Petroleum and Coal

Article **Open Access**

A novel approach of fines migration control using nanoparticle through zeta potential measurements

Mohamed Mansour[1], El-Abbas Moustafa [2] Mohamed Eleraki[3] and Ahmed Noah[2]*

[1] *Faculty of Petroleum Engineering, the British University in Egypt*
[2] *Egyptian Petroleum Research Institute (EPRI), Egypt*
[3] *Faculty of Science, Zagazig University, Egypt*

Received March 4, 2020; Accepted June 3, 2020

Abstract

Fines are described in the pores as any unconsolidated or loose particles of the porous media. The formation damage caused by the movement of fines includes the surface contact, the bridging or straining of pores and the sedimentation of infiltration. These fines are small enough to pass through 400 U.S. mesh screen or pore throats causing pore plugging and permeability decline. Different factors affected on fines migration such as flow rate, salinity, pH value, Reservoir temperature, oil polarity and as well as the changes of chemical environment induced by Enhanced Oil Recovery (EOR) agents.

In this study, different concentrations of nanoparticles were used to fix fines on its sources and prevent its mobilization at different flow rates. Different types and concentrations of nanoparticles were used in treating the Abu-Rawash Sandstone reservoir.

Zeta potential values were determined at different concentrations of Nanofluids to observe the effect of nanoparticles on reducing the migration of the rock fines. The results investigated that using MgO and SiO_2 nanoparticles types would minimize the fines migration at high flow rates. The calculation of the dimensionless total interaction energy between fines and separation distance confirmed the experimental results. Total interactions energy shown that the nanoparticle of magnesium oxide with concentration 0.5 g/L has the highest efficiency to reduce fine migration by affecting the surface proper-ties of coated fines onto the grain surfaces in porous medium. Finally, the adsorption efficiency of fines coated with nanofluids, shown that the different concentrations of magnesium oxide nanoparticles has the best ability to attach or contact fines on the grain surfaces compared with the other type used in this study (Silica SiO_2).

Keywords: *Formation Damage; Fines Migration; Nanoparticles; Zeta Potential; Permeability Reduction; Fluid Flow Rate.*

1. Introduction

Zeta potential is a physical property, which used to measure the interaction changes between two particles or a property, which measure the magnitude of the attraction or repulsion forces between particles. The values of Zeta potential provide a good indication of the net charge on the nanoparticle (NP) surface or on the particles coated with nanoparticles. These values can be used as a criterion to determine particles tendency to aggregate in aqueous media. When the charged NP are mixed with liquid, the layers of the opposite charge were attracted on the surface to form thin layer of charged particles called “Stern layer” as shown in Figure 1. This result in formation of electrical double layer force, which is composed, of the Stern layer and diffusive layer. The ions in diffuse layer were moved by the effect of dispersion of the NPs in the liquid phase that result from the application of electrical filed, kinetic energy as long as the gravity. This movement result in formation of boundary between these ions and remaining ions in bulk dispersant. The difference in electrostatic potential between these double layers is called Zeta Potential.

The term Formation Damage is known as any decline in well productivity. Formation Fines are known as the loose or unconsolidated particles in the pore space of the porous media [1].

They are usually small enough reaches to than 37 microns, this small size make it migrate with the fluid flow in sandstone reservoirs causing pore plugging and permeability decline [2-3].

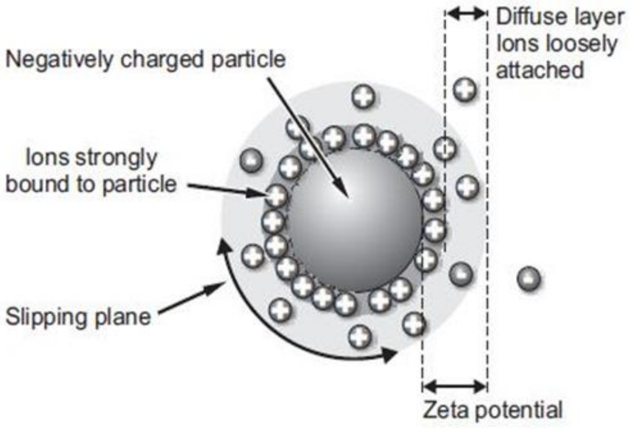


Figure 1. Zeta potential mechanism

These particles can classify as clay and non-clay particles, charged and non-charged particles and either deposited naturally with rock sediments over geologic times or introduced through complex drilling and completion processes.

Khilar and Fogler [4] mentioned that there are many forces affecting on the detachment of fines from grain surfaces. These forces included attractive and repulsive forces. The attraction forces included the "London-Van der Waals (V_{LVA}) and acid-base interaction (V_{AB})" and the repulsion included also the "Electric Double Layer (V_{DLR}), Born (V_{BR}), and hydrodynamic forces (V_{HB})".

They reported that the first factor which effects on fines movement is the salt concentration of the fluid and composition. They performed a critical salt concentration (CSC) and showed that the injected fluid concentration must be higher than the CSC value, to prevent the permeability reduction. Furthermore, other studies stated that higher flow rate [5-6] and lower pH value are the other reasons of permeability reduction.

Lemon *et al.* [7] reported that the change of salinity of the pore fluid is the main chemical mobilization of fines in oil reservoirs. Eleraki *et al*. [8] reported that using MgO nanofluids could prevent the fines migration at high flow rates of production The contact between fresh water and clay-containing formation can make clays expand, migrate and plug so fines might be released easily [6]. In sometimes decreasing salinity of in-situ fluids increases the pH value and once the pH increases it can dissolve the silica cement causing more fines and the result can be fines migration [1].

The fluid inside the reservoir moves towards the wellbore, the fluid velocity increases and at a critical velocity these fines can be move with the fluid and move with it. These fines are captured by porous media and block the pore throat area causing plug of the flow path which leads to productivity decline as shown in Figure 2. This work discuss the effect of flow rates on fines migration and use unique techniques to prevent fines mobilization at high flow rates.

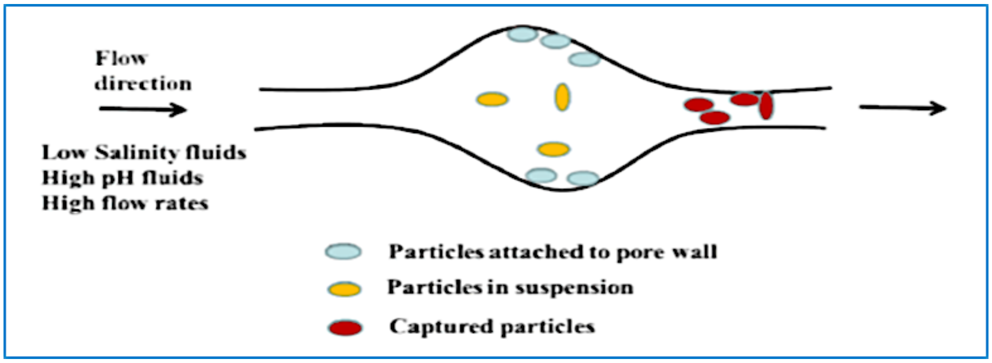


Figure 2. Blockage of the pore throat area by fines migration [10]

Faergestad [9] mentioned that Clay particles found in the reservoir rocks such as semectites, kolinites and illites become unstable as a result of swelling or expansion of lattice space of a clay particle, at low-saline water or fresh water. Clay minerals can expand and increase in volume up to 20 times of their original volume through adsorption of layers of water between their unit cells. The negative charge nature of clay minerals will attract positive ions to align them around the clay plate. Clay lattice cations will exchange places with water solution cations. Clay lattice cations are initially equilibrium with those in surrounding water. As a result of salinity change, the cations exchange process occurs and cause clay particles to swell or break apart and dispersed within the fluid and plug the pore throats.

Khilar *et al.* [4] reported that the hydrodynamic force resulted at high fluid flow rate is the main factor on fines migration. Gruesbeck and Collins first studied the permeability decline above the critical flow rate [11]. So to overcome formation damage due to fines migration, the fluid flow rate must kept less than the critical value of the flow rate. They presented that when the interaction distance between fines and surface of pores are more than nanometer, the born repulsion force is negligible and hence, it is ignored for acid-base interaction, which is one or two orders of magnitude less than Van der Waals attraction and double layer repulsion.

The hydrodynamic forces are neglected, which the effect of gravity forces. Therefore, the final above equation represented only dominant forces are "London Van der Waals" attraction and "double layer" repulsion as shown in the following equation (2):

$$V_T = V_{DLR} + V_{LVA} \qquad \text{Eq. (2)}$$

All effect forces during the fine migration process. The following equation (3) is given for the double-layer potential of a constant potential case, suggesting that pores and fines are similar to the sphere-plate system:

$$V_{DLR} = (\varepsilon * \tfrac{a_P}{4}) \left[2\, \psi_{01}\psi_{02}\, \ln\left(\tfrac{1+exp(-kh)}{1-exp(-kh)}\right) + ({\psi^2}_{01} + {\psi^2}_{02}) \ln(1 - exp(-2kh)) \right] \qquad \text{Eq. (3)}$$

where: a_P *is particle radius,* 10^{-5} *m; H is distance of separation, m; ε is dielectric constant in* J^{-1}*, 6.94257* $e^{-12;}$ *K is Debye length* $\left(\sum_i \frac{n_i^0 e^3 Z_i^2}{k_B T}\right)^{0.5}$ *9.6**$10^{-9})^{-1}$ m^{-1}*.*

The apparent zeta potential (mV) ψ_{01} and ψ_{02} obtained by Zeta potential measurements by using Malvern Zetasiser Version 7.12, for different nano-solution samples. Thus, "London Van der Waals" attraction force for the sphere-plate system is shown in the following Equation:

$$V_{LVA} = \frac{-A_{123}}{6} x \left[\frac{2 * (1+H)}{H * (2+H)} + \ln\left(\frac{H}{2+H}\right) \right]$$

where: $H = \frac{h}{a_p}$ and A_{123} is Hamaker constant between grain surface and the fines, which separated by an aqueous solution, ($6 * 10^{-21}$).

The final dimensionless form of total interaction energy represented as the following equation:

$$V_{T,Dimensionless} = \frac{V_T}{K_B * T}$$

where: V_T is dominant forces $V_T = V_{DLR} + V_{LVA}$; k_B is Boltzman constant 1.38e^{-23}, T is temperature, K.

Nanotechnology was used extensively in recent years in oil and gas industry. The nanoparticles have a high surface area and small size (1-100 nm) gives it the ability to exist in the small pore throats without changing in the porosity and permeability of the formation [12]. Recently nanoparticles are used to mitigate and overcome the fines migration problem.

Reza *et al.* [13] reported that using nano silica with different concentrations can increase the value of the critical flow rate and mitigate the fines migration.

Abhishek *et al.* [14] studied the effect of nano silica on modification the surface of berea sandstone on controlling fines migration. Three types of nano silica were used in the experimental work, silica with a stabilizer (3-mercaptopropyl trimethoxysilane) and sulfonate-functionalized silica. The results investigated that silica NPs could reduce the fines migration and improve water injectivity in the Berea sandstone.

Ahmadi *et al.* [15-17] showed the effects on fines migration of nanoparticles SiO_2, MgO and Al_2O_3 were investigated. The results showed that MgO NPs could control fines movement at different flow rate more than other nanoparticles used. Assef *et al.* [18] reported that using MgO nanoparticles would minimize the formation damage mechanism related to fines migration problem and have the ability to prevent fines migration by a range. Rozo *et al.* [19] Suggested a new technique of utilizing a non-acid based fluid namely fines migration control agent to reduce and prevent the formation damage resulting from fines migration to address the conventional acidization job limitations.

This work using a unique technique on modifying Abu Rawash sandstone by the adsorption of Sio_2 and MgO nanoparticles and this was confirmed by the "Scanning Electron Microscope Imaging". The nanoparticles can be adsorbed on the pore surfaces and reduce the repulsion forces between fine particles and pore or grain surfaces. Zeta potential measurements and the total interaction energy between fines and grain surfaces were calculated. Nanoparticles were used to fixate formation fines and prevent their movement near the wellbore region at high flow rates. The unique technique used in this work to prevent fines movement above the critical flow rate is the changing the potential surfaces between fines and grain surfaces to fix these fines at their sources. Using Nanoparticles with extremely surface areas are an appropriate choice for mobilization of fixate formation fines and changing the potential surface. The nanoparticles used in this study are on the order of ten nanometers (SiO_2 ranges from 5 to 15 nm and MgO ranges from 30 to 40 nm) because of their small size compared with the pore throats sizes, nanoflow doesn't have any effect on blockage of pore throats or reservoir permeability.

2. Experimental work

Two different types of NPs SiO_2 and MgO were used on treating Abu Rawash Sandstone and to reduce the fines movement in the porous media of formations. It shows that MgO NPs is the best one. Injection MgO NPs into the porous medium improves adsorption of fines by 81% more than the reference case. Table 1 shows that the measurement of Zeta Potential values for reference case, coated with SiO_2 and coated with MgO at different nano-fluids concentration with 0.25 and 0.75 % weight of nano-particles.

Table 1. Mean Zeta Potential values for reference case, coated with SiO2 and coated with MgO at different nano-fluids concentration with 0.25 and 0.75 % weight of nano-particles

Experiment test	Mean Zeta potential	Different % with reference case	Mean Zeta potential	Different % with reference case
Nanofluid concentration, %wt.	0.25		0.75	
Reference case	-22.30	---	-22.30	---
Coated with SiO_2	-19.50	12.56	-10.10	54.71
Coated with MgO	-7.32	67.18	-4.20	81.17

The particles stability in nano-fluids affected by the total interactions energy. There are two different types of forces affected on the particles in this nano-fluids, these forces are repressible for detachment of fines from the pore or grain surfaces. These forces include the colloidal forces and hydrodynamic forces [20-21]. The total energy of interactions include two different types of forces, attractive and repulsive forces. These forces include "Electric Double layer repulsion, London van der Waals attraction, Born Repulsion, Acid-Base interaction, and hydrodynamic forces". The total interaction energy calculation between fines and grain or pore surfaces is necessary.

Nano-particles with small sizes relative to the size of the pores and throats sizes, could easily move into porous media without causing decline in the permeability. The effects of different concentrations and types of nano-particles on the reduction of fine migration are also investigated in porous media by using experimental tests. Zeta potential measurements are performed to confirm the certain mechanisms for this phenomenon and to calculate the percentage of permeability remediation by calculating the total interaction energy, attraction and repulsion forces. Figure 3 shows the Mean values measurement of zeta potential with using SiO_2 and MgO Nano-particles at different nano-fluid concentrations.

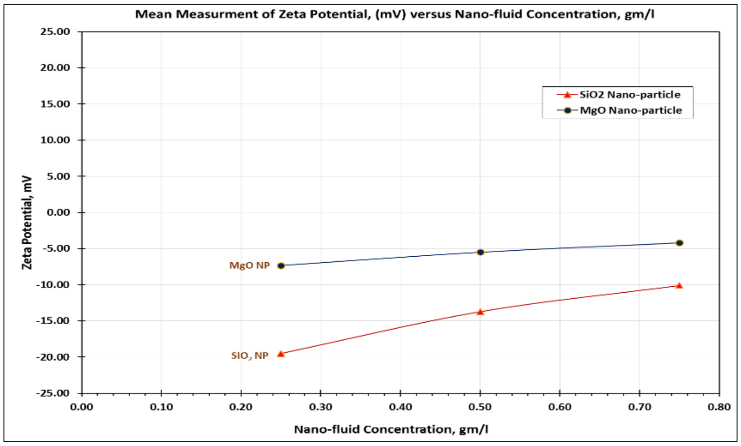


Figure 3. Mean measurement of Zeta potential of SiO_2 and MgO Nano-particles as a function of Nano-fluid concentrations.

Figure 3 shows that, treatment the core samples with MgO NPs is more effective than treatment with SiO_2 NPs as the mean values of zeta potential for MgO give indicate about attraction force more than other NPs used.

The Malvern ZetaSizer (verion 7.12) instrument were used in this study to particle size, Zeta potential and molecular weight. These parameters measured over a wide range of concentrations. The hydro mV and/or LV units has been designed to create a suspension of particles in water or other liquid media. The results section gives four pieces of information such as the mean value of zeta potential (mV), zeta deviation (mV), conductivity (mS/cm) and peak 1 and 2 ψ_{01} and ψ_{02} obtained by using Malvern ZetaSizer Version 7.12, for different nano-solution samples.

The Figures 4 and 5 describe the zeta potential mean values measured by ZetaSizer instrument. These values were given with using different concentration of nanoparticles as well as with the reference case (without treatment with nanoparticles).

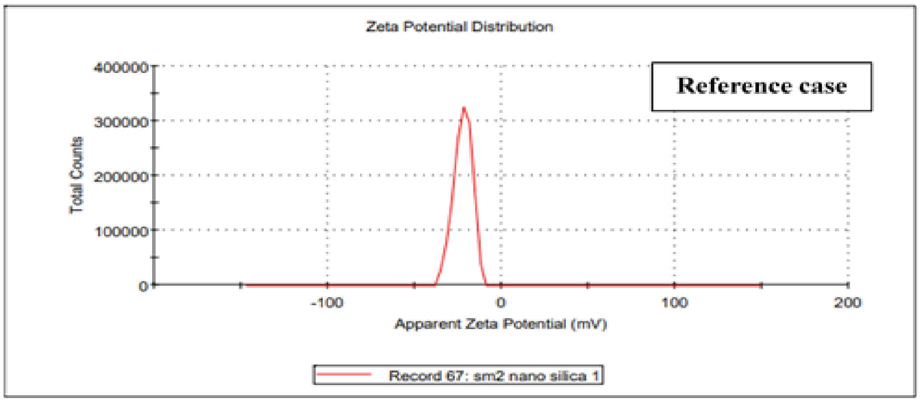
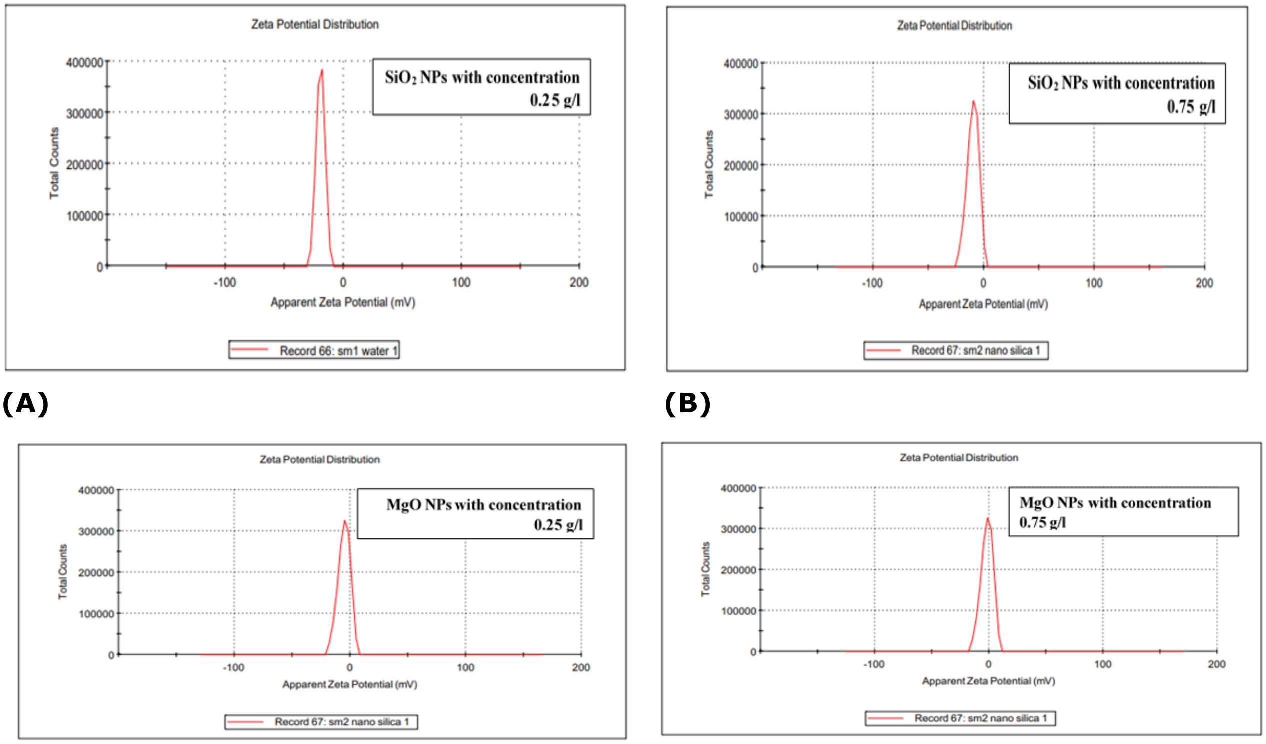


Figure 4. Zeta potential report for reference case of clear from nano-solution sample that measure at ambient condition and shown the result of zeta potential for mean value, mV (-22.3 mV) and graph represent zeta potential distribution.

Figure 5 (A) shows Zeta Potential measurement for SiO_2 nano-particle at concentration nano-fluid of 0.25 g/L. The mean value of zeta potential result: -19.5 mV. The peak 1: -32.0 mV and Peak 2: -7.0mV. Figure 5 (B) shows Zeta Potential measurement for SiO_2 nano-particle at concentration nano-fluid of 0.75 g/L. The mean value of zeta potential result: -10.10 mV. The peak 1: -23.9 and Peak 2: +3.6mV. Figure 5 (C) shows Zeta Potential measurement for SiO_2 nano-particle at concentration nano-fluid of 0.75 g/L. The mean value of zeta potential result: -7.32 mV. The peak 1: -21.12mV and Peak 2: +6.38 mV. Figure 5 (D) shows Zeta

Potential measurement for SiO_2 nano-particle at concentration nano-fluid of 0.75 g/L. The mean value of zeta potential result: -4.20 mV. The peak 1: -18 mV and Peak 2: +9.5 mV.



(A) **(B)**

(C) **(D)**

Figure 5. Zeta potential report from Malvern Zetasizer Instrument while using different nano-solution and concentrations. The result of zeta potential for mean value (mV) and graph represent zeta potential distribution.

The "London van der Waals" interaction energy between two similar particles or bodies for the sphere-plate system is always attractive, and therefore, the interaction between the fine particle and the pore surface structure leads to be stronger. The best expression for the "London van der Waals" energy obtain from the system geometry adoption. Therefore, it is very important to calculate the sphere-plate geometry. The "London van der Waals" energy of interaction has shown in the following Equation [22].

$$V_{LVA} = \frac{-A_{132}}{6} x \left[\frac{2*(1+H)}{H*(2+H)} + \ln\left(\frac{H}{2+H}\right)\right]$$

where: $H = \frac{h}{a_p}$ and A_{132} is Hamaker constant between fine particles an pore or grain surfaces, which separated by an aqueous solution or medium, ($6 * 10^{-21}$).

The attractive potential is represented by the negative sign obtained. While the positive sigh represent repulsion potential. Substantially, the major order in calculating the V_{LVA} is to obtain, an accurate value for the Hamaker constant, A132.

The final dimensionless form of total energy of interaction formula shows in the following equation:

$$V_{T,Dimensionless} = \frac{V_T}{K_B * T}$$

The table 2 shows that the summary of different effective potential forces depending the type of energy and the effect on media and fine migration, pore and particles surfaces (solids and/or fluids).

Table 2. Different effective types of potential forces in fine migration

Force and effective	Symbol	Comment
"Electric double-layer Repulsion force"	V_{DLR}	Its affect
"London Van der Waals Attraction force"	V_{LVA}	Its affect
"Born Repulsion forces"	V_{BR}	Neglectable because of V_{BR} neglected for distances more than 1 nm [4]
"Acid-Base Interaction Attraction force"	V_{AB}	Neglecting because of as distilled water was used for all the experiments
"Hydrodynamic potential Repulsion force"	V_{HR}	Do not affecting

According to the interaction between two colloidal particles, the potential energy of interaction between colloidal particles included two components (a) An attractive potential energy due to van der Waals interactions and (b) An electrostatic potential energy due to electrical double-layer overlap. In addition to the van der Waals, parameter depends primarily on the bulk material properties of the particles and the medium [23].

Table 3. Fitting of zeta potential values before and after peak the graph at low and high concentration 0.25 and 0.75 gm/l for SiO_2 and MgO nano-solutions.

Item parameter	Peak	Reference case	Coated with SiO_2	Coated with MgO
Standard Dev.	----	5.17	3.62	3.47
Zeta Potential value @ 0.25 gm/cc nano-solution, mV	Peak 1, $\psi 01$	-37.0	-32.0	+6.5
	Peak 2, $\psi 02$	-8.0	-7.0	-21.0
Zeta Potential value @ 0.75 gm/cc nano-solution, mV	Peak 1, $\psi 01$	-37.0	+3.6	+9.5
	Peak 1, $\psi 02$	-8.0	-24.0	-18.0

The next following equations represent the interaction potential of double-layer potential force for a sphere-plate system are given below. Thus, the following expressions forms for potential and charge density $V_{DLR}^{\psi-\psi}$ and $V_{DLR}^{\sigma-\sigma}$ [24-25] and for mixed boundary conditions case $V_{DLR}^{\psi-\sigma}$ [23]are written. It can be calculate the Double-layer Potential (V_{DLR}) with the following equations.

Case 1: Constant potential case [24]

$$V_{DLR}^{\psi-\psi} = \left(\varepsilon * \left(\frac{a_P}{4}\right)\right)\left[2\,\psi_{01}\psi_{02}\,\ln\left(\frac{1+exp(-kh)}{1-exp(-kh)}\right) + ({\psi^2}_{01} + {\psi^2}_{02})\ln(1-exp(-2kh))\right]$$

Potential (+ve sign)

Case 2: Constant charge case [25]

$$V_{DLR}^{\sigma-\sigma} = \left(\varepsilon * \frac{a_P}{4}\right)\left[2\,\psi_{01}\psi_{02}\,\ln\left(\frac{1+exp(-kh)}{1-exp(-kh)}\right) - ({\psi^2}_{01} + {\psi^2}_{02})\ln(1-exp(-2kh))\right]$$

Charge (-ve sign)

Case 3: Mixed case [23]

$$V_{DLR}^{\psi-\sigma} = \left(\varepsilon * \frac{a_P}{4}\right)\left[2\,\psi_{01}\psi_{02}\,\left(\frac{\pi}{2} - tan^{-1}\sin\mathrm{h}(kh)\right) - ({\psi^2}_{02} - {\psi^2}_{01})\ln(1+exp(-2kh))\right]$$

The all above equations present analytical expressions of closed-form for V_{DLR} for three different boundary conditions (potential, charge density and mixed of $V_{DLR}^{\psi-\psi}$,$V_{DLR}^{\sigma-\sigma}$ and$V_{DLR}^{\psi-\sigma}$). These equations mentions above are valid for low to moderate zeta potentials values < 60 mV, when the thickness size of the double-layer is smaller than the fine particle size, $k*a_P >> 1$, The above equations were used to determine the dimensionless total interaction energy at different distances between grain surfaces and fines. The total interaction energy is almost attractive for the two types of nano-particles used (SiO_2 and MgO) at all distances.

Table 4.The results of average dimensionless of total energy interaction through the distance between fine and pore surface from 1.0 to 50.0 nm for without coated, SiO2 and MgO nano-particles.

Parameter	Nano-fluid concentration, g/L	Average dimensionless*
Without coated	0	-8.600E-34
SiO_2 Nano-particle	0.25	-6.383E-34
	0.75	-8.489E-34
MgO Nano-particle	0.25	-8.527E-34
	0.75	-8.595E-34

Total Energy Interaction formula, $V_{TDimensionless}$ through the distance between fine and pore surface from 1.0 to 50.0 nm

3. Results and discussion

Nanotechnology has been widely used in many aspects in oil and gas industry. Nano solutions that contain nanoparticles have a unique chemical, electrical and magnetic properties which give it the opportunities to improve oil and gas production by making it easier to separate oil and gas in the rock reservoirs.

The main function of nanoparticles in this work is to reduce the repulsion forces between fines and grain surfaces. The potential surfaces of fines are usually less than the potential surfaces of rock grains, so the nanoparticles injected would have a stronger attractive force with fines than that with rock grains. Therefore, the nanoparticles are coating the fines surfaces rather than the pore surfaces. Adsorption of nanoparticles on the fines surfaces could change the surfaces potential of fines, which consequently reduce the repulsion force between fines and grain surfaces.

Mathematical forms were applied to calculate the dimensionless and total energy of interaction through the boundary conditions for the rock or grains surfaces and confirm the experimental results obtained, which was validated from SEM images for the same core samples.

The different surface forces were found to be responsible for the fines detachment and their release from the pore space surfaces. Electric double-layer attractive forces, London van der Waals attraction, Born repulsion, acid-base energy and hydrodynamic forces are the often forces in the controlling of fines migration or movement from porous media. Therefore, when total interaction energy between pore space surfaces and fines becomes positive, which demonstrates the another repulsive forces are bigger than attractive forces, so the detachment of fines would take place.

To reduce the fines migration or fixing fines on its sources, it should be study the different remediation different techniques for provide the practical recipes to achieve the reduction. The zeta potential parameters at certain concentration of nanoparticles for SiO_2 and MgO samples was measured and the dimensionless total interaction of energy was calculated to verify the results with different cases for constant potential case, constant charged case and the mixed case.

In the previous section, it was measured values of zeta potential at low and high concentrations for each two types of SiO_2 and MgO nanoparticles by Zeta Meter Apparatus (Malvern ZetaSizer Version 7.12) and calculation of the total surface forces affected on the fine and pore surface in the rock. All results, calculations and interpretation has been investigated. In addition to, measure Zeta potential for the Reference case (without coating).

The range of mean result of zeta potential measured with low and high concentration with SiO_2 nanofluids range between (-19.5 mV) to (-10.10 mV), while that result of MgO nanoparticles at low and high concentration, range between (-7.32 mV) to (-4.20 mV). The mean result measured for the zeta potential for reference case without coating, is 22.3 mV.

Computational studies made to compare the electrostatic potential energy interaction for a system of two spherical double layers in the mixed case, dimensionless total energy attractive force, $V^{\Psi-\sigma}$, with that for the constant surface potential, $V^{\Psi-\Psi}$, and the constant surface charge density, $V^{\sigma-\sigma}$ cases. It is shown that the dimensionless total energy of interaction at changeable the distances of separation for different concentrations of Nano solutions with used of SiO_2 and MgO nanoparticles such as 0.25, 0.50 and 0.75 g/L. The improvement of fines adsorption in porous media or grains has been increase with increase of coated nano-solution at concentrations 0.5 and 0.75 % by weight of SiO_2 and MgO, but the best result for dimensionless total potential energy on interaction at concentration 0.5 g/L MgO nanoparticles. Therefore, there is a net attractive potential force between fines and different distance through minerals of porous media surfaces.

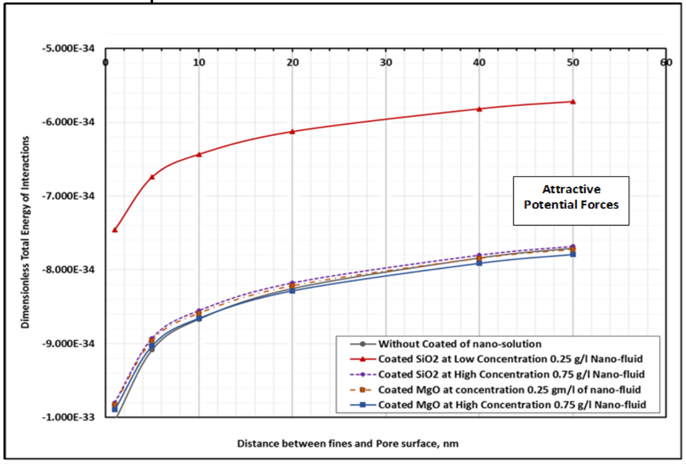


Figure 6.Result of dimensionless total energy of interaction are calculate and determine through double-layer potential for without coated (Reference Case -clear from nano-solution), coated SiO2 and MgO nano-solutions at low and high concentration 0.25, 0.75 gm

The Figure 6 illustrate the results and shapes of electrostatic potential energy with separation distance of closest approach plots for low and high concentrations of nano-solutions, such as 0.25 and 0.75 g/L for SiO_2 and MgO nanoparticles, respectively. However, it has been indicate that the significant improvement of MgO nanoparticle on mitigate fine migration with high concentration 0.5 and slowly 0.75 g/L of nano-solutions.

In Figure 6 (Case 1), the effect of MgO nano-particle at concentration 0.5 g/L on the dimensionless total energy of interaction and calculated the total energy is found in Tables (P-1 to P-5) are validated in Appendix B. from all calculations of $V_{T\ DLT\ dimensionless}$, it should be noted that the Born repulsion becomes negligible at distances more than 1 nm, and also hydrodynamic potential can be neglected because it is important only at high velocity and with large particles compared with the electric double-layer and London van-der Waals potentials

It is clear from the figure that represent the negative sign results of dimensionless total energy of interactions ($V_{T\ DLT\ dimensionless}$) for without coated (reference case – clear from nanoparticles or untreated), coated SiO_2 and MgO nano-solutions at low and high concentration 0.25 and 0.75 g/L, respectively. It was found that a much closed difference change between high concentration 0.75 g/l of SiO_2 and (0.25, 0.75 g/L) for MgO nanoparticles which represent the attractive potential forces (negative sign), but the best and highest effective with 0.75 g/L for MgO nanoparticles.

The results of experiments show that both concentrations of MgO have the best efficiency in remediation of fine migration. The theory of electric double-layer potential and London vander Waals potential has been evaluate the situation of based on attraction forces and zeta potential values, MgO exhibits the most attractive force.

The Figure 7 give results for electrostatic potential energy that are observed on the second case: constant charge density. For such systems, the preceding Equation for case 2: constant charge density should be used to evaluate the electrostatic potential energy. The results in the previous Tables and Figure indicate that use of this case for the interaction of spherical double layers are given the repulsion forces (positive sign), and therefore, the effective surface potential becomes not effect on the improvement of mitigate of fine migration at different separation distance between fine and pore surface. However, the results obtained with the constant surface charge density case and extent to which these limitations also to the situation in which the particles are not identical.

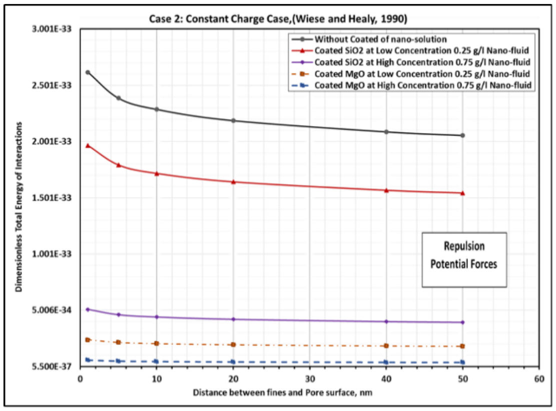


Figure 1. Result of dimensionless total energy of interaction are calculate and determine through double-layer potential for without coated (Reference Case -clear from nano-solution), coated SiO2 and MgO nano-solutions at low and high concentration 0.25, 0.75 gm

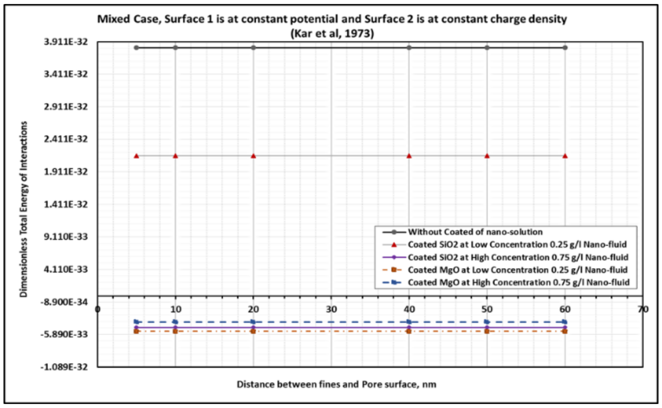


Figure 8. Result of dimensionless total interaction energy calculated and determined through double-layer potential without coated (Reference Case -clear from nano-solution), coated SiO2 and MgO nano-solutions at low and high concentration 0.25, 0.75 gm

The Figure 8 gives results for the electrostatic potential energy, which are intermediate between those for the constant surface potential and constant surface charge density cases. It was found that these calculations of electrostatic energy forces at different parameters such as on pore wall system in porous medium and fines particle.

Simple approaches are available to calculate the dimensionless total interaction energy forces with mixed case. It may be the negative sign accounts for used highest concentration SiO_2 nano-particle and medium concentration for MgO nano-particles that it is an attractive potential, while the reference case (without nano-particle) or low concentration SiO_2 nano-fluids, V_T represented by positive value as a result of the strong repulsion force, which is depend on the type of nano-fluids and nano-fluids concentration. Furthermore, it decays slowly and weak interaction energy between a pair of atoms especially slowly decaying of "London van-der Waals" repulsion force.

4. Conclusions

Two different types and concentrations of nanoparticles were used in this study. Silica dioxide and magnesium oxide nanofluids were used to treat Abu Rawash Sandstone to decrease fines migration and permeability reduction.

The zeta potential measurement, which represent the double-layer potential were used to calculate the total interactions of energy. The Zeta potential results investigated that Injection MgO NPs into the porous medium improves adsorption of fines compared with Sio_2 NPs. The adsorption of fines in case of MgO NPs reaches to 81.17% compared with the reference case. While in case of SiO_2 NPs reaches to 54.71%.

The calculation of the dimensionless total interaction energy between fines and separation distance confirmed the experimental result and showed that the attraction potentials and repulsion forces between fines and pore walls for separation of different distances and effect of coated nanoparticles were improved and compared with different cases in this study.

Total interactions energy shown that the nanoparticle of magnesium oxide with concentration 0.5 g/L has the highest efficiency to reduce fine migration by affecting the surface properties of coated fines onto the grain surfaces in porous medium. Finally, the adsorption efficiency of fines coated with nanofluids, shown that the different concentrations of magnesium oxide nanoparticles has the best ability to attach or contact fines on the grain surfaces compared with the other type used in the study (silica SiO_2).

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To whom correspondence should be addressed: Mohamed Mansour, Faculty of Petroleum Engineering, the British University in Egypt, E-mail: Mansour.Mohamed@bue.edu.eg