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Ionic Surface Dielectric Properties Distribution on Reservoir Sandstone

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Abstract: The petrophysical and dielectric properties for both carbonate and saturated sandstone with monovalent and divalent electrolyte they are accurately modeling of anisotropic dielectric properties has been the major research area in oil and gas industries for effective sweep efficiency. The reservoir petrophysical properties consist of cation and anion exchange capacity on a specific area and the sandstone porosity. The transportation of the ions is a charge carrier that mediates conduction in the pore fluids under the electrical double layers that exist between the minerals and the pore fluids interface. The dielectric anisotropic and the frequency-dependent behavior of reservoir sandstone with the minerals will be fully elucidated, it was revealed from the result obtained the effect of the anisotropic dielectric properties on the reservoir sandstone based on the influx of NaCl electrolyte modify the wettability of rock formation from oil-wet to water-wet at 9000 and 11000 ppm concentration with the aids of the electromagnetic field. The resistivity index of the reservoir sandstone reduces with the increase of electrolyte to the system.

Keywords: Dielectric, petrophysical, ions, anisotropic, sandstone, NaCl electrolyte

1. Introduction

Reservoir sandstone is the most abundant sedimentary rock, and it has been gaining significant attention in oil and gas exploration as a source of rock unconventional reservoirs. Among the characteristics of sandstone reservoir physical and petrophysical are the most important parameters, the electrical, and more precisely dielectric properties are one of the most efficient approaches for the differential of geofluids kinds and concentration also their transport properties [1-6]. In recent years, sandstone dielectric response to the high frequency, 200-1000 MHz of the electromagnetic field is one of the major interests in the oil and gas industries. Different equipment or tools have been established that depend on the link between the dielectric properties and imperative variables such as water saturation [7, 8]. The behavior of dielectric properties of rocks has been experimentally studied for the past two decades at low range frequencies around 10 Mhz. The behavior of the dielectric properties of the sandstone is extremely complex because some study reported the frequencies at lower range while others investigation shows the frequencies at higher ranges from hundreds of MHz to GHz [9-12]. The real effective dielectric permittivity, Kr, known as dielectric constant, is mostly dependent on the polarizability of the material medium (i.e., the capability for microscopic charge

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separation to occur). Reservoir sandstone comprised of feldspar, quartz, and minerals clays. The minerals charges on the sandstone are zero which is lower than the conventional pH in a sandstone reservoir. The sandstone is negatively charged as pH functions. It was recommended by Austad et all that a mechanism where ions particularly Ca2+, which is the polar oil components, adsorb to the negatively charged surface. At this instance, the low salinity passes through the press and adsorbed positively charged are substituted by H+ which raise to pH increase near the surface and absorption of oil polar component. The dielectric loss known as the imaginary part of dielectric permittivity, Ki, is a measure of a.c. conductivity which responsible for the migration of unbound charges such as ions through the pore fluid [13-16]. Hence, a real sandstone reservoir is comprised of three or more various components, to mention view a clean sandstone reservoir may consist of rock grain, sands, water, and oil, of which each has different dielectric constants. Most solid properties including the common rock-forming minerals and non-polar liquids such as oil are much less easily polarized than water, the content of the moisture is determined from the functional correlation with the dielectric permittivity measure at a high-frequency range (i.e., 10 MHz -1 GHz) [17]. Dielectric properties of reservoir sandstone are one of the essential parameters in geoscientists and petrophysical in evaluating the effectiveness of oil-gas reservoirs to more specifically before and during the exploration. The reservoir sandstone surface is either negative or positively charged in an aqueous medium by separation or ionization of the surface by adsorption of ions from the solution to the uncharged surface. The fluid interaction on the surface of the sandstone is affected by the adsorption of ions on the reservoir sandstone. This research aims to provide insight on the dielectric anisotropic of reservoir sandstone in respect to the influence on the wettability alteration. Keysight network analyzer were used to determine electrical property of the reservoir sandstone using S-parameters for the reflection and transmission coefficient and (FESEM) EDX mapping for the ion distribution on the sandstone.

2. Materials and Methods

Berea sandstone was saturated with NaCl electrolyte at various concentrations from 3000, 5000, 7000, 9000, and 11000 ppm, respectively. The Berea sandstone has a porosity of 26% and permeability of 600mD as measure from helium porosimeter. The sandstone was aged in 11,000 ppm of brine solution for completely 15 days at 80oC to create spontaneous imbibition [9], followed by crude oil of 42 API to replicate reservoir environment before saturated at different NaCl electrolyte concentrations to attain homogenous distribution of fluid formation. The sandstone was deposited in an autoclave that was placed in an oven at 80oC for 24hours for proper saturation. The sandstone was cut into chips for the dielectric characterization (figure 1 d) and Figure 2 shows the experimental procedure flow chart used in this study. The Keysight Network analyzer was used for the characterization of dielectric properties of the sandstone using P-band figure 1c and figure 1a illustrate the dry sandstone and the saturated sandstone with oil and bine. (FESEM) EDX mapping was used for the morphological analysis for the ion distribution.

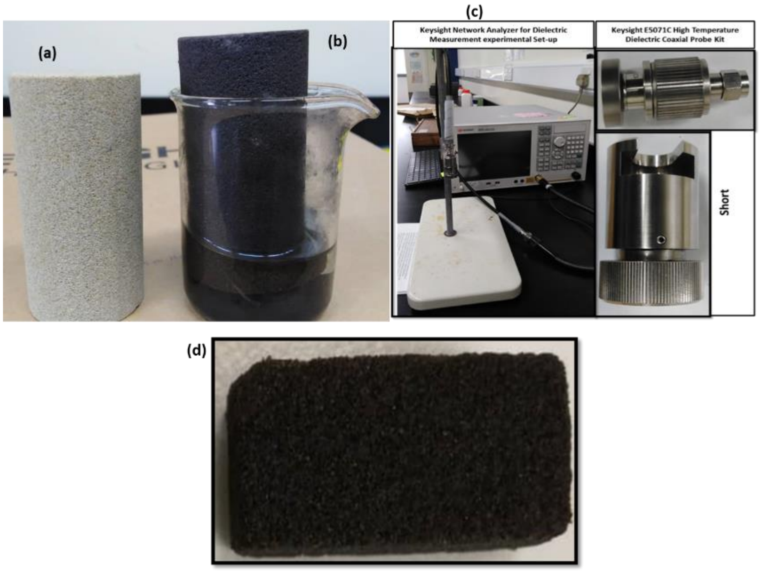

Fig. 1 - (a) dry sandstone; (b) saturated sandstone with oil and brine (c) Keysight Network analyzer for dielectric measurement experimental set-up with one probe; (d) Saturated sandstone after cutting into the chip for P-band measurement with a length of 11.86 mm and a diameter of 7.16mm

3. Result and Discussion

3.1 Dielectric Behavior of Sandstone

The dielectric properties of the reservoir sandstone are a significant parameter that can be used to infer other properties in the porous medium such as permeability, water saturation, porosity, etc. Dielectric isotropic of sandstone reservoir have been studies by different researchers both at low frequency and high frequency (MHz to MHz, MHz to GHz) range of frequency. The permittivity of the dielectric constant is an essential property for the porous medium that quantifies the storage of energy within the system when it is subjected to an electric field. Figure 3 shows the dielectric behavior of saturated reservoir sandstone which describes the electric behavior of the sandstone at a specific frequency range. The interface on the dielectric behavior of the sandstone due to polarization causes an enhancement for fluid mobility. The increase in the salinity of the reservoir affects the pore fluid f o through the electromagnetic propagation, at 9000, and 11,000 ppm it was observed that the response of dielectric behavior toward the high-frequency range changed due to ionic conduction that led to polarization within the environment. Resistivity analysis was used to determine the wettability effect due to an increase in the concentration of electrolytes, it was found that there is a dominant impact on resistivity because of the drastic change in the fluid distribution in the pore space Figure 3. Dielectric properties are related to the frequency and the time scale because of the polarization mechanisms at different frequency range [9, 18]. The behavior of the reservoir sandstone/rock was aimed to understand the improvement and the link between the dielectric behavior and the properties of the reservoir such as lithology, grain geometry, heterogeneity, and the water saturation of the rock system.

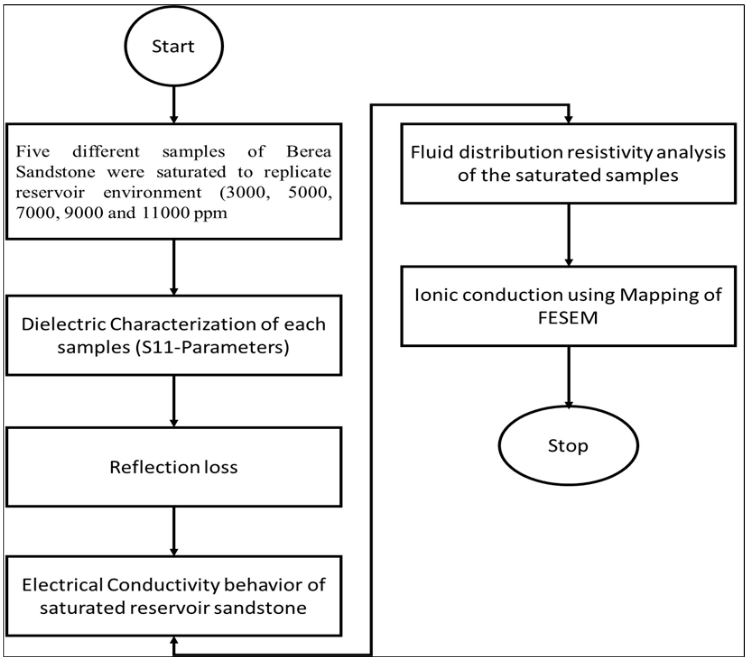

Fig. 2 - Flow chart of the experimental procedure

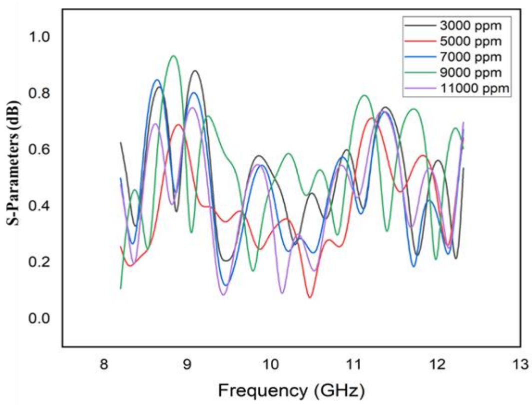

Fig. 3 - Dielectric behavior of saturated reservoir sandstone at different electrolyte concentration

This behavior of the dielectric reck properties will enable the understanding of the field data from the aquifers and the oil reservoir sandstone [19]. With the introduction of Maxwell's equations for the time-dependent development of the magnetic and electric field properties. It is likely to model the driving of a system through external fields, and the connecting addition and loss of energy. The reaction of a material to an applied electric field is represented by the complex dielectric constant or effective permittivity, $\boldsymbol{\epsilon}$:

$$\varepsilon = \varepsilon' + i\varepsilon'' = \varepsilon' + i\frac{\sigma}{\omega\varepsilon_0} \quad (1)$$

Where ε' *and* ε'' the real and imaginary permittivity respectively, σ is the conductivity, ω is the angular frequency and while ε_0 is the permittivity of the free space. In the porous medium ε' serve as the energy storage and ε' is allied with loss or energy dissipation within a medium. The loss is a measure of the power removed from the electromagnetic field by a dielectric process. The power removed is converted to other forms of energy, which is mainly heat [20]. The resistivity index of the water-wet of the reservoir sandstone is significantly lower than that of oil-wet at 9000 ppm and 11000 ppm concentration of electrolyte Figure 4. Optimization of such loss processes can be of great benefit in several electromagnetic absorption applications [21, 22] and is an important aim of this research. The main dielectric loss processes are Electrical conduction, Dielectric resonance, and Dielectric Relaxation.

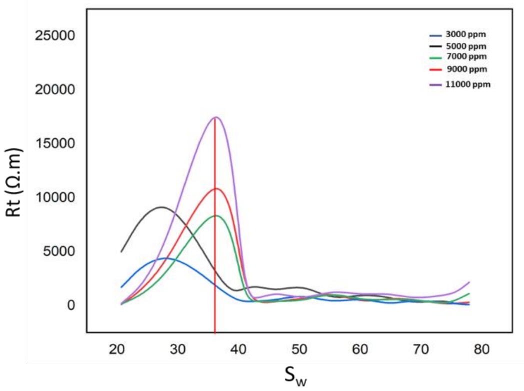

Fig. 4 - Resistivity analysis for the fluid distribution at different electrolyte concentration

3.2 Electrical Properties of Reservoir Sandstone

Figure 5 describes the sandstone reservoir saturations under varying electrolyte concentrations. It was observed that when the NaCl electrolyte increased to 11000 ppm, reflection increase to -45dB at 8.5GHz. In summary, the RL values increase with an increase in the concentration of electrolytes Sandstone is profuse of the sedimentary rocks and it has gained a lot of interest in hydrocarbon exploration for the past decays as source rock and unconventional reservoir. In the reservoir sandstone, dielectric properties are one of the most distinctive for differential of geofluid types and their influence on the transport properties among the petrophysical characteristics. Bulk anisotropy of sedimentary rocks can evolve from the sprinkling of rock units having varied electrical properties.

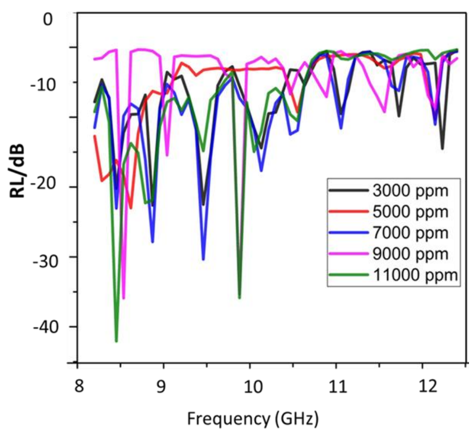

Fig. 5 - Reflection loss of saturated reservoir sandstone at varying electrolyte concentrations.

When a particle is immersed inside an aqueous solution with an excess of ions, the ions will redistribute themselves around the surface of the particles to neutralize their surface charge. Table 1 describes the concentration of electrolyte and RL in rock sample. The high level of reflection loss values may be attributed to the good performance of EM waves.

Table 1 - RL value of the rock sample calculated from the concentration of electrolyte

Concentration	RL (dB)	Freq. (GHz)
3000 ppm	-22.62	8.87
5000 ppm	-22.99	8.62
7000 ppm	-30.21	9.46
9000 ppm	-35.32	9.88
11000 ppm	-42.22	8.45

Figure 6 shows reservoir sandstone at varying electrolyte concentrations. From the obtained result salt alteration change the thickness of EDL and the properties of the surface charges. It was observed from the result that increase the electrolyte concentration modifies the electric field flux within the electric double layer region, this will affect ions distribution in the reservoir environment. The region containing the accumulated ions is referred to as the Electric double layer (EDL) [23]. It consists of two layers, the inner layer (also known as the stern layer) and the outer layer (also known as the diffuse layer). The stern layer comprises ions whose charges are opposite to that of the particle's surface and are therefore called counter-ions. The diffuse layer is the layer of free ions containing both the counterions and co-ions, ions having a similar charge to the particle's surface.

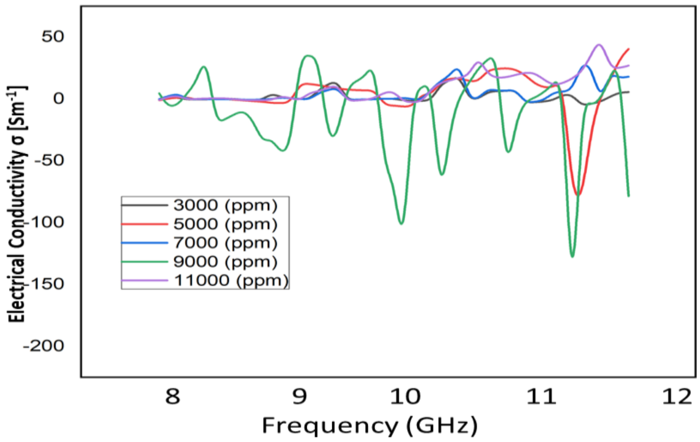

Fig. 6 - Behaviour of electrical properties of reservoir sandstone at different electrolyte concentration

The diffuse layer ions, unlike the stern layer ions, are free to move due to the electrostatic force of attraction to the surface charge otherwise [24-26]. The thickness of EDL is called Debye length, K-1 (nm), and for electrolyte solution in atmospheric temperature, K-1 is equal to:

$$K\text{-}1 = \frac{0.304}{\sqrt{I}} \tag{2}$$

where I stand for the ionic strength of the electrolyte solution, which is expressed as

$$I = \frac{1}{2}\sum z_i 2C_i \tag{3}$$

where z is the valence of ions and C is the molarity of ions present in the solution [25, 26].

From equations, an increase in the concentration of ions will lead to a decrease in Debye length. The significance of this is that at high ions concentration, the surface potential is neutralized within a shorter range due to effective screening of the surface of the particle. When two charged surfaces move closer to each other, there would be interactions between their corresponding EDLs. This interaction can be Van der Waals attraction and electrostatic repulsion. The summation of the two forces gives rise to a net force, described by the DLVO theory (named after Derjaguin, Landau, Verwey, and Overbeek). DLVO theory is used to evaluate the stability of a mixture (colloid). If the dispersed phase and the dispersing medium are both liquids, the mixture is called emulsion [23, 25, 27, 28]. The space region between the inner and outer parts of EDL is what is known as the slip plane [25]. Zeta potential describes the electrostatic potential in this plane and is one of the few measurable parameters that gives us information about EDL [29].

3.3 Ionic Conduction

The electrical properties of a heterogeneous medium may vary significantly from those of its components. Certainly, the effective complex permittivity of the overall system depends not only on the permittivity of the environments but also on their ionic distribution, Figure 7. Sandstone reservoirs consist of different elemental compositions, but the major concern of this study is the influence of the influx of Na^+ and Cl^- injected from sodium chloride solution. It clearly shows from the result that the influx of Na^+ and Cl^- influence better dispersion most especially at 9000 and 11,000 ppm, respectively.

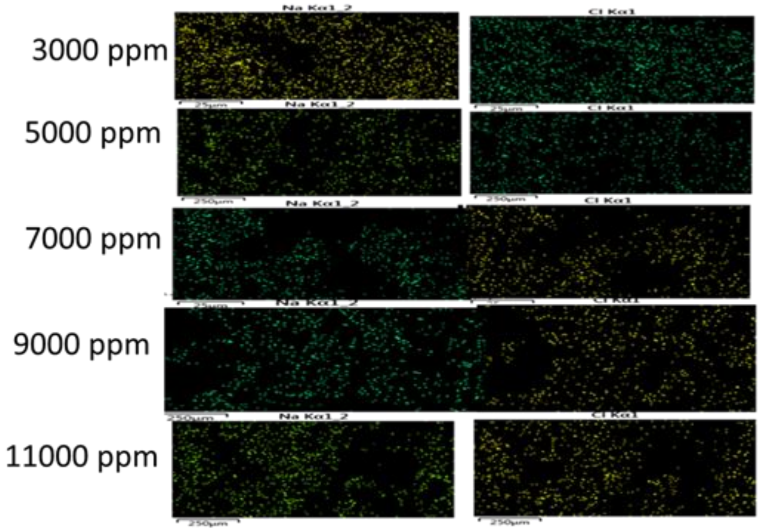

Fig. 7 - Ionic distribution on reservoir sandstone

The microstructure effects on the electrical properties of the reservoir sandstone are of great interest in both fundamental and applied research. Most especially different numbers of research have been conducted in porous materials, such as oil reservoir rock [30, 31]. To investigate the dielectric properties of a material medium, the composition, and the fluids saturation in the pore space. The reservoir sandstone is saturated with hydrocarbon oil, connate water, and brine solution. The sandstone reservoir comprising two phases i.e., oil and porous matrix which has low permittivity while the other phase with brine has high permittivity due to the conductivity of the electrolyte presence. Moreover, the introduction of an external electric field will generate a charge carrier concentration cutoff across the interfaces between conducting phase (water) and insulating (porous matrix and oil) regions. At this instance, it produces interfacial polarization within the reservoir environment.

4. Conclusion

This study investigates the ionic dielectric distribution in reservoir sandstone under the electric double layer region. It was deduced from the result obtained that there is a strong distribution of ions due to external electric fields. The increase in the electrolyte concentration with the aids of an electric field contributes to fluid mobility within the reservoir environments. Ion conduction to mediate the transport of charges at different electronic conduction which mediates between the pore fluid and charges ions in an aqueous solution of NaCl electrolyte were the major parameters for the fluid mobility in the reservoir sandstone. The resistivity index of the water-wet of reservoir sandstone decrease with an increase in the concentration of the electrolyte. Hence the resistivity tends towards constant water saturation greater than 40%.

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