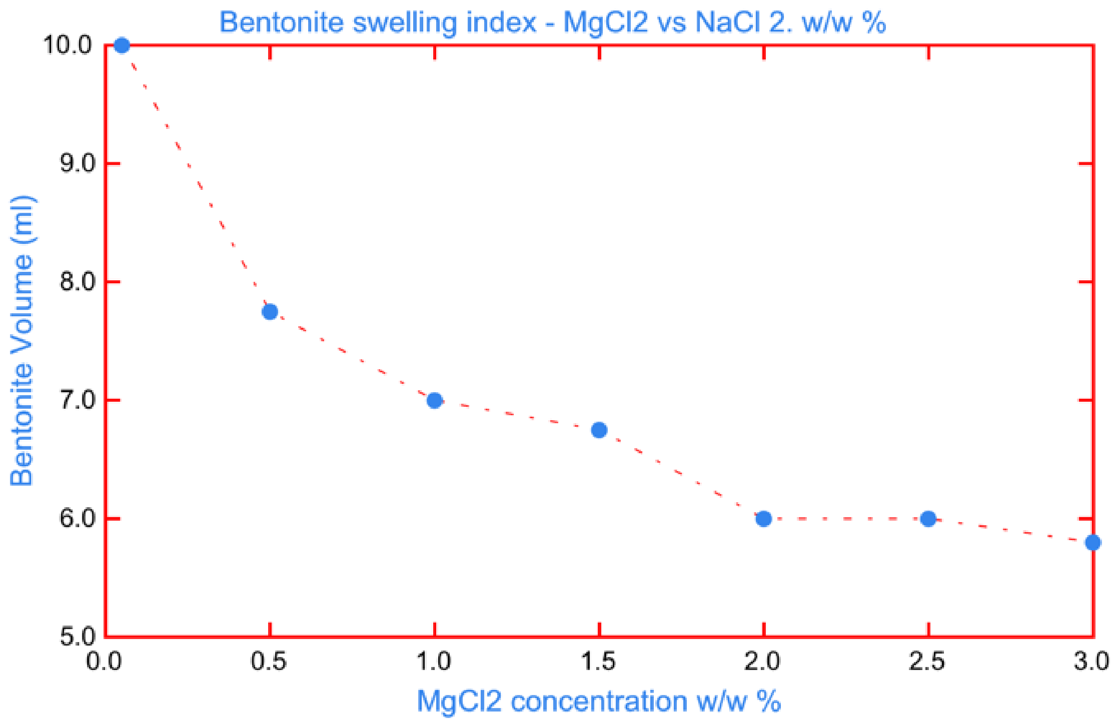

FIGURE A.2.5 MgCl effect on bentonite's swelling ability while NaCl is 2%

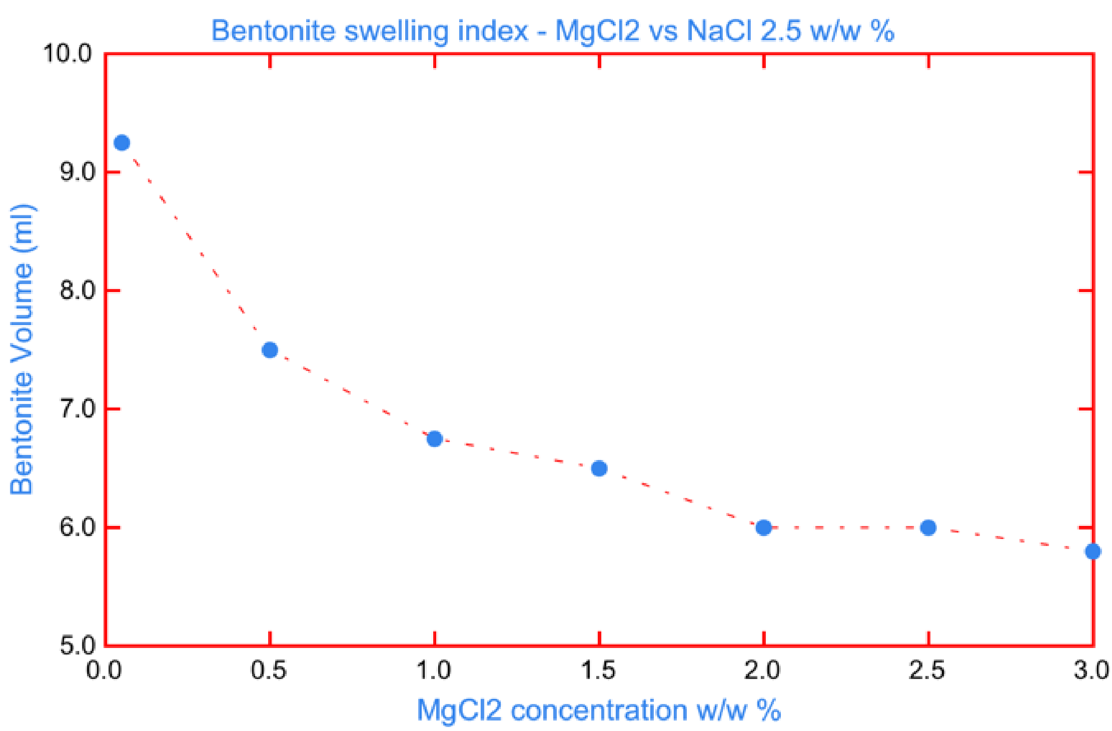

FIGURE A.2.6 MgCl effect on bentonite's swelling ability while NaCl is 2.5%

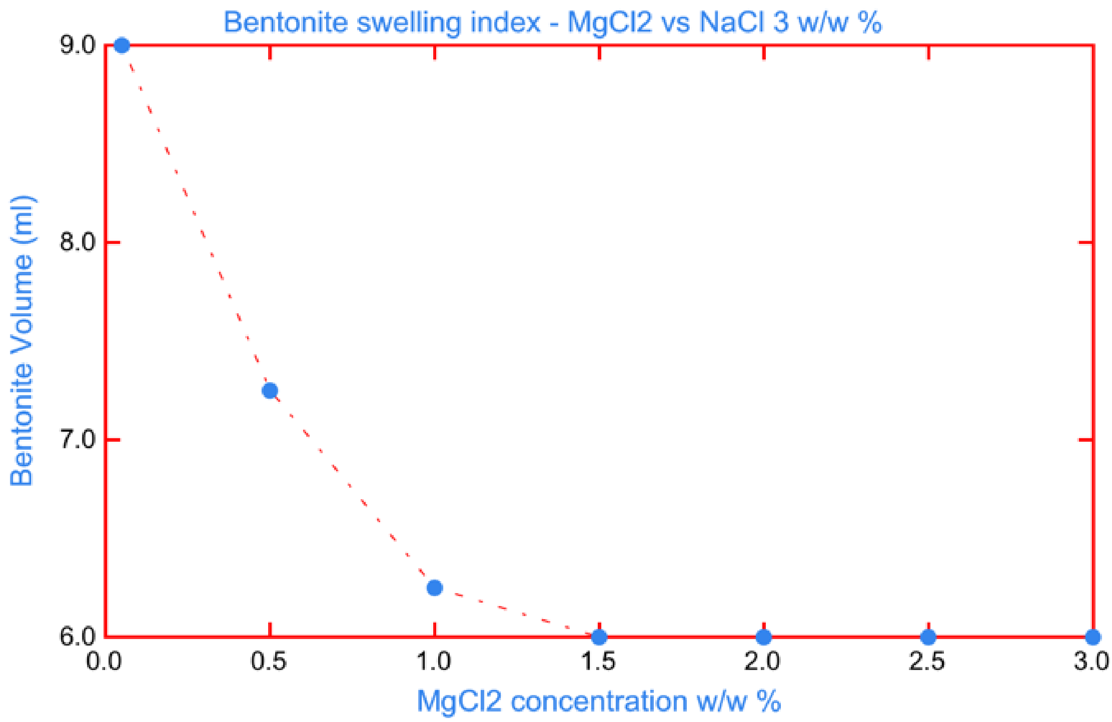

FIGURE A.2.7 MgCl effect on bentonite's swelling ability while NaCl is 3%

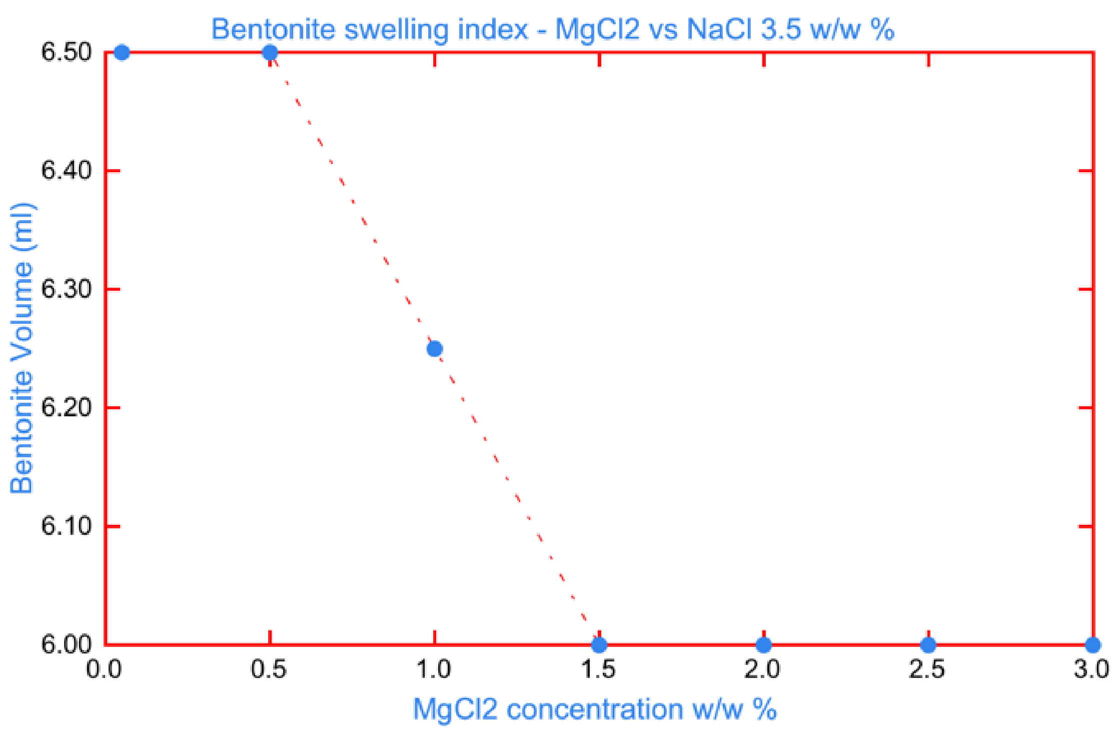

FIGURE A.2.8 MgCl effect on bentonite's swelling ability while NaCl is 3.5%

APPENDIX 3

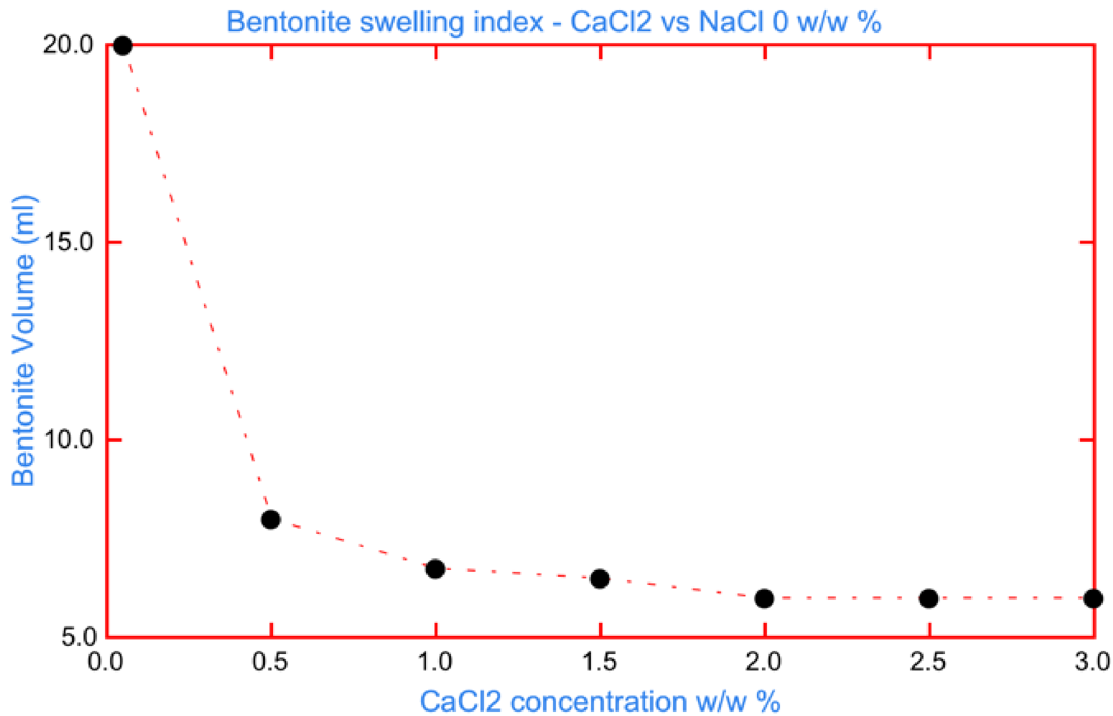

FIGURE A.3.1 CaCl effect on bentonite's swelling ability while NaCl is 0%

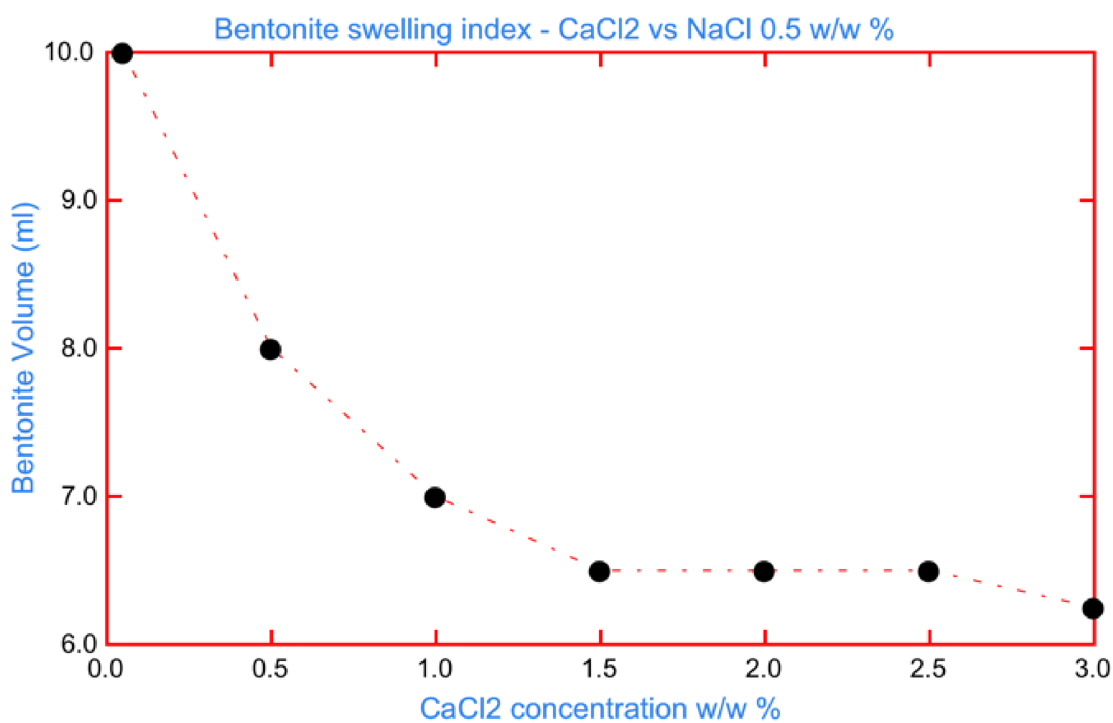

FIGURE A.3.2 CaCl effect on bentonite's swelling ability while NaCl is 0.5%

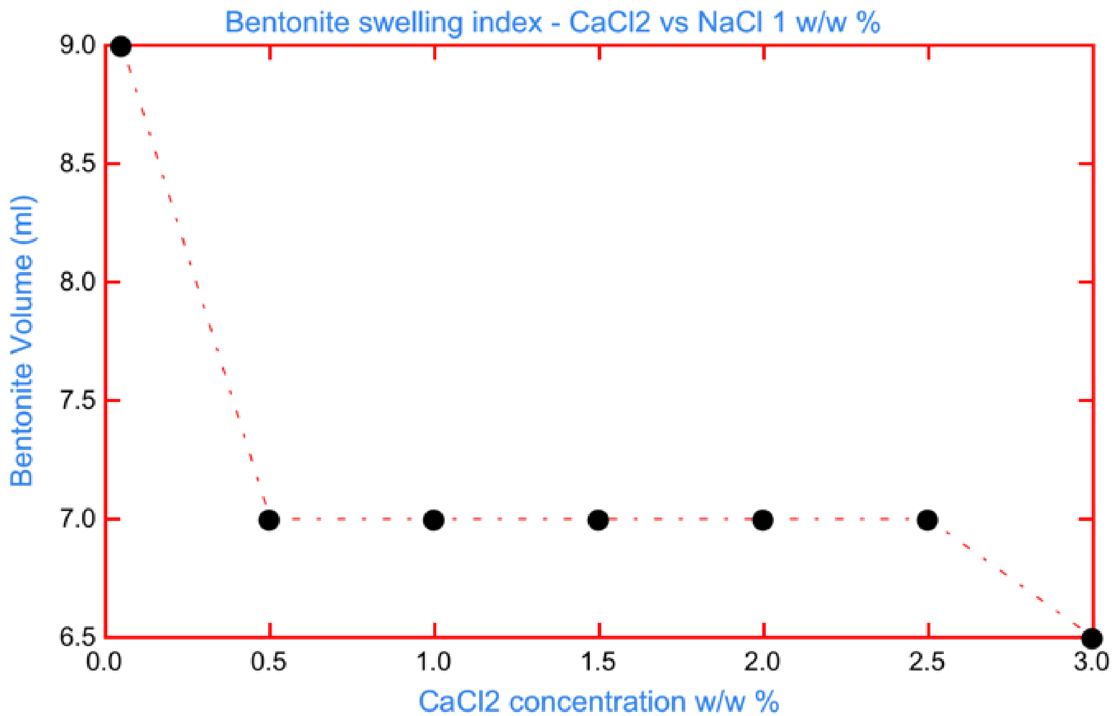

FIGURE A.3.3 MgCl effect on bentonite's swelling ability while NaCl is 1%

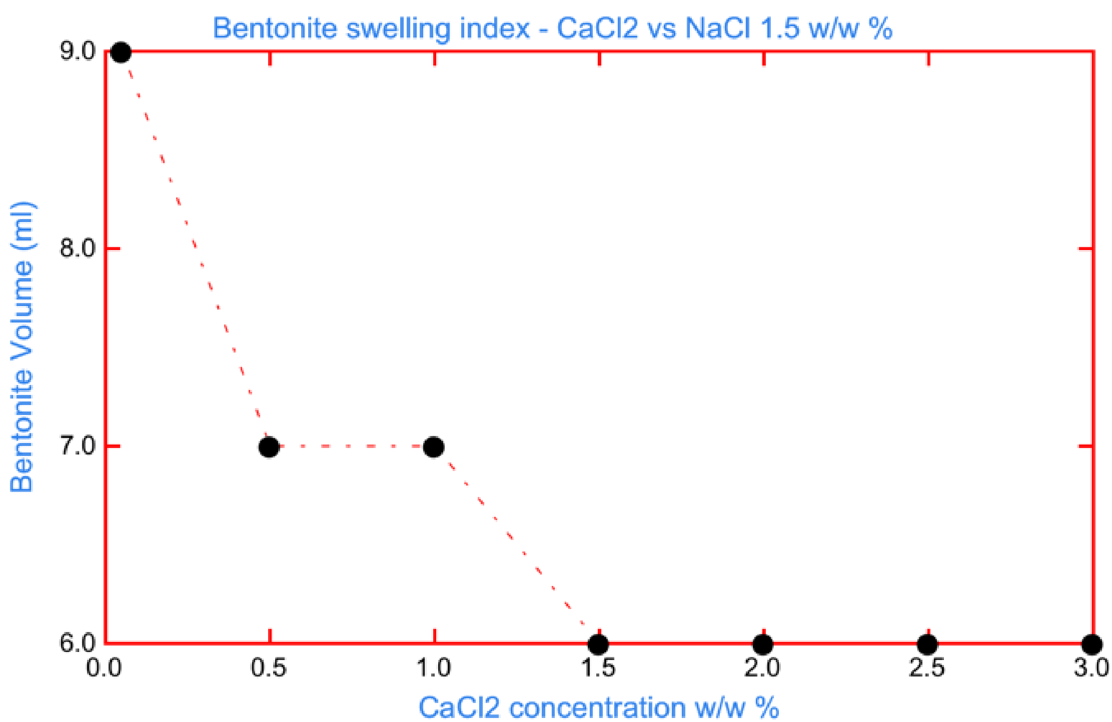

FIGURE A.3.4 MgCl effect on bentonite's swelling ability while NaCl is 1.5%

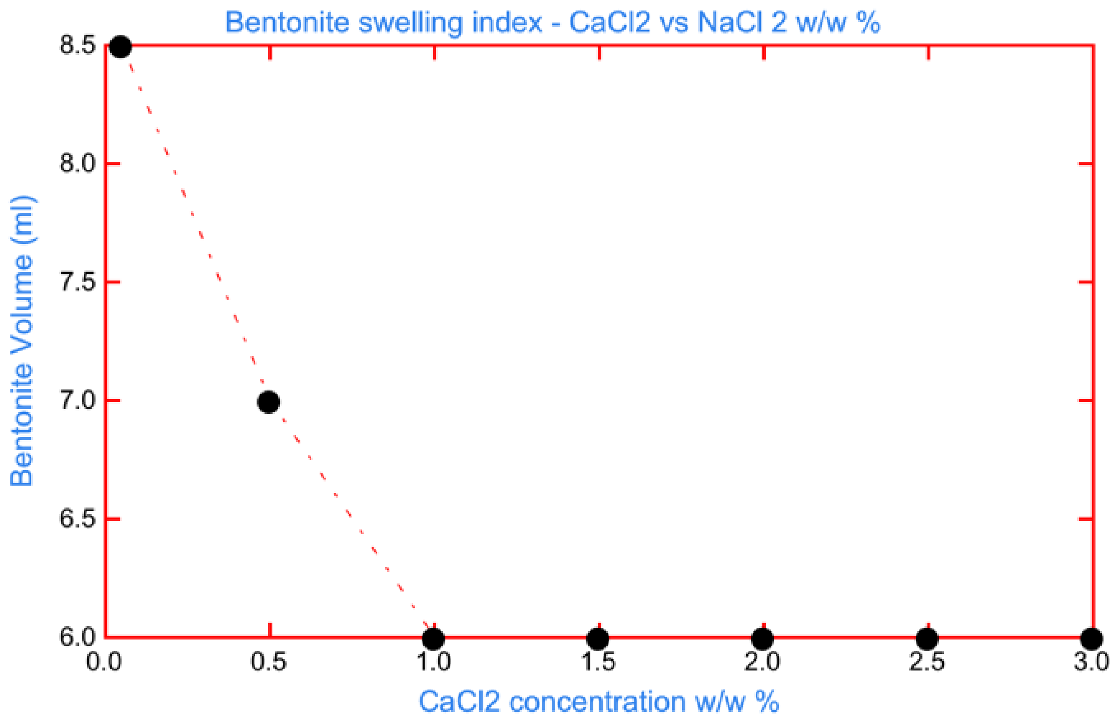

FIGURE A.3.5 MgCl effect on bentonite's swelling ability while NaCl is 2%

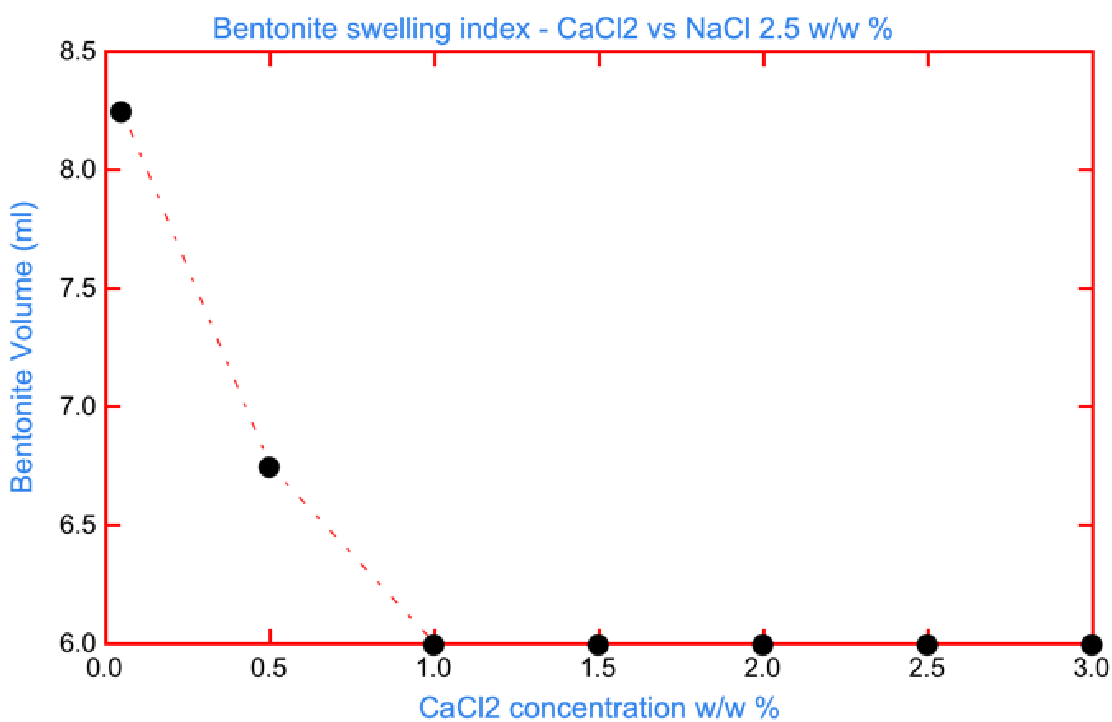

FIGURE A.3.6 MgCl effect on bentonite's swelling ability while NaCl is 2.5%

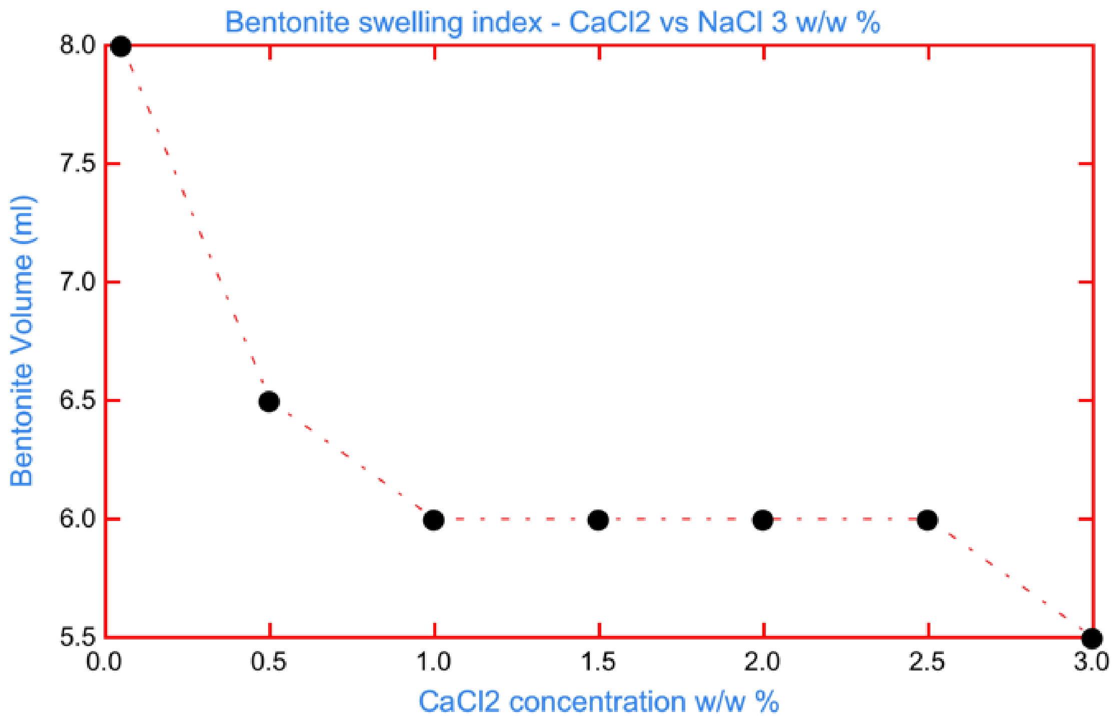

FIGURE A.3.7 MgCl effect on bentonite's swelling ability while NaCl is 3%

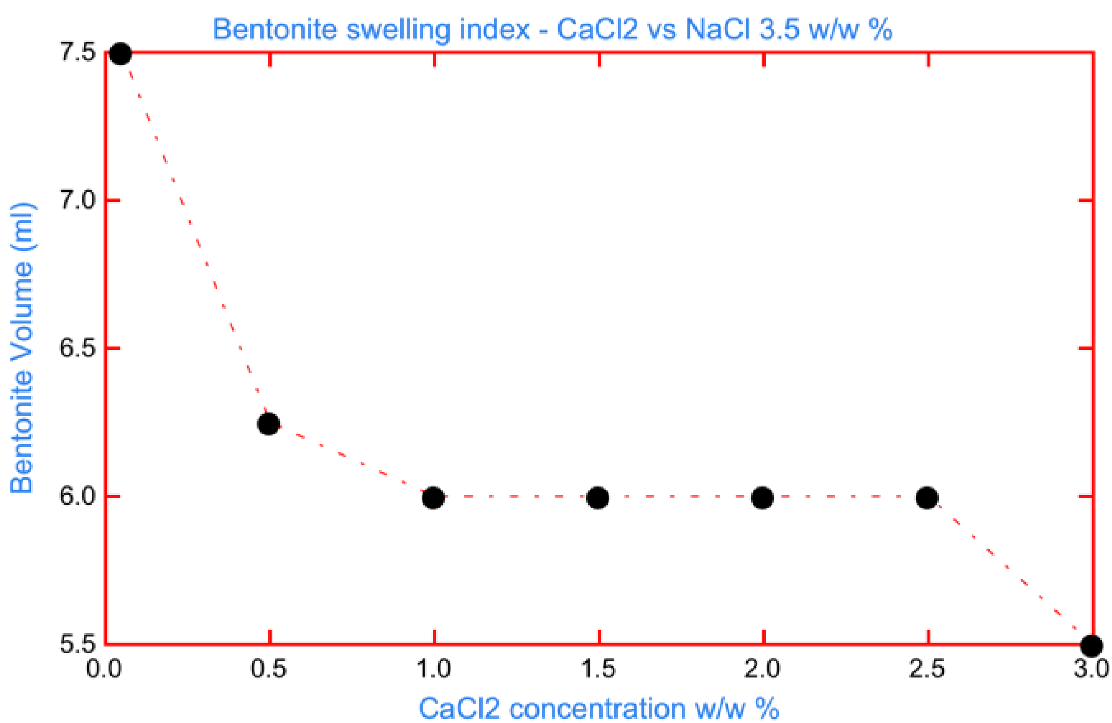

FIGURE A.3.8 MgCl effect on bentonite's swelling ability while NaCl is 3.5%

APPENDIX 4

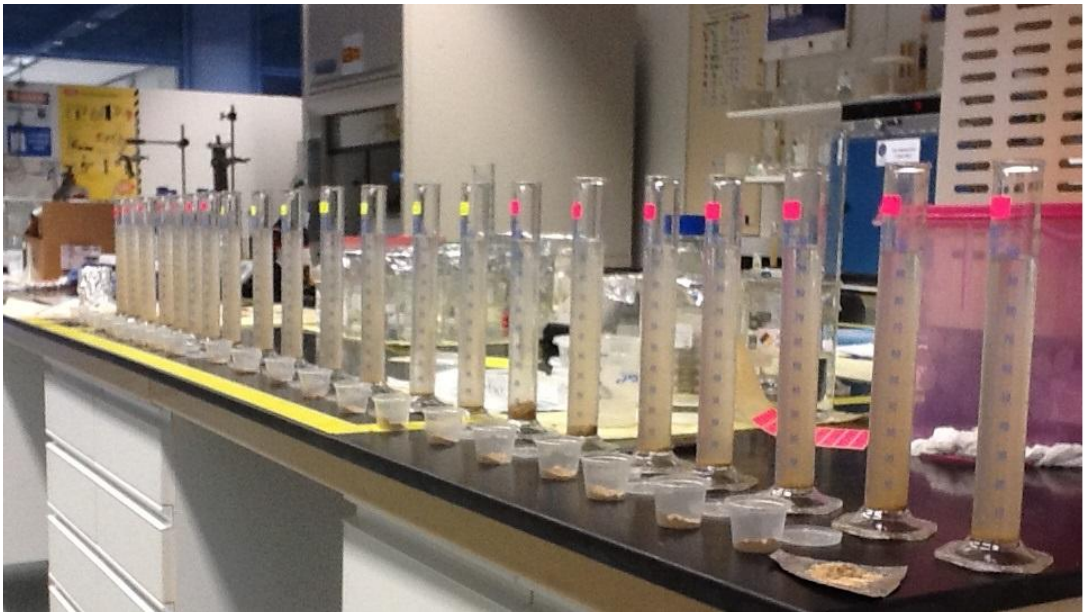

FIGURE A.4.1 Salinity effect experiment

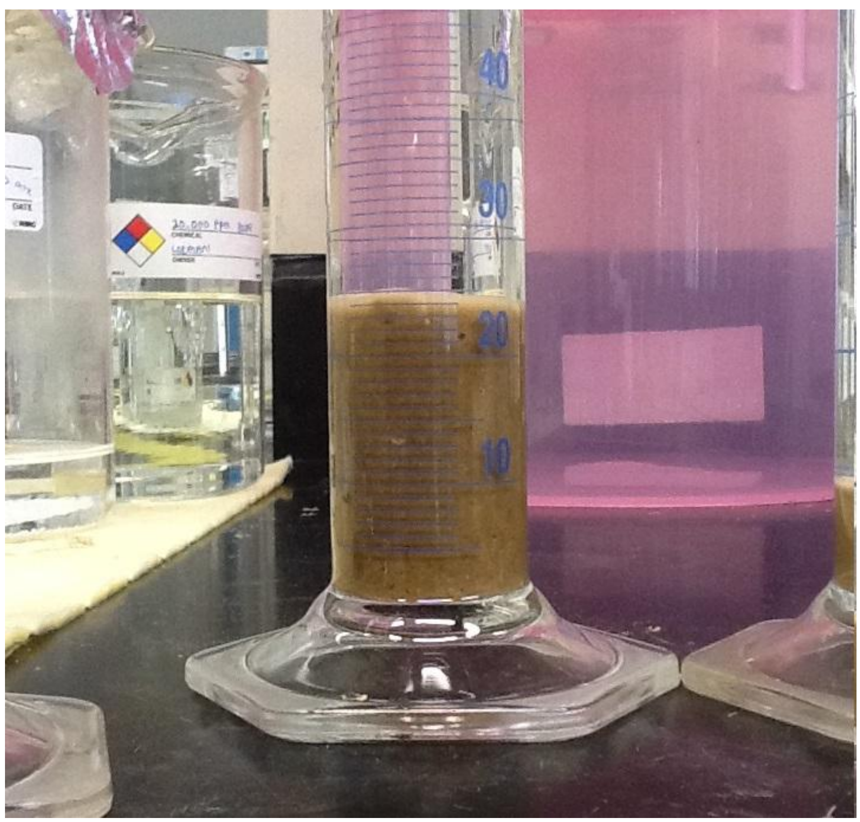

FIGURE A.4.2 Salinity effect experiment

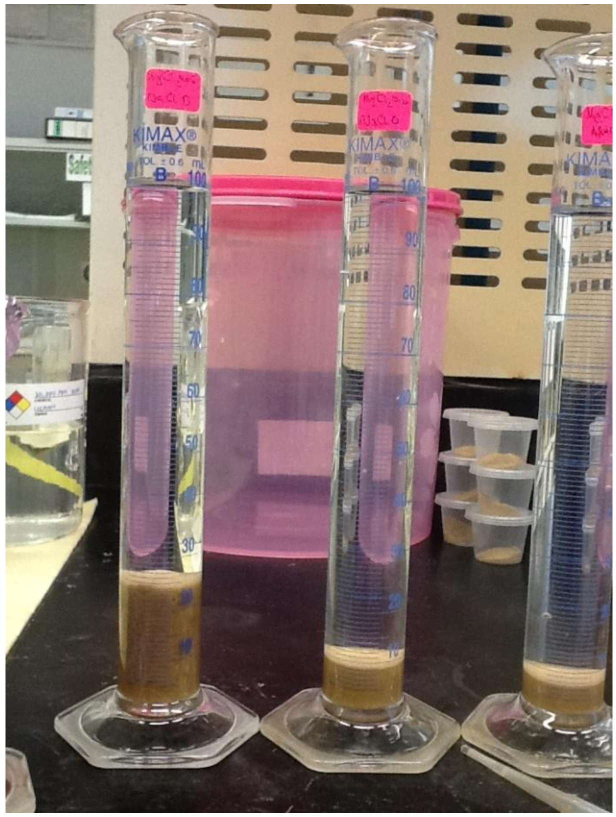

FIGURE A.4.3 Salinity effect experiment