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# Rapid Detection of Salt Contamination in Bentonite Drilling Mud in Deep Oil Well Applications

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## Abstract

One of the most critical challenges and issues in oil well drilling is to maintain the rheological properties of the drilling fluids. If the drilling fluid becomes contaminated with salts from the formation, it will affect the performance of the drilling. At present, there are no reliable methods to detect the drilling mud contamination during the drilling operations.

In this study, an electrical resistivity was selected as the most sensing property of the drilling mud based on series of experiments. Effects of 0.1%, 1% and 3% salt contamination on bentonite drilling muds up to 10% bentonite were investigated using the 2-probe method. When the salt contamination was 3%, the resistivity of the drilling mud changed by 1600 % and 918 % for 2% and 10% drilling muds respectively. The temperature effect on the density and electrical resistivity was studied. As the temperature increased from 5$^{\circ}$ C to 85$^{\circ}$ C, the average changes in the density and electrical resistivity were 0.4% and 750% respectively. The CIGMAT penetrometer instrument was used to evaluate the penetration in drilling mud under the impact of salt contamination. With the 3% salt contamination, the CIGMAT penetrometer penetration increased by 35 % and 70% for 2% and 10% drilling mud respectively. Also, the salt movement in the drilling mud was investigated using model tests. Finally, a model was developed relating the electrical resistivity to the level of salt contamination.

## Introduction

Drilling fluid has a vital role during the drilling operations. It supplies as medium of carrying the cuttings from the bottom hole to the surface. It provides pressure on the well walls and avoids the walls from collapsing and the formation fluid from entering the wells. Furthermore, it operates as a lubricant for the bit and the drilling string. Water based drilling muds are used in on shore and offshore drilling operations. For drilling operations under HPHT conditions, the industry prefers to use oil based mud (OBM), which has benefit over water based mud (WBM) since it can maintain its rheological properties at high range of temperatures. However, this is not always feasible due to logistic, environmental restrictions control, cost, cuttings and used mud disposal difficulties, and safety which make the WBM preferable (Elward-Berry and Darby, 1997).

One of the most challenging associated with drilling deep and ultra-deep wells is to maintain desirable rheological properties of the drilling fluids (Hassiba and Amani 2013) where salt can be one of the sources of contamination that affects the drilling mud properties (Raheem and Vipulanandan 2014). Bentonite mud can be contaminated during drilling of salt beds and the probability to encounter such type of layer during drilling operation is higher for deep wells. In addition, salts also can be present by design such as salts added to the drilling fluid system to have a salt saturated water based mud, or in offshore operations where seawater is used in preparing the drilling fluids (Rossi et al. 1999; Rojas et al. 2006). Bentonite clays in fresh water are effective for controlling the amount of fluid loss to the formation, by the formation of a "mud cake" along the walls of the wellbore. However, under saline conditions in the wellbore, the filtration control is lost due to flocculation of the clay particles. Furthermore, shale swelling within the formation may have negative consequences during the drilling operation (Chenevert 1970; Sherwood 1994).

It has been found that presence of salt (sodium chloride, NaCl) or contamination increases the filtration of the water based drilling fluid by 30%. Presence of sodium chloride can be detected by measuring resistivity due to influence of salt (sodium chloride, NaCl) on the increasing the conductivity. Therefore, by adding sodium chloride the resistivity decreased by 86% (Basirat et al. 2013). Plastic viscosity of a 6% (w/w) bentonite mud with different percentage (0 to 0.3% w/w) of salt content was determined with a Fann viscometer (Ali et al. 2013). Salt had a tendency to reduce the plastic viscosity and electrical resistivity of bentonite mud. The addition of 0.1% salt, decreased the plastic viscosity and electrical resistivity by about 10% and 18% respectively.

## Objective

The overall objectives of this study were to quantify the changes in the electrical resistivity of different bentonite drilling mud contaminated with salt for deep oil well and seabed applications. Furthermore, mathematical model quantification was proposed to predict the changes of the electrical resistivity.

The specific objectives were as follows:

1. Characterize the electrical properties and pH of different bentonite drilling mud contaminated with salt.
2. Study the CIGMAT penetrometer penetration for different drilling mud contents under impact of salt contamination.
3. Investigate the salt movement in the drilling mud using experimental model tests.

## Materials and Methods

In this study, different bentonite drilling mud (2%, 4%, 6%, 8% and 10%) was studied under various salt contaminations (0.1%, 1% and 3%). The changes in the electrical resistivity were quantified using AC-LCR meter. In addition, conductivity meter and CIGMAT penetrometer have been used.

## Electrical Resistivity Measurement (for Monitoring)

The electrical resistivity of the drilling mud contaminated with different salt content was measured using 2-probe electrical resistivity method through AC-LCR device using wide range of measured frequencies from 20 Hz to 300 kHz.

It was shown that at high frequency (300 kHz), the effect of contact resistance will diminish and the measured resistance is only the bulk resistance of the material (Vipulanandan and Prashanth 2013).

After inspecting all of the measured electrical impedance through LCR device, it was found that the drilling mud contaminated with salt has a behavior like resistor more than capacitor at high frequency and such behavior can be idealized (Figure 1) and modeled (Eq. 1) as follows (Vipulanandan and Prashanth 2013):

$$Z = R_b + \frac{2R_c}{1+\omega^2 R_c^2 C_c^2} - j\frac{2\omega R_c^2 C_c}{1+\omega^2 R_c^2 C_c^2} \qquad (1)$$

Where Z is the impedance, Rb is the bulk resistance, Rc is the contact resistance, ω is the angular frequency of the applied signal, Cc is the contact capacitance, and σ is the applied stress.

## Results and Analysis

### 1. Density

#### (a) Room Temperature

The impact of salt effect on the density of the drilling mud with different bentonite content in room temperature has been shown in Figure 2. As the bentonite content increased, the density increased linearly. The density increased by 1.65% as the salt content changed from 0% to 3%.

#### (b) Temperature Effect

The impact of the salt effect on the density of the drilling mud with different bentonite content in different temperature has been shown in Figure 3. The density increased linearly with the increase of the bentonite content in the drilling mud in both tested temperatures (5□ C to 85□C) with higher density for higher salt content. As the temperature changed from 5□ C to 85□C, the density changed by 0.4% and 3% for 0% and 3% salt contents respectively.

### 2. pH

The variation of pH with different bentonite contents under different salt contamination impact have been shown in Figure 4. In general, as the salt content was increased to 3%, the pH decreased possibly due to the interaction between bentonite and salt. The pH reduced from 8.8 to 8.2 with 3% salt contamination with a change of 7 %.

### 3. Resistivity

#### (a) Room Temperature

The variation of electrical resistivity vs. salt content of 2% and 10% bentonite drilling mud at room temperature has been shown in Figure 5. As the salt content increased, the electrical resistivity decreased having highest impact at 0.1% salt content. As the salt content increased from 0.1% to 3%, the average decrease in the electrical resistivities were 1600% and 918% for 2% and 10% bentonite content respectively.

#### (b) Temperature Effect

The variation of electrical resistivity versus salt content of (2% and 10%) bentonite content at different temperatures can be seen in Figure 6. As the temperature increased from 5□ C to 85□ C, the electrical resistivity decreased by 500% and 750% as an average rate for 2% and 10% bentonite content respectively.

The electrical resistivity vs. temperature of 2% and 10% bentonite content of 0% and 3% salt contents can be seen in Figs. 7 and 8 respectively. As the temperature increased from 5□ C to 85□ C, the electrical resistivity decreased by 130% and 354% for 0% salt content and 870% and 1328% for 3% salt content of 2% and 10% bentonite content respectively.

### 4. Model Test

#### (a) Method of Monitoring

Impedance versus frequency two drilling mud contents (2% to 10%) under different salt contaminations (0.1%, 1% and 3%) have been studied as shown through Figs. 9 and 10. As the bentonite content increased, the measured impedance decreased for all measured frequencies which leads that the bentonite is highly conductive material where higher contents give lower electrical resistivity. Salt contamination decreased the measured electrical impedance for both tested bentonite drilling mud contents. All tested bentonite drilling mud with and without salt contamination showed pure resistance behavior at high measured frequency (300 kHz) where the effect of contact resistance is minor and negligible.

#### (b) Sensing the Contamination during Downward and Upward Flow

One of challenging practical issues is to sense the contamination regardless of the position of it with respect to drilling mud. Herein, the flow of salt contamination downward and upward have been studied through experimental models and compared as shown in Figure 11. The electrical resistivity versus time (almost 2 days) of 6% bentonite drilling mud under the impact of the downward and upward salt contamination have been investigated. The downward movement of salt was higher than the upward which clearly captured by the change in electrical resistivity of the drilling mud. The salt downward movement last 250% longer than the upward movement for stabilized resistance reading. From the recorded electrical resistivity at any time, the salt contamination content can be identified as shown in Figure 11.

### *(c) CIGMAT Penetrometer*

The CIGMAT penetrometer penetration versus salt content of 2% and 10% bentonite content drilling mud of 6.8 gm CIGMAT penetrometer has been studied as shown in Figure 12. As the salt increased from 0% to 3%, the CIGMAT penetration of 2% and 10% drilling mud increased by 35% to 70% respectively.

### *(d) Model*

The following mathematical models were used to predict the changes in the electrical resistivity of drilling mud due to salt contamination:

$$\left(\frac{\Delta\rho}{\rho_o}\right)-\left(\frac{\Delta\rho}{\rho_o}\right)_o=\frac{\text{Salt}(\%)}{A+B*\text{Salt}(\%)} \quad (2)$$

Where: A and B are model parameters depend on the bentonite content, (Δρ/ρo) represents the relative change in resistivity of salt contaminated drilling mud and (Δρ/ρo)o represents the relative change in electrical resistivity due to bentonite content only. Also the uncontaminated water resistivity is $\rho_o$ and the change in resistivity is Δρ.

### *(e) Electrical Resistivity Model Parameters*

Both parameters A and B of the electrical resistivity model (Eq.2) can be correlated with the bentonite content as follows:

$$A=-0.004*\text{Bent.}\%+0.005 \quad (3)$$

$$B=-0.02*\text{Bent.}\%+0.04 \quad (4)$$

## Conclusions

Based on the main results of the study, the following conclusions can be advanced:

1. The change in the electrical resistivity of the drilling mud decreased as the salt content increased and the proposed mathematical models has a very good agreement with the experimental results.
2. An increase in the temperature caused a slight change in the density (0.4% to 3%) with a tremendous change in the electrical resistivity up to 750%.
3. Both downward and upward salt contamination movement with salt concentration amount in drilling mud can be captured by electrical resistivity method.
4. CIGMAT penetrometer penetration is good tool to sense the contamination in the drilling mud with a change level of 35% to 70% when the salt concentration changed from 1% to 3%.

## Acknowledgements

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## References

1. Ali K., Vipulanandan C. and Richardson D. (2013),” Salt (NaCl) Contamination on the Resistivity and Plastic Viscosity of a Bentonite Drilling Mud”, proceeding of CIGMAT Conference and Exhibition.
2. Basirat B., Vipulanandan C. and Richardson D. (2013), “Effect of Salt Contamination on the Filtration Loss in 4% Bentonite Drilling Mud with Xanthan Gum”, proceeding of THC-2013 Conference and Exhibition.
3. Chenevert, M. E: “Shale Alteration by Water Adsorption”, Journal of Petroleum Technology, September 1970, pp.1141-1147.
4. El-Sakhawy N.R.,Youssef K. M. and Badawy R. A. E. (2008),”Prediction of the Axial Bearing Capacity of Piles by Five-Cone Penetration Test Based Design Methods” ,(IAMAG),1-6 Oct 2008,India.
5. Elward-Berry J. and Darby J. B. (1997),” Rheologically Stable, Nontoxic, High-Temperature Water-Based Drilling Fluid. SPE Drilling & Completion, 12(3), pp.158-162.
6. Hale A. H., Mody F. K. and Salisbury D. P. (1992),“Experimental Investigation of the Influence of Chemical Potential on Wellbore Stability”, IADC/SPE Paper 23885, presented at the IADC/SPE Drilling Conference in New Orleans, Louisiana, Feb. 18-21.
7. Hassiba J.K. and Amani M. (2013), “The Effect of Salinity on the Rheological Properties of Water Based Mud under High Pressures and High Temperatures for Drilling Offshore and Deep Wells”, Earth Science Research; Vol. 2, No. 1, pp (175-186).
8. Horsrud P., Bostrom B., Sonstebo E.F. and Holt R.M. (1998), “ Interaction Between Shale and Water – Based Drilling Fluids: Laboratory Exposure Tests Give New Insight into Mechanisms and Field Consequences of KCl Contents”, SPE 48986 presented at the SPE Annual Technical Conference and Exhibition held in New Orleans, Louisiana, 27-30, September.
9. Mody F.K. and Hale A.H. (1993), “ A Borehole Stability Model to Couple the Mechanics and Chemistry of Drilling Fluid Shale Interaction”, SPE/IADC 25728, presented at the SPE/IADC Drilling Conference held in Amsterdam 23-25 February.
10. Raheem A. and Vipulanandan C. (2014),” Effect of Salt Contamination on the Bentonite Drilling Mud Shear Strength and Electrical Resistivity”, proceeding of THC-2014 Conference and Exhibition.
11. Rojas J.C., Clark D.E., Greene B. and Zhang J. (2006),” Optimized Salinity Delivers Improved Drilling Performance”, AADE Drilling Fluids Technical Conference, Houston, TX, April 11-12.
12. Rossi S., Luckham P. F., Zhu S. and Briscoe B. J. (1999),” High-Pressure/High-Temperature Rheology of Na+-Montmorillonite Clay Suspensions”, Presented at the SPE International Symposium on Oilfield Chemistry, 16-19.

13. Salisbury D.P. and Deem C.K. (1990), "Test Show How Oil Muds Increase Shale Stability", World Oil, October, pp. 57-65.
14. Sherwood J.D. (1994)," Thixotropic Mud, Compacted Cake and Swelling Shale", Les Comptes Rend. 29 Coll Ann. Groupe Franc. Rheol.., La Thixotropie.
15. Van Oort E., Hale A.H. and Mody F.K. (1995), "Manipulation of Coupled Osmotic Flows for Stabilisation of Shales Exposed to Water-Based Drilling Fluids", SPE 30499 presented at the SPE Annual Technical Conference & Exhibition held in Dallas, USA, 22-25 October.
16. Vipulanandan C. and Prashanth P. (2013), "Impedance Spectroscopy Characterizationof a Piezoresistive Structural Polymer Composite Bulk Sensor", Journal of Testing and Evaluation, Vol. 41, No. 6, pp. 898-904.
17. Walker, B. F., (1983), "Vane Shear Strength Testing", In-Situ Testing for Geotechnical Investigations, Ed. M. C. Ervin, A.A. Balkema, Rotterdam, pp. 65-72.

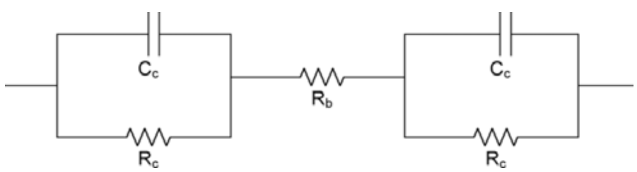


**Figure 1. Material Impedance Idealization.**

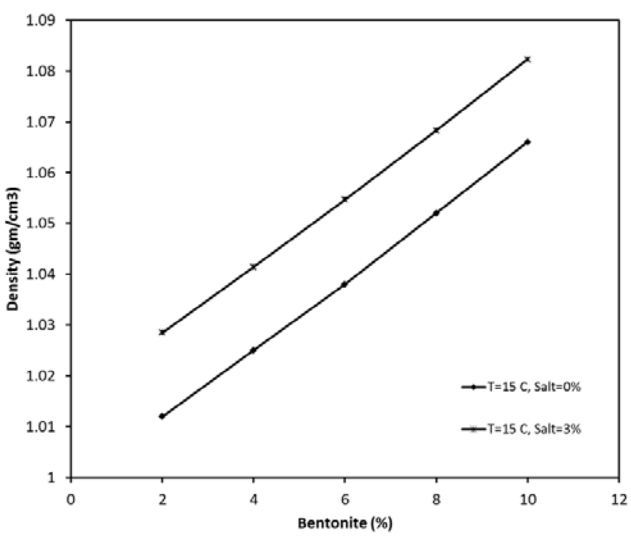


**Figure 2. Salt Effect on the Density of the Drilling Mud with Different Bentonite Content in Room Temperature.**

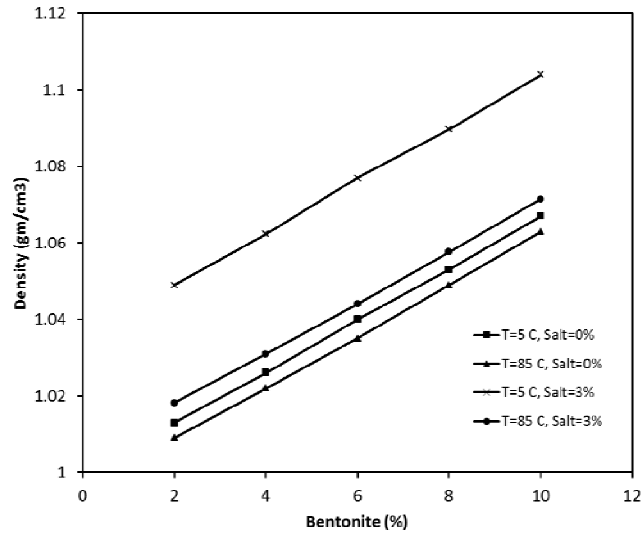


**Figure 3. Salt Effect on the Density of the Drilling Mud with Different Bentonite Content in Different Temperatures.**

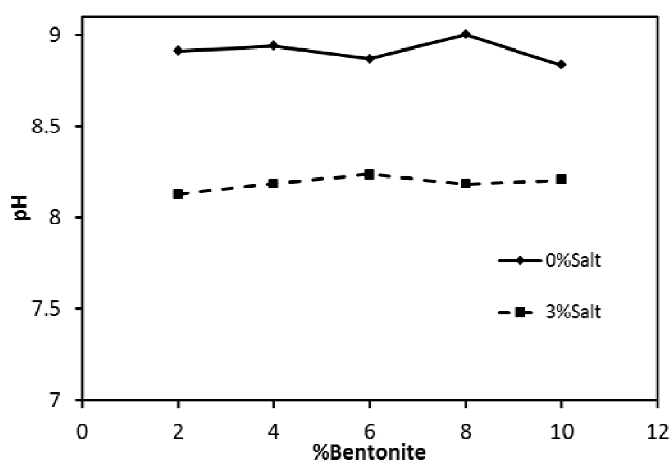


**Figure 4. The Variation of pH Change with Bentonite Content for Different Salt Contamination.**

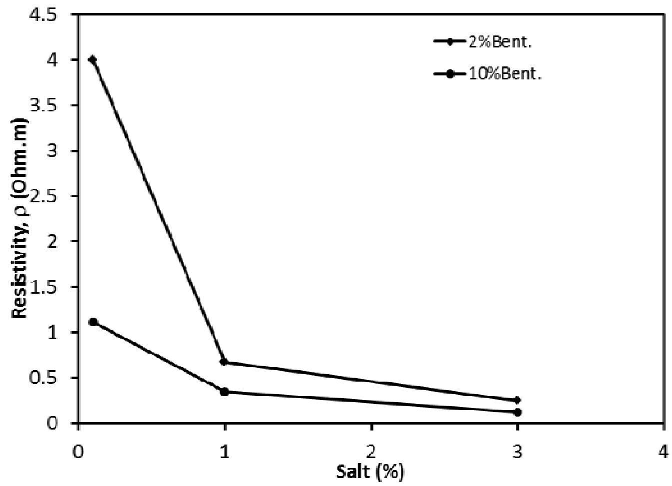


**Figure 5. The Variation of Electrical Resistivity vs. Salt Content of (2% and 10%) Bentonite Content at Room Temperature.**

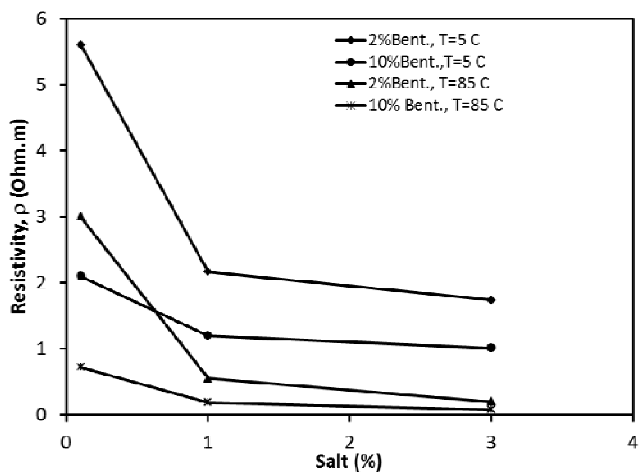


**Figure 6. The Variation of Electrical Resistivity vs. Salt Content of (2% and 10%) Bentonite Content at Different Temperatures.**

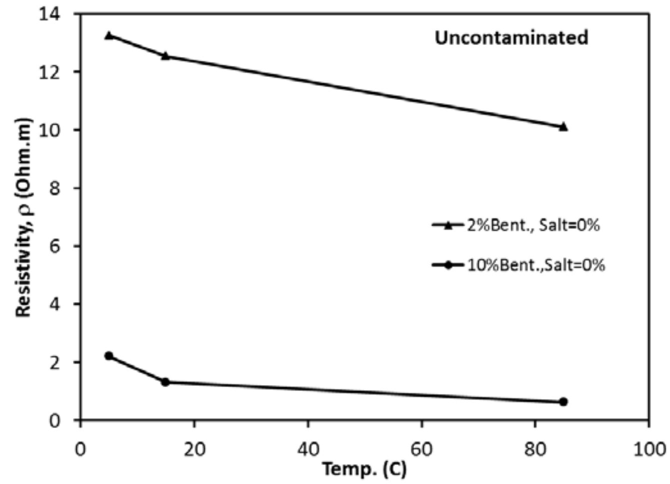


**Figure 7. The Variation of Electrical Resistivity vs. Temperature of (2% and 10%) Bentonite Content (0% Salt).**

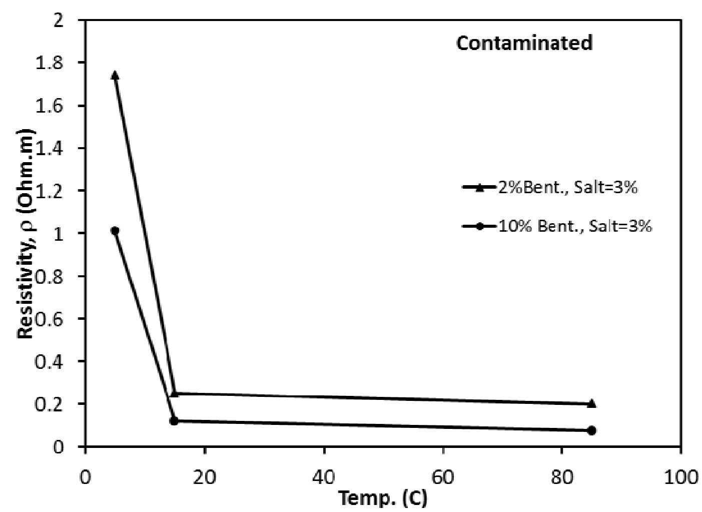


**Figure 8. The Variation of Electrical Resistivity vs. Temperature of (2% and 10%) Bentonite Content (3% Salt).**

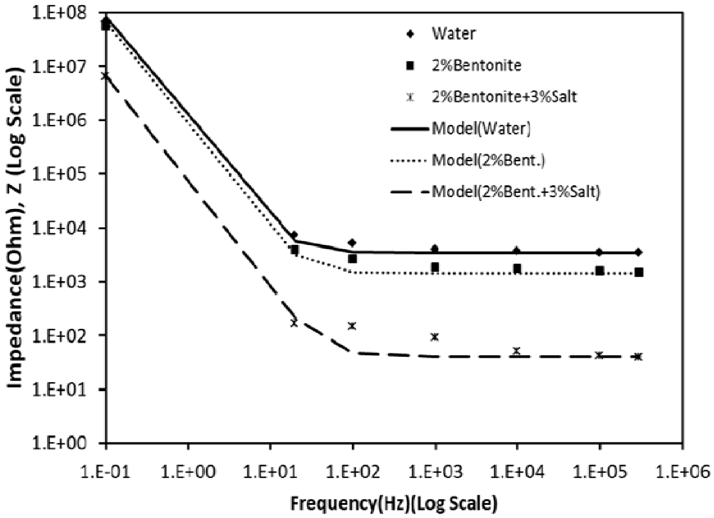


**Figure 9. Impedance versus Frequency Modeling of Drilling Mud (2% Bentonite) under Different Salt Contamination.**

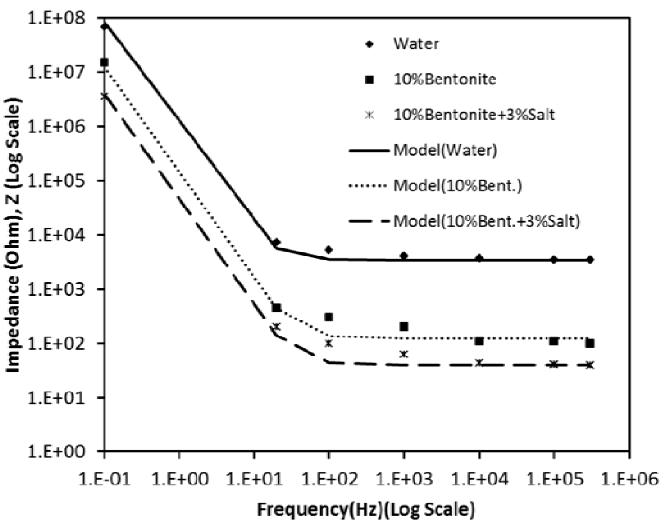


**Figure 10. Impedance versus Frequency Modeling of Drilling Mud (10% Bentonite) under Different Salt Contamination.**

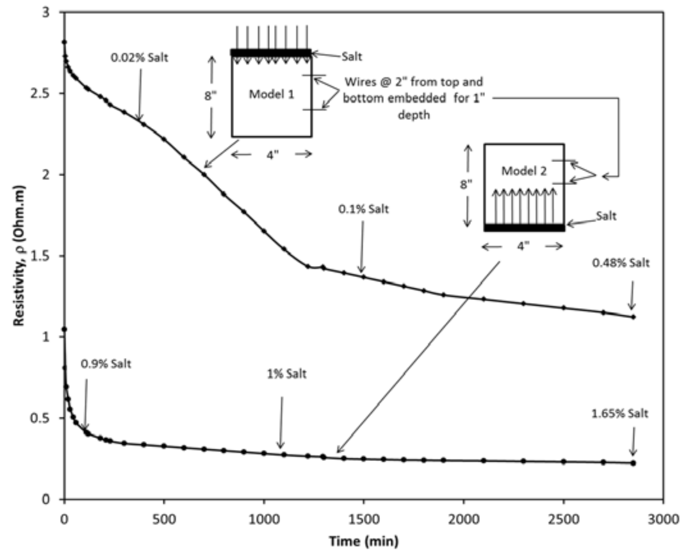


**Figure 11. The Variation of Electrical Resistivity Change with Time of 6% Bentonite Drilling Mud in Room Temperature.**

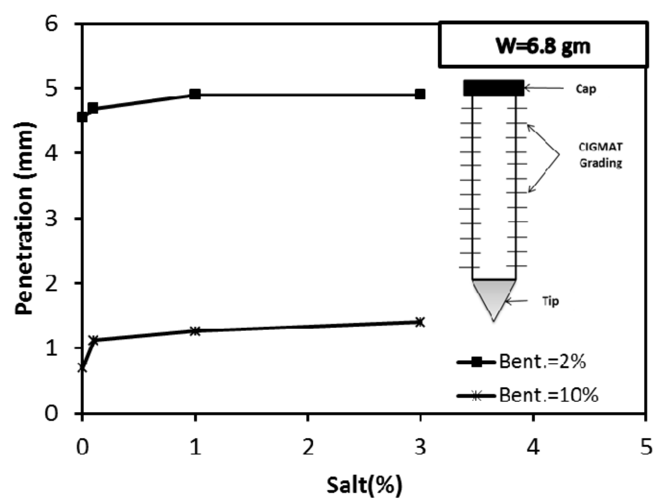


**Figure 12. The Variation of CIGMAT Penetration vs. Salt Content of Different Bentonite Content (W1=6.7 gm).**

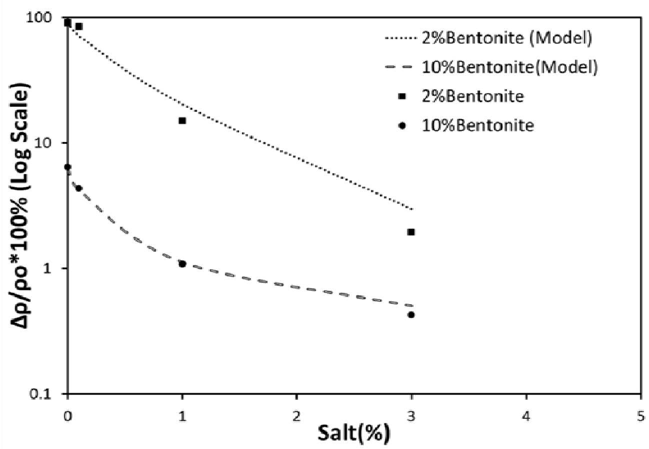


**Figure 13. Salt Effect on the Resistivity Change of the Drilling Mud with Different Bentonite Content.**

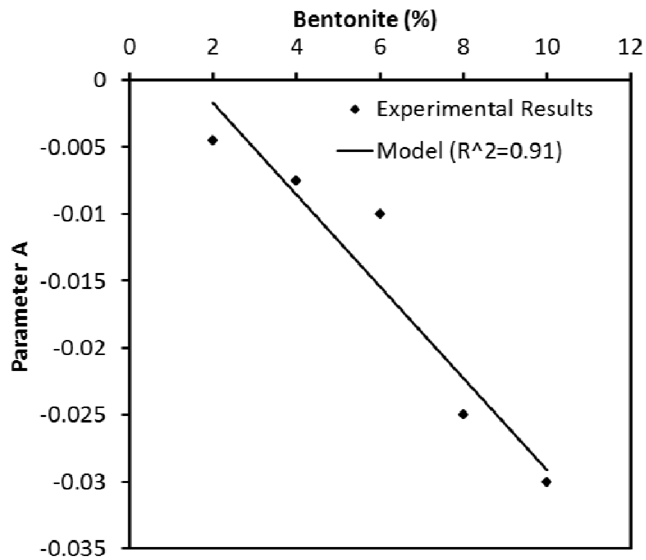


**Figure 14. Correlation of Parameter A with the Bentonite Content Compared with the Experimental Results.**

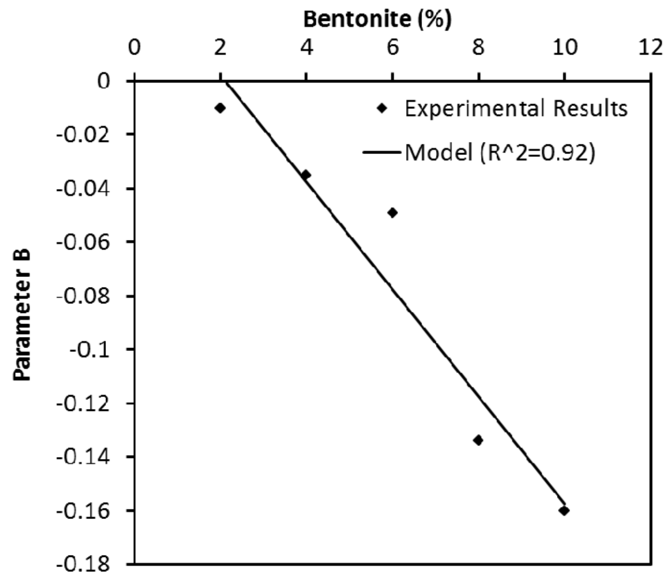


**Figure 15. Correlation of Parameter B with the Bentonite Content Compared with the Experimental Results.**