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Zeta Potential and Its Impact for Enhancing Oil Recovery in Sandstone and Carbonate Reservoirs: A Review

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Abstract

Enormous worldwide energy demand and increasing the need for more oil recovery with high efficiency are one of the factors driving more interest in enhanced oil recovery mechanisms for extracting more oil from reservoirs. Through the past decades a rapid development of enhanced oil recovery mechanisms, among that the effect of zeta potential has become very interesting topic because it has a significant importance on wettability alteration and then oil recovery. Several studies have been used zeta potential measurements to interpret wettability alteration in EOR processes by modification the charges on rock surface as a response when it exposes to different injected brines. Zeta potential (ζ) is an important parameter which required to measure the electrical potential (positive, negative, or neutral charge) on rock minerals or colloidal surface when it expose to an electrolyte. It dominants the electrostatic interactions between rock surface and polar groups in the brines. The electrical charges of the rock- brine and oil- brine interfaces can modify by controlling the salinity of injection water. Therefore, it can be used for choosing and designing the optimum composition of the water (brine) injection in carbonate and sandstone reservoirs, which leads to increase the oil recovery.

In this paper, an integrated literature review is conducted to summarize the definition, methods of measurement, behaviour and characterization of zeta potential mechanism and its impact on oil- water and rock - water interface that should be considered in designing the injection brine project.

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1. Introduction

Oil will continue to be the most significant energy source utilized to fulfil global demands, with demand increasing by 35% over the next two decades due to increased energy use and diminishing supplies. Only around 30–40% of the original oil in place (OIIP) can be recovered using conventional primary and secondary oil production processes. More than sixty percent of the oil is still stuck in the ground. Since primary and secondary oil recovery do not always provide the desired results, the use of enhanced oil recovery (EOR) or tertiary recovery has become an increasingly appealing method for obtaining and moving the remaining oil [1].

There are three distinct stages in the oil recovery process: primary, secondary, and tertiary. The primary recovery method makes use of both natural flow and artificial lift, which ultimately results in the production of less than thirty percent of OOIP [2]. According to Darcy's law, continued oil extraction results in a reduction in the pressure gradient inside the reservoir, this in turn results in a reduction in the amount of oil that can be produced [3]. Secondary oil recovery is used as an alternate approach to extract additional crude oil from the reservoir once primary oil recovery has been used up as a viable option for doing so. This occurs when the main oil recovery process is no longer an option. This approach makes use of pressure maintenance strategies including flooding with water and injecting gas at regular intervals.

Due to this, a tertiary or enhanced recovery phase (EOR) has been put in place to make it easier to get more oil out of oil reservoirs. EOR is a broad term for several different methods, such as chemical flooding, gas injection, microbiological recovery, and thermal recovery. The goal of using EOR is to increase the oil production that didn't produce through the secondary recovery phase [4].

Since the molecules of two fluids are attracted to one other upon contact, a force is exerted between them termed the interfacial tension; in oil reservoirs, this force is often between water and hydrocarbons. The interfacial tension raises capillary forces, which are crucial to extracting hydrocarbons from the pores' medium. It is widely understood that capillary and viscous forces play a crucial role in the stability of the displacement front [5, 6].

Although the interfacial tension (IFT) is a significant component that affects the rock's wettability, there are a great number of other factors that can impact the wettability as well. furthermore, during this research, we will concentrate on another additional significant aspect, which is the modification of the rock's surface electrical charge. This change will influence the wettability of the rock and will lead to an increase in the electrical double layer. The electric force, which is comprised of the double-layer, electrostatic, and Vander Waals forces, is the most important and dominating force in the reservoir. When two surfaces in an electrolyte solution have charges that are complementary to one another, a phenomenon known as double layer repulsion can take place. The zeta potential which may also serve as a wettability indicator, is measured in order to get an estimate of the force that exists between the two layers which can either be attraction or repulsion.

2. Electrical Double Layer Theory, EDL

An EDL, or electrical double layer, is a system that explains the distribution of charges and illustrates the interaction between a layer with additional surface charges and a layer that contains more charges. It's a principle that plays a significant role in maintaining the electrostatic stability of colloids. When negatively charged ions from the dispersed phase adsorb on the surface of colloidal particles, the particles acquire a negative electric charge. This transformation happens at the particle's surface. The positively charged counterions around a negatively charged particle are attracted to it [7]. The electrical double layer is the name given to the layer that may be found surrounding a dispersed phase particle. EDL has a neutral electrical charge which is made up of adsorbed ions on the particle surface and a thin layer of the oppositely charged dispersion medium. EDL is a transition area between the outer diffuse region and the inner molecular layer [8]. There are three parts that make up the:

i. Surface charge refers to the ions that have been adsorbed onto the particle's surface and carry a charge, often a negative one.
ii. Stern layer: counterions, charged in the opposite direction as the surface charge, they are attracted toward the surface particle and bound to it by electrostatic force.
iii. Diffuse layer, which encases the particle, is a thin layer of the dispersion phase (the solvent). The diffuse layer has the highest concentration of counterions and the highest concentration of free ions. Ions in the diffuse layer are affected by the charged particle's electrostatic force.

Maximum electric potential within the electric double layer occurs near the particle's surface (Stern layer). The potential is stated to be at its lowest near the electric double layer border and decreases to zero as one moves away from the surface. As a colloidal particle travels through a dispersion medium, a thin film of the surrounding liquid stays adhered to it. For this layer, the boundary is the sliding plane (shear plane). The electric potential at the sliding plane, or zeta potential, is a key variable in the colloidal particle interaction concept [9]. Figure 1 explains the components of EDL. Theoretically, the rock-oil-water system is more stable at larger electrostatic repulsive forces, and hence higher zeta potentials, but at higher attractive Van der Waals forces, the system becomes less stable [10].

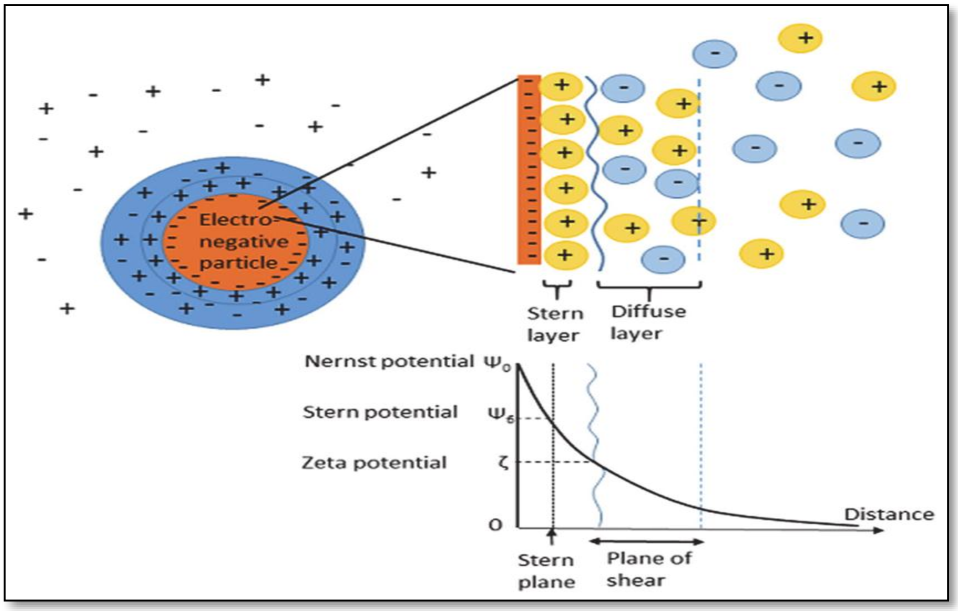

Figure 1: Electrical Double Layer Components [10]

3. Zeta Potential, ζ

The electrical potential, also known as the zeta potential, of the interface between the oil and brine or the mineral and brine is one of the most important factors to consider when assessing the wettability of crude oil, brine, and mineral systems. The term "zeta potential" refers to the electrical potential that is produced at the interface between a solid and a liquid as a result of the relative movement of water and particles. This potential is referred to as the "zeta potential" [11]. The zeta potentials of particles can be used to predict the electrical potentials of such particles; a bigger zeta potential suggests a higher surface potential of a charged particle, whereas a smaller zeta potential indicates a lower surface potential. The value of the zeta potential may be used to make predictions about the short-term and long-term stability of emulsions. This is another reason why the zeta potential is important. Emulsions with a low zeta potential are more likely to coagulate or flocculate, which poses a risk to their physical stability; in contrast, emulsions with a high zeta potential are electrically maintained [12]. It is possible to quantify the ion adsorption and desorption activities that are taking place in the Stern layer by making use of the zeta potential. This defines the electrical potential of the surface that is furthest away from the shear layer [10].

4. Role of Zeta Potential in EOR

In the context of enhanced oil recovery, zeta potential plays an important role in determining the stability of suspensions used in various EOR techniques such as surfactant flooding and polymer flooding. In these techniques, the addition of surfactants or polymers can reduce the interfacial tension between the oil and water phases, leading to improved oil displacement and recovery. The stability of these suspensions is critical for their effectiveness, and zeta potential provides a measure of this stability by characterizing the repulsive forces between the suspended particles [13]. Higher zeta potential values indicate a more stable suspension, with the particles less likely to aggregate or settle. This stability is important in ensuring that the surfactants or polymers remain evenly distributed in the oil and water phases, allowing them to be more effective in reducing interfacial tension and improving oil recovery [14]. In summary, the measurement of zeta potential can provide important information about the stability of suspensions used in EOR and can be used to optimize the design and implementation of these techniques.

Comprehensive experimental work conducted in recent years has shown that adjusting the salinity of the injected water is an improved oil recovery strategy that increases oil recovery in sandstone and carbonate reservoirs. Complex ion interactions exist between formation water, crude oil, injection water, and the rock surface. How do the minerals that make up sandstone formations have a surface charge, and how does that charge impact how well the rocks drain floodwaters [15]. By determining the zeta potential at the brine-oil and rock-brine interfaces, Jackson et al. came up with the idea that the optimal concentration for the injection brine should be used when the salinity of the surrounding water is modified. It has been demonstrated that increasing the amount of normalized zeta potential that has accumulated can boost oil recovery. By analyzing the zeta potentials of crude oil, brine, and minerals at the same time, they were able to demonstrate that a positive charge may exist at the interface between the oil and the brine. Furthermore, choosing a composition for the injected water with the opposite ionic charge, it is possible to achieve a positive zeta potential at the brine/mineral interface. This may be done by selecting a positive zeta potential. The zeta potential polarity of the interfaces should be the same in order to generate repulsion, since this will make the water film more stable. The fact that, when exposed to water, the wettability changes in the direction of becoming more so highlighted the relevance of the zeta potential at both the oil-brine and rock-brine interfaces. In addition to this, they found a link between the contact angle and the absolute magnitude of the total of the zeta potential at these contacts. This was a very interesting finding [16, 17].

In addition to this, they found a link between the contact angle and the absolute magnitude of the total of the zeta potential at these contacts. This was a very interesting finding. According to this correlation, a larger modulus (which indicates that the interfaces have the same polarity) corresponds to a smaller contact angle. This leads one to believe that the zeta potential plays a significant role (a more water-wet state). Alteration of wettability is strongly dependent on the surface electrical charge at the crude oil/brine and rock/brine interfaces. Surfaces with electrical charges that are opposite to one another attract one another, whereas surfaces with charges that are the same generate a strong force of repulsion. There is a strong connection between the surface charges of the interfaces and the quantifiable zeta potential, which refers to the electrical potential at the sliding plane of the EDL. The ionic strength as well as the types of ions that are present in the solution have an effect on the zeta potential. This, in turn, has an effect on the thickness of the EDL as well as the surface charge, both of which modify the wettability of the crude oil-brine-rock system [18].

Because it is believed that the expansion of the double layer is responsible for the change in wettability, [19] also suggested looking into the charges that are present at both interfaces. [20] examined the zeta potential at the interfaces of rock-brine and brine-oil to identify which interface has a stronger influence on the contact angle and disjoining pressure. Their findings can be found in the next paragraph. They concluded that the most significant contributors to the observed shift in wettability were the interactions between the brine and the oil.

5. Factors Affecting the Zeta Potential

Zeta is affected by a wide range of factors, some of which are PH, salt content, ionic strength (water salinity), temperature, and the quantity of chemical additives (like surfactant, polymer, alkali, etc.). The ionic concentration (electrolyte concentration) n0, the cation's valence v, the medium's dielectric constant D, and the temperature T influence the ionic and potential distributions in the vicinity of charged surfaces. Other factors that have an impact on these distributions include the dielectric constant of the medium and the temperature [21]. In the field of physics, this distance is typically referred to as the double layer thickness, and it is expressed by the notation that appears below:

$$1/k \;=\; (\varepsilon_0 DKT\,/2e^2v^2n_0\,)^{1/2} \qquad (1)$$

Where K; constant of Boltzmann (1.38×10-23 J°K-1), and ε_0 is the free space permittivity.

The surface potential and the thickness of the diffuse double layer are both shown to be influenced by the dielectric constant, as shown by equation 1. When the dielectric constant is increased, the number of double layers that are present grows [22, 23]. When it comes to calculating zeta potential, temperature can also be a very important factor to consider [24]. The thickness of the diffuse double layer is influenced by the ionic strength. As ionic concentration increases, the thickness of the double layer decreases [25].

It is a generally held belief that oil recovery may be increased during water flooding by altering the composition of the injected brine. This is typically accomplished by reducing the overall salinity to a level of less than 5000 ppm [26]. A reduction in salinity increases the EDL between crude oil and rock surfaces and also eliminates cations that adsorbed on the surface of rock, which results in release of oil that was previously adsorbed. In addition, a decrease in salinity results in the formation of more negative oil/brine and rock/brine surfaces, which results in an increase in the repulsion forces between the two types of surfaces [27]. Modest gains in oil recovery have been noticed when higher salinity NaCl brine is injected into a core with crude oil and $CaCl_2$ brine of the same ionic strength [28]. This may be due to (i) a change in surface charge due to the different affinities of Na^{+2} and Ca^{2+} cations for clay minerals, (ii) a change in the local PH [29].

The PH of the solution has an effect on the magnitude of the charge that is present on the particles' surfaces. Because of this, the PH of the medium is the factor that has the most impact on the zeta potential. In addition to that, temperature, ionic strength, and additive concentration are all very significant factors to take into account [12]. Although they are quite comparable to one another, the zero charge point (PZC) and the iso-electric point (IEP) are not always the same thing. When H^+ and OH^- ions become the ions that determine the interface potential, the PH value indicates PZC. At the point where there is no net electrical charge on the surface, the point of zero charge is defined as PZC. The zeta potential is often quantified in electrokinetic ideas, and the point at which there is shear plane's zero net charge is regarded as occurring at a zeta potential of zero. This phenomenon is referred to as the Isoelectric Point, in other words, it is the value of pH below which a colloidal particle cannot move when subjected to an electrical field (Figure 2) [30].

It is necessary to determine the PH values that correlate to IEP, in addition to their dependencies on the concentration and composition of a background electrolyte. By doing so, we are able to gain an understanding of the state of the oxide surfaces as well as the nature of the interface interaction [31]. When the salinity is high (more than 0.4 mol.dm3), the value of zeta potential become to be low, non-zero, steady, and limiting (i.e. correlates to $-50 \leq \zeta > 50$ mV). The zeta-offset value is the name given to this number. When the zeta-offset has been achieved, the value of is no longer influenced by the electrolyte's salinity, PH level, temperature, or the additive's specific makeup [32].

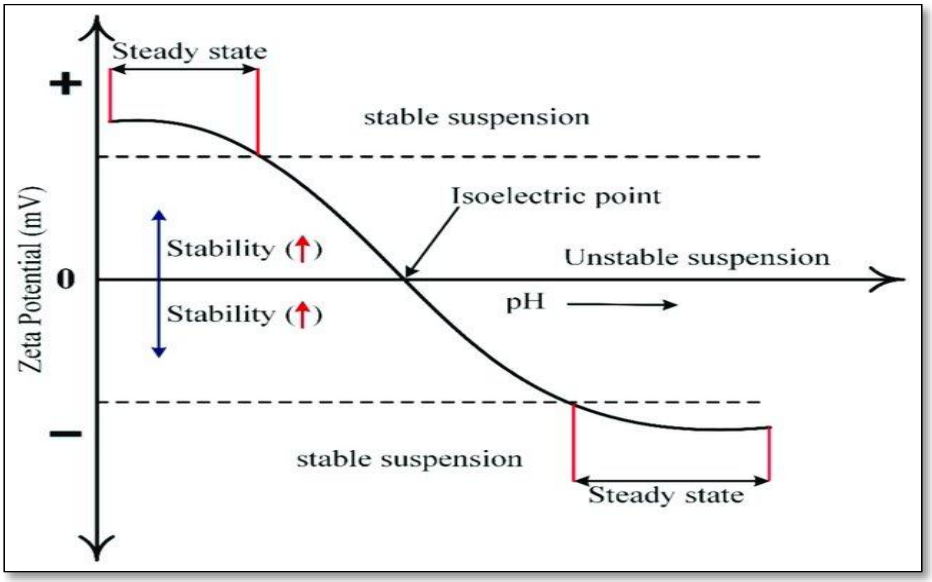

Figure 2: The Relation Between Zeta Potential and PH [30]

6. Zeta Potential in Sandstone and Carbonate Reservoirs

Zeta potential is primarily utilized to quantify the surface and electro-kinetic properties at rock/brine and oil/brine interfaces. The surface charges on rock/brine and oil/brine are the basic features that control the aqueous water film stability on the rock surfaces and then the rock wettability [17]. The water film stability is dependent on the strength of electrical interactions between rock, brine and oil. This charge on the interfaces can be characterized to predict the impact of rock/brine and oil/brine interactions on disjoining pressure, which is a combination of three forces namely structural, electrostatic and van der Waals forces. If the overall resulting balance of forces is repulsive, then disjoining pressure is higher and the two interfaces (rock/brine and oil/brine interface) will be pushed apart thus creating thick water film. The thickness of water films decides oil wet and water wet nature of rock [33, 34].

Using chemicals as surfactants to change the surface properties of sandstone and carbonate can help get more oil extracted from it. By changing the salinity of injection water and adding surfactants (such as sodium dodecyl benzene sulfonate, SDBS, and cetyltrimethylammonium bromide, CTAB), the electrical charge of the sandstone surfaces and the oil–brine interfacial tension has been changed. Low salinity injection brine changes the sandstone surface to a more negatively charged state than high salinity water. So, if the interface between the oil and the brine is negatively charged, it creates strong forces of repulsion that push the oil away from the brine, making it easier for the oil to separate and move. The idea is that SDBS led to more oil being recovered. This is because SDBS makes the surface of the sandstone have a negative zeta potential, while CTAB makes the surface have a positive zeta potential [35]. Overall, the zeta potential in sandstone and carbonate can differ due to differences in surface chemistry, mineralogy, and texture. These differences can have implications for the behavior and stability of the particles in suspension, as well as their interactions with other components in the system.

6.1 Zeta Potential in Sandstone Reservoirs

In general sandstone rocks are composed of silicate minerals while carbonates are composed of carbonate minerals. These minerals have different properties, including surface charge, which can lead to difference in their zeta potential depending on specific conditions such as PH, ionic strength, and the presence of other minerals or impurities. Generally, however, sandstones and carbonates have different zeta potentials due to their different mineral compositions.

In sandstones, the silicate minerals typically have a negative surface charge, which results in a negative charge can help to stabilize the sandstone particles in suspension and prevent them from flocculating or settling out of the liquid which is important in a variety of industrial and environmental applications [43]. For example, a negative zeta potential can help to prevent sandstone particles from clogging pipelines or contaminating water supplies [44]. In addition, the zeta potential in sandstone can also affect the rate of chemical reactions that occur on the surface of sandstone particles, such as adsorption and desorption of ions [29]. Understanding the zeta potential in sandstone can therefore provide valuable information for optimizing processes like oil and gas production, water treatment, and environmental remediation. High zeta potential values in sandstone indicate a high degree of stability, meaning that the clay minerals and suspensions present in the pore water are less likely to settle out. On the other hand, low zeta potential values refer to a lower degree of stability and may lead to the precipitation of minerals and the formation of aggregates that cause problems in oil and gas reservoirs.

In the oil-brine-rock system the wettability state of sandstone can be directly affected by the rock mineralogy [45, 46]. The surface chemistry of sandstone surface depends on the chemical reaction of the mineral group of the surface. Furthermore, the clay content, PH, and brine salinity can influence their surface charge [46, 47]. The overall contribution of these parameters cause the difference in sandstone surface charge [48, 49].

The zeta potential can vary depending on the mineral composition, texture of the rock, and the valence of cations. When it comes to boosting the absolute values of the zeta potential to more negative, monovalent cations are more effective than divalent cations where the divalent cations can enhance flocculation and settling at 25°C and low brine salinity [50]. Saeed et al, [41] conducted a triple-layer modeling study of reservoir parameters' effect on sandstone wettability using low salinity water. They reported that both sandstone and clay minerals have a negative zeta potential. They also concluded that the effect of studied parameters can be ordered: ionic strength and brine composition > PH > temperature > sandstone mineralogy > oil TAN > oil TBN. To understand the impact of electrical surface charge and the extension of double layer on typical sandstone minerals [15] conducted research on four different types of sandstone rocks (Buff Berea, Grey Berea, Parker, and Bandera that contained varying amounts of clay), several minerals (such as quartz, micas, and feldspars), and different types of brines (sea water, 20% diluted sea water, 0.5 wt % NaCl, 0.5 wt% $MgCl_2$, and 0.5 wt % $CaCl_2$) and PH. They found that the impact of salinity on zeta potential in sandstone minerals. Their results revealed that the zeta potential value of sandstone is negative and became more negative with decreasing the salinity. The zeta potential values of Buff Berea and Bandera sandstone particles are significantly affected by changes in solution PH. At any PH between 5 and 10, Bandera has a greater negative zeta potential than Buff Berea. Based on the data, it appears that 0.5 wt% NaCl solutions are generally more stable for most minerals than 0.5 wt% $CaCl_2$ and 0.5 wt% $MgCl_2$ solutions. Using 0.5 wt% NaCl has the greatest effect on the surface charge of feldspars, followed by micas and clays.

Different results was reported by Alarouj et al, [40]. They used four sandstone reservoir samples from Middle Cretaceous Wasia Formation in central eastern Arabia and reported that there were two sandstone samples that have a positive values of zeta potential which is not observed before while the other two have a negative zeta value. Hidayat et al, [42] performed the first-time zeta potentials measurements on intact clayey San Saba sandstone samples saturated with NaCl solutions. They found that all zeta potential values were negative, and the mineralogy (clay content) played a key role in determining the amount of zeta potential. Analysis of the zeta potential of mineral surfaces is used to determine the impact of clay minerals on wettability changes. The wettability of reservoir rock is associated with the adsorption of crude fractions on the rock, however researchers have traditionally focused more on the bulk mineralogy than on the contacting minerals. Multiple minerals interact with crude oil to increase the wettability of rocks. The clays present in reservoir rocks may be contacting minerals in the crude oil, and their surface chemistry is influenced by the brine composition and pH in the reservoir. Knowing the dynamics of these interactions is crucial. Clay minerals' surface chemistry (charge) varies depending on their surroundings because of electrostatic contact or ion dissolution. Clay minerals are amenable to adsorption by polar components of crude oil due to their surface charge and the enormous surface area they give. Surface chemistry of clays in the reservoir can be altered by a variety of well activities such as drilling, water flooding, gas, and surfactants injection. Adsorption requires the presence of opposing charges on the clays and the polar crude oil elements, and charge reversal has been observed in the literature [51].

Vinogradov & Jackson, [38] demonstrated zeta potential measurement in intact natural sandstones at elevated temperatures. Their study revealed that the temperature dependence of the (negative) zeta potential in natural sandstones saturated with NaCl solution depends on ionic strength. The temperature dependence of the zeta potential can be stated by the temperature dependence of the pH, which is recognized to control the surface charge of metal oxides such as quartz. Table 1 summarize some current studies of zeta potential in sandstone.

Table 1: Current Studies of Zeta Potential in Sandstone Rocks

Reference	Rock / mineral	Brine / solution	PH	Zeta	Flooding results
Mahmoud et al, 2015 [36]	Sandstone	HEDTA	< 7 > 7	+ve for Fe -ve for Fe	20%
Shehata et al, 2015 [37]	Sandstone Buff Berea, Grey Berea, Parker, and Bandera	SW DSW	7	-ve -ve -ve -ve	-
Vinogradov & Jackson, 2015 [38]	Sandstone	NaCl electrolytes	<8	-ve	-

Ezzati & Khamehchi, 2020 [39]	Sandstone	Nanofluid	-	-ve	-
Alarouj et al, 2021 [40]	Sandstone	NaCl brine / NaCl + divalent ions	7 6.2	-ve +ve	-
Saeed et al, 2022 [41]	Sandstone	LSW	2-11	-ve	-
Hidayat et al, 2022 [42]	Sandstone	NaCl solution	1-9	-ve	-

6.2 Zeta Potential in Carbonate Reservoirs

The carbonate minerals that make up carbonates almost always have a positive surface charge, which gives carbonates their characteristically positive zeta potential. This charge can also serve to stabilize the carbonate particles that are already in suspension, preventing them from flocculating or settling out of the liquid in which they are currently suspended. In carbonate reservoirs, high zeta potential values indicate a high degree of electrostatic repulsion between mineral surfaces and suspended particles in the reservoir fluid. This repulsion can help to prevent particle agglomeration and deposition that can improve reservoir permeability and enhance oil recovery. However, excessively high zeta potential values may also lead to instability and emulsion formation in the reservoir fluid, which in turn can complicate oil production, and processing. Therefore, maintaining an optimal range of zeta potential values is important for optimizing reservoir performance.

Mohammed et al, [52] examined the impact of sulfate-based scales (anhydrite & barite) on calcite minerals surface charge. Their results showed that the sulfate-based scales did not induce the wettability alteration by themselves where they created a calcite surface negatively charged which is inhibitive of asphaltene adsorption. Also, they reported that adding the chelating agent EDTA could control the sulfate-based scales. Udoh & Vinogradov [54] investigated the effect of brine salinity and biosurfactants composition on IFT, zeta potential and EOR. They found that the rock-brine interface is positively charged when saturated with formation water while the injection of control salinity brine with biosurfactants turned the surface charge to negative and this result in shifting the wettability from oil-wet to water-wet state. Moreover, adding more biosurfactants to CSW leading to increase the negatively zeta potential value. Jackson et al, [53] measured the zeta potential at rock-water and oil-water interfaces in terms of improving oil recovery using controlled salinity water of carbonate rocks. They concluded that if the oil-water is negatively charged, the injected brine composition should be modified to produce more negative zeta potential on rock-water interface through dilution the formation brine or seawater. While if the oil-water interface is positively charged, the injected brine composition should contain more Ca^{+2} and Mg^{+2} ions.

The potential-determining ions on both calcite and dolomite surface have been determined by Derkani et al, [55]. Their results showed that the Calcite particles are negatively charged in water, while dolomite particles had a positive surface charge. However, both calcite and dolomite particles showed similar trends of zeta potential by increasing the salt concentration. Also, they detected Ca^{+2} and Mg^{+2} ions as potential-determining ions for calcite surface and HCO_3^- and SO_4^{-2} anions as strong potential-determining ions for dolomite surfaces. Table 2 summarize some current studies of zeta potential in carbonate rocks.

Table 2: Current Studies of Zeta Potential in Carbonate Rocks

Reference	Rock / mineral	Brine/solution	PH	Zeta	Flooding performance
Mahmoud et al. 2014, [52]	Limestone	EDTA	< 7 > 7	+ve -ve	20%
Jackson et al. 2016 [53]	Limestone	FW SW DSW	-	+ve -ve -ve	-
Udoh & Vinogradov 2019 [54]	Limestone	Biosurfactant & CSB	-	-ve	-
Derkani et al. 2019 [55]	Calcite dolomite	Aqueous Electrolyte Solutions	7 10	-ve +ve	-
Collini et al. 2020 [56]	Limestone	CSW	5-8	-ve	-
Kumar & Mandal, 2020 [57]	Limestone	SW DSW	8 8.5	+ve -ve	11-17.5%
Gopani et al. 2021 [58]	Dolomitic limestone	25% DSW 10% DSW 1% DSW	-	-ve -ve More -ve	20% 21.5% 21.5%
Mohammed et al. 2022 [59]	Calcite	DI SW FW	8.5 7.4 6.2	-ve -ve +ve	-

In summary, zeta potential in sandstone and carbonate rocks have some differences due to different mineral composition and pore structure of the two types of rocks. Here are a few ways in which zeta potential can differ between sandstone and carbonate:

1. Mineral composition: sandstone is composed mainly of quartz and feldspar, while carbonates are composed primarily of calcite and dolomite. The different mineral composition of the two types of rocks can lead to differences in the electrical properties and zeta potential.

2. Pore structure: the pore structure of sandstone and carbonate rocks can also affect zeta potential. Carbonates tend to have a more complex pore structure with a variety of pore sizes and shapes, while sandstone is characterized by a more uniform structure.

3. Ionic strength: the ionic strength of the pore water can also influence the zeta potential in both sandstone and carbonate. In general, carbonates have a higher ionic strength due to the presence of dissolved ions such as calcium and magnesium, whereas sandstones have a lower ionic strength.

4. Surface charge: the surface charge of minerals present in the rock can also influence the zeta potential. Due to the presence of negatively charged sites on the calcite and dolomite minerals, carbonates have more negatively surface charge. In contrast the sandstone has a more neutral surface charge.

7. Methods of Measuring Zeta Potential

The key sources of information for the approach that is widely used to measure zeta potential are the electrokinetic and electroacoustic effects. There are no ways that directly quantify zeta potential; nevertheless, it has been experimentally determined via the electrophoretic mobility (electrophoreses), steam potential, and colloid vibration current (electroacoustic Phenomena).

1) Electrophoretic Mobility:

Electrophoresis is a method that involves moving solid particles relative to liquids while under the influence of external electrical fields. The variable that is being measured is called the electrophoretic mobility, abbreviated as u_e, and it refers to the rate at which particles are transported in response to the presence of electrical fields, denoted by E [60].

$$v_e = u_e \, \mathrm{E} \qquad (2)$$

Then after, the equation of Helmholtz-Smoluchowskie for electrophoresis was being used so that the zeta potential may be calculated [61].

$$u_e = \frac{\varepsilon_0 \, \varepsilon_R \, \zeta}{\mu} \qquad (3)$$

Where ε_r is the dielectric constant or relative permittivity, ε_0 permittivity of free space, and μ viscosity of fluid.

2) Streaming Potential:

The electric potential difference of the current due to the movement of charge through the electrolyte or brine is known as the streaming potential. A solid surface (plug samples) is moved in relation to the electrolyte, which is enclosed in a sealed container. The plug's rims are indicators of streaming capacity [62]. Finding the flowing current may be done in a straightforward manner by comparing the electric current upstream and downstream of the plug. Connecting non-polarizable electrodes to an electrometer recorder with an enough resistance will do this. The inaccuracy introduced by the polarization electrode should be the primary concern when calculating the streaming potential [63]. This occurs when there is a concentration of charges on the electrode's surface. This creates a second double layer, dramatically altering the ion distribution in the sample. An alternative solution would be to utilize electrodes that cannot be polarized.

3) Electroacoustic Phenomena or Colloid Vibration Current Method:

Sound waves are used in the electroacoustic method to determine zeta potential. Two phenomena define their underlying process. When an acoustic wave is sent through a suspension of colloids, a colloid vibration current is produced. This occurs because particles and their surroundings have differing densities. The alternating electromotive force is generated when the charged particles in the suspension move with respect to the liquid as a result of vibrations induced by the propagating wave [63]. Second, the effect is inverted when an electric field perpendicular to the one being applied is applied to the colloidal solution. As particles travel, they set off a sonic wave, the magnitude of which is known as electrokinetic sonic. In both cases, the frequency of the response matches the frequency of the applied field. Since the electroacoustic approach may be used to extremely concentrated dispersions, it offers a substantial advantage [64]. No matter whether the technique is used to test it, the zeta potential will always be the same. There have been several empirical studies showing that all of the methods are roughly equivalent. This study will employ electrophoresis to assess the zeta potential of suspended particles.

8. Conclusions

Based on the review of zeta potential and its impact for enhancing oil recovery in sandstone and carbonate reservoirs, the following conclusions can be made:

- Zeta potential is a crucial factor in understanding the behavior of oil-water-rock systems in reservoirs, as it provides information about the surface charge of rock and oil-in-water suspensions.
- In sandstone reservoirs, high zeta potential values can reduce the stability of oil-in-water emulsions and lead to higher oil recovery.

- In carbonate reservoirs, the zeta potential of rock surfaces affects the wettability of the rock, which in turn affects the oil recovery. The zeta potential can be used to alter the wettability of carbonate rocks, leading to improved oil recovery.

- The use of zeta potential measurements and applications in enhancing oil recovery in both sandstone and carbonate reservoirs holds great promise and is a promising area for further research and development.

- Further studies and developments in the field of zeta potential and its impact on oil recovery are necessary to better understand the mechanisms behind zeta potential and its impact on oil recovery, which can lead to improved production and increased reserves.

- Zeta potential can also be used to optimize the design of oil recovery processes, such as chemical flooding, by controlling the stability of oil-in-water emulsions and the wettability of rock surfaces.

- The relationship between Zeta potential and oil recovery is complex and may be influenced by other factors, such as rock permeability, fluid viscosity, and temperature. Therefore, a thorough understanding of Zeta potential and its impact on oil recovery requires a comprehensive and multidisciplinary approach that considers all relevant factors.

- The development of advanced zeta potential measurement techniques, such as microfluidics and in situ measurements has greatly improved our ability to understand and control the behavior of oil-water-rock systems in reservoirs.

- The integration of zeta potential measurements with other tools and techniques, such as numerical simulations, laboratory experiments, and field tests are essential for a comprehensive and robust assessment of zeta potential and its impact on oil recovery.

- The study of zeta potential and its impact on oil recovery is a rapidly evolving field, and advances in this area are expected to lead to new and improved methods for enhancing oil recovery in both sandstone and carbonate reservoirs.

- In addition to its impact on oil recovery, zeta potential has applications in other areas of petroleum engineering, such as improved understanding of fluid behavior in porous media, rock-fluid interactions, and wellbore stability.

- Zeta potential also has potential applications in other industries, such as water treatment, food and beverage processing, and biotechnology.

- The study of zeta potential has significant implications for both industry and society, as it can contribute to the efficient and sustainable recovery of valuable resources and the development of new technologies for resource utilization and environmental protection.

- The development of new and improved methods for measuring and controlling Zeta potential, and for applying this knowledge to enhance oil recovery, will require interdisciplinary collaboration between experts from various fields, including physics, chemistry, biology, and engineering.

Conflict of Interest: The authors declare that they have no conflict of interest.

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