EVALUATION OF WETTABILITY ALTERATION IN SANDSTONE ROCKS BY DIELECTRIC MEASUREMENTS

BY

Sulaiman Abdullah Sulaiman Alarifi

A Thesis Presented to the
DEANSHIP OF GRADUATE STUDIES

KING FAHD UNIVERSITY OF PETROLEUM & MINERALS

DHAHRAN, SAUDI ARABIA

In Partial Fulfillment of the
Requirements for the Degree of

MASTER OF SCIENCE

In

PETROLEUM ENGINEERING

December 2015

KING FAHD UNIVERSITY OF PETROLEUM & MINERALS
DHAHRAN- 31261, SAUDI ARABIA
DEANSHIP OF GRADUATE STUDIES

This thesis, written by **Sulaiman Abdullah Sulaiman Alarifi** under the direction his thesis advisor and approved by his thesis committee, has been presented and accepted by the Dean of Graduate Studies, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE IN PETROLEUM ENGINEERING**

Mohamed Mahmoud

Dr. Mohamed A. Mahmoud
(Advisor)

Dr. Abdullah S. Sultan
Department Chairman

Dr. Hasan Y. Al-Yousef
(Member)

Dr. Salam A. Zummo
Dean of Graduate Studies

Wael A. Abdallah
(Member)

27 \12\15
Date

This work is dedicated to my family

ACKNOWLEDGMENTS

I would like to acknowledge the great cooperation and support I received from the petroleum engineering department at King Fahd University of Petroleum and Minerals.

My sincere gratitude goes to my thesis advisor Dr. Mohammed Mahmoud for allowing me to join his research activates and for the guidance and support from him. Also, I would like to acknowledge my Master degree thesis committee members Dr. Hasan Y. Al-Yousef and Dr. Wael A. Abdallah for their valuable comments and contribution.

I would like to extend my gratitude to the chairman of the petroleum engineering department Dr. Abdullah S. Sultan for his continues support and encouragement.

I am very thankful for Schlumberger Dhahran Carbonate Research Center (SDCR) represented by committee member Dr. Wael Abdallah. I appreciate his full support of the research I conducted in their laboratories. I would like to express appreciation to Mr. Salah Al-Ofi who has been a great mentor throughout my work at SDCR

TABLE OF CONTENTS

CHAPTER 4: Evaluating the effect of DTPA-K5 and different water salinities on Sandstone rocks' surface charge

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

SW : Seawater

LS : Low salinity water

DI : De-ionized Water

ROS : Residual Oil Saturation

ζ : **Zeta potential**

TDS : Total Dissolved Solids

ppm : Parts per million

DTPA-K5 : Diethylenetriaminepentaacetic acid, Potassium salt

ε^* : **Complex permittivity**

ε_r : **Relative dielectric constant (Relative permittivity)**

σ : **Conductivity**

S : Siemens

ω : **Circular frequency**

ε_0 : **Vacuum permittivity**

N_c : **Capillary number**

N_B : **Bond number**

ABSTRACT

Full Name	:	Sulaiman Abdullah Sulaiman Alarifi
Thesis Title	:	Evaluation of Wettability Alteration in Sandstone Rocks by Dielectric Measurements.
Major Field	:	Petroleum Engineering
Date of Degree	:	December 2015

Wettability is one of the most crucial physical properties of the reservoir rocks. The alteration in wettability affects significantly the oil recovery. The rock mineralogy (ion content) is considered one of the main factors that affect the wettability of any rock and altering the mineralogy will lead to a change in the rock wettability. Chelating agents are responsible for changing the rock's mineralogy; they are being newly introduced as stand-alone enhanced oil recovery fluids in sandstone and carbonate rocks used in low concentrations in seawater. Chelating agents were proved to affect the rock surface charges and altering the rock wettability. In the petroleum industry, measuring the physical properties behind wettability is a challenge. Recently laboratory experiments zeta potential and other methods are being used to determine the wettability change. At the moment, no logging tool is capable to capture the wettability of any reservoir which leads to a challenge of finding a way to use well-known logging tool readings into qualifying the wettability and wettability alteration. The main objective of this work is, qualifying the effect of removing some ionic components from the sandstone rocks on the surface charge of sandstone rocks along with studying the ability of chelating agents to absorb certain cations present in sandstone rocks' surfaces. Therefore, altering wettability will be evaluated in this work using zeta potential measurements. Where, changing the rock's surface charge toward a more repulsive surface leading to a more water wet surface, therefore more oil recovery. Also, evaluating chelating agents' effect on surface charge by their ability of absorbing certain cations and changing the rock's mineralogy measured using mass spectrometry analysis and also dielectric laboratory measurements as a new evaluation technique. Also, this work will investigate the effect of certain ions, chelating agents and different water salinities on conductivity conducted using laboratory dielectric measurements at high frequency (500 MHz to 1 GHz).

ملخص الرسالة

الأسم كامل: سليمان عبدالله سليمان العريفي

عنوان الرسالة: تقييم تغير التبلل الصخري في صخور الرملية بواسطة قياسات العزل الكهربائي

التخصص: هندسة البترول

تاريخ الدرجة العلمية: ديسمبر 2015

خاصية التبلل الصخري هي واحدة من الخصائص الفيزيائية الأكثر أهمية في صخور المكمن النفطي. والتغيير في التبلل الصخري يؤثر بشكل كبير على استخراج النفط. يعتبر تركيب الصخور المعدني (محتوى الأيوني) أحد العوامل الرئيسية التي تؤثر على خاصية التبلل في أي صخرة حيث ان تغييرتركيبة المعادن يؤدي إلى تغيير في خاصية التبلل للصخور. ال (تشليتنق اجيينت) هي المسؤولة عن تغيير التركيبه المعدنية للصخور؛ وقد قدمت حديثا على أنها وسيلة تعزيزللأنتاج النفطي بحد ذاتها في استخراج النفط من الحجر الرملي والصخور الكربونية حيث تستخدم بتركيز منخفض مع مياه البحر. وقد أثبتت ال(تشيليتنق ايجنت) أنها تؤثر على شحنه الصخور السطحية وتغيير التبلل الصخري. في الصناعة النفطية، وقياس الاسبابو الخصائص الفيزيائية وراء التبلل الصخري يعتبر تحدي. في الآونة الأخيرة تستخدم قياسات مختبراتيه لي جهد ال "زيتا" وغيرها من الطرق لتحديد تغيير التبلل الصخري. في الوقت الراهن، لا يوجد اداه تخطيط للابار النفطية قادرة على التقاط خصائص التبلل الصخري الأمر الذي يؤدي إلى التحدي المتمثل في إيجاد وسيلة لاستخدام اداة تسجيل قراءات الابار النفطية في دراسه وتقييم التببلل الصخري. الهدف الرئيسي من هذا العمل هو دراسة تأثير إزالة بعض المكونات الأيونية من الصخور من الحجر الرملي على شحنة سطح الصخورالرملية جنبا إلى جنب مع دراسة قدرة ال (نشيليتنق ايجنت) على امتصاص بعض الكاتيونات الموجودة في أسطح الصخور الرملية ز لذلك، سيتم تقييم تغيير التبلل الصخري في هذا العمل باستخدام قياسات جهد "زيتا". حيث ، تغيير شحنة سطح الصخرة تجاه سطح منفر (دافع) مما يؤدي سطح ذو قابلية على امتصاص الماء، و بالتالي زيادة في انتاج النفط. أيضا، تقييم تأثير ال (تشليتنق ايجنت) على جهد واشارة سطح الصخور من خلال قدرتها على امتصاص بعض الكاتيونات وتغيير التركيب المعدمي للصخور عن طريق القياس باستخدام التحليل الطيفي الشامل وكذلك القياسات المخبرية للعزل الكهربائي كتقنية جديدة للتقييم. أيضا، فإن هذا العمل يتم فيه دراسة تأثير بعض الأيونات، وال (كليتنق ايجنت) والملوحة والمياه المختلفة على الموصلية بقياسات أجريت باستخدام القياسات مختبريه لي العزل الكهربائي في وتيرة عالية (500 ميغاهيرتز إلى 1 غيغاهرتز).

CHAPTER 1

THESIS OVERVIEW

1.1 Introduction:

Wettability as defined by *Craig* in 1971 is; the tendency of one fluid to adhere or spread on a rock surface in the presence of another immiscible fluid. In other words, it is the preference of a solid (rock surface) to be in contact with one fluid rather than the other. Basically, a drop of the preferred wetting fluid will displace the other fluid from the rock surface. On the other hand, if the non-wetting fluid is dropped onto the surface already covered by the wetting fluid, it will pass by the surface minimizing its contact with the rock. In the petroleum industry, most of the time, wettability has been simplified as either water wet or oil wet systems, while it is not the reality always. As a matter of fact, the reservoir rock could be neither water nor oil wet, just a stage combining those two wetting phases (Intermediate wet or mixed wet). The consequences of not fully understanding the wettability conditions of a reservoir could lead to many damaging results. Also, different wettability conditions lead to different relative permeability curves which show the importance of wettability in well and core log analysis. Wettability effect in the reservoir is crucial and plays a major role in oil recovery and it is a major key in explaining the reservoir behavior since the oil/water/solid relationships influence most of the reservoir performance aspects. Therefore, wettability has an impact at the porous medium scale and leading to a great impact at the field (reservoir) scale affecting the economics of any petroleum production project. Determining wettability has many difficulties in the industry mainly because it is a time consuming process. Also, it requires always some lab experiments (using Amott or USBM technique) on core samples from the reservoir, and the process of extracting the core samples might alter the wettability.

Altering the wettability of a rock to enhance the oil recovery became an important research filed and also a very practical mechanism to optimize the oil recovery. The improvement of oil recovery caused by wettability alteration has been proven in laboratories and at the filed scale. Many factors will contribute to set the wettability preference for a rock. Altering the factors causing the wettability will change the wettability of any rock. Therefore, low-salinity water or adding different surfactant to the reservoir as water flooding recovery mechanisms have been used to alter wettability. The magnificent enhancement cause by wettability alteration led to further investigation into controlling the wettability of a reservoir and recording the alteration in order to predict any oil recovery changes.

In the literature, it has been proven that the ionic content of a rock plays a major role in wettability and hence in oil recovery. For this work, a quantification study and experiments are performed in order to capture the effect of lowering ionic strength of sandstone rocks in wettability and rock surface charge. The experimental studies include changing the surface charge of four different sandstone rocks with different ionic content using seawater, diluted (low salinity) water and adding chelating agent to both types of water. Recording the change of surface charge (zeta potential) and contact angel along the change of water salinity and chelating agent effect is performed in this work.

Chelating Agents are organic compounds that form soluble, complex molecules with metal ions that can control the reactivity of multivalent metal ions by inactivating the ions (seize metal ions and control them) so that they cannot normally react with other elements or ions. Using Chelating Agents in Enhanced Oil Recovery depends on the phenomena of capturing cations from the water injected and the formation brine which will lead for cation release from the rock in order to achieve equilibrium at the rock surface. Also, surface of the rock will change to more water wet through promotion of ion exchange whenever cations are being captured for the rock surface or from the connate water. Chelating agent fluid system could be added to seawater without dilution and a main advantage of Chelating agents is the capability to use them at very low concentrations. Also, a main advantage of chelating agents is the effect they have on the rock dissolution process where they force the rock to release the oil that is attached to the surface and this leads to an increase in oil recovery. They have been successfully used as an additive in the oil and gas industry in many aspects. For example, for scale removal process, iron control and matrix stimulation. Recently, they are being used as standalone fluids for EOR, stimulation and water alteration applications (*Attia et al.* 2014). A main objective of this work is, quantifying the effect of removing some ionic components from the sandstone rocks on wettability by observing the alteration of zeta potential and contact angel along these changes.

Dielectric logging introduced since 1970s, it was made to measure the water porosity in flushed zone. It eventually disappeared due to modern accuracy of other devices. New enhanced dielectric measurement logging tools are introduced and tested. The new tools are available and being used nowadays in many fields and they are more capable to adopt for many reservoir conditions. Dielectric tools have a great advantage and better accuracy over other tools especially when the salinities of connate water and injected water are varying widely. The main idea behind this tool is the dielectric permittivity and conductivity that controls the electromagnetic wave propagation in pore space. Taking into account that water has a high dielectric permittivity that is much higher than any other fluid or mineral in the reservoir; dielectric measurements become very sensitive to any water presence at the rock pore scale (*Schmitt et al. 2011*). Basically, Dielectric Permittivity of a material is a measure of a material's ability to store charge when an electric field is applied (*Sheriff, 1991*). In petroleum industry, dielectric permittivity measurements can be used to distinguish between water and oil saturated zones because of the large contrast between relative dielectric permittivity of oil and water. For water it is around 80 and oil around 2 (*Wright and Nelson 1993*; *Abraham 1999*). The newly developed tools for dielectric measurements are performed at different discrete frequencies from 20 MHz to 1 GHz; main advantage is the continuous measurement of dielectric dispersion along the reservoir layers (*Hizem et al. 2008*). In the literature, many have related dielectric measurements to other properties; such as water saturation, water salinity and rock texture using several models and interpretations.

1.2 Problem statement:

Determining wettability alteration has many difficulties in the industry. It requires always some lab experiments on core samples and it is a time consuming procedure. In the literature, it has been observed that the change in zeta potential will indicate qualitatively the change in rock wettability. Therefore, wettability will be evaluated in this work using zeta potential measurements. Chelating agents showed good potential to enhance oil recovery for sandstone rocks. A main advantage of Chelating agents is the capability to use them at very low concentrations. Also, the effect they have on the rock dissolution process where they force the rock to release the oil that is attached to the surface and this leads to an increase in oil recovery. Chelating agents proved their effect on mineralogy and surface charge by their ability to absorb certain cations which lead to more water wet rock surface. Evaluating these effects on sandstone rocks along with the change in dielectric measurements is what this work is aiming to reach.

1.3 Main objectives:

- Evaluating the wettability alteration of chelating agent and different brines on different sandstone rocks by measuring:
  - Oil recovery after core flooding for sandstone rock with DTPA-K5 chelating agent.
  - DTPA-K5 chelating agent effect on sandstone rock’s ions content (Mineralogy).
  - Change in the value of zeta potential of sandstone rocks with high and low salinity water due to mineralogy change.

- Proposing the use of laboratory dielectric measurement setup as an evaluation technique, relating the effect of seawater, low salinity water, deionized (DI) water and chelating agent on certain cations with dielectric and conductivity measurements.

1.4 Work organization:

- Core flooding using seawater on Berea sandstone, then enhancing the recovery using 5 wt% DTPA-K5 in seawater.

- ICP element analyzer is used to measure the effect of DTPA-K5 chelating agent and salinity on the mineralogy of the rocks. Powder is filtrated from all the mixtures prepared for zeta potential, the change in Fe^{+3}, Ca^{+2}, Al^{+3} and Mg^{+2} elements will be measured and recorded.

- Measuring zeta potential for the rock's powder from 4 sandstone rocks. Also, from the powder dried after conditioning for 2, 6, 12, 24 hours, in DTPA-K5 in seawater mixture. Each powder sample will be mixed for 24 hours with seawater and also low salinity water. The effect of seawater, low salinity water and DI water in zeta potential measurements will be observed.

- Dielectric measurements are conducted on the same fluid/powder mixtures as done in zeta potential. The fluids are measured first apart from the powder to know its dielectric and conductive properties before measuring the powder within it.

- Studying the effect of DTPA-K5 chelating agent when added to different water salinities by measuring the change in conductivity at high frequencies using the Dielectric laboratory measurement tool. Also, studying the effect of different concentrations of certain cations when added as salts to DI water and DI water with the presence of 5wt% DTPA-K5.

CHAPTER 2

LITERATURE REVIEW:

2.1 Wettability:

The effect of surfactant or low salinity water flooding in wettability alteration in sandstone has been investigated in the literature. Those two mechanisms are the most used methods to alter wettability and investigations have been done more than 40 years ago. Keeping in mind, using low-salinity and surfactant to improve oil-recovery have high potential because of its low cost and its harmless effects environmentally (*Bernard* 1967). Injected water has been found to play a major role in altering the wettability preference. Especially, the effect of salinity of the injected water in preventing inorganic salts precipitation (*Chie Kozaki 2012*). Many publications proved that water composition and salinity content can affect oil recovery. As *Rao et al.* reported in 2006, Nonionic Surfactant increased recovery from 56% to 94% by increasing its concentration from 0 ppm to 5000 ppm. Also, it converted the original water-wet nature of Berea sandstone to mixed-wettability which has been shown by relative permeability curves shift. Also, Anionic surfactant increased recovery from 52% to 78% (using 0 ppm to 3500 ppm) which developed mixed wettability condition. The work done in Berea sandstones at ambient conditions which developed unique kind of heterogeneous wettability "mixed-wettability", resulting in higher oil recovery in initially water wet sandstone.

Xie et al. in 2008 showed that water-soluble chemical surfactants are altering the wettability of strong water-wet sandstone surfaces. Spontaneous imbibition tests used to estimate the change in wettability of rocks and several core-flooding experiments done to evaluate the enhancement in gas deliverability. Surfactant altered the wettability to intermediate-wet and an increase in gas deliverability by 56% occurred. *Wu* and *Firoozabadi* in 2009 reported that Nacl is making a rock that is saturated with brine more water-wet. Experiments conducted using Berea sandstone showed that Silica is normally negatively charged using spontaneous imbibition experiments. Also, the adsorption of surfactants is changed due to salinity and pH of the brine; this affects wettability because of the change that occurred in the charge of the rock surface and fluid interfaces. Positively charged cationic surfactants are normally attracted to negatively charged surfaces while negatively charged anionic surfactants are acting the opposite. At low pH values, the surface charge of Silica and calcite in water is positive and it becomes negative at high pH values. When pH increases above 2 to 3.7, silica become negatively charged. *Nasralla et al*. in 2011 showed lower contact angle after using low-salinity water into sandstone rock making it more water wet, a strong negative surface charge occurs at rock/brine and oil/brine interfaces. Meaning that, an expansion of the double-layer due to the repulsive forces between rock and oil surfaces (wettability alteration) and oil recovery increased (proved by coreflood experiments). While seawater with multi-cation brines showed almost zero zeta potential against a wide range of pH, low salinity provided more water wet surface with highly negative zeta potential. They concluded that, double- layer expansion is a primary mechanism caused by low salinity to enhance oil recovery. At the field scale, low-salinity showed success in altering the wettability and enhancing oil recovery proved by many such as; *Robertson* in 2007, *Lager et al.* in 2008 and *Seccombe et al*. in 2010. The ionic strength plays an important role in enhancing oil recovery in sandstone rocks in lab experiments as proven by *Morrow et al*. 1998 and *Zhang et al*. in 2007. It has been suggested by *Lager et al*. in 2006 that the reason for increased oil recovery by low-salinity water is the ionic exchange between the mineral surface and the invading brine. They found that the primary mechanism behind the enhancement in oil recovery is the multicomponent ionic exchange between rock surfaces and water. In 2009, *Ligthelm et al*. concluded that wettability alteration caused by low-salinity-water flooding was due to change in ionic strength (decrease in the ionic content). Because of some multivalent cations such as calcium and magnesium, oil is being absorbed at the rock's surface. Therefore, the negativity charged ions are acting like a bridge between the oil and clay minerals. Also, they proved that injecting low salinity water will lower the salinity of formation water which will reduce the multivalent cations in the brine solution leading to a decrease in the screening potential of the cations. In another prospective, an increase in the absolute level of zeta potential means an increase in the double layer surrounding the clay and oil particles and eventually it will cause repulsion between particles. Also, *Nasralla et al*. in 2012 studied the effect of double layer expansion on oil recovery and proved it is a primary in enhancing the recovery of oil. They proved their findings by conducting contact angel, zeta potential and low salinity water flooding experiments.

2.2 Zeta potential:

Zeta potential is the potential at the shear plane of the electrical double-layer. Zeta potential value is related to the thickness of the double layer and also, the charge of the interface surface between the mineral and brine. The change in zeta potential will indicate qualitatively the change in rock wettability; a good trend is shown between contact angel (wettability change) and zeta potential in Figure-1 (*Nasralla and Nasr-El-Din, 2014*). It has been found that, the rock wettability is strongly related to the water film stability located in-between rock surface and crude oil (*Hirasaki* 1991; *Buckley et al*. 1996). Moreover, water film stability depends on the electrical double-layer repulsive forces from surface charges at the solid/water and water/oil interfaces. A repulsive electrostatic force will form if similar charges interfere, that makes the dis-joining pressure high and form a thick water film; this leads to a water wet surface system (*Dubey and Doe* 1993).

Buckley et al. in 1989 studied the effect of water salinity on surface charge between oil and solutions with different concentrations of NaCl. They reported that because of the low ionic strength of NaCl solutions, a stronger negative charge of zeta potential occurred, giving evidence that electro-kinetic charge of both rock with brine and oil with brine interfaces are affected greatly by the ionic strength of water. *Menezes et al.* in 1989 measured the effect of surfactant in the oil-based muds on wettability alteration using contact angle and zeta potential measurements. They found out that Zeta potential of silica particles was negatively charged (pH: 2.5-13) where it gave positive charge at low pH and negative charge at high pH due to H^+ and OH^- ions (potential determining ions). Also, they proved that oil wetting agents (i.e. EZ-Mul, DV-33 and DWA) made zeta potential less negative through whole pH range (even smaller positive at low pH). They concluded that increase in negative Zeta potential in silica caused by adsorption of anionic surfactants. *Farooq et al*. in 2011 studied the zeta potential relationship with pH value and ionic valiancy (Na^+, Ca^{+2} and Mg^{+2}), where it is strongly related to the surface charge. Zeta potential for Berea, Silica and Kaolinite gave a highly negative charge in fresh water at pH more than 6. They found that Ca^{+2} and Mg^{+2} reduce the Zeta potential more than Na^+ ions for all the minerals. *Alotaibi et al.* in 2011 found that the surface charges are affected by ionic strength of water. At low ionic strength of multi-cation brines, surface charge becomes more negative for clays, Berea Scioto Sandstones. This conclusion has been presented by *Kia et al.* in 1987 and *Menezes et al*. in 1989 that above pH value of 2, sandstone and clays have negative charges when interacting with brines.

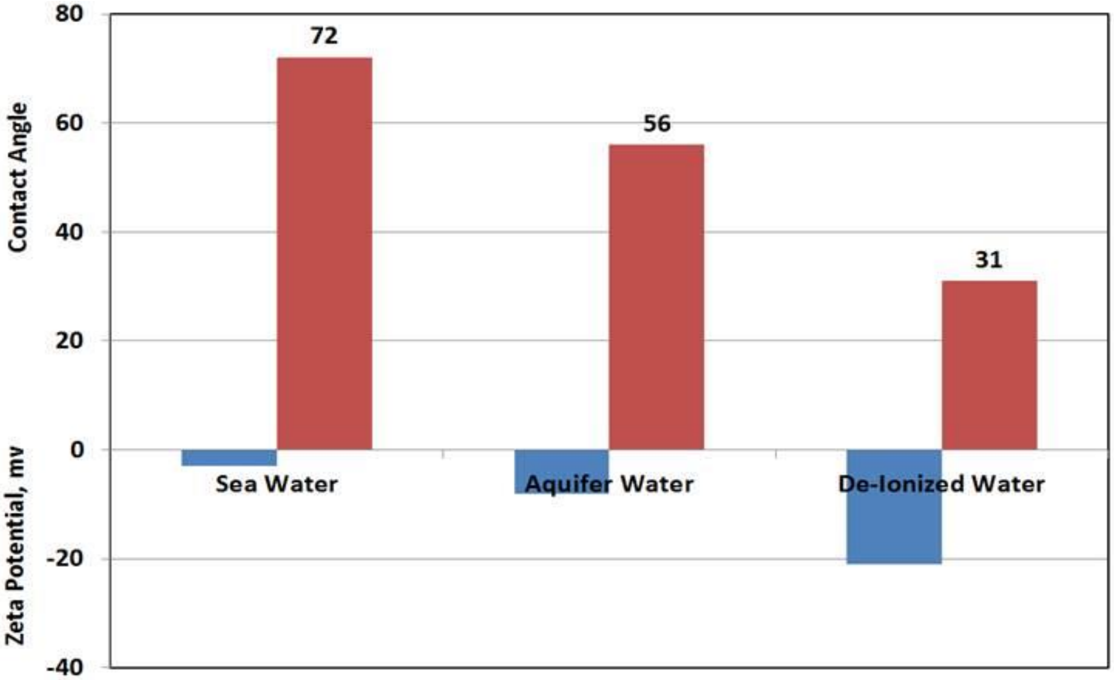

Figure 1: Relationship between the sandstone wettability and zeta potential for different waters and crushed Berea sandstone cores. (After *Nasralla and Nasr-El-Din, 2014*).

2.3 Chelating agents:

Chelating agents have been used successfully as additives in the oil and gas industry, for example during scale removal, iron control and matrix stimulation. Recently they are being used as standalone fluids for some applications. Chelating agents are organic compounds that can control the reactivity of multi valente metal ions. Chelates can seize meatal ions and control it (*De Wolf et al.* 2014). It is a recent field of study, in 1998, *Fredd and Fogler* were the first to use Chelating agents and they used them as stimulation fluids. Chelating agents were previously used to remove calcium sulfate anhydrite scale (*Moore et al. 1972*, *Jamialahmadi et al. 1991*) and remove sulfate and carbonate minerals from clay assemblages (*Bodine and Fernalld*, *1973*). *De Wolf et al.* in 2014 studied the effect of four different Chelating agents in sandstone and showed improvements in permeability and high calcite dissolution capacity by conducting dissolution, corrosion, thermal stability and coreflood experiments. In 2004, *Frenier et al.* used a chelating agent to remove Fe^{+3}; Ca^{+2} and Mg^{+2} carbonate minerals without causing damage by clay degradation and precipitated byproducts in sandstone rocks. Eventually, chelating agents stimulated sandstone at high temperatures. *Mahmoud et al*. in 2011 showed the effect of using a chelating agent (GLDA) in Berea sandstone rocks for stimulation (acidizing) purposes that resulted in an enhancement in the permeability. pH value of any fluid has an effect on the amount of chelated cations (*Mahmoud et al*. 2011).

As pH value increased, chelated cations from rock increases. Chelating agents has proved an increase in oil recovery estimations by 30% in Berea sandstone cores after flooding test due to the rock dissolution process that occurred caused by chelating agents. Chelating agents also showed an effect on altering rocks to more water-wet. *Attia et al.* in 2014 proved wettability alteration by chelating agent using Zeta potential measurements where they showed more negative values of Zeta potential after using chelating agent more than using seawater or low salinity water, confirming wettability alteration to more water-wet system. They added 5wt% EDTA to low salinity water with 1,000 ppm iron which changed Zeta potential form +6.5 to -24 mV. In 2015, *Mahmoud* and *Abdelgawad* introduced three chelating agents; ethylenediaminetetraacetic acid (EDTA), hydroxyethylethylenediaminetriacetic acid (HEDTA) and diethylenetriaminepentaacetic acid (DTPA) at high pH levels to be used for the first time as standalone EOR fluids. Coreflood experiments, interfacial and surface tensions and Zeta-potential measurements were performed. Since, sandstone rocks usually contain clay minerals, such as illite, kaolinite and chlorite (contains iron), and iron minerals, such as siderite and ankerite shown in Table -1 with iron weight percent, the effect of the iron was investigated. From *Martell and Calvin* 1952, the stability-constant value represents the bond strength between the chelating agents and metal ions (Fe^{+3}, Ca^{+2} and Mg^{+2}). For DTPA chelating agent the value of Log (Stability Constant) for Ca^{+2} is 10.9, Fe^{+3} is 28 and Mg^{+2} is 9.3. This shows that DTPA has a higher potential in seizing the Ferric ion (Fe^{+3}) more than any other ion. They have found that Chelating agents are increasing the oil recovery after they conducted coreflooding experiments. The ferric ions affected the zeta-potential value of low salinity water (10 time diluted) and Berea sandstone core. Zeta potential value before adding the 1,000 ppm of iron was -12 mV and after adding it became +6.5 mV. Also, they proved that adding 10wt% of DTPA chelating agent to seawater showed much less IFT (0.8 mN/m) than distilled water (4.2 mN/m) where both were at pH =11. They concluded that using low salinity water caused damage by scale precipitation while using chelating agents will avoid this damage and furthermore they will enhance permeability. Also, Chelating agents showed good potential oil recovery for sandstone rocks and increases negative Zeta potential indicating a more water-wet rock surface.

Table 1: Chemical composition of iron minerals in sandstone (*Mahmoud* and *Abdelgawad 2015*).

Iron Mineral	Chemical Formula	Iron (wt%)
Chlorite	$Mg_4Fe_6Al_4Si_6O_{20}(OH)_{16}$	26
Ankerite	$Ca(Mg,Fe)(CO_3)_2$	16
Siderite	$FeCO_3$	62
Hematite	Fe_2O_3	70
Magnetite	Fe_3O_4	72
Illite	(K,H3O)(Al,Mg,Fe)2(Si,Al)4O10[(OH)2,(H2O)]	1.43

2.4 Dielectric measurement:

Water has a high dielectric permittivity that is much higher than any other fluid or mineral in the reservoir as shown in Table -2. Dielectric measurements become very sensitive to any water presence at the rock pore scale. Electronic polarization is a dominate source of dielectric behavior for most matrix constituents such as quartz, calcite and dolomite. Water molecules are polar because of its shape, due to the nonsymmetrical arrangements of atoms. Therefore, it acts like a permanent electric dipole. Dielectric Permittivity of a material is a measure of the ability of a material to store charge when an electric field is applied (*Sheriff*, 1991) which is called the dielectric permittivity of free-space resulting in a dimensionless quantity known as the relative permittivity ε_r. In the petroleum industry dielectric permittivity measurements can be used to distinguish between water and oil saturated zones because of the large difference between relative dielectric permittivity of oil and water. For water around 80 and oil around 2 (*Wright and Nelson* 1993; *Abraham* 1999).

Table -2: Relative dielectric permittivity of fluids and minerals (*Schmitt et al. 2011*).

Material	ε_r
Quartz	4.4
Sandstone	4.65
Limestone	7.5 - 9.2
Dolomite	6.8
Clay	5.0 - 5.8
Anhydrite	6.4
Halite	5.9
Gypsum	4.16
Oil	2-2.2
Gas (Air)	1.0
Water*	50 - 78

*Salinity increase will reduce permittivity of water due to several mechanisms.

According to *W.G. Anderson* in 1986, water tends to occupy most of the rock surface and the small pores when injected into a water-wet reservoir. This water will form a continuous phase, while oil will be isolated in pockets even at high oil saturations. On the contrary, oil-wet surfaces will be in contact with oil as its preferred phase and water will be isolated. Generating an electric field on the water-wet rocks, the dissolved ions in water will have the capability to move along the film of water surrounding and occupying the cores which makes water travel for long distances before being trapped. While, if the electric field is generated on oil-wet rocks, the distance traveled by the ions contained in spherical water droplets inside the larger pores, will have more or less water inclusions creating two different electrical responses and allowing determination of rock wettability (*Bona et al., 2001*). Basically, Permittivity considered being the sensitivity of a medium to an electric field excitation. Main physical phenomena contribute to the permittivity: 1- displacement of the electronic cloud of atoms 2- the coherent orientation on pre-existing microscopic electric dipoles and 3- the polarization effect at the interfaces. Sources of these three mechanisms are: Electronic polarization (rock permittivity), Molecular orientation (water molecules) and interfacial polarization (pore geometry and ions) known as Maxwell-Wagner effect. The term polarization implies the orientation in the direction of the applied external field ($\vec{E}$). The effectiveness of a given polarization process varies with the frequency and the molecule/particle involved (*Hizem et al. 2008*). According to *Xiuwen et al.* in 1983 , Dielectric constants which are presented as the relative permittivity $\mathcal{E}_r$ for crude oil and minerals of sedimentary rocks are small (2 to 8), for water very high (80) it depends mainly on water volume. With 60 MHz frequency used, experimental formula for dielectric constant for the field of investigation for sandstone depends on water saturation, porosity, shaliness (f_{shv}) (in volume percent) have been introduced. Experiments showed that dielectric constant decreases as salinity increase. However, rocks saturated with water with salinity less than 20,000 ppm have little change in dielectric constant (*Xiuwen et al.* 1983). Even that there are many dielectric forward models exist in the literature to convert dielectric measurements into water saturation, water salinity, rock texture, no model to convert it to wettability. New approach proposed by *Sassi and Kadoura* in 2014 to estimate rock wettability from dielectric dispersion (dielectric constant or relative permittivity); their objective was to provide an in-situ quantitative estimate of reservoir wettability from the multi-frequency dielectric log response. A model developed that can account for two phases of water: water bound to the grain surface and water freely dispersed in the pore space. The new model predicts water surface which is linked to wettability. Laboratory experiments were conducted on carbonate and sandstone rocks. Experiments validated the model and results indicate the potential for multi-frequency dielectric measurements to provide new properties such as: volume fraction of bound water and water-wet specific surface area which is strongly linked to rock wettability. Samples were initially water-wet and went through different aging stages to alter wettability toward oil-wet. More frequency leads to less permittivity. As water is drained out and displaced by crude oil to start the aging process (A_s^w) which is the water-wet specific surface area which is the volume of water wetting the grain surfaces, decreased as the rock wettability shift to oil-wet. For sandstone, fully water saturated, A_s =50.430 m^2/g, then before aging it becomes 12.028 and after aging it reduced to 10.823. The laboratory device, measuring dielectric used in this study, comprises an Agilent network analyzer (NA), ENA series E50771C, controlled using a laptop computer. The network analyzer is calibrated using a set of short, open, and 50-ohm standards from Agilent. The coaxial probe operates in reflection mode; thus, reflection coefficient S11 (scattering parameter) is measured in sequence on the flat ends of the core plug. The measured complex reflection coefficients (S11) are recorded in the form of an amplitude (in decibels) and phase (in degrees) as a function of frequency, which was varied from 10 MHz to 1 GHz and inverted into ε' and σ dielectric characteristics of the core sample (*Sassi and Kadoura* 2014).

2.5 Main Literature findings encouraged this work:

- It has been found by Hirasaki, in 1991 and Buckley et al., in 1996 that, the rock wettability is strongly related to the water film stability located in-between rock surface and crude oil

- Water film stability depends on the electrical double-layer repulsive forces from surface charges at the solid/water and water/oil interfaces. A repulsive electrostatic force will form a water wet surface system, Dubey and Doe, 1993

- Cation exchange is responsible for higher oil recovery from low salinity water injection; cation exchange leads to a reduction in electrostatic attraction forces between crude oil and rock surface by changing the rock surface charge, Nasralla et al. 2011

- When electric charge become more negative at the brine/rock interface, the repulsion forces between rock and oil increase make it more water-wet surface as a result of expansion the electric double layer and stabilizing and thickening the water film surrounding the rock, Nasralla et al. 2013

- Correlating zeta potential measurements to contact angel tests and core flooding results demonstrates that electrical double layer expansion, which is a function of the brine salinity and pH, could be the primary mechanism for IOR by low salinity water flooding, Nasralla and Nasr-El-Din, 2014. Therefore, change in zeta potential will indicate qualitatively the change in rock wettability

- Dielectric laboratory measurements have the ability to observe the change in conductivity at high frequency due to the presence of free ions and salts in fluids.

CHAPTER 3

MATERIALS PREPARATION AND METHODOLOGY

3.1 Materials:

3.1.1 Rock samples:

Four different sandstone rocks with different properties of porosity and permeability shown in Table-3 and different mineral concentrations in weight percent as shown in Table-4. The main difference of these sandstone rocks this work concern about is their difference in certain cation's content as shown in Table-6. These concentrations have been calculated using the well-known minerals present in these rocks along with the weight percent of each ion in them as shown in Table-5.

Table -3: Sandstone rocks' properties

Property	Berea	Bandera	Kentucky	Scioto
Porosity %	20	15	10	10
Permeability, md	100	8	0.01	0.2

Table-4: Mineralogy of sandstone cores in wt% (*Mahmoud et al*. 2015)

Mineral	Berea	Bandera	Kentucky	Scioto
Quartz	87	58	66	71
Dolomite	1	16	-	-
Calcite	2	-	-	-
Kaolinite	4	3	Trace	Trace
Illite	1	10	14	18
Chlorite	2	1	-	4
Potassium feldspar	3	-	3	2
Plagioclase	-	12	17	5
MW (gm)	98.94	149.47	156.89	161.22

Table-5: Minerals formulas and molecular weights with cations content

Iron Mineral	Chemical Formula	Fe^{+3} (wt%)	Ca^{+2} (wt%)	Al^{+3} (wt%)	Mg^{+2} (wt%)	MW
Clinochlore - Chhlorite	(Mg,Fe)5Al(Si3Al)O10(OH)8	11.73	-	9.07	15.31	595.22
Ankerite	$CaMg(Co_3)_2$	-	21.74	-	13.18	184.38
Calcite	$CaCo_3$	-	40.05	-	-	100.08
Kaolinite	$Al_2Si_2O_5(OH)_4$	-	-	20.91	-	258.12
Potassium feldspar	$K_2O.Al_2O_3.6SiO_2$	-	-	9.69	-	556.64
Illite	(K,H3O)(Al,Mg,Fe)2(Si,Al)4O10[(OH)2,(H2O)]	1.43	-	9.01	1.87	389.34
Plagioclase	$(Na,Ca)(Si,Al)_4O_8$	-	7.40	9.96	-	270.77

Table-6: Ions weight percent in sandstones

Sandstone	Fe^{+3}	Ca^{+2}	Al^{+3}	Mg^{+2}	**Total**
	(wt%)	(wt%)	(wt%)	(wt%)	(wt%)
Berea	0.25	1.02	1.40	0.46	**3.13**
Bandera	0.26	4.37	2.81	2.45	**9.89**
Kentucky	0.20	1.26	3.25	0.26	**4.97**
Scioto	0.73	0.37	2.68	0.95	**4.73**

3.1.2 Fluids:

1-Areabian Gulf seawater and low salinity water –diluted 10 times- prepared by dissolving salt in de-ionized water. Ionic content shown in Table-7:

Table 7: Ionic content of Formation water, seawater and low salinity water

Composition of Formation water, Arabian Gulf Seawater and low salinity water (Total dissolved solids)			
Ions	Seawater	Low salinity water	Formation Water
Sodium	18,300	1,830	59,491
Calcium	650	65	19,040
Magnesium	2,110	211	2,439
Sulfate	4,290	429	350
Chloride	32,200	3,220	132,060
Bicarbonate	120	12	354
Total Dissolved Solids (TDS)	57,670	5,767	213,734

2- A commercially available chelating agent named DTPA-K5 has been used. DTPA-K5 (diethylenetriaminepentaacetic acid, Potassium salt) chemical structure shown in Figure-2:

DTPA acid molecular weight = 393.35 ($C_{14}H_{23}N_3O_{10}$) and the molecular weight of DTPA-K5 ($C_{14}H_{18}N_3O_{10}K_5$) = 583.8 gm with pH value of 11 and density of 1.25 g/mL. DTPA-K5 stability constants shown in Table-8

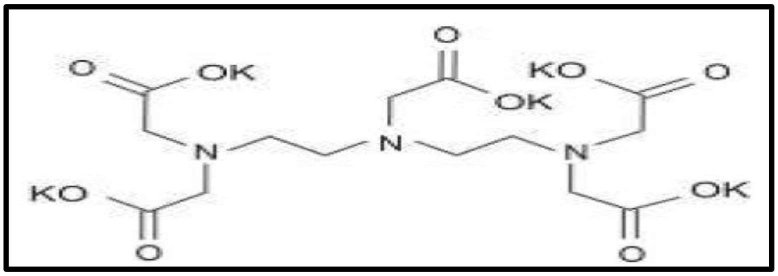

Figure 2: DTPA-K5 Chelating Agent chemical structure (After *Mahmoud and Abdelgawad.* 2015)

Table 8: Stability constants of DTPA-K5 with different cations (*Martell and Smith, 2003*)

	Stability constants for DTPA chelating agent			
ions	Al^{+3}	Ca^{+2}	Fe^{+3}	Mg^{+2}
Log K values*	18.6	10.8	28	9.3

*The equilibrium constant for the equilibrium that exists between a transition metal ion surrounded by water molecule ligands and the same transition metal ion surrounded by ligands of another kind in a ligand displacement reaction.

3.2 Materials Preparation:

3.2.1 Seawater:

Prepared in the lab using De-ionized water with dissolving the salt compositions shown in Table-9:

Table 9: Arabian Gulf Seawater salt composition (*Lindolf* and *Stoffer* 1983).

Dry salt	
Chemical formula	Concentration
	g/l
$Na\ HCO_3$	0.17
Na_2SO_4	6.34
$NaCl$	41.17
$CaCl_2$	1.8
$MgCl_2$	8.27
Total (g/L)	57.75

3.2.2 Low salinity water:

A 10 times diluted seawater to form low salinity water using the equation:

$$C_1V_1 = C_2V_2 \tag{1}$$

Where *C* is the salts concentrations and *V* is the volume of de-ionized water needed.

3.2.3 Preparing different cation concentrations in DI water using salts:

$FeCl_3$ salt has been used to produce several Fe^{+3} cation concentrations in de-ionized water as shown in table-10. The same is done to produce 1000 ppm of Ca^{+2}, Na^{+} and Mg^{+2}, - Tables (11, 12, and 13)

Table-10: Different Fe^{+3} concentrations prepared using Fecl$_3$ salt in DI water

Fe ion concentration (ppm)	Amount of FeCl$_3$ salt (gm)	Di-ionized water volume (liter)	Cl ion concentration (ppm)
0	0	0.02	0
500	0.029	0.02	953.45
1000	0.058	0.02	1906.89
2000	0.116	0.02	3813.79
3000	0.174	0.02	5720.68
4000	0.233	0.02	7627.57

Table-11: Different Ca^{+2} concentrations prepared using CaCl$_2$ salt in DI water

Ca ion concentration (ppm)	Amount of CaCl$_2$.2H$_2$O salt (gm)	Di-ionized water volume (liter)	Water salinity (ppm)	Cl ion concentration (ppm)
1000	0.073	0.02	2774.556	1774.56

Table-12: Different Na^{+} concentrations prepared using Nacl salt in DI water

Na ion concentration (ppm)	Amount of NaCl salt (gm)	Di-ionized water volume (liter)	Water salinity (ppm)	Cl ion concentration (ppm)
1000	0.051	0.02	2544	1544.82

Table-13: Different Mg^{+2} concentrations prepared using MgCl$_2$ salt in DI water

Mg ion concentration (ppm)	Amount of MgCl$_2$.6H$_2$O salt (gm)	Di-ionized water volume (liter)	Water salinity (ppm)	Cl ion concentration (ppm)
1000	0.167	0.02	3921.811	2921.81

3.3 The amount of salinity of used salts in DI water, seawater and low salinity water equivalence to NaCl:

Table- 14: amount of salinity of formation water, seawater and low salinity water and different salts in DI water equivalence to NaCl salinity.

Liquid	Salinity (ppm)	NaCl equivalence
Seawater	57,670	54404.7
Low salinity water	5,767	5440.47
Formation water	213,734	209,130
$MgCl_2$ salt in DI water	3921.811	4351.811
$CaCl_2$ salt in DI water	2774.556	2694.556
NaCl salt in DI water	2544	2544

3.4 Preparation calculations and data:

3.4.1 Procedure of conditioning sandstone rocks' powder with chelating agent:

1- Sandstone rocks are crushed into very fine powder using ROCKLAB crushing machine - for all the four different sandstone rocks.

2- Mixing 1 gram powder of the sandstone rocks with 5 wt% DTPA-K5 in seawater using a magnetic stirring device.

3- The molarity ratio between the chelating agent and the rock's powder has to be 1:1 molarity ratio. Table 15 illustrates the quantities used in each mixing procedure.

Sample calculation:

1 gram powder of Berea sandstone; molecular weight = 98.94 gm.

DTPA - K5 molecular weight = 583.8 gm

Molarity desired (1:1)

Molecular weight 583.8 gm: 98.94 gm

Weight: X: 1 gm

Therefore X = $\frac{1\,x\,583.8}{98.94}$ = 5.900 gm of DTPA-K5

The DTPA-K5 liquid used consists of 60% de-ionized water.

DTPA-K5 liquid = $\frac{5.9}{0.4}$ = 14.75 gm of DTPA-K5 liquid

Maintaining the 5 wt% of DTPA-K5 in seawater:

Seawater weight (gm) = $\frac{5.9-0.6x14.75x0.05}{0.05} = 109.15\ gm\ of\ sea\ water$

4- After the desired conditioning period, the powder liquid mixture is filtered through a 0.45 µm filter paper using a vacuum pump, glass funnel and a flask.
5- The conditioned powder is taken to be dried for around 24 hrs.
6- The filtrate liquid is taken to be tested for ion content.
Note: Every sandstone rock powder and every conditioning period is done separately

Table- 15: 5 wt% DTPA -K5 and seawater mixtures

Rock powder (gm)	Seawater volume (mL)	DTPA-K5 mass (gm)	DTPA -K5 volume (liquid) DTPA -K5 as 40% in DI water (mL)
Berea (1:1 molarity ratio)			
1	109	5.9	14.75
Bandera (1:1 molarity ratio)			
1	72.25	3.904	9.76
Kentucky (1:1 molarity ratio)			
1	68.79	3.716	9.29
Scioto (1:1 molarity ratio)			
1	67	3.62	9.05

3.4.2 The amount of cations in samples:

The amount of cations present in one gram of the used sandstone rocks is shown in the table below: Table-16

Table- 16: cation concentrations in 1 gram of different sandstone powders.

	ppm			
1 gram of:	Mg	Al	Ca	Fe
Berea	42.68	130.70	95.17	23.26
Bandera	298.64	343.18	532.43	31.74
Kentucky	33.51	415.39	161.01	25.62
Scioto	124.70	351.71	48.62	95.48

3.5 Solubility of sandstone rocks' powder mixed with DTPA-K5 as 5wt% in seawater:

While mixing 5 wt% DTPA -K5 with seawater along with each sandstone powder for 2,6,12 and 24 hours, the solubility of the powder is recorded as shown in table 17.

Table- 17: Solubility results

Mixing period	Before mixing (gm)	After mixing and dried (gm)	Change (gm)	Change %
Berea				
2 hrs	**1**	0.9537	0.0463	4.63
6 hrs		0.96	0.04	4
12 hrs		0.974	0.026	2.6
24 hrs		0.94	0.06	6
Bandera				
2 hrs	**1**	0.9392	0.0608	6.08
6 hrs		0.94	0.06	6
12 hrs		0.936	0.064	6.4
24 hrs		0.941	0.059	5.9
Kentucky				
2 hrs	**1**	0.9755	0.0245	2.45
6 hrs		0.986	0.014	1.4
12 hrs		0.963	0.037	3.7
24 hrs		0.937	0.063	6.3
Scioto				
2 hrs	**1**	0.9672	0.0328	3.28
6 hrs		0.946	0.054	5.4
12 hrs		0.955	0.045	4.5
24 hrs		0.939	0.061	6.1

3.6 Coreflooding experiment:

To observe the effectiveness and the enhancement of using DTPA-K5 in low concentration in seawater on the oil recovery of Berea sandstone rock after being flooded by seawater is the main reason behind coreflooding experiment conducted. Also, another reason is to track the change on the rock's mineralogy while flooding by the chelating agent. Core-flooding experiment was performed with the apparatus setup shown in Figure-3. Coreflooding setup consists of the following: a coreholder and transfer cells (accumulators), differential pressure transducers, backpressure regulators, automatic fractional collector to collect the effluent samples, and an Isco syringe dual piston pump. The flooding system can handel temperature up to 350 ^{o}F and pressure up to 5,000 psi. The Berea sandstone core (6 in. length and 1.5 in. diameter) was loaded into the coreholder then the overburden pressure was applied; backpressure was set to 1,000 psig , temperature of 100 ^{o}C and flooding started by injection formation water. Dead oil was injected into the core to establish the connate water saturation. The oil density is 0.87 g/cm^3, oil gravity is 31 API and oil viscosity is 13.1 cp. The oil used was Arabian medium oil and its composition listed in Table 18. The total acid and base numbers of the oil were 0.3 and 0.09 mg of KOH/g respectively. The core permeability before flooding was measured by formation brine at four different rates. After flooding, the core was cleaned from the oil with distillation by toluene and then the core was dried and saturated with formation brine. The final permeability was measured by formation brine at the same four flow rates (1, 2, 3, and 4 cc/min). Berea sandstone core properties are shown in Table 19. Also, the effluent resulted from the coreflooding experiment were collected per every 0.2 pore volumes or so, and then effluent analysis (ion content analysis) is performed on the samples collected (using ICP-MS) to record the dissolved cations (SO_4^{-2}, Ca^{+2}, Mg^{+2}, Fe^{+3} and Al^{+3}) in the effluent from the rock.

Table.18: Oil composition

Component	Mol%	**Component**	Mol%
C_5	1.23	**C_9**	14.51
C_6	4.23	**C_{10}**	14.43
C_7	10.66	**C_{11}**	11.15
C_8	15.81	**C_{12+}**	27.98

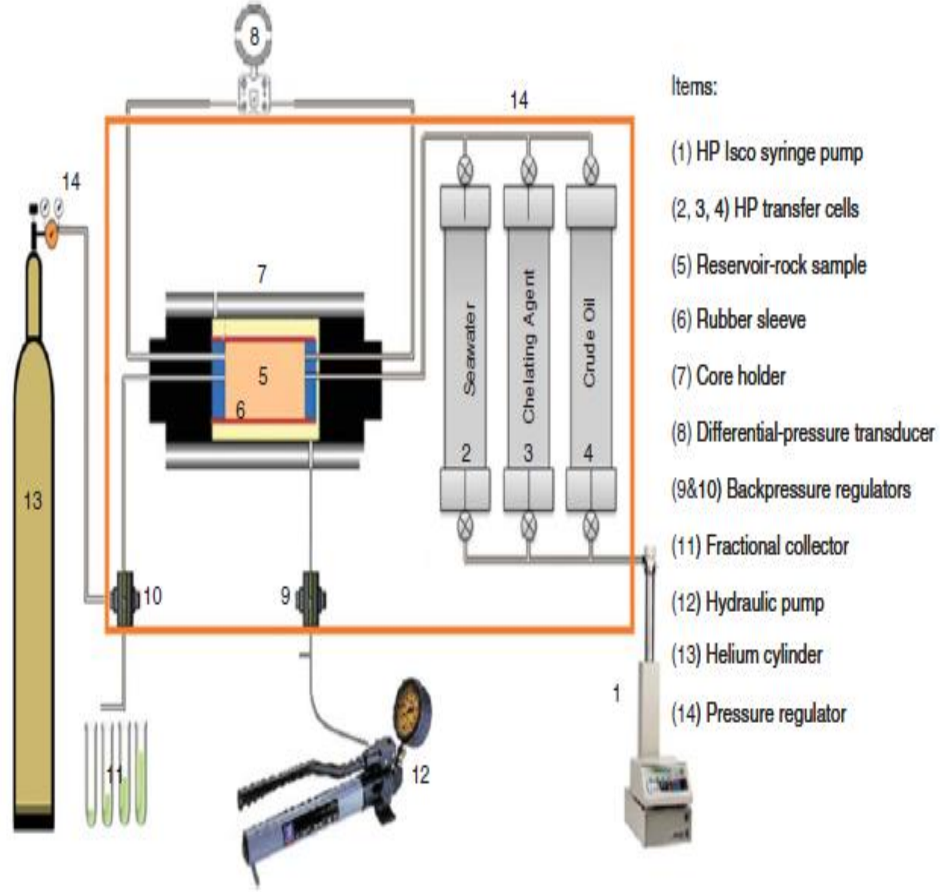

Figure 3: Core flooding set-up

Table 19: Core and oil properties

Berea sandstone			
Core aged in oil	4 weeks	**Rate**	0.25 cc/min
Oil API	31	**Back press**	1000 psi
Perm, md	76	**Length**	6 in
Porosity	20.5	**Diameter**	1.5 in
Temperature	100 ^{o}C	**Pore volume**	35.67 cc

3.7 Inductively coupled plasma - mass spectrometry (ICP-MS):

Tracking the change on the sandstone rocks' mineralogy due to conditioning with DTPA-K5 chelating agent is the main reason for conducting the ICP measurements. DTPA-K5 chelating agent is added to seawater at low concentrations. Powder of each sandstone rock is added to the chelating agent and seawater mixture and conditioned (mixed) for 2, 6, 12 and 24 hours and then filtered and the powder is dried after each conditioning period. The filtered liquid is taken after each conditioning period and the change in the concentrations of ions (Fe^{+3}, Ca^{+2}, Al^{+3} and Mg^{+2}) in the filtrate liquid is to be observed to determine the effect of the chelating agent on the rock mineralogy using ICP element analyzer (Inductively coupled plasma - mass spectrometry) Figure-4. The filtrate liquid resulted after conditioning the rock powders with 5 wt% DTPA -K5 and seawater is used to measure the ions content absorbed by the chelating agent from the rock powder. The base ion content values in the fluid mixture (5 wt% DTPA -K5 in seawater) are measure too to compare the change of ion content in the fluid mixture by increasing the conditioning period. Giving a clear observation of the mineralogy change in sandstone rocks due to mixing 5 wt% DTPA -K5 in seawater for different periods. Also, to capture the effect of seawater and low salinity water when mixed with the rock powder for 24 hours prior to zeta potential experiments, the change in the ions concentrations is measured using ICP for the liquid resulted from the filtrate of seawater or low salinity water with each powder type.

Figure 4: ICP-MS element analyzer

3.8 Zeta potential:

Zeta potential value is related to the thickness of the double layer and also, the charge of the interface surface between the mineral and brine. The main reason for conducting zeta potential measurements is as it has been observed in the literature: the more negative values of zeta potential for the brine/rock mixture, the more water wet the rock's surface is. Also, relating the mineralogy change in the rock after treating it by chelating agent with change in zeta potential value as a qualitative measure of wettability alteration. The device used is *Zetapals* manufactured by Brookhaven Instruments cooperation (Figure 5). The *zetapals* instrument uses a phase-analysis light-scattering (PALS) technique to determine the electrophoretic mobility (speed measurement) of charged colloidal suspensions, and calculates the ζ – Potential (in mV) with the Smoluchowsky and Huckel model.

Seawater and also low salinity water are added to the rock's powder and then conditioned for at least 24 hours using the multi-wrist shaker and pH value is measured. The concentrations of the fluid and powder are 0.125 grams of powder with 25 grams of fluid (0.5 wt%). To prepare good suspension from conditioned mixture to be used to the specifications of zeta potential analyzer in terms of particle size and particles concentration, conditioned mixture is filtered through 5.0 µm aqueous hydrophobic syringe filter and transferred to a transparent plastic square cuvette (volume ≈ 1.5 ml) and an assembly of two palladium electrodes was immersed in the sample. An electric field is generated across the sample by applying alternating current through the two electrodes which will force charged particles to move. At the same time, a laser beam from the recorded shift of the phase, an electrophoretic mobility pf particles will be measured which has a unit of (micron/second)/ (volt/cm). From the measured electrophoretic mobility, the zeta potential will be calculated using Sholuchowski model for aqueous suspension or the Huckel model for particles suspended in solvents. For the low salinity water mixtures, a 2.0 Hz frequency is implemented while a 20.0 Hz is used with the high salinity (seawater) mixtures. The main reason behind increasing the frequency with the higher salinity is to avoid electrode polarization (ions participate at the electrode) leading to wrong and inconsistent readings. Smoluchowsky's equation is given as follows:

$$\zeta = 113000\, EM\, \frac{v_t}{D_t} \qquad \textbf{(2)}$$

Where ζ = zeta potential (mV); v_t=viscosity of the suspending liquid in poises at temperature t; D_t= dielectric constant of the suspending liquid at temperature t; and *EM*=electrophoretic mobility at actual temperature. Zeta potential values are measured for the four sandstones with the seawater (mixed for 24 hours) and with the low salinity water (mixed for 24 hours) at ambient conditions. Different zeta potential readings are conducted then taking the average. For the base case, unconditioned powder is mixed with seawater or low salinity water for 24 hrs. Also the conditioned powders (dried after being filtered) are also mixed with seawater or low salinity water for 24 hrs. Mixing the powder with powder is done by shaking the samples using the mentioned multi-wrist shaker. Always, the powder to liquid ratio is 0.5 wt%. Zeta potential value is measure at least 10 times and the average is taken with consideration of consistency of the results. Many samples have been repeated three times to insure the readings consistency and accuracy.

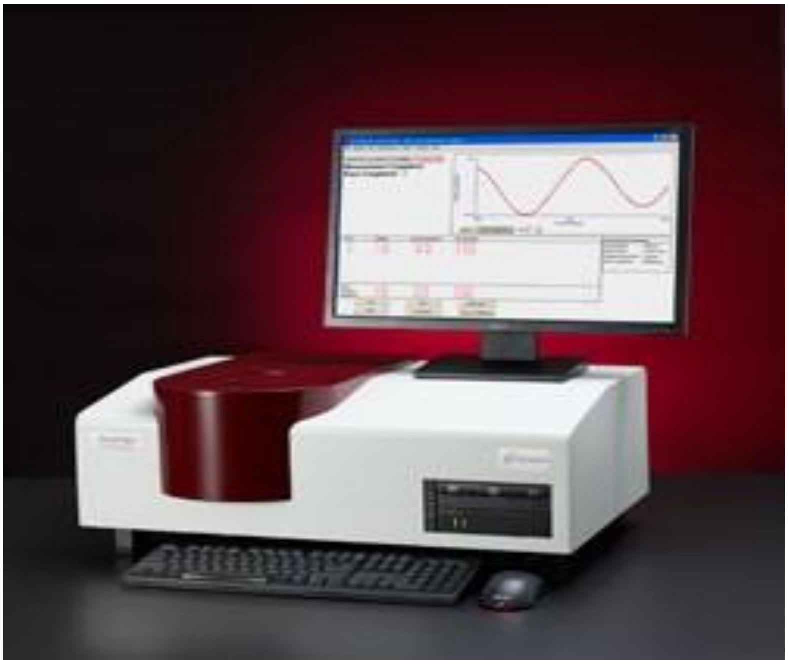

Figure 5: ZetaPALS instrument for ζ – Potential measurements

3.9 Dielectric measurement:

For dielectric equipment, the type of sample holder (fixture) required depends on the physical type of the material (solid, liquid, powder, gas). Dielectric measurements are performed on fluids only with different salinities and on powders from sandstone rocks with the same fluids formed for zeta potential measurements. Before testing the samples, De-ionized water and different water salinities are tested to as a base scenario before any additives. The device used is the Keysight 85070E Dielectric Probe Kit (Figure 6), used with a Keysight network analyzer, determines the intrinsic electromagnetic properties of many dielectric materials. The 85070E has a frequency range of 200 MHz to 50 GHz. The network analyzer is calibrated using a set of short, open (Air), and De-ionized water. The quality of contact between the sample and the probe is essential in reducing any measurement errors. The open-ended probe operates in reflection mode. To perform a reflection measurement, only one port of the network analyzer is used. The S11 scattering parameter (S-parameter), also called reflection coefficient, is measured by the network analyzer. The S-parameters are recorded in the form of an amplitude (in dB) and phase (in degrees) as a function of frequency which was varied from 500 MHz to 20 GHz. The device yields two values: e' and e" as function of frequency. e' is the real part of the complex permittivity representing the relative dielectric constant (unit less), relative to vacuum permittivity. e" is the imaginary part of the complex permittivity and relates to conductivity, it is also a unit less value. These two outcomes of the device readings are then inverted to estimate the conductivity and the permittivity of the sample. The quality of the measurement technique is routinely verified using the known dielectric property de-ionized water. The common expression for dielectric properties where they are related to complex number (complex permittivity $\mathcal{E}^*$) where it has a real and imaginary part is:

$$\mathcal{E}^* = \mathcal{E}_r + \frac{i\,\sigma}{\omega\,\varepsilon_0} \quad \textbf{(3)}$$

Where $\mathcal{E}_r$ is relative dielectric constant (Relative permittivity) which is a dimensionless quantity equal to the ratio of the medium and vacuum permittivities, $i = \sqrt{-1}$, σ is conductivity in (S/m), ω is circular frequency ($2\pi f$) (rd/s) , ε_0 is the vacuum permittivity in $\varepsilon_0 = 8.854187817 \times 10^{-12}$ F/m and f is the frequency (1/second or Hertz). σ is the conductivity as a function of frequency (Siemens/meter).

$$\sigma = e"\omega\,\varepsilon_0 \quad \textbf{(4)}$$

Where e" is the imaginary part of the dielectric permittivity complex (unit less).

All the measurements are done on ambient conditions. At least three readings are conducted showing a high consistency in the results. The average is taken of these readings and this procedure is repeated another time to insure the accuracy of the measurements. The uncertainty of the device is within 5 % error. The frequency range of the device considered on the comparison is from 500 MHz to 20 GHz. Knowing that the Dielectric logging tool has a frequency from 20 MHz to 1 GHz. Therefore, for comparison, readings are taken from 500MHz to 1 GHz, presenting the effect of volumetric polarization – which is due to the molecule volume (no coupling or interfacial polarization). The effect of presence of ions is clearly shown on the conductivity readings rather than the relative dielectric constant.

Figure 6: Keysight 85070E Dielectric Probe Kit, Dielectric experimental apparatus for powder samples

CHAPTER 4

EVALUATING THE EFFECT OF DTPA-K5 AND DIFFERENT WATER SALINITIES ON SANDSTONE ROCKS' SURFACE CHARGE

4.1 Effect of DTPA-K5 chelating agent on oil recovery

From the coreflooding experiment, with the setup of 1000 psig backpressure and 100 ^{o}c temperature, Seawater (57,000 ppm salinity) was injected into the core (76 md permeability, 0.205 porosity, 6 inch length and 1.5 inch diameter) - with 0.25 cc/min injection rate - for 3 pore volumes (107 cc) until water cut reached 100%. The recovery reached 55.9 %; then the chelating agent (DTPA-K5 as 5wt% in seawater with 11 pH value) was injected through the core in secondary recovery mode -with 0.25 cc/min injection rate- for 4 pore volumes (142 cc) to recover the residual oil. The contact time of the chelating agent mixture with the core was 9.4 hrs. Reaching an increase of the recovery until it reached 75.1%, Figure 7. After flooding, the core was cleaned from the oil with distillation by toluene and then the core was dried and saturated with formation brine. The final permeability was measured by formation brine at the same four flow rates (1, 2, 3 and 4 cc/min). An enhancement in permeability by 10% becoming 83.6 md was observed. To track the change in the mineralogy of the rock due to seawater and chelating agent injection, effluent analysis is conducted per every 0.2 pore volumes or so using the ICP-MS element analyzer device (Figure 8).

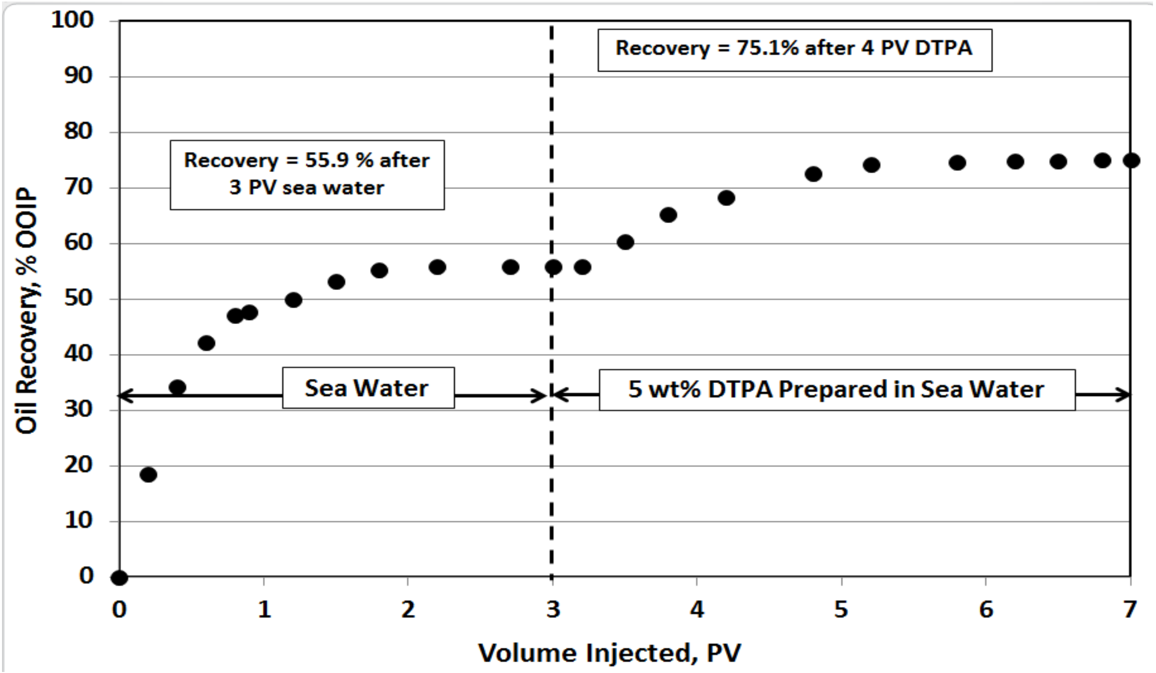

Figure 7: Berea sandstone core flooding experiment

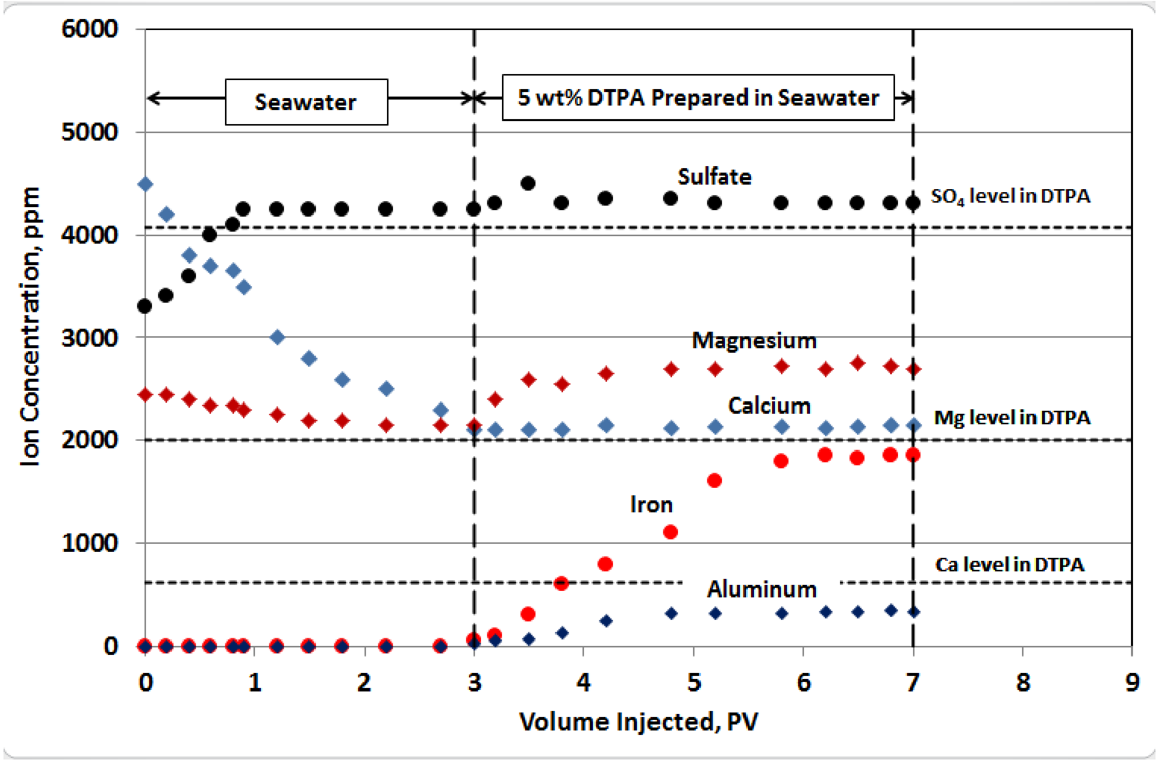

Figure 8: Berea sandstone effluent analysis with 3 pore volumes flooding of seawater followed by 4 pore volumes flooding with 5wt% DTPA-K5 in seawater

Results and discussion:

Bashiri and Kasiri (2011) used the Franklin equation to predict the capillary-desaturation curve which is the relation between the residual oil saturation (ROS) and capillary number. They compared the Franklin model prediction with the experimental data, and they got a good match. The Franklin equation can be written as follows:

$$S_{or} = 0.02 + 0.0505 \log\left(\frac{0.01227}{N_c + 0.5\, N_B}\right) \qquad \textbf{(5)}$$

$$N_C = \frac{\mu\nu}{\sigma\, COS\theta} \qquad \textbf{(6)}$$

$$N_B = \frac{\Delta\rho g k}{\sigma} \qquad \textbf{(7)}$$

Where S_{or} is ROS, N_c is the capillary number, N_B is the bond number, μ is the injected fluid viscosity, ν is the injection velocity, $\boldsymbol{\theta}$ is the contact angle, σ is the IFT, k is the rock's permeability, g is the gravity acceleration and $\Delta\rho$ is the density difference between the displacing and displaced fluids.

From the results of this coreflooding experiment, using DTPA-K5 chelating agent as 5 wt% in seawater as a secondary recovery after seawater flooding proved an enhancement in the oil recovery by 19.2 %. On the basis of Equation (5) increasing both the capillary and bond numbers will reduce the ROS and increase the oil recovery. DTPA-K5 has higher density and higher $\Delta\rho$ compared with seawater, as shown in Table-20. DTPA-K5 enhanced the wettability toward more water wet; this will reduce the contact angel and decrease the ROS. Also the permeability enhancement can be attributed to the dissolution caused by DTPA-K5 resulting in a multi-cation exchange between the chelating agent and the Berea sandstone rock's surface. From the effluent analysis (Figure 8) an Fe^{+3} and Al^{+3} ions started to appear in the effluent after DTPA-K5 is used for flooding, since both cations are not present in the seawater formation brine or DTPA-K5, the source is the Berea sandstone rock only. DTPA-K5 was able to absorb Fe^{+3} from the rock leading to increase of its concentration until it reached around 1,850 ppm by the end of the flooding experiment. Also Al^{+3} has been absorbed from the rock but at a lower rate than Fe^{+3} leading to a concentration increase till around 350 ppm. Comparing Figures 7 and 8, it can be noticed that recovery increase is coupled with the absorption of cations from the rock due to chelating agent effect leading to dissolution and changing of the rock's surface charge to more repulsive surface. For the Mg^{+2}, its concentration in the effluent started as its concentration in formation brine (2450 ppm), then continued to decrees reaching its concentration in seawater (2,110 ppm) and clearly after introducing DTPA-K5 to the flooding fluids, an increase of the Mg^{+2} ion is noticed (reached 2,700 ppm) where the excess ions came from the rock's mineralogy (around 590 ppm) after being absorbed by the chelating agent. The increase in Mg^{+2} concentration is less than the increase in Fe^{+3} concentration proving the higher stability constant of DTPA-K5 with Fe^{+3} than with Mg^{+2}- Table-8. For SO_4^{-2} concentration in the effluent, it started to increase reaching the seawater concentration after the first pore volume is flooded, SO_4^{-2} precipitation occurred form the presence of formation water and chelating agent showed no effect on SO_4^{-2} concentration. For Ca^{+2} level, its concentration was declining in the effluent and expected to reach its concentration in seawater (650 ppm) but, after introducing DTPA-K5 in the flooding fluid, Ca^{+2} concentration started to be stable rather than increasing. This behavior explain the effect of the chelating agent in absorbing Ca^{+2} ions for the rock until it was fully saturated at 2,150 ppm. At the end of flooding, Ca^{+2} predicted to be 650 ppm as in seawater but it appeared to be 2,150 with around 1,500 ppm absorbed from the Berea sandstone by the chelating agent. Summarizing the effluent analysis (Figure 8); DTPA_K5 absorbed 1,850 ppm of Fe^{+3}, 350 ppm of Al^{+3}, 590 ppm Mg^{+2} and 1,500 ppm Ca^{+2} (expectation only).

Table 20: Seawater and 5wt% DTPA-K5 chelating agent in seawater properties

Fluid	Density (g/cm^3)	Viscosity (μ) (cp)	Density Difference ($\Delta\rho = \rho_f - \rho_{oil}$)
Seawater	1.04	1.14	0.17
5 wt% DTPA	1.25	1.17	0.38

4.2 Effect of DTPA-K5 chelating agent on dissolving cations from the sandstone rocks' surfaces

DTPA-K5 chelating agent is added to seawater at low concentrations (5wt%). Powder of each sandstone rock is added to the chelating agent and seawater mixture and conditioned (mixed) for 2, 6, 12 and 24 hours and then filtered (separating the powder from the fluid) then the filtered liquid is taken after each conditioning period and the change in the concentrations of ions (Fe^{+3}, Ca^{+2}, Al^{+3} and Mg^{+2}) in the filtrate liquid is to observed to determine the effect of the chelating agent on the rock mineralogy using ICP element analyzer (Inductively coupled plasma - mass spectrometry). The ionic content of the base fluid is 5wt% DTPA-K5 in seawater is measured first. Table-21. With almost zero values of Fe and Al ions (not present in seawater or DTPA-K5) and similar value of the Mg and Ca ions as seawater prepared. Then, each filtrate ionic content from the conditioning procedure with Berea, Bandera, Kentucky and Scioto sandstone rocks' powder with the DTPA-SW mixture (5wt% DTPA-K5 in seawater) is measured, Forming a trend as the period of conditioning increases from 2,6,12 to 24 hours. The main ion that showed a clear trend and has been affected more than other ions is the ferric ion (Fe^{+3}). Knowing the total amount of Fe^{+3} in each sandstone powder (Table-16) the percentage of the total ions absorbed by the DTPA-SW mixture from the sandstone rock's powder ion content is reported in the following plots (Figures: 9-12). Also, Berea sandstone rock's powder has been mixed and conditioned with DTPA-K5 as 5wt% in De-ionized water and showed similar effect on the Fe^{+3} absorption ratio (Figure 13). There hasn't been a noticeable amount of Ca^{+2}, Al^{+3} and Mg^{+2} being absorbed from the sandstone rocks by the DTPA-SW mixture.

Table 21: Ionic content in 5 wt% DTPA-K5 in Seawater

Liquid	Mg^{2+} ppm	Al^{3+} ppm	Ca^{2+} ppm	Fe^{+3} ppm
5 wt% DTPA-K5 in Seawater	2413	0.032	658.1	0.1409

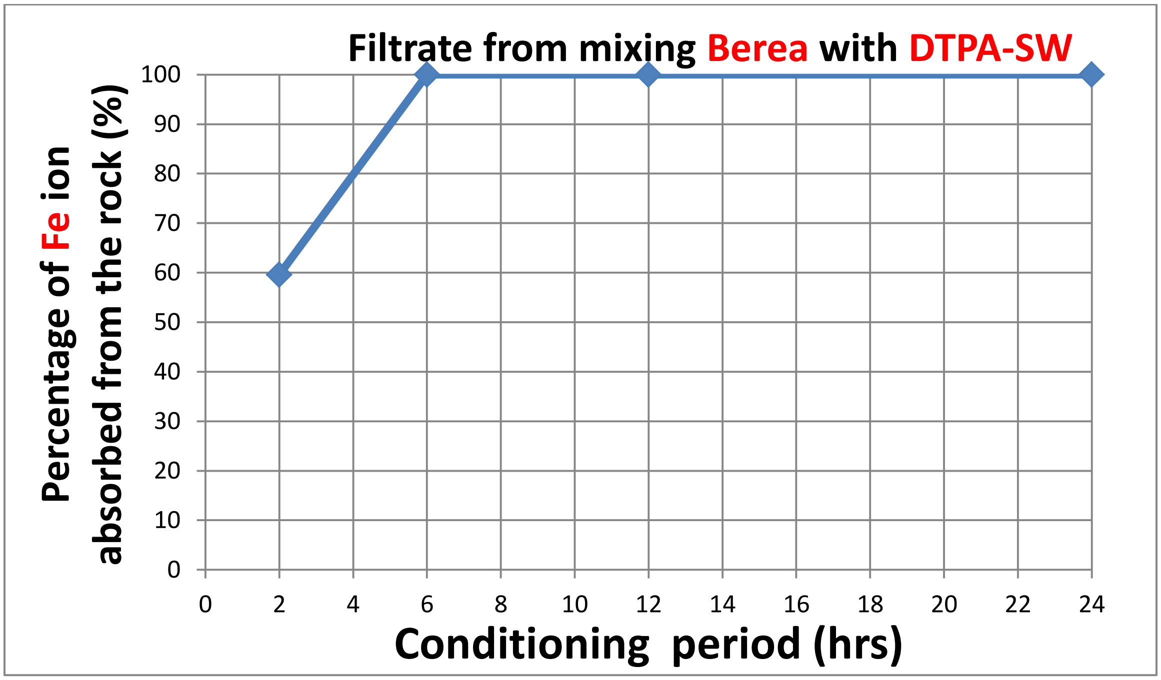

Figure 9: % of Fe^{+3} ions absorbed from the Berea after being treated with DTPA mixture for 2, 6, 12 and 24 hours

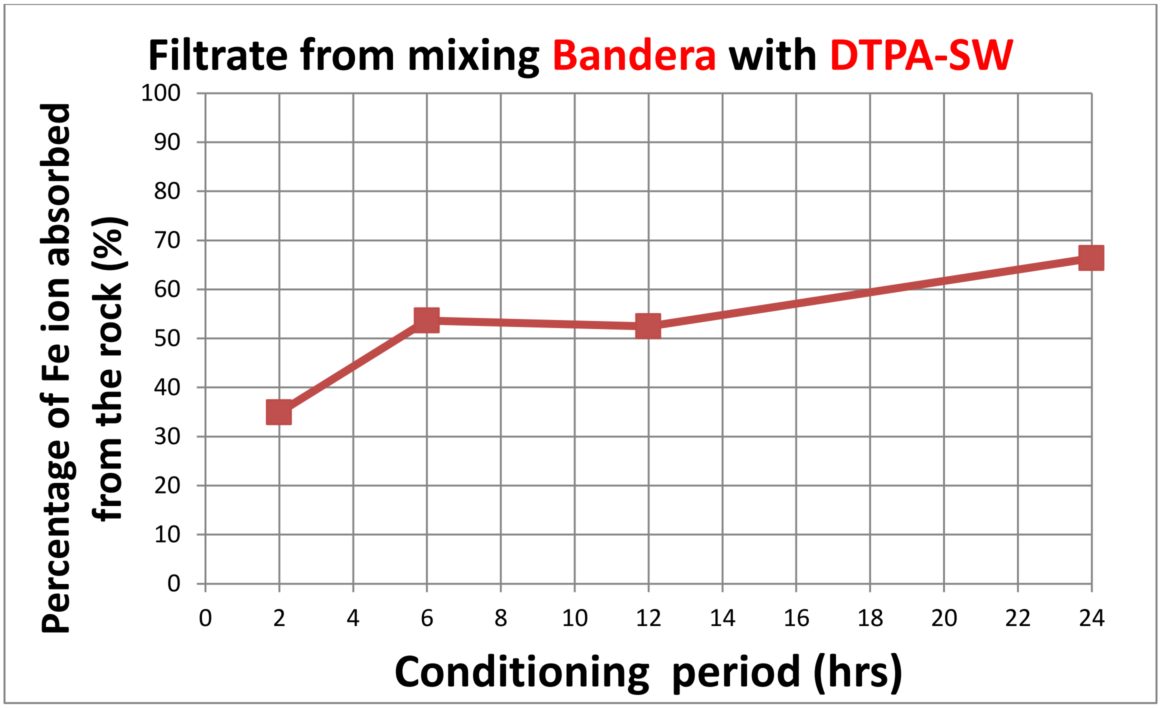

Figure 10: % of Fe^{+3} ions absorbed from the Bandera after being treated with DTPA mixture for 2, 6, 12 and 24 hours

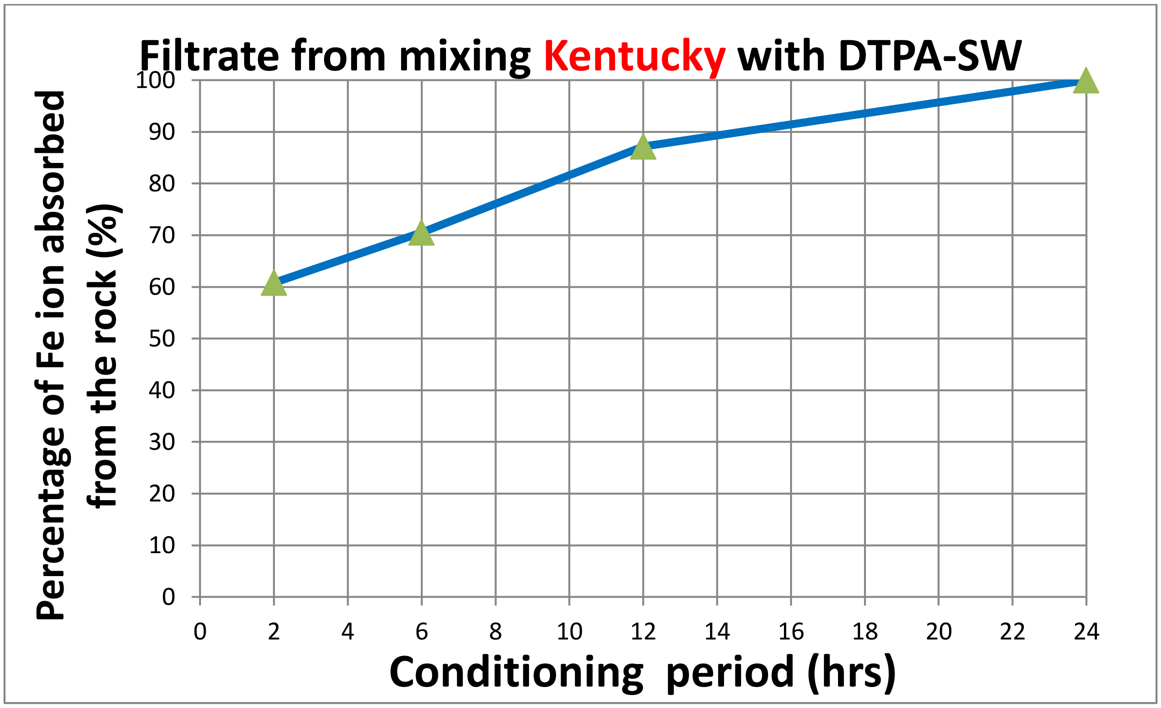

Figure 11: % of Fe^{+3} ions absorbed from the Kentucky after being treated with DTPA mixture for 2, 6, 12 and 24 hours

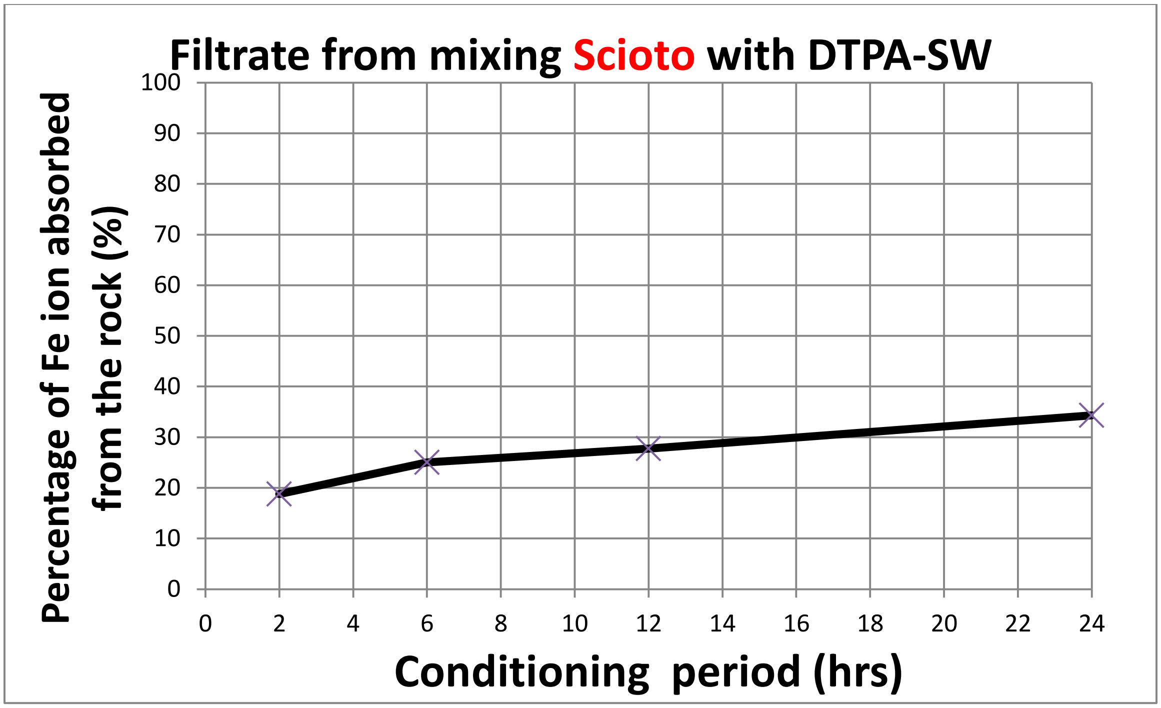

Figure 12: % of Fe^{+3} ions absorbed from the Scioto after being treated with DTPA mixture for 2, 6, 12 and 24 hours

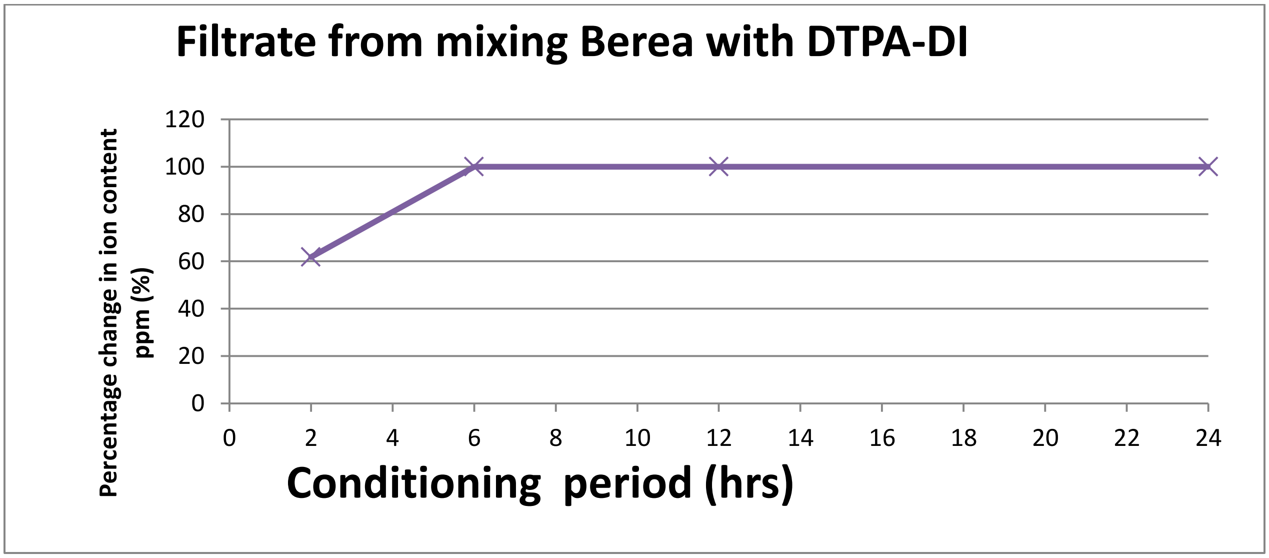

Figure 13: % of Fe^{+3} ions absorbed from the Berea after being treated with DTPA-K5 in DI water for 2, 6, 12 and 24 hours.

Results and discussion:

From the element analysis of the filtrate fluids resulted from mixing DTPA-K5 chelating agent with different sandstone rocks' powder, the ferric ion ($Fe^{+3)}$ shown to be absorbed from the sandstone rocks' surface's mineralogy more than other cations (Ca^{+2}, Al^{+3} and Mg^{+2}). For the Berea sandstone, after 2 hours of conditioning with DTPA-SW mixture (figure 9) or DTPA-DI mixture (figure 13), around 60 % of total ferric ion has been absorbed from the powder. After 6 hours of condition, the entire ferric ion has been absorbed leaving the Berea sandstone rock's surface without any presence of Fe^{+3}. For Bandera sandstone, the percentage of ferric ion that has been absorbed is much less than Berea (figure 10). For Bandera, it has a much more cations in its mineralogy than any other sandstone due to much higher Ca^{+2} and Mg^{+2} cation content (table-6), therefore the amount added of DTPA-SW mixture and the conditioning periods were not enough to seize all the ferric ion like Berea but it reached around 70% ferric ion absorbed after 24 hours of conditioning. Noticing that the change of Fe ion absorbed from the 6 and 12 hours conditioning periods is almost zero. For Kentucky sandstone rock, All the ferric ion have been absorbed after its powder have been conditioned for 24 hours, showing a clear increasing trend as conditioning period increases the ferric ion absorbed from the powder by DTPA-SW mixture increases (Figure 11). For Scioto sandstone rock, not the ferric ion have been absorbed after its powder have been conditioned for 24 hours (only 35%), even that it showed a clear increasing trend as conditioning period increases the ferric ion absorbed from the powder by DTPA-SW mixture increases (figure 12). The reason behind this behavior is that the amount of ferric ion in Scioto is much higher than any other sandstone rock (around 3 times higher) as shown in table-6. Also, reaching a maximum of 35% of ferric ion absorbed from the rock is equivalent to a higher amount of ferric ion (in ppm) absorbed from any sandstone rock conditioned by DTPA-SW mixture, which can be attributed to chelating agent being fully saturated by cations and not able to absorb more easily.

4.3 Effect of absorbing certain cations from sandstone - using DTPA-K5 chelating agent - on zeta potential values

The Powder dried powder that has been conditioned by chelating agent for different periods is taken to be used in zeta potential measurements. 0.5 wt% of powder to liquid is used in all the measurements. Treated (conditioned) powder is mixed with seawater, low salinity water or De-ionized water for 24 hours on all the measurements. A base scenario, measuring zeta potential for untreated powder mixed with brine (seawater or low salinity water) which is referred to as zero hours conditioning. Powder mixed with brine is then filtered through a 5.0 micro-meter aqueous hydrophobic syringe filter. All measurements are an average of 10 readings. Also, all measurements have been repeated at least 3 times resulting in high consistency. Measurements are done following the procedures done in the literature which complies with the device using instructions. For high salinity water (seawater with salinity = 57,670 ppm) device set a frequency of 20 Hz to overcome the device's limitation, while other measurements are done using frequency of 2 Hz – default. Table-22 shows the average conductance (micro Siemens) that has been measured using the *Zetapals* device.

Table-22: Electrical conductance values for different fluids

Fluid/powder mixture	Conductance (µS)
Sandstone powder soaked in Seawater	150,0000
Sandstone powder soaked in Low salinity water	22,000
Sandstone powder soaked in De-ionized water	180
Sandstone powder soaked in 5wt% DTPA-K5 in Seawater	150,000
Sandstone powder soaked in 5wt% DTPA-K5 in low salinity water	50,000
Sandstone powder soaked in 5wt% DTPA-K5 in DI water	37,000
Sandstone powder soaked in 10wt% DTPA-K5 in Seawater	173,000

For all the measurements, the increase in the powder conditioning (treating) period with chelating agent is measured with the change in zeta potential value. The increase in conditioning period goes from zero (unconditioned powder) to 2,6,12 and 24 hours. All the samples after being conditioned (also the unconditioned powders) are mixed by brine (seawater, low salinity water or De-ionized water) for 24 hours prior to the zeta potential measurement. The following figures (Figures 14-22) present the measurements summarized in tables 23, 24 and 25. Also all the pH values of the mixtures are recorded giving values around 7 as presented by seawater and low salinity water.

Table 23: Zeta potential results (DI water samples) with Berea

Rock	Rock Powder condition	liquid mixed for 24 hours	ζ - zeta potential (mV)
Berea	not conditioned (zero hours)	DI water	-26.75
	Conditioned for 2 hrs with 5wt% DTPA in DI water		-32.77
	Conditioned for 6 hrs with 5wt% DTPA in DI water		-37.84
	Conditioned for 12 hrs with 5wt% DTPA in DI water		-42.27
	Conditioned for 24 hrs with 5wt% DTPA in DI water		-53.3

Table 24: Zeta potential results (DI water samples) with Berea

Rock	Rock Powder condition	liquid mixed for 24 hours	ζ - zeta potential (mV)	PH
Berea	not conditioned (zero hrs)	Seawater	15.49	7.8
	conditioned w/ 5 wt% DTPA in SW for 2 hrs		-6.74	7.7
	conditioned w/ 5 wt% DTPA in SW for 6 hrs		-10.49	7.78
	conditioned w/ 5 wt% DTPA in SW for 12 hrs		-17.37	7.74
	conditioned w/ 5 wt% DTPA in SW for 24 hrs		-16.95	7.68
Bandera	not conditioned (zero hrs)	Seawater	16.76	7.7
	conditioned w/ 5 wt% DTPA in SW for 2 hrs		-16.7	7.6
	conditioned w/ 5 wt% DTPA in SW for 6 hrs		-20.97	7.74
	conditioned w/ 5 wt% DTPA in SW for 12 hrs		-21.11	7.57
	conditioned w/ 5 wt% DTPA in SW for 24 hrs		-25.91	7.63
Kentucky	not conditioned (zero hrs)	Seawater	-7.03	7.74
	conditioned w/ 5 wt% DTPA in SW for 2 hrs		-7.54	7.7
	conditioned w/ 5 wt% DTPA in SW for 6 hrs		-8.8	7.8
	conditioned w/ 5 wt% DTPA in SW for 12 hrs		-10.19	7.67
	conditioned w/ 5 wt% DTPA in SW for 24 hrs		-11.03	7.69
Scioto	not conditioned (zero hrs)	Seawater	5.84	7.74
	conditioned w/ 5 wt% DTPA in SW for 2 hrs		-14.24	7.7
	conditioned w/ 5 wt% DTPA in SW for 6 hrs		-16.02	7.75
	conditioned w/ 5 wt% DTPA in SW for 12 hrs		-13.36	7.64
	conditioned w/ 5 wt% DTPA in SW for 24 hrs		-9.98	7.72

Table 25: Zeta potential results (low salinity water samples)

Rock	Rock Powder condition	liquid mixed for 24 hours	ζ - zeta potential (mV)	pH
Berea	not conditioned	Low salinity water	-19.56	7.5
	conditioned w/ 5 wt% DTPA in SW for 2 hrs		-21.45	7.63
	conditioned w/ 5 wt% DTPA in SW for 6 hrs		-23.91	7.23
	conditioned w/ 5 wt% DTPA in SW for 12 hrs		-24.52	7.6
	conditioned w/ 5 wt% DTPA in SW for 24 hrs		-21.91	7.55
Bandera	not conditioned	Low salinity water	-20.7	7.2
	conditioned w/ 5 wt% DTPA in SW for 2 hrs		-24.09	7.2
	conditioned w/ 5 wt% DTPA in SW for 6 hrs		-24.55	7.2
	conditioned w/ 5 wt% DTPA in SW for 12 hrs		-24.65	7.61
	conditioned w/ 5 wt% DTPA in SW for 24 hrs		-25.19	7.49
Kentucky	not conditioned	Low salinity water	-18.03	7.6
	conditioned w/ 5 wt% DTPA in SW for 2 hrs		-20.53	7.4
	conditioned w/ 5 wt% DTPA in SW for 6 hrs		-22.28	7.3
	conditioned w/ 5 wt% DTPA in SW for 12 hrs		-24.7	7.54
	conditioned w/ 5 wt% DTPA in SW for 24 hrs		-21.98	7.44
Scioto	not conditioned	Low salinity water	-16.28	7.53
	conditioned w/ 5 wt% DTPA in SW for 2 hrs		-18.54	7.3
	conditioned w/ 5 wt% DTPA in SW for 6 hrs		-18.9	7.2
	conditioned w/ 5 wt% DTPA in SW for 12 hrs		-23.26	7.61
	conditioned w/ 5 wt% DTPA in SW for 24 hrs		-20.28	7.65

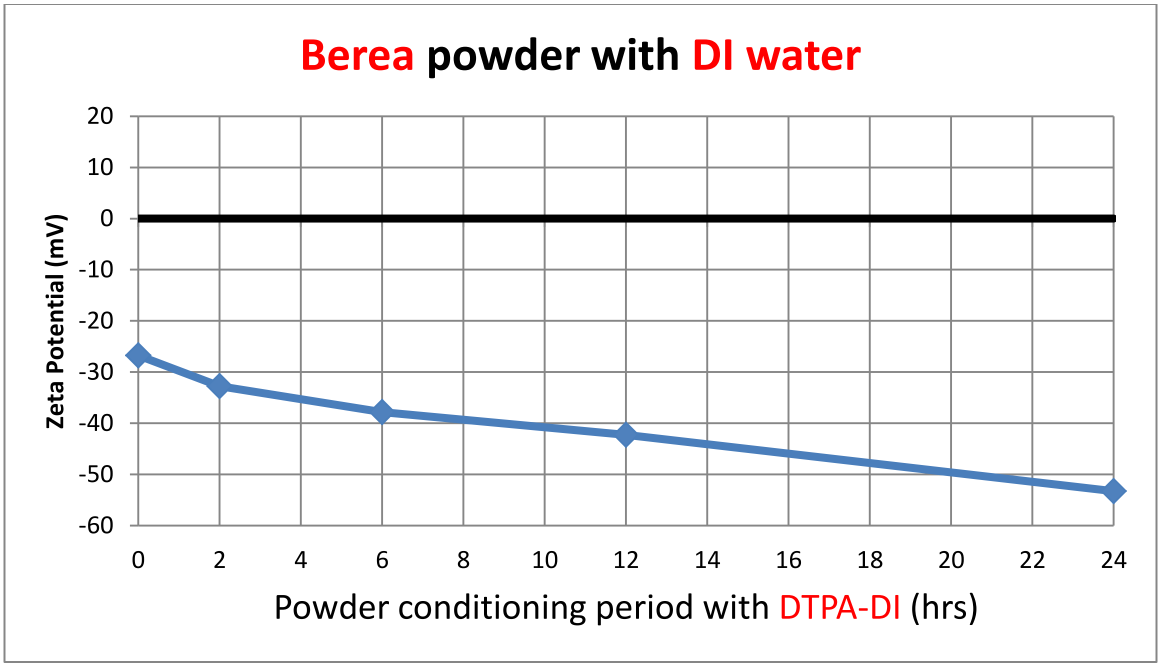

Figure 14: Zeta potential values of Berea sandstone different powders (unconditioned, conditioned with DTPA-DI for 2, 6, 12 and 24 hours) then mixed with DI water for 24 hours.

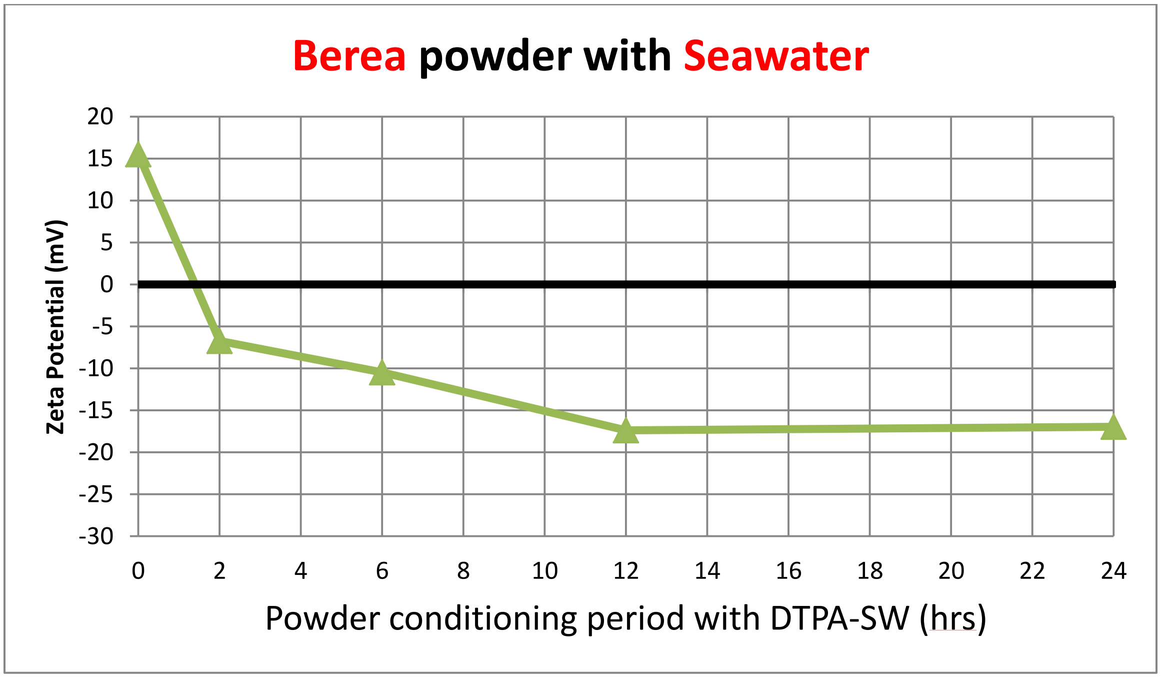

Figure 15: Zeta potential values of Berea sandstone different powders (unconditioned, conditioned with DTPA-SW for 2, 6, 12 and 24 hours) then mixed with SW water for 24 hours.

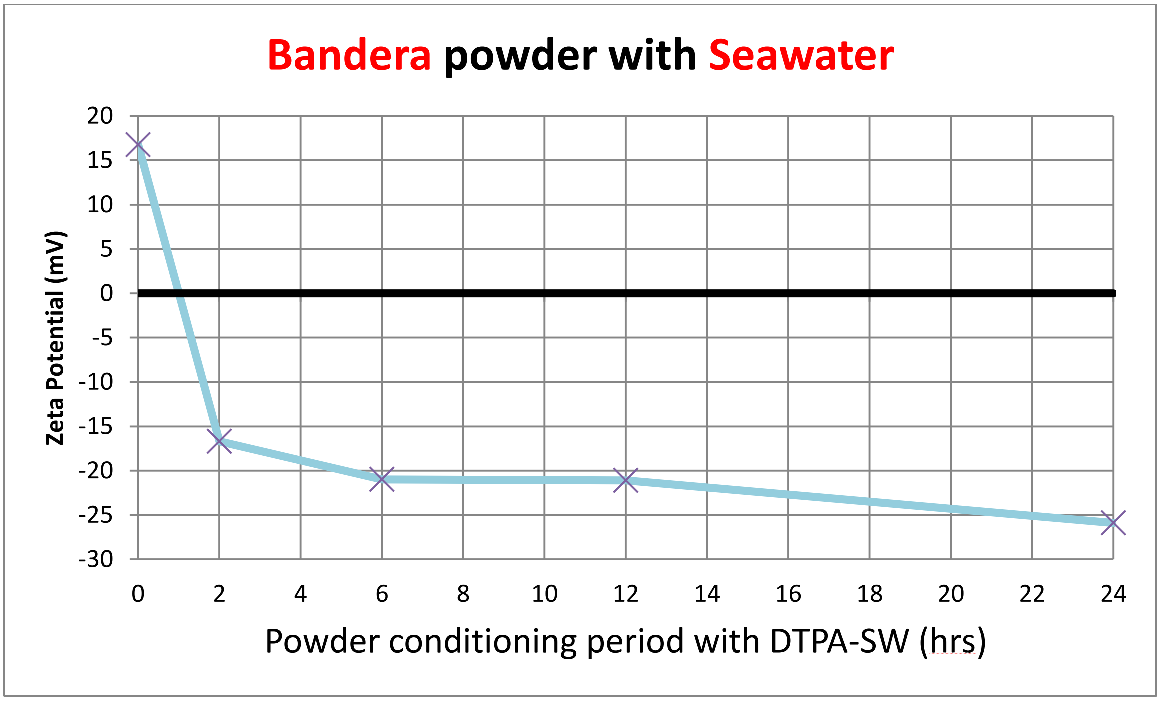

Figure 16: Zeta potential values of Bandera sandstone different powders (unconditioned, conditioned with DTPA-SW for 2, 6, 12 and 24 hours) then mixed with SW water for 24 hours.

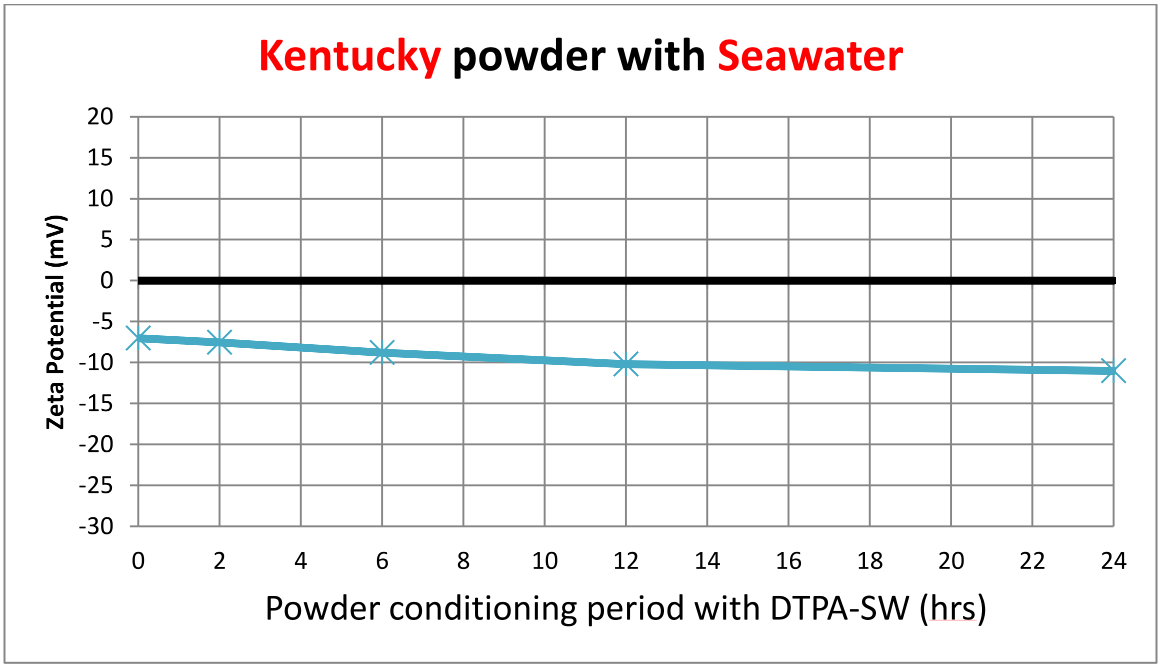

Figure 17: Zeta potential values of Kentucky sandstone different powders (unconditioned, conditioned with DTPA-SW for 2, 6, 12 and 24 hours) then mixed with SW water for 24 hours.

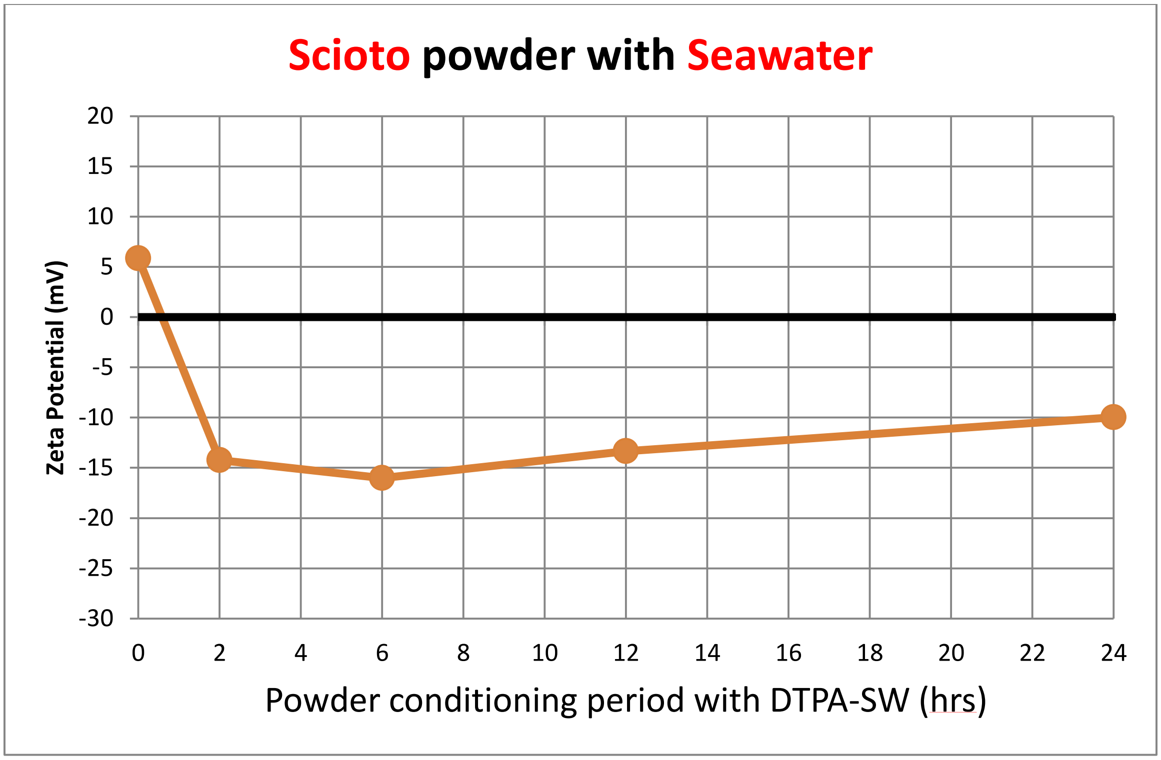

Figure 18: Zeta potential values of Scioto sandstone different powders (unconditioned, conditioned with DTPA-SW for 2, 6, 12 and 24 hours) then mixed with SW water for 24 hours.

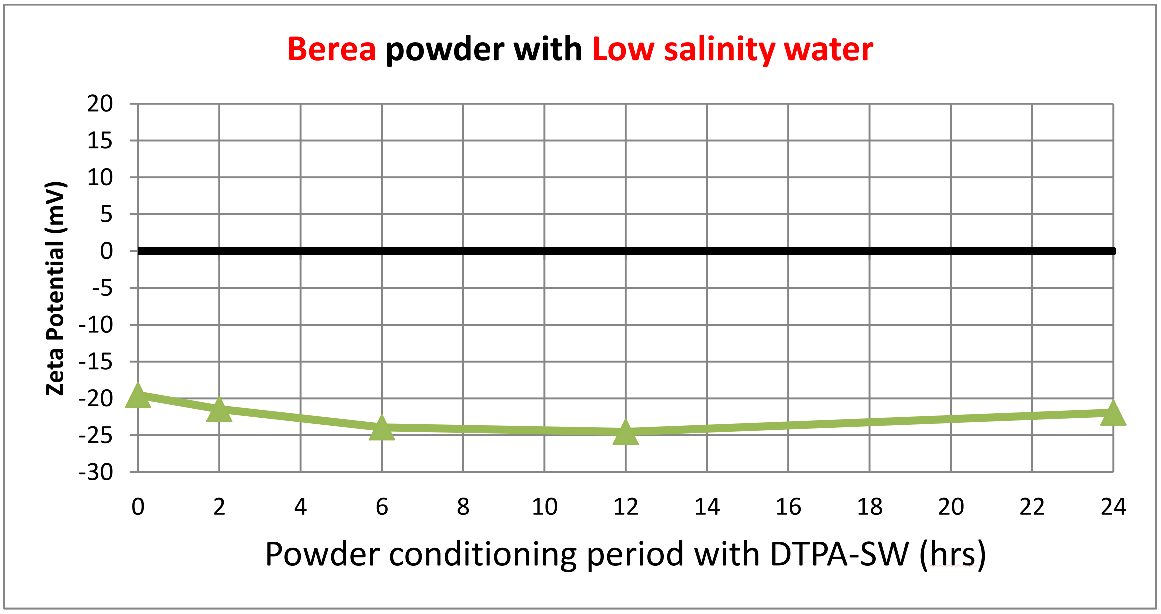

Figure 19: Zeta potential values of Berea sandstone different powders (unconditioned, conditioned with DTPA-SW for 2, 6, 12 and 24 hours) then mixed with LS water for 24 hours.

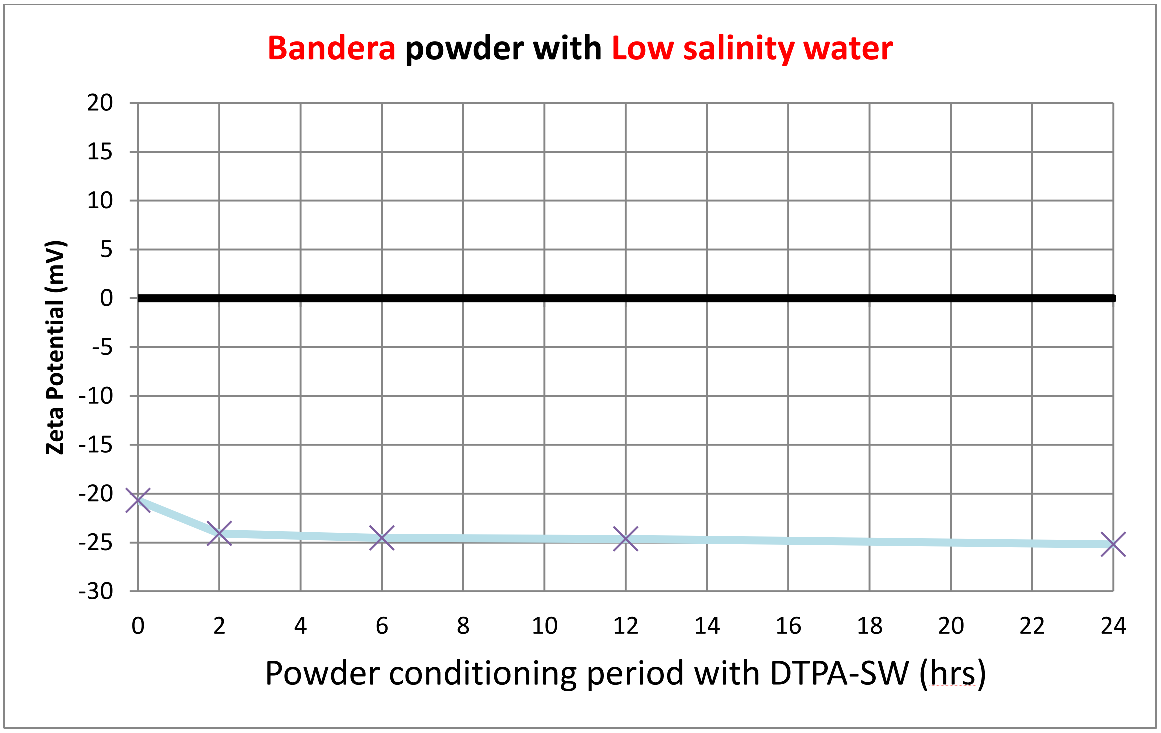

Figure 20: Zeta potential values of Bandera sandstone different powders (unconditioned, conditioned with DTPA-SW for 2, 6, 12 and 24 hours) then mixed with LS water for 24 hours.

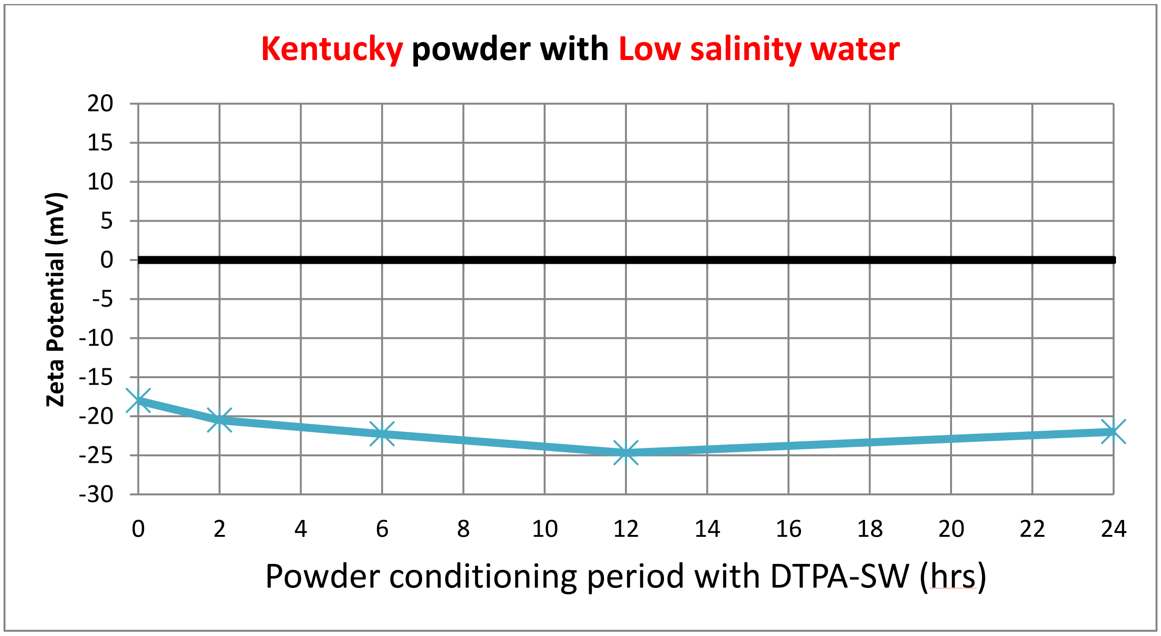

Figure 21: Zeta potential values of Kentucky sandstone different powders (unconditioned, conditioned with DTPA-SW for 2, 6, 12 and 24 hours) then mixed with LS water for 24 hours.

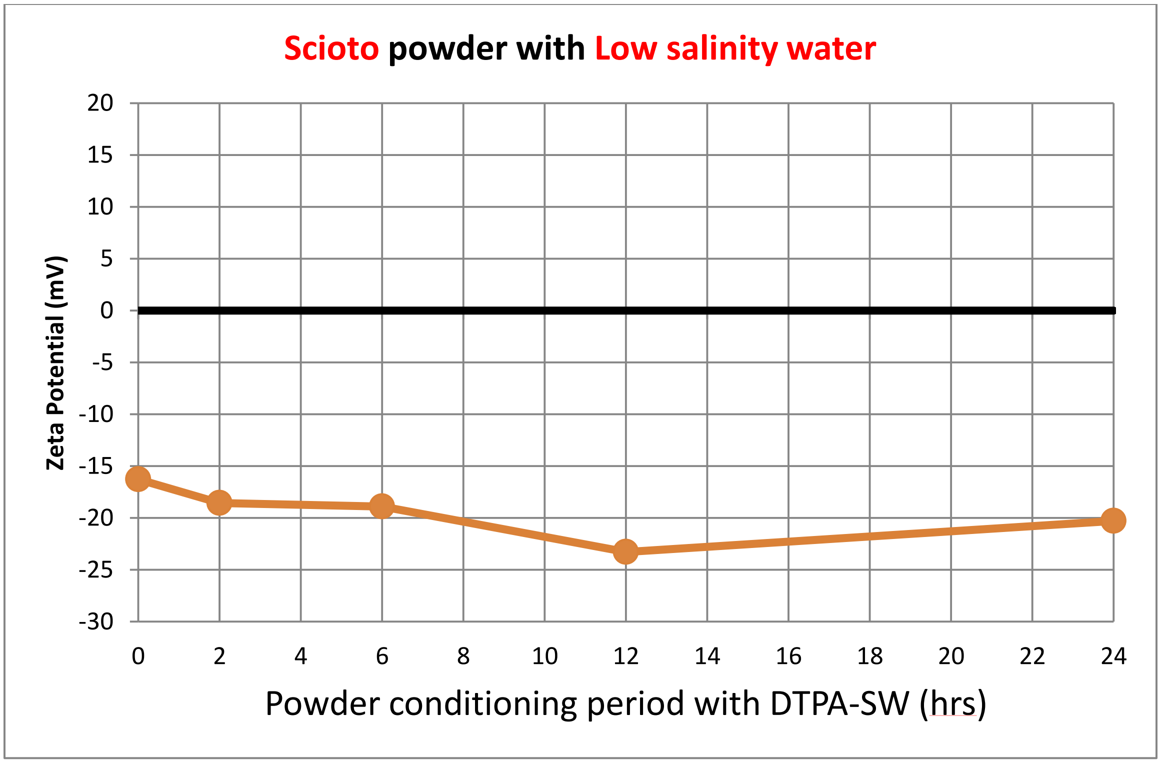

Figure 22: Zeta potential values of Scioto sandstone different powders (unconditioned, conditioned with DTPA-SW for 2, 6, 12 and 24 hours) then mixed with LS water for 24 hours.

4.4 Relating the amount of ferric ion dissolved from the rock with zeta potential value:

From the ICP measurements conducted on the filtrates from conditioned with chelating agent, the following figures (Figures 23-26) relates the percentage change of ferric ion absorbed from the rock after being conditioned with cheating agent with change in zeta potential values.

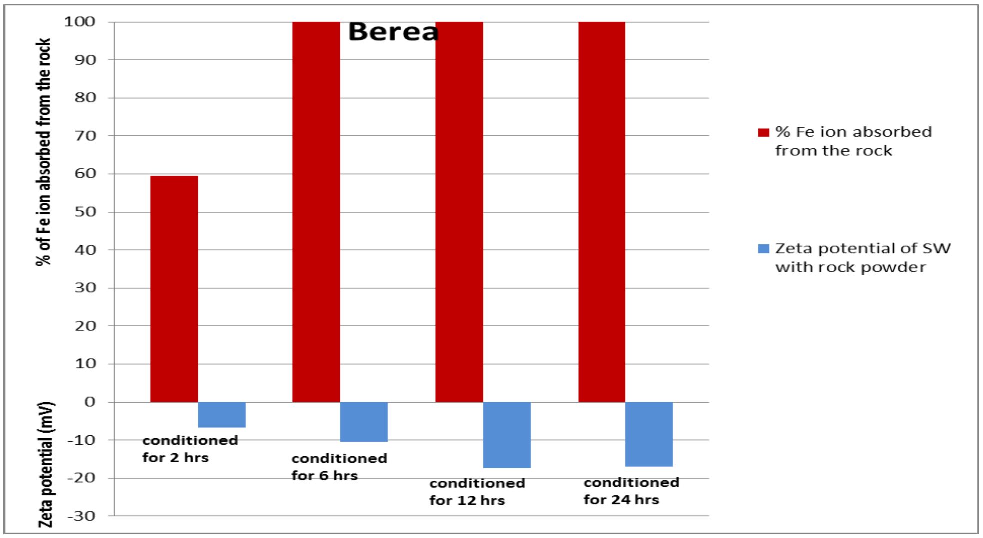

Figure 23: Zeta potential values of Berea sandstone with % of ferric ion absorbed from the powder after being conditioned with DTPA-SW for different time periods.

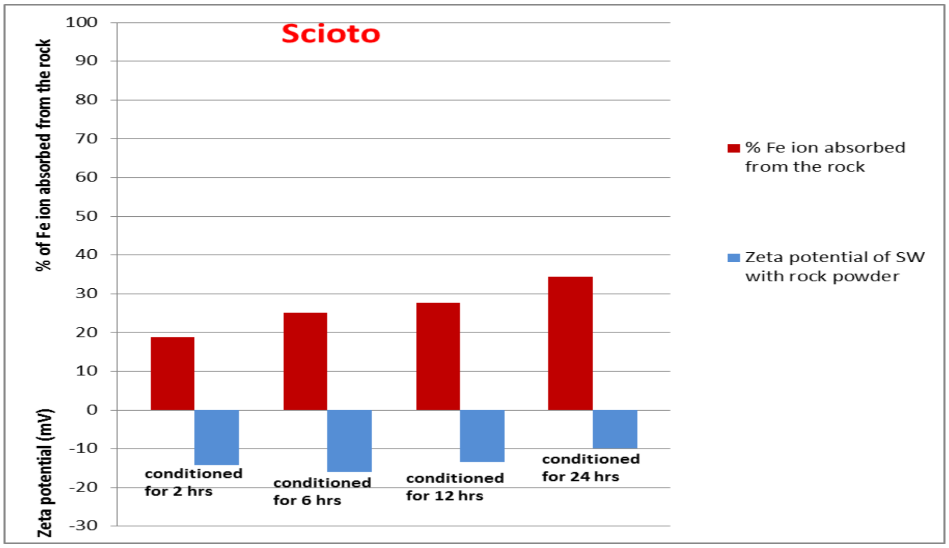

Figure 24: Zeta potential values of Scioto sandstone with % of ferric ion absorbed from the powder after being conditioned with DTPA-SW for different time periods.

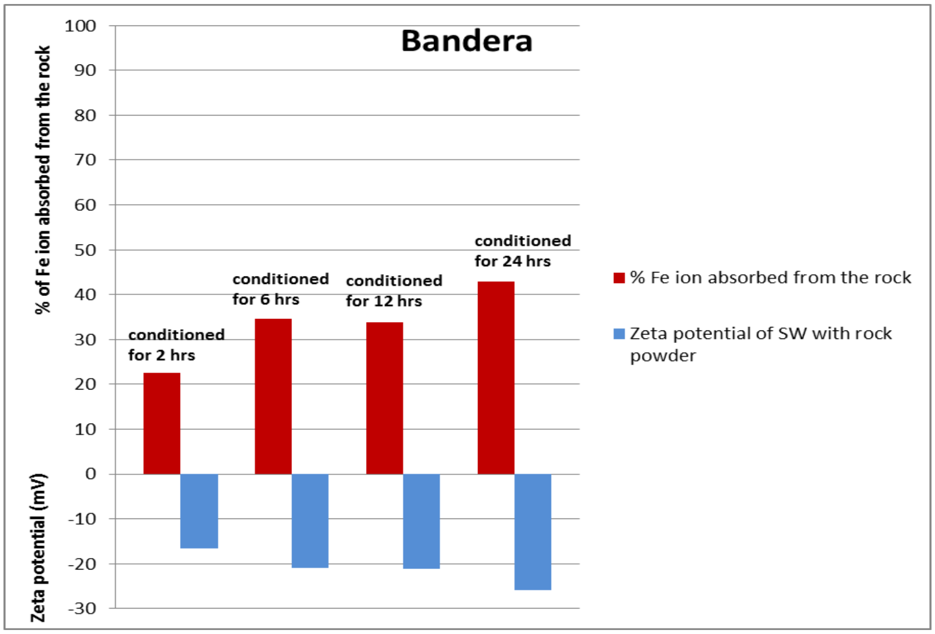

Figure 25: Zeta potential values of Bandera sandstone with % of ferric ion absorbed from the powder after being conditioned with DTPA-SW for different time periods.

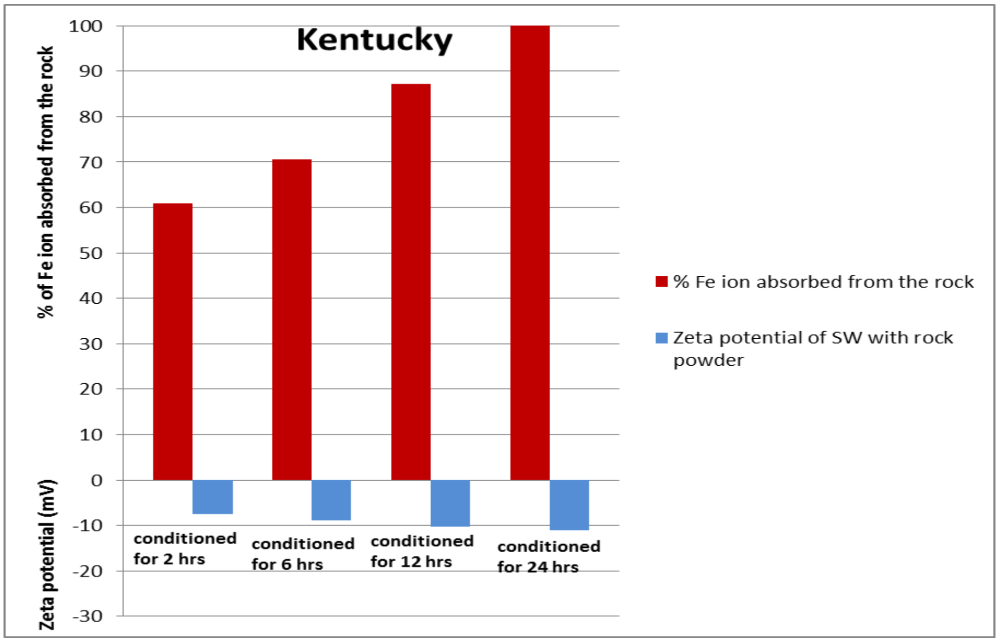

Figure 26: Zeta potential values of Kentucky sandstone with % of ferric ion absorbed from the powder after being conditioned with DTPA-SW for different time periods.

4.5 Effect on zeta potential values of mixing unconditioned Berea sandstone with seawater for different periods vs. mixing the conditioned powder with seawater for 24 hours:

Table-26: Zeta potential results (mixed with Seawater samples)

Rock	Rock Powder condition	liquid mixed	ζ - zeta potential (mV)
Berea	not conditioned	SW for 2 hrs	20.62
	not conditioned	SW for 6 hrs	14.55
	not conditioned	SW for 15 hrs	14.1
	not conditioned	SW for 24 hrs	11.67
	conditioned w/ 5 wt% DTPA in SW for 2 hrs	SW for 24 hrs	-6.74
	conditioned w/ 5 wt% DTPA in SW for 6 hrs		-10.49
	conditioned w/ 5 wt% DTPA in SW for 12 hrs		-17.37
	conditioned w/ 5 wt% DTPA in SW for 24 hrs		-16.95

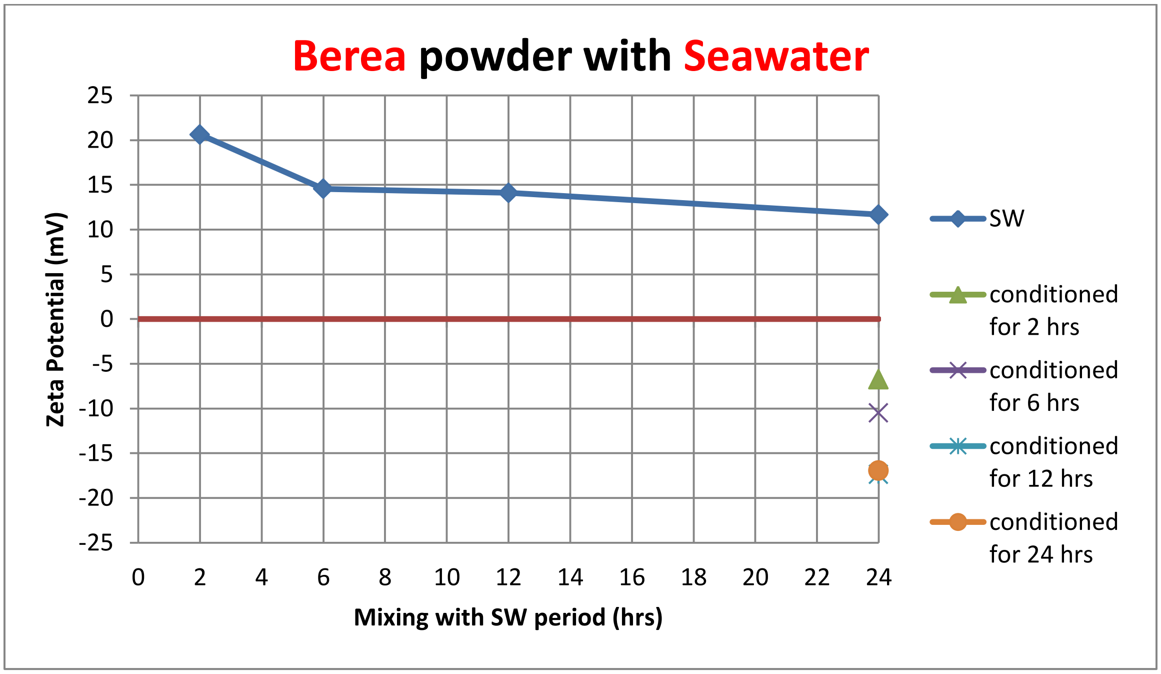

Figure 27: Zeta potential values of untreated Berea sandstone powder mixed with seawater for different periods vs. mixing the treated powder with seawater for 24 hours.

4.6 Effect on zeta potential values of mixing unconditioned Berea sandstone with low salinity water for different periods vs. mixing the conditioned powder with low salinity water for 24 hours:

Table-27: Zeta potential results (mixed with low salinity samples)

Rock	Rock Powder condition	liquid mixed	ζ - zeta potential (mV)
Berea	not conditioned	LS for 2 hrs	-15.77
	not conditioned	LS for 6hrs	-15.88
	not conditioned	LS for 15 hrs	-16.39
	not conditioned	LS for 24 hrs	-19.09
	conditioned w/ 5 wt% DTPA in SW for 2 hrs	LS for 24 hrs	-21.45
	conditioned w/ 5 wt% DTPA in SW for 6 hrs		-23.91
	conditioned w/ 5 wt% DTPA in SW for 12 hrs		-24.52
	conditioned w/ 5 wt% DTPA in SW for 24 hrs		-21.91

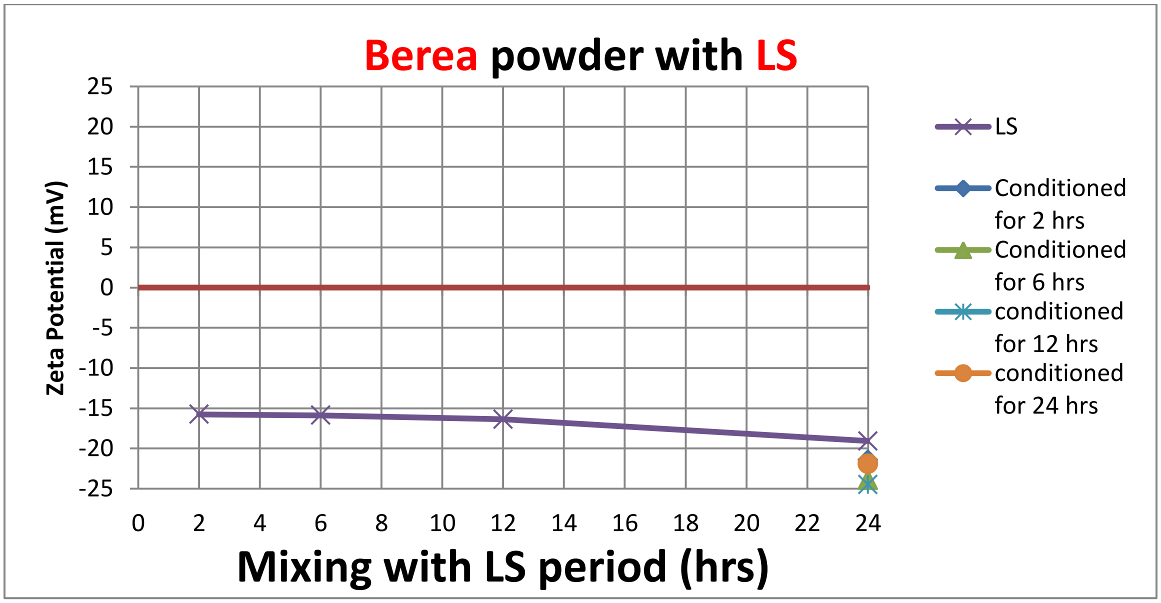

Figure 28: Zeta potential values of untreated Berea sandstone powder mixed with low salinity for different periods vs. mixing the treated powder with low salinity for 24 hours.

4.7 Zeta potential measurements methodology in reservoir concepts terms:

In the zeta potential laboratory measurements; first, the rock powder is conditioned with the chelating agent mixture in order to absorb cations and change the mineralogy of its surface (for 2, 6, 12 or 24 hrs). In the reservoir concept it could be implemented by saying that, chelating agent mixture is flooded into the reservoir as a (pre-flush) to change the rock's surface and alter its wettability. The chelating agent mixture is 5wt% DTPA-K5 with seawater. Second, in the lab measurements the powder is filtered and dried then mixed with seawater or low salinity water for 24 hours. Which can be implemented in the reservoir as a secondary flooding procedure is performed using seawater or low salinity water into the more water wet rock's surface. Finally, in the lab measurements, Zeta potential is measured for the powder/brine mixture and recording the change in Zeta potential as mineralogy of the rock changes due to conditioning for different time periods. Where Zeta potential values showed a more negative values after the rock's surface is pre-flushed with the chelating agent mixture (more water-wet) prior to seawater or low salinity flooding.

4.8 Effect on Zeta potential values of mixing different Berea sandstone powders with De-ionized water or 5wt% of DTPA-K5 in De-ionized water:

For all the measurements, “mixed” refers to being mixed for 24 hours prior to Zeta potential measurements. “Treated” refers to being conditioned for 24 hours with 5wt% DTPA-K5 in De-ionized water.

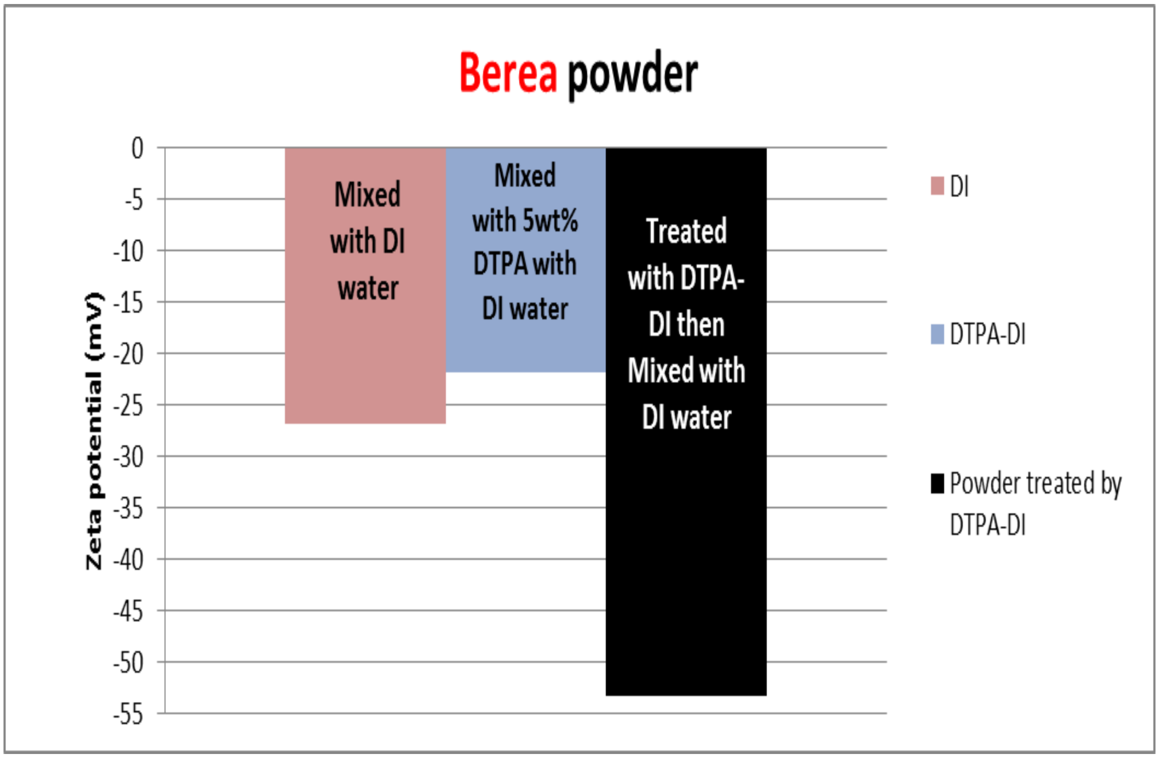

Figure 29: Zeta potential values of mixing unconditioned Berea sandstone powder with De-ionized water for 24 hours, mixing 5wt% of DTPA-K5 in De-ionized water with unconditioned Berea sandstone for 24 hours and mixing De-ionized water with conditioned (treated) Berea sandstone (conditioned with DTPA-DI for 24 hours) for 24 hours.

4.8.1 Zeta potential measurements methodology in reservoir concepts terms:

Mixing with the DI water or 5 wt% DTPA-K5 in DI water for 24 hours is the flooding term in the reservoir, while conditioning (treating) with DTPA-DI for 24 hours is considered as a pre-flush stage or primary flooding using 5 wt% DTPA-K5 in DI water followed by secondary flooding using DI water for 24 hours.

4.9 Effect on Zeta potential values of mixing different Berea sandstone powders with seawater or 5wt% of DTPA-K5 in seawater water:

For all the measurements, “mixed” refers to being mixed for 24 hours prior to zeta potential measurements. “Treated” refers to being conditioned for 24 hours with 5wt% DTPA-K5 in seawater.

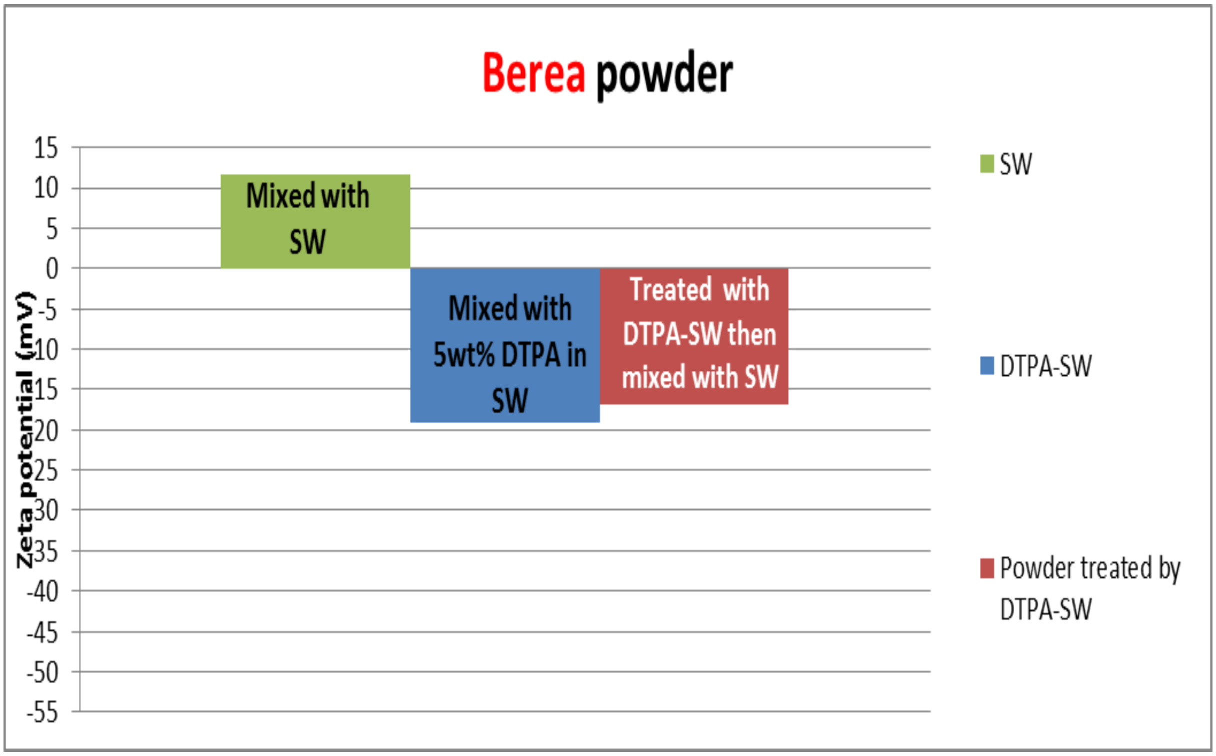

Figure 30: Zeta potential values of mixing unconditioned Berea sandstone powder with seawater for 24 hours, mixing 5wt% of DTPA-K5 in seawater with unconditioned Berea sandstone for 24 hours and mixing seawater with conditioned (treated) Berea sandstone (conditioned with DTPA-SW for 24 hours) for 24 hours.

4.9.1 Zeta potential measurements methodology in reservoir concepts terms:

Mixing with the seawater or 5 wt% DTPA-K5 in seawater for 24 hours is the flooding term in the reservoir, while conditioning (treating) with DTPA-SW for 24 hours is considered as a pre-flush stage or primary flooding using 5 wt% DTPA-K5 in seawater followed by secondary flooding using seawater for 24 hours.

4.10 Effect on Zeta potential values of mixing different Berea sandstone powders with low salinity water or 5wt% of DTPA-K5 in seawater:

For all the measurements, “mixed” refers to being mixed for 24 hours prior to zeta potential measurements. “Treated” refers to being conditioned for 24 hours with 5wt% DTPA-K5 in low salinity water (DTPA-SW).

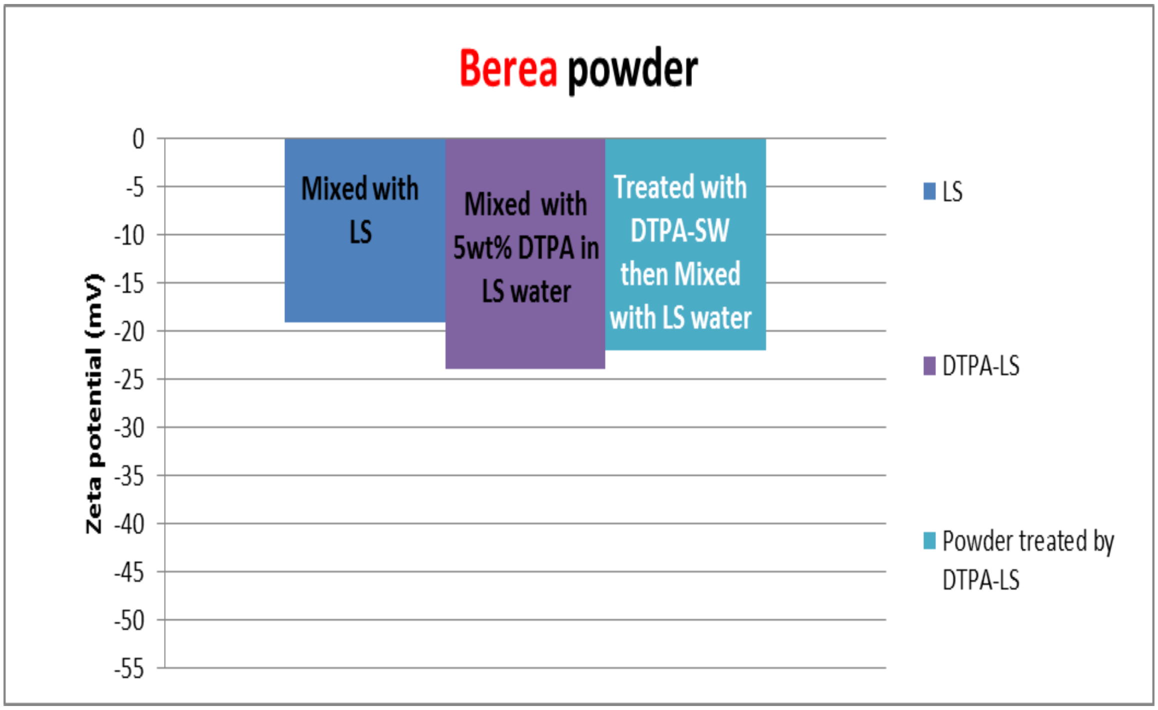

Figure 31: Zeta potential values of mixing unconditioned Berea sandstone powder with low salinity water for 24 hours, mixing 5wt% of DTPA-K5 in low salinity water with unconditioned Berea sandstone for 24 hours and mixing low salinity water with conditioned (treated) Berea sandstone (conditioned with DTPA-SW for 24 hours) for 24 hours.

4.10.1 Zeta potential measurements methodology in reservoir concepts terms:

Mixing with the Low salinity water or 5 wt% DTPA-K5 in low salinity water for 24 hours is the flooding term in the reservoir, while conditioning (treating) with DTPA-SW for 24 hours is considered as a pre-flush stage or primary flooding using 5 wt% DTPA-K5 in seawater followed by secondary flooding using low salinity water for 24 hours.

4.11 Result and discussion:

Zeta potential measurements showed the following: Zeta potential value for sandstone rocks with seawater becomes more negative for all the samples after the sandstone being treated with DTPA-K5 – indicating a more water wet surface (Figures 15 -18). Especially for Berea, Bandera and Scioto (Figures 15,16 and 18) where zeta values were positive and moved to more negative as the powder being treated with chelating agent for different periods. The zeta potential value of unconditioned Kentucky powder was negative (figure 17), which can be explained by the fact that Kentucky has the lowest ration of ferric ion in its mineralogy (Table-6). Zeta potential values for low salinity water flooding were all negative (Figures 19 -22), and treating the powder with chelating agent made zeta values more negative but the reduction in zeta value was less than what occurred in the seawater flooding. Zeta potential measurements also showed the effect of changing the surface mineralogy of sandstone rocks by the absorption of multivalent cations making the rock surface more water wet especially on Berea, Kentucky and Bandera where the trend between zeta potential being more negative as the percentage of ferric ion being absorbed increases (Figures 23, 25 and 26). While the trend is not the same with Scioto where the ratio of ferric ion absorbed does not exceed 35% leaving many ferric ions of the rock's surface effecting surface charge values (Figure 24). Also, the effect of using 5wt% DTPA-K5 in Seawater in Berea sandstone as a pre-flush fluid before seawater flooding is observed – measurements become much more negative (from +11.6 to -16.95) (figure 27). Also, the effect of using 5wt% DTPA-K5 in Seawater as a pre-flush fluid before low salinity flooding is observed –measurements become more negative (From -19.09 to -21.91) (Figure 28), but again the effect on low salinity water flooding is less than the effect on seawater flooding. From the observed results, using DTPA-DI as a pre-flush and then flooding with DI water decreases the value of surface charge from –26.75 for the unconditioned Berea sandstone mixed for 24 hours with DI water until it become the lowest value of zeta potential (-53.3) after 24 hours treatment by DTPA-DI and mixed with DI for another 24 hours (figure 14). Also, using DI as the primary flooding mechanism will result in a surface charge lower than using DTPA-DI as the primary flooding mechanism (-26.75 and –21.82 respectively) (figure 29), but other factors have to be considered when comparing these two mechanisms where DTPA-DI could result to a better oil recovery due to dissolution effect for instant. From Figure 30, the effect of using DTPA-SW as a flooding or pre-flush mechanism is clearly noticeable making the surface charge more negative for Berea sandstone. While the difference between flooding with DTPA-SW and using it as a pre-flush and then flooding with seawater is not much (-19.07 and – 16.95 respectively). From Figure 31, the effect of using DTPA-LS as a flooding or using DTPA-SW as pre-flush mechanism to low salinity water does not produce a clearly noticeable difference (-23.91 and -21.91 respectively). Also, the difference between flooding with DTPA-LS and flooding with low salinity water is not much (-23.91 and -19.09 respectively). Also, it can be concluded that, using

5wt% DTPA-K5 in Seawater as a flooding fluid gives same surface charge values as flooding with low salinity water: - 19.07 (DTPA-SW) and -19.09 (LS). Also, using 5wt% DTPA-K5 in Seawater as a pre-flush to seawater flooding gives a close value of surface charge as flooding with low salinity water: - 16.95 (DTPA-SW) and -19.09 (LS) - Figure-32.

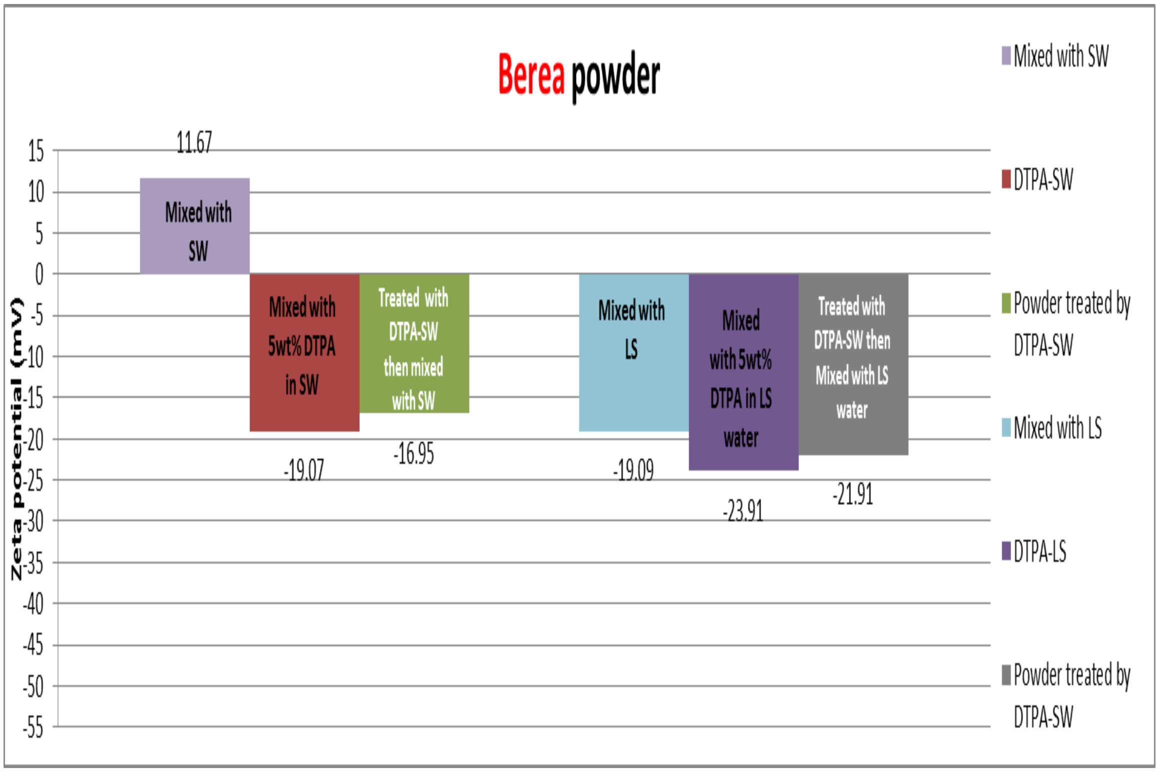

Figure 32: Zeta potential values -Comparison between seawater and low salinity water in different conditions.

CHAPTER 5

EVALUATING SURFACE CHARGE CHANGE AND DTPA-K5 EFFECT ON DIELECTRIC MEASUREMENTS

5.1 Effect of sandstone rocks' surface charge change on Dielectric measurements

Exactly the same samples used in Zeta potential measurements are used to measure the effect of changing the rock's surface charge (Zeta potential) on the relative dielectric constant and conductivity values of the brine/powder mixtures. Samples from Berea mixed with seawater, Berea mixed with low salinity water and Bandera mixed with seawater are used here to measure the dielectric values.

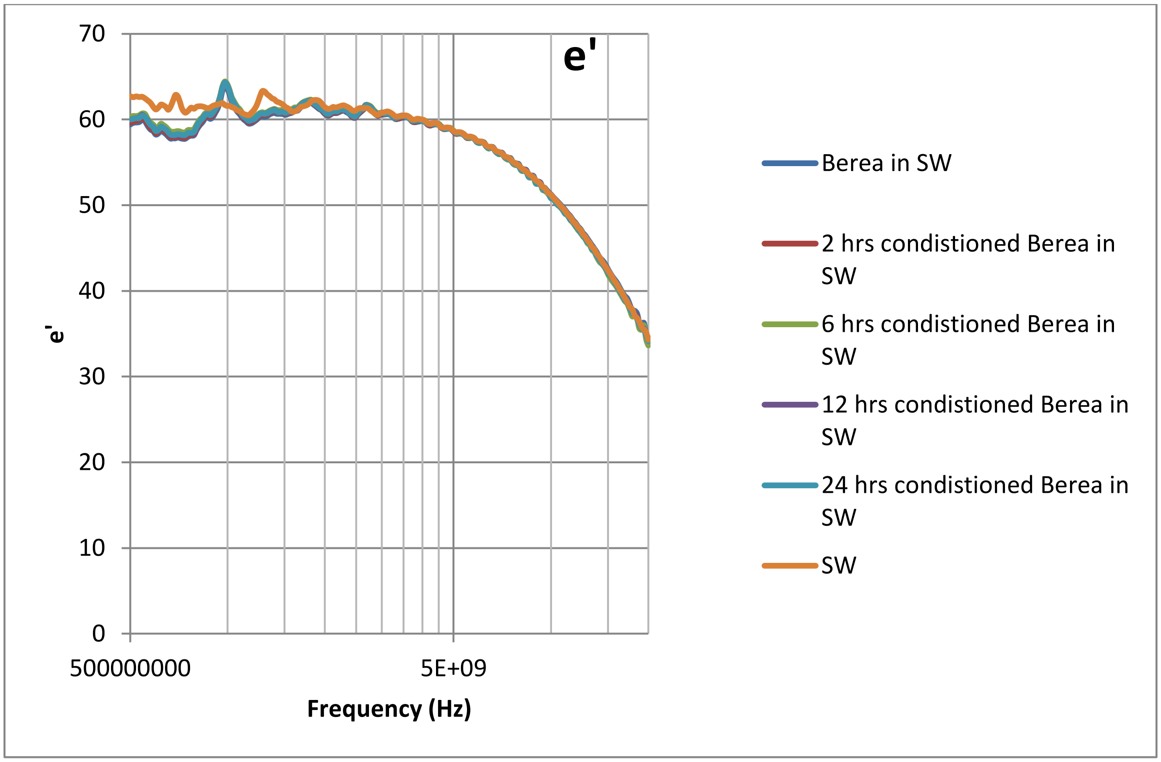

Figure 33: Relative dielectric constant (e') values of different Berea sandstone powders mixed with seawater

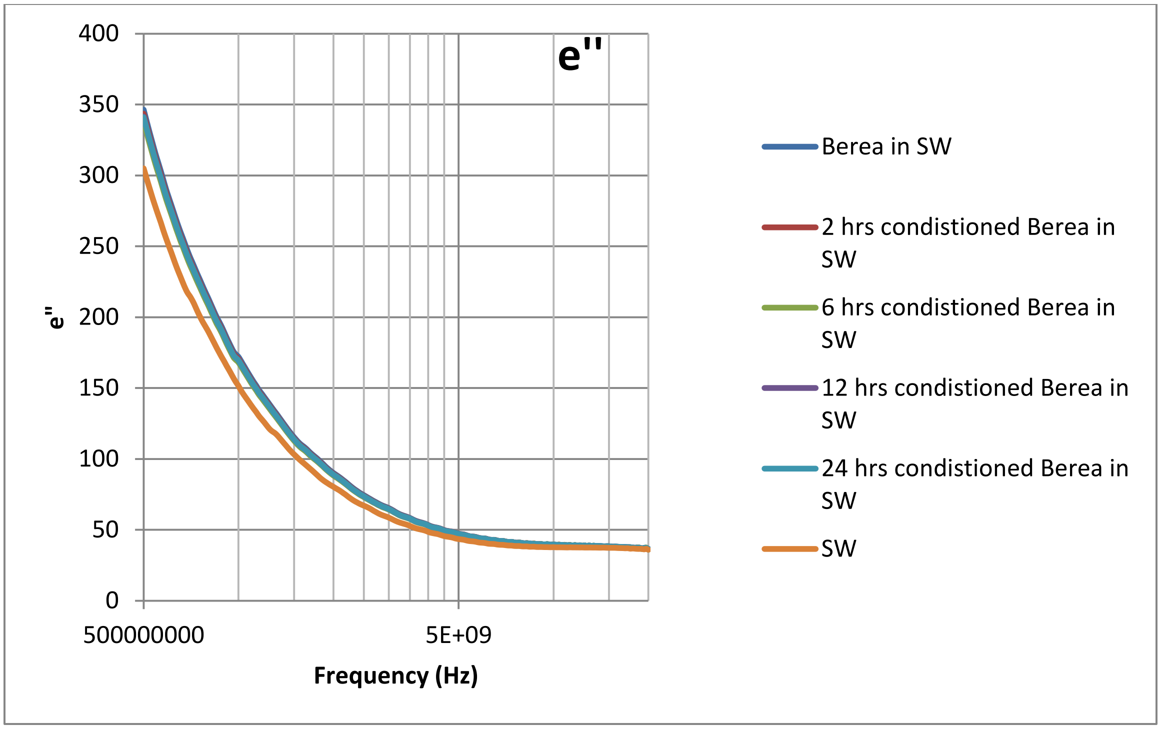

Figure 34: Imaginary dielectric constant (e”) values of different Berea sandstone powders mixed with seawater

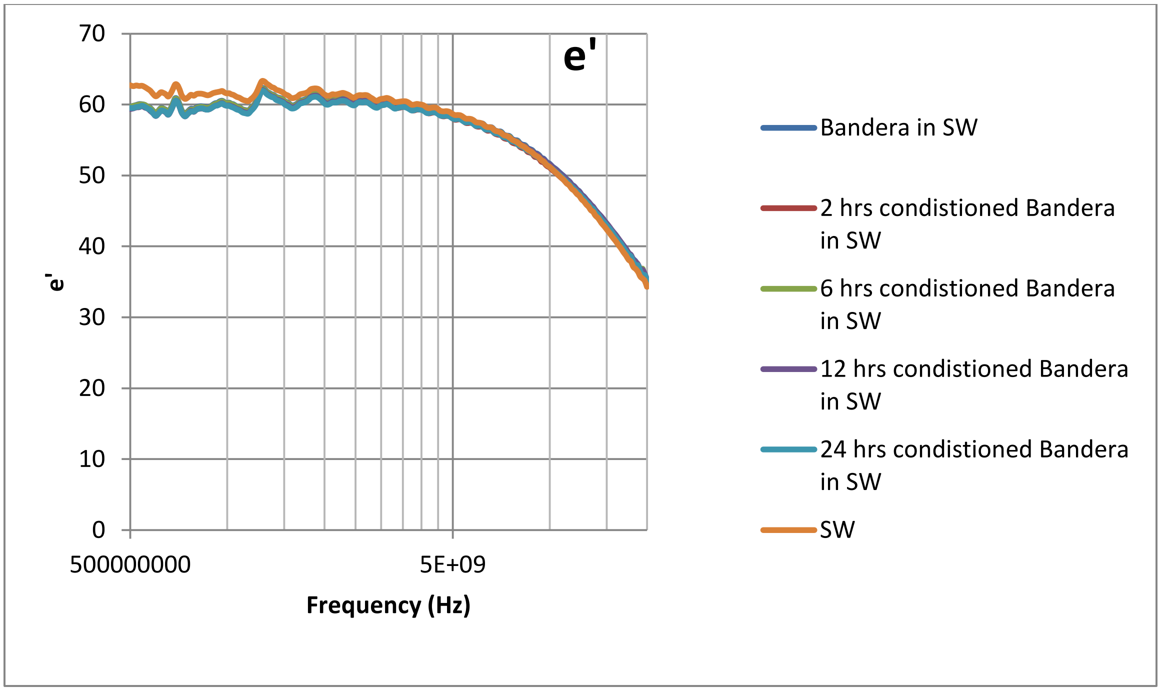

Figure 35: Relative dielectric constant (e’) values of different Bandera sandstone powders mixed with seawater.

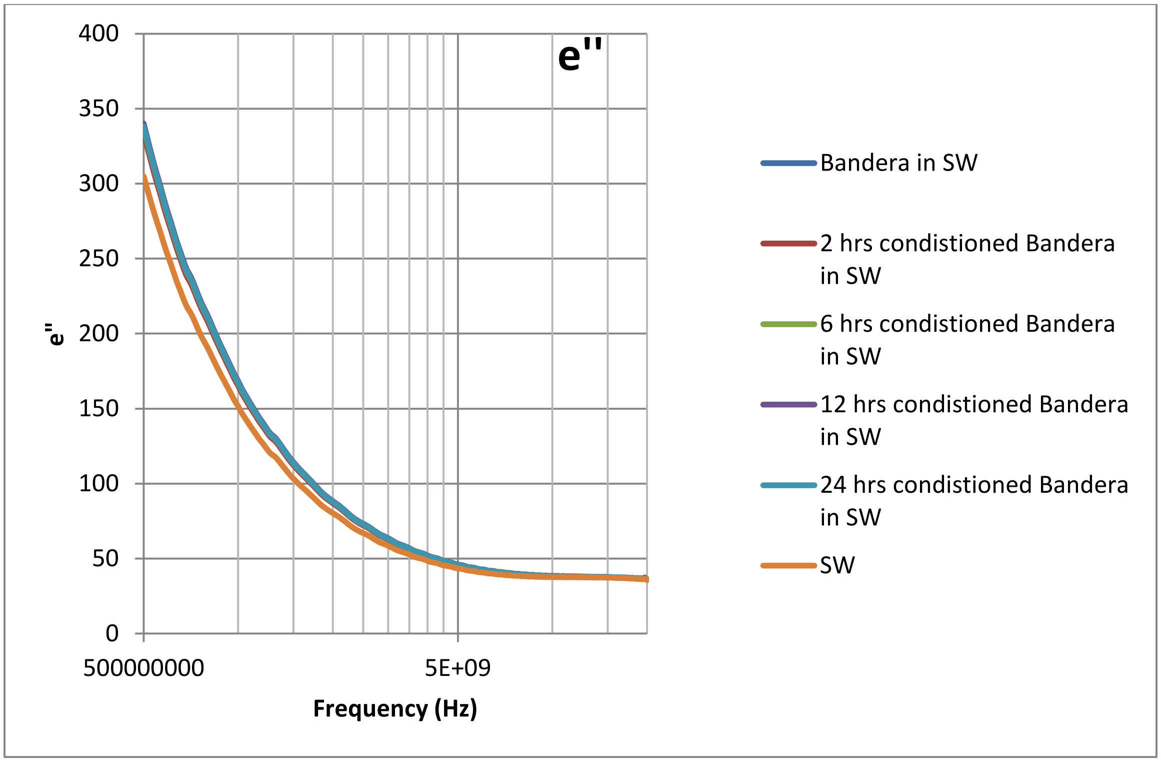

Figure 36: Imaginary dielectric constant (e”) values of different Bandera sandstone powders mixed with seawater

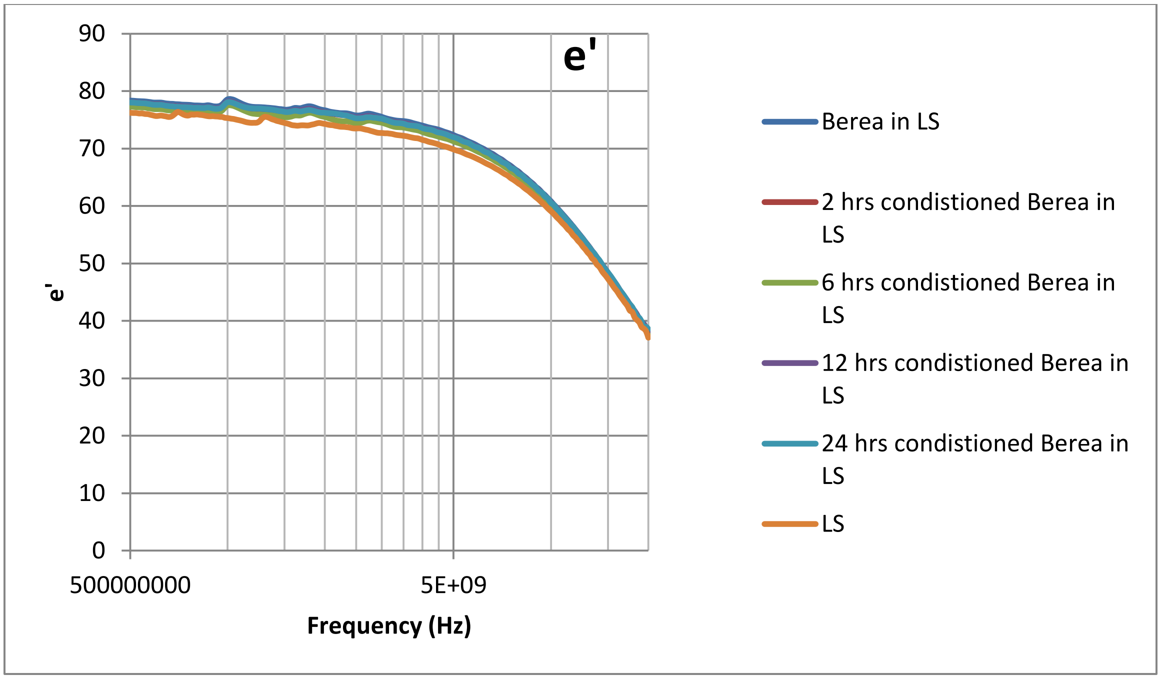

Figure 37: Relative dielectric constant (e’) values of different Berea sandstone powders mixed with low salinity water.

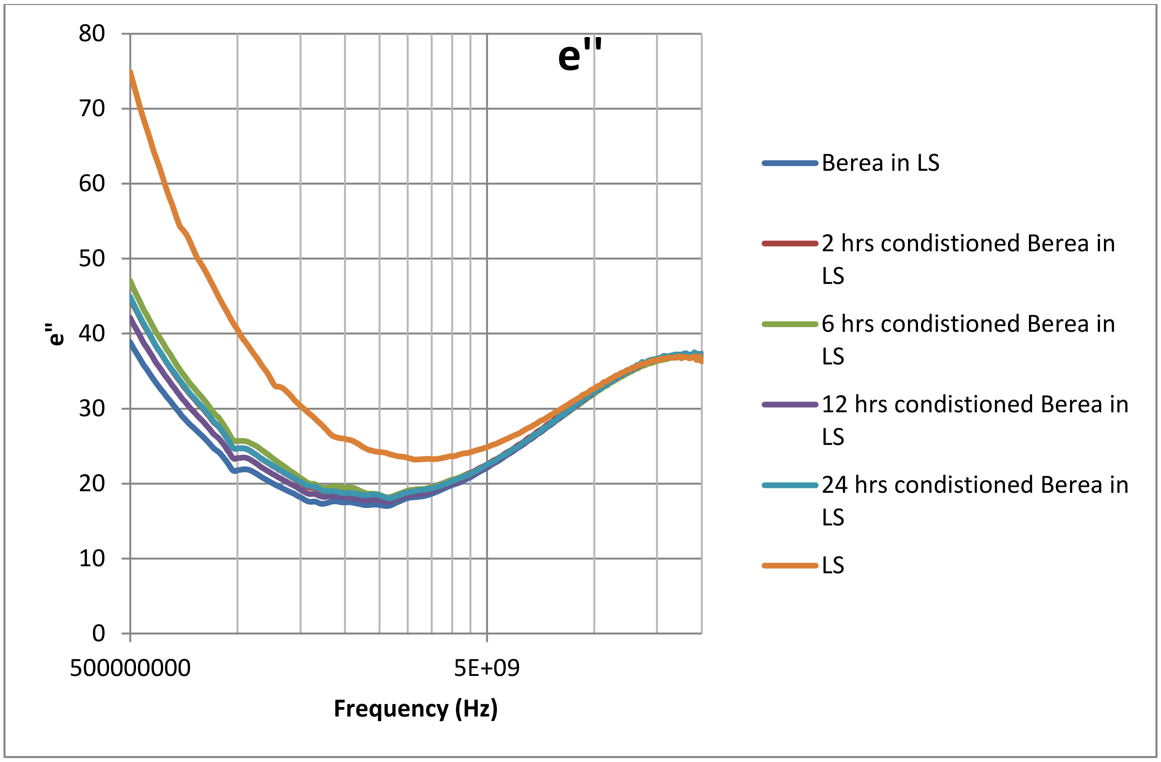

Figure 38: Imaginary dielectric constant (e”) values of different Berea sandstone powders mixed with low salinity water.

Results and discussion:

The double layer effect is not observed (Figures 33-38) using the dielectric measurement due to the high frequency (starts from 500 MHz comparing to 2 and 20 Hz in zeta potential measurements), where the electrical weave bypasses the double layer effect. Having the powder conditioned for any time period gave similar values of e’ and e” as if it has not been conditioned at all. The difference here is within the uncertainty of the device (5%). The clear effect shown in these measurements is the change in the imaginary dielectric value of seawater or low salinity water when powder is added, indicating an increase in the conductivity by the powder particles’ presence. Using laboratory dielectric measurements to observe the change in the surface charge is not applicable.

5.2 Effect of DTPA-K5 when added to different brines on the dielectric laboratory measurements

As DTPA-K5 being a salt ($C_{14}H_{18}N_3O_{10}K_5$) and being added as 5 wt% (50,000 ppm) the dielectric values differed from different water salinities, especially in the imaginary part which is converted into conductivity.

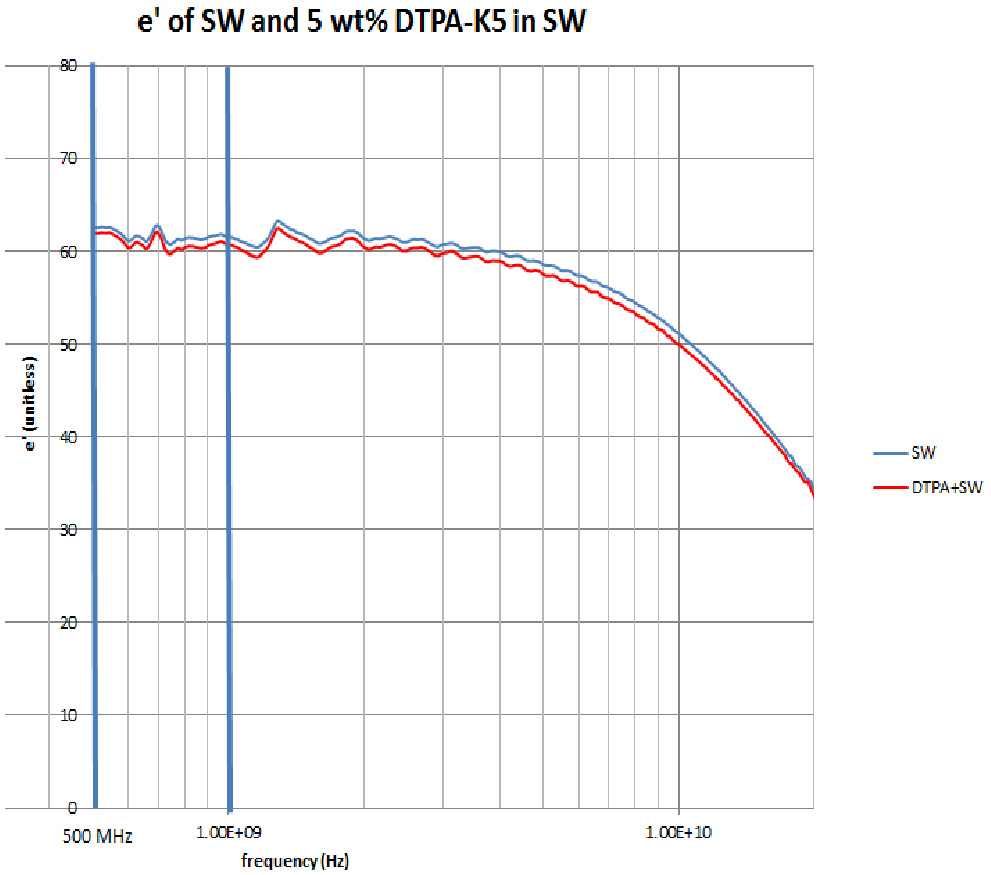

Figure 39: Relative dielectric constant (e’) values of seawater and 5 wt% DTPA-K5 in seawater

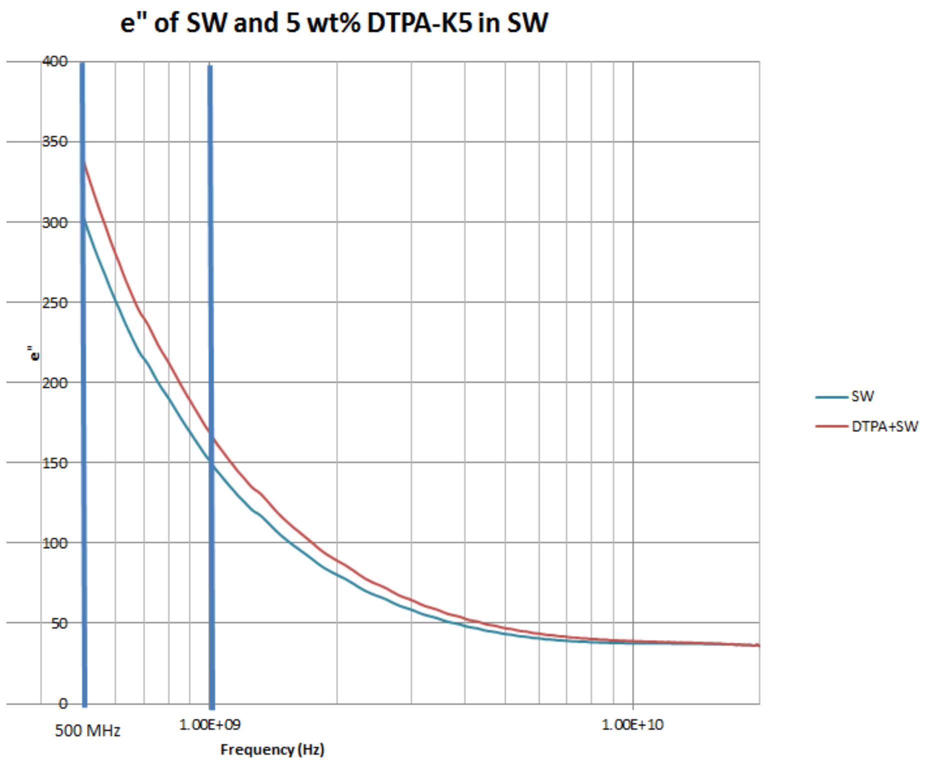

Figure 40: Imaginary dielectric constant (e”) values of seawater and 5 wt% DTPA-K5 in seawater

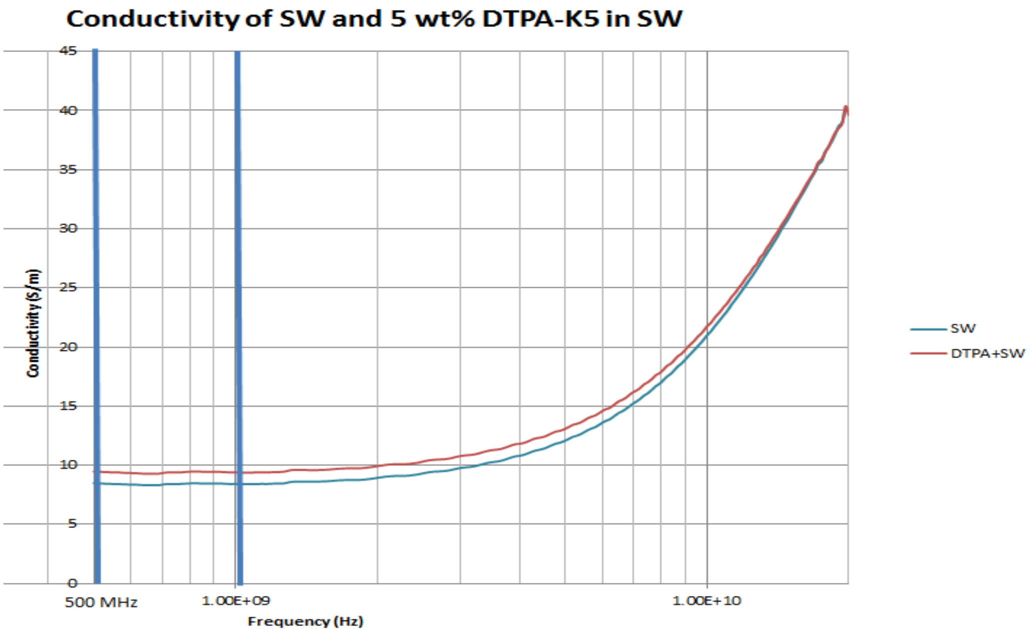

Figure 41: Conductivity (σ) values of seawater and 5 wt% DTPA-K5 in seawater

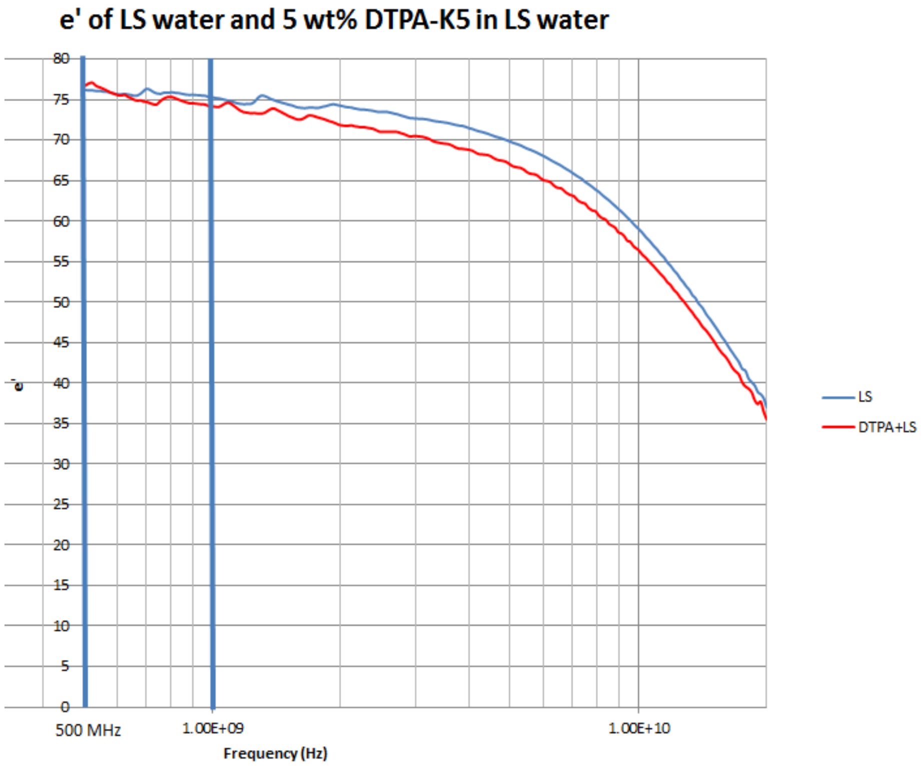

Figure 42: Relative dielectric constant (e’) values of Low salinity water and 5 wt% DTPA-K5 in low salinity water.

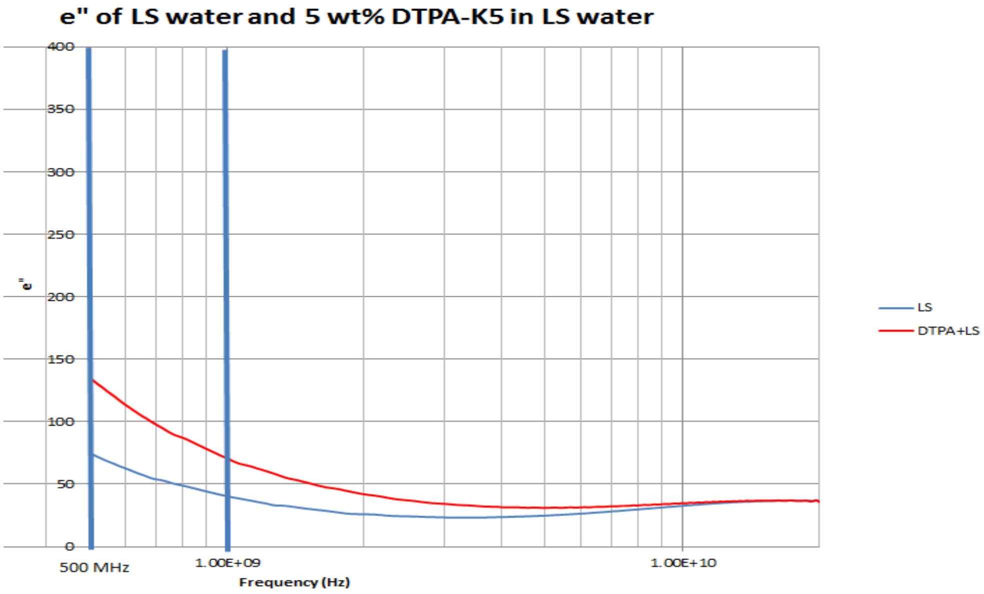

Figure 43: Imaginary dielectric constant (e”) values of low salinity water and 5 wt% DTPA-K5 in low salinity water.

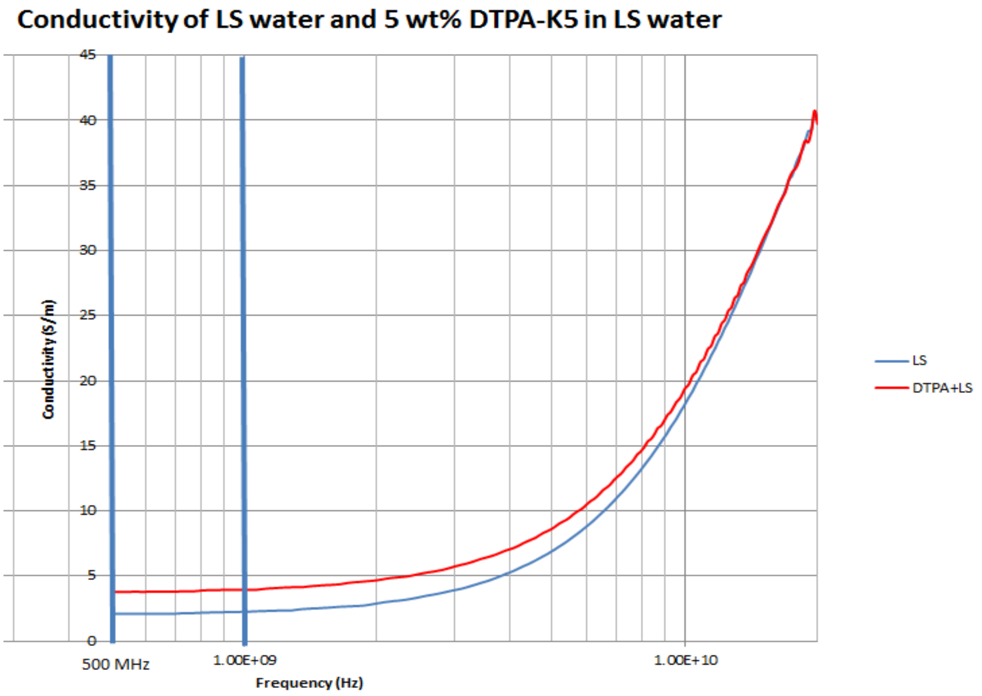

Figure 44: Conductivity (σ) values of low salinity water and 5 wt% DTPA-K5 in low salinity water.

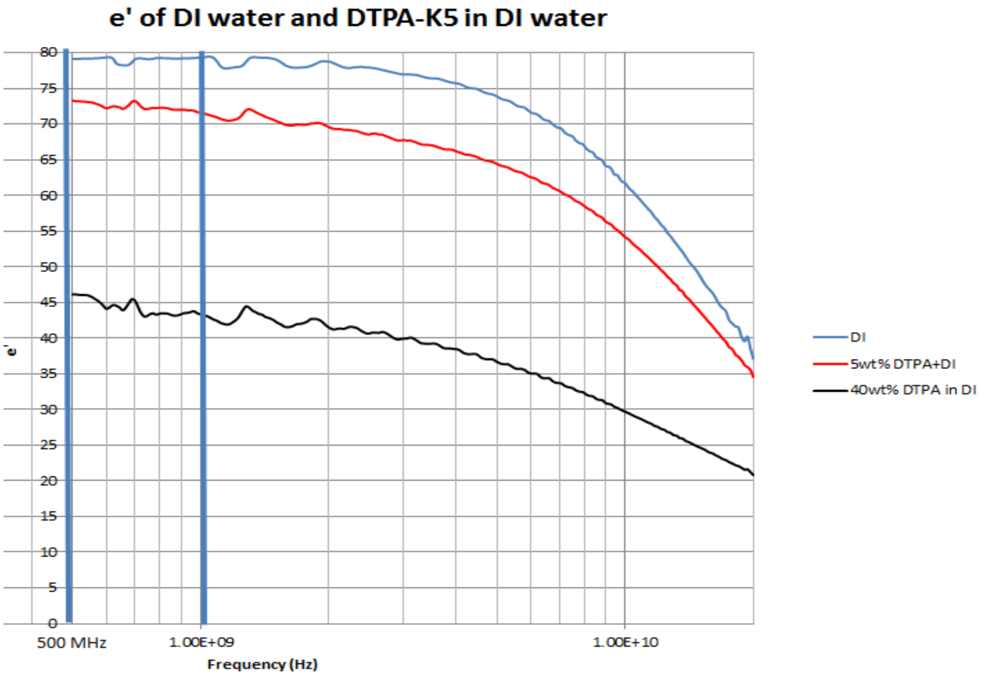

Figure 45: Relative dielectric constant (e') values of DI water, 5 wt% DTPA-K5 in DI water and 40 wt% DTPA-K5 in DI water

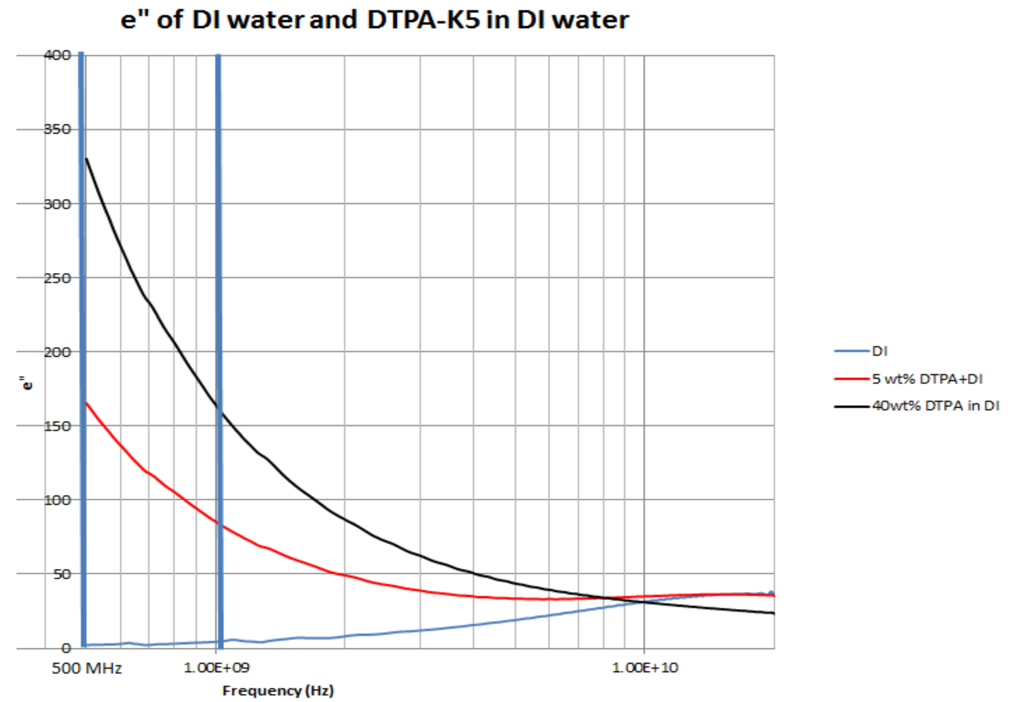

Figure 46: Imaginary dielectric constant (e”) values of DI water, 5 wt% DTPA-K5 in DI water and 40 wt% DTPA-K5 in DI water

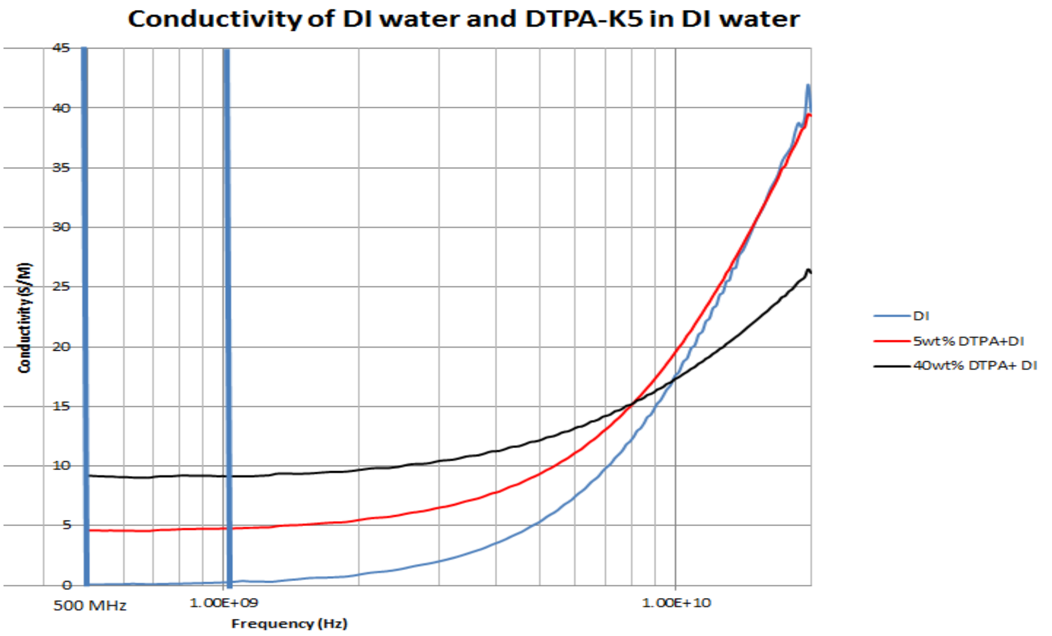

Figure 47: Conductivity (σ) values of DI water, 5 wt% DTPA-K5 in DI water and 40 wt% DTPA-K5 in DI water

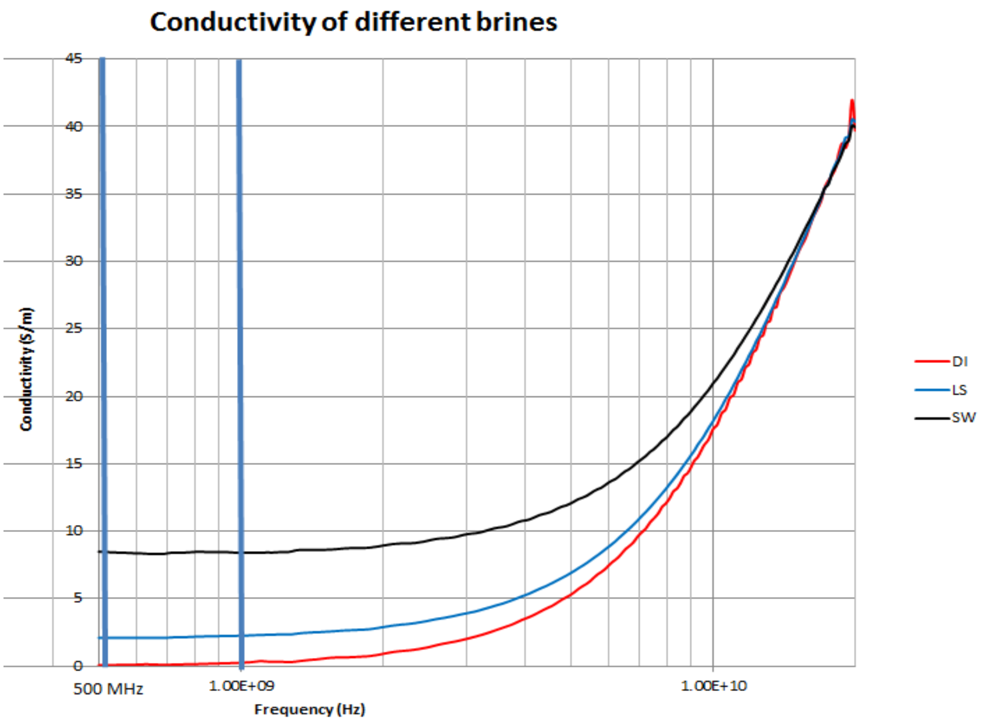

Figure 48: Conductivity (σ) values of DI water, seawater and low salinity water.

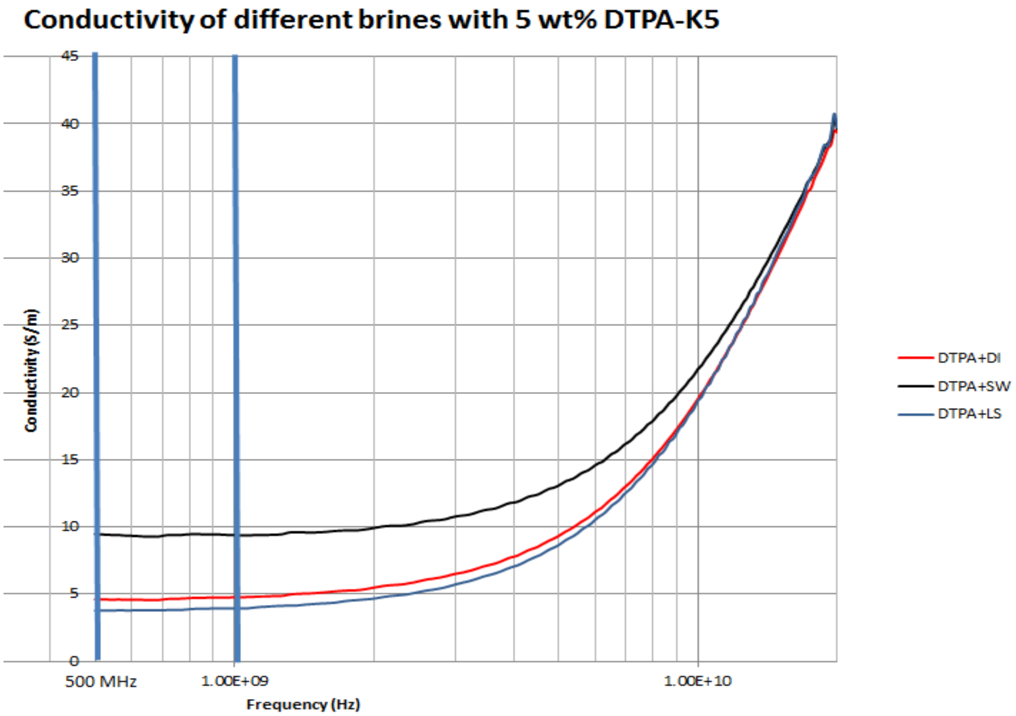

Figure 49: Conductivity (σ) values of 5 wt% DTPA-K5 in DI water, 5 wt% DTPA-K5 in seawater and 5 wt% DTPA-K5 in low salinity water.

Results and discussion:

Measurements from 500 MHz to 1 GHz will be considered in the comparison. For all the measurements, adding DTPA-K5 to any brine will increase the conductivity (also e” and decrease e’), which is caused by the increase of free ions due to the added salts. The change in the dielectric constant is more noticeable when the ionic ratio of added salts to the salinity of the brine is high. It can be noticed in the high difference of e’, e” and conductivity in DI water whenever DTPA-K5 as 50,000 ppm (5 wt%) and 400,000 ppm (40 wt%) are added (figures 45-47). Also, in low salinity water the difference in dielectric parameters when adding DTPA-K5 (figures: 42-44) is more than when added to seawater (figures 39-41). Which can be explained by, the frequency range of dielectric measurements is within 500MHz to 1GHz which is presenting the volumetric (bulk) polarization of the salts (or molecules). For all the measurements, the effect of ions presence is clear on the imaginary part of relative permittivity (meaning conductivity also) more than the real part (e’). The conductivity of a brine increases as the salinity increases (Figure-48). Comparing the conductivity of seawater, low salinity water and DI water at frequency of 800 MHz are shown in table-28. Adding DTPA-K5 to low salinity water will lead to lower conductivity than adding DTPA-K5 in DI water (Figure-49) - which indicates less free ions due to the ion exchange occurring between the DTPA-K5 chelating agent (absorbed free cations) and the low salinity water cations. While the conductivity of seawater when DTPA-K5 is added is still higher than DTPA-K5 in DI or low salinity, where the chelating agent here have absorbed some of the free ions until it was fully saturated leaving behind free ions that increased the conductivity beyond low salinity water and DI water conductivity – Figure-49 and table-28.

Table-28: Dielectric parameters of different brines at 800 MHz.

liquid	e’	e”	Conductivity (S/m)
DTPA as 40% in DI	43.4	206.75	9.2
DI	79.3	3.09	0.14
5wt% DTPA in DI	72.3	105.7	4.7
SW	61.3	190.4	8.5
5wt% DTPA in SW	60.5	212	9.5
LS	76	49	2.177
5wt% DTPA in LS	75.3	87	3.88

5.3 Effect of DTPA-K5 when added to different brines with different Fe^{+3} concentrations on the dielectric laboratory measurements:

Different (Fe^{+3}) concentrations are added (from 500 to 4000 ppm) according to Table-10 on Seawater, low salinity water and De-ionized water. The change on the dielectric parameters is recoded along with the change after adding 5wt% DTPA-K5 to these mixtures (brine with $FeCl_3$ salt).

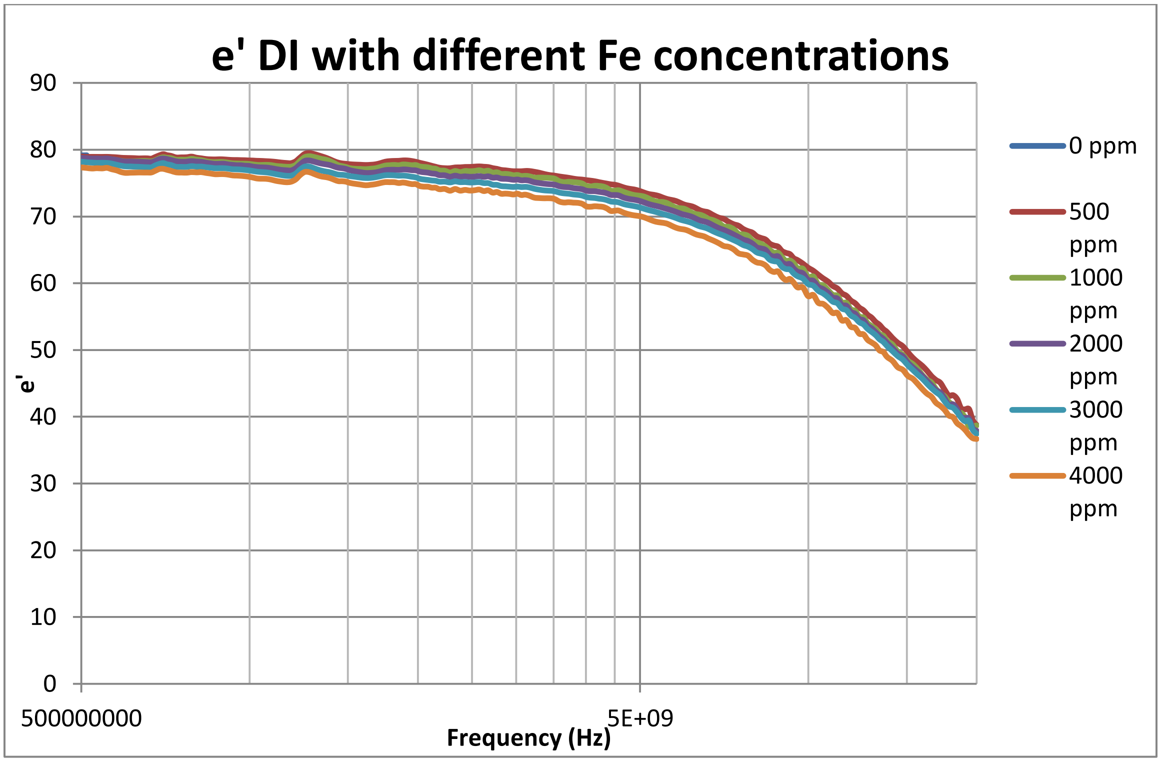

Figure 50: Relative dielectric constant (e') values of DI water with different (Fe^{+3}) concentrations

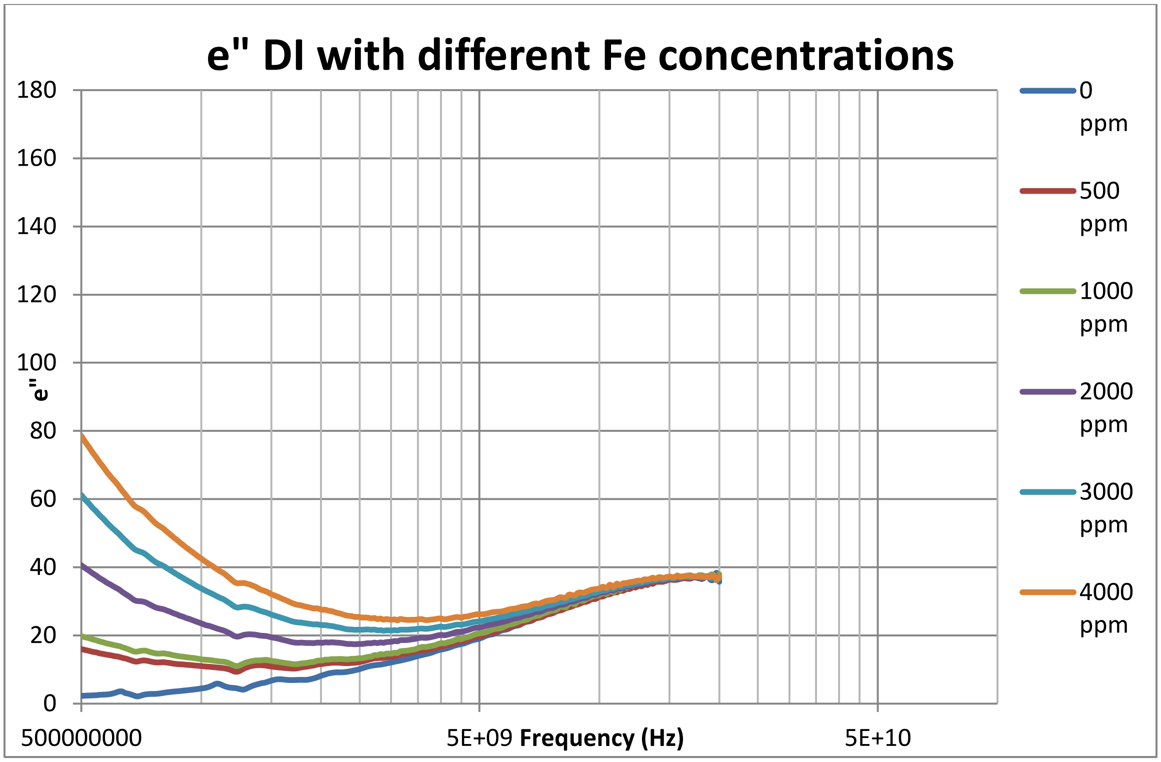

Figure 51: Imaginary dielectric constant (e") values of DI water with different (Fe^{+3}) concentrations

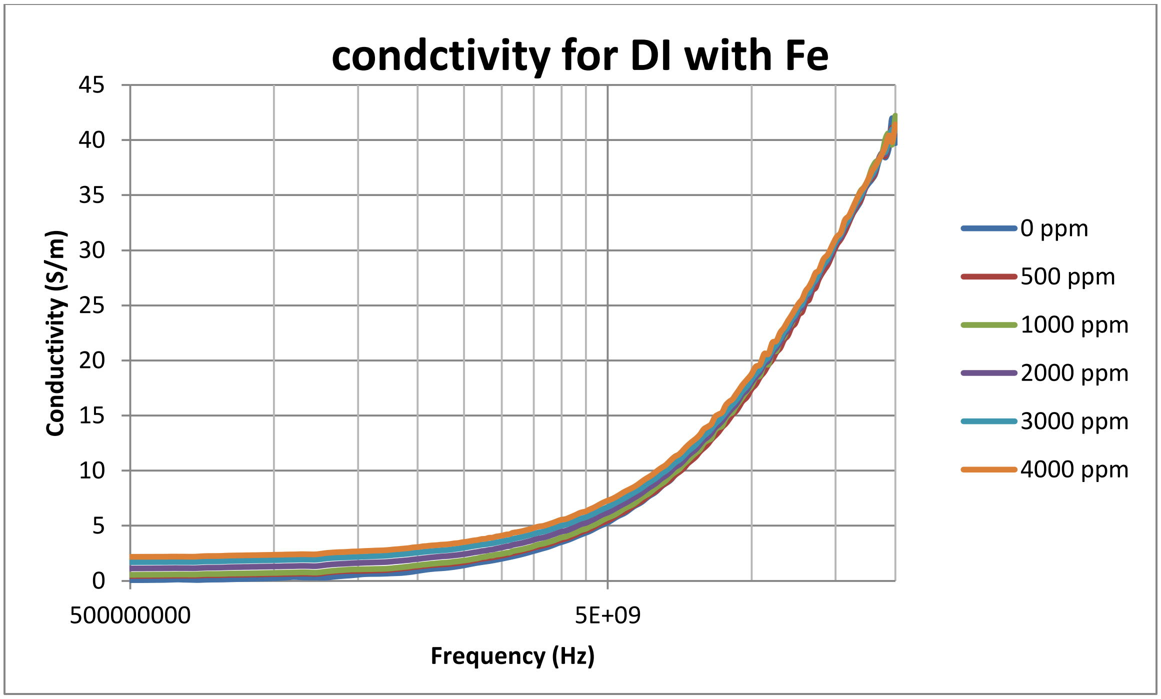

Figure 52: Conductivity (σ) values of DI water with different (Fe^{+3}) concentrations

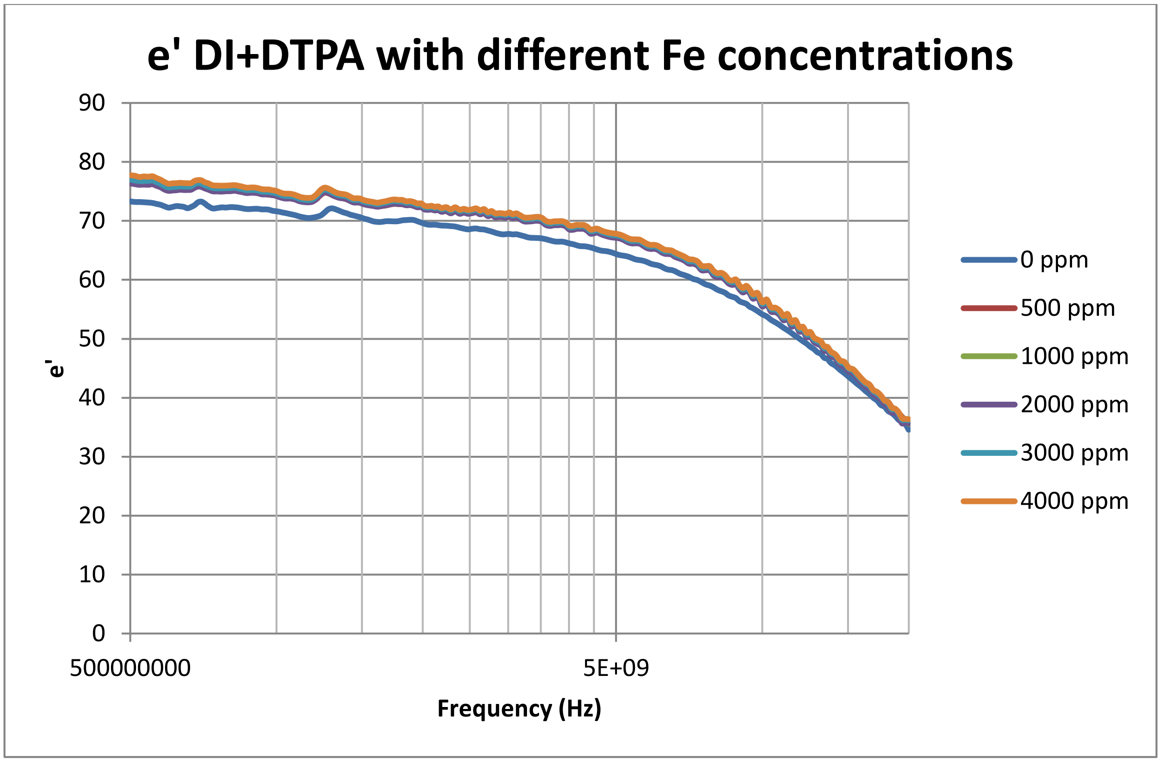

Figure 53: Relative dielectric constant (e') values of 5 wt% DTPA-K5 in DI water with different (Fe^{+3}) concentrations

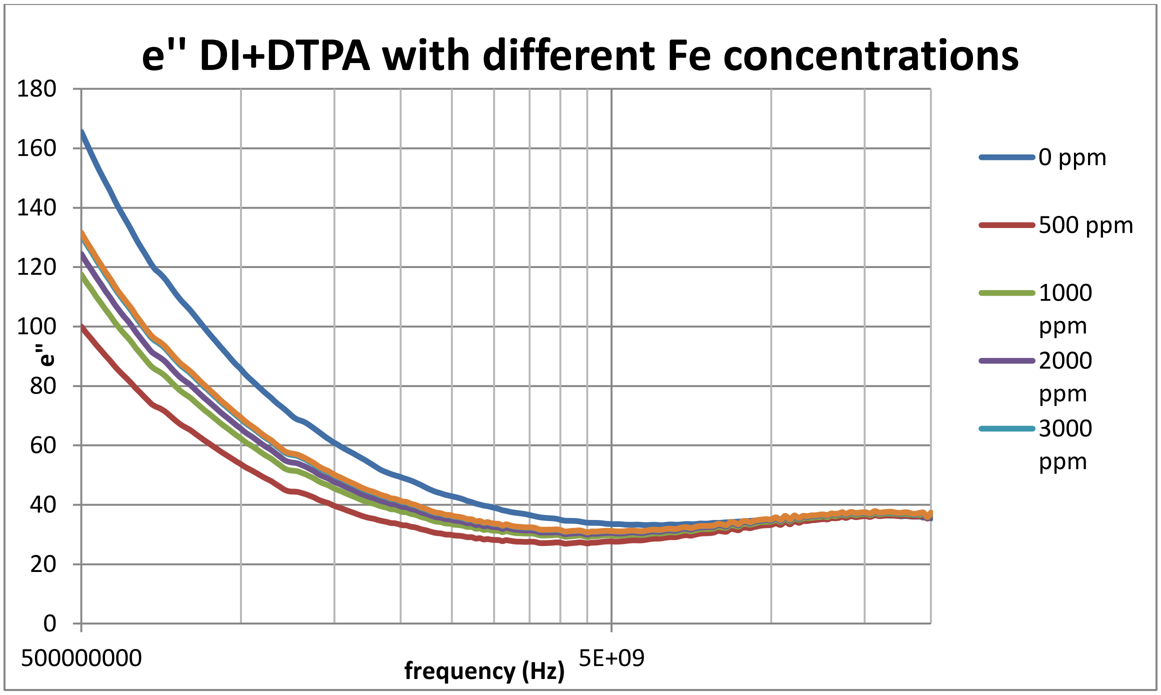

Figure 54: Imaginary dielectric constant (e") values of 5 wt% DTPA-K5 in DI water with different (Fe^{+3}) concentrations

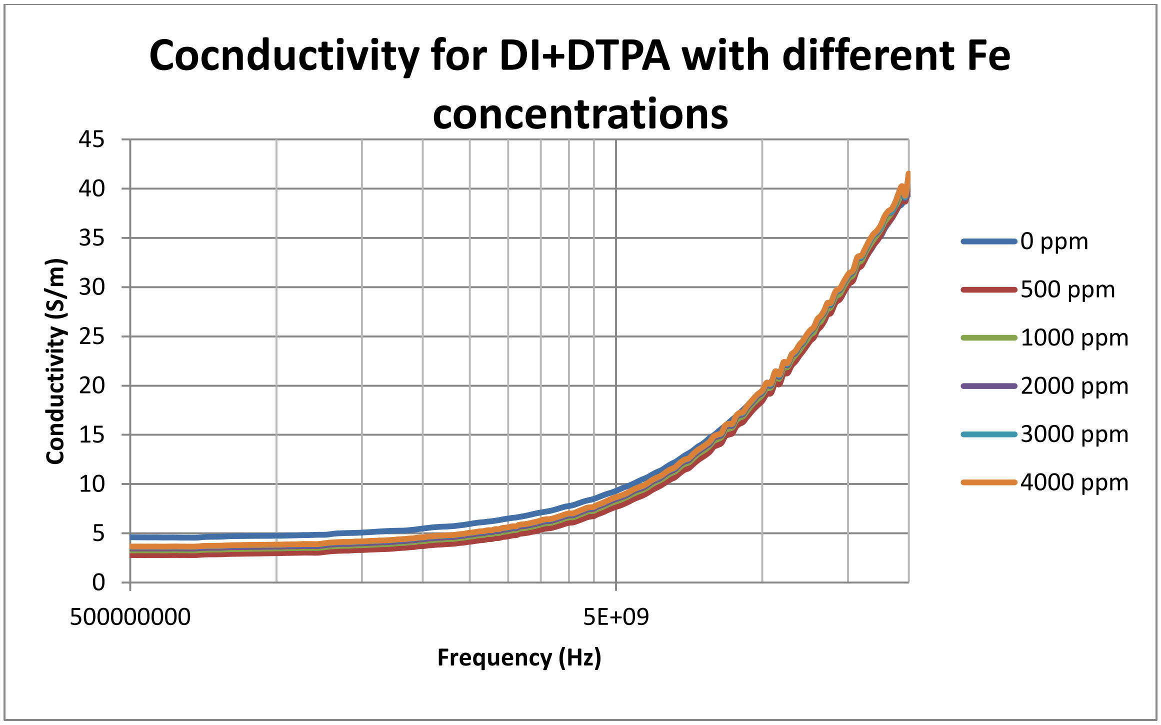

Figure 55: Conductivity (σ) values of 5 wt% DTPA-K5 in DI water with different (Fe^{+3}) concentrations

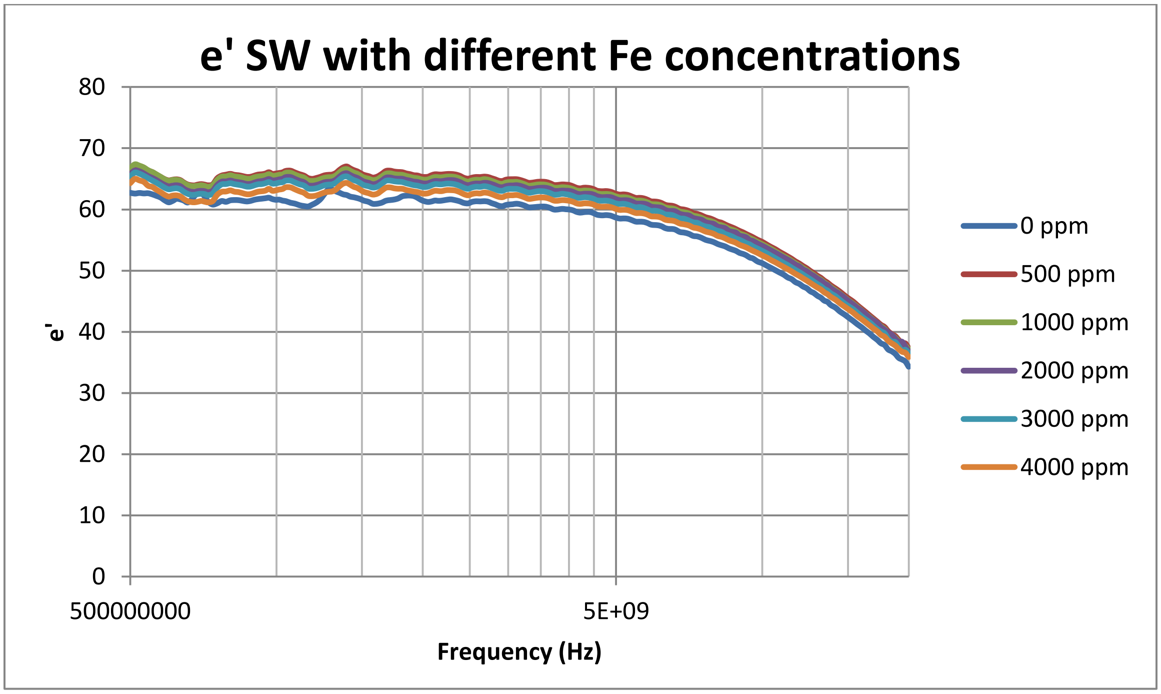

Figure 56: Relative dielectric constant (e') values of seawater with different (Fe^{+3}) concentrations

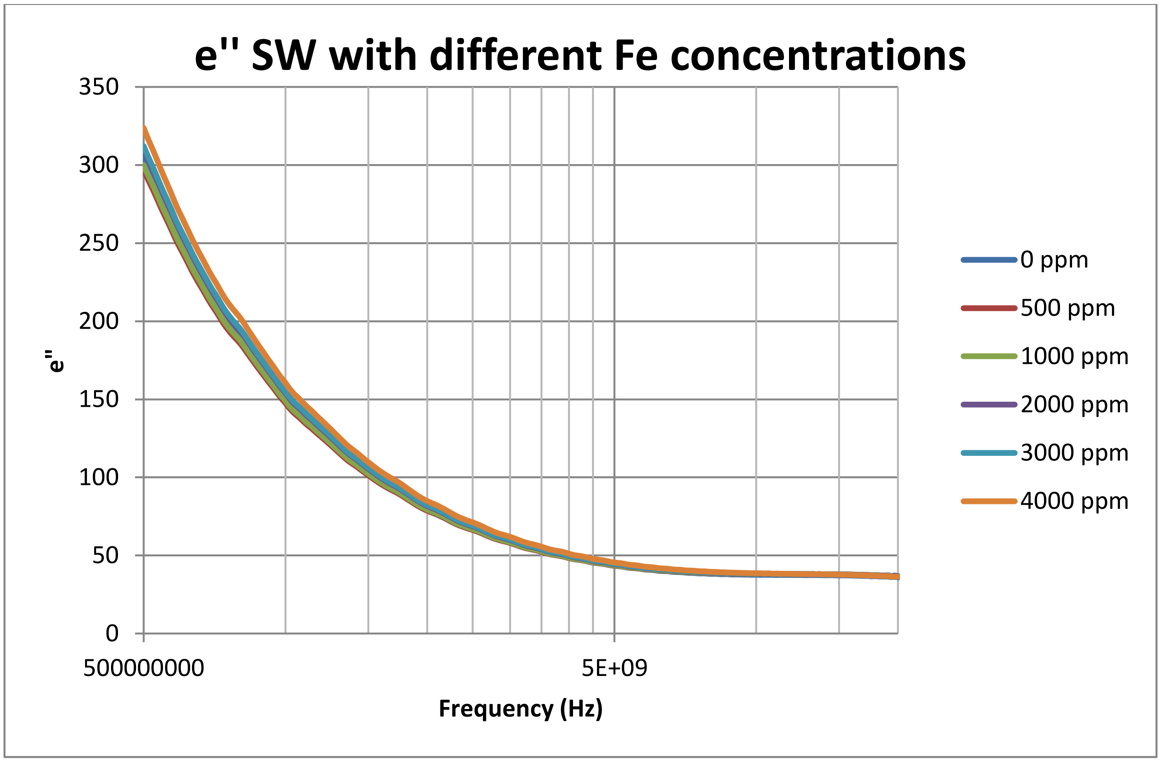

Figure 57: Imaginary dielectric constant (e”) values of seawater with different (Fe^{+3}) concentrations

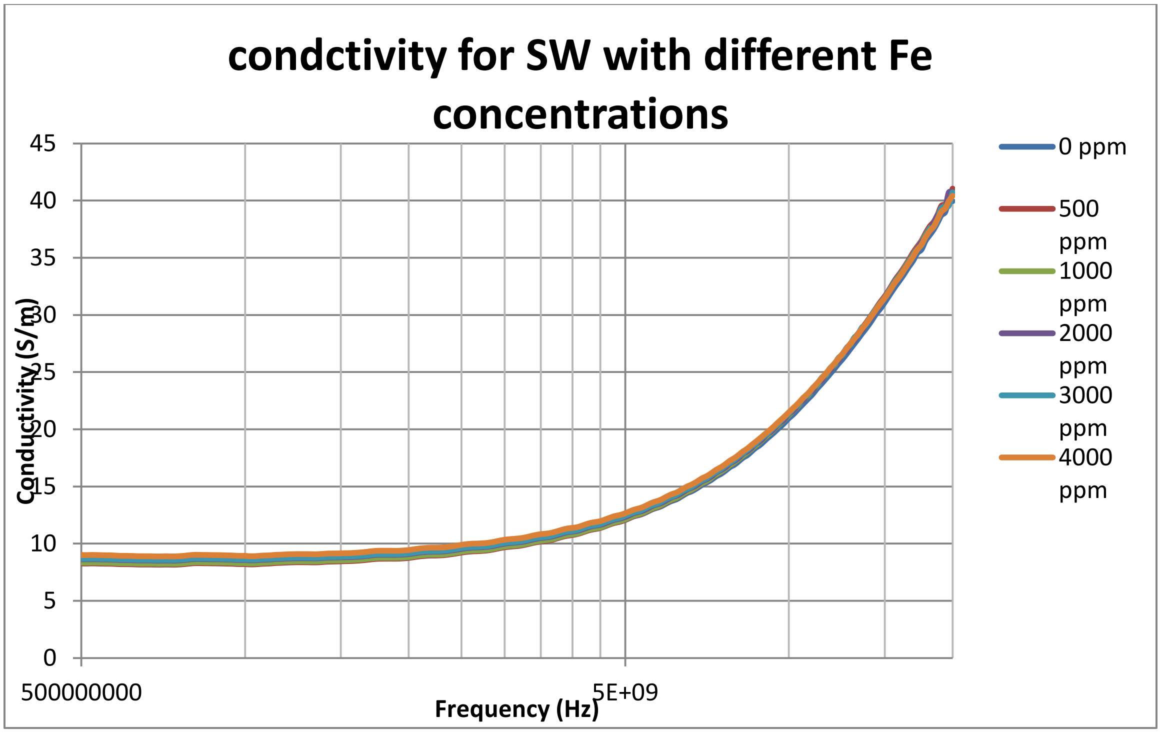

Figure 58: Conductivity (σ) values of seawater with different (Fe^{+3}) concentrations

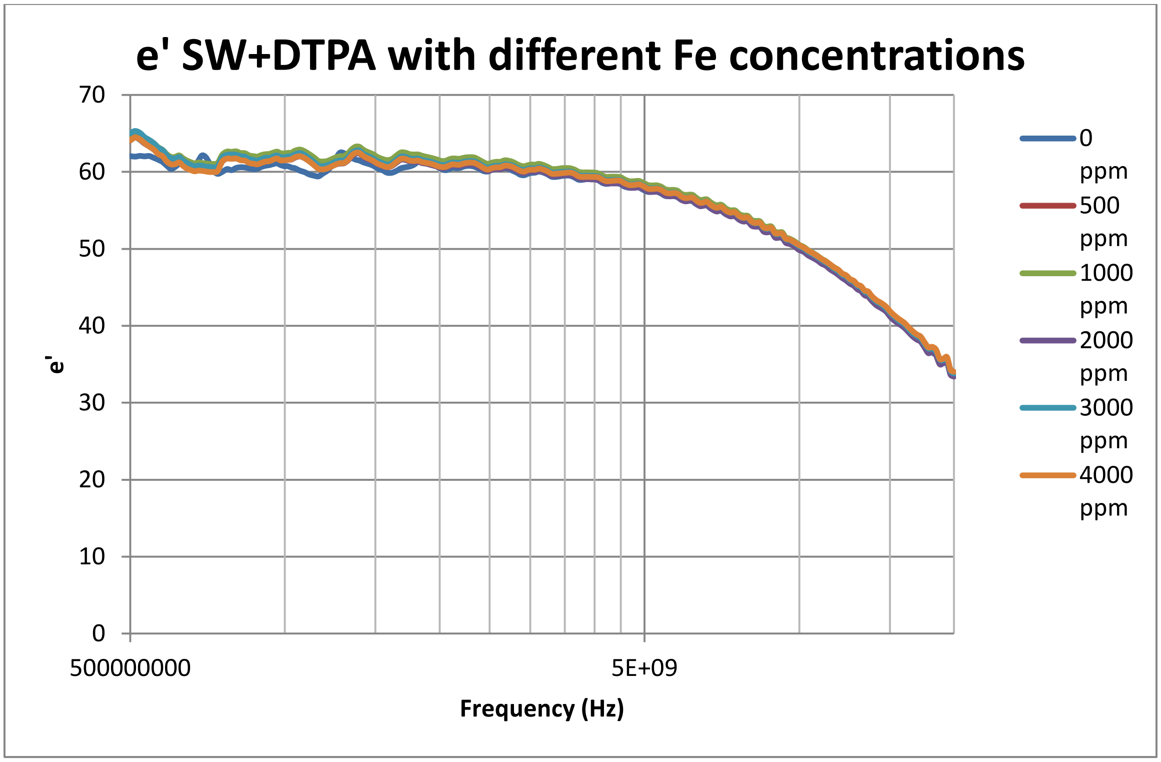

Figure 59: Relative dielectric constant (e’) values of 5 wt% DTPA-K5 in seawater with different (Fe^{+3}) concentrations

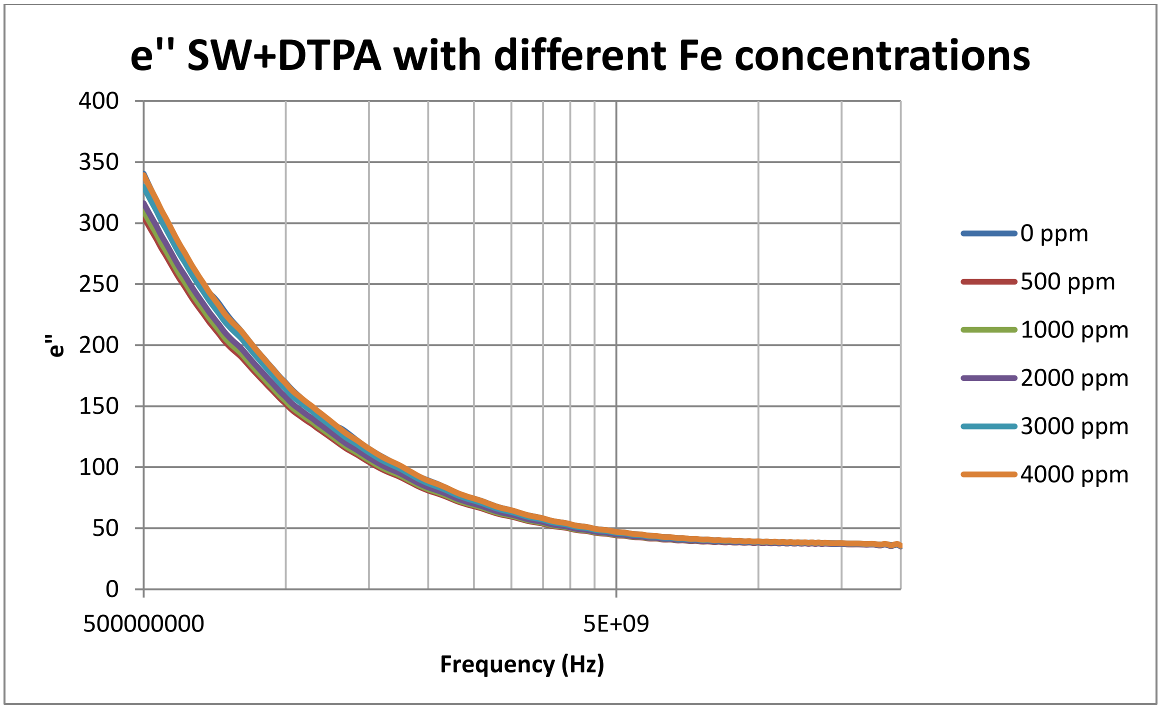

Figure 60: Imaginary dielectric constant (e”) values of 5 wt% DTPA-K5 in seawater with different (Fe^{+3}) concentrations

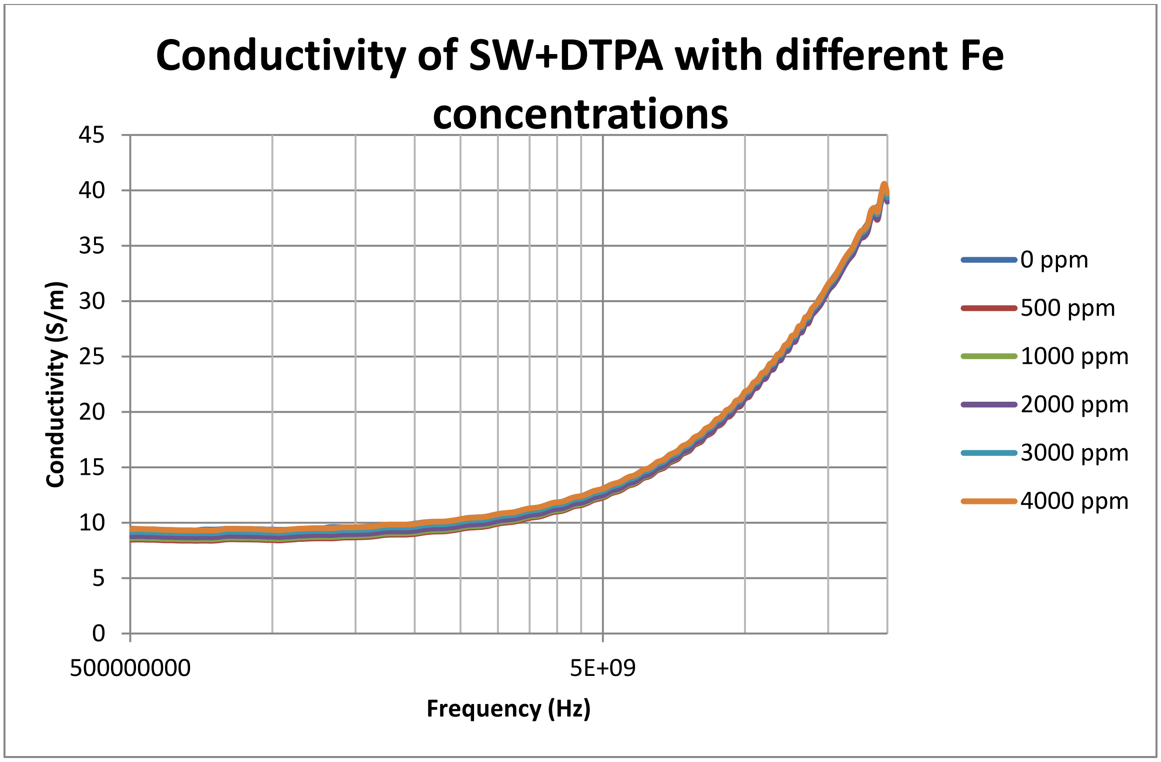

Figure 61: Conductivity (σ) values of 5 wt% DTPA-K5 in seawater with different (Fe^{+3}) concentrations

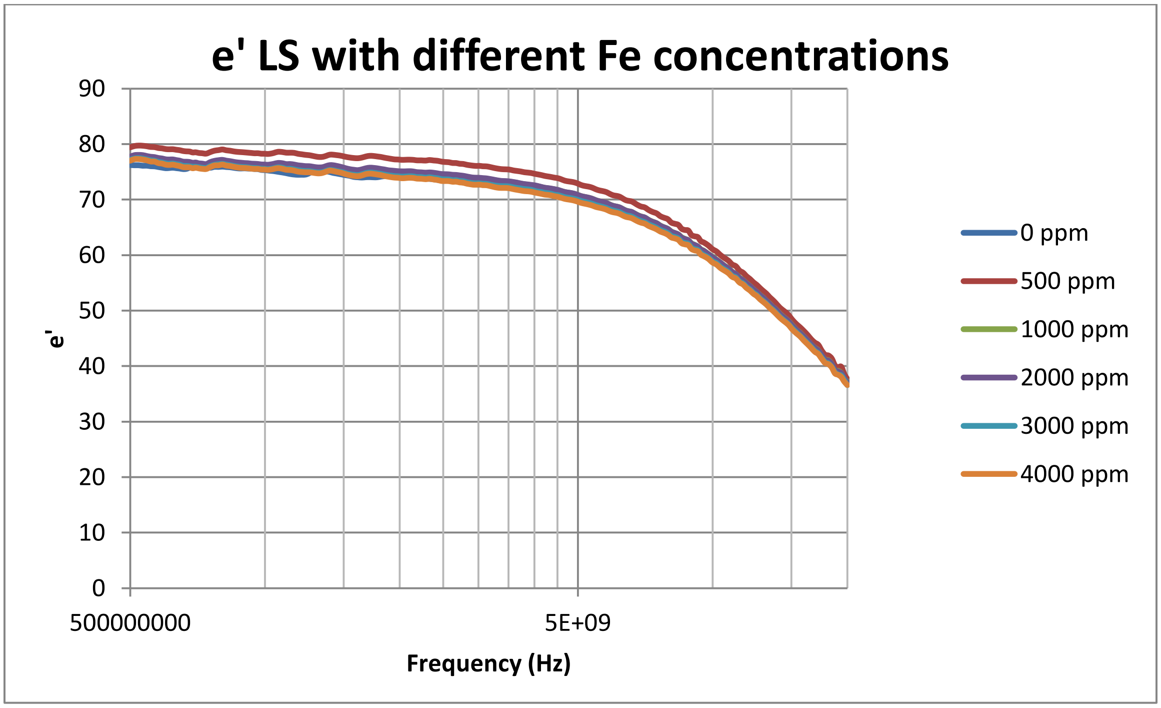

Figure 62: Relative dielectric constant (e') values of low salinity water with different (Fe^{+3}) concentrations

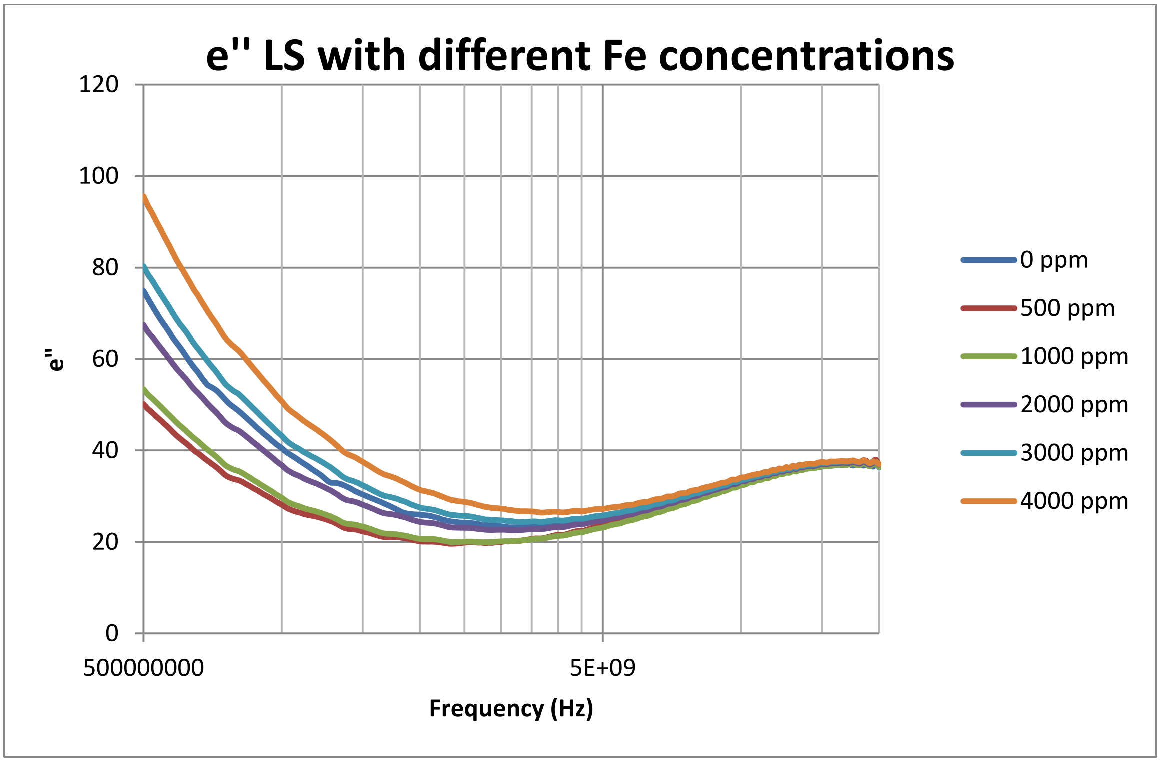

Figure 63: Imaginary dielectric constant (e”) values of low salinity water with different (Fe^{+3}) concentrations

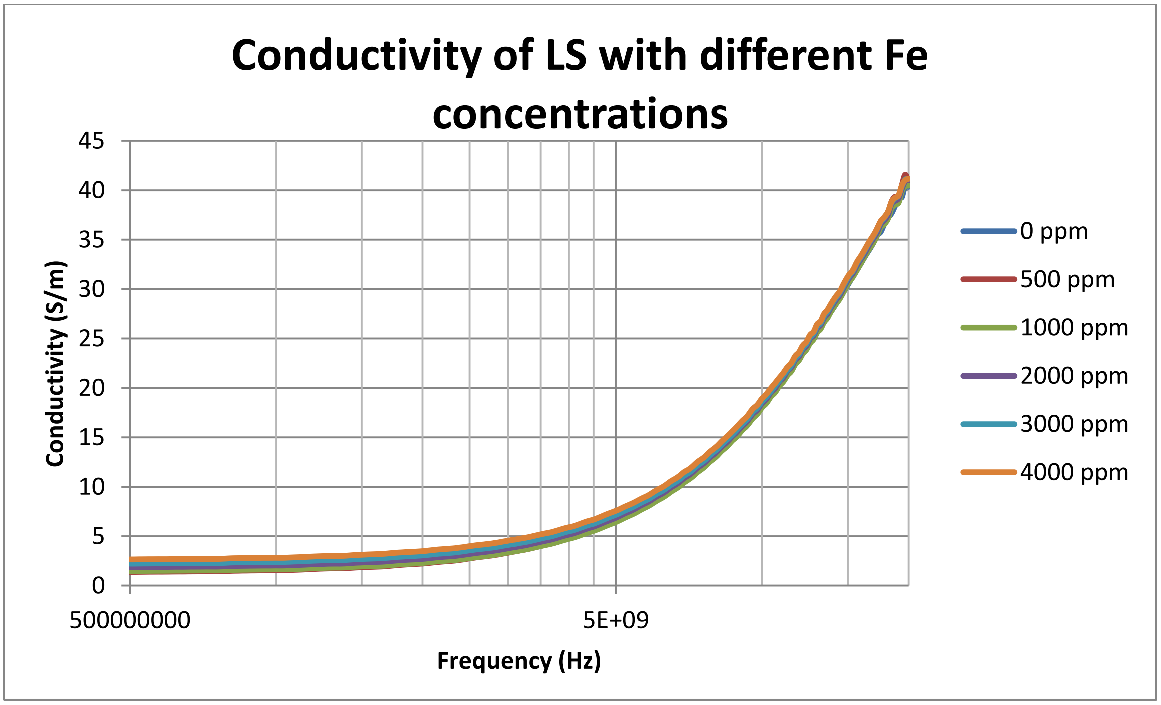

Figure 64: Conductivity (σ) values of low salinity water with different (Fe^{+3}) concentrations

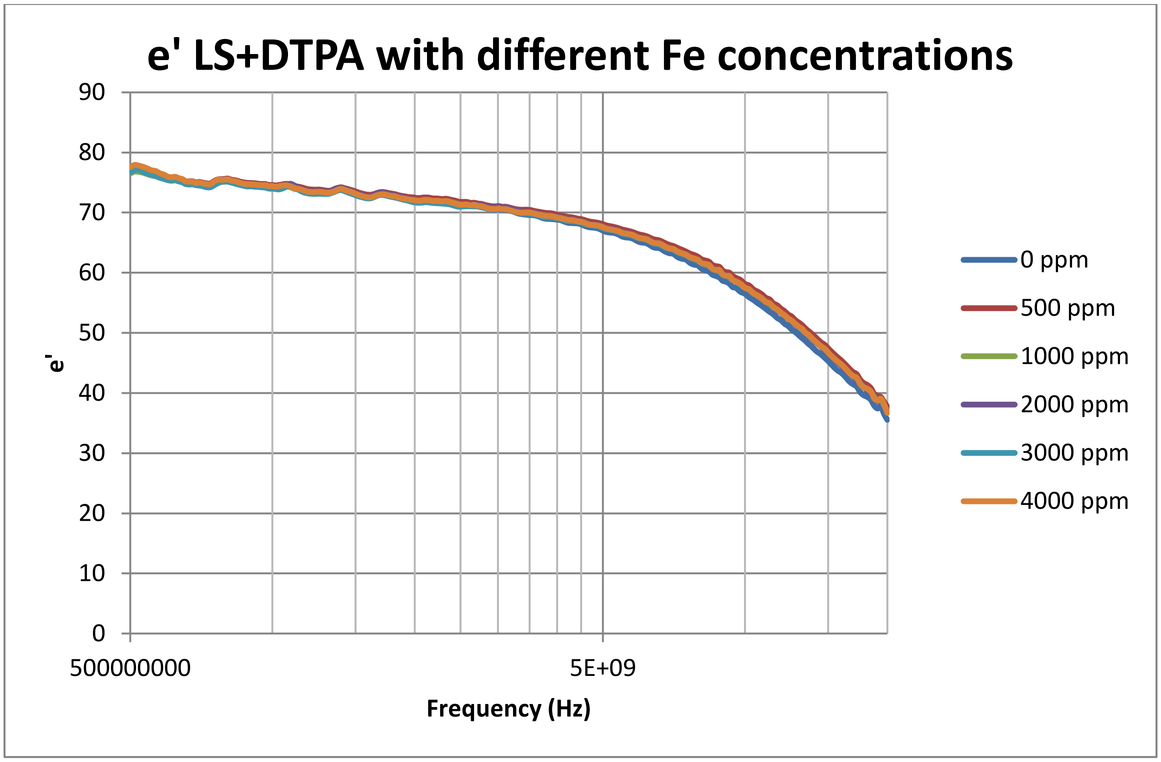

Figure 65: Relative dielectric constant (e') values of 5 wt% DTPA-K5 in low salinity water with different (Fe^{+3}) concentrations

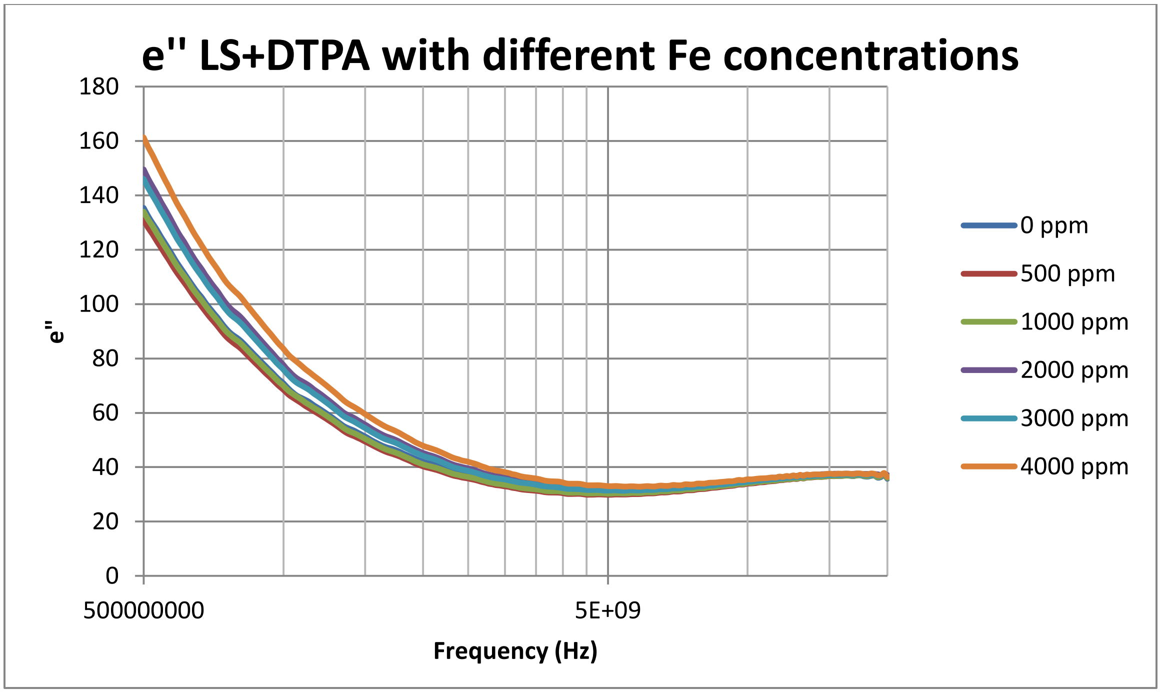

Figure 66: Imaginary dielectric constant (e") values of 5 wt% DTPA-K5 in low salinity water with different (Fe^{+3}) concentrations

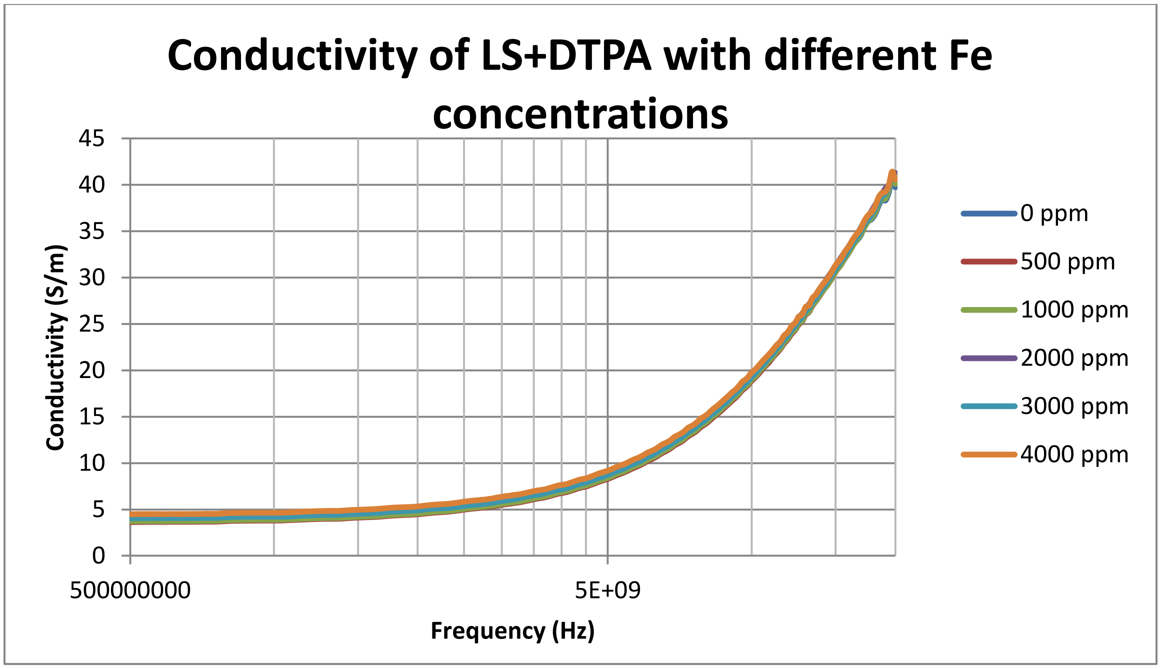

Figure 67: Conductivity (σ) values of 5 wt% DTPA-K5 in low salinity water with different (Fe^{+3}) concentrations

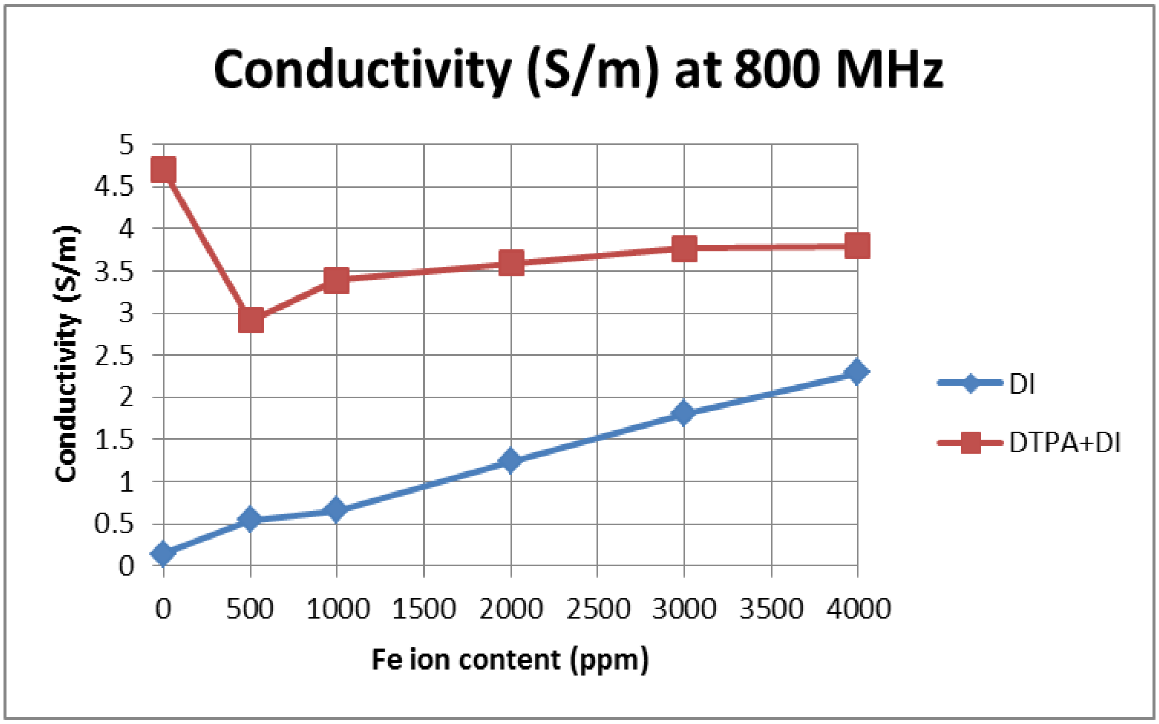

Figure 68: Conductivity (σ) values at 800 MHz of DI water and 5 wt% DTPA-K5 in DI water with different (Fe^{+3}) concentrations

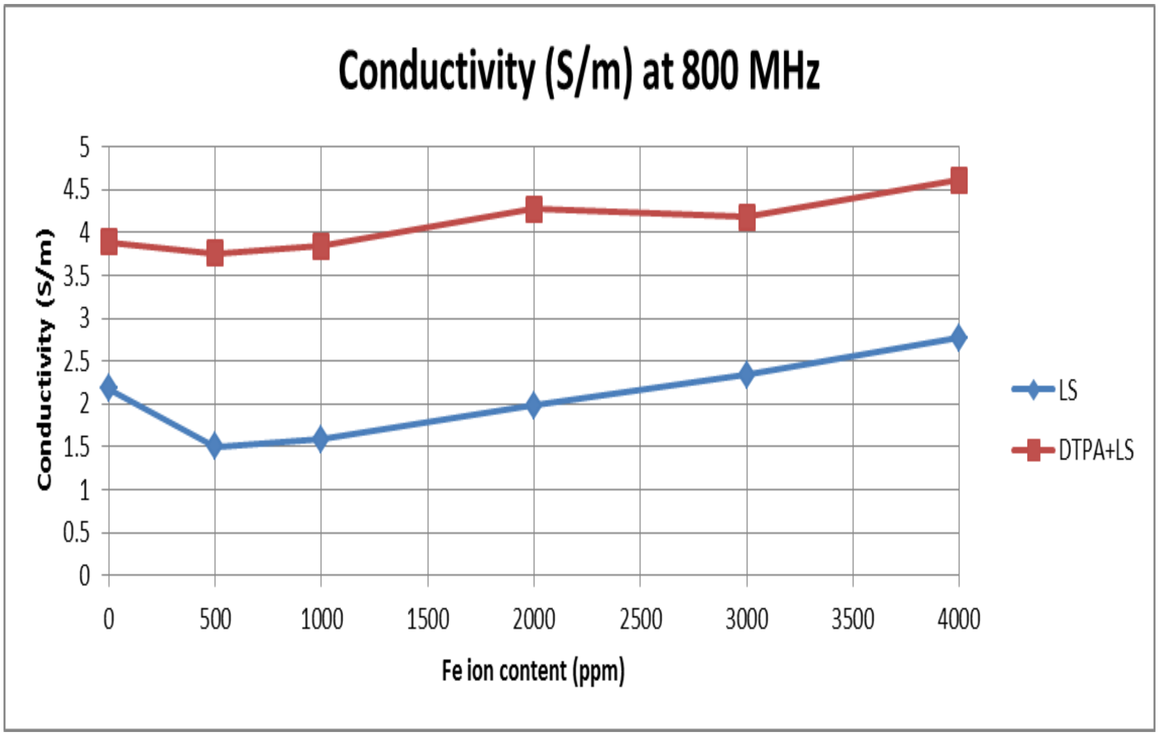

Figure 69: Conductivity (σ) values at 800 MHz of Low salinity water and 5 wt% DTPA-K5 in Low salinity water with different (Fe^{+3}) concentrations

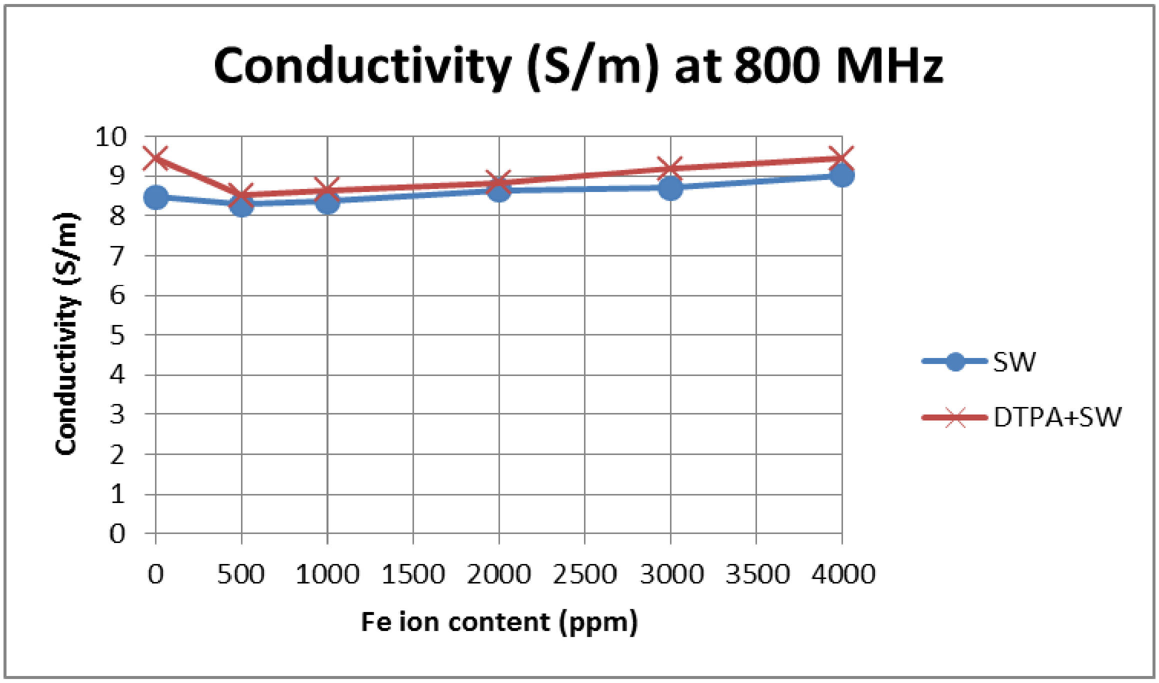

Figure 70: Conductivity (σ) values at 800 MHz of seawater and 5 wt% DTPA-K5 in seawater with different (Fe^{+3}) concentrations

Results and discussion:

From figures 50, 54, 56, 59, 62 and 65; the change in the real (relative) dielectric constant (e') as ferric ion concentrations increases is not noticeable and lies with the devices uncertainty. The effect of adding $FeCl_3$ salt is much clearer when added to DI water then when added to low salinity water while its effect when added to seawater is the lowest (figures 50-67). Ignoring the change on the real part of dielectric permittivity (since it lies with the device's uncertainty) a summary of the change on conductivity at 800 MHz are plotted (figures: 68-70). In figure 68; a comparison between adding ferric ion to DI water and to 5 wt% DTPA-K5 in DI water is plotted. The trend when $FeCl_3$ salt is added to DI water shows an increasing on conductivity. While the trend when $FeCl_3$ salt added to 5 wt% DTPA-K5 in DI water shows a decreases of 38% (from 4.707 to 2.908 S/m) when 500 ppm Fe^{+3} is added, then the trend starts to increase but in slower rate than the increase in DI water when $Fecl_3$ salt is added from 500 to 4000 ppm Fe^{+3} (increase rate of adding Fe^{+3} from 500 ppm to 4000 ppm on 5 wt% DTPA-K5 in DI water is 0.025% increase , while in DI water the rate is 0.05% increase). In figures 69 and 70; both brines (seawater and low salinity water) experience a decrease in the conductivity when 500 ppm of Fe^{+3} is added (the decrease in low salinity is higher – equals 31.21%- than the decrease in seawater – equals 2.16 %). Then, the conductivity increases as Fe^{+3} concentrations increases. Also, whenever 5 wt% DTPA-K5 is added the conductivity decreases when 500 ppm Fe^{+3} is added then starts to increase as Fe^{+3} concentration increases. Adding 500 ppm of Fe^{+3} to Low salinity water will lead to reduction on the low salinity water conductivity (31.2 % decrease) – less free ions – but it is a much more reduction on low salinity water conductivity than: Adding DTPA-K5 and 500 ppm of Fe^{+3} to low salinity water (3.22% decrease) (figure 69). The effect on conductivity of adding DTPA-K5 in seawater starts to be negligible after adding 1000 ppm Fe^{+3} (figure 70). Also, adding 500 ppm of Fe^{+3} to seawater will lead to reduction on the seawater conductivity (2.1% decrease) – less free ions – but it is a less reduction on seawater conductivity than: Adding DTPA-K5 and 500 ppm of Fe^{+3} to seawater (10% decrease)

5.4 Effect on conductivity at high frequency of adding DTPA-K5 to De-ionized water with different salts

5.4.1 Effect of adding DTPA-K5 in DI water with 1000 ppm Fe^{+3}:

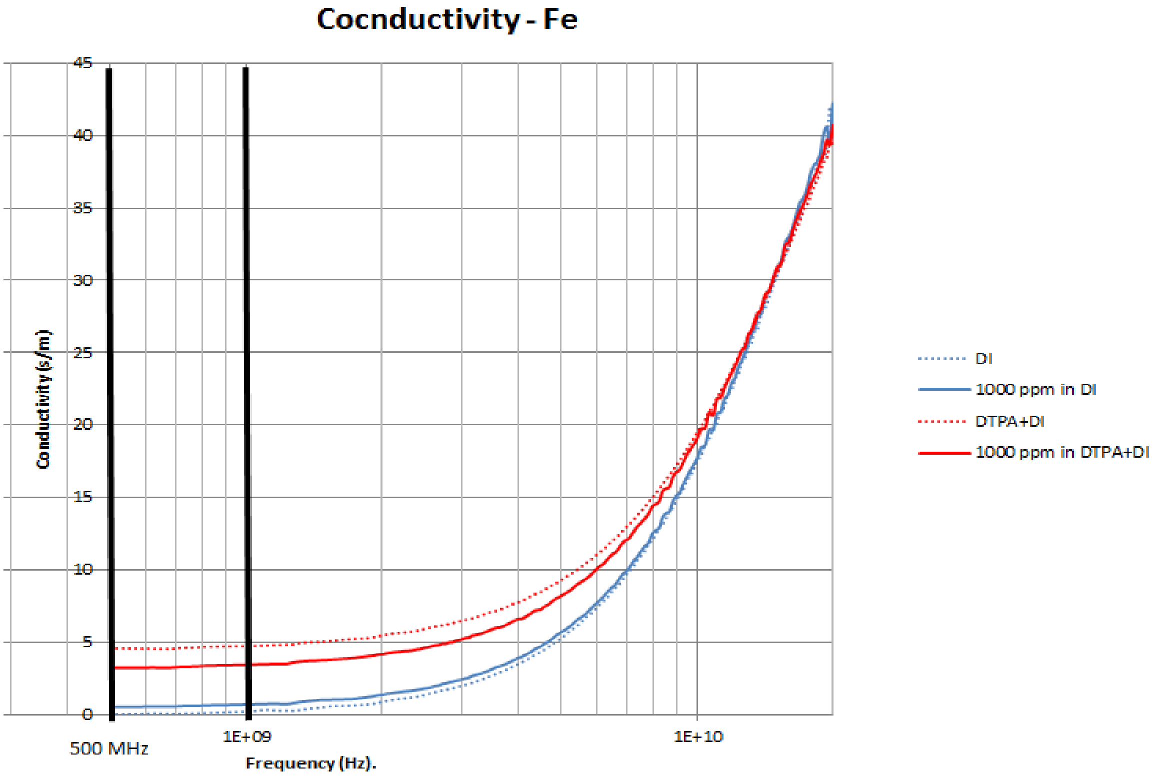

Figure 71: Conductivity (σ) values of DI water and 5 wt% DTPA-K5 in DI water with 0 and 1000 ppm (Fe^{+3}) concentrations

Table 29: Conductivity (σ) values at 800 MHz of DI water and 5 wt% DTPA-K5 in DI water with 0 and 1000 ppm (Fe^{+3}) concentrations

Liquid	Conductivity at 800 MHz (S/m)
DI water	0.14
DI water + 1000 ppm Fe^{+3}	0.66
5wt% DTPA in DI water	4.7
5wt% DTPA in DI water + 1000 ppm Fe^{+3}	3.39

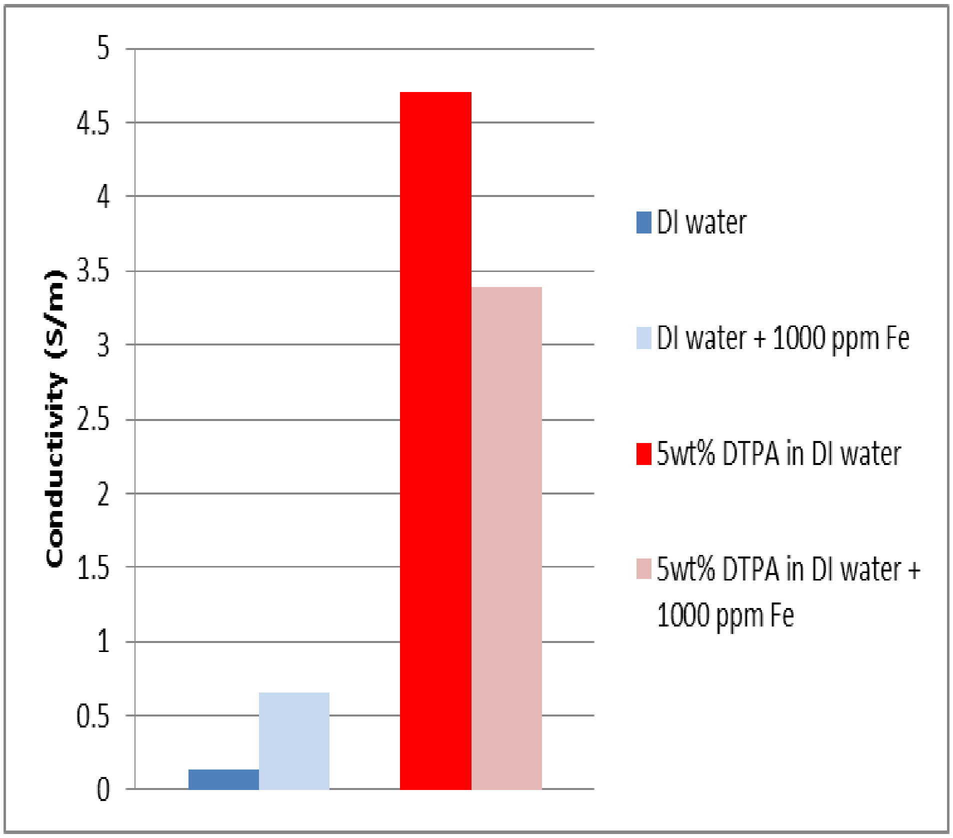

Figure 72: Comparison between the conductivity (σ) values at 800 MHz of DI water and 5 wt% DTPA-K5 in DI water with 0 and 1000 ppm (Fe^{+3}) concentrations

5.4.2 Effect of adding DTPA-K5 in DI water with 1000 ppm Mg^{+2}:

Table 30: Conductivity (σ) values at 800 MHz of DI water and 5 wt% DTPA-K5 in DI water with 0 and 1000 ppm (Mg^{+2}) concentrations

liquid	Conductivity at 800 MHz (S/m)
DI water	0.14
DI water + 1000 ppm Mg^{+2}	0.93
5wt% DTPA in DI water	4.7
5wt% DTPA in DI water + 1000 ppm Mg^{+2}	4.24

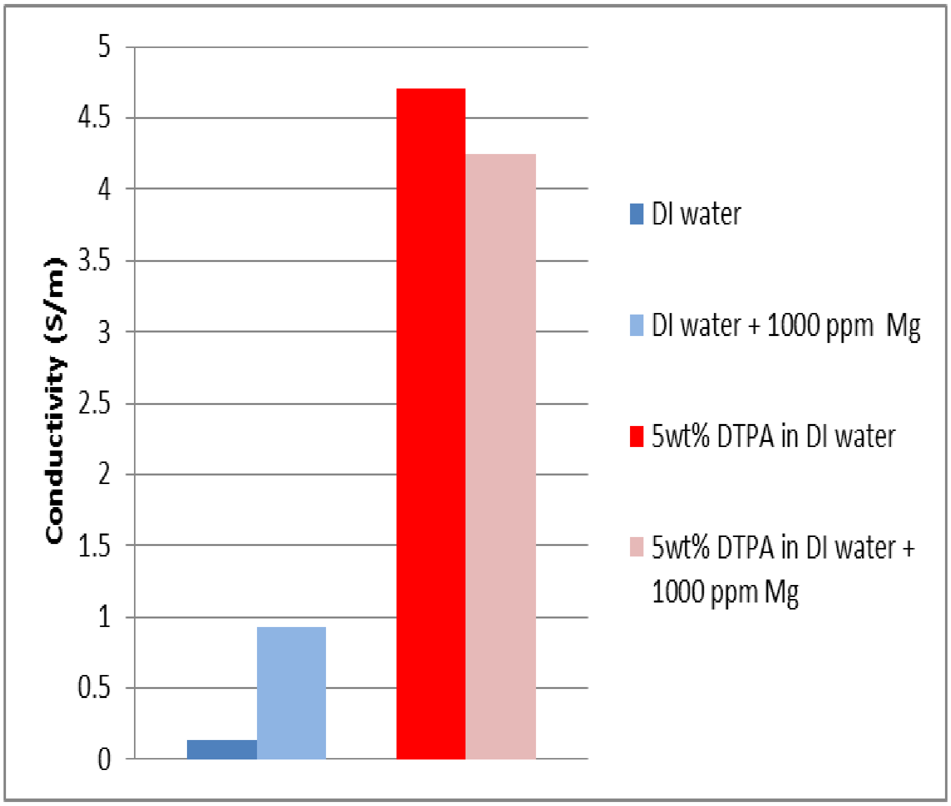

Figure 73: Comparison between the conductivity (σ) values at 800 MHz of DI water and 5 wt% DTPA-K5 in DI water with 0 and 1000 ppm (Mg^{+2}) concentrations

5.4.3 Effect of adding DTPA-K5 in DI water with 1000 ppm Ca^{+2}:

Table 31: Conductivity (σ) values at 800 MHz of DI water and 5 wt% DTPA-K5 in DI water with 0 and 1000 ppm (Ca^{+2}) concentrations

liquid	Conductivity at 800 MHz (S/m)
DI water	0.14
DI water + 1000 ppm Ca^{+2}	0.69
5wt% DTPA in DI water	4.7
5wt% DTPA in DI water + 1000 ppm Ca^{+2}	4.64

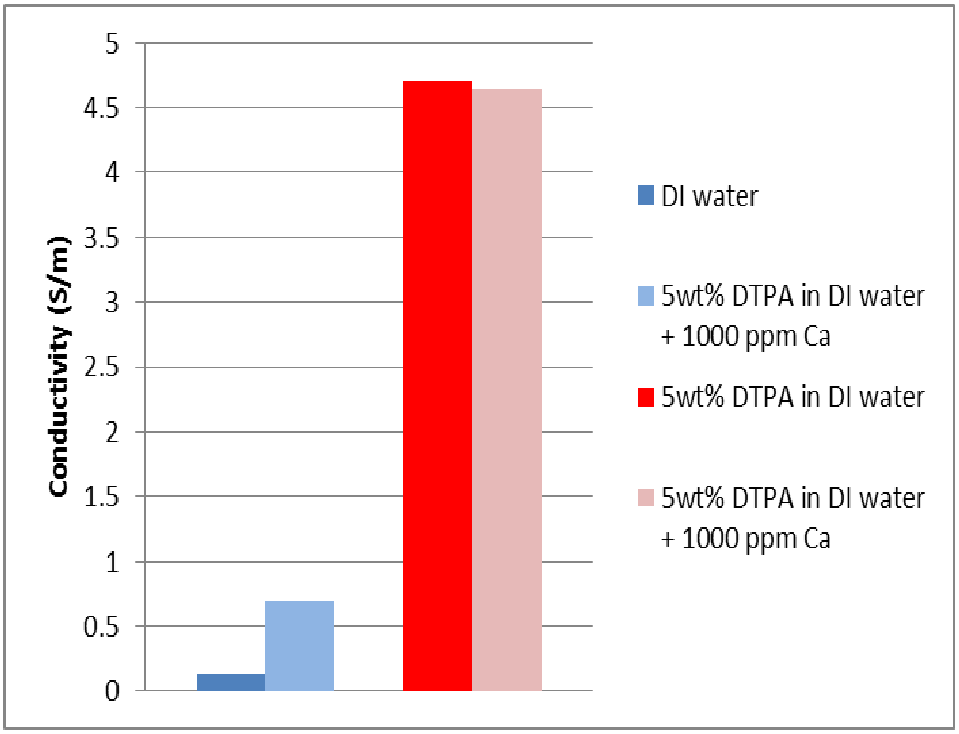

Figure 74: Comparison between the conductivity (σ) values at 800 MHz of DI water and 5 wt% DTPA-K5 in DI water with 0 and 1000 ppm (Ca^{+2}) concentrations

5.4.4 Effect of adding DTPA-K5 in DI water with 1000 ppm Na^+:

Table 32: Conductivity (σ) values at 800 MHz of DI water and 5 wt% DTPA-K5 in DI water with 0 and 1000 ppm (Na^+) concentrations

liquid	Conductivity at 800 MHz (S/m)
DI water	0.14
DI water + 1000 ppm Na^+	0.6
5wt% DTPA in DI water	4.7
5wt% DTPA in DI water + 1000 ppm Na^+	3.62

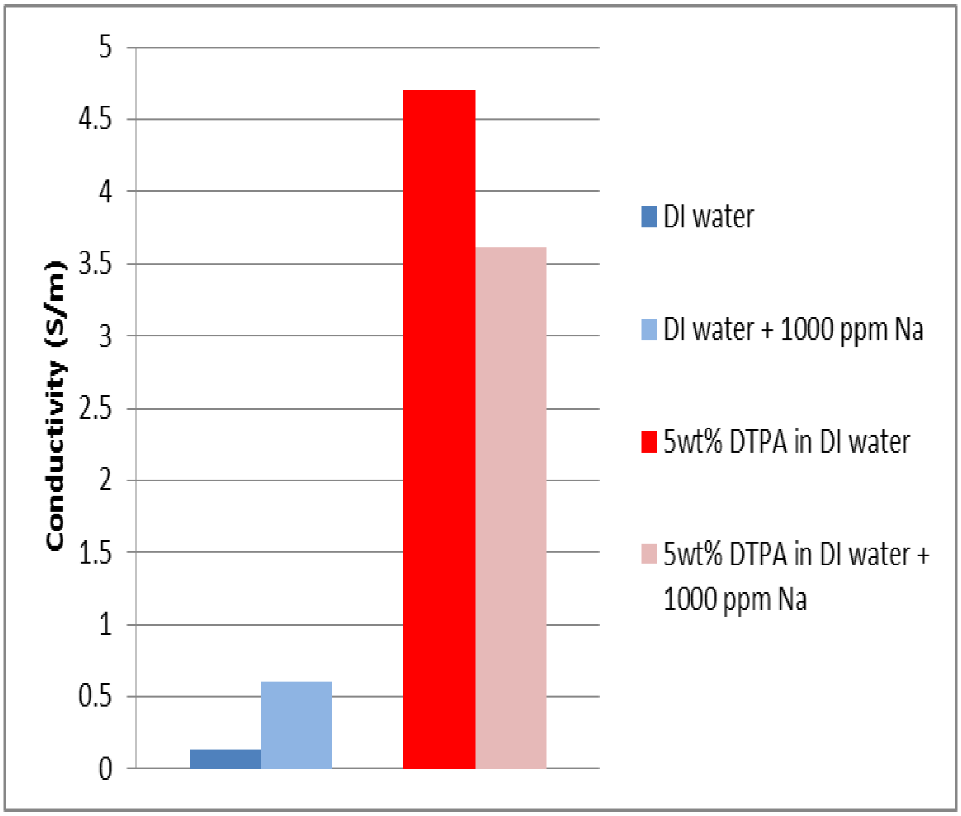

Figure 75: Comparison between the conductivity (σ) values at 800 MHz of DI water and 5 wt% DTPA-K5 in DI water with 0 and 1000 ppm (Na^+) concentrations

5.4.5 Results and discussion:

Adding the multivalent cations (Fe^{+3} Mg^{+2} Ca^{+2} and Na^+) to DI water will increase the conductivity. Also, adding DTPA-K5 salt with concentration of 50,000 ppm (5 wt%) will also increase the conductivity of DI water. But, When adding any of the $feCl_3$, $MgCl_2$, $CaCl_2$ or NaCl salts - containing each 1000 ppm of the cations Fe^{+3}, Mg^{+2}, Ca^{+2} and Na^+ respectively following the calculations in tables 10-13 – to the DTPA-K5 in DI water, the conductivity decreases (figures 71-75). For the divalent elements (Mg^{+2} and Ca^{+2}) the reduction in the DI with DTPA-K5 is less (tables 30 and 31) than the reduction occurs when adding the monovalent or trivalent elements (Na^+ and Fe^{+3} respectively) (tables 32 and 29). Whenever is DTPA-K5 chelating agent is present, the addition of salts will reduce the conductivity rather than increasing it (like when the liquid is DI only) due the absorption of cations by the chelating agent resulting in a reduction of the free ions on the liquid (less conductive liquid).

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion:

Through comprehensive study on wettability change through rock's surface charge change and ion exchange mechanisms by conducting coreflooding, ion content analysis, zeta potential and dielectric parameters' measurements on different brines, a chelating agent and sandstone rocks, it can be concluded that:

- Chelating agent (DTPA-K5) increased oil recovery for Berea sandstone rocks after being flooded with seawater. Used as a secondary flooding fluid in low concentrations (5wt%)
- From the effluent analysis for the coreflooding experiment conducted, an increase in the ferric, magnesium, calcium and aluminum cations occurred by the introduction of DTPA-K5 as a flooding fluid where it absorbed these cations from the rock.
- Chelating agent (DTPA-K5) proved its effect on sandstone's rocks mineralogy (by the absorption of certain cations) especially absorbing the ferric cation leading to surface charge change.
- As it has been observed in the literature: the more negative values of Zeta potential for the brine/rock mixture, the more water wet the rock's surface is, Therefore, relating the mineralogy change in the rock after treating by chelating agent with change in Zeta potential value as a qualitative measure of wettability alteration is accomplished.
- Zeta potential value for sandstone rocks with seawater becomes more negative after the sandstone being treated with DTPA-K5 – indicating a more water wet surface
- The effect of changing the surface mineralogy of sandstone rocks by the absorption of multivalent cations making the rock surface more water wet.
- The effect of using 5wt% DTPA-K5 in Seawater as a pre-flush fluid before seawater flooding showed more negative Zeta potential values (more repulsive surfaces)
- Using 5wt% DTPA-K5 in Seawater as a flooding fluid gives same surface charge values as flooding with low salinity water- according to Zeta potential values comparison.
- Using 5wt% DTPA-K5 in Seawater as a pre-flush to seawater flooding gives close value of surface charge as flooding with low salinity water- according to zeta potential values comparison.

- The frequency range of dielectric measurements is with high frequency (500MHz to 1GHz). Presenting the volumetric (bulk) polarization of the salts (molecules).
- The effect of ion exchange is clear on the imaginary part of relative permittivity (high frequency conductivity) rather than the real dielectric constants.
- The double layer effect is not observed using the dielectric measurements – due to the high frequency which bypasses the double layer effect.
- The change in the dielectric constant is more noticeable when the ionic ratio of added salts is high comparing to the salinity of the liquid being added to.
- Adding salts will not lead to increase in conductivity in the presence of DTPA-K5 chelating agent. Conductivity decreases due to the absorption of free ions by DTPA-K5 chelating agent.
- Adding DTPA-K5 to low salinity water will lead to lower conductivity at high frequency than DTPA-K5 added in DI water, which shows less free ions due to the ion exchange occurred.
- Adding $FeCl_3$ to seawater will lead to reduction of the seawater conductivity at high frequency, indicating less free ions in the liquid. But, it is a less reduction on seawater conductivity than in adding DTPA-K5 and $FeCl_3$ salt to seawater.
- Less conductivity at high frequency after adding ions to DTPA-K5, due to multivalent cations absorption by the chelating agent balancing out the free ions
- Observing the effect of chelating agent with different salts on high frequency conductivity using laboratory dielectric measurements.
- Introducing laboratory dielectric measurement tool as an evaluation technique into the ion exchange that occurs between different ions from the reservoir rocks' surface with different brines and additives. - As Zeta potential is an evaluation tool of rock surface/brine interaction.

6.2 Recommendations:

- Further coreflooding and effluent analysis to observe the effect of chelating agent on the rock's mineralogy and mainly on the oil recovery.

- Further investigation on Zeta potential value change due to the change of mineralogy.

- Relating the Zeta potential measurements conducted to other wettability qualification techniques to further prove the change in wettability due to change in zeta potential value.

- Using dielectric laboratory measurement to investigate several ionic exchange phenomena occurring in the reservoir.

- Further study to investigate the physics occurring at the high frequency conductivity and relate it to resistivity or dielectric logging tools.

- Investigate and explain further the effect of certain cation exchange on laboratory dielectric measurements.

- Studying the physical and chemical mechanisms of high frequency conductivity in the presence of salts and chelating agents.

- Studying the effect of adding different salts with the chelating agent on conductivity to observe the cation competition on being absorbed by the chelating agent.

References:

1- Abdallah, Wael, Jill S. Buckley, Andrew Carnegie, John Edwards, Bernd Herold, Edmund Fordham, Arne Graue et al. "Fundamentals of wettability." Schlumberger Technology 38 (1986): 1125-1144.

2- Abraham, J. D., 1999, Physical modeling of a prototype slim-hole time-domain dielectric logging tool: MSc thesis, Dept. of Geophysics, Colorado School of Mines, Golden.

3- Almarzooq, A., AlGhamdi, T., Sassi, K. and Badri, M. (2013). Characterization of Shale Gas Rocks Using Dielectric Dispersion and Nuclear Magnetic Resonance. SPE-168081. SPE Saudi Arabia Section Technical Symposium and Exhibition.

4- Alotaibi, M., Nasralla, R. and Nasr-El-Din, H. (2011). Wettability Studies Using Low-Salinity Water in Sandstone Reservoirs. SPE Reservoir Evaluation & Engineering, 14(06): 713-725.

5- Anderson, W. (1986). Wettability Literature Survey- Part 1: Rock/Oil/Brine Interactions and the Effects of Core Handling on Wettability. Journal of Petroleum Technology, 38(10): 1125-1144.

6- Attia, M., Mahmoud, M., Al-Hashim, H. and Sultan, A. (2014). Shifting to a New EOR Area for Sandstone Reservoirs With High Recovery, No Damage, and Low Cost. SPE-169670. SPE EOR Conference at Oil and Gas West Asia.

7- Bernard, G. (1967). Effect of Floodwater Salinity on Recovery Of Oil from Cores Containing Clays. SPE-1725. SPE California Regional Meeting.

8- Bashiri, A. and Kasiri, N. 2011. Properly Use Effect of Capillary Number on Residual Oil Saturation. SPE-150800-MS. Presented at the Nigeria Annual International Conference and Exhibition, Abuja, Nigeria, 30 July-3 August. http"??dx.doi.org/10.2118/150800-MS.

9- Barthelmy, Dave. 'Illite Mineral Data'. *Webmineral.com*. N.p., 2015. Web. 15 Nov. 2015.

10- Bona, N., Rossi, E. and Capaccioli, S. (2001). Electrical Measurements in the 100 Hz to 10 GHz Frequency Range for Efficient Rock Wettability Determination. SPE Journal, 6(01): 80-88.

11- Brown, P., A. Mazzella, and D. Wright. Monitoirng of a Controlled Dnapl Spill Using a Prototype Dielectric Logging Tool. U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-06/092 (NTIS PB2007-101961), 2006.

12- Buckley, J., Bousseau, C. and Liu, Y. (1996). Wetting Alteration by Brine and Crude Oil: From Contact Angles to Cores. SPE Journal, 1(03), pp.341-350.

13- Chattopadhyay, S., Jain, V. and Sharma, M. (2002). Effect of Capillary Pressure, Salinity, and Aging on Wettability Alteration in Sandstones and Limestones. SPE-75189. SPE/DOE Improved Oil Recovery Symposium.

14- Craig, F.F. Jr. 1971. The Reservoir Engineering Aspects of Waterflooding, Vol. 3, 29-77. Richardson, Texas: Monograpgh Series, SPE.

15- Donadille, J. M., & Faivre, O. (2015, March 8). Water Complex Permittivity Model for Dielectric Logging. Society of Petroleum Engineers. doi:10.2118/172566-MS

16- Dubey, S. and Doe, P. (1993). Base Number and Wetting Properties of Crude Oils. SPE Reservoir Engineering, 8(03): 195-200.

17- Farooq, U., Tweheyo, M., Sjöblom, J. and Øye, G. (2011). Surface Characterization of Model, Outcrop, and Reservoir Samples in Low Salinity Aqueous Solutions. Journal of Dispersion Science and Technology, 32(4): 519-531.

18- Fredd, C. and Fogler, H. (1998). Alternative Stimulation Fluids and Their Impact on Carbonate Acidizing. SPE Journal, 3(01): 34-41.

19- Frenier, W., Brady, M., Al-Harthy, S., Arangath, R., Chan, K., Flamant, N. and Samuel, M. (2004). Hot Oil and Gas Wells Can Be Stimulated Without Acids. SPE Production & Facilities, 19(04): 189-199.

20- Geng, X., Yong, Y., Lu, D. and Zhao, S. (1983). Dielectric Log-A Logging Method for Determining Oil Saturation. Journal of Petroleum Technology, 35(10): 1797-1805.

21- Hirasaki, G. (1991). Wettability: Fundamentals and Surface Forces. SPE Formation Evaluation, 6(02): 217-226.

22- Hizem, M., Budan, H., Deville, B., Faivre, O., Mosse, L. and Simon, M. (2008). Dielectric Dispersion: A New Wireline Petrophysical Measurement. SPE-116130. SPE Annual Technical Conference and Exhibition.

23- JAMIALAHMADI, M. and MÜLLER-STEINHAGEN, H. (1991). Reduction of Calcium Sulfate Scale Formation During Nucleate Boiling by Addition of EDTA. Heat Transfer Engineering, 12(4): 19-26.

24- Keysight.com, (2015). *85070E Dielectric Probe Kit | Keysight (Agilent)*. [online] Available at: http://www.keysight.com/en/pd-304506-pn-85070E/dielectric-probe-kit?cc=SA&lc=eng.

25- Kia, S., Fogler, H., Reed, M. and Vaidya, R. (1987). Effect of Salt Composition on Clay Release in Berea Sandstones. SPE Production Engineering, 2(04): 277-283.

26- kozaki, C. (2012). Efficiency of low salinity polymer flooding in sandstone cores. MSc thesis University of Texas Austin.

27- Lager, A., Webb, K., Collins, I. and Richmond, D. (2008). LoSal Enhanced Oil Recovery: Evidence of Enhanced Oil Recovery at the Reservoir Scale. SPE-113976. SPE Symposium on Improved Oil Recovery.

28- Ligthelm, D., Gronsveld, J., Hofman, J., Brussee, N., Marcelis, F. and van der Linde, H. (2009). Novel Waterflooding Strategy By Manipulation Of Injection Brine Composition. SPE-119835. EUROPEC/EAGE Conference and Exhibition.
29- Lindolf, J, Stoffer, K. 1983. A Case Study of Seawater Injection Incompatibility. Journal of Petroleum Technology, 35(7): 1256 – 1262.
30- M. W. Bodine, Jr., T. H. Fernalld, (1973). Edta Dissolution of Gypsum, Anhydrite, and Ca-Mg Carbonates. SEPM Journal of Sedimentary Research, Vol. 43.
31- Mahmoud, M. and Abdelgawad, K. (2015). Chelating Agent Enhanced Oil Recovery for Sandstone and Carbonate Reservoirs. SPE 172183-PA. SPE Journal.
32- Mahmoud, M., Nasr-El-Din, H. and De Wolf, C. (2015). High-Temperature Laboratory Testing of Illitic Sandstone Outcrop Cores With HCl-Alternative Fluids. SPE Production & Operations, 30(01): 43-51.
33- Mahmoud, M., Nasr-El-Din, H., De Wolf, C. and Alex, A. (2011). Sandstone Acidizing Using A New Class of Chelating Agents. SPE-139815. SPE International Symposium on Oilfield Chemistry.
34- Mahmoud, M., Nasr-El-Din, H., De Wolf, C., LePage, J. and Bemelaar, J. (2011). Evaluation of a New Environmentally Friendly Chelating Agent for High-Temperature Applications. SPE Journal, 16(03): 559-574.
35- MARTELL, A. and CALVIN, M. (1952). Chemistry of the Metal Chelate Compounds. Soil Science, 74(5): 403.
36- MARTELL, A and Smith, R. (203). NIST Critically selected stability constants of metal complexes (NIST standard reference database 46, Version 7.0. 2003)
37- Menezes, J., Yan, J. and Sharma, M. (1989). The Mechanism of Wettability Alteration Due to Surfactants in Oil-Based Muds. SPE-18460. SPE International Symposium on Oilfield Chemistry.
38- Menezes, J., Yan, J. and Sharma, M. (1989). The Mechanism of Wettability Alteration Due to Surfactants in Oil-Based Muds. SPE-18460. SPE International Symposium on Oilfield Chemistry.
39- Moore, E., Crowe, C. and Hendrickson, A. (1965). Formation, Effect and Prevention of Asphaltene Sludges During Stimulation Treatments. Journal of Petroleum Technology, 17(09): 1023-1028.
40- Morrow, N., Tang, G., Valat, M. and Xie, X. (1998). Prospects of improved oil recovery related to wettability and brine composition. Journal of Petroleum Science and Engineering, 20(3-4): 267-276.
41- Nasralla, R. and Nasr-El-Din, H. (2014). Double-Layer Expansion: Is It a Primary Mechanism of Improved Oil Recovery by Low-Salinity Waterflooding?. SPE Reservoir Evaluation & Engineering, 17(01): 49-59.

42- Nasralla, R., Bataweel, M. and Nasr-El-Din, H. (2011). Investigation of Wettability Alteration by Low Salinity Water. SPE-146322. Offshore Europe.

43- Nasralla, R., Bataweel, M. and Nasr-El-Din, H. (2013). Investigation of Wettability Alteration and Oil-Recovery Improvement by Low-Salinity Water in Sandstone Rock. Journal of Canadian Petroleum Technology, 52(02): 144-154.

44- Nasralla, R. A., Alotaibi, M. B., & Nasr-El-Din, H. A. (2011, January 1). Efficiency of Oil Recovery by Low Salinity Water Flooding in Sandstone Reservoirs. Society of Petroleum Engineers. doi:10.2118/144602-MS

45- Nasralla, R. A., & Nasr-El-Din, H. A. (2012, January 1). Double-Layer Expansion: Is It A Primary Mechanism of Improved Oil Recovery by Low-Salinity Waterflooding? Society of Petroleum Engineers. doi:10.2118/154334-MS

46- Parkinson, M., Munk, T., Brookley, J., Caetano, A., Albuquerque, M., Cohen, D. and Reekie, M. (2010). Stimulation of Multilayered High-Carbonate-Content Sandstone Formations in West Africa Using Chelant-Based Fluids and Mechanical Diversion. SPE-128043. SPE International Symposium and Exhibition on Formation Damage Control.

47- Rao, D., Ayirala, S., Abe, A. and Xu, W. (2006). Impact of Low-Cost Dilute Surfactants on Wettability and Relative Permeability. SPE-99609. SPE/DOE Symposium on Improved Oil Recovery.

48- Robertson, E. (2007). Low-Salinity Waterflooding to Improve Oil Recovery-Historical Field Evidence. SPE-109965. SPE Annual Technical Conference and Exhibition.

49- Sandstone. Cores and Coring Services at Kocurek Industries. 2015. http://www.kocurekindustries.com/sandstone-cores.

50- Sassi, K., & Kadoura, A. (2014). A New Model to Determine Wettability from Multi-frequency Dielectric Dispersion Measurements. SPE-SAS-318

51- Schmitt, D.P., Al-Harbi, A., Saldungaray, P., Akkurt, R., and Zhang, T., 2011, Revisiting dielectric logging in Saudi Arabia: recent experiences and applications in development and application wells. SPE-149131. Presented at the SPE/DGS Saudi Arabia Section Technical Symposium and Exhibition, Al-Khobar, Saudi Arabia, 15-18 May.

52- Seccombe, J., Lager, A., Jerauld, G., Jhaveri, B., Buikema, T., Bassler, S., Denis, J., Webb, K., Cockin, A. and Fueg, E. (2010). Demonstration of Low-Salinity EOR at Interwell Scale, Endicott Field, Alaska. SPE-129692. SPE Improved Oil Recovery Symposium.

53- Sheriff, R. (1991). Encyclopedic dictionary of exploration geophysics. Tulsa, Okla.: SEG Book Mart.

54- Schlumberger, *Log interpretation charts* (2009 ed.). (2009). New York: Schlumberger.

55- Wang, W. and Gupta, A. (1995). Investigation of the Effect of Temperature and Pressure on Wettability Using Modified Pendant Drop Method. SPE-30544. Proceedings of SPE Annual Technical Conference and Exhibition.

56- Wright, D.L. and Nelson, P.H. 1993. Borehole dielectric logging: a review and laboratory experiment. In Proceeding of the 5th Int. Symp. On Geophysics for minerals, Geotechnical and Environmental Applications. Minerals and Geotechnical Logging Society, paper T.

57- Wu, S. and Firoozabadi, A. (2010). Effect of Salinity on Wettability Alteration to Intermediate Gas-Wetting. SPE Reservoir Evaluation & Engineering, 13(02): 228-245.

58- Xie, X., Liu, Y., Sharma, M. and Weiss, W. (2009). Wettability alteration to increase deliverability of gas production wells. Journal of Natural Gas Science and Engineering, 1(1-2): 39-45.

59- Yuhua, B., Tinghui, L., Huimin, S., Mengling, Z. and Hongtao, C. (2013). Application of Facies-Controlled Reservoir Prediction Technology in Slope Zone, North Dagang. SPE-16964. International Petroleum Technology Conference.

60- Zhang, Y., Xie, X. and Morrow, N. (2007). Waterflood Performance By Injection Of Brine With Different Salinity For Reservoir Cores. SPE-109849.. SPE Annual Technical Conference and Exhibition.

Appendix A: Materials preparation figures:

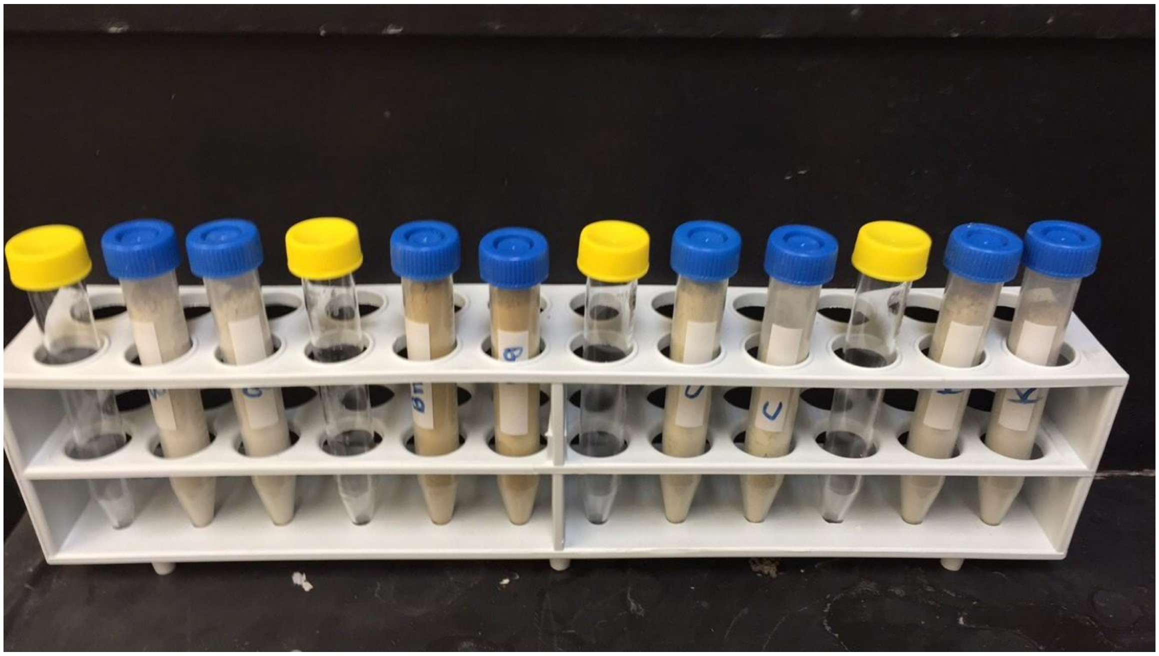

Figure A.1: Sandstone rock's powder after being crushed.

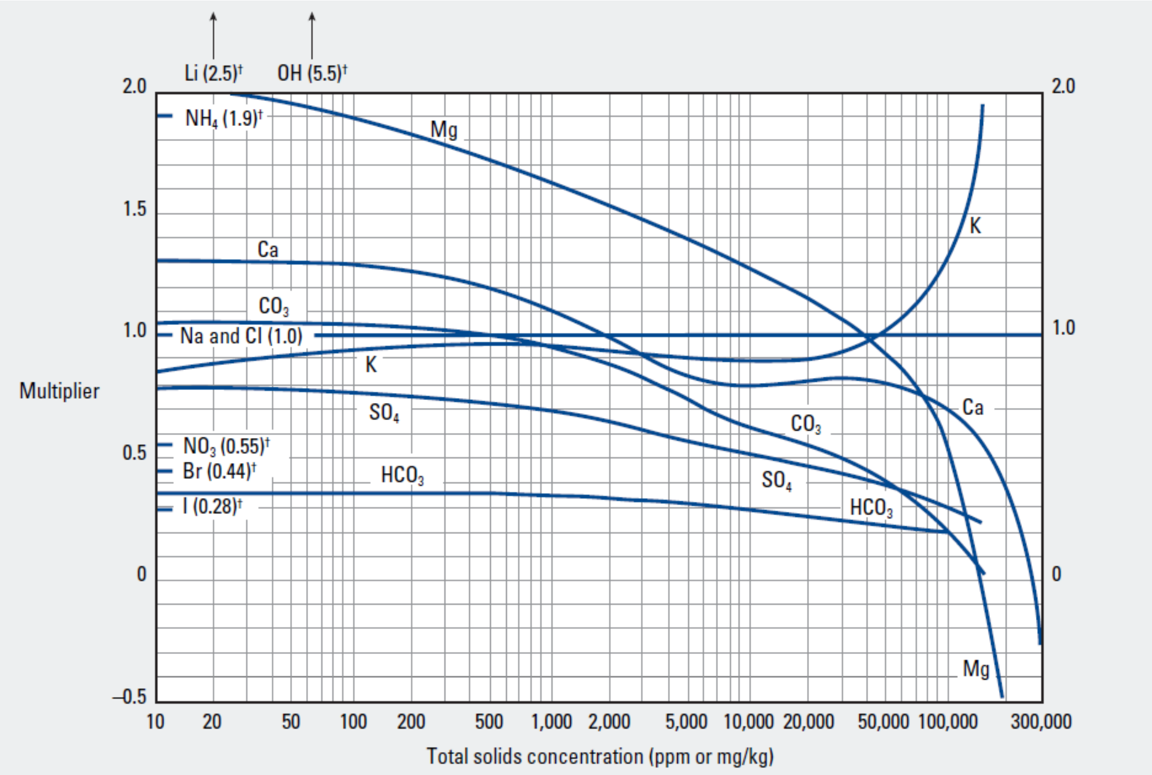

Figure A.2: Nacl equivalent vs. salts concentrations chart

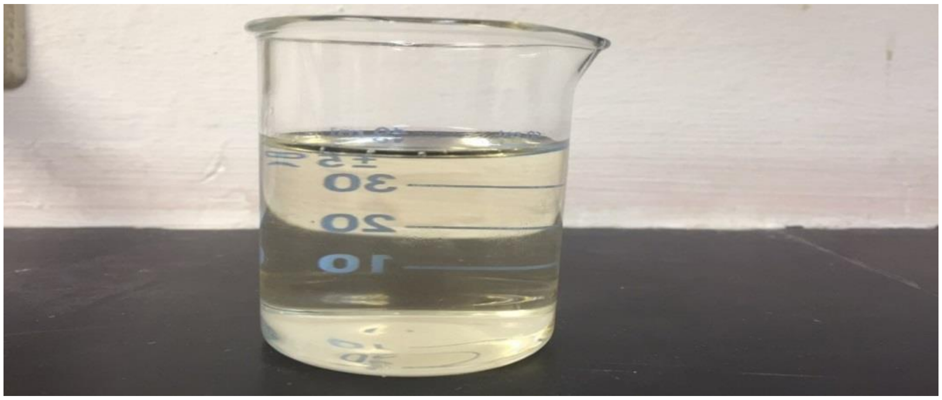

Figure A.3: DTPA-K5 as 40wt% in DI water

Appendix B: Coreflooding raw data:

Table B.1: Coreflooding and effluent data analysis.

		Cation concentration, ppm				
PV	**% Recovery**	SO4	Ca	Mg	Fe	Al
0	**0**	3300	4500	2450	0	0
0.2	**18.47**	3400	4200	2450	0	0
0.4	**34.21**	3600	3800	2400	0	0
0.6	**42.24**	4000	3700	2350	0	0
0.8	**47.13**	4100	3650	2350	0	0
0.9	**47.76**	4250	3500	2300	0	0
1.2	**49.90**	4250	3000	2250	0	0
1.5	**53.14**	4250	2800	2200	0	0
1.8	**55.29**	4250	2600	2200	0	0
2.2	**55.79**	4250	2500	2150	0	0
2.7	**55.81**	4250	2300	2150	0	0
3	**55.85**	4250	2100	2150	50	25
3.2	**55.91**	4300	2100	2400	100	50
3.5	**60.25**	4500	2100	2600	300	75
3.8	**65.25**	4300	2100	2550	600	125
4.2	**68.25**	4350	2150	2650	800	250
4.8	**72.54**	4350	2125	2700	1100	325
5.2	**74.24**	4300	2130	2700	1600	320
5.8	**74.56**	4300	2140	2725	1800	325
6.2	**74.85**	4300	2125	2700	1850	330
6.5	**74.90**	4300	2130	2750	1825	335
6.8	**75.05**	4300	2150	2725	1850	345
7	**75.08**	4300	2150	2700	1860	335

Appendix C: ICP analysis figures and raw data:

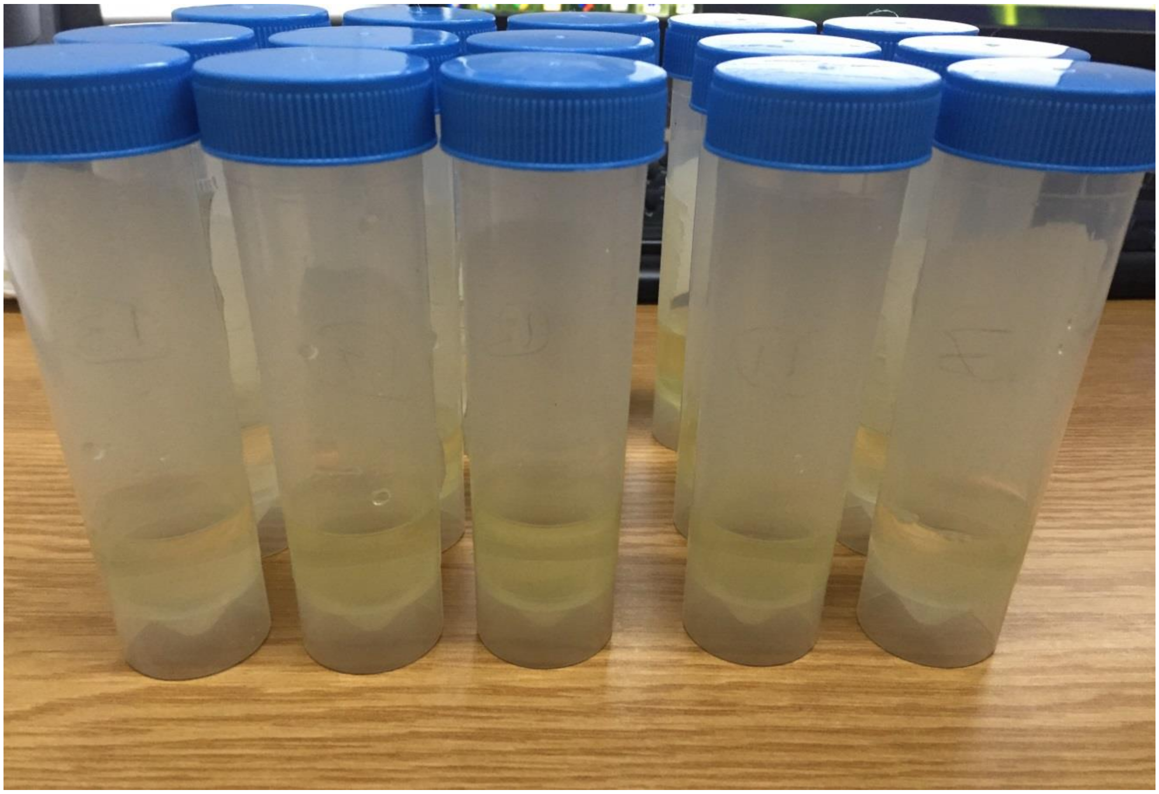

Figure C.1: Filtrate from mixing different sandstone rock’s powder with 5 wt% DTPA-K5 in seawater

Table-C.1: Ion content for fluids

Base fluids	description	Mg ppm	Al ppm	Ca ppm	Fe ppm
DTPA mixture (5 wt% DTPA -K5 & Seawater)	mixing 1.2 gm DTPA with 8.8 gm Seawater	2413	0.03244	658.1	0.1409
5 wt% DTPA & DI	mixing 1.25gm DTPA (2.5ml DTPA) w/ 25 gm DI	0.22	0.0306	0.1785	0.31

Table-C.2: Ion content for fluids from mixing sandstone powders with DTPA-SW

Rock Powder	Liquid	filtered after conditioned for	Mg ppm	Al ppm	Ca ppm	Fe ppm
Berea	DTPA mixture 5 wt% DTPA & Seawater	2 hrs	1858	0.5695	694.2	14
		6 hrs	1754	1.157	677.6	27.18
		12 hrs	1957	1.187	754.8	24.39
		24 hrs	1868	1.175	715.6	26.25
Bandera		2 hrs	1735	1.083	669.6	11.23
		6 hrs	1979	2.891	796.9	17.16
		12 hrs	1939	2.39	776.1	16.8
		24 hrs	1935	2.906	770.6	21.2
Kentucky		2 hrs	2009	1.371	792.3	15.72
		6 hrs	1959	1.844	770.6	18.21
		12 hrs	2090	1.931	819.6	22.47
		24 hrs	2091	1.928	807.3	27.83
Scioto		2 hrs	2074	2.617	836.9	18.04
		6 hrs	2038	2.206	810.2	24.02
		12 hrs	1975	2.468	772.2	26.62
		24 hrs	2085	4.12	819.1	32.9

Table-C.3: Ion content for fluids from mixing Berea powder with DTPA-DI

Rock Powder	Liquid	filtered after conditioned for	Mg ppm	Al ppm	Ca ppm	Fe ppm
Berea	5 wt% DTPA & DI	conditioned for 2 hrs	5.259	0.9541	26.02	15.41
		conditioned for 6 hrs	6.336	1.145	24.21	29.4
		conditioned for 12 hrs	7.071	0.7998	20.5	25.98
		conditioned for 24 hrs	6.717	1.31	18.24	28.1

Table C.4: % percentage absorbed cations form the rock after mixing with DTPA-SW mixture

% percentage of absorbed cations from the rock (%)	Conditioning period (hrs)	Berea	
	-	Al	Fe
	0	0.03	0.14
	2	0.41	59.58
	6	0.86	100.00
	12	0.88	100.00
	24	0.87	100.00
	Conditioning period (hrs)	Bandera	
	-	Al	Fe
	0	0.03	0.14
	2	0.31	34.93
	6	0.83	53.61
	12	0.69	52.48
	24	0.84	66.34
	Conditioning period (hrs)	Kentucky	
	-	Al	Fe
	0	0.03	0.14
	2	0.32	60.80
	6	0.44	70.52
	12	0.46	87.14
	24	0.46	100.00
	Conditioning period (hrs)	Scioto	
	-	Al	Fe
	0	0.03	0.14
	2	0.73	18.75
	6	0.62	25.01
	12	0.69	27.73
	24	1.16	34.31

Table C.5: % percentage absorbed ferric form the Berea after mixing with DTPA-DI mixture

	Conditioning period (hrs)	**Fe**
% percentage of absorbed ferric from Berea (%)	0	1.02
	2	61.83
	6	100
	12	100
	24	100

Appendix D: Zeta potential figures and raw data:

Table D.1: Zeta potential values for sandstone rocks with seawater

Rock	**Rock Powder condition**	**liquid mixed for 24 hours**	**ζ - zeta potential (mV)**	**PH**	Mobility	Conductance
Berea	not conditioned	SW	15.49	7.8	1.21	150000
	conditioned w/ 5 wt% DTPA in SW for 2 hrs		-6.74	7.7	-0.53	144000
	conditioned w/ 5 wt% DTPA in SW for 6 hrs		-10.49	7.78	-0.82	154500
	conditioned w/ 5 wt% DTPA in SW for 12 hrs		-17.37	7.74	-1.36	133000
	conditioned w/ 5 wt% DTPA in SW for 24 hrs		-16.95	7.68	-1.32	147000
Bandera	not conditioned	SW	16.76	7.7	1.31	138000
	conditioned w/ 5 wt% DTPA in SW for 2 hrs		-16.7	7.6	-1.3	154000
	conditioned w/ 5 wt% DTPA in SW for 6 hrs		-20.97	7.74	-1.64	145500
	conditioned w/ 5 wt% DTPA in SW for 12 hrs		-21.11	7.57	-1.65	154000
	conditioned w/ 5 wt% DTPA in SW for 24 hrs		-25.91	7.63	-2.02	168000
Kentucky	not conditioned	SW	-7.03	7.74	-0.55	147000
	conditioned w/ 5 wt% DTPA in SW for 2 hrs		-7.54	7.7	-0.59	132000
	conditioned w/ 5 wt% DTPA in SW for 6 hrs		-8.8	7.8	-0.69	168000
	conditioned w/ 5 wt% DTPA in SW for 12 hrs		-10.19	7.67	-0.8	164500
	conditioned w/ 5 wt% DTPA in SW for 24 hrs		-11.03	7.69	-0.86	152000
Scioto	not conditioned	SW	5.84	7.74	0.46	138000
	conditioned w/ 5 wt% DTPA in SW for 2 hrs		-14.24	7.7	-1.11	142000
	conditioned w/ 5 wt% DTPA in SW for 6 hrs		-16.02	7.75	-1.25	158000
	conditioned w/ 5 wt% DTPA in SW for 12 hrs		-13.36	7.64	-1.04	123000
	conditioned w/ 5 wt% DTPA in SW for 24 hrs		-9.98	7.72	-0.78	163000

Table D.2: Zeta potential values for sandstone rocks with low salinity water

Rock	**Rock Powder condition**	**liquid mixed for 24 hours**	**ζ - zeta potential (mV)**	**PH**	Mobility	Conductance
Berea	not conditioned	LS	-19.56	7.5	-1.53	25000
	conditioned w/ 5 wt% DTPA in SW for 2 hrs		-21.45	7.63	-1.68	21000
	conditioned w/ 5 wt% DTPA in SW for 6 hrs		-23.91	7.23	-1.87	24500
	conditioned w/ 5 wt% DTPA in SW for 12 hrs		-24.52	7.6	-1.92	18900
	conditioned w/ 5 wt% DTPA in SW for 24 hrs		-21.91	7.55	-1.71	21000
Bandera	not conditioned	LS	-20.7	7.2	-1.62	20000
	conditioned w/ 5 wt% DTPA in SW for 2 hrs		-24.09	7.2	-1.88	22500
	conditioned w/ 5 wt% DTPA in SW for 6 hrs		-24.55	7.2	-1.92	24700
	conditioned w/ 5 wt% DTPA in SW for 12 hrs		-24.65	7.61	-1.93	23000
	conditioned w/ 5 wt% DTPA in SW for 24 hrs		-25.19	7.49	-1.97	21000
Kentucky	not conditioned	LS	-18.03	7.6	-1.41	23000
	conditioned w/ 5 wt% DTPA in SW for 2 hrs		-20.53	7.4	-1.6	21500
	conditioned w/ 5 wt% DTPA in SW for 6 hrs		-22.28	7.3	-1.74	23000
	conditioned w/ 5 wt% DTPA in SW for 12 hrs		-24.7	7.54	-1.93	21000
	conditioned w/ 5 wt% DTPA in SW for 24 hrs		-21.98	7.44	-1.72	22000
Scioto	not conditioned	LS	-16.28	7.53	-1.27	19000
	conditioned w/ 5 wt% DTPA in SW for 2 hrs		-18.54	7.3	-1.45	24000
	conditioned w/ 5 wt% DTPA in SW for 6 hrs		-18.9	7.2	-1.48	24000
	conditioned w/ 5 wt% DTPA in SW for 12 hrs		-23.26	7.61	-1.83	24000
	conditioned w/ 5 wt% DTPA in SW for 24 hrs		-20.28	7.65	-1.58	20000

Table D.3: Zeta potential values for Berea with DI water

Rock	**Rock Powder condition**	**liquid mixed**	**ζ - zeta potential (mV)**	Mobility	Conductance
Berea	not conditioned	DI for 2 hrs	-21.73	-1.7	182
	not conditioned	DI for 6 hrs	-21.79	-1.7	106
	not conditioned	DI for 15 hrs	-25.83	-2.02	197
	not conditioned	DI for 24 hrs	-26.75	-2.09	231
	Conditioned for 2 hrs with 5wt% DTPA in DI water	DI for 24 hrs	-32.77	-2.56	267
	Conditioned for 6 hrs with 5wt% DTPA in DI water		-37.84	-2.96	148
	Conditioned for 12 hrs with 5wt% DTPA in DI water		-42.27	-3.3	132
	Conditioned for 24 hrs with 5wt% DTPA in DI water		-53.3	-4.16	264

Table D.4: Zeta potential values for Berea with seawater

Rock	**Rock Powder condition**	**liquid mixed**	**ζ - zeta potential (mV)**	Mobility	Conductance
Berea	not conditioned	SW for 2 hrs	20.62	1.61	176000
	not conditioned	SW for 6 hrs	14.55	0.92	174000
	not conditioned	SW for 15 hrs	14.1	1.1	167000
	not conditioned	SW for 24 hrs	11.67	0.91	177000

Table D.5: Zeta potential values for Berea with low salinity water

Rock	**Rock Powder condition**	**liquid mixed**	**ζ - zeta potential (mV)**	Mobility	Conductance
Berea	not conditioned	LS for 2 hrs	-15.77	-1.23	21000
	not conditioned	LS for 6hrs	-15.88	-1.24	32000
	not conditioned	LS for 15 hrs	-16.39	-1.28	25000
	not conditioned	LS for 24 hrs	-19.09	-1.49	22000

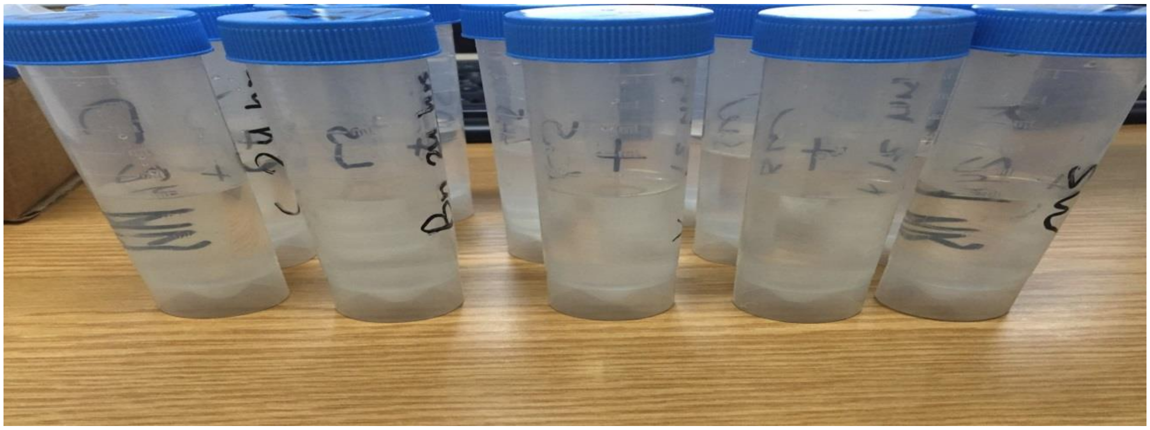

Figure D.1: Zeta potential powder/brine mixtures after conditioning for 24 hours

Appendix E: Dielectric measurements and high frequency conductivity figures and raw data:

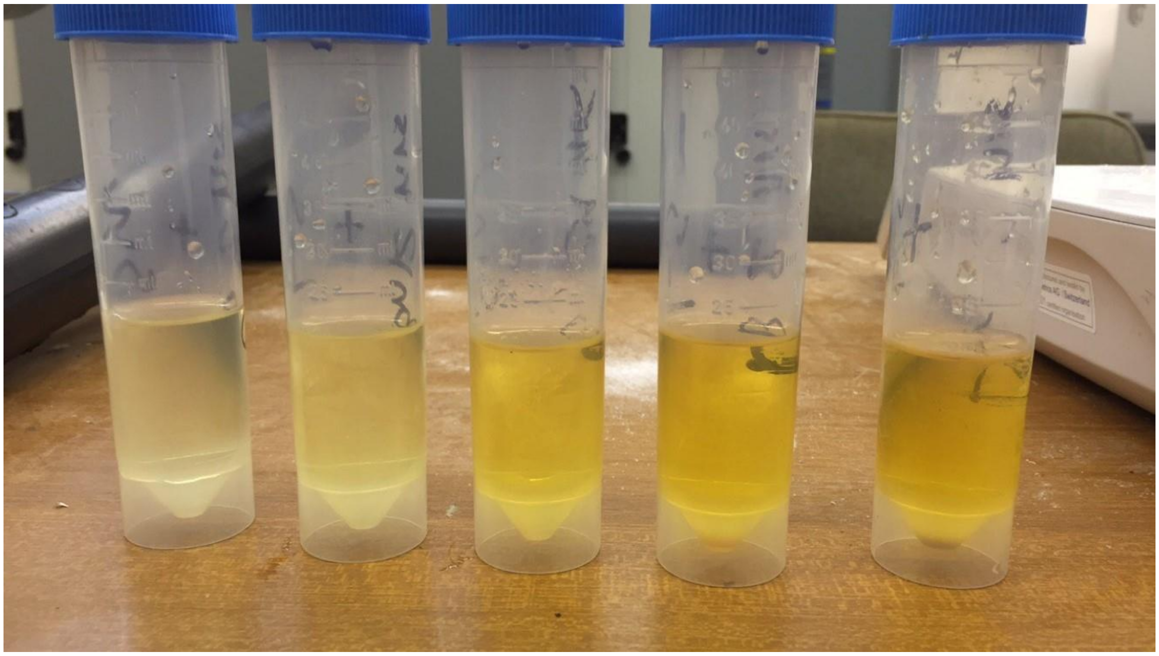

Figure E.1: Fecl$_3$ added to DI water (from the left: 500, 1000,2000,3000,4000 ppm of Fe^{+3})

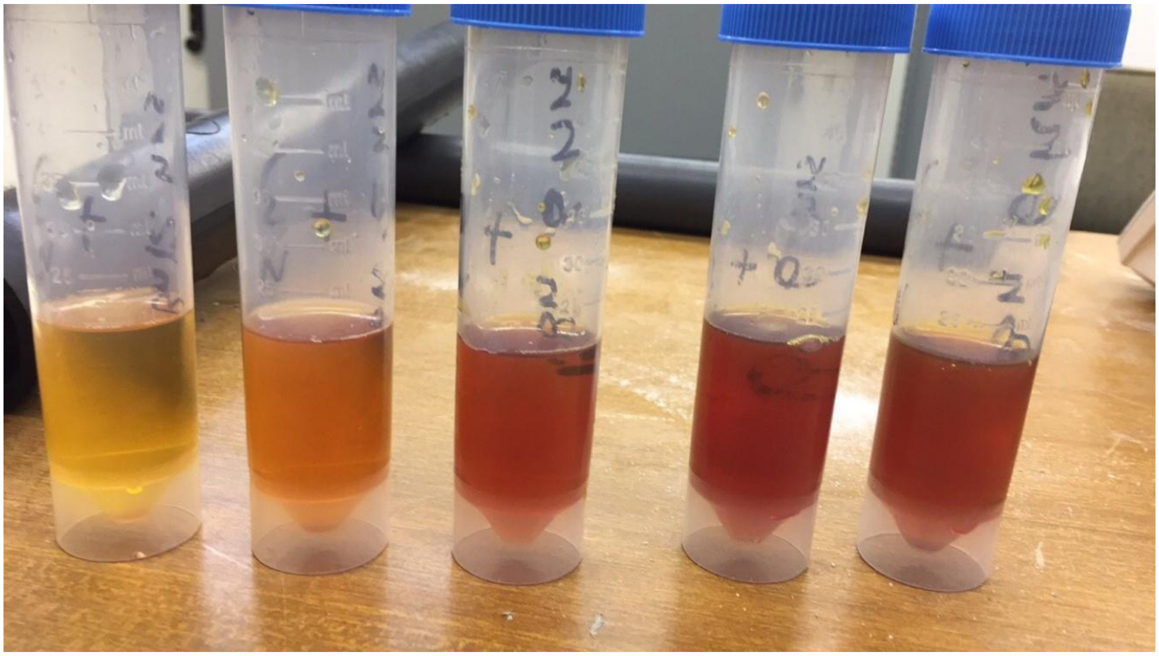

Figure E.2: Fecl$_3$ added to DI water with 5wt% DTPA-K5 (from the left: 500, 1000,2000,3000,4000 ppm of Fe^{+3})

Table: E.1: DI water dielectric measurements:

frequency	e'	e''	sensitivity	Conductivity
Hz	-	-		S/m
500000000.00	79.15	2.22	328.58	0.06
511153138.74	79.17	2.30	322.23	0.07
522306277.48	79.18	2.34	316.12	0.07
533459416.22	79.20	2.39	310.28	0.07
544612554.96	79.19	2.43	304.66	0.07
555765693.70	79.22	2.55	299.34	0.08
566918832.44	79.25	2.60	294.17	0.08
578071971.18	79.28	2.64	289.19	0.08
589225109.92	79.33	2.76	284.47	0.09
600378248.66	79.38	2.96	280.03	0.10
611531387.40	79.41	3.23	275.80	0.11
622684526.14	79.18	3.54	271.71	0.12
633837664.88	78.51	3.51	267.30	0.12
644990803.62	78.33	3.06	262.74	0.11
656143942.36	78.27	2.89	258.65	0.11
667297081.10	78.25	2.62	254.59	0.10
678450219.84	78.34	2.34	250.68	0.09
689603358.58	78.70	2.10	247.00	0.08
700756497.32	79.10	2.21	243.81	0.09
711909636.06	79.25	2.46	240.78	0.10
723062774.80	79.25	2.65	237.75	0.11
739191613.69	79.17	2.78	233.37	0.11
755320452.58	79.12	2.81	229.09	0.12
771449291.47	79.19	2.84	225.03	0.12
787578130.36	79.28	2.96	221.23	0.13
803706969.24	79.31	3.13	217.62	0.14
819835808.13	79.28	3.27	214.13	0.15
835964647.02	79.25	3.39	210.74	0.16
852093485.91	79.22	3.50	207.48	0.17
868222324.80	79.20	3.58	204.32	0.17
884351163.69	79.21	3.66	201.29	0.18
900480002.58	79.22	3.76	198.39	0.19
916608841.47	79.24	3.86	195.60	0.20
932737680.36	79.25	3.95	192.90	0.21
948866519.25	79.27	4.05	190.31	0.21
964995358.14	79.30	4.17	187.83	0.22
981124197.03	79.32	4.25	185.41	0.23
997253035.92	79.34	4.41	183.13	0.24
1013381874.81	79.37	4.50	180.88	0.25
1029510713.70	79.43	4.66	178.78	0.27
1045639552.59	79.48	4.89	176.82	0.28
1068963878.60	79.38	5.34	174.17	0.32
1092288204.60	78.85	5.83	171.53	0.35
1115612530.60	78.09	5.68	168.31	0.35
1138936856.61	77.83	5.19	165.04	0.33
1162261182.61	77.85	4.84	162.12	0.31
1185585508.61	77.93	4.64	159.48	0.31
1208909834.62	78.02	4.57	157.06	0.31
1232234160.62	78.04	4.43	154.65	0.30
1255558486.62	78.24	4.17	152.27	0.29
1278882812.63	78.75	4.09	150.28	0.29
1302207138.63	79.24	4.44	148.80	0.32

1325531464.64	79.42	4.89	147.36	0.36
1348855790.64	79.40	5.23	145.82	0.39
1372180116.64	79.36	5.51	144.27	0.42
1395504442.65	79.33	5.75	142.75	0.45
1418828768.65	79.33	5.97	141.29	0.47
1442153094.65	79.32	6.10	139.79	0.49
1465477420.66	79.25	6.33	138.42	0.52
1488801746.66	79.15	6.59	137.13	0.55
1512126072.67	79.02	6.83	135.85	0.57
1545855976.43	78.71	7.08	133.92	0.61
1579585880.19	78.30	7.12	131.84	0.63
1613315783.95	78.06	7.03	129.80	0.63
1647045687.71	77.94	6.93	127.87	0.63
1680775591.47	77.93	6.87	126.11	0.64
1714505495.23	77.96	6.89	124.52	0.66
1748235398.99	77.98	6.92	123.00	0.67
1781965302.75	78.03	6.95	121.58	0.69
1815695206.52	78.18	6.93	120.20	0.70
1849425110.28	78.36	6.98	118.97	0.72
1883155014.04	78.59	7.16	117.96	0.75
1916884917.80	78.80	7.37	117.02	0.79
1950614821.56	78.82	7.64	116.10	0.83
1984344725.32	78.80	8.00	115.30	0.88
2018074629.08	78.77	8.30	114.47	0.93
2051804532.84	78.59	8.55	113.57	0.98
2085534436.60	78.40	8.81	112.71	1.02
2119264340.36	78.23	8.97	111.79	1.06
2152994244.13	78.04	9.08	110.85	1.09
2186724147.89	77.95	9.15	109.96	1.11
2235501823.50	77.87	9.15	108.64	1.14
2284279499.11	77.96	9.20	107.53	1.17
2333057174.73	78.00	9.35	106.56	1.21
2381834850.34	78.07	9.53	105.70	1.26
2430612525.96	78.00	9.75	104.85	1.32
2479390201.57	77.97	9.99	104.11	1.38
2528167877.19	77.91	10.29	103.46	1.45
2576945552.80	77.84	10.61	102.86	1.52
2625723228.41	77.75	10.87	102.23	1.59
2674500904.03	77.62	11.08	101.57	1.65
2723278579.64	77.53	11.22	100.90	1.70
2772056255.26	77.40	11.34	100.21	1.75
2820833930.87	77.31	11.43	99.56	1.79
2869611606.48	77.20	11.59	98.99	1.85
2918389282.10	77.10	11.75	98.46	1.91
2967166957.71	77.02	11.93	98.00	1.97
3015944633.33	76.97	12.10	97.57	2.03
3064722308.94	76.97	12.28	97.21	2.09
3113499984.55	76.98	12.45	96.87	2.15
3162277660.17	76.96	12.61	96.53	2.22
3232816303.12	76.90	12.86	96.08	2.31
3303354946.08	76.75	13.12	95.63	2.41
3373893589.03	76.59	13.40	95.22	2.51
3444432231.99	76.47	13.71	94.92	2.63
3514970874.94	76.44	13.98	94.68	2.73
3585509517.90	76.43	14.23	94.47	2.84
3656048160.86	76.34	14.48	94.22	2.94

3726586803.81	76.18	14.68	93.92	3.04
3797125446.77	76.03	14.97	93.73	3.16
3867664089.72	75.90	15.31	93.66	3.29
3938202732.68	75.81	15.65	93.64	3.43
4008741375.63	75.74	15.83	93.48	3.53
4079280018.59	75.64	16.03	93.35	3.63
4149818661.54	75.43	16.24	93.16	3.75
4220357304.50	75.23	16.51	93.06	3.87
4290895947.45	75.10	16.82	93.10	4.01
4361434590.41	75.04	17.07	93.15	4.14
4431973233.36	75.02	17.29	93.20	4.26
4502511876.32	74.88	17.48	93.14	4.38
4573050519.27	74.68	17.65	93.01	4.49
4675058253.08	74.42	18.08	93.11	4.70
4777065986.90	74.28	18.49	93.34	4.91
4879073720.71	74.17	18.76	93.44	5.09
4981081454.52	73.92	18.99	93.40	5.26
5083089188.33	73.60	19.38	93.52	5.48
5185096922.14	73.42	19.85	93.89	5.72
5287104655.95	73.33	20.15	94.17	5.92
5389112389.76	73.13	20.32	94.19	6.09
5491120123.57	72.77	20.64	94.27	6.30
5593127857.38	72.52	21.12	94.69	6.57
5695135591.20	72.45	21.47	95.15	6.80
5797143325.01	72.31	21.64	95.30	6.97
5899151058.82	71.96	21.87	95.34	7.17
6001158792.63	71.63	22.30	95.69	7.44
6103166526.44	71.50	22.66	96.19	7.69
6205174260.25	71.37	22.83	96.42	7.88
6307181994.06	71.03	23.06	96.52	8.09
6409189727.87	70.68	23.48	96.91	8.37
6511197461.68	70.55	23.88	97.51	8.64
6613205195.50	70.45	24.04	97.84	8.84
6760721185.62	69.93	24.29	97.90	9.13
6908237175.74	69.56	24.92	98.74	9.57
7055753165.86	69.41	25.27	99.45	9.91
7203269155.98	68.81	25.46	99.40	10.20
7350785146.10	68.49	26.07	100.35	10.66
7498301136.22	68.32	26.31	100.92	10.97
7645817126.34	67.70	26.59	101.02	11.30
7793333116.46	67.35	27.23	102.05	11.80
7940849106.58	67.20	27.30	102.45	12.05
8088365096.70	66.58	27.65	102.70	12.44
8235881086.82	66.23	28.28	103.79	12.95
8383397076.94	66.03	28.25	103.98	13.17
8530913067.06	65.41	28.64	104.33	13.58
8678429057.18	65.18	29.21	105.57	14.10
8825945047.30	64.89	29.14	105.59	14.30
8973461037.42	64.18	29.54	105.86	14.74
9120977027.54	64.07	30.02	107.16	15.22
9268493017.66	63.73	30.05	107.31	15.48
9416009007.78	62.95	30.40	107.42	15.92
9563524997.90	62.88	30.79	108.65	16.37
9776851640.19	62.07	30.92	108.57	16.81
9990178282.47	61.72	31.60	110.28	17.56
10203504924.76	61.01	31.57	110.04	17.91

10416831567.05	60.54	32.33	111.78	18.73
10630158209.33	59.91	32.21	111.51	19.04
10843484851.62	59.38	32.95	113.15	19.87
11056811493.90	58.79	32.75	112.75	20.13
11270138136.19	58.22	33.54	114.47	21.02
11483464778.48	57.71	33.31	114.15	21.27
11696791420.76	57.02	34.02	115.53	22.12
11910118063.05	56.54	33.79	115.24	22.38
12123444705.34	55.92	34.45	116.68	23.22
12336771347.62	55.48	34.22	116.42	23.47
12550097989.91	54.79	34.89	117.80	24.35
12763424632.19	54.31	34.59	117.30	24.55
12976751274.48	53.73	35.28	118.92	25.46
13190077916.77	53.18	34.90	118.04	25.59
13403404559.05	52.62	35.60	119.79	26.53
13616731201.34	52.11	35.17	118.84	26.63
13830057843.62	51.51	35.89	120.58	27.60
14138554951.44	50.65	35.75	120.14	28.10
14447052059.26	50.02	35.93	120.93	28.87
14755549167.08	49.33	36.16	121.74	29.67
15064046274.90	48.46	36.41	122.23	30.50
15372543382.72	47.59	36.44	122.15	31.15
15681040490.54	46.96	36.36	122.18	31.70
15989537598.36	46.44	36.62	123.40	32.56
16298034706.17	45.64	36.77	123.74	33.32
16606531813.99	44.78	36.68	123.21	33.87
16915028921.81	44.24	36.64	123.51	34.46
17223526029.63	43.80	37.03	125.26	35.46
17532023137.45	42.56	36.92	123.82	35.99
17840520245.27	42.07	36.68	123.58	36.39
18149017353.09	41.66	36.58	123.89	36.92
18457514460.91	41.50	37.09	126.65	38.06
18766011568.73	40.13	37.16	125.36	38.77
19074508676.54	39.58	36.22	122.65	38.42
19383005784.36	40.22	36.46	126.44	39.30
19691502892.18	38.50	38.35	130.23	41.98
20000000000.00	37.11	35.71	119.81	39.71

Table: E.2: DI water with (1,000 ppm ferric ion concentrations) dielectric measurements:

	1,000 ppm ferric ion			
frequency	e'	e''	sensitivity	Conductivity
Hz	-	-		S/m
500000000.00	78.62	19.78	346.57	0.55
511153138.74	78.58	19.43	339.75	0.55
522306277.48	78.53	19.18	333.31	0.56
533459416.22	78.58	18.83	327.01	0.56
544612554.96	78.59	18.57	321.06	0.56
555765693.70	78.61	18.23	315.25	0.56
566918832.44	78.55	17.97	309.72	0.57
578071971.18	78.45	17.66	304.31	0.57
589225109.92	78.33	17.46	299.21	0.57
600378248.66	78.25	17.23	294.28	0.58
611531387.40	78.26	17.01	289.53	0.58
622684526.14	78.26	16.86	285.02	0.58
633837664.88	78.29	16.52	280.47	0.58
644990803.62	78.32	16.24	276.14	0.58

656143942.36	78.30	15.91	271.88	0.58
667297081.10	78.27	15.58	267.73	0.58
678450219.84	78.43	15.26	263.79	0.58
689603358.58	78.71	15.22	260.27	0.58
700756497.32	78.87	15.40	257.07	0.60
711909636.06	78.78	15.50	253.83	0.61
723062774.80	78.73	15.52	250.61	0.62
739191613.69	78.49	15.21	245.73	0.63
755320452.58	78.50	14.90	241.12	0.63
771449291.47	78.50	14.67	236.76	0.63
787578130.36	78.63	14.66	232.84	0.64
803706969.24	78.51	14.72	229.08	0.66
819835808.13	78.43	14.56	225.25	0.66
835964647.02	78.26	14.40	221.53	0.67
852093485.91	78.16	14.15	217.89	0.67
868222324.80	78.13	14.00	214.49	0.68
884351163.69	78.17	13.84	211.21	0.68
900480002.58	78.15	13.74	208.10	0.69
916608841.47	78.05	13.59	205.02	0.69
932737680.36	77.96	13.48	202.08	0.70
948866519.25	77.94	13.40	199.29	0.71
964995358.14	77.91	13.29	196.56	0.71
981124197.03	77.91	13.14	193.89	0.72
997253035.92	77.87	13.00	191.29	0.72
1013381874.81	77.80	12.90	188.81	0.73
1029510713.70	77.73	12.83	186.43	0.73
1045639552.59	77.71	12.79	184.17	0.74
1068963878.60	77.74	12.63	180.95	0.75
1092288204.60	77.70	12.48	177.84	0.76
1115612530.60	77.56	12.32	174.83	0.76
1138936856.61	77.51	12.27	172.05	0.78
1162261182.61	77.45	12.02	169.19	0.78
1185585508.61	77.46	11.63	166.33	0.77
1208909834.62	77.71	11.16	163.57	0.75
1232234160.62	78.34	11.00	161.36	0.75
1255558486.62	78.89	11.32	159.70	0.79
1278882812.63	79.02	11.78	158.12	0.84
1302207138.63	78.92	12.09	156.37	0.88
1325531464.64	78.75	12.34	154.62	0.91
1348855790.64	78.59	12.50	152.84	0.94
1372180116.64	78.49	12.64	151.14	0.96
1395504442.65	78.25	12.65	149.30	0.98
1418828768.65	77.97	12.71	147.57	1.00
1442153094.65	77.67	12.80	145.92	1.03
1465477420.66	77.54	12.78	144.27	1.04
1488801746.66	77.41	12.60	142.51	1.04
1512126072.67	77.23	12.43	140.79	1.05
1545855976.43	77.14	12.31	138.59	1.06
1579585880.19	77.12	12.12	136.43	1.06
1613315783.95	77.08	11.95	134.38	1.07
1647045687.71	77.15	11.80	132.48	1.08
1680775591.47	77.23	11.63	130.64	1.09
1714505495.23	77.41	11.53	129.00	1.10
1748235398.99	77.62	11.57	127.59	1.12
1781965302.75	77.68	11.75	126.31	1.16
1815695206.52	77.72	11.84	125.00	1.20
1849425110.28	77.67	11.96	123.74	1.23
1883155014.04	77.79	12.13	122.66	1.27
1916884917.80	77.75	12.22	121.48	1.30
1950614821.56	77.68	12.53	120.56	1.36
1984344725.32	77.70	12.61	119.51	1.39
2018074629.08	77.49	12.67	118.34	1.42
2051804532.84	77.42	12.88	117.46	1.47

2085534436.60	77.36	12.87	116.38	1.49
2119264340.36	77.20	13.00	115.44	1.53
2152994244.13	77.14	13.03	114.49	1.56
2186724147.89	76.89	13.03	113.44	1.58
2235501823.50	76.85	13.08	112.19	1.63
2284279499.11	76.58	13.00	110.75	1.65
2333057174.73	76.81	12.96	109.68	1.68
2381834850.34	76.65	13.11	108.66	1.74
2430612525.96	76.81	13.12	107.72	1.77
2479390201.57	76.77	13.26	106.87	1.83
2528167877.19	76.82	13.29	105.99	1.87
2576945552.80	76.92	13.46	105.34	1.93
2625723228.41	76.77	13.70	104.66	2.00
2674500904.03	76.86	13.80	104.01	2.05
2723278579.64	76.56	14.19	103.49	2.15
2772056255.26	76.62	14.16	102.75	2.18
2820833930.87	76.37	14.50	102.26	2.27
2869611606.48	76.38	14.39	101.48	2.30
2918389282.10	76.31	14.64	101.09	2.38
2967166957.71	76.18	14.64	100.39	2.42
3015944633.33	76.21	14.70	99.90	2.47
3064722308.94	76.06	14.90	99.46	2.54
3113499984.55	76.09	14.84	98.88	2.57
3162277660.17	76.03	15.31	98.88	2.69
3232816303.12	75.82	15.43	98.17	2.77
3303354946.08	75.83	15.53	97.65	2.85
3373893589.03	75.81	15.74	97.27	2.95
3444432231.99	75.77	15.92	96.88	3.05
3514970874.94	75.66	16.28	96.69	3.18
3585509517.90	75.28	16.59	96.28	3.31
3656048160.86	75.14	16.58	95.70	3.37
3726586803.81	75.20	16.75	95.52	3.47
3797125446.77	75.14	16.94	95.30	3.58
3867664089.72	75.08	17.13	95.12	3.68
3938202732.68	74.93	17.47	95.06	3.82
4008741375.63	74.56	17.70	94.71	3.94
4079280018.59	74.50	17.68	94.35	4.01
4149818661.54	74.60	17.93	94.47	4.14
4220357304.50	74.57	18.16	94.48	4.26
4290895947.45	74.49	18.38	94.44	4.38
4361434590.41	74.25	18.73	94.46	4.54
4431973233.36	73.86	18.89	94.13	4.66
4502511876.32	73.87	18.91	93.99	4.73
4573050519.27	73.93	19.26	94.32	4.90
4675058253.08	73.67	19.50	94.19	5.07
4777065986.90	73.41	19.89	94.28	5.28
4879073720.71	73.21	20.32	94.52	5.51
4981081454.52	73.12	20.58	94.66	5.70
5083089188.33	72.98	20.71	94.62	5.85
5185096922.14	72.67	20.92	94.55	6.03
5287104655.95	72.35	21.31	94.70	6.26
5389112389.76	72.19	21.73	95.10	6.51
5491120123.57	72.17	21.93	95.37	6.70
5593127857.38	71.99	22.03	95.35	6.85
5695135591.20	71.62	22.27	95.35	7.05
5797143325.01	71.32	22.69	95.69	7.31
5899151058.82	71.24	23.06	96.21	7.56
6001158792.63	71.14	23.25	96.49	7.76
6103166526.44	70.85	23.44	96.56	7.96
6205174260.25	70.51	23.79	96.82	8.21
6307181994.06	70.34	24.14	97.29	8.47
6409189727.87	70.24	24.35	97.66	8.68
6511197461.68	70.01	24.50	97.79	8.87

6613205195.50	69.66	24.73	97.92	9.09
6760721185.62	69.43	25.35	98.88	9.53
6908237175.74	69.06	25.63	99.22	9.85
7055753165.86	68.49	25.81	99.16	10.13
7203269155.98	68.45	26.35	100.32	10.55
7350785146.10	68.08	26.67	100.76	10.90
7498301136.22	67.39	27.07	100.95	11.29
7645817126.34	67.32	27.32	101.69	11.61
7793333116.46	67.10	27.48	102.14	11.91
7940849106.58	66.40	28.27	102.99	12.48
8088365096.70	66.12	28.33	103.21	12.74
8235881086.82	65.89	28.24	103.26	12.93
8383397076.94	65.50	29.30	105.06	13.66
8530913067.06	64.97	29.35	104.96	13.92
8678429057.18	64.57	29.15	104.59	14.07
8825945047.30	64.57	30.04	106.73	14.74
8973461037.42	63.91	30.27	106.79	15.11
9120977027.54	63.31	30.16	106.31	15.30
9268493017.66	63.41	30.69	108.01	15.81
9416009007.78	62.98	30.98	108.54	16.22
9563524997.90	62.20	31.28	108.55	16.63
9776851640.19	62.17	31.67	110.16	17.21
9990178282.47	60.88	31.83	109.42	17.68
10203504924.76	61.02	32.54	111.99	18.46
10416831567.05	59.83	32.15	110.29	18.62
10630158209.33	59.68	33.32	113.41	19.70
10843484851.62	58.97	32.58	111.71	19.65
11056811493.90	58.26	33.84	114.18	20.81
11270138136.19	58.13	33.29	113.79	20.86
11483464778.48	57.09	34.14	114.90	21.80
11696791420.76	57.07	34.03	115.64	22.13
11910118063.05	56.08	34.55	116.15	22.88
12123444705.34	55.87	34.56	116.83	23.30
12336771347.62	54.99	35.04	117.44	24.04
12550097989.91	54.87	35.03	118.25	24.44
12763424632.19	54.02	35.26	118.33	25.02
12976751274.48	53.58	35.55	119.29	25.65
13190077916.77	53.15	35.79	120.16	26.25
13403404559.05	52.39	35.81	119.86	26.69
13616731201.34	52.15	36.39	121.95	27.55
13830057843.62	51.38	35.94	120.46	27.64
14138554951.44	50.83	36.63	122.71	28.79
14447052059.26	49.77	36.54	122.02	29.35
14755549167.08	49.28	36.72	123.11	30.13
15064046274.90	48.39	36.87	123.33	30.88
15372543382.72	47.91	36.77	123.66	31.43
15681040490.54	47.19	37.44	125.64	32.64
15989537598.36	46.25	37.16	124.52	33.04
16298034706.17	45.55	37.24	124.89	33.75
16606531813.99	45.13	37.48	126.29	34.61
16915028921.81	44.15	37.62	126.21	35.38
17223526029.63	43.53	37.33	125.58	35.75
17532023137.45	43.06	37.33	126.15	36.39
17840520245.27	42.24	37.66	126.93	37.36
18149017353.09	41.71	37.62	127.21	37.96
18457514460.91	40.68	37.26	125.37	38.24
18766011568.73	40.58	37.20	126.48	38.81
19074508676.54	39.87	37.85	128.56	40.14
19383005784.36	38.55	37.68	126.55	40.61
19691502892.18	38.60	36.17	123.24	39.61
20000000000.00	38.70	37.96	130.99	42.21

Table: E.3: DI water with DTPA-K5 dielectric measurements:

frequency	e'	e''	sensitivity	conductivity
Hz				S/m
500000000.00	73.32	165.54	519.65	4.60
511153138.74	73.21	161.77	508.42	4.60
522306277.48	73.21	158.15	497.69	4.59
533459416.22	73.17	154.66	487.38	4.59
544612554.96	73.11	151.43	477.65	4.59
555765693.70	73.05	148.45	468.45	4.59
566918832.44	72.88	145.57	459.59	4.59
578071971.18	72.72	142.44	450.60	4.58
589225109.92	72.45	139.68	442.26	4.58
600378248.66	72.24	137.11	434.34	4.58
611531387.40	72.37	134.66	426.83	4.58
622684526.14	72.52	132.12	419.35	4.57
633837664.88	72.47	129.56	411.97	4.57
644990803.62	72.38	127.21	405.01	4.56
656143942.36	72.15	125.10	398.43	4.56
667297081.10	72.36	122.95	392.05	4.56
678450219.84	72.67	120.85	385.86	4.56
689603358.58	73.16	119.16	380.37	4.57
700756497.32	73.27	118.13	375.75	4.60
711909636.06	72.95	116.89	370.88	4.63
723062774.80	72.52	115.49	365.87	4.64
739191613.69	72.12	113.08	358.37	4.65
755320452.58	72.18	110.78	351.28	4.65
771449291.47	72.30	108.74	344.73	4.66
787578130.36	72.26	107.05	338.75	4.69
803706969.24	72.34	105.34	332.94	4.71
819835808.13	72.32	103.43	326.99	4.72
835964647.02	72.25	101.56	321.21	4.72
852093485.91	72.11	99.71	315.59	4.72
868222324.80	72.02	97.93	310.18	4.73
884351163.69	72.01	96.25	305.03	4.73
900480002.58	72.05	94.64	300.10	4.74
916608841.47	72.04	93.00	295.23	4.74
932737680.36	71.96	91.50	290.62	4.75
948866519.25	71.95	89.94	286.04	4.75
964995358.14	71.90	88.41	281.59	4.74
981124197.03	71.72	87.05	277.38	4.75
997253035.92	71.65	85.85	273.51	4.76
1013381874.81	71.56	84.39	269.37	4.76
1029510713.70	71.42	83.12	265.53	4.76
1045639552.59	71.32	82.02	261.99	4.77
1068963878.60	71.14	80.43	256.99	4.78
1092288204.60	70.98	78.88	252.16	4.79
1115612530.60	70.75	77.40	247.52	4.80
1138936856.61	70.59	76.07	243.21	4.82
1162261182.61	70.49	74.57	238.81	4.82
1185585508.61	70.55	73.34	234.91	4.84
1208909834.62	70.69	72.14	231.15	4.85
1232234160.62	70.90	70.83	227.38	4.85
1255558486.62	71.40	69.52	223.80	4.85
1278882812.63	71.97	68.67	220.91	4.88
1302207138.63	72.13	68.21	218.45	4.94
1325531464.64	71.95	67.58	215.74	4.98
1348855790.64	71.70	66.69	212.74	5.00
1372180116.64	71.45	65.76	209.75	5.02
1395504442.65	71.29	64.78	206.79	5.03
1418828768.65	71.06	63.83	203.90	5.04
1442153094.65	70.91	62.87	201.08	5.04
1465477420.66	70.76	62.03	198.46	5.05
1488801746.66	70.62	61.21	195.92	5.07
1512126072.67	70.41	60.53	193.58	5.09

1545855976.43	70.20	59.49	190.24	5.11
1579585880.19	69.94	58.54	187.09	5.14
1613315783.95	69.83	57.68	184.18	5.17
1647045687.71	69.83	56.80	181.38	5.20
1680775591.47	69.95	55.89	178.66	5.22
1714505495.23	69.94	55.03	176.02	5.25
1748235398.99	69.92	54.07	173.32	5.26
1781965302.75	69.95	53.17	170.77	5.27
1815695206.52	70.10	52.23	168.28	5.27
1849425110.28	70.14	51.46	166.03	5.29
1883155014.04	70.18	50.90	164.09	5.33
1916884917.80	70.15	50.37	162.20	5.37
1950614821.56	69.93	49.92	160.39	5.41
1984344725.32	69.72	49.54	158.71	5.47
2018074629.08	69.51	49.08	156.96	5.51
2051804532.84	69.36	48.67	155.35	5.55
2085534436.60	69.35	48.24	153.82	5.59
2119264340.36	69.36	47.73	152.23	5.62
2152994244.13	69.28	47.18	150.57	5.65
2186724147.89	69.21	46.63	148.96	5.67
2235501823.50	69.19	45.73	146.59	5.68
2284279499.11	69.12	44.98	144.43	5.71
2333057174.73	69.04	44.33	142.46	5.75
2381834850.34	68.85	43.86	140.72	5.81
2430612525.96	68.68	43.35	139.00	5.86
2479390201.57	68.56	43.01	137.55	5.93
2528167877.19	68.67	42.65	136.25	6.00
2576945552.80	68.71	42.29	134.96	6.06
2625723228.41	68.58	41.84	133.50	6.11
2674500904.03	68.54	41.29	131.99	6.14
2723278579.64	68.37	40.89	130.64	6.19
2772056255.26	68.20	40.41	129.22	6.23
2820833930.87	67.99	40.07	127.99	6.28
2869611606.48	67.83	39.72	126.80	6.34
2918389282.10	67.72	39.52	125.86	6.41
2967166957.71	67.75	39.22	124.90	6.47
3015944633.33	67.78	38.91	123.96	6.53
3064722308.94	67.71	38.57	122.94	6.57
3113499984.55	67.74	38.15	121.90	6.61
3162277660.17	67.61	37.94	121.06	6.67
3232816303.12	67.41	37.54	119.74	6.75
3303354946.08	67.18	37.29	118.65	6.85
3373893589.03	67.12	37.08	117.75	6.96
3444432231.99	67.10	36.83	116.86	7.05
3514970874.94	67.04	36.48	115.85	7.13
3585509517.90	66.89	36.13	114.80	7.20
3656048160.86	66.70	35.81	113.80	7.28
3726586803.81	66.53	35.63	113.03	7.38
3797125446.77	66.47	35.52	112.45	7.50
3867664089.72	66.49	35.42	111.97	7.62
3938202732.68	66.36	35.27	111.35	7.72
4008741375.63	66.17	34.91	110.39	7.78
4079280018.59	66.05	34.66	109.68	7.86
4149818661.54	65.86	34.62	109.21	7.99
4220357304.50	65.71	34.57	108.80	8.11
4290895947.45	65.70	34.53	108.51	8.24
4361434590.41	65.62	34.36	107.99	8.33
4431973233.36	65.49	34.12	107.36	8.41
4502511876.32	65.33	33.95	106.82	8.50
4573050519.27	65.13	33.92	106.47	8.63
4675058253.08	64.94	33.90	106.08	8.81
4777065986.90	64.86	33.83	105.74	8.99
4879073720.71	64.69	33.62	105.15	9.12

4981081454.52	64.43	33.52	104.67	9.28
5083089188.33	64.20	33.49	104.34	9.47
5185096922.14	64.09	33.49	104.17	9.66
5287104655.95	63.95	33.34	103.77	9.80
5389112389.76	63.70	33.28	103.43	9.97
5491120123.57	63.45	33.29	103.22	10.16
5593127857.38	63.35	33.33	103.19	10.36
5695135591.20	63.22	33.24	102.96	10.52
5797143325.01	62.99	33.16	102.68	10.69
5899151058.82	62.72	33.22	102.57	10.90
6001158792.63	62.58	33.28	102.60	11.10
6103166526.44	62.45	33.22	102.47	11.27
6205174260.25	62.22	33.13	102.21	11.43
6307181994.06	61.91	33.23	102.19	11.66
6409189727.87	61.73	33.35	102.32	11.88
6511197461.68	61.65	33.37	102.43	12.08
6613205195.50	61.46	33.29	102.25	12.24
6760721185.62	61.04	33.37	102.20	12.55
6908237175.74	60.80	33.53	102.46	12.88
7055753165.86	60.52	33.49	102.38	13.14
7203269155.98	60.15	33.52	102.34	13.42
7350785146.10	59.96	33.70	102.77	13.78
7498301136.22	59.60	33.65	102.61	14.03
7645817126.34	59.23	33.74	102.70	14.34
7793333116.46	59.02	33.92	103.16	14.70
7940849106.58	58.70	33.88	103.11	14.96
8088365096.70	58.30	34.00	103.24	15.29
8235881086.82	58.06	34.11	103.59	15.62
8383397076.94	57.79	34.14	103.74	15.91
8530913067.06	57.33	34.26	103.84	16.25
8678429057.18	57.12	34.34	104.18	16.57
8825945047.30	56.89	34.38	104.44	16.87
8973461037.42	56.37	34.49	104.45	17.21
9120977027.54	56.14	34.58	104.80	17.54
9268493017.66	55.92	34.67	105.19	17.87
9416009007.78	55.44	34.75	105.23	18.20
9563524997.90	55.18	34.86	105.61	18.54
9776851640.19	54.69	34.96	105.90	19.01
9990178282.47	54.16	35.11	106.25	19.50
10203504924.76	53.79	35.19	106.69	19.97
10416831567.05	53.21	35.21	106.71	20.40
10630158209.33	52.80	35.46	107.45	20.96
10843484851.62	52.35	35.39	107.48	21.34
11056811493.90	51.86	35.58	107.99	21.87
11270138136.19	51.43	35.65	108.35	22.34
11483464778.48	50.96	35.76	108.74	22.83
11696791420.76	50.48	35.85	109.06	23.32
11910118063.05	50.05	35.87	109.30	23.75
12123444705.34	49.57	35.99	109.70	24.26
12336771347.62	49.16	36.02	110.02	24.71
12550097989.91	48.65	36.10	110.27	25.19
12763424632.19	48.26	36.06	110.41	25.59
12976751274.48	47.72	36.25	110.91	26.16
13190077916.77	47.44	36.17	111.13	26.53
13403404559.05	46.78	36.32	111.32	27.07
13616731201.34	46.58	36.34	111.91	27.51
13830057843.62	45.91	36.35	111.72	27.95
14138554951.44	45.42	36.39	112.28	28.61
14447052059.26	44.73	36.44	112.55	29.28
14755549167.08	44.16	36.43	112.82	29.89
15064046274.90	43.52	36.46	113.10	30.54
15372543382.72	42.93	36.46	113.34	31.16
15681040490.54	42.32	36.48	113.59	31.80

15989537598.36	41.79	36.42	113.76	32.38
16298034706.17	41.14	36.43	113.93	33.02
16606531813.99	40.62	36.36	114.06	33.58
16915028921.81	39.98	36.34	114.09	34.18
17223526029.63	39.53	36.43	114.80	34.89
17532023137.45	38.77	36.10	113.68	35.20
17840520245.27	38.47	36.21	114.70	35.92
18149017353.09	37.74	36.14	114.34	36.47
18457514460.91	37.40	36.01	114.60	36.96
18766011568.73	36.89	36.00	114.82	37.56
19074508676.54	36.24	36.00	114.80	38.18
19383005784.36	35.95	35.68	114.49	38.46
19691502892.18	35.54	36.07	116.20	39.50
20000000000.00	34.57	35.41	113.31	39.37

Table: E.4: DI water with DTPA-K5 with (1,000 ppm ferric ion concentrations) dielectric measurements:

frequency	e'	e''	sensitivity	conductivity
Hz				S/m
500000000.00	76.52	117.52	459.47	3.27
511153138.74	76.37	114.82	449.66	3.26
522306277.48	76.29	112.53	440.65	3.27
533459416.22	76.33	110.04	431.66	3.26
544612554.96	76.33	107.89	423.35	3.27
555765693.70	76.39	105.66	415.18	3.27
566918832.44	76.13	103.66	407.44	3.27
578071971.18	75.88	101.46	399.68	3.26
589225109.92	75.52	99.60	392.49	3.26
600378248.66	75.34	97.82	385.62	3.27
611531387.40	75.38	96.29	379.26	3.27
622684526.14	75.43	94.61	372.90	3.28
633837664.88	75.50	92.71	366.42	3.27
644990803.62	75.46	91.11	360.45	3.27
656143942.36	75.45	89.49	354.58	3.26
667297081.10	75.49	87.92	348.92	3.26
678450219.84	75.81	86.50	343.63	3.26
689603358.58	76.03	85.56	339.04	3.28
700756497.32	75.96	84.86	334.78	3.31
711909636.06	75.74	84.02	330.42	3.33
723062774.80	75.52	83.02	325.97	3.34
739191613.69	75.26	81.26	319.33	3.34
755320452.58	75.20	79.61	313.08	3.34
771449291.47	75.18	78.13	307.22	3.35
787578130.36	75.24	77.03	302.02	3.37
803706969.24	75.23	75.93	296.95	3.39
819835808.13	75.31	74.55	291.72	3.40
835964647.02	75.17	73.26	286.68	3.41
852093485.91	75.05	71.95	281.76	3.41
868222324.80	74.90	70.84	277.20	3.42
884351163.69	74.94	69.64	272.69	3.42
900480002.58	74.94	68.52	268.40	3.43
916608841.47	74.86	67.34	264.10	3.43
932737680.36	74.70	66.33	260.10	3.44
948866519.25	74.67	65.35	256.26	3.45
964995358.14	74.64	64.32	252.47	3.45
981124197.03	74.56	63.36	248.81	3.46
997253035.92	74.46	62.47	245.33	3.46
1013381874.81	74.27	61.48	241.77	3.46
1029510713.70	74.11	60.60	238.44	3.47
1045639552.59	74.02	59.90	235.41	3.48
1068963878.60	74.01	58.77	231.04	3.49

1092288204.60	73.86	57.57	226.68	3.50
1115612530.60	73.56	56.49	222.54	3.50
1138936856.61	73.42	55.59	218.78	3.52
1162261182.61	73.33	54.40	214.81	3.52
1185585508.61	73.43	53.31	211.11	3.51
1208909834.62	73.88	52.21	207.63	3.51
1232234160.62	74.59	51.64	204.97	3.54
1255558486.62	75.01	51.47	202.76	3.59
1278882812.63	74.87	51.26	200.42	3.65
1302207138.63	74.55	50.74	197.71	3.67
1325531464.64	74.27	50.21	195.06	3.70
1348855790.64	74.07	49.54	192.36	3.72
1372180116.64	74.00	48.91	189.82	3.73
1395504442.65	73.85	48.07	187.05	3.73
1418828768.65	73.55	47.43	184.53	3.74
1442153094.65	73.31	46.94	182.25	3.76
1465477420.66	73.31	46.44	180.13	3.78
1488801746.66	73.26	45.76	177.81	3.79
1512126072.67	73.03	45.19	175.61	3.80
1545855976.43	72.84	44.52	172.74	3.83
1579585880.19	72.73	43.77	169.90	3.84
1613315783.95	72.58	43.07	167.19	3.86
1647045687.71	72.69	42.43	164.73	3.89
1680775591.47	72.80	41.73	162.29	3.90
1714505495.23	72.96	41.17	160.11	3.92
1748235398.99	73.07	40.68	158.05	3.95
1781965302.75	73.01	40.34	156.17	4.00
1815695206.52	72.98	39.79	154.11	4.02
1849425110.28	72.83	39.34	152.17	4.05
1883155014.04	72.85	39.01	150.51	4.08
1916884917.80	72.70	38.53	148.64	4.11
1950614821.56	72.49	38.42	147.23	4.17
1984344725.32	72.48	37.99	145.58	4.19
2018074629.08	72.09	37.56	143.79	4.21
2051804532.84	72.01	37.48	142.60	4.28
2085534436.60	72.03	37.00	141.03	4.29
2119264340.36	71.87	36.74	139.66	4.33
2152994244.13	71.92	36.39	138.33	4.36
2186724147.89	71.65	35.88	136.68	4.36
2235501823.50	71.78	35.47	134.99	4.41
2284279499.11	71.44	34.83	132.87	4.42
2333057174.73	71.78	34.36	131.35	4.46
2381834850.34	71.39	34.16	129.83	4.52
2430612525.96	71.54	33.71	128.35	4.56
2479390201.57	71.33	33.63	127.18	4.64
2528167877.19	71.43	33.27	125.88	4.68
2576945552.80	71.56	33.17	124.95	4.75
2625723228.41	71.24	32.92	123.63	4.81
2674500904.03	71.45	32.53	122.49	4.84
2723278579.64	70.96	32.52	121.44	4.92
2772056255.26	71.13	31.95	120.11	4.92
2820833930.87	70.77	32.04	119.32	5.03
2869611606.48	70.82	31.52	118.04	5.03
2918389282.10	70.75	31.67	117.58	5.14
2967166957.71	70.67	31.37	116.55	5.18
3015944633.33	70.86	31.25	115.95	5.24
3064722308.94	70.59	31.22	115.21	5.32
3113499984.55	70.73	30.77	114.21	5.33
3162277660.17	70.52	31.13	114.04	5.47
3232816303.12	70.11	30.74	112.60	5.53
3303354946.08	70.06	30.46	111.57	5.59
3373893589.03	70.08	30.40	110.92	5.70
3444432231.99	70.12	30.31	110.28	5.80

3514970874.94	69.98	30.36	109.74	5.93
3585509517.90	69.51	30.19	108.71	6.02
3656048160.86	69.34	29.73	107.54	6.04
3726586803.81	69.41	29.65	107.07	6.14
3797125446.77	69.38	29.69	106.71	6.27
3867664089.72	69.37	29.75	106.42	6.40
3938202732.68	69.19	29.86	106.08	6.54
4008741375.63	68.70	29.69	105.19	6.62
4079280018.59	68.69	29.25	104.30	6.64
4149818661.54	68.81	29.31	104.19	6.76
4220357304.50	68.76	29.44	104.07	6.91
4290895947.45	68.72	29.55	103.96	7.05
4361434590.41	68.45	29.68	103.71	7.20
4431973233.36	68.03	29.41	102.82	7.25
4502511876.32	68.11	29.11	102.30	7.29
4573050519.27	68.16	29.34	102.50	7.46
4675058253.08	67.79	29.39	102.05	7.64
4777065986.90	67.57	29.60	101.98	7.86
4879073720.71	67.44	29.71	101.89	8.06
4981081454.52	67.33	29.67	101.61	8.22
5083089188.33	67.15	29.57	101.22	8.36
5185096922.14	66.88	29.61	100.96	8.54
5287104655.95	66.60	29.70	100.80	8.73
5389112389.76	66.40	29.86	100.82	8.95
5491120123.57	66.33	29.91	100.83	9.13
5593127857.38	66.24	29.87	100.70	9.29
5695135591.20	65.95	29.82	100.38	9.44
5797143325.01	65.63	29.93	100.28	9.65
5899151058.82	65.42	30.19	100.52	9.90
6001158792.63	65.37	30.34	100.80	10.13
6103166526.44	65.23	30.34	100.75	10.29
6205174260.25	64.92	30.34	100.55	10.47
6307181994.06	64.61	30.52	100.66	10.71
6409189727.87	64.50	30.71	100.97	10.95
6511197461.68	64.43	30.75	101.11	11.13
6613205195.50	64.17	30.67	100.87	11.28
6760721185.62	63.78	31.08	101.37	11.68
6908237175.74	63.42	31.35	101.70	12.04
7055753165.86	63.06	31.06	101.14	12.19
7203269155.98	62.90	31.44	101.91	12.59
7350785146.10	62.58	31.81	102.50	13.00
7498301136.22	61.98	31.81	102.18	13.26
7645817126.34	61.81	31.84	102.41	13.54
7793333116.46	61.76	32.07	103.15	13.90
7940849106.58	61.07	32.56	103.57	14.38
8088365096.70	60.63	32.36	103.11	14.55
8235881086.82	60.67	32.27	103.44	14.78
8383397076.94	60.32	33.17	105.10	15.46
8530913067.06	59.52	32.96	104.17	15.63
8678429057.18	59.40	32.66	103.92	15.76
8825945047.30	59.60	33.48	106.20	16.43
8973461037.42	58.55	33.55	105.47	16.74
9120977027.54	58.16	33.30	104.99	16.89
9268493017.66	58.51	33.62	106.59	17.33
9416009007.78	57.84	33.92	106.81	17.76
9563524997.90	57.12	34.17	106.84	18.17
9776851640.19	57.27	34.22	107.97	18.60
9990178282.47	55.81	34.31	106.91	19.06
10203504924.76	56.18	34.84	109.33	19.76
10416831567.05	54.95	34.22	107.12	19.82
10630158209.33	54.85	35.34	110.17	20.89
10843484851.62	54.37	34.36	108.23	20.71
11056811493.90	53.48	35.49	110.19	21.82

11270138136.19	53.75	34.94	110.28	21.89
11483464778.48	52.47	35.41	110.24	22.61
11696791420.76	52.72	35.53	111.79	23.10
11910118063.05	51.60	35.59	111.07	23.57
12123444705.34	51.56	35.80	112.40	24.13
12336771347.62	50.63	35.86	111.96	24.60
12550097989.91	50.70	36.09	113.55	25.18
12763424632.19	49.83	35.82	112.42	25.42
12976751274.48	49.48	36.42	114.19	26.28
13190077916.77	49.13	36.17	113.96	26.53
13403404559.05	48.34	36.45	114.24	27.17
13616731201.34	48.21	36.69	115.56	27.78
13830057843.62	47.44	36.38	114.40	27.97
14138554951.44	46.87	36.88	116.06	28.99
14447052059.26	45.97	36.53	114.93	29.34
14755549167.08	45.67	36.80	116.49	30.19
15064046274.90	44.73	36.91	116.44	30.91
15372543382.72	44.39	36.55	116.24	31.24
15681040490.54	43.58	37.19	117.87	32.42
15989537598.36	42.94	36.77	116.90	32.69
16298034706.17	42.25	36.99	117.58	33.52
16606531813.99	41.75	37.04	118.14	34.20
16915028921.81	40.97	37.00	117.90	34.80
17223526029.63	40.64	36.87	118.26	35.31
17532023137.45	39.93	36.80	118.00	35.87
17840520245.27	39.07	36.91	117.98	36.61
18149017353.09	38.97	36.76	118.72	37.10
18457514460.91	38.11	36.60	117.82	37.56
18766011568.73	37.62	36.61	118.22	38.20
19074508676.54	37.10	36.60	118.45	38.82
19383005784.36	36.59	36.84	119.52	39.71
19691502892.18	36.01	35.95	116.79	39.36
20000000000.00	35.56	36.62	119.36	40.72

Table: E.5: seawater dielectric measurements:

frequency	e'	e''	sensitivity	conductivity
Hz				S/m
5.00E+08	62.7197	304.9365	713.0321	8.47771
5.11E+08	62.5926	297.6961	696.7949	8.461032
5.22E+08	62.687	290.7801	681.2988	8.444795
5.33E+08	62.6154	284.111	666.405	8.427303
5.45E+08	62.6449	277.9498	652.4469	8.41692
5.56E+08	62.454	272.1534	639.2255	8.410168
5.67E+08	62.2032	266.6549	626.6059	8.405617
5.78E+08	61.9311	260.7764	613.6158	8.382033
5.89E+08	61.4748	255.4766	601.5857	8.370117
6.00E+08	61.1642	250.4601	590.1641	8.361085
6.12E+08	61.3938	245.7576	579.4417	8.356509
6.23E+08	61.7349	240.8536	568.5809	8.339123
6.34E+08	61.643	236.1401	558.0362	8.322369
6.45E+08	61.4422	231.8666	548.2829	8.315548
6.56E+08	61.1285	227.8333	538.9804	8.31219
6.67E+08	61.5243	223.8189	529.9168	8.304532
6.78E+08	62.1997	220.0875	521.4377	8.30257
6.90E+08	62.8426	217.0052	514.026	8.320869
7.01E+08	62.735	214.8093	507.9015	8.369883
7.12E+08	62.0941	212.2115	501.1746	8.400264
7.23E+08	61.2781	209.2776	493.9964	8.413911
7.39E+08	60.7961	204.5222	483.1356	8.406141
7.55E+08	61.0034	200.1711	473.1495	8.406821
7.71E+08	61.3751	196.2968	464.0452	8.420149

7.88E+08	61.2461	192.9192	455.7508	8.448279
8.04E+08	61.4879	189.4644	447.5309	8.466902
8.20E+08	61.5373	185.7401	439.0142	8.467042
8.36E+08	61.5134	182.0699	430.6567	8.463017
8.52E+08	61.4069	178.4498	422.4999	8.454783
8.68E+08	61.3054	175.1083	414.8522	8.453506
8.84E+08	61.3898	171.8162	407.4119	8.448664
9.00E+08	61.5806	168.8338	400.5406	8.453424
9.17E+08	61.688	165.6577	393.467	8.442962
9.33E+08	61.7596	162.7742	386.9075	8.441979
9.49E+08	61.8308	159.8048	380.2997	8.431291
9.65E+08	61.9095	156.8623	373.8062	8.416722
9.81E+08	61.6886	154.1884	367.7235	8.411527
9.97E+08	61.5772	151.8751	362.2698	8.421532
1.01E+09	61.5996	149.0982	356.2147	8.401265
1.03E+09	61.4368	146.6353	350.661	8.393992
1.05E+09	61.3532	144.41	345.5225	8.396116
1.07E+09	61.0916	141.4067	338.4948	8.404893
1.09E+09	60.9436	138.4061	331.5927	8.406044
1.12E+09	60.6893	135.562	325.0111	8.409119
1.14E+09	60.5554	132.925	318.8645	8.417933
1.16E+09	60.4836	130.1132	312.5621	8.408611
1.19E+09	60.7897	127.863	307.2757	8.429017
1.21E+09	61.1447	125.6081	302.0846	8.443271
1.23E+09	61.6961	123.2284	296.8392	8.443125
1.26E+09	62.5361	121.0411	292.0351	8.450239
1.28E+09	63.283	119.4714	288.2063	8.495596
1.30E+09	63.2621	118.3455	284.8799	8.569017
1.33E+09	62.9422	116.7764	280.879	8.606851
1.35E+09	62.7203	114.8738	276.4654	8.615603
1.37E+09	62.4651	112.9003	271.9855	8.61401
1.40E+09	62.3462	110.9608	267.6554	8.609937
1.42E+09	62.0901	109.1006	263.4431	8.607089
1.44E+09	61.9925	107.2097	259.2876	8.596954
1.47E+09	61.8567	105.5354	255.4782	8.599564
1.49E+09	61.6898	103.9369	251.8209	8.604107
1.51E+09	61.4435	102.5155	248.4382	8.619393
1.55E+09	61.2515	100.4607	243.6648	8.635041
1.58E+09	60.9181	98.5522	239.1406	8.65583
1.61E+09	60.9401	96.8422	235.0991	8.687267
1.65E+09	61.1082	95.1277	231.1647	8.711878
1.68E+09	61.4299	93.4164	227.3563	8.730357
1.71E+09	61.5308	91.7543	223.6045	8.747108
1.75E+09	61.6219	90.0315	219.8188	8.751723
1.78E+09	61.8082	88.3374	216.1639	8.75272
1.82E+09	62.1525	86.6585	212.6419	8.748896
1.85E+09	62.2526	85.2271	209.4474	8.764227
1.88E+09	62.2699	83.9556	206.5039	8.790932
1.92E+09	62.1835	82.846	203.8036	8.830123
1.95E+09	61.9095	81.7461	201.0831	8.866204
1.98E+09	61.5522	80.7995	198.5932	8.915074
2.02E+09	61.3338	79.8056	196.1249	8.955086
2.05E+09	61.2221	78.8411	193.7733	8.994724
2.09E+09	61.3045	77.9469	191.6388	9.038896
2.12E+09	61.454	76.9045	189.3407	9.06225
2.15E+09	61.4048	75.8017	186.9009	9.074464
2.19E+09	61.4369	74.7879	184.6528	9.093362
2.24E+09	61.5623	73.0969	181.154	9.086009
2.28E+09	61.6415	71.6277	178.018	9.097654
2.33E+09	61.5141	70.297	175.0475	9.119296
2.38E+09	61.3294	69.229	172.4856	9.168512
2.43E+09	61.0594	68.1712	169.9412	9.213313
2.48E+09	60.9926	67.3378	167.8643	9.283312

2.53E+09	61.2373	66.554	166.0467	9.355763
2.58E+09	61.3349	65.6814	164.0654	9.411239
2.63E+09	61.3071	64.7415	161.9569	9.452156
2.67E+09	61.348	63.6255	159.6484	9.461786
2.72E+09	61.2774	62.6497	157.5252	9.486592
2.77E+09	61.0272	61.688	155.3612	9.508278
2.82E+09	60.8358	60.8542	153.4419	9.544809
2.87E+09	60.5932	60.1845	151.7665	9.603
2.92E+09	60.5277	59.6005	150.3357	9.671465
2.97E+09	60.7285	58.9985	149.0419	9.733793
3.02E+09	60.8087	58.3131	147.5807	9.77887
3.06E+09	60.8528	57.5779	146.0448	9.811742
3.11E+09	60.931	56.8222	144.5187	9.837077
3.16E+09	60.872	56.1206	143.0166	9.867826
3.23E+09	60.6529	55.2686	141.0465	9.934789
3.30E+09	60.3496	54.6156	139.3621	10.03162
3.37E+09	60.3623	54.0106	137.9631	10.13234
3.44E+09	60.4259	53.352	136.5445	10.21804
3.51E+09	60.4651	52.5359	134.8981	10.26779
3.59E+09	60.4449	51.7161	133.237	10.31041
3.66E+09	60.2392	51.0289	131.6903	10.37355
3.73E+09	59.9786	50.5337	130.4263	10.47108
3.80E+09	59.9954	50.1227	129.4856	10.58251
3.87E+09	60.0897	49.6992	128.5986	10.68802
3.94E+09	60.0332	49.1586	127.453	10.76457
4.01E+09	59.9825	48.4368	126.0471	10.79649
4.08E+09	59.8429	47.9053	124.8945	10.86591
4.15E+09	59.5858	47.5562	123.963	10.97325
4.22E+09	59.4779	47.236	123.1911	11.08464
4.29E+09	59.555	46.9336	122.5911	11.19776
4.36E+09	59.5898	46.4601	121.7067	11.26701
4.43E+09	59.5603	45.9413	120.7187	11.32139
4.50E+09	59.367	45.5214	119.7822	11.39645
4.57E+09	59.1241	45.2211	119.01	11.49863
4.68E+09	59.0325	44.8987	118.2773	11.67132
4.78E+09	59.07	44.4961	117.537	11.81904
4.88E+09	58.9741	43.8823	116.3775	11.9049
4.98E+09	58.699	43.4731	115.4281	12.04047
5.08E+09	58.5135	43.2042	114.7903	12.21105
5.19E+09	58.5262	42.9609	114.3684	12.38595
5.29E+09	58.4744	42.4773	113.5176	12.48746
5.39E+09	58.2454	42.0912	112.6969	12.61269
5.49E+09	58.0066	41.8999	112.2031	12.79302
5.59E+09	57.9983	41.7337	111.9542	12.97899
5.70E+09	57.9626	41.4062	111.4284	13.11199
5.80E+09	57.7875	41.0265	110.706	13.22445
5.90E+09	57.513	40.8803	110.3007	13.4092
6.00E+09	57.455	40.7523	110.1246	13.59836
6.10E+09	57.4056	40.5109	109.7749	13.74758
6.21E+09	57.242	40.1743	109.1683	13.86122
6.31E+09	56.953	40.0641	108.844	14.05044
6.41E+09	56.82	39.9926	108.7371	14.2522
6.51E+09	56.8073	39.8878	108.6944	14.44109
6.61E+09	56.7132	39.5944	108.2531	14.55945
6.76E+09	56.3222	39.4007	107.7883	14.8114
6.91E+09	56.2094	39.3326	107.8269	15.10842
7.06E+09	56.0146	39.0909	107.4908	15.33622
7.20E+09	55.6767	38.8972	107.1086	15.57927
7.35E+09	55.5867	38.8671	107.283	15.88602
7.50E+09	55.3468	38.6081	106.8982	16.09683
7.65E+09	55.0211	38.5348	106.7721	16.38235
7.79E+09	54.857	38.523	106.9412	16.69331
7.94E+09	54.6584	38.2816	106.6524	16.9027

8.09E+09	54.3545	38.2508	106.6535	17.20285
8.24E+09	54.1436	38.2477	106.8177	17.51518
8.38E+09	53.9553	38.0293	106.6002	17.72709
8.53E+09	53.6427	38.0413	106.6934	18.04472
8.68E+09	53.434	38.0467	106.9005	18.35935
8.83E+09	53.2273	37.8689	106.7537	18.58417
8.97E+09	52.8984	37.8436	106.7706	18.88216
9.12E+09	52.7305	37.857	107.0594	19.19936
9.27E+09	52.4906	37.7997	107.1271	19.48034
9.42E+09	52.141	37.7523	107.0838	19.76557
9.56E+09	51.9868	37.7473	107.3705	20.07257
9.78E+09	51.4848	37.6693	107.2981	20.47792
9.99E+09	51.2138	37.7193	107.7906	20.95251
1.02E+10	50.8184	37.6065	107.7861	21.33592
1.04E+10	50.4444	37.6332	108.1105	21.79746
1.06E+10	50.0721	37.6085	108.3314	22.22925
1.08E+10	49.6963	37.5785	108.5383	22.65726
1.11E+10	49.3493	37.5217	108.727	23.06809
1.13E+10	48.8899	37.6026	109.0707	23.56385
1.15E+10	48.6128	37.5558	109.3821	23.98
1.17E+10	48.1138	37.545	109.4627	24.41845
1.19E+10	47.8401	37.533	109.8617	24.85584
1.21E+10	47.4042	37.5087	109.9975	25.28467
1.23E+10	47.1198	37.5278	110.4579	25.74268
1.26E+10	46.6275	37.4608	110.4013	26.14107
1.28E+10	46.3342	37.4609	110.8028	26.58548
1.30E+10	45.8905	37.4689	110.9932	27.0356
1.32E+10	45.5783	37.4681	111.3625	27.47946
1.34E+10	45.1011	37.4419	111.4078	27.90437
1.36E+10	44.8841	37.4446	111.9347	28.35053
1.38E+10	44.3705	37.3943	111.8499	28.75601
1.41E+10	43.9405	37.3703	112.347	29.37858
1.44E+10	43.3052	37.4212	112.6972	30.06049
1.48E+10	42.8244	37.3028	112.8469	30.60525
1.51E+10	42.2932	37.2776	113.1493	31.22401
1.54E+10	41.7827	37.2776	113.5459	31.86345
1.57E+10	41.2395	37.243	113.7824	32.47272
1.60E+10	40.7651	37.1462	113.9544	33.0255
1.63E+10	40.2186	37.077	114.0613	33.59998
1.66E+10	39.7415	37.0383	114.3674	34.20024
1.69E+10	39.176	36.9329	114.3065	34.73644
1.72E+10	38.7075	36.9806	114.8578	35.41565
1.75E+10	38.1352	36.6532	114.0956	35.73083
1.78E+10	37.8436	36.797	115.2516	36.5022
1.81E+10	37.1092	36.6506	114.6778	36.98566
1.85E+10	36.82	36.5107	114.9677	37.47076
1.88E+10	36.4032	36.5	115.3973	38.08588
1.91E+10	35.7459	36.522	115.441	38.73531
1.94E+10	35.4731	36.188	115.1201	39.00182
1.97E+10	35.1427	36.6027	117.0709	40.07663
2.00E+10	34.2954	35.9294	114.4332	39.95573

Table: E.6: seawater with (1,000 ppm ferric ion concentrations) dielectric measurements:

frequency	e'	e''	sensitivity	conductivity
Hz				S/m

500000000	66.6915	300.0576	706.2295	8.342069
511153138.7	67.3677	293.4001	691.0045	8.338932
522306277.5	67.151	287.4461	676.9295	8.347969
533459416.2	66.8478	281.3116	662.779	8.344267
544612555	66.4004	275.0724	648.6893	8.329786
555765693.7	66.0846	269.4258	635.6786	8.325879
566918832.4	65.708	263.9307	623.0828	8.319744
578071971.2	65.305	258.2215	610.278	8.299912
589225109.9	64.9096	252.8021	598.1	8.282493
600378248.7	64.668	248.0569	587.1072	8.28086
611531387.4	64.8136	243.4004	576.4393	8.276357
622684526.1	64.8314	238.943	566.1978	8.272972
633837664.9	64.6986	234.2016	555.6429	8.254049
644990803.6	64.3007	229.9749	545.9117	8.247705
656143942.4	63.9974	226.1259	536.897	8.249898
667297081.1	63.8129	222.3309	528.0709	8.249321
678450219.8	63.8107	218.5141	519.3721	8.243215
689603358.6	63.8705	214.7854	510.8939	8.235752
700756497.3	63.9545	211.4045	503.0508	8.237217
711909636.1	63.8315	208.3063	495.6667	8.245679
723062774.8	63.6876	205.0414	488.1195	8.243596
739191613.7	63.9405	200.382	477.5366	8.235973
755320452.6	64.8252	196.499	468.3787	8.252599
771449291.5	65.3482	193.1251	460.0749	8.284099
787578130.4	65.386	190.2174	452.5137	8.329963
803706969.2	65.5823	187.1854	444.9351	8.365056
819835808.1	65.391	183.6869	436.708	8.373446
835964647	65.316	179.9779	428.3013	8.365776
852093485.9	65.1821	176.4619	420.3024	8.360598
868222324.8	65.014	173.1117	412.6304	8.357118
884351163.7	65.0241	169.8403	405.2209	8.351503
900480002.6	65.2449	166.726	398.1917	8.347887
916608841.5	65.3739	163.5262	391.0961	8.334327
932737680.4	65.4358	160.6177	384.5119	8.330136
948866519.3	65.5387	157.6818	377.9782	8.319282
964995358.1	65.756	154.6703	371.43	8.299106
981124197	65.5042	151.9764	365.3165	8.290855
997253035.9	65.5243	149.6128	359.8334	8.296087
1013381875	65.6667	146.7736	353.7385	8.270281
1029510714	65.7029	144.3971	348.3656	8.265869
1045639553	65.9837	142.2987	343.5275	8.273363
1068963879	65.9864	139.8379	337.3743	8.311647
1092288205	65.6795	137.113	330.8636	8.327508
1115612531	65.4028	134.5974	324.7786	8.349284
1138936857	65.195	132.464	319.3702	8.388739
1162261183	64.7277	129.948	313.4193	8.397935
1185585509	64.6586	127.7695	308.162	8.422853
1208909835	64.725	125.5242	302.923	8.437631
1232234161	64.9579	123.2888	297.8291	8.447263
1255558487	65.1706	121.0893	292.8512	8.453604
1278882813	65.2635	118.8406	287.8406	8.45074
1302207139	65.3005	116.6932	283.032	8.449379
1325531465	65.5596	114.564	278.3737	8.443789
1348855791	66.067	112.5177	273.9822	8.438894
1372180117	66.4921	110.8256	270.1449	8.455716
1395504443	66.5795	109.2747	266.4664	8.479105
1418828769	66.3123	107.8047	262.8446	8.504854
1442153095	66.0169	106.1374	258.969	8.510968
1465477421	65.8365	104.5392	255.2741	8.518389
1488801747	65.5245	102.9803	251.6399	8.524917
1512126073	65.223	101.5532	248.24	8.538484
1545855976	65.0225	99.4344	243.3926	8.546826
1579585880	64.7943	97.5251	238.9168	8.56562

1613315784	64.9232	95.7614	234.8539	8.590314
1647045688	65.3841	94.17	231.2324	8.624171
1680775591	65.8394	92.7735	227.9661	8.670274
1714505495	65.8937	91.4295	224.6981	8.716144
1748235399	65.7468	90.0005	221.2833	8.748709
1781965303	65.6749	88.4157	217.7181	8.760478
1815695207	65.6461	86.7514	214.1031	8.758275
1849425110	65.4638	85.2112	210.6573	8.762592
1883155014	65.3217	83.6458	207.233	8.758493
1916884918	65.1664	82.2281	204.0649	8.764264
1950614822	65.0986	80.981	201.2199	8.783221
1984344725	64.9296	79.8347	198.5211	8.808622
2018074629	64.8436	78.8746	196.1703	8.850617
2051804533	64.9081	78.0505	194.1151	8.904527
2085534437	65.1255	77.1966	192.1158	8.951889
2119264340	65.2899	76.2624	190.0093	8.986587
2152994244	65.2648	75.3	187.8078	9.014404
2186724148	65.2436	74.2734	185.5405	9.030805
2235501824	65.3586	72.6994	182.2433	9.036599
2284279499	65.368	71.2181	179.0879	9.045629
2333057175	65.2919	69.9307	176.2275	9.071778
2381834850	65.0609	68.9801	173.8426	9.135548
2430612526	64.7296	67.9896	171.3893	9.18877
2479390202	64.5426	67.1939	169.3347	9.263474
2528167877	64.7487	66.3383	167.4197	9.325442
2576945553	64.8463	65.4086	165.3813	9.372151
2625723228	64.8186	64.3865	163.173	9.400326
2674500904	64.9441	63.2676	160.9321	9.408562
2723278580	64.8658	62.2828	158.8156	9.431035
2772056255	64.6729	61.3544	156.7486	9.456859
2820833931	64.4465	60.617	154.9758	9.507605
2869611606	64.2327	59.9635	153.3602	9.567738
2918389282	64.1807	59.4363	152.0429	9.64482
2967166958	64.3969	58.8538	150.8163	9.70992
3015944633	64.473	58.2257	149.4674	9.764213
3064722309	64.4693	57.519	147.9754	9.801705
3113499985	64.5025	56.7747	146.4663	9.828854
3162277660	64.3982	56.0618	144.9428	9.857487
3232816303	64.1512	55.1556	142.9027	9.914477
3303354946	63.8694	54.4796	141.2199	10.00664
3373893589	63.9478	53.908	139.9464	10.11309
3444432232	64.0651	53.2748	138.6353	10.20325
3514970875	64.0823	52.5031	137.0803	10.26138
3585509518	64.0193	51.7005	135.4525	10.3073
3656048161	63.8194	51.0096	133.9309	10.36962
3726586804	63.556	50.5872	132.8014	10.48217
3797125447	63.5407	50.208	131.9231	10.60052
3867664090	63.6313	49.7786	131.0612	10.7051
3938202733	63.5891	49.2099	129.9146	10.7758
4008741376	63.495	48.5623	128.6264	10.82447
4079280019	63.3216	48.0087	127.4442	10.88937
4149818662	63.0821	47.6459	126.526	10.99395
4220357304	63.009	47.3713	125.8805	11.11639
4290895947	63.0861	47.0566	125.2964	11.2271
4361434590	63.0723	46.6103	124.4539	11.30343
4431973233	63.0097	46.0922	123.4745	11.35857
4502511876	62.8463	45.6255	122.5117	11.42251
4573050519	62.6124	45.364	121.8306	11.53497
4675058253	62.5082	45.0763	121.1879	11.71749
4777065987	62.528	44.6813	120.4949	11.86824
4879073721	62.4337	44.1068	119.4433	11.96581
4981081455	62.1628	43.7068	118.5483	12.1052
5083089188	61.9784	43.4554	117.9791	12.28204

5185096922	61.9961	43.1882	117.5713	12.45148
5287104656	61.9057	42.7208	116.7603	12.55904
5389112390	61.6684	42.3747	116.0361	12.69764
5491120124	61.4455	42.2016	115.6226	12.88514
5593127857	61.4496	42.012	115.3935	13.06554
5695135591	61.3621	41.6818	114.8627	13.19926
5797143325	61.1638	41.3483	114.2366	13.32818
5899151059	60.8869	41.2179	113.8902	13.51993
6001158793	60.842	41.0956	113.7815	13.71291
6103166526	60.7979	40.8619	113.4962	13.86669
6205174260	60.6153	40.5503	112.9534	13.99095
6307181994	60.3288	40.4332	112.6532	14.17988
6409189728	60.2115	40.3584	112.5979	14.38256
6511197462	60.1644	40.2209	112.5122	14.56169
6613205195	60.0304	39.9666	112.1426	14.69631
6760721186	59.6664	39.8023	111.8046	14.96237
6908237176	59.5313	39.7292	111.8781	15.26076
7055753166	59.3548	39.4104	111.4801	15.46156
7203269156	58.9947	39.3308	111.3307	15.75294
7350785146	58.8539	39.2824	111.4864	16.05576
7498301136	58.6095	39.056	111.211	16.28358
7645817126	58.2923	38.9649	111.1134	16.5652
7793333116	58.1396	38.9317	111.318	16.87042
7940849107	57.9047	38.7528	111.1639	17.11076
8088365097	57.5673	38.7023	111.1411	17.40591
8235881087	57.4132	38.6619	111.359	17.70486
8383397077	57.1537	38.5376	111.2983	17.96403
8530913067	56.834	38.5064	111.351	18.26533
8678429057	56.6471	38.4554	111.5318	18.55657
8825945047	56.434	38.3702	111.6182	18.83018
8973461037	56.0602	38.3545	111.6478	19.13707
9120977028	55.8701	38.3532	111.942	19.45101
9268493018	55.6361	38.2333	111.9445	19.7038
9416009008	55.3188	38.2621	112.1465	20.03249
9563524998	55.0851	38.2588	112.3951	20.34457
9776851640	54.6803	38.1887	112.5359	20.76027
9990178282	54.3137	38.1835	112.8698	21.21036
10203504925	53.9291	38.1265	113.0724	21.63094
10416831567	53.5452	38.1244	113.3991	22.08197
10630158209	53.1363	38.1281	113.7064	22.53637
10843484852	52.7353	38.0546	113.8551	22.94432
11056811494	52.3484	38.0544	114.1874	23.39559
11270138136	52.0004	38.0571	114.5861	23.84867
11483464778	51.5921	38.0456	114.864	24.29274
11696791421	51.1913	38.0392	115.164	24.73986
11910118063	50.8354	38.0235	115.5111	25.18067
12123444705	50.4093	38.0215	115.7793	25.63034
12336771348	50.0525	37.9966	116.1012	26.06426
12550097990	49.6303	38.0009	116.3856	26.51796
12763424632	49.2506	37.9985	116.7195	26.96701
12976751274	48.8401	38.0007	117.0129	27.41932
13190077917	48.5241	37.968	117.3726	27.84609
13403404559	48.0663	37.9572	117.5452	28.2884
13616731201	47.7232	38.0076	118.0643	28.7768
13830057844	47.2816	37.9176	118.0514	29.15842
14138554951	46.7775	37.8958	118.5329	29.7917
14447052059	46.2172	37.8868	118.941	30.43451
14755549167	45.6393	37.8636	119.268	31.06536
15064046275	45.0877	37.7936	119.5038	31.65622
15372543383	44.5924	37.7684	119.9523	32.28297
15681040491	44.0533	37.7883	120.435	32.94818
15989537598	43.5136	37.6554	120.4746	33.47822
16298034706	42.9546	37.6365	120.7842	34.10701

16606531814	42.4395	37.5467	120.9608	34.66968
16915028922	41.9344	37.4946	121.2513	35.26474
17223526030	41.4517	37.4444	121.5816	35.85982
17532023137	40.9017	37.3282	121.5615	36.38884
17840520245	40.4697	37.2953	122.0215	36.99651
18149017353	39.8504	37.2137	121.9284	37.55391
18457514461	39.4646	37.0054	121.9167	37.97847
18766011569	39.0291	37.0386	122.5423	38.64788
19074508677	38.4234	36.9919	122.5369	39.23369
19383005784	38.0536	36.7452	122.3907	39.60234
19691502892	37.707	36.7142	122.9809	40.19871
20000000000	37.1659	36.5935	122.829	40.69426

Table: E.7: seawater with DTPA-K5 dielectric measurements:

frequency	e'	e''	sensitivity	conductivity
Hz				S/m
5E+08	62.0623	340.4911	767.2975	9.466184
5.11E+08	61.9905	332.4228	749.7489	9.448024
5.22E+08	62.0816	324.6919	732.9732	9.429656
5.33E+08	62.0245	317.2482	716.8237	9.410219
5.45E+08	62.0704	310.3675	701.7902	9.398597
5.56E+08	61.8383	303.932	687.5485	9.3922
5.67E+08	61.594	297.7106	673.8282	9.384569
5.78E+08	61.2952	291.1111	659.659	9.357069
5.89E+08	60.8121	285.1569	646.5885	9.342526
6E+08	60.3913	279.6127	634.3533	9.334284
6.12E+08	60.6558	274.3515	622.7477	9.328789
6.23E+08	61.0214	268.8549	610.9615	9.308618
6.34E+08	60.929	263.6164	599.5939	9.290726
6.45E+08	60.684	258.8172	588.9985	9.282091
6.56E+08	60.2993	254.3289	578.9856	9.278847
6.67E+08	60.7304	249.8627	569.2276	9.270856
6.78E+08	61.4455	245.6736	560.0465	9.267778
6.9E+08	62.1408	242.3859	552.3463	9.294069
7.01E+08	61.9464	239.9113	545.8501	9.347963
7.12E+08	61.2225	237.0013	538.6853	9.381554
7.23E+08	60.2695	233.6843	530.9158	9.395171
7.39E+08	59.7559	228.4292	519.2694	9.388751
7.55E+08	60.0117	223.5873	508.5343	9.390258
7.71E+08	60.3721	219.2789	498.7705	9.405966
7.88E+08	60.2385	215.4975	489.8761	9.437024
8.04E+08	60.5176	211.6717	481.1226	9.459315
8.2E+08	60.6137	207.4853	471.8978	9.458306
8.36E+08	60.5795	203.4016	462.9049	9.454563
8.52E+08	60.4551	199.3359	454.0349	9.444347
8.68E+08	60.3571	195.5977	445.7569	9.442649
8.84E+08	60.4284	191.9028	437.6976	9.436376
9E+08	60.6564	188.5704	430.2995	9.441625
9.17E+08	60.8056	185.028	422.6596	9.430195
9.33E+08	60.8882	181.7932	415.5536	9.428363
9.49E+08	61.029	178.4713	408.4	9.416135
9.65E+08	61.1207	175.1469	401.3106	9.397814
9.81E+08	60.89	172.1452	394.7161	9.391135
9.97E+08	60.7517	169.5207	388.7837	9.399987
1.01E+09	60.7462	166.4499	382.2539	9.378985
1.03E+09	60.5707	163.6815	376.2052	9.369785
1.05E+09	60.4821	161.1381	370.588	9.368702
1.07E+09	60.1698	157.7696	362.9855	9.377466
1.09E+09	59.972	154.4343	355.5689	9.37951
1.12E+09	59.6678	151.2728	348.4833	9.383684
1.14E+09	59.5149	148.3182	341.8419	9.392761

1.16E+09	59.4273	145.2139	335.0768	9.384499
1.19E+09	59.8039	142.7098	329.4273	9.407752
1.21E+09	60.1645	140.2055	323.8568	9.424496
1.23E+09	60.8035	137.5499	318.2031	9.424378
1.26E+09	61.7289	135.1324	313.063	9.433994
1.28E+09	62.5014	133.3949	309.0074	9.485695
1.3E+09	62.4423	132.1082	305.4753	9.565529
1.33E+09	62.0785	130.3288	301.1606	9.605713
1.35E+09	61.8375	128.1634	296.339	9.612331
1.37E+09	61.6025	125.9379	291.4773	9.608746
1.4E+09	61.4846	123.7049	286.6808	9.598808
1.42E+09	61.2641	121.5612	282.0433	9.590122
1.44E+09	61.1117	119.4459	277.5127	9.578153
1.47E+09	60.967	117.5566	273.3659	9.579113
1.49E+09	60.7648	115.7627	269.3941	9.58307
1.51E+09	60.4945	114.1537	265.7264	9.597921
1.55E+09	60.2487	111.8504	260.5565	9.614036
1.58E+09	59.9027	109.7292	255.7125	9.637505
1.61E+09	59.893	107.7971	251.3266	9.669981
1.65E+09	60.1344	105.8889	247.1196	9.697399
1.68E+09	60.4743	103.9871	243.0251	9.718257
1.71E+09	60.6077	102.1001	238.9365	9.733392
1.75E+09	60.7086	100.2133	234.8979	9.741469
1.78E+09	60.9394	98.3033	230.9173	9.740169
1.82E+09	61.3348	96.4342	227.1074	9.735835
1.85E+09	61.4397	94.8277	223.6436	9.751493
1.88E+09	61.4638	93.3739	220.4303	9.777115
1.92E+09	61.3423	92.0762	217.4396	9.813922
1.95E+09	61.0253	90.8548	214.5317	9.854136
1.98E+09	60.6107	89.7393	211.7813	9.901454
2.02E+09	60.3752	88.6305	209.1401	9.945339
2.05E+09	60.2285	87.5448	206.6022	9.9877
2.09E+09	60.366	86.5293	204.3125	10.03413
2.12E+09	60.5292	85.3653	201.8344	10.05925
2.15E+09	60.4892	84.135	199.1992	10.07207
2.19E+09	60.5195	83.0036	196.7726	10.0923
2.24E+09	60.7321	81.1205	192.9962	10.08335
2.28E+09	60.7888	79.4425	189.5208	10.09024
2.33E+09	60.6887	77.8973	186.2321	10.10525
2.38E+09	60.4386	76.6919	183.4419	10.15688
2.43E+09	60.1193	75.4896	180.6633	10.20239
2.48E+09	60.0529	74.5822	178.4909	10.28204
2.53E+09	60.3077	73.7016	176.5442	10.36053
2.58E+09	60.4267	72.7131	174.4045	10.41878
2.63E+09	60.3885	71.6561	172.1158	10.46168
2.67E+09	60.4911	70.4055	169.6199	10.47004
2.72E+09	60.4	69.287	167.267	10.49163
2.77E+09	60.1518	68.162	164.8505	10.50615
2.82E+09	59.9216	67.2324	162.7689	10.54521
2.87E+09	59.6311	66.4238	160.8672	10.59854
2.92E+09	59.5765	65.801	159.3962	10.67763
2.97E+09	59.7603	65.1152	157.972	10.74295
3.02E+09	59.8741	64.3491	156.4086	10.79108
3.06E+09	59.9072	63.5448	154.7593	10.82855
3.11E+09	60.0455	62.6691	153.0755	10.84929
3.16E+09	59.975	61.8554	151.3934	10.87619
3.23E+09	59.7188	60.839	149.1563	10.93609
3.3E+09	59.3704	60.0834	147.3058	11.03593
3.37E+09	59.3612	59.4039	145.7971	11.14411
3.44E+09	59.4586	58.6527	144.2635	11.23323
3.51E+09	59.5223	57.7666	142.5237	11.2901
3.59E+09	59.5004	56.7955	140.6221	11.32306
3.66E+09	59.2781	55.9644	138.8451	11.37687

3.73E+09	58.9779	55.3854	137.4408	11.4764
3.8E+09	58.987	54.9175	136.4241	11.59484
3.87E+09	59.0822	54.4453	135.4763	11.70869
3.94E+09	59.0336	53.8466	134.2513	11.79113
4.01E+09	59.0274	52.9992	132.6695	11.81344
4.08E+09	58.8655	52.3218	131.276	11.86767
4.15E+09	58.5534	51.8941	130.2	11.97419
4.22E+09	58.4478	51.5608	129.4276	12.09952
4.29E+09	58.5172	51.2254	128.7831	12.22172
4.36E+09	58.5692	50.6959	127.8253	12.29423
4.43E+09	58.5674	50.0709	126.686	12.33905
4.5E+09	58.3742	49.5241	125.5512	12.39854
4.57E+09	58.0936	49.1648	124.6709	12.50142
4.68E+09	57.9449	48.8039	123.8593	12.68647
4.78E+09	58.0041	48.3476	123.0622	12.84208
4.88E+09	57.9733	47.6073	121.7453	12.91547
4.98E+09	57.6507	47.0848	120.589	13.04078
5.08E+09	57.4003	46.7574	119.826	13.21531
5.19E+09	57.4233	46.4794	119.3722	13.40036
5.29E+09	57.4333	45.9114	118.4347	13.49701
5.39E+09	57.1896	45.4054	117.4124	13.60579
5.49E+09	56.8812	45.1477	116.7709	13.78465
5.59E+09	56.8561	44.9736	116.5142	13.98658
5.7E+09	56.8729	44.5668	115.9054	14.11285
5.8E+09	56.7171	44.09	115.0402	14.21194
5.9E+09	56.3868	43.8768	114.4925	14.39208
6E+09	56.3018	43.7216	114.2631	14.58916
6.1E+09	56.3012	43.4316	113.8817	14.73873
6.21E+09	56.1759	42.9751	113.1048	14.82757
6.31E+09	55.8081	42.8147	112.6422	15.01507
6.41E+09	55.6508	42.7344	112.5161	15.2293
6.51E+09	55.6688	42.6052	112.4724	15.42491
6.61E+09	55.6264	42.2241	111.9262	15.52643
6.76E+09	55.1657	41.9172	111.2142	15.7574
6.91E+09	55.0344	41.8567	111.2735	16.07798
7.06E+09	54.9215	41.4886	110.797	16.27689
7.2E+09	54.502	41.1936	110.1642	16.49904
7.35E+09	54.4083	41.1889	110.4032	16.835
7.5E+09	54.2224	40.8287	109.8929	17.02267
7.65E+09	53.826	40.6515	109.5184	17.28222
7.79E+09	53.6727	40.6654	109.7669	17.62169
7.94E+09	53.5471	40.3072	109.3375	17.79708
8.09E+09	53.15	40.2069	109.1234	18.08258
8.24E+09	52.9616	40.2157	109.3522	18.41641
8.38E+09	52.8474	39.8811	108.9922	18.5903
8.53E+09	52.4196	39.8413	108.8741	18.89854
8.68E+09	52.2892	39.8586	109.2064	19.23368
8.83E+09	52.1394	39.5624	108.8919	19.41525
8.97E+09	51.6873	39.4934	108.6929	19.70533
9.12E+09	51.5927	39.5071	109.079	20.03621
9.27E+09	51.3813	39.3659	109.0165	20.2875
9.42E+09	50.939	39.2502	108.7331	20.54981
9.56E+09	50.8464	39.2587	109.1293	20.87628
9.78E+09	50.3373	39.0514	108.7892	21.22926
9.99E+09	50.053	39.101	109.2765	21.72002
1.02E+10	49.6876	38.8753	109.0733	22.05577
1.04E+10	49.2849	38.9016	109.3711	22.53213
1.06E+10	48.9282	38.7639	109.3699	22.91218
1.08E+10	48.5889	38.7345	109.633	23.35425
1.11E+10	48.2448	38.5798	109.609	23.7186
1.13E+10	47.8255	38.6408	109.9727	24.21444
1.15E+10	47.5209	38.4883	110.0039	24.57541
1.17E+10	47.0411	38.4984	110.1668	25.03852

1.19E+10	46.7911	38.3618	110.3061	25.40471
1.21E+10	46.3533	38.3891	110.5653	25.87814
1.23E+10	46.1026	38.2674	110.7356	26.25002
1.26E+10	45.6048	38.2813	110.8718	26.71363
1.28E+10	45.345	38.0894	110.8499	27.03152
1.3E+10	44.8755	38.2267	111.324	27.58239
1.32E+10	44.6332	38.0132	111.2656	27.87924
1.34E+10	44.1303	38.0816	111.5112	28.38112
1.36E+10	43.9568	37.9661	111.7965	28.74538
1.38E+10	43.411	37.9769	111.8212	29.20402
1.41E+10	42.9766	37.842	112.0147	29.7494
1.44E+10	42.4016	37.8341	112.3055	30.39218
1.48E+10	41.9699	37.699	112.4825	30.93032
1.51E+10	41.4247	37.6753	112.7588	31.55713
1.54E+10	40.8846	37.58	112.8379	32.12193
1.57E+10	40.3698	37.4454	112.8355	32.6492
1.6E+10	39.9804	37.3916	113.2608	33.24368
1.63E+10	39.4217	37.3353	113.3751	33.83405
1.66E+10	38.9481	37.1832	113.351	34.33404
1.69E+10	38.4417	37.078	113.3874	34.87291
1.72E+10	38.049	37.1802	114.2262	35.6068
1.75E+10	37.3703	36.8391	113.2197	35.91205
1.78E+10	37.1021	36.8064	113.8702	36.51153
1.81E+10	36.525	36.6352	113.5144	36.97012
1.85E+10	36.2262	36.6838	114.3435	37.64841
1.88E+10	35.6363	36.5982	114.1939	38.18835
1.91E+10	35.1829	36.343	113.7626	38.54547
1.94E+10	35.1397	36.1306	114.2648	38.93996
1.97E+10	34.3485	36.8705	116.3107	40.36984
2E+10	33.5898	35.6361	112.0526	39.62957

Table: E.8: seawater with DTPA-K5 with (1,000 ppm ferric ion concentrations) dielectric measurements:

frequency	e'	e''	sensitivity	conductivity
Hz				S/m
500000000	64.7895	309.5965	720.3035	8.607266
511153138.7	65.2006	302.8987	704.9661	8.608899
522306277.5	64.9298	296.5482	690.2808	8.612311
533459416.2	64.4856	290.3433	676.024	8.612165
544612555	64.0648	283.7198	661.3332	8.591648
555765693.7	63.7284	278.1237	648.3802	8.594664
566918832.4	63.2118	272.2783	635.2005	8.582881
578071971.2	62.8749	266.5178	622.3566	8.566576
589225109.9	62.3042	260.923	609.8731	8.548556
600378248.7	61.9531	255.8814	598.38	8.542064
611531387.4	61.9555	251.3148	587.8561	8.54547
622684526.1	62.148	246.4096	576.9333	8.531489
633837664.9	61.7709	241.6892	566.3585	8.517937
644990803.6	61.4783	237.3999	556.5512	8.513992
656143942.4	61.2659	233.3145	547.1843	8.512165
667297081.1	61.1085	229.5119	538.3505	8.515764
678450219.8	61.2313	225.5456	529.4297	8.508471
689603358.6	61.1588	221.696	520.7334	8.500733
700756497.3	61.1146	218.3619	512.9452	8.508307
711909636.1	61.0512	215.0208	505.1931	8.511469
723062774.8	61.0393	211.825	497.7774	8.516328
739191613.7	61.1347	206.8431	486.6551	8.501533
755320452.6	62.2347	202.8834	477.4125	8.520732
771449291.5	62.6452	199.3918	468.9073	8.552909

787578130.4	62.6083	196.3869	461.1994	8.600136
803706969.2	62.6759	193.2798	453.4723	8.637407
819835808.1	62.4568	189.5592	444.9128	8.641137
835964647	62.4317	185.8214	436.4643	8.637395
852093485.9	62.144	182.1604	428.1935	8.630588
868222324.8	62.0537	178.7191	420.395	8.62782
884351163.7	61.9925	175.372	412.849	8.623512
900480002.6	62.1976	172.1723	405.6659	8.620581
916608841.5	62.3027	168.9047	398.4497	8.60845
932737680.4	62.3448	165.9188	391.7285	8.605067
948866519.3	62.505	162.84	384.9666	8.591428
964995358.1	62.6362	159.7869	378.324	8.573646
981124197	62.439	156.9615	372.0221	8.56281
997253035.9	62.3976	154.5096	366.3764	8.567616
1013381875	62.4779	151.6402	360.2036	8.5445
1029510714	62.4981	149.1071	354.5768	8.535488
1045639553	62.7569	146.9298	349.6039	8.542619
1068963879	62.9052	144.27	343.1845	8.575081
1092288205	62.6794	141.6118	336.787	8.600741
1115612531	62.2969	139.157	330.7639	8.632123
1138936857	61.8813	136.8914	325.0991	8.669119
1162261183	61.4177	134.1707	318.8344	8.670828
1185585509	61.3563	131.8767	313.3939	8.693609
1208909835	61.4242	129.5147	307.9724	8.705869
1232234161	61.659	127.2337	302.7913	8.717552
1255558487	61.8953	124.8986	297.6027	8.719542
1278882813	62.0407	122.6382	292.5631	8.720787
1302207139	62.0566	120.3967	287.5927	8.717537
1325531465	62.4088	118.2564	282.9295	8.715932
1348855791	62.9468	116.275	278.6173	8.720694
1372180117	63.2826	114.6548	274.8426	8.747874
1395504443	63.267	113.0069	270.9762	8.768703
1418828769	62.9066	111.4194	267.1467	8.790022
1442153095	62.6444	109.6652	263.1401	8.793856
1465477421	62.4603	107.9798	259.3047	8.798747
1488801747	62.2472	106.3017	255.5156	8.79987
1512126073	61.9512	104.8171	252.0238	8.812909
1545855976	61.6935	102.6115	247.0104	8.819911
1579585880	61.5382	100.5985	242.3918	8.835557
1613315784	61.6789	98.7771	238.2252	8.860838
1647045688	62.133	97.2101	234.6154	8.902586
1680775591	62.5278	95.7846	231.2655	8.951681
1714505495	62.5018	94.4506	227.9695	9.004151
1748235399	62.3108	92.9424	224.4079	9.034684
1781965303	62.2631	91.3085	220.7583	9.047105
1815695207	62.267	89.5849	217.0453	9.044341
1849425110	62.0961	88.0088	213.5333	9.05028
1883155014	61.9711	86.4083	210.0454	9.047752
1916884918	61.8549	84.9205	206.7684	9.051233
1950614822	61.7243	83.6534	203.8561	9.07307
1984344725	61.5662	82.4101	201.0039	9.092781
2018074629	61.4137	81.3562	198.471	9.129081
2051804533	61.451	80.4905	196.3323	9.182898
2085534437	61.6378	79.5924	194.2373	9.229712
2119264340	61.7491	78.6559	192.0852	9.268631
2152994244	61.7315	77.6609	189.823	9.297035
2186724148	61.713	76.6224	187.5218	9.316417
2235501824	61.8633	75.028	184.1759	9.326046
2284279499	61.9153	73.4607	180.8823	9.330469
2333057175	61.8828	72.1071	177.9213	9.354112
2381834850	61.6057	71.0399	175.3263	9.408343
2430612526	61.278	69.9807	172.759	9.457866
2479390202	61.0572	69.1334	170.597	9.530857

2528167877	61.2144	68.2498	168.5921	9.594149
2576945553	61.3205	67.3321	166.5485	9.647762
2625723228	61.3235	66.3166	164.3436	9.682118
2674500904	61.5093	65.1764	162.0708	9.692421
2723278580	61.4505	64.174	159.9152	9.717406
2772056255	61.3039	63.1621	157.7279	9.735489
2820833931	61.0424	62.3788	155.8544	9.783938
2869611606	60.8175	61.6133	154.0473	9.830979
2918389282	60.7371	61.1119	152.7395	9.916723
2967166958	60.8764	60.5264	151.444	9.985872
3015944633	60.9667	59.924	150.1187	10.04901
3064722309	60.9429	59.2458	148.6363	10.09597
3113499985	61.0505	58.4611	147.0844	10.1208
3162277660	60.9549	57.7546	145.5566	10.15514
3232816303	60.7008	56.722	143.2955	10.19604
3303354946	60.3899	55.9666	141.4562	10.27977
3373893589	60.3884	55.3779	140.0804	10.38884
3444432232	60.4736	54.7793	138.7721	10.4914
3514970875	60.5061	54.0678	137.2888	10.56719
3585509518	60.477	53.187	135.5306	10.60365
3656048161	60.304	52.3873	133.8333	10.64969
3726586804	60.0096	51.8639	132.5109	10.74671
3797125447	59.9335	51.4684	131.5428	10.86663
3867664090	59.9482	51.1122	130.7182	10.99189
3938202733	59.9232	50.5947	129.6333	11.07904
4008741376	59.9123	49.8876	128.2764	11.11987
4079280019	59.7837	49.1962	126.883	11.15872
4149818662	59.5094	48.7623	125.8125	11.25155
4220357304	59.3509	48.4674	125.0539	11.3736
4290895947	59.3746	48.2344	124.5324	11.50811
4361434590	59.3801	47.8559	123.783	11.6055
4431973233	59.3655	47.2638	122.6901	11.64729
4502511876	59.2932	46.6946	121.6041	11.69017
4573050519	59.0351	46.3606	120.7709	11.78838
4675058253	58.791	46.0207	119.9085	11.96298
4777065987	58.7947	45.745	119.3553	12.15078
4879073721	58.8308	45.1555	118.3374	12.25031
4981081455	58.5832	44.5981	117.1735	12.35205
5083089188	58.2922	44.2751	116.3745	12.51372
5185096922	58.2441	44.1338	116.0792	12.72411
5287104656	58.2574	43.6996	115.3669	12.84679
5389112390	58.083	43.1928	114.3957	12.94279
5491120124	57.7447	42.9246	113.6998	13.10589
5593127857	57.6586	42.8408	113.5321	13.32329
5695135591	57.6683	42.5643	113.1352	13.47872
5797143325	57.5595	42.0599	112.2608	13.55756
5899151059	57.1776	41.8184	111.6078	13.7169
6001158793	57.0132	41.7931	111.5219	13.94565
6103166526	57.0453	41.6874	111.4829	14.14683
6205174260	57.0176	41.2279	110.7881	14.22474
6307181994	56.6484	40.9535	110.1131	14.36235
6409189728	56.367	40.9175	109.9398	14.58181
6511197462	56.3945	40.9512	110.183	14.82609
6613205195	56.4332	40.5927	109.754	14.92654
6760721186	55.9501	40.2263	108.9027	15.12176
6908237176	55.6689	40.3313	109.0991	15.49204
7055753166	55.7363	39.9469	108.7651	15.67204
7203269156	55.254	39.6432	108.0446	15.87806
7350785146	55.0045	39.826	108.4573	16.27795
7498301136	55.0043	39.4792	108.1579	16.46002
7645817126	54.5213	39.1927	107.4783	16.66204
7793333116	54.3222	39.4122	108.0517	17.07863
7940849107	54.2906	39.1094	107.8272	17.26821

8088365097	53.7433	38.8475	107.1298	17.47121
8235881087	53.6291	39.0709	107.8407	17.89215
8383397077	53.5907	38.8077	107.7051	18.08994
8530913067	52.9845	38.6041	107.0527	18.31168
8678429057	52.8789	38.8193	107.7933	18.73217
8825945047	52.9136	38.5088	107.6626	18.8982
8973461037	52.2178	38.4363	107.1623	19.17789
9120977028	52.1536	38.6321	107.9456	19.59245
9268493018	52.1423	38.2556	107.6367	19.7153
9416009008	51.4857	38.281	107.3755	20.04238
9563524998	51.3439	38.5287	108.203	20.48809
9776851640	51.0091	38.0542	107.5106	20.68716
9990178282	50.5523	38.3529	108.2973	21.30446
10203504925	50.2576	37.9745	107.852	21.54471
10416831567	49.8151	38.2226	108.5681	22.13885
10630158209	49.4865	37.8798	108.1489	22.38961
10843484852	49.1216	38.1038	108.9309	22.97398
11056811494	48.7004	37.7393	108.3278	23.20187
11270138136	48.4029	38.0496	109.4106	23.84397
11483464778	47.9592	37.6424	108.6638	24.03529
11696791421	47.6063	37.9768	109.7429	24.69928
11910118063	47.2485	37.5575	109.0675	24.87207
12123444705	46.7967	37.8991	110.0365	25.54783
12336771348	46.5059	37.4745	109.4237	25.70612
12550097990	46.0683	37.8527	110.5128	26.41455
12763424632	45.7698	37.4081	109.8211	26.54801
12976751274	45.3125	37.7963	110.9166	27.27184
13190077917	45.0739	37.349	110.286	27.39211
13403404559	44.5097	37.7057	111.1489	28.10097
13616731201	44.3401	37.3138	110.7412	28.2515
13830057844	43.7991	37.5601	111.3623	28.88351
14138554951	43.2207	37.3799	111.2052	29.38612
14447052059	42.8206	37.216	111.3612	29.89566
14755549167	42.3379	37.3363	112.1233	30.63274
15064046275	41.6155	37.3319	112.1498	31.2695
15372543383	41.1319	37.0548	111.8225	31.67301
15681040491	40.6922	37.0841	112.3907	32.33417
15989537598	40.2267	37.0133	112.6318	32.90735
16298034706	39.681	37.0103	112.9117	33.53953
16606531814	39.14	36.9366	112.9886	34.10633
16915028922	38.7029	36.7377	112.8749	34.55285
17223526030	38.3754	36.8025	113.7181	35.24508
17532023137	37.6664	36.8218	113.7173	35.89519
17840520245	36.9815	36.4104	112.4597	36.1187
18149017353	37.0706	36.2376	113.3539	36.56888
18457514461	36.5666	36.7047	115.0683	37.66986
18766011569	35.5651	36.3889	113.4063	37.96995
19074508677	35.5319	35.644	112.2748	37.8041
19383005784	35.529	36.3091	115.6188	39.13234
19691502892	34.1258	36.4519	114.5112	39.91151
20000000000	33.8758	35.3764	111.7985	39.34076

Table: E.9: low salinity water dielectric measurements:

frequency	e'	e''	sensitivity	conductivity
Hz				S/m
5E+08	76.224	74.9012	408.1127	2.08237
5.11E+08	76.1851	73.2487	399.6499	2.081853
5.22E+08	76.182	71.6405	391.5378	2.080573

5.33E+08	76.0995	70.1071	383.7558	2.079517
5.45E+08	76.1112	68.6792	376.3665	2.079754
5.56E+08	76.0113	67.3864	369.3431	2.082395
5.67E+08	75.9875	66.1574	362.6261	2.085444
5.78E+08	75.8655	64.7646	355.9069	2.081703
5.89E+08	75.7606	63.6099	349.6566	2.084036
6E+08	75.6564	62.5415	343.6937	2.087817
6.12E+08	75.6878	61.4148	337.8688	2.088291
6.23E+08	75.7418	60.2156	332.1285	2.084857
6.34E+08	75.6652	59.1031	326.6161	2.082991
6.45E+08	75.5956	58.076	321.3475	2.082809
6.56E+08	75.4948	57.179	316.3656	2.086099
6.67E+08	75.5324	56.1276	311.3732	2.082547
6.78E+08	75.7525	55.1462	306.6319	2.080332
6.9E+08	76.0841	54.293	302.1871	2.081816
7.01E+08	76.3716	53.9067	298.3822	2.100434
7.12E+08	76.2745	53.4979	294.5623	2.117682
7.23E+08	76.0566	53.0033	290.7189	2.130974
7.39E+08	75.8061	52.0319	285.0577	2.138582
7.55E+08	75.7377	50.9959	279.5628	2.141735
7.71E+08	75.8966	50.0791	274.4472	2.148142
7.88E+08	75.884	49.416	269.7459	2.164016
8.04E+08	75.9384	48.7185	265.1875	2.177162
8.2E+08	75.8689	48.0019	260.725	2.188187
8.36E+08	75.8227	47.2109	256.3242	2.194469
8.52E+08	75.7287	46.46	252.0928	2.201231
8.68E+08	75.6373	45.7009	247.9797	2.206251
8.84E+08	75.6069	44.9349	243.9966	2.20957
9E+08	75.633	44.2649	240.2521	2.216321
9.17E+08	75.5873	43.5619	236.5614	2.220189
9.33E+08	75.5681	42.9616	233.0923	2.228123
9.49E+08	75.5053	42.2836	229.6207	2.23088
9.65E+08	75.4911	41.6729	226.3331	2.236032
9.81E+08	75.345	41.0963	223.1312	2.24195
9.97E+08	75.3184	40.6291	220.1711	2.252899
1.01E+09	75.2548	40.005	217.1034	2.254169
1.03E+09	75.1843	39.4756	214.2138	2.259742
1.05E+09	75.1368	39.0388	211.51	2.269748
1.07E+09	75.0091	38.4415	207.74	2.284875
1.09E+09	74.8955	37.7921	204.0513	2.295289
1.12E+09	74.7632	37.176	200.5182	2.306084
1.14E+09	74.6103	36.6084	197.1537	2.318353
1.16E+09	74.514	35.9509	193.816	2.323339
1.19E+09	74.4674	35.3814	190.6991	2.332422
1.21E+09	74.4786	34.8293	187.7228	2.341196
1.23E+09	74.5045	34.176	184.7316	2.341605
1.26E+09	74.7532	33.4472	181.824	2.335048
1.28E+09	75.2335	32.9676	179.3684	2.344322
1.3E+09	75.5212	32.9364	177.4237	2.384819
1.33E+09	75.4728	32.8316	175.3522	2.41981
1.35E+09	75.3121	32.6153	173.1816	2.446167
1.37E+09	75.1022	32.2866	170.9331	2.463387
1.4E+09	74.9799	31.9491	168.7729	2.479071
1.42E+09	74.8172	31.5886	166.6297	2.492066
1.44E+09	74.723	31.1505	164.4835	2.497903
1.47E+09	74.6109	30.8411	162.5294	2.513091
1.49E+09	74.5151	30.522	160.6233	2.526673
1.51E+09	74.4063	30.2464	158.8092	2.543085
1.55E+09	74.2794	29.838	156.2708	2.564708
1.58E+09	74.0848	29.4376	153.8059	2.585502
1.61E+09	74.0194	29.0829	151.5332	2.608893
1.65E+09	73.9707	28.7038	149.3221	2.628719
1.68E+09	74.0304	28.2878	147.1919	2.643675

1.71E+09	74.0447	27.9177	145.1682	2.661446
1.75E+09	74.0145	27.5003	143.1393	2.673231
1.78E+09	74.0235	27.0982	141.2116	2.684966
1.82E+09	74.1407	26.6659	139.3587	2.692144
1.85E+09	74.2294	26.3605	137.6964	2.710751
1.88E+09	74.3619	26.1994	136.2715	2.743321
1.92E+09	74.4532	26.1012	134.9543	2.781991
1.95E+09	74.398	26.0232	133.6385	2.822483
1.98E+09	74.3122	26.004	132.42	2.869171
2.02E+09	74.2374	25.922	131.1821	2.90874
2.05E+09	74.1371	25.8324	129.9616	2.947134
2.09E+09	74.0821	25.7672	128.8346	2.988022
2.12E+09	74.0543	25.6223	127.6665	3.019273
2.15E+09	73.9553	25.4316	126.4469	3.044498
2.19E+09	73.8935	25.2709	125.3131	3.072656
2.24E+09	73.7915	24.9262	123.5977	3.098348
2.28E+09	73.7749	24.6998	122.1246	3.137197
2.33E+09	73.7242	24.4916	120.7144	3.177179
2.38E+09	73.6523	24.4142	119.4985	3.233354
2.43E+09	73.5388	24.2779	118.2458	3.281149
2.48E+09	73.4922	24.2305	117.182	3.340461
2.53E+09	73.5111	24.1952	116.2167	3.401217
2.58E+09	73.5053	24.138	115.2577	3.458643
2.63E+09	73.4044	24.0529	114.253	3.511685
2.67E+09	73.2969	23.9051	113.2097	3.554942
2.72E+09	73.2119	23.8185	112.2882	3.606664
2.77E+09	73.0718	23.7211	111.3562	3.656251
2.82E+09	72.9571	23.6382	110.4883	3.707585
2.87E+09	72.83	23.5992	109.6944	3.765473
2.92E+09	72.7355	23.5637	108.9545	3.823718
2.97E+09	72.7083	23.4962	108.2474	3.876491
3.02E+09	72.6965	23.3995	107.5429	3.924001
3.06E+09	72.6534	23.3213	106.866	3.974139
3.11E+09	72.6542	23.216	106.2116	4.019161
3.16E+09	72.6058	23.2126	105.6679	4.08153
3.23E+09	72.532	23.2214	104.9373	4.174155
3.3E+09	72.4007	23.2621	104.2498	4.272709
3.37E+09	72.3231	23.2825	103.6146	4.367774
3.44E+09	72.2688	23.294	103.0247	4.461294
3.51E+09	72.2016	23.265	102.4125	4.546989
3.59E+09	72.1305	23.2677	101.871	4.638777
3.66E+09	72.0115	23.3176	101.3839	4.740181
3.73E+09	71.9069	23.3815	100.9555	4.844877
3.8E+09	71.8226	23.4665	100.597	4.95453
3.87E+09	71.7843	23.5454	100.2931	5.063537
3.94E+09	71.6564	23.6426	99.9696	5.17717
4.01E+09	71.4914	23.6349	99.5099	5.268184
4.08E+09	71.3987	23.6957	99.2142	5.374675
4.15E+09	71.2481	23.822	98.9782	5.496757
4.22E+09	71.1202	23.9191	98.7439	5.612976
4.29E+09	71.0379	24.0175	98.5674	5.730268
4.36E+09	70.928	24.0493	98.3019	5.832181
4.43E+09	70.821	24.0996	98.0804	5.938902
4.5E+09	70.6764	24.1993	97.9081	6.058384
4.57E+09	70.5399	24.2867	97.7419	6.175522
4.68E+09	70.3853	24.4402	97.601	6.353177
4.78E+09	70.2473	24.5626	97.465	6.524312
4.88E+09	70.0583	24.6782	97.3034	6.694991
4.98E+09	69.881	24.8376	97.2375	6.879113
5.08E+09	69.6892	24.986	97.1693	7.061934
5.19E+09	69.5495	25.1624	97.2111	7.25451
5.29E+09	69.3812	25.2838	97.1743	7.432919
5.39E+09	69.1734	25.453	97.1877	7.627029

5.49E+09	68.9656	25.6317	97.2337	7.825958
5.59E+09	68.8102	25.8167	97.3603	8.028874
5.7E+09	68.6345	25.9767	97.4498	8.225972
5.8E+09	68.4402	26.1446	97.551	8.427431
5.9E+09	68.2353	26.3159	97.662	8.63191
6E+09	68.0379	26.4798	97.7864	8.835863
6.1E+09	67.8343	26.6208	97.8857	9.033904
6.21E+09	67.6076	26.7883	98.0135	9.242688
6.31E+09	67.393	27.0192	98.2618	9.475606
6.41E+09	67.2074	27.2073	98.4921	9.695891
6.51E+09	67.0243	27.3815	98.718	9.913277
6.61E+09	66.8144	27.5307	98.8891	10.12345
6.76E+09	66.4829	27.7899	99.191	10.4467
6.91E+09	66.2029	28.0455	99.5701	10.77282
7.06E+09	65.8577	28.3506	99.9741	11.12256
7.2E+09	65.5395	28.5267	100.226	11.42563
7.35E+09	65.2769	28.784	100.6929	11.76479
7.5E+09	64.8717	29.0516	101.0246	12.11245
7.65E+09	64.5765	29.2846	101.4506	12.4498
7.79E+09	64.2529	29.5317	101.8817	12.79708
7.94E+09	63.9069	29.7433	102.2397	13.13274
8.09E+09	63.6152	29.9995	102.7581	13.49193
8.24E+09	63.2285	30.229	103.1238	13.84309
8.38E+09	62.8896	30.4414	103.5333	14.19005
8.53E+09	62.5913	30.6846	104.0651	14.5551
8.68E+09	62.2267	30.9119	104.4928	14.91647
8.83E+09	61.8843	31.1087	104.9057	15.2666
8.97E+09	61.5305	31.3316	105.361	15.63298
9.12E+09	61.2152	31.4884	105.7572	15.96949
9.27E+09	60.8548	31.806	106.3991	16.39145
9.42E+09	60.4751	31.9386	106.6778	16.72176
9.56E+09	60.152	32.0866	107.0714	17.06243
9.78E+09	59.5843	32.4577	107.8113	17.64477
9.99E+09	59.0982	32.6716	108.3794	18.14859
1.02E+10	58.6227	32.975	109.1546	18.70826
1.04E+10	58.0389	33.1545	109.5282	19.20336
1.06E+10	57.5654	33.5152	110.451	19.80983
1.08E+10	57.0177	33.6373	110.7755	20.28099
1.11E+10	56.5611	33.9305	111.6102	20.86024
1.13E+10	55.9703	34.1188	112.0152	21.38071
1.15E+10	55.5555	34.3965	112.9057	21.96273
1.17E+10	54.9214	34.5002	113.0603	22.43817
1.19E+10	54.4995	34.7786	113.9571	23.03177
1.21E+10	53.9391	34.8619	114.1878	23.50045
1.23E+10	53.5079	35.1257	115.0523	24.09493
1.26E+10	52.9086	35.1808	115.1461	24.55003
1.28E+10	52.4609	35.4053	115.8989	25.12665
1.3E+10	51.9117	35.5158	116.205	25.62635
1.32E+10	51.4915	35.6711	116.8481	26.16152
1.34E+10	50.8647	35.7787	117.0022	26.66483
1.36E+10	50.5355	35.9532	117.8592	27.22134
1.38E+10	49.8806	36.0044	117.8131	27.68718
1.41E+10	49.3283	36.1139	118.5526	28.39086
1.44E+10	48.4812	36.3857	119.1544	29.22868
1.48E+10	47.8712	36.392	119.5064	29.85798
1.51E+10	47.1813	36.4928	119.9416	30.56666
1.54E+10	46.506	36.6359	120.5111	31.31495
1.57E+10	45.7725	36.6738	120.6682	31.97643
1.6E+10	45.1906	36.735	121.1755	32.65992
1.63E+10	44.4552	36.8111	121.4066	33.35901
1.66E+10	43.8352	36.8045	121.6205	33.98435
1.69E+10	43.1975	36.835	121.8895	34.64436
1.72E+10	42.6239	36.9951	122.6627	35.42953

1.75E+10	41.7916	36.7093	121.5529	35.78552
1.78E+10	41.5311	36.8974	123.0543	36.6018
1.81E+10	40.5768	36.8841	122.4553	37.22129
1.85E+10	40.1327	36.7025	122.4136	37.66761
1.88E+10	39.7059	36.8088	123.2962	38.4081
1.91E+10	38.9111	36.9393	123.441	39.1779
1.94E+10	38.6399	36.4673	122.8041	39.30284
1.97E+10	38.1519	37.0125	124.9696	40.52532
2E+10	37.0706	36.285	121.5953	40.35118

Table: E.10: low salinity water with (1,000 ppm ferric ion concentrations) dielectric measurements:

frequency	e'	e''	sensitivity	conductivity
Hz				S/m
500000000	77.1447	53.394	383.3679	1.484436
511153138.7	77.3892	52.2386	375.6095	1.48471
522306277.5	77.4575	51.384	368.4327	1.492287
533459416.2	77.4163	50.4942	361.4525	1.497759
544612555	77.3057	49.6296	354.7281	1.502891
555765693.7	77.1906	48.7352	348.2069	1.50603
566918832.4	77.1507	47.8751	341.9475	1.509141
578071971.2	76.9807	47.0466	335.9025	1.5122
589225109.9	76.9341	46.1867	330.0423	1.513204
600378248.7	76.8092	45.4394	324.4765	1.516899
611531387.4	76.7739	44.7641	319.1812	1.522116
622684526.1	76.785	44.0271	313.993	1.524359
633837664.9	76.6811	43.3129	308.9549	1.526492
644990803.6	76.5971	42.6668	304.1458	1.530181
656143942.4	76.4446	42.0633	299.5032	1.534623
667297081.1	76.4191	41.407	294.9709	1.536357
678450219.8	76.3972	40.7471	290.5597	1.537142
689603358.6	76.2656	40.1654	286.3251	1.540106
700756497.3	76.2771	39.617	282.2794	1.543647
711909636.1	76.142	39.047	278.2803	1.545652
723062774.8	76.0874	38.4901	274.4204	1.547477
739191613.7	75.9773	37.5543	268.8603	1.543533
755320452.6	76.3231	36.7001	263.7112	1.541337
771449291.5	76.5384	36.1895	259.0899	1.552348
787578130.4	76.6738	35.7819	254.7282	1.566954
803706969.2	76.7322	35.5175	250.6659	1.587228
819835808.1	76.5997	35.1015	246.5324	1.600117
835964647	76.5074	34.5774	242.4322	1.607235
852093485.9	76.387	34.0827	238.4915	1.614806
868222324.8	76.3004	33.5139	234.6097	1.617913
884351163.7	76.2549	33.0531	230.9756	1.62531
900480002.6	76.1972	32.5181	227.3693	1.628165
916608841.5	76.1668	32.0637	223.9693	1.634169
932737680.4	76.0871	31.5768	220.6201	1.637672
948866519.3	76.0588	31.1391	217.4348	1.642897
964995358.1	76.0102	30.6265	214.2572	1.643319
981124197	75.9455	30.1689	211.2234	1.645821
997253035.9	75.937	29.7645	208.345	1.650453
1013381875	75.8979	29.2569	205.4277	1.648544
1029510714	75.9667	28.7746	202.6462	1.647173
1045639553	76.0643	28.4498	200.122	1.654095
1068963879	76.2532	28.0827	196.7168	1.669172
1092288205	76.2266	27.7781	193.4456	1.687093
1115612531	76.1031	27.4351	190.2248	1.701841
1138936857	76.1276	27.1423	187.2301	1.71888
1162261183	76.0667	26.9265	184.4008	1.740134
1185585509	75.9515	26.7037	181.6501	1.760368

1208909835	75.8819	26.4348	178.9648	1.776925
1232234161	75.8081	26.1738	176.3797	1.793326
1255558487	75.7863	25.8584	173.8419	1.805252
1278882813	75.6925	25.59	171.4105	1.819702
1302207139	75.5897	25.2118	168.9392	1.825505
1325531465	75.5543	24.8519	166.5881	1.831677
1348855791	75.5922	24.3939	164.2255	1.829557
1372180117	75.7872	24.1046	162.1784	1.839121
1395504443	75.9315	23.9198	160.2896	1.856043
1418828769	75.9398	23.8738	158.559	1.883435
1442153095	75.8408	23.7955	156.809	1.908119
1465477421	75.7222	23.6334	155.0164	1.92577
1488801747	75.5857	23.4619	153.2584	1.942224
1512126073	75.4346	23.2907	151.5439	1.958257
1545855976	75.2606	22.9817	149.1	1.975379
1579585880	75.1578	22.6433	146.7443	1.988759
1613315784	75.1008	22.3164	144.5089	2.001901
1647045688	75.2337	22.0073	142.457	2.015448
1680775591	75.4228	21.8423	140.6661	2.041302
1714505495	75.536	21.7856	139.0352	2.076862
1748235399	75.5193	21.7443	137.4337	2.113706
1781965303	75.4516	21.6686	135.8368	2.146986
1815695207	75.3564	21.5145	134.2014	2.172068
1849425110	75.2616	21.404	132.6732	2.201055
1883155014	75.1456	21.2426	131.1326	2.224298
1916884918	75.0793	21.0463	129.6279	2.243215
1950614822	75.0248	20.8784	128.2099	2.264477
1984344725	74.9847	20.7346	126.8707	2.287768
2018074629	74.9783	20.6619	125.6715	2.318498
2051804533	74.9678	20.6337	124.5618	2.354031
2085534437	74.9819	20.6345	123.5358	2.392822
2119264340	74.9634	20.6322	122.5295	2.431251
2152994244	74.8824	20.6021	121.4964	2.466343
2186724148	74.7893	20.5031	120.4162	2.492945
2235501824	74.7291	20.3284	118.9134	2.526838
2284279499	74.6759	20.1529	117.4796	2.559682
2333057175	74.7162	19.9946	116.1743	2.593805
2381834850	74.6884	20.0124	115.0865	2.650391
2430612526	74.5994	20.0167	114.0027	2.70525
2479390202	74.5103	20.0497	113.0018	2.764088
2528167877	74.4664	20.0772	112.0683	2.822333
2576945553	74.4415	20.0877	111.1709	2.87829
2625723228	74.3766	20.0525	110.241	2.927633
2674500904	74.3507	20.0025	109.3567	2.974584
2723278580	74.2697	19.997	108.5293	3.028001
2772056255	74.1936	19.9549	107.6969	3.075748
2820833931	74.0991	19.9699	106.9514	3.132222
2869611606	73.9853	19.9886	106.2308	3.189368
2918389282	73.9093	20.0485	105.6106	3.253301
2967166958	73.8711	20.1034	105.0366	3.316734
3015944633	73.8487	20.1393	104.4801	3.377279
3064722309	73.8016	20.1693	103.926	3.437013
3113499985	73.7597	20.1517	103.3463	3.488669
3162277660	73.6871	20.1843	102.8274	3.549056
3232816303	73.5613	20.205	102.0719	3.631943
3303354946	73.4302	20.2802	101.42	3.725003
3373893589	73.3231	20.4009	100.8796	3.827189
3444432232	73.2845	20.4991	100.3995	3.926012
3514970875	73.2314	20.5861	99.9343	4.023416
3585509518	73.123	20.6532	99.4405	4.117536
3656048161	73.02	20.7071	98.9664	4.209498
3726586804	72.8833	20.8172	98.5648	4.313529
3797125447	72.7643	20.9623	98.2469	4.425813

3867664090	72.6814	21.1306	98.0136	4.544224
3938202733	72.589	21.2488	97.7378	4.652985
4008741376	72.5023	21.3346	97.4516	4.755451
4079280019	72.3862	21.3809	97.1172	4.849631
4149818662	72.2409	21.4851	96.8519	4.957534
4220357304	72.1169	21.6519	96.7022	5.080944
4290895947	72.0276	21.8456	96.635	5.212081
4361434590	71.9405	21.9806	96.5166	5.330501
4431973233	71.852	22.0777	96.3682	5.440642
4502511876	71.7445	22.1483	96.1857	5.544909
4573050519	71.5846	22.2915	96.0682	5.668191
4675058253	71.3598	22.5368	95.9784	5.858392
4777065987	71.2295	22.7854	96.0095	6.052253
4879073721	71.093	22.9598	95.9693	6.228804
4981081455	70.8895	23.1176	95.8735	6.402735
5083089188	70.6301	23.3284	95.821	6.593437
5185096922	70.4712	23.605	95.9748	6.8055
5287104656	70.3295	23.8114	96.0753	7.000064
5389112390	70.1354	23.9598	96.0698	7.179589
5491120124	69.8741	24.1463	96.0694	7.372431
5593127857	69.6908	24.4329	96.3046	7.598519
5695135591	69.5393	24.6426	96.4847	7.803506
5797143325	69.3631	24.7871	96.568	7.989855
5899151059	69.0996	24.981	96.647	8.194048
6001158793	68.8685	25.271	96.9116	8.432507
6103166526	68.7352	25.4949	97.2031	8.651824
6205174260	68.5675	25.6224	97.3342	8.840421
6307181994	68.2884	25.8102	97.4461	9.051611
6409189728	68.0219	26.0849	97.7122	9.2959
6511197462	67.8735	26.3554	98.1176	9.541785
6613205195	67.7235	26.4918	98.3346	9.741428
6760721186	67.3137	26.7322	98.5167	10.04909
6908237176	66.9841	27.1585	99.0965	10.43211
7055753166	66.761	27.3488	99.4615	10.72953
7203269156	66.3316	27.6148	99.7213	11.0604
7350785146	66.0027	28.0326	100.3611	11.45767
7498301136	65.7471	28.2152	100.7362	11.76373
7645817126	65.3077	28.4572	100.9966	12.09805
7793333116	65.0064	28.8633	101.7163	12.50744
7940849107	64.7446	29.0189	102.0886	12.81289
8088365097	64.2545	29.2626	102.3295	13.16051
8235881087	63.9785	29.6523	103.1103	13.57899
8383397077	63.7176	29.8226	103.5529	13.9016
8530913067	63.2054	30.0576	103.7813	14.25768
8678429057	62.9265	30.4056	104.5388	14.67215
8825945047	62.6821	30.5113	104.9249	14.97342
8973461037	62.1207	30.8028	105.2146	15.36913
9120977028	61.8436	31.1256	105.9718	15.7855
9268493018	61.5475	31.2021	106.2581	16.08022
9416009008	61.0451	31.4962	106.6621	16.49013
9563524998	60.777	31.8191	107.4693	16.92018
9776851640	60.2132	31.9495	107.753	17.3685
9990178282	59.7011	32.4202	108.787	18.00894
10203504925	59.1665	32.5288	109.089	18.45511
10416831567	58.6302	32.9803	110.0848	19.10246
10630158209	58.0905	33.0564	110.3257	19.53865
10843484852	57.6273	33.4947	111.4431	20.19501
11056811494	57.0133	33.5681	111.5657	20.63744
11270138136	56.5685	33.9331	112.5866	21.26434
11483464778	55.955	33.9598	112.6094	21.68389
11696791421	55.4831	34.4228	113.8232	22.38784
11910118063	54.9213	34.4471	113.9236	22.81224
12123444705	54.4195	34.8134	114.8954	23.46776

12336771348	53.8396	34.8178	114.9136	23.88372
12550097990	53.374	35.1595	115.9057	24.53516
12763424632	52.8074	35.1258	115.848	24.9283
12976751274	52.341	35.4956	116.9189	25.61177
13190077917	51.7609	35.4017	116.6784	25.96394
13403404559	51.2954	35.7557	117.7256	26.64769
13616731201	50.6892	35.734	117.5958	27.05538
13830057844	50.2818	35.9746	118.4781	27.66426
14138554951	49.4432	36.1139	118.7677	28.39086
14447052059	48.7738	36.1431	119.0799	29.03379
14755549167	48.1791	36.3835	120.0748	29.85101
15064046275	47.3709	36.5902	120.571	30.64824
15372543383	46.5882	36.548	120.4331	31.23982
15681040491	46.0385	36.656	121.1473	31.96091
15989537598	45.3207	36.7534	121.4887	32.67628
16298034706	44.6541	36.8591	121.9458	33.40251
16606531814	43.9258	36.8889	122.0487	34.06229
16915028922	43.3149	36.8387	122.1428	34.64784
17223526030	42.8525	36.9443	122.992	35.38088
17532023137	41.9635	37.1736	123.3088	36.23813
17840520245	41.209	36.8589	122.2495	36.56361
18149017353	41.0464	36.7882	123.175	37.12452
18457514461	40.4223	37.207	124.6217	38.18537
18766011569	39.2516	36.9343	122.6957	38.53905
19074508677	39.1487	36.5155	122.6179	38.72842
19383005784	38.7753	37.0164	124.8874	39.89463
19691502892	37.7405	36.9352	123.7803	40.44068
20000000000	37.2387	36.3914	122.3269	40.46951

Table: E.11: low salinity water with DTPA-K5 dielectric measurements:

frequency	e'	e''	sensitivity	conductivity
Hz				S/m
500000000	76.6686	135.3884	481.71	3.764009
511153139	76.9779	132.3712	471.5625	3.762216
522306277	77.128	129.7916	462.2116	3.769389
533459416	76.7387	127.4171	453.292	3.779447
544612555	76.5395	124.7904	444.3277	3.778923
555765694	76.3518	122.4541	435.9626	3.784114
566918832	76.1123	120.1027	427.7832	3.785932
578071971	75.8984	117.6861	419.7314	3.782738
589225110	75.7318	115.3514	411.9832	3.77923
600378249	75.5745	113.3107	404.7787	3.78264
611531387	75.5431	111.3203	397.8409	3.78523
622684526	75.6307	109.3159	391.0632	3.784867
633837665	75.3733	107.4004	384.4921	3.78515
644990804	75.2149	105.5455	378.1566	3.785231
656143942	74.9827	103.8811	372.1801	3.789962
667297081	74.9003	102.3878	366.5753	3.798976
678450220	74.9369	100.6187	360.7855	3.795735
689603359	74.7894	99.0263	355.2909	3.797074
700756497	74.7503	97.5806	350.1164	3.802155
711909636	74.6296	96.1472	345.0408	3.805929
723062775	74.4911	94.7957	340.1732	3.811218
739191614	74.4252	92.5729	333.0019	3.804872
755320453	74.8499	90.6833	326.5525	3.808533
771449291	75.1915	89.1367	320.6961	3.823518
787578130	75.37	88.0378	315.5172	3.855334
803706969	75.3552	86.9245	310.4341	3.884536
819835808	75.187	85.5672	305.163	3.900618
835964647	75.0075	84.0646	299.851	3.907511
852093486	74.8333	82.5978	294.7129	3.913406

868222325	74.6966	81.1492	289.7375	3.917548
884351164	74.5784	79.7803	284.9737	3.923011
900480003	74.5755	78.3782	280.3212	3.924357
916608841	74.5346	77.08	275.8895	3.928483
932737680	74.4846	75.781	271.5545	3.930239
948866519	74.4451	74.5338	267.3852	3.932399
964995358	74.4014	73.2068	263.2089	3.928039
981124197	74.2258	72.0703	259.311	3.931692
997253036	74.2112	71.0711	255.7132	3.94092
1.013E+09	74.1563	69.7925	251.8359	3.932612
1.03E+09	74.1095	68.6216	248.1699	3.928175
1.046E+09	74.2043	67.5887	244.7868	3.929663
1.069E+09	74.5167	66.3101	240.3375	3.941322
1.092E+09	74.6509	65.5046	236.5447	3.978398
1.116E+09	74.376	64.7376	232.7968	4.015773
1.139E+09	74.0356	63.8798	229.0314	4.045408
1.162E+09	73.6855	62.7676	225.0587	4.056378
1.186E+09	73.4799	61.871	221.4957	4.078676
1.209E+09	73.4172	60.9271	218.0205	4.095468
1.232E+09	73.3441	59.9846	214.6337	4.109909
1.256E+09	73.3779	59.0058	211.3287	4.11937
1.279E+09	73.3105	58.0476	208.0924	4.127758
1.302E+09	73.2911	57.0355	204.8848	4.129757
1.326E+09	73.3827	56.0573	201.8337	4.13163
1.349E+09	73.6453	55.1203	198.9657	4.134055
1.372E+09	73.8577	54.4895	196.5198	4.157412
1.396E+09	73.9404	53.9623	194.2215	4.187172
1.419E+09	73.7498	53.4656	191.9157	4.217971
1.442E+09	73.5735	52.8146	189.4841	4.235108
1.465E+09	73.369	52.1804	187.112	4.251926
1.489E+09	73.1831	51.543	184.7956	4.266834
1.512E+09	72.9796	50.9546	182.5784	4.284208
1.546E+09	72.7901	49.9572	179.3144	4.294042
1.58E+09	72.5939	49.1038	176.3137	4.312782
1.613E+09	72.5815	48.32	173.5568	4.334564
1.647E+09	72.7842	47.6286	171.0827	4.361869
1.681E+09	73.0602	47.1181	168.9396	4.403486
1.715E+09	73.0619	46.7268	166.9042	4.454553
1.748E+09	72.919	46.2043	164.7074	4.491397
1.782E+09	72.7808	45.6406	162.5271	4.5222
1.816E+09	72.666	44.9476	160.2547	4.537834
1.849E+09	72.5259	44.3657	158.1638	4.562294
1.883E+09	72.364	43.775	156.1029	4.583649
1.917E+09	72.2472	43.2134	154.1463	4.605891
1.951E+09	72.0833	42.6637	152.2309	4.627316
1.984E+09	71.9146	42.1883	150.449	4.654878
2.018E+09	71.8326	41.7687	148.8166	4.686918
2.052E+09	71.8035	41.4221	147.3397	4.725712
2.086E+09	71.7956	41.1601	146.0197	4.773017
2.119E+09	71.8551	40.7986	144.6438	4.807614
2.153E+09	71.7541	40.4412	143.2316	4.841345
2.187E+09	71.699	40.0462	141.8278	4.869165
2.236E+09	71.6189	39.3743	139.7258	4.89426
2.284E+09	71.6044	38.7576	137.7876	4.922722
2.333E+09	71.5162	38.1747	135.9125	4.952223
2.382E+09	71.4398	37.8005	134.3564	5.006202
2.431E+09	71.2264	37.4821	132.8491	5.065692
2.479E+09	71.046	37.1862	131.4333	5.126558
2.528E+09	71.0625	36.9052	130.1875	5.187912
2.577E+09	71.072	36.5774	128.9236	5.241037
2.626E+09	71.0635	36.2066	127.6363	5.286106
2.675E+09	71.0428	35.8008	126.3354	5.323958
2.723E+09	71.0352	35.4584	125.1594	5.36921

2.772E+09	70.874	35.1694	123.9941	5.420835
2.821E+09	70.7658	34.8507	122.853	5.466234
2.87E+09	70.594	34.6893	121.9043	5.535002
2.918E+09	70.4675	34.5283	121.0102	5.602961
2.967E+09	70.5281	34.3964	120.2941	5.674847
3.016E+09	70.5054	34.2598	119.5502	5.745229
3.065E+09	70.4759	34.0371	118.7158	5.800198
3.113E+09	70.4359	33.8493	117.9443	5.860001
3.162E+09	70.342	33.6166	117.1019	5.910891
3.233E+09	70.1595	33.3577	115.9906	5.996202
3.303E+09	69.8755	33.1819	114.96	6.094747
3.374E+09	69.7382	33.0466	114.1149	6.199509
3.444E+09	69.6561	32.9296	113.3682	6.306716
3.515E+09	69.5896	32.6698	112.4801	6.385095
3.586E+09	69.5408	32.4264	111.6567	6.464706
3.656E+09	69.364	32.2102	110.8089	6.547937
3.727E+09	69.1039	32.0742	110.0358	6.64609
3.797E+09	68.9675	32.0028	109.461	6.756816
3.868E+09	68.9426	31.9597	109.0315	6.873067
3.938E+09	68.8881	31.8382	108.5005	6.971813
4.009E+09	68.8299	31.6396	107.8858	7.05242
4.079E+09	68.7147	31.4627	107.2785	7.136392
4.15E+09	68.4882	31.4013	106.761	7.245626
4.22E+09	68.3059	31.3991	106.3765	7.368271
4.291E+09	68.2697	31.4463	106.1929	7.502685
4.361E+09	68.2305	31.4059	105.9055	7.616225
4.432E+09	68.1887	31.3297	105.5847	7.720626
4.503E+09	68.0395	31.2368	105.1696	7.820249
4.573E+09	67.8098	31.1462	104.704	7.919727
4.675E+09	67.5735	31.2312	104.436	8.118483
4.777E+09	67.5012	31.2897	104.2981	8.311163
4.879E+09	67.3764	31.1397	103.8475	8.447943
4.981E+09	67.0795	31.0535	103.3613	8.600691
5.083E+09	66.7861	31.1337	103.1376	8.799493
5.185E+09	66.6815	31.2838	103.2051	9.019356
5.287E+09	66.6043	31.2093	102.9939	9.174895
5.389E+09	66.3803	31.1029	102.6196	9.320029
5.491E+09	66.0316	31.1648	102.3936	9.515343
5.593E+09	65.8706	31.3598	102.5586	9.752752
5.695E+09	65.8182	31.4075	102.6262	9.945728
5.797E+09	65.6484	31.3071	102.3732	10.09151
5.899E+09	65.3079	31.334	102.1598	10.2779
6.001E+09	65.0661	31.5279	102.3113	10.52033
6.103E+09	64.9885	31.6398	102.5159	10.73713
6.205E+09	64.8606	31.5555	102.3799	10.8875
6.307E+09	64.5192	31.5836	102.2108	11.07634
6.409E+09	64.2113	31.7678	102.3313	11.32112
6.511E+09	64.1238	31.9565	102.7022	11.56962
6.613E+09	64.0307	31.9308	102.7397	11.74143
6.761E+09	63.5592	31.9163	102.4819	11.99789
6.908E+09	63.2563	32.2375	102.9713	12.38305
7.056E+09	63.1201	32.2933	103.2319	12.66937
7.203E+09	62.5932	32.2923	102.9756	12.93385
7.351E+09	62.3273	32.6253	103.5895	13.33483
7.498E+09	62.1826	32.61	103.7723	13.59605
7.646E+09	61.6474	32.6918	103.6783	13.89831
7.793E+09	61.3413	33.0576	104.3584	14.32497
7.941E+09	61.2252	32.9588	104.4701	14.5525
8.088E+09	60.6801	33.0966	104.4875	14.88481
8.236E+09	60.3775	33.4759	105.2472	15.32998
8.383E+09	60.2072	33.3138	105.2072	15.529
8.531E+09	59.6853	33.4849	105.3363	15.88341
8.678E+09	59.4526	33.8809	106.2624	16.34915

8.826E+09	59.2036	33.6672	106.0417	16.52218
8.973E+09	58.6528	33.864	106.2005	16.89653
9.121E+09	58.4999	34.1978	107.1574	17.34358
9.268E+09	58.1658	34.0811	107.0172	17.56394
9.416E+09	57.6038	34.2525	107.1283	17.93322
9.564E+09	57.4866	34.5037	108.0111	18.34775
9.777E+09	56.8379	34.4314	107.7748	18.71772
9.99E+09	56.504	34.861	108.9952	19.36477
1.02E+10	55.9128	34.752	108.7672	19.71643
1.042E+10	55.4835	35.2098	109.9479	20.39381
1.063E+10	54.9547	35.026	109.6508	20.70282
1.084E+10	54.5078	35.5259	110.9282	21.41969
1.106E+10	54.0025	35.2739	110.5102	21.68615
1.127E+10	53.5042	35.7589	111.7071	22.40849
1.148E+10	53.0688	35.5369	111.4493	22.6909
1.17E+10	52.4826	35.976	112.4305	23.398
1.191E+10	52.1073	35.7625	112.2729	23.68335
1.212E+10	51.5275	36.1837	113.2413	24.39148
1.234E+10	51.1353	36.0006	113.1142	24.69508
1.255E+10	50.5578	36.3541	113.9406	25.36879
1.276E+10	50.145	36.135	113.6798	25.64451
1.298E+10	49.6534	36.5157	114.7229	26.34783
1.319E+10	49.1522	36.2364	114.1469	26.57612
1.34E+10	48.7152	36.657	115.3911	27.3194
1.362E+10	48.173	36.3896	114.7478	27.55176
1.383E+10	47.7538	36.7509	115.8863	28.26124
1.414E+10	46.9915	36.6348	115.6413	28.80037
1.445E+10	46.4722	36.6882	116.2445	29.47167
1.476E+10	45.8238	36.8389	116.8672	30.22464
1.506E+10	45.1485	36.911	117.2256	30.91695
1.537E+10	44.3976	36.8734	117.1346	31.51796
1.568E+10	43.778	36.7762	117.1032	32.06571
1.599E+10	43.3362	36.8602	117.8958	32.77123
1.63E+10	42.7035	36.9618	118.37	33.49558
1.661E+10	41.9466	36.8309	117.9278	34.00873
1.692E+10	41.4683	36.7202	118.0628	34.53639
1.722E+10	41.0737	37.0257	119.5758	35.45884
1.753E+10	40.1188	36.9631	118.8775	36.03293
1.784E+10	39.6091	36.6123	118.1828	36.31898
1.815E+10	39.3342	36.5346	118.7697	36.8686
1.846E+10	38.879	36.819	120.0984	37.78717
1.877E+10	37.8893	36.8481	119.5169	38.44911
1.907E+10	37.428	36.1405	117.7005	38.33069
1.938E+10	37.7289	36.4053	120.5802	39.23602
1.969E+10	36.4763	37.2228	121.9242	40.75558
2E+10	35.5423	35.7363	116.4343	39.741

Table: E.12: low salinity water with DTPA-K5 with (1,000 ppm ferric ion concentrations) dielectric measurements:

frequency	e'	e''	sensitivity	conductivity
Hz				S/m
500000000	76.5053	134.0099	479.9423	3.725684
511153138.7	76.834	131.0793	469.915	3.725498

522306277.5	76.7604	128.6847	460.7666	3.737243
533459416.2	76.6214	126.0234	451.5273	3.738107
544612555	76.3698	123.5822	442.794	3.742336
555765693.7	76.1567	121.1378	434.285	3.743437
566918832.4	76.0423	118.8521	426.2067	3.74651
578071971.2	75.7901	116.3842	418.0819	3.740891
589225109.9	75.6192	114.1424	410.4518	3.739619
600378248.7	75.3871	112.1159	403.2573	3.742754
611531387.4	75.2881	110.2879	396.5011	3.750125
622684526.1	75.3472	108.3688	389.8369	3.752075
633837664.9	75.1734	106.2875	383.0688	3.745928
644990803.6	75.0388	104.4761	376.7866	3.746879
656143942.4	74.7202	102.8653	370.8563	3.752902
667297081.1	74.7336	101.2606	365.1396	3.757153
678450219.8	74.6971	99.6218	359.4977	3.758128
689603358.6	74.5731	97.9955	353.9633	3.757549
700756497.3	74.6158	96.5357	348.7883	3.761441
711909636.1	74.5342	95.1043	343.7313	3.764646
723062774.8	74.4022	93.7164	338.8159	3.767825
739191613.7	74.3658	91.597	331.7756	3.764761
755320452.6	74.8478	89.7347	325.375	3.768694
771449291.5	75.071	88.3446	319.6832	3.789541
787578130.4	75.1164	87.0943	314.2864	3.814016
803706969.2	75.1558	86.01	309.2546	3.843668
819835808.1	74.9937	84.5358	303.8415	3.853601
835964647	74.871	83.0556	298.5697	3.860611
852093485.9	74.6914	81.5875	293.4286	3.865539
868222324.8	74.5501	80.1672	288.4833	3.870141
884351163.7	74.466	78.8178	283.7601	3.875683
900480002.6	74.4405	77.4389	279.1261	3.877327
916608841.5	74.4222	76.1229	274.678	3.879703
932737680.4	74.3162	74.87	270.3877	3.882992
948866519.3	74.3305	73.638	266.2513	3.885136
964995358.1	74.282	72.3425	262.1097	3.881664
981124197	74.1873	71.1738	258.1994	3.882785
997253035.9	74.1415	70.1591	254.5716	3.890349
1013381875	74.0983	68.9361	250.7672	3.884356
1029510714	74.1465	67.9015	247.3004	3.886954
1045639553	74.236	67.0628	244.1538	3.899086
1068963879	74.3446	65.9659	239.8622	3.920863
1092288205	74.2033	64.9372	235.7088	3.943937
1115612531	73.9237	63.7937	231.4945	3.957221
1138936857	73.8805	62.8513	227.7189	3.980275
1162261183	73.6564	61.8758	223.9532	3.998745
1185585509	73.4977	61.0134	220.4499	4.022141
1208909835	73.4046	60.0819	216.9779	4.038655
1232234161	73.3782	59.1676	213.644	4.053931
1255558487	73.3948	58.2226	210.3738	4.064693
1278882813	73.3113	57.3133	207.193	4.075542
1302207139	73.225	56.3395	204.0093	4.079362
1325531465	73.2478	55.3933	200.9727	4.08269
1348855791	73.3837	54.3788	197.9635	4.078442
1372180117	73.6259	53.6188	195.3721	4.09098
1395504443	73.753	53.0036	192.979	4.112783
1418828769	73.6777	52.5248	190.7392	4.14375
1442153095	73.5007	51.9655	188.4169	4.167021
1465477421	73.3611	51.3537	186.0974	4.184562
1488801747	73.1826	50.7275	183.7967	4.199325
1512126073	72.9946	50.12	181.5615	4.214036
1545855976	72.7644	49.2196	178.4008	4.230642
1579585880	72.6044	48.3669	175.4163	4.24806
1613315784	72.5302	47.5743	172.6227	4.267671
1647045688	72.7289	46.8316	170.0828	4.288879

1680775591	72.9396	46.2512	167.8278	4.322469
1714505495	73.0042	45.7773	165.7108	4.364035
1748235399	72.8944	45.2776	163.5568	4.401315
1781965303	72.771	44.7326	161.4046	4.432233
1815695207	72.6594	44.09	159.1949	4.451252
1849425110	72.5042	43.5015	157.0878	4.473425
1883155014	72.3611	42.9029	155.0256	4.492332
1916884918	72.3052	42.2473	152.9838	4.502919
1950614822	72.2043	41.7362	151.1435	4.52672
1984344725	72.1239	41.2286	149.3627	4.548989
2018074629	72.061	40.8119	147.7428	4.579554
2051804533	72.0362	40.4917	146.3023	4.619566
2085534437	72.0998	40.1964	144.9738	4.661264
2119264340	72.1294	39.882	143.6418	4.699604
2152994244	72.0518	39.5484	142.2705	4.734465
2186724148	71.9649	39.1495	140.8462	4.760136
2235501824	71.9493	38.5622	138.884	4.793315
2284279499	71.8765	37.9846	136.9663	4.824541
2333057175	71.913	37.4623	135.2322	4.859807
2381834850	71.7735	37.1569	133.7315	4.920965
2430612526	71.5977	36.7894	132.1814	4.972074
2479390202	71.4158	36.5551	130.8439	5.039553
2528167877	71.3876	36.2653	129.5637	5.097959
2576945553	71.3713	35.9742	128.3317	5.154607
2625723228	71.241	35.6087	126.9838	5.198813
2674500904	71.262	35.1957	125.6985	5.233973
2723278580	71.1491	34.855	124.4628	5.277841
2772056255	71.0693	34.4743	123.2291	5.313695
2820833931	70.9072	34.2432	122.167	5.370949
2869611606	70.7568	33.9555	121.069	5.417918
2918389282	70.6638	33.8341	120.245	5.490312
2967166958	70.6573	33.6397	119.4086	5.550004
3015944633	70.6788	33.4632	118.6386	5.611642
3064722309	70.5882	33.2706	117.803	5.66958
3113499985	70.595	32.9775	116.9248	5.709075
3162277660	70.4797	32.8205	116.1652	5.770911
3232816303	70.3106	32.455	114.9233	5.833938
3303354946	70.1412	32.2229	113.8922	5.9186
3373893589	70.0578	32.0813	113.0738	6.01842
3444432232	70.0631	31.9439	112.3573	6.117933
3514970875	70.0171	31.794	111.6266	6.213926
3585509518	69.8962	31.5779	110.7903	6.295544
3656048161	69.7786	31.3135	109.9219	6.365649
3726586804	69.6196	31.1819	109.2247	6.461197
3797125447	69.5144	31.1403	108.7126	6.574715
3867664090	69.4682	31.1453	108.3308	6.697927
3938202733	69.3584	31.086	107.8434	6.807099
4008741376	69.2591	30.8836	107.1934	6.883909
4079280019	69.1452	30.6598	106.5243	6.954277
4149818662	68.9879	30.6054	106.0691	7.061978
4220357304	68.8399	30.6121	105.7222	7.183589
4290895947	68.7798	30.6573	105.5168	7.314439
4361434590	68.7049	30.6371	105.2285	7.429784
4431973233	68.6004	30.4954	104.7673	7.515028
4502511876	68.5168	30.3485	104.3298	7.59786
4573050519	68.3533	30.3284	104.0174	7.711781
4675058253	68.0908	30.3607	103.6509	7.892198
4777065987	67.9868	30.435	103.5068	8.084138
4879073721	67.8994	30.3665	103.2045	8.23818
4981081455	67.6918	30.2766	102.7912	8.385518
5083089188	67.4181	30.272	102.4617	8.555945
5185096922	67.2673	30.4026	102.4573	8.7653
5287104656	67.1565	30.4049	102.3268	8.938418

5389112390	66.9946	30.3392	102.0703	9.091186
5491120124	66.7278	30.3515	101.8474	9.267024
5593127857	66.5599	30.4934	101.9241	9.483306
5695135591	66.4473	30.5451	101.9404	9.672635
5797143325	66.3103	30.4898	101.7881	9.828059
5899151059	66.0277	30.5166	101.6301	10.00979
6001158793	65.8125	30.6797	101.7582	10.2373
6103166526	65.7201	30.7723	101.9189	10.44274
6205174260	65.5757	30.7345	101.8396	10.60423
6307181994	65.2869	30.7611	101.7219	10.78789
6409189728	65.0304	30.9326	101.8736	11.02348
6511197462	64.9392	31.1178	102.2353	11.26598
6613205195	64.836	31.0851	102.2522	11.43045
6760721186	64.4287	31.1236	102.15	11.6999
6908237176	64.1093	31.4383	102.6078	12.07607
7055753166	63.9494	31.4404	102.7573	12.33476
7203269156	63.5432	31.4847	102.7128	12.61039
7350785146	63.2633	31.8373	103.3414	13.01275
7498301136	63.0293	31.8516	103.4757	13.27985
7645817126	62.6236	31.8796	103.441	13.55302
7793333116	62.3713	32.229	104.1559	13.96591
7940849107	62.1684	32.2559	104.39	14.24214
8088365097	61.6659	32.3076	104.3059	14.52997
8235881087	61.4433	32.63	105.0618	14.9426
8383397077	61.3027	32.6777	105.4474	15.23248
8530913067	60.7162	32.7553	105.3229	15.53733
8678429057	60.4808	33.02	106.0017	15.93373
8825945047	60.3878	33.0731	106.4943	16.23063
8973461037	59.7401	33.2013	106.3941	16.56587
9120977028	59.5152	33.4226	107.0429	16.95043
9268493018	59.3916	33.4162	107.41	17.22128
9416009008	58.8067	33.5893	107.4904	17.586
9563524998	58.5631	33.8899	108.2997	18.02136
9776851640	58.1502	33.8194	108.4088	18.38502
9990178282	57.5532	34.2276	109.2164	19.01292
10203504925	57.2125	34.2002	109.5283	19.40337
10416831567	56.6029	34.5369	110.1985	20.00406
10630158209	56.2031	34.5759	110.5709	20.43678
10843484852	55.7517	34.823	111.3112	20.99589
11056811494	55.2184	34.8261	111.4114	21.41085
11270138136	54.8582	35.1264	112.4274	22.01213
11483464778	54.2974	35.0499	112.3077	22.37994
11696791421	53.8476	35.4335	113.3861	23.04517
11910118063	53.3556	35.3755	113.4109	23.42706
12123444705	52.8725	35.6994	114.3192	24.06501
12336771348	52.3986	35.5857	114.2361	24.41047
12550097990	51.9644	35.9437	115.3196	25.0824
12763424632	51.4884	35.7287	114.9812	25.35617
12976751274	51.0128	36.1976	116.2732	26.1183
13190077917	50.6293	35.9166	115.9165	26.34158
13403404559	50.0552	36.3248	116.9029	27.07182
13616731201	49.6212	36.1992	116.8198	27.4076
13830057844	49.1419	36.4076	117.4841	27.99724
14138554951	48.4337	36.4816	117.8403	28.67993
14447052059	47.7916	36.4361	117.9967	29.26916
14755549167	47.2589	36.6556	119.0398	30.07425
15064046275	46.5093	36.7956	119.4637	30.82029
15372543383	45.8339	36.7075	119.3999	31.37615
15681040491	45.2231	36.841	120.0499	32.12221
15989537598	44.7041	36.8116	120.4206	32.72802
16298034706	44.0313	36.9003	120.8064	33.43985
16606531814	43.3547	36.9196	120.9734	34.09063
16915028922	42.8019	36.8054	120.989	34.61652

17223526030	42.4533	36.981	122.2642	35.41603
17532023137	41.46	37.0112	121.7627	36.07982
17840520245	40.8947	36.7512	121.2583	36.45677
18149017353	40.6495	36.725	122.1234	37.06074
18457514461	40.2036	37.058	123.676	38.03245
18766011569	39.0887	36.8604	122.1089	38.46194
19074508677	38.7573	36.3518	121.2318	38.5548
19383005784	38.7278	36.694	123.7346	39.54716
19691502892	37.7815	37.2549	124.926	40.79073
20000000000	36.8051	36.0571	120.25	40.09775

Table: E.13: DI water with (1,000 ppm Mg^{+2}) dielectric measurements:

frequency	e'	e''	sensitivity	Conductivity
Hz	-	-		S/m
500000000	78.0788	30.0359	357.4741	0.835045
511153138.7	78.2161	29.3369	350.2924	0.833805
522306277.5	78.3898	28.8372	343.6005	0.837486
533459416.2	78.3844	28.5649	337.3692	0.847292
544612555	78.2644	28.1391	331.1816	0.852113
555765693.7	78.2553	27.7371	325.2734	0.85714
566918832.4	78.1322	27.3609	319.5782	0.862483
578071971.2	78.1126	26.9181	314.0441	0.865218
589225109.9	78.0396	26.446	308.649	0.866444
600378248.7	78.0181	26.1051	303.5881	0.871464
611531387.4	77.9897	25.8121	298.7526	0.87769
622684526.1	77.99	25.3705	293.9228	0.878408
633837664.9	77.8883	25.0009	289.2942	0.881116
644990803.6	77.8073	24.5985	284.7819	0.882188
656143942.4	77.7233	24.282	280.5009	0.885896
667297081.1	77.689	24.1419	276.5487	0.895756
678450219.8	77.6054	23.7887	272.4825	0.897404
689603358.6	77.5741	23.5245	268.6396	0.902026
700756497.3	77.4403	23.2222	264.847	0.904836
711909636.1	77.3637	22.8722	261.126	0.905382
723062774.8	77.2171	22.5612	257.5277	0.907063
739191613.7	77.11	21.9241	252.3294	0.90111
755320452.6	77.2984	21.3221	247.4453	0.895489
771449291.5	77.5547	20.9774	243.0384	0.899825
787578130.4	77.8279	20.8418	239.0249	0.9127
803706969.2	77.8393	20.8791	235.2766	0.933058
819835808.1	77.7569	20.7177	231.4419	0.944425
835964647	77.6078	20.5567	227.7276	0.955522
852093485.9	77.5257	20.2692	224.035	0.960336
868222324.8	77.4582	20.0287	220.5237	0.966903
884351163.7	77.3919	19.795	217.138	0.973373
900480002.6	77.3179	19.5316	213.8328	0.977937
916608841.5	77.2878	19.3244	210.7081	0.984893
932737680.4	77.2135	19.0752	207.6266	0.989299
948866519.3	77.2144	18.8654	204.7074	0.995337
964995358.1	77.1224	18.5717	201.7633	0.996497
981124197	77.0901	18.3684	199.0185	1.002062
997253035.9	77.0314	18.1608	196.347	1.007023
1013381875	77.0098	17.8569	193.6649	1.006186
1029510714	76.9913	17.5634	191.0686	1.005399
1045639553	77.0449	17.2452	188.5462	1.00265
1068963879	77.3234	16.8727	185.1777	1.002875
1092288205	77.661	16.8667	182.3519	1.024393
1115612531	77.7115	16.9923	179.6904	1.054058
1138936857	77.633	17.035	177.0165	1.0788
1162261183	77.4543	16.9793	174.3178	1.097293
1185585509	77.354	16.9293	171.7574	1.116018

1208909835	77.2378	16.8559	169.2652	1.133039
1232234161	77.1409	16.7644	166.8549	1.148631
1255558487	77.045	16.6512	164.508	1.16247
1278882813	76.9205	16.5272	162.2237	1.175247
1302207139	76.8075	16.3159	159.9345	1.181382
1325531465	76.7727	16.0694	157.7086	1.184374
1348855791	76.8558	15.7812	155.5592	1.183599
1372180117	77.0317	15.7357	153.7677	1.200595
1395504443	77.1103	15.7819	152.0953	1.224587
1418828769	77.1035	15.8443	150.4725	1.249978
1442153095	76.9808	15.7896	148.7379	1.26614
1465477421	76.84	15.7177	147.0321	1.280759
1488801747	76.7178	15.6617	145.4032	1.296507
1512126073	76.6304	15.5815	143.8114	1.310076
1545855976	76.5274	15.3384	141.4727	1.318403
1579585880	76.4476	15.1424	139.2843	1.329956
1613315784	76.4641	14.9545	137.2359	1.341499
1647045688	76.6483	14.7889	135.3672	1.35438
1680775591	76.8808	14.8159	133.8019	1.38464
1714505495	77.0048	14.973	132.4003	1.427404
1748235399	76.9746	15.1263	130.9966	1.470387
1781965303	76.9006	15.2197	129.5765	1.508011
1815695207	76.8147	15.2557	128.1493	1.54019
1849425110	76.7429	15.2706	126.7671	1.570334
1883155014	76.6296	15.3454	125.4814	1.606806
1916884918	76.5637	15.3135	124.158	1.632186
1950614822	76.4282	15.2771	122.8438	1.656958
1984344725	76.2935	15.2597	121.5964	1.683691
2018074629	76.2849	15.2475	120.4618	1.710941
2051804533	76.2153	15.2328	119.3357	1.73786
2085534437	76.1645	15.32	118.3685	1.776541
2119264340	76.1253	15.3462	117.3786	1.808361
2152994244	76.0187	15.3632	116.382	1.839178
2186724148	75.966	15.3531	115.4178	1.866763
2235501824	75.868	15.2632	113.991	1.897229
2284279499	75.895	15.2131	112.7367	1.932262
2333057175	75.8781	15.1265	111.4823	1.962289
2381834850	75.9248	15.1976	110.4894	2.012731
2430612526	75.8457	15.3009	109.5177	2.067911
2479390202	75.7946	15.4066	108.6135	2.123982
2528167877	75.7436	15.5294	107.7771	2.18303
2576945553	75.7162	15.6176	106.9612	2.237787
2625723228	75.7056	15.6967	106.1883	2.291693
2674500904	75.6476	15.7721	105.4253	2.345478
2723278580	75.6266	15.8495	104.7229	2.399975
2772056255	75.5186	15.9217	103.9977	2.454091
2820833931	75.4727	15.9616	103.31	2.503532
2869611606	75.3673	16.0702	102.692	2.564151
2918389282	75.297	16.1564	102.1024	2.621724
2967166958	75.2878	16.2842	101.6273	2.686628
3015944633	75.2699	16.4122	101.1754	2.752259
3064722309	75.2672	16.5213	100.7408	2.815364
3113499985	75.2423	16.6679	100.3583	2.885552
3162277660	75.1822	16.7702	99.9271	2.948746
3232816303	75.0811	16.9703	99.3943	3.050491
3303354946	74.8876	17.1868	98.8591	3.156817
3373893589	74.7088	17.3825	98.3526	3.26094
3444432232	74.568	17.5836	97.918	3.367632
3514970875	74.4698	17.7013	97.4538	3.459601
3585509518	74.4013	17.8158	97.0429	3.551856
3656048161	74.2747	17.9628	96.6592	3.651616
3726586804	74.1049	18.0849	96.2448	3.747369
3797125447	73.9817	18.246	95.939	3.852315

3867664090	73.904	18.4512	95.7479	3.968008
3938202733	73.8345	18.6173	95.5438	4.076749
4008741376	73.7844	18.7559	95.3503	4.180662
4079280019	73.7001	18.8937	95.1503	4.285482
4149818662	73.5289	19.0691	94.9486	4.400059
4220357304	73.3841	19.2679	94.8169	4.521502
4290895947	73.28	19.5127	94.7953	4.655481
4361434590	73.2178	19.7006	94.7608	4.77758
4431973233	73.1966	19.8835	94.7754	4.899922
4502511876	73.0595	20.0626	94.7028	5.022746
4573050519	72.8664	20.2042	94.5525	5.137441
4675058253	72.652	20.5376	94.5795	5.338704
4777065987	72.5091	20.8446	94.67	5.536738
4879073721	72.3597	21.0286	94.6294	5.704885
4981081455	72.1077	21.257	94.5784	5.887417
5083089188	71.838	21.5672	94.6415	6.095659
5185096922	71.6819	21.9059	94.8756	6.315637
5287104656	71.5628	22.1213	95.0092	6.503209
5389112390	71.3563	22.2876	95.0146	6.678512
5491120124	71.0483	22.5665	95.0903	6.890081
5593127857	70.8382	22.9385	95.4099	7.133767
5695135591	70.7403	23.2008	95.7164	7.346935
5797143325	70.5728	23.3806	95.8582	7.536485
5899151059	70.2792	23.5863	95.9218	7.736571
6001158793	70.0033	23.9246	96.203	7.983236
6103166526	69.8507	24.2124	96.5632	8.216601
6205174260	69.7009	24.3667	96.754	8.407171
6307181994	69.4044	24.5857	96.8901	8.62218
6409189728	69.1103	24.9232	97.2133	8.881904
6511197462	68.9506	25.2394	97.672	9.137745
6613205195	68.8097	25.4221	97.9711	9.348083
6760721186	68.372	25.6629	98.1209	9.647125
6908237176	68.0294	26.1345	98.7508	10.03877
7055753166	67.8236	26.4783	99.3762	10.38802
7203269156	67.3282	26.6897	99.4708	10.68987
7350785146	66.9981	27.1589	100.1893	11.10056
7498301136	66.7718	27.4079	100.7098	11.42715
7645817126	66.2798	27.6774	100.9489	11.76653
7793333116	65.9073	28.1598	101.7031	12.20259
7940849107	65.7224	28.2747	102.1129	12.4843
8088365097	65.2226	28.5984	102.474	12.8618
8235881087	64.8493	29.1007	103.32	13.32639
8383397077	64.5986	29.1151	103.5141	13.5718
8530913067	64.1202	29.4627	103.9838	13.9755
8678429057	63.8241	29.9607	104.9836	14.45747
8825945047	63.4818	29.9161	104.9734	14.68133
8973461037	62.9819	30.2737	105.466	15.10514
9120977028	62.7672	30.6966	106.499	15.56793
9268493018	62.3305	30.7947	106.6306	15.87027
9416009008	61.8029	31.0666	106.9565	16.26521
9563524998	61.6126	31.3665	107.8396	16.67951
9776851640	60.897	31.5677	108.0372	17.16094
9990178282	60.5307	32.0745	109.3664	17.81691
10203504925	59.8445	32.1832	109.4437	18.25903
10416831567	59.419	32.7354	110.8196	18.96062
10630158209	58.7805	32.7539	110.7961	19.35985
10843484852	58.2878	33.3613	112.2222	20.11458
11056811494	57.7239	33.2918	112.1342	20.46757
11270138136	57.1324	33.8442	113.3216	21.20863
11483464778	56.6755	33.8321	113.5285	21.60235
11696791421	56.0196	34.2906	114.4326	22.30186
11910118063	55.5826	34.293	114.7036	22.71019
12123444705	54.9461	34.7478	115.6517	23.42354

12336771348	54.4612	34.7088	115.7431	23.80895
12550097990	53.8421	35.1313	116.6622	24.51549
12763424632	53.3427	35.0642	116.6525	24.88458
12976751274	52.832	35.4898	117.7866	25.60759
13190077917	52.2385	35.3441	117.4032	25.9217
13403404559	51.7628	35.8136	118.7221	26.69084
13616731201	51.1235	35.6295	118.1366	26.97626
13830057844	50.6747	36.075	119.4616	27.74147
14138554951	49.856	36.0692	119.4304	28.35572
14447052059	49.235	36.2541	120.2465	29.12296
14755549167	48.489	36.4573	120.8689	29.91156
15064046275	47.7174	36.6348	121.3679	30.6856
15372543383	46.8863	36.7088	121.4584	31.37726
15681040491	46.2253	36.675	121.5724	31.97747
15989537598	45.6932	36.8575	122.5331	32.76883
16298034706	44.9472	36.998	122.9414	33.52839
16606531814	44.16	36.9221	122.6267	34.09294
16915028922	43.6135	36.8878	122.9093	34.69402
17223526030	43.0978	37.2156	124.3164	35.6407
17532023137	42.099	37.1914	123.649	36.25549
17840520245	41.5127	36.9103	123.0536	36.6146
18149017353	41.133	36.9085	123.7338	37.24592
18457514461	40.6746	37.2357	125.2678	38.21483
18766011569	39.5755	37.2577	124.4302	38.8765
19074508677	39.1049	36.7199	123.1709	38.94521
19383005784	39.3007	36.9291	125.8047	39.80054
19691502892	37.9072	37.7765	126.9439	41.36183
20000000000	37.0315	36.412	121.925	40.49242

Table: E.14: DI water with DTPA-K5 with (1,000 ppm Mg^{+2}) dielectric measurements:

frequency	e'	e''	sensitivity	Conductivity
Hz	-	-		S/m
500000000	77.3383	149.9922	500.2866	4.170017
511153138.7	77.7134	146.2832	489.2506	4.157619
522306277.5	78.0138	143.3494	479.4911	4.163133
533459416.2	78.0784	140.5677	470.1342	4.16952
544612555	77.8784	138.0115	461.2587	4.179286
555765693.7	77.596	135.2104	452.281	4.178313
566918832.4	77.2449	132.7773	443.9723	4.185467
578071971.2	76.8628	130.114	435.5773	4.182203
589225109.9	76.6878	127.5063	427.4683	4.177458
600378248.7	76.4928	125.1416	419.8403	4.17759
611531387.4	76.5391	122.9795	412.6978	4.181678
622684526.1	76.579	120.7659	405.6423	4.181302
633837664.9	76.4876	118.4608	398.6056	4.174956
644990803.6	76.2377	116.5172	392.1371	4.178715
656143942.4	75.8905	114.5952	385.8085	4.180851
667297081.1	75.8347	112.8595	379.9088	4.187516
678450219.8	75.7972	111.0058	373.9878	4.187577
689603358.6	75.6493	109.2366	368.2668	4.188579
700756497.3	75.5504	107.6114	362.8509	4.192997
711909636.1	75.4468	106.0686	357.6385	4.198662
723062774.8	75.2396	104.6113	352.6232	4.20585
739191613.7	75.0963	102.2928	345.2992	4.204373
755320452.6	75.2355	100.2619	338.6027	4.210817
771449291.5	75.3521	98.1731	332.0068	4.211134
787578130.4	75.6429	96.3887	326.0028	4.221035
803706969.2	76.4075	94.972	320.7442	4.244167
819835808.1	76.5732	94.0234	316.0757	4.286097
835964647	76.1889	92.64	310.859	4.306115
852093485.9	75.9115	91.0487	305.5406	4.313801

868222324.8	75.6402	89.4954	300.3933	4.320468
884351163.7	75.5296	87.9199	295.3761	4.323257
900480002.6	75.5083	86.424	290.5959	4.327206
916608841.5	75.4662	84.8924	285.8705	4.326652
932737680.4	75.4088	83.5022	281.4181	4.330685
948866519.3	75.358	82.0795	277.0237	4.330509
964995358.1	75.3775	80.598	272.6653	4.324627
981124197	75.164	79.3615	268.6335	4.329453
997253035.9	75.1149	78.1615	264.7755	4.334085
1013381875	74.9689	76.8741	260.854	4.33164
1029510714	74.8601	75.6218	257.0676	4.328895
1045639553	74.855	74.4877	253.5257	4.330776
1068963879	74.9943	72.9027	248.6409	4.333171
1092288205	75.0529	71.6699	244.2988	4.352845
1115612531	74.9546	70.3499	239.9286	4.363912
1138936857	75.1065	69.4062	236.2208	4.395387
1162261183	74.9436	68.5667	232.6501	4.431147
1185585509	74.6216	67.7597	229.1714	4.466872
1208909835	74.4676	66.7921	225.642	4.489709
1232234161	74.3564	65.8066	222.1958	4.508809
1255558487	74.3647	64.7549	218.7906	4.520732
1278882813	74.2642	63.7496	215.4891	4.533226
1302207139	74.1305	62.6952	212.1882	4.539558
1325531465	74.0802	61.6741	209.0334	4.545608
1348855791	74.0812	60.5365	205.8184	4.540273
1372180117	74.1885	59.4703	202.8007	4.537435
1395504443	74.3653	58.408	199.8722	4.532134
1418828769	74.563	57.6299	197.372	4.546498
1442153095	74.6516	57.0757	195.1635	4.576798
1465477421	74.6194	56.5538	193.0053	4.608293
1488801747	74.4225	55.9913	190.7829	4.635073
1512126073	74.1416	55.4383	188.5858	4.661193
1545855976	73.8279	54.4935	185.3439	4.683957
1579585880	73.5176	53.6339	182.2952	4.71066
1613315784	73.3271	52.769	179.3733	4.733664
1647045688	73.3531	51.9263	176.6444	4.755456
1680775591	73.5009	51.0731	174.0313	4.773106
1714505495	73.7015	50.2962	171.6059	4.79483
1748235399	73.8041	49.7351	169.4775	4.834617
1781965303	73.7915	49.1664	167.355	4.871546
1815695207	73.7153	48.5537	165.2068	4.9019
1849425110	73.4951	47.9435	163.0515	4.930213
1883155014	73.3345	47.2559	160.8784	4.948132
1916884918	73.1411	46.5871	158.76	4.965476
1950614822	72.9682	45.9864	156.7813	4.987697
1984344725	72.7718	45.3952	154.8493	5.008714
2018074629	72.6131	44.8546	153.0382	5.033191
2051804533	72.5997	44.4105	151.4558	5.066649
2085534437	72.7112	43.996	150.0119	5.101874
2119264340	72.8328	43.6059	148.64	5.138419
2152994244	72.8745	43.2247	147.2766	5.174567
2186724148	72.8301	42.868	145.9351	5.212264
2235501824	72.7729	42.2086	143.8717	5.246566
2284279499	72.6451	41.5455	141.8286	5.276821
2333057175	72.5363	40.918	139.8965	5.308098
2381834850	72.4097	40.4024	138.1497	5.350791
2430612526	72.2637	40.0033	136.5898	5.406432
2479390202	72.0741	39.7299	135.2113	5.477237
2528167877	72.0839	39.4255	133.9482	5.542201
2576945553	72.0663	39.0859	132.6678	5.600471
2625723228	71.9662	38.6463	131.252	5.642298
2674500904	71.9603	38.1295	129.829	5.670261
2723278580	71.878	37.696	128.5036	5.708033

2772056255	71.7907	37.2359	127.1728	5.739355
2820833931	71.6531	36.8961	125.9986	5.787049
2869611606	71.4895	36.6419	124.9454	5.846558
2918389282	71.3658	36.5004	124.0925	5.922976
2967166958	71.3941	36.3111	123.2971	5.990741
3015944633	71.3926	36.1052	122.4881	6.054695
3064722309	71.3412	35.8157	121.566	6.103286
3113499985	71.3337	35.5087	120.6705	6.147277
3162277660	71.2552	35.2195	119.7748	6.192733
3232816303	71.0706	34.8193	118.4916	6.258932
3303354946	70.8351	34.5591	117.3968	6.347706
3373893589	70.725	34.3954	116.5497	6.452543
3444432232	70.7437	34.1936	115.7781	6.548799
3514970875	70.7125	33.9547	114.9571	6.63622
3585509518	70.6471	33.6373	114.0407	6.706118
3656048161	70.5288	33.3227	113.1189	6.774095
3726586804	70.3141	33.1926	112.4003	6.877834
3797125447	70.1796	33.1548	111.8921	7.00004
3867664090	70.1395	33.115	111.4749	7.12152
3938202733	70.0746	32.9836	110.9407	7.222629
4008741376	69.997	32.746	110.2736	7.299035
4079280019	69.8653	32.4821	109.5512	7.367613
4149818662	69.6399	32.3532	108.9575	7.46527
4220357304	69.4722	32.3481	108.5958	7.590968
4290895947	69.431	32.3631	108.3816	7.721421
4361434590	69.3782	32.268	108.024	7.825292
4431973233	69.3221	32.0767	107.5471	7.904711
4502511876	69.2046	31.8655	107.0055	7.977646
4573050519	68.9906	31.7795	106.5731	8.08076
4675058253	68.7464	31.821	106.2582	8.2718
4777065987	68.6971	31.8477	106.1182	8.459379
4879073721	68.6366	31.6563	105.6851	8.588092
4981081455	68.3996	31.5039	105.1754	8.725436
5083089188	68.099	31.5355	104.8939	8.913056
5185096922	67.9994	31.6426	104.9251	9.122801
5287104656	67.9342	31.5671	104.7457	9.280081
5389112390	67.7513	31.42	104.3694	9.415049
5491120124	67.4369	31.4389	104.1293	9.599032
5593127857	67.297	31.5798	104.2545	9.821171
5695135591	67.2286	31.582	104.2601	10.00099
5797143325	67.0834	31.4445	103.9948	10.1358
5899151059	66.7462	31.4604	103.7831	10.31936
6001158793	66.5453	31.633	103.9617	10.5554
6103166526	66.497	31.7221	104.1829	10.76506
6205174260	66.4093	31.5784	104.0161	10.8954
6307181994	66.0618	31.5565	103.7781	11.06683
6409189728	65.7823	31.7395	103.9427	11.31104
6511197462	65.7375	31.8892	104.3193	11.54526
6613205195	65.675	31.783	104.282	11.68708
6760721186	65.2051	31.7815	104.0682	11.94721
6908237176	64.9118	32.1046	104.5962	12.332
7055753166	64.8437	32.0009	104.7019	12.55465
7203269156	64.3532	32.0344	104.5625	12.83055
7350785146	64.0992	32.387	105.2494	13.23743
7498301136	63.9819	32.2993	105.3725	13.46651
7645817126	63.4753	32.3315	105.2438	13.74513
7793333116	63.2452	32.6892	106.0255	14.16533
7940849107	63.1334	32.6334	106.2521	14.40882
8088365097	62.5486	32.6673	106.0508	14.69174
8235881087	62.3944	32.9919	106.9226	15.10833
8383397077	62.2577	32.919	107.1205	15.34496
8530913067	61.6277	33.0386	107.0288	15.67171
8678429057	61.5007	33.3258	107.9176	16.08129

8825945047	61.3893	33.1792	108.0389	16.2827
8973461037	60.714	33.3862	108.0597	16.65813
9120977028	60.5602	33.6705	108.9502	17.07616
9268493018	60.4145	33.5109	109.0162	17.27008
9416009008	59.8232	33.7261	109.1803	17.65762
9563524998	59.6896	34.0202	110.1578	18.09064
9776851640	59.1736	33.8356	109.9186	18.39383
9990178282	58.7259	34.2945	111.0697	19.05008
10203504925	58.2862	34.1636	111.0528	19.38261
10416831567	57.8495	34.5916	112.1933	20.03574
10630158209	57.3819	34.4542	112.1217	20.36484
10843484852	56.9995	34.8299	113.2672	21.00005
11056811494	56.4226	34.6527	112.9333	21.30424
11270138136	56.1264	35.1029	114.4052	21.9974
11483464778	55.5523	34.8742	113.9497	22.26775
11696791421	55.1472	35.3445	115.3176	22.98729
11910118063	54.6327	35.1099	114.9286	23.25117
12123444705	54.2333	35.5668	116.3019	23.97563
12336771348	53.7371	35.3047	115.8598	24.21772
12550097990	53.3426	35.7961	117.3446	24.9794
12763424632	52.8639	35.4717	116.7654	25.17378
12976751274	52.457	35.9869	118.308	25.96627
13190077917	52.0028	35.5958	117.5854	26.1063
13403404559	51.5415	36.1123	119.0525	26.91345
13616731201	51.1017	35.8327	118.6001	27.13011
13830057844	50.6403	36.2113	119.7409	27.84629
14138554951	49.882	36.1662	119.7264	28.43198
14447052059	49.3849	36.0993	120.1337	28.99861
14755549167	48.8483	36.3345	121.2456	29.81081
15064046275	48.0611	36.5183	121.731	30.58802
15372543383	47.3598	36.3961	121.5498	31.10998
15681040491	46.8556	36.3493	121.9461	31.69349
15989537598	46.3739	36.5408	123.041	32.48726
16298034706	45.7331	36.6041	123.4475	33.17143
16606531814	45.0782	36.5411	123.4478	33.74114
16915028922	44.5802	36.5043	123.8385	34.33333
17223526030	44.1827	36.6573	124.9955	35.10603
17532023137	43.336	36.8096	125.17	35.88329
17840520245	42.531	36.442	123.8474	36.15005
18149017353	42.5957	36.2628	125.0022	36.59431
18457514461	42.1668	36.9086	127.6135	37.87913
18766011569	40.8483	36.762	125.7115	38.35926
19074508677	40.6938	35.9011	124.1863	38.07679
19383005784	40.988	36.6401	128.8462	39.48907
19691502892	39.4036	37.032	127.9528	40.54667
20000000000	38.7797	35.8048	123.9871	39.81717

Table: E.15: DI water with (1,000 ppm Ca^{+2}) dielectric measurements:

frequency	e'	e''	sensitivity	Conductivity
Hz	-	-		S/m
500000000	78.3345	21.9614	348.825	0.610561
511153138.7	78.3915	21.4107	341.8028	0.608529
522306277.5	78.5416	20.9524	335.1783	0.608497
533459416.2	78.7458	20.751	329.0929	0.615516
544612555	78.7315	20.4777	323.1108	0.620109

555765693.7	78.7024	20.3094	317.4662	0.627607
566918832.4	78.6286	20.0209	311.8892	0.631108
578071971.2	78.542	19.741	306.5239	0.634527
589225109.9	78.4913	19.4327	301.3264	0.636669
600378248.7	78.4574	19.2078	296.3959	0.641212
611531387.4	78.4591	18.9283	291.5926	0.64362
622684526.1	78.4173	18.7516	287.0437	0.64924
633837664.9	78.3999	18.5056	282.581	0.652199
644990803.6	78.3453	18.2693	278.2619	0.655201
656143942.4	78.2764	18.0847	274.1288	0.659796
667297081.1	78.2529	17.8717	270.1096	0.663108
678450219.8	78.2213	17.6165	266.1699	0.664564
689603358.6	78.2022	17.4749	262.4688	0.670059
700756497.3	78.1262	17.3337	258.8658	0.675395
711909636.1	78.062	17.1957	255.3799	0.680681
723062774.8	77.9377	17.0203	251.9356	0.684293
739191613.7	77.7477	16.6788	247.0299	0.685521
755320452.6	77.7682	16.2412	242.2844	0.682101
771449291.5	77.828	15.9084	237.8376	0.682391
787578130.4	77.9565	15.5698	233.5786	0.68183
803706969.2	78.3371	15.3872	229.7122	0.687633
819835808.1	78.5586	15.5939	226.3515	0.710855
835964647	78.3758	15.7546	222.9665	0.732309
852093485.9	78.1457	15.6365	219.4066	0.740843
868222324.8	78.0121	15.4564	215.942	0.746171
884351163.7	77.9856	15.2975	212.6519	0.752219
900480002.6	77.9035	15.2265	209.5479	0.762383
916608841.5	77.7778	15.0984	206.4788	0.76951
932737680.4	77.6733	14.9297	203.4752	0.774301
948866519.3	77.6117	14.7337	200.5516	0.777349
964995358.1	77.5366	14.5438	197.724	0.780373
981124197	77.4828	14.3403	194.9772	0.782315
997253035.9	77.4297	14.1912	192.3701	0.786907
1013381875	77.4134	13.9868	189.7945	0.788117
1029510714	77.3514	13.8168	187.3167	0.790929
1045639553	77.3501	13.6492	184.9354	0.793576
1068963879	77.4513	13.276	181.512	0.789095
1092288205	77.6054	13.0928	178.4374	0.795186
1115612531	77.6357	12.9561	175.4966	0.803687
1138936857	77.8771	12.7859	172.7161	0.809711
1162261183	78.0613	12.9053	170.3255	0.83401
1185585509	78.0082	13.0383	167.969	0.859514
1208909835	77.9224	13.0792	165.6068	0.879173
1232234161	77.8462	13.0677	163.2881	0.895347
1255558487	77.7906	13.0581	161.0666	0.911625
1278882813	77.732	13.0168	158.895	0.925623
1302207139	77.6551	12.9844	156.8048	0.940159
1325531465	77.5788	12.91	154.7473	0.951515
1348855791	77.5294	12.7998	152.7328	0.959993
1372180117	77.5325	12.6427	150.7604	0.964606
1395504443	77.6401	12.5041	148.9118	0.970248
1418828769	77.8469	12.4728	147.2745	0.983995
1442153095	78.0199	12.6666	145.918	1.015712
1465477421	78.0213	12.8903	144.5772	1.050368
1488801747	77.8723	13.072	143.1869	1.082127
1512126073	77.6213	13.1605	141.7048	1.106521
1545855976	77.2906	13.1346	139.5005	1.128977
1579585880	77.0146	12.9454	137.239	1.136993
1613315784	76.8522	12.7379	135.0952	1.142658
1647045688	76.8006	12.5328	133.0843	1.147765
1680775591	76.8572	12.3312	131.2017	1.152429
1714505495	77.0237	12.2122	129.5285	1.164212
1748235399	77.2271	12.2528	128.1103	1.191062

1781965303	77.3308	12.4126	126.8373	1.229876
1815695207	77.3524	12.5856	125.6025	1.270621
1849425110	77.2878	12.6866	124.3106	1.304611
1883155014	77.2268	12.7484	123.0356	1.334876
1916884918	77.1508	12.746	121.7393	1.35853
1950614822	77.0537	12.7227	120.4587	1.379907
1984344725	76.9759	12.6916	119.2253	1.400337
2018074629	76.9518	12.6389	118.0418	1.418227
2051804533	76.9594	12.6239	116.9541	1.44022
2085534437	77.0214	12.6665	115.9972	1.468835
2119264340	77.0998	12.7623	115.1424	1.50388
2152994244	77.1447	12.918	114.3739	1.546455
2186724148	77.1354	13.1078	113.6472	1.59376
2235501824	77.0317	13.326	112.5473	1.656433
2284279499	76.8687	13.4171	111.347	1.704147
2333057175	76.7603	13.4086	110.1308	1.739434
2381834850	76.6916	13.4279	109.0215	1.778357
2430612526	76.6354	13.4987	108.0277	1.824344
2479390202	76.5291	13.6254	107.115	1.878423
2528167877	76.4303	13.7378	106.2407	1.931178
2576945553	76.3674	13.8297	105.4076	1.981605
2625723228	76.3254	13.9058	104.6142	2.030225
2674500904	76.3153	13.9639	103.8594	2.07658
2723278580	76.3079	14.0329	103.158	2.124901
2772056255	76.2981	14.1135	102.5037	2.175384
2820833931	76.2618	14.2275	101.9036	2.231543
2869611606	76.1974	14.3484	101.326	2.289421
2918389282	76.1188	14.509	100.8129	2.354398
2967166958	76.0442	14.6832	100.3474	2.422489
3015944633	75.9656	14.8574	99.9082	2.491526
3064722309	75.8879	15.0001	99.459	2.556139
3113499985	75.8258	15.1079	99.0084	2.615484
3162277660	75.7664	15.1816	98.5455	2.669419
3232816303	75.649	15.2765	97.8804	2.746022
3303354946	75.5187	15.3929	97.2746	2.827319
3373893589	75.4164	15.5626	96.7891	2.919528
3444432232	75.3556	15.7829	96.4308	3.02276
3514970875	75.3205	15.9787	96.1028	3.122931
3585509518	75.3093	16.1417	95.7903	3.218098
3656048161	75.252	16.279	95.4481	3.30932
3726586804	75.1243	16.4592	95.1333	3.410508
3797125447	74.9972	16.7132	94.9337	3.528692
3867664090	74.8797	17.0082	94.8178	3.657685
3938202733	74.789	17.2532	94.6917	3.778043
4008741376	74.7003	17.432	94.5151	3.885567
4079280019	74.6047	17.5522	94.2879	3.981202
4149818662	74.4559	17.682	94.0505	4.079995
4220357304	74.286	17.8854	93.9022	4.197078
4290895947	74.1774	18.1401	93.8887	4.327996
4361434590	74.1049	18.3824	93.9119	4.457904
4431973233	74.0377	18.5459	93.8629	4.570295
4502511876	73.9464	18.6767	93.7717	4.675781
4573050519	73.7986	18.8258	93.6687	4.786947
4675058253	73.5355	19.1464	93.6338	4.977065
4777065987	73.378	19.5089	93.7781	5.18195
4879073721	73.2918	19.7249	93.8372	5.351202
4981081455	73.0888	19.8976	93.7608	5.510912
5083089188	72.813	20.1852	93.7846	5.705056
5185096922	72.6492	20.5632	94.0601	5.928526
5287104656	72.5581	20.8257	94.2827	6.122329
5389112390	72.3904	20.9944	94.3318	6.291003
5491120124	72.11	21.2516	94.4037	6.488611
5593127857	71.888	21.6532	94.7469	6.734045

5695135591	71.7958	21.936	95.0879	6.946414
5797143325	71.6497	22.1059	95.2403	7.125599
5899151059	71.3531	22.3192	95.3085	7.320948
6001158793	71.0663	22.7059	95.6419	7.576576
6103166526	70.9417	23.0525	96.1139	7.822983
6205174260	70.8357	23.2088	96.3591	8.007664
6307181994	70.5392	23.3446	96.3759	8.186928
6409189728	70.2208	23.7091	96.7078	8.449234
6511197462	70.0767	24.0761	97.256	8.716581
6613205195	69.9596	24.2747	97.6075	8.926167
6760721186	69.543	24.4679	97.712	9.197904
6908237176	69.1652	25.0101	98.4005	9.606868
7055753166	69.0203	25.3	99.0206	9.925744
7203269156	68.5648	25.4932	99.1352	10.21064
7350785146	68.2133	26.0505	99.9583	10.64753
7498301136	68.0525	26.273	100.5263	10.95397
7645817126	67.5352	26.5023	100.6663	11.26696
7793333116	67.22	27.0522	101.597	11.72263
7940849107	67.0423	27.2188	102.111	12.01808
8088365097	66.487	27.4623	102.2606	12.35085
8235881087	66.1921	27.9963	103.2607	12.82064
8383397077	66.0138	28.0976	103.7128	13.0975
8530913067	65.4016	28.3705	103.8646	13.45742
8678429057	65.1661	28.8744	104.9565	13.93328
8825945047	64.9395	28.8963	105.2377	14.18086
8973461037	64.3189	29.2427	105.5316	14.59072
9120977028	64.1395	29.6859	106.6541	15.05535
9268493018	63.8632	29.637	106.7589	15.27364
9416009008	63.2389	30.0666	107.2235	15.74165
9563524998	63.0781	30.4516	108.3174	16.193
9776851640	62.4484	30.5395	108.4352	16.60199
9990178282	61.9648	31.1851	109.8536	17.32286
10203504925	61.3873	31.2431	110.0083	17.72567
10416831567	60.9206	31.8502	111.4306	18.4479
10630158209	60.3395	31.8234	111.4165	18.80986
10843484852	59.8678	32.4412	112.8984	19.55982
11056811494	59.2348	32.3789	112.7232	19.90633
11270138136	58.7877	32.9983	114.2907	20.67854
11483464778	58.2033	32.875	114.059	20.99123
11696791421	57.7328	33.5247	115.6921	21.80373
11910118063	57.1284	33.3914	115.3909	22.11311
12123444705	56.6601	33.9936	116.96	22.91513
12336771348	56.0922	33.8405	116.6627	23.21333
12550097990	55.6047	34.4444	118.234	24.03615
12763424632	54.9678	34.2609	117.718	24.31449
12976751274	54.5909	34.8101	119.3962	25.11715
13190077917	53.9267	34.5783	118.6879	25.36005
13403404559	53.5369	35.168	120.4668	26.20969
13616731201	52.8704	34.9157	119.6728	26.43582
13830057844	52.4655	35.4625	121.3424	27.27046
14138554951	51.5644	35.5325	121.3571	27.9338
14447052059	50.926	35.5376	121.7025	28.5474
14755549167	50.3123	35.8723	122.9453	29.43159
15064046275	49.5011	36.2009	123.7791	30.32216
15372543383	48.6118	36.1589	123.4488	30.90723
15681040491	47.9485	36.1738	123.7148	31.54047
15989537598	47.5019	36.3854	124.9699	32.3491
16298034706	46.773	36.6494	125.7793	33.21248
16606531814	45.9018	36.6191	125.4316	33.81316
16915028922	45.3832	36.5065	125.5845	34.3354
17223526030	45.0165	36.8422	127.383	35.2831
17532023137	43.8193	37.0916	127.0865	36.1582
17840520245	43.0266	36.56	125.3035	36.2671

18149017353	43.0797	36.5412	126.961	36.87526
18457514461	42.5294	37.2875	129.6481	38.26799
18766011569	41.1764	37.1051	127.554	38.71727
19074508677	40.8987	36.2478	125.7643	38.4445
19383005784	41.2082	36.9174	130.2863	39.78793
19691502892	39.5266	37.7563	130.6605	41.33971
20000000000	38.6903	36.1672	124.9672	40.22018

Table: E.16: DI water with DTPA-K5 with (1,000 ppm Ca^{+2}) dielectric measurements:

frequency	e'	e''	sensitivity	Conductivity
Hz	-	-		S/m
500000000	74.7273	164.3601	518.3278	4.569467
511153138.7	74.8803	160.5464	507.103	4.563003
522306277.5	75.2514	157.1767	496.7627	4.564704
533459416.2	75.0865	154.4103	487.3705	4.58012
544612555	74.985	151.206	477.6784	4.578844
555765693.7	74.6315	148.4783	468.7629	4.588322
566918832.4	74.3322	145.5329	459.7886	4.587554
578071971.2	73.888	142.6539	451.0805	4.585268
589225109.9	73.5734	139.8107	442.6166	4.580584
600378248.7	73.4337	137.2583	434.7576	4.582081
611531387.4	73.4578	134.8843	427.3153	4.586478
622684526.1	73.4215	132.3953	419.8773	4.583949
633837664.9	73.2513	129.9804	412.6716	4.580945
644990803.6	72.9774	127.7161	405.7595	4.580346
656143942.4	72.6906	125.7293	399.3621	4.587064
667297081.1	72.6592	123.7274	393.1091	4.590757
678450219.8	72.7714	121.64	386.8981	4.588741
689603358.6	72.7697	119.6941	380.9707	4.589562
700756497.3	72.6315	117.8893	375.3019	4.593468
711909636.1	72.6113	116.3265	370.0779	4.604714
723062774.8	72.3596	114.5326	364.6095	4.604731
739191613.7	72.1886	112.0818	357.0947	4.606714
755320452.6	72.4445	109.6765	349.9228	4.606213
771449291.5	72.7273	107.478	343.2044	4.610267
787578130.4	73.006	105.459	336.8857	4.61824
803706969.2	73.8415	103.9535	331.5116	4.645538
819835808.1	73.8716	102.8072	326.5635	4.68651
835964647	73.5322	101.1743	321.0315	4.702808
852093485.9	73.2474	99.4217	315.4958	4.710506
868222324.8	72.9564	97.6749	310.0867	4.715341
884351163.7	72.8748	95.9557	304.8813	4.718399
900480002.6	72.8236	94.33	299.9114	4.723056
916608841.5	72.8033	92.6597	295.0003	4.722523
932737680.4	72.6847	91.1962	290.4255	4.72972
948866519.3	72.657	89.6058	285.8075	4.727597
964995358.1	72.6287	88.0699	281.3459	4.725545
981124197	72.4051	86.6751	277.0957	4.728436
997253035.9	72.3485	85.4793	273.2312	4.73986
1013381875	72.2777	83.9523	269.0144	4.730477
1029510714	72.0882	82.6499	265.1227	4.731212
1045639553	72.0704	81.4329	261.4603	4.734576
1068963879	72.2441	79.7582	256.4467	4.740646
1092288205	72.285	78.378	251.9044	4.760259
1115612531	72.1698	76.9462	247.3726	4.773091
1138936857	72.3653	75.8061	243.4215	4.800682
1162261183	72.2424	74.8322	239.6901	4.836057
1185585509	71.9591	73.8668	236.019	4.869466
1208909835	71.8349	72.7573	232.3109	4.890684
1232234161	71.7438	71.6238	228.6733	4.907381

1255558487	71.773	70.4607	225.1204	4.919071
1278882813	71.6656	69.347	221.6678	4.931256
1302207139	71.546	68.1931	218.235	4.937643
1325531465	71.4799	67.0947	214.9593	4.945127
1348855791	71.4941	65.8885	211.6463	4.941676
1372180117	71.6058	64.7463	208.5135	4.939981
1395504443	71.7821	63.6685	205.5479	4.940319
1418828769	71.9582	62.8196	202.9352	4.95592
1442153095	72.0037	62.1955	200.6161	4.987346
1465477421	71.9374	61.6261	198.3803	5.02161
1488801747	71.7347	60.9703	196.0328	5.047245
1512126073	71.4522	60.3605	193.7594	5.075046
1545855976	71.142	59.2905	190.3505	5.09628
1579585880	70.871	58.3088	187.153	5.121256
1613315784	70.7019	57.3339	184.0869	5.14316
1647045688	70.7556	56.4002	181.24	5.16518
1680775591	70.9393	55.4633	178.5171	5.183399
1714505495	71.1035	54.6494	176.0136	5.209829
1748235399	71.182	53.9961	173.7484	5.248817
1781965303	71.1434	53.3919	171.5601	5.290221
1815695207	71.0216	52.6971	169.2781	5.320211
1849425110	70.8318	52.005	167.0243	5.347872
1883155014	70.6224	51.2746	164.7608	5.368927
1916884918	70.4596	50.5557	162.5816	5.388468
1950614822	70.284	49.8837	160.5001	5.4104
1984344725	70.0757	49.2411	158.4871	5.433054
2018074629	69.989	48.6239	156.5997	5.456148
2051804533	69.9619	48.0907	154.8887	5.486511
2085534437	70.0982	47.6197	153.3714	5.522086
2119264340	70.223	47.1844	151.934	5.560102
2152994244	70.2308	46.7591	150.4881	5.597681
2186724148	70.1587	46.3603	149.0711	5.636888
2235501824	70.0798	45.6827	146.9574	5.6784
2284279499	69.9381	44.9466	144.7974	5.708806
2333057175	69.8558	44.2641	142.7916	5.742172
2381834850	69.7304	43.7131	140.9879	5.789251
2430612526	69.5528	43.2094	139.2646	5.839735
2479390202	69.4023	42.8778	137.8252	5.911212
2528167877	69.3951	42.5207	136.4731	5.977306
2576945553	69.3872	42.1104	135.0952	6.03384
2625723228	69.2724	41.6571	133.6402	6.08187
2674500904	69.2423	41.0888	132.1189	6.11034
2723278580	69.1505	40.6185	130.7254	6.150566
2772056255	69.0332	40.1564	129.3606	6.189506
2820833931	68.9013	39.7752	128.1232	6.238627
2869611606	68.7372	39.4555	126.9773	6.295494
2918389282	68.6365	39.2608	126.0587	6.370911
2967166958	68.6503	39.0252	125.1823	6.438523
3015944633	68.6507	38.7625	124.2886	6.500314
3064722309	68.5681	38.4771	123.3384	6.55681
3113499985	68.5476	38.1202	122.3543	6.599381
3162277660	68.4609	37.8449	121.4592	6.654364
3232816303	68.2642	37.4006	120.0927	6.722933
3303354946	68.027	37.0777	118.9008	6.810315
3373893589	67.9611	36.8421	117.9732	6.911541
3444432232	67.9466	36.6323	117.1515	7.015861
3514970875	67.8956	36.3456	116.236	7.103506
3585509518	67.8117	36.0125	115.265	7.179651
3656048161	67.678	35.6814	114.293	7.253589
3726586804	67.4569	35.4952	113.4833	7.354955
3797125447	67.3292	35.3923	112.8775	7.472448
3867664090	67.2928	35.3258	112.413	7.596961
3938202733	67.1977	35.1739	111.8134	7.702253

4008741376	67.0781	34.8937	111.0389	7.777754
4079280019	66.9534	34.6279	110.2992	7.854324
4149818662	66.7558	34.4843	109.6936	7.957006
4220357304	66.5687	34.4107	109.2128	8.074988
4290895947	66.5356	34.3936	108.9461	8.205873
4361434590	66.4566	34.2985	108.5524	8.317708
4431973233	66.3667	34.0953	108.0123	8.402157
4502511876	66.2621	33.8669	107.4387	8.478704
4573050519	66.0557	33.7751	106.992	8.588193
4675058253	65.8112	33.738	106.5494	8.77012
4777065987	65.7114	33.7478	106.321	8.964083
4879073721	65.6147	33.5743	105.856	9.10843
4981081455	65.3875	33.3723	105.2613	9.242915
5083089188	65.1136	33.3411	104.897	9.423382
5185096922	64.985	33.4287	104.8555	9.637747
5287104656	64.8936	33.3172	104.5725	9.794574
5389112390	64.6983	33.1817	104.1786	9.942945
5491120124	64.3969	33.1496	103.8587	10.12135
5593127857	64.2334	33.2693	103.9125	10.3466
5695135591	64.1385	33.2579	103.8482	10.53169
5797143325	63.9754	33.1234	103.5443	10.67697
5899151059	63.6671	33.0865	103.2644	10.85274
6001158793	63.4439	33.2257	103.3537	11.08686
6103166526	63.3318	33.3192	103.4951	11.30704
6205174260	63.2157	33.197	103.3043	11.45386
6307181994	62.9181	33.1223	103.0171	11.61596
6409189728	62.6325	33.242	103.0618	11.84648
6511197462	62.5354	33.4042	103.3795	12.09375
6613205195	62.4299	33.3458	103.3426	12.26175
6760721186	62.0083	33.2575	103.0163	12.50207
6908237176	61.6801	33.5272	103.3964	12.87845
7055753166	61.5641	33.4834	103.502	13.13627
7203269156	61.1252	33.4223	103.2413	13.38644
7350785146	60.8157	33.7356	103.7728	13.78864
7498301136	60.672	33.6812	103.8774	14.04267
7645817126	60.2031	33.6495	103.6614	14.30546
7793333116	59.9174	33.9698	104.2846	14.72026
7940849107	59.7711	33.9201	104.4327	14.97694
8088365097	59.2491	33.9085	104.2105	15.24995
8235881087	58.9976	34.2143	104.8955	15.66812
8383397077	58.854	34.1522	105.0551	15.91981
8530913067	58.2781	34.1862	104.8643	16.21607
8678429057	58.0572	34.4806	105.6094	16.63854
8825945047	57.9267	34.3717	105.7214	16.86791
8973461037	57.324	34.4687	105.6254	17.19824
9120977028	57.1582	34.7282	106.4112	17.61257
9268493018	56.9662	34.5837	106.3918	17.82296
9416009008	56.385	34.7429	106.4529	18.18997
9563524998	56.1956	35.023	107.2824	18.62389
9776851640	55.696	34.878	107.0941	18.9605
9990178282	55.1971	35.2301	107.9152	19.56979
10203504925	54.7804	35.1317	107.9396	19.93185
10416831567	54.272	35.4342	108.6704	20.52378
10630158209	53.8372	35.3274	108.6543	20.88096
10843484852	53.3845	35.6286	109.4841	21.48161
11056811494	52.87	35.5024	109.3075	21.82663
11270138136	52.501	35.832	110.343	22.4543
11483464778	51.9789	35.6553	110.0351	22.7665
11696791421	51.5403	36.04	111.1078	23.43963
11910118063	51.0506	35.8152	110.7276	23.71825
12123444705	50.599	36.1729	111.7367	24.3842
12336771348	50.1376	35.9505	111.3884	24.66071
12550097990	49.6878	36.3012	112.3981	25.33187

12763424632	49.2257	36.0627	111.9929	25.5932
12976751274	48.8122	36.4423	113.1446	26.29486
13190077917	48.3311	36.1536	112.5645	26.51539
13403404559	47.8761	36.4794	113.5253	27.18704
13616731201	47.426	36.2883	113.2155	27.47506
13830057844	46.9977	36.528	114.0137	28.08983
14138554951	46.2827	36.5069	114.0718	28.69982
14447052059	45.7287	36.4761	114.3709	29.30129
14755549167	45.1526	36.5883	114.9948	30.01904
15064046275	44.5031	36.7064	115.5003	30.74557
15372543383	43.75	36.5673	115.1118	31.25632
15681040491	43.1642	36.5168	115.2474	31.83954
15989537598	42.8076	36.5796	116.1112	32.52176
16298034706	42.117	36.6782	116.4443	33.23858
16606531814	41.4401	36.5552	116.1618	33.75416
16915028922	40.9831	36.4246	116.258	34.25837
17223526030	40.6358	36.6013	117.4539	35.0524
17532023137	39.6742	36.6605	117.0906	35.73795
17840520245	39.0715	36.2455	116.0022	35.95512
18149017353	39.0344	36.1497	116.985	36.48018
18457514461	38.537	36.5681	118.6091	37.52967
18766011569	37.4732	36.4074	117.2766	37.98926
19074508677	37.287	35.7172	116.0794	37.88174
19383005784	37.392	36.0914	118.8438	38.89771
19691502892	36.0587	36.4763	118.5891	39.93823
20000000000	35.3801	35.4538	115.1755	39.42684

Table: E.17: DI water with (1,000 ppm Na$^+$) dielectric measurements:

frequency	e'	e''	sensitivity	Conductivity
Hz	-	-		S/m
500000000	79.4768	18.0801	345.0046	0.502655
511153138.7	79.6008	17.6227	338.1157	0.500867
522306277.5	79.8046	17.3369	331.6962	0.503496
533459416.2	79.8432	17.2689	325.7173	0.51223
544612555	79.7414	17.1429	319.8779	0.519124
555765693.7	79.761	16.9485	314.2234	0.523748
566918832.4	79.6629	16.7854	308.7831	0.529117
578071971.2	79.6917	16.5256	303.4665	0.531176
589225109.9	79.6375	16.3138	298.3806	0.534485
600378248.7	79.6485	16.0852	293.4665	0.536971
611531387.4	79.6333	15.9104	288.7715	0.541002
622684526.1	79.6318	15.6605	284.1595	0.542217
633837664.9	79.5821	15.616	279.9039	0.55036
644990803.6	79.5073	15.4097	275.6115	0.552646
656143942.4	79.4432	15.2889	271.5583	0.557795
667297081.1	79.4508	15.2528	267.7339	0.565937
678450219.8	79.3472	15.0139	263.7943	0.566384
689603358.6	79.3251	14.912	260.1375	0.571787
700756497.3	79.1599	14.7698	256.5097	0.575494
711909636.1	79.0266	14.5937	252.967	0.577683
723062774.8	78.8652	14.362	249.4546	0.577418
739191613.7	78.7476	13.9039	244.4632	0.571469
755320452.6	78.9372	13.4179	239.7202	0.563527
771449291.5	79.194	13.2386	235.4996	0.56787
787578130.4	79.4732	13.229	231.6244	0.579322
803706969.2	79.4739	13.3716	227.9829	0.597558
819835808.1	79.3926	13.345	224.2988	0.608338
835964647	79.2673	13.301	220.7185	0.61826
852093485.9	79.2126	13.15	217.1843	0.623035
868222324.8	79.1748	13.0432	213.8274	0.629672
884351163.7	79.1276	12.9457	210.5966	0.636575

900480002.6	79.0481	12.8136	207.4372	0.641571
916608841.5	79.0241	12.7236	204.4387	0.648475
932737680.4	78.9654	12.5648	201.4655	0.65165
948866519.3	78.9776	12.4686	198.6743	0.657843
964995358.1	78.8945	12.2949	195.863	0.659704
981124197	78.8804	12.1858	193.2313	0.664779
997253035.9	78.8274	12.0675	190.6592	0.669147
1013381875	78.8095	11.8503	188.0758	0.667731
1029510714	78.8011	11.6865	185.6276	0.668982
1045639553	78.8661	11.46	183.2118	0.666294
1068963879	79.1478	11.1828	179.9592	0.66468
1092288205	79.5203	11.247	177.2211	0.683082
1115612531	79.6196	11.4646	174.6735	0.711167
1138936857	79.5877	11.6634	172.1795	0.738625
1162261183	79.4504	11.7423	169.6366	0.75885
1185585509	79.3724	11.8155	167.2157	0.778904
1208909835	79.2655	11.8881	164.8816	0.799108
1232234161	79.1805	11.9342	162.6216	0.817684
1255558487	79.0638	11.9667	160.4267	0.835431
1278882813	78.9087	11.9809	158.28	0.85196
1302207139	78.7459	11.9079	156.1188	0.862213
1325531465	78.6411	11.7632	153.9819	0.866991
1348855791	78.6327	11.5346	151.867	0.865102
1372180117	78.7505	11.5017	150.0716	0.877551
1395504443	78.8177	11.5612	148.4138	0.897084
1418828769	78.8445	11.644	146.8271	0.91861
1442153095	78.7748	11.6036	145.1333	0.930472
1465477421	78.6751	11.5592	143.4777	0.941903
1488801747	78.5968	11.565	141.935	0.957374
1512126073	78.5411	11.5278	140.4083	0.969245
1545855976	78.4697	11.4013	138.2116	0.979992
1579585880	78.4137	11.2907	136.1348	0.991661
1613315784	78.4457	11.2005	134.2033	1.004745
1647045688	78.6358	11.1104	132.4284	1.0175
1680775591	78.88	11.2176	130.9586	1.048356
1714505495	79.0246	11.4615	129.6637	1.092646
1748235399	79.0118	11.7231	128.3842	1.139571
1781965303	78.94	11.9112	127.0675	1.180195
1815695207	78.8781	12.0308	125.7463	1.214609
1849425110	78.7907	12.1277	124.4484	1.247138
1883155014	78.6746	12.2704	123.2394	1.284825
1916884918	78.5955	12.3484	122.0308	1.316152
1950614822	78.4197	12.3461	120.741	1.339061
1984344725	78.2705	12.3707	119.536	1.364931
2018074629	78.2638	12.3755	118.4276	1.38867
2051804533	78.1975	12.3912	117.343	1.413672
2085534437	78.154	12.5088	116.4163	1.450548
2119264340	78.1226	12.5652	115.4702	1.480654
2152994244	78.0294	12.6274	114.5344	1.511666
2186724148	78.0201	12.6831	113.6716	1.542121
2235501824	77.9239	12.6828	112.3513	1.576483
2284279499	77.9837	12.6951	111.1958	1.612444
2333057175	77.963	12.7288	110.0798	1.651247
2381834850	78.03	12.8456	109.1593	1.701238
2430612526	77.9495	13.0041	108.2553	1.757499
2479390202	77.903	13.194	107.4535	1.818949
2528167877	77.8327	13.383	106.6871	1.881302
2576945553	77.7763	13.5412	105.9388	1.940267
2625723228	77.7476	13.6999	105.2535	2.000164
2674500904	77.6523	13.8359	104.5407	2.057545
2723278580	77.631	13.9096	103.8453	2.10623
2772056255	77.5006	14.0614	103.2029	2.167354
2820833931	77.4561	14.0869	102.5111	2.20949

2869611606	77.3543	14.218	101.9287	2.268615
2918389282	77.2871	14.3191	101.3661	2.323583
2967166958	77.2821	14.4842	100.9455	2.389657
3015944633	77.2655	14.6528	100.5479	2.457215
3064722309	77.2786	14.822	100.2005	2.525789
3113499985	77.2582	15.0222	99.8901	2.600648
3162277660	77.2107	15.1305	99.4849	2.660434
3232816303	77.1121	15.3934	99.0363	2.767036
3303354946	76.9018	15.6612	98.5592	2.8766
3373893589	76.7131	15.8979	98.1025	2.98243
3444432232	76.5628	16.1459	97.7257	3.092282
3514970875	76.4611	16.3037	97.319	3.18645
3585509518	76.422	16.4601	96.9931	3.281576
3656048161	76.3056	16.6476	96.6779	3.384252
3726586804	76.137	16.8085	96.3211	3.482887
3797125447	76.0011	17.0193	96.0766	3.593319
3867664090	75.9095	17.2717	95.9433	3.714351
3938202733	75.831	17.5051	95.8267	3.833203
4008741376	75.78	17.6895	95.7005	3.942964
4079280019	75.693	17.8617	95.5542	4.051403
4149818662	75.5086	18.0466	95.3639	4.164124
4220357304	75.3511	18.2667	95.2605	4.286556
4290895947	75.2348	18.5421	95.2785	4.423908
4361434590	75.1689	18.7717	95.3046	4.552313
4431973233	75.1642	19.0126	95.4202	4.685304
4502511876	75.0192	19.2122	95.3793	4.809846
4573050519	74.8015	19.3303	95.1892	4.915229
4675058253	74.5778	19.7268	95.3041	5.127939
4777065987	74.4249	20.0764	95.4576	5.332689
4879073721	74.2733	20.2902	95.474	5.504563
4981081455	74.0058	20.5219	95.4291	5.683821
5083089188	73.7175	20.8789	95.5508	5.901121
5185096922	73.5572	21.2634	95.8591	6.130399
5287104656	73.4585	21.5215	96.0897	6.32688
5389112390	73.2441	21.6857	96.1044	6.498152
5491120124	72.9043	21.9867	96.1929	6.713054
5593127857	72.68	22.4084	96.5809	6.968908
5695135591	72.6048	22.7341	97.0198	7.199146
5797143325	72.4395	22.8986	97.1645	7.381118
5899151059	72.1097	23.1114	97.2144	7.580798
6001158793	71.8025	23.4988	97.5466	7.841154
6103166526	71.6659	23.8266	98.001	8.085678
6205174260	71.5146	23.9866	98.22	8.276026
6307181994	71.1952	24.2039	98.3445	8.488283
6409189728	70.8688	24.5853	98.7107	8.761487
6511197462	70.7098	24.944	99.2523	9.030798
6613205195	70.5821	25.1366	99.6032	9.243101
6760721186	70.1021	25.347	99.6813	9.528373
6908237176	69.7605	25.8946	100.4528	9.946622
7055753166	69.5842	26.2472	101.1594	10.29735
7203269156	69.0075	26.4536	101.1687	10.59531
7350785146	68.6908	26.9788	102.017	11.02695
7498301136	68.4969	27.2154	102.5908	11.34689
7645817126	67.9256	27.5203	102.8064	11.69974
7793333116	67.5418	28.0717	103.6834	12.16441
7940849107	67.3966	28.1128	104.0564	12.41281
8088365097	66.837	28.4968	104.459	12.8161
8235881087	66.4731	29.0723	105.468	13.31339
8383397077	66.2015	28.9916	105.5002	13.51423
8530913067	65.6758	29.4068	106.0423	13.94898
8678429057	65.4181	29.9698	107.2396	14.46186
8825945047	65.0406	29.8615	107.0929	14.65453
8973461037	64.4876	30.2493	107.583	15.09296

9120977028	64.3412	30.7102	108.8161	15.57482
9268493018	63.882	30.771	108.8679	15.85805
9416009008	63.2563	31.0837	109.1412	16.27417
9563524998	63.1595	31.3716	110.1755	16.68222
9776851640	62.3383	31.5678	110.229	17.161
9990178282	62.0547	32.1465	111.8688	17.8569
10203504925	61.2756	32.1877	111.6933	18.26159
10416831567	60.846	32.8645	113.3527	19.03539
10630158209	60.1806	32.7857	113.1154	19.37864
10843484852	59.7288	33.5281	114.926	20.21515
11056811494	59.1132	33.3302	114.5138	20.49118
11270138136	58.5112	34.0262	116.0207	21.32268
11483464778	58.0516	33.8838	115.9769	21.63536
11696791421	57.3501	34.4778	117.1255	22.42361
11910118063	56.9165	34.3857	117.2271	22.77158
12123444705	56.2608	34.9198	118.3471	23.53948
12336771348	55.7941	34.7928	118.2997	23.86657
12550097990	55.1314	35.3324	119.44	24.65582
12763424632	54.6206	35.1444	119.1521	24.9415
12976751274	54.1119	35.674	120.5693	25.7405
13190077917	53.4925	35.4224	119.9037	25.97912
13403404559	53.015	36.0012	121.5184	26.83065
13616731201	52.3889	35.6857	120.6496	27.01881
13830057844	51.8932	36.2816	122.2938	27.90035
14138554951	51.024	36.2058	122.0175	28.46311
14447052059	50.4365	36.392	122.9442	29.23374
14755549167	49.6849	36.614	123.639	30.04012
15064046275	48.8929	36.7811	124.1006	30.80814
15372543383	48.0119	36.8626	124.1362	31.50873
15681040491	47.3164	36.8152	124.1746	32.09972
15989537598	46.8326	36.9864	125.2452	32.88343
16298034706	46.084	37.1633	125.7787	33.67818
16606531814	45.2062	37.0268	125.1196	34.18962
16915028922	44.6856	36.9596	125.3936	34.76155
17223526030	44.2681	37.4282	127.477	35.84431
17532023137	43.0594	37.3291	126.1315	36.38972
17840520245	42.5854	37.0125	125.7009	36.71598
18149017353	42.2094	37.0794	126.6452	37.41838
18457514461	41.8032	37.4042	128.339	38.38776
18766011569	40.6131	37.4646	127.4122	39.09239
19074508677	40.0344	36.7304	125.3038	38.95634
19383005784	40.5945	36.8658	128.6368	39.73232
19691502892	39.0902	38.2401	131.25	41.86943
20000000000	37.7606	36.3499	123.3893	40.42336

Table: E.18: DI water with DTPA-K5 with (1,000 ppm Na$^+$) dielectric measurements:

frequency	e'	e''	sensitivity	Conductivity
Hz	-	-		S/m
500000000	79.1258	127.0313	471.6885	3.531668
511153138.7	79.4209	123.9099	461.4234	3.521731
522306277.5	79.7291	121.4245	452.2442	3.526393
533459416.2	79.7566	119.183	443.5866	3.535207
544612555	79.6352	117.0448	435.262	3.544369
555765693.7	79.3614	114.7655	426.9576	3.546519
566918832.4	79.1158	112.7109	419.1681	3.552924
578071971.2	78.7138	110.4495	411.2837	3.550135
589225109.9	78.5744	108.318	403.8092	3.548796
600378248.7	78.3691	106.4012	396.7657	3.551981
611531387.4	78.4301	104.4806	389.9467	3.552659
622684526.1	78.4628	102.7218	383.4858	3.556558

633837664.9	78.3898	100.7299	376.8696	3.550059
644990803.6	78.1857	99.0414	370.7431	3.551971
656143942.4	77.8664	97.5697	364.9937	3.559699
667297081.1	77.8456	96.0674	359.4051	3.564466
678450219.8	77.781	94.486	353.8409	3.564385
689603358.6	77.6464	93.0016	348.4939	3.566062
700756497.3	77.5721	91.7125	343.516	3.573509
711909636.1	77.4647	90.4287	338.6426	3.579566
723062774.8	77.3209	89.1636	333.8937	3.584782
739191613.7	77.1284	87.2018	327.029	3.584113
755320452.6	77.3074	85.4445	320.7041	3.588513
771449291.5	77.3132	83.6937	314.5244	3.59004
787578130.4	77.6465	82.1426	308.8396	3.597172
803706969.2	78.3025	80.9575	303.855	3.617879
819835808.1	78.5293	80.1777	299.4079	3.654935
835964647	78.173	79.1149	294.5953	3.677438
852093485.9	77.9176	77.7756	289.6081	3.684935
868222324.8	77.6667	76.5163	284.8474	3.693891
884351163.7	77.5507	75.1961	280.1616	3.697594
900480002.6	77.5292	73.9332	275.6858	3.701798
916608841.5	77.4477	72.6631	271.2931	3.70337
932737680.4	77.3548	71.4947	267.1243	3.707939
948866519.3	77.3225	70.3261	263.0645	3.710401
964995358.1	77.2736	69.0897	259.0094	3.707129
981124197	77.1377	68.0567	255.2628	3.712736
997253035.9	77.0151	67.0798	251.6699	3.7196
1013381875	76.9161	65.9474	247.9754	3.715951
1029510714	76.7692	64.9328	244.4818	3.717014
1045639553	76.77	63.9785	241.1793	3.719763
1068963879	76.8987	62.6816	236.6642	3.725652
1092288205	76.9409	61.6124	232.5341	3.742006
1115612531	76.8741	60.5162	228.4625	3.753913
1138936857	77.0396	59.7371	224.9638	3.783058
1162261183	76.9262	59.0674	221.6185	3.817251
1185585509	76.6381	58.4478	218.3795	3.853011
1208909835	76.4515	57.6627	215.0674	3.876038
1232234161	76.3565	56.83	211.8222	3.893768
1255558487	76.317	55.9683	208.648	3.907313
1278882813	76.221	55.0928	205.5166	3.917642
1302207139	76.0737	54.2408	202.4733	3.927402
1325531465	75.9802	53.3313	199.453	3.930713
1348855791	75.9691	52.4018	196.5089	3.930166
1372180117	76.0194	51.4523	193.629	3.925682
1395504443	76.2156	50.5452	190.9206	3.922025
1418828769	76.3609	49.8679	188.5336	3.934144
1442153095	76.4871	49.4374	186.4964	3.964297
1465477421	76.4765	49.0757	184.5397	3.998939
1488801747	76.3179	48.626	182.4736	4.025359
1512126073	76.0497	48.1794	180.4121	4.050872
1545855976	75.7536	47.416	177.4048	4.075615
1579585880	75.4599	46.7075	174.5558	4.102315
1613315784	75.2932	46.0004	171.845	4.126484
1647045688	75.2817	45.3045	169.2919	4.149026
1680775591	75.427	44.5475	166.8076	4.163248
1714505495	75.6087	43.9173	164.5663	4.186718
1748235399	75.7077	43.4209	162.5222	4.22083
1781965303	75.6994	43.0162	160.6063	4.262167
1815695207	75.6065	42.5106	158.5878	4.291799
1849425110	75.4122	42.0332	156.6117	4.322434
1883155014	75.2363	41.4798	154.6056	4.343321
1916884918	75.041	40.9323	152.6442	4.36276
1950614822	74.863	40.4841	150.8577	4.390916
1984344725	74.6867	39.9861	149.0556	4.411897

2018074629	74.5249	39.534	147.3581	4.436159
2051804533	74.5163	39.186	145.902	4.470603
2085534437	74.6212	38.8222	144.5226	4.501909
2119264340	74.7211	38.4939	143.2244	4.536033
2152994244	74.7751	38.1979	141.9764	4.572793
2186724148	74.7	37.8837	140.6747	4.606229
2235501824	74.6534	37.39	138.832	4.64761
2284279499	74.4729	36.8308	136.8999	4.677993
2333057175	74.4243	36.3347	135.1723	4.713528
2381834850	74.2714	35.9594	133.5924	4.762371
2430612526	74.1818	35.6336	132.1574	4.815868
2479390202	74.0053	35.4602	130.9101	4.888608
2528167877	74.0066	35.2186	129.725	4.95082
2576945553	73.9953	34.9529	128.5454	5.008269
2625723228	73.8559	34.5949	127.2165	5.0508
2674500904	73.8584	34.1541	125.9056	5.079077
2723278580	73.713	33.8223	124.6787	5.121467
2772056255	73.661	33.4266	123.4609	5.152208
2820833931	73.5005	33.2477	122.4785	5.214808
2869611606	73.3681	33.0151	121.4757	5.267868
2918389282	73.2693	32.9648	120.7511	5.349249
2967166958	73.2658	32.7987	119.971	5.411252
3015944633	73.2919	32.6198	119.2182	5.470208
3064722309	73.1983	32.4098	118.3747	5.522893
3113499985	73.2039	32.1003	117.4931	5.557214
3162277660	73.098	31.9523	116.7665	5.618253
3232816303	72.8918	31.6416	115.5917	5.687725
3303354946	72.7103	31.47	114.6499	5.78031
3373893589	72.6394	31.3783	113.927	5.886538
3444432232	72.666	31.2257	113.2319	5.980383
3514970875	72.6183	31.0716	112.517	6.072738
3585509518	72.4716	30.8291	111.6492	6.146259
3656048161	72.3452	30.5892	110.8281	6.218408
3726586804	72.184	30.5434	110.2624	6.328893
3797125447	72.0782	30.5695	109.8601	6.4542
3867664090	72.0603	30.5514	109.4922	6.570207
3938202733	71.9673	30.4779	109.0198	6.67394
4008741376	71.8061	30.2897	108.3635	6.75153
4079280019	71.6619	30.0967	107.7329	6.826554
4149818662	71.4954	30.0582	107.3115	6.935715
4220357304	71.3634	30.1161	107.0659	7.067196
4290895947	71.3297	30.1434	106.8787	7.191829
4361434590	71.2339	30.1007	106.5644	7.299702
4431973233	71.1155	29.9326	106.076	7.376337
4502511876	70.9916	29.7906	105.6335	7.458187
4573050519	70.8307	29.8059	105.389	7.578921
4675058253	70.6081	29.8745	105.1331	7.765811
4777065987	70.5246	29.9322	105.0139	7.950584
4879073721	70.4159	29.8533	104.7096	8.098953
4981081455	70.199	29.7789	104.3379	8.247673
5083089188	69.9494	29.8525	104.1665	8.43738
5185096922	69.8456	29.9449	104.1811	8.633341
5287104656	69.723	29.9046	104.008	8.79134
5389112390	69.5075	29.8941	103.8097	8.957811
5491120124	69.2478	29.9862	103.7343	9.155489
5593127857	69.1342	30.0945	103.8446	9.35925
5695135591	69.0189	30.1064	103.8299	9.533713
5797143325	68.8122	30.072	103.6688	9.693386
5899151059	68.5124	30.1823	103.6416	9.900133
6001158793	68.3596	30.3589	103.8822	10.13025
6103166526	68.2733	30.4349	104.0552	10.32824
6205174260	68.1111	30.3635	103.9365	10.47623
6307181994	67.785	30.4381	103.8758	10.67461

6409189728	67.5658	30.6399	104.1399	10.91917
6511197462	67.5137	30.7466	104.4532	11.13159
6613205195	67.3682	30.6965	104.4276	11.28756
6760721186	66.927	30.8438	104.4945	11.59471
6908237176	66.6436	31.1342	104.9914	11.95925
7055753166	66.4673	31.0808	105.0768	12.19368
7203269156	66.0558	31.2301	105.2327	12.50841
7350785146	65.81	31.5442	105.8776	12.89295
7498301136	65.5762	31.5301	106.007	13.14581
7645817126	65.1322	31.6457	106.1077	13.45358
7793333116	64.9312	31.9424	106.8356	13.84172
7940849107	64.6873	32.0323	107.1715	14.14341
8088365097	64.1724	32.0972	107.1238	14.43534
8235881087	64.0181	32.339	107.8686	14.80934
8383397077	63.798	32.4432	108.2982	15.12317
8530913067	63.2123	32.58	108.3042	15.45417
8678429057	63.0538	32.7501	108.9574	15.80349
8825945047	62.9336	32.8266	109.5064	16.10966
8973461037	62.2575	33.0282	109.5223	16.4795
9120977028	62.0705	33.1978	110.1704	16.83642
9268493018	61.9142	33.2119	110.579	17.11599
9416009008	61.3695	33.4406	110.8445	17.50814
9563524998	61.1116	33.6848	111.5674	17.91229
9776851640	60.7018	33.6729	111.8545	18.30538
9990178282	60.0641	34.0287	112.5398	18.90244
10203504925	59.7296	34.0992	113.1218	19.34607
10416831567	59.1433	34.3181	113.6266	19.87733
10630158209	58.7743	34.4701	114.3422	20.37424
10843484852	58.3244	34.6022	114.896	20.86276
11056811494	57.7253	34.7439	115.2318	21.36031
11270138136	57.4354	34.9613	116.2446	21.90867
11483464778	56.7988	34.9925	116.2788	22.34329
11696791421	56.4427	35.314	117.431	22.96745
11910118063	55.866	35.2746	117.4016	23.36024
12123444705	55.471	35.5823	118.4732	23.98608
12336771348	54.957	35.5201	118.4901	24.36547
12550097990	54.558	35.881	119.6969	25.03864
12763424632	54.0575	35.7015	119.4465	25.33686
12976751274	53.5781	36.1162	120.6516	26.05957
13190077917	53.1824	35.9202	120.5353	26.34422
13403404559	52.6375	36.2853	121.5094	27.04239
13616731201	52.2711	36.1872	121.6739	27.39851
13830057844	51.7036	36.4132	122.2623	28.00155
14138554951	51.0281	36.4605	122.6782	28.66334
14447052059	50.446	36.4962	123.2336	29.31744
14755549167	49.8315	36.6915	124.1381	30.10371
15064046275	49.0639	36.794	124.4809	30.81895
15372543383	48.4782	36.7287	124.724	31.39427
15681040491	47.8518	36.8655	125.4225	32.14357
15989537598	47.2556	36.9261	125.9657	32.82982
16298034706	46.621	36.9767	126.3864	33.50908
16606531814	46.0621	36.9805	126.8228	34.14687
16915028922	45.4407	37.018	127.2078	34.81648
17223526030	44.8953	37.04	127.7021	35.47253
17532023137	44.208	37.1355	128.088	36.20099
17840520245	43.5571	37.0035	127.8492	36.70705
18149017353	43.2054	36.8984	128.3544	37.23572
18457514461	42.794	37.0931	129.6532	38.06848
18766011569	41.8478	37.1861	129.3767	38.80179
19074508677	41.3317	36.683	128.1778	38.90607
19383005784	41.3343	36.9921	130.8376	39.86844
19691502892	40.2309	37.09	130.1353	40.61017
20000000000	39.6294	36.5409	128.474	40.63576

Vitae

Name : Sulaiman Abdullah Sulaiman Alarifi

Nationality : Saudi

Date of Birth : 24-Jan-1990

Email : saa0539@gmail.com

Address : P.O. Box 1004 - 31261 KFUPM , Dhahran, Saudi Arabia

Academic Background : B.Sc. in Petroleum Engineering from KFUPM – 2012

Publications : 1- SPE-172729: Productivity Index Prediction for Oil Horizontal Wells Using different Artificial Intelligence Techniques.

2- SPE-173394: Improving Multiphase Choke Performance Prediction and Well Production Test Validation Using Artificial Intelligence; A New Milestone