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# A Review on Controlling Bentonite-Based Drilling Mud Properties

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## ABSTRACT

Sepiolite nanoparticles were added to the bentonite-based drilling mud to control its properties, and the effects of sepiolite nanoparticles on rheological properties and loss of the bentonite-based drilling mud filtration at different temperature and pressure conditions were examined by experiments. Plastic viscosity, yield point, and fluid loss were measured at different temperature and pressure conditions for the bentonite-based drilling muds with and without sepiolite nanoparticles. The core flooding experiments were also performed under reservoir pressure and temperature, and fluid loss and formation damage were measured. The results indicate that sepiolite nanoparticles can be used to enhance the plastic viscosity and yield point of saline and fresh bentonite-based drilling mud; the bentonite-based drilling mud with sepiolite nanoparticles demonstrates the stability of rheological properties over a wide range of temperature and pressure, particularly at high temperatures and pressures. Moreover, sepiolite nanoparticles decrease fluid loss and the permeability at reservoir pressure and temperature. Sepiolite nanoparticles are an ideal additive for bentonite-based drilling mud.

**KEYWORDS:** Bentonite-based drilling mud, drilling fluid property, High temperature-high pressure; Sepiolite, Nanoparticles

## 1. INTRODUCTION

Bentonite clay is added to the drilling mud as an additive for fluid loss control to provide a fundamental filter cake. Because of the flocculation of bentonite particles, at high temperatures, the flocculation causes the particles to join together to form a loose and open network, which in turn increases filtration and affects the bentonite yields [1]. It has been found that sepiolite mud provides good rheological properties at 200 °C [2]. However, largesize sepiolite mud is not recommended in the drilling industry due to the unacceptable high fluid dissipation [3-4]. Altun et al. [3] reported that sepiolite-based drilling mud has a better performance when the grain size is reduced. The smaller the grain size, the better the sepiolite performance to control the mud rheological properties. The nanoparticles possess special features such as small size (1 to 100 nm), high specific surface area, and high adsorption capacity. For any applications, it is cheap due to the lack of nanoparticles [5]. Nanoparticles were successfully examined to reduce mud permeability in the shale formation [6-7], reduce the mud cake thickness [8], and control the mud rheology at high temperature and pressure [9]. It is possible to resize the nanoparticles to control the drilling mud yields [10]. According to Cai [7], the effective size of nanoparticles to plug a shale cavity is between 3 to 10 nm. All of these previous studies used nanoparticles to prevent the mud filtrate flow into the shale by blocking the formation pores, but the use of sepiolite nanoparticles as drilling mud has not been reported. In the present study, sepiolite nanoparticles ($H_{27.64}Mg_8O_{45.82}Si_{12}$) were added to bentonite-based drilling mud to enhance its efficiency in rheology and fluid loss. Firstly, mineral composition and qualitative analysis of sepiolite nanoparticles were performed using the X-ray diffraction (XRD) system. Then the effects of sepiolite nanoparticles on the rheological properties of drilling mud at different temperatures and pressures were studied.

## 2. EXPERIMENTS

In this study, the average diameter of sepiolite nanoparticles was 50 nm as shown in (**Fig 1**) Three experiments were performed and the methods were described as follows:

1. Experiment 1: To investigate the effect of sepiolite nanoparticles on the rheological properties of bentonite-based drilling mud, plastic viscosity, yield point, and fluid loss were measured at low pressure and low temperature for the bentonite-based drilling mud with and without sepiolite nanoparticles. The experiments were carried out with both fresh water-based drilling muds (600 ml of de-ionized water + 50 g of bentonite) and brine-based drilling mud (600 ml of de-ionized water + 50 g of bentonite + 2% NaCl), respectively.

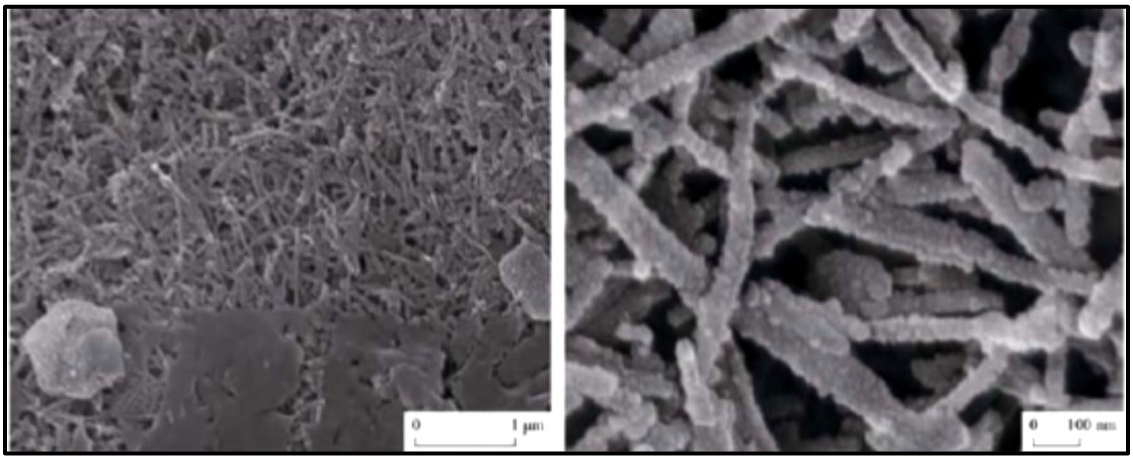


**Fig 1.** SEM images of sepiolite nanoparticles [13].

The different designed drilling mud compositions are shown in (**Table 1**)The yields amount was measured using a FANN viscometer (FANN® Instrument Company, Houston) and the fluid loss was carried out using a filter pressure (FANN® Instrument Company, Houston).

2. Experiment 2: Drilling of deep wells brings big challenges due to changing mud properties under high-pressure and high-temperature conditions. Hence, using an OFITE HTHP viscometer, plastic viscosity, and yield point at high pressure and temperature were measured for bentonite-based drilling mud with and without sepiolite nanoparticles. Bentonite-based drilling mud without sepiolite nanoparticles is composed of ionized water + 7.7% bentonite. Bentonite-based drilling mud with sepiolite nanoparticles is composed of de-ionized water + 6.1% bentonite + 1.4% freshwater nanoparticles. Both of these drilling muds have a pH value of 10.

**Table 1.**The amount of bentonite and sepiolite nanoparticles were added to different drilling muds

| SN | Drilling mud type | Amount of bentonite | | Amount of nanoparticles | |
|---|---|---|---|---|---|
| | | Mass/g | Percentage/% | Mass/g | Percentage/% |
| **1** | | 1.35 | 0.2 | 0 | 0 |
| **2** | | 4.60 | 0.7 | 0 | 0 |
| **3** | | 8.80 | 1.3 | 0 | 0 |
| **4** | Brine | 13.50 | 2.0 | 0 | 0 |
| **5** | Based | 17.00 | 2.5 | 0 | 0 |
| **6** | | 0 | 0 | 1.35 | 0.2 |
| **7** | | 0 | 0 | 4.60 | 0.7 |
| **8** | | 0 | 0 | 8.80 | 1.3 |
| **9** | | 0 | 0 | 13.50 | 2.0 |
| **10** | | 0 | 0 | 17.00 | 2.5 |
| **11** | | 1.35 | 0.2 | 0 | 0 |
| **12** | | 4.60 | 0.7 | 0 | 0 |
| **13** | Fresh | 8.80 | 1.3 | 0 | 0 |
| **14** | Water | 13.50 | 2.0 | 0 | 0 |
| **15** | Based | 0 | 0 | 1.35 | 0.2 |
| **16** | | 0 | 0 | 4.60 | 0.7 |
| **17** | | 0 | 0 | 8.80 | 1.3 |
| **18** | | 0 | 0 | 13.50 | 2.0 |

3. Experiment 3: The samples of sandstone leaf cores were used to compare the amount of fluid loss in the formation and the texture of the damage caused by the bentonite-based mud contamination with sepiolite nanoparticles. The bentonite-based drilling

mud without sepiolite nanoparticles consists of de-ionized water + 7.5% bentonite + 2% Sodium chloride (NaCl). The bentonite-based drilling mud with sepiolite nanoparticles consists of de-ionized water + 7.5% bentonite + 1.3% sepiolite nanoparticles + 2% NaCl. Berea Sandstone samples were the most commonly used homogenous sandstone sample for oil industry research [11]. The primary parameters of the Berea sandstone core are shown in (**Table 2**) The gas permeability was measured using a steady-state gas permeameter (GasPerm, VINCI Technologies, USA). Porosity was measured using Helium Porosimeter (He Porosimeter, VINCI Technologies, and USA). The formation damage caused by mud invasion was investigated using the reservoir apparatus of reservoir formation damage testing at Sultan Qaboos University. Firstly, after the core brine saturation through vacuum drying, the core was loaded and placed horizontally in the core holder. Next, the 10.35 MPa (1500 psi) enclosed pressure was applied to the core. Brine was injected with a flow rate of 0.5 ml per minute and the initial permeability was measured. The mud was circulated at the pressure of 1.04 MPa (150 psi) from the other side of the core. The displacement of muds was for 6 hours and the standing time was 6 hours, and the dynamic and static filtration rates were measured. Finally, brine was injected and the permeability of the recycle was measured. The core flooding experiments were performed at 60 °C.

**Table 2.**Core dimensions, porosity and permeability.

| **Core number** | **Length/mm** | **Diameter/mm** | **Permeability/mm** | **Pore volume/mm** | **Porosity/%** |
|---|---|---|---|---|---|
| 1 | 76.42 | 37.92 | 36.57 | 11.35 | 13.16 |
| 2 | 78.30 | 37.92 | 48.82 | 12.47 | 14.11 |

## 3. RESULTS AND DISCUSSIONS

### 3.1. Experiment 1

(**Fig 1** and **Fig 2**) show the differences in plastic viscosity and yield point of bentonite-based mud with and without sepiolite nanoparticles at room temperature and pressure, respectively. Both parameters were improved by adding sepiolite nanoparticles to the bentonite-based drilling mud. The higher yield point means more ability of the drilling mud to the lift cuttings. Hence, adding sepiolite nanoparticles to the mud enhances the cutting ability compared to adding bentonite alone. Our results also showed that due to the flocculation of bentonite clays, the amount of bentonite-based drilling mud reduces after adding 2% NaCl. Furthermore, our results showed a reduction in bentonite-based drilling mud’s yield after adding 2% NaCl due to the flocculation of bentonite clay. Arieh et al. [12] demonstrated that sepiolite has a stable structure for controlling the rheological properties of drilling mud even in systems with high salt content. (**Fig 4**) shows the difference of the fluid loss in bentonite-based with and without sepiolite nanoparticles at room temperature and pressure of 0.69 MPa (100 psi). This indicates that in fresh water-based drilling mud, fluid loss is not reduced by adding sepiolite nanoparticles. In the salt-based drilling mud, fluid loss even increases by adding the sepiolite nanoparticles. Therefore, sepiolite nanoparticles are not as effective as a fluid loss controller at low pressure and low temperature. Salt addition significantly increased the fluid loss for bentonite-based mud with and without sepiolite nanoparticles. However, as shown in (**Fig 5**), adding starch as an additive to the filtration control reduced the fluid loss of up to 36% of bentonite-based mud with sepiolite nanoparticles.

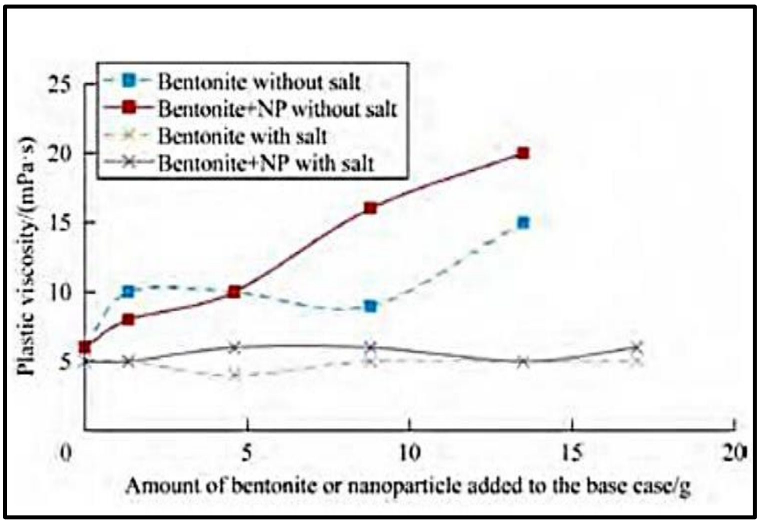


**Fig 2.**The effect of sepiolite nanoparticles on viscous stains of plastic viscosity [13].

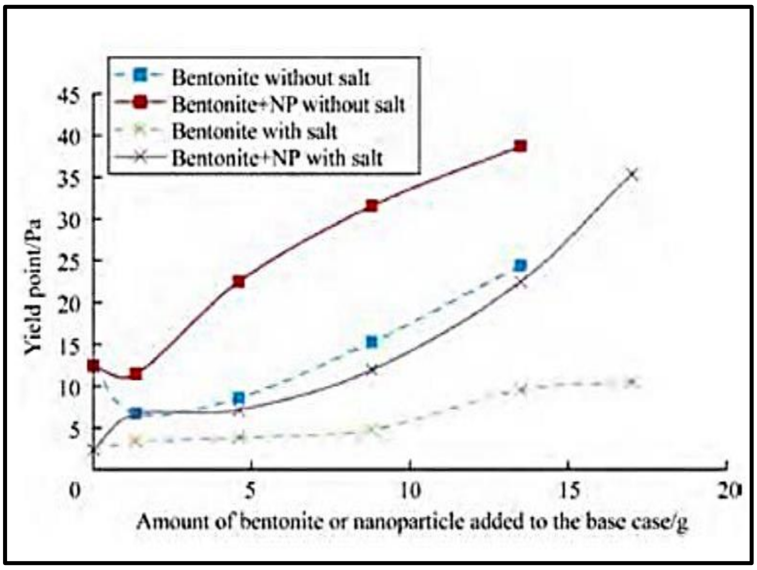


**Fig 3.** Effect of sepiolite nanoparticles on the yield point of drilling mud [13].

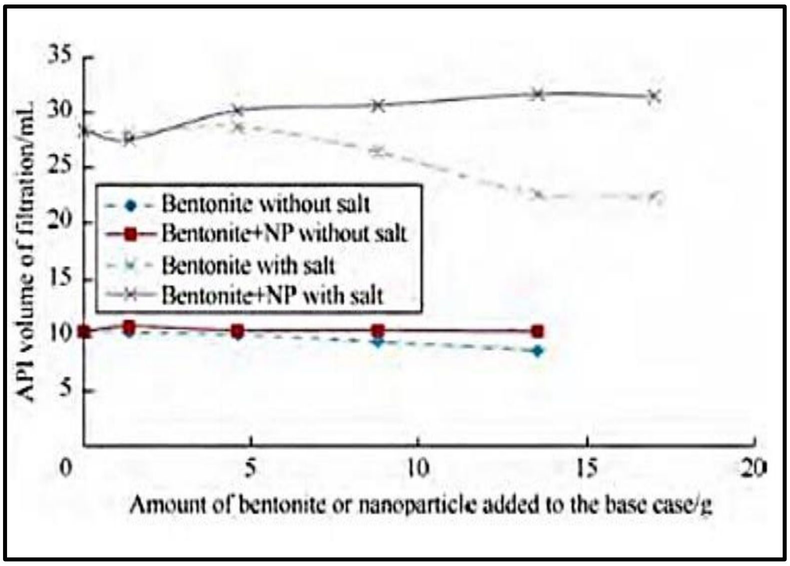


**Fig 4.** Effect of sepiolite nanoparticles on fluid loss of drilling mud [13].

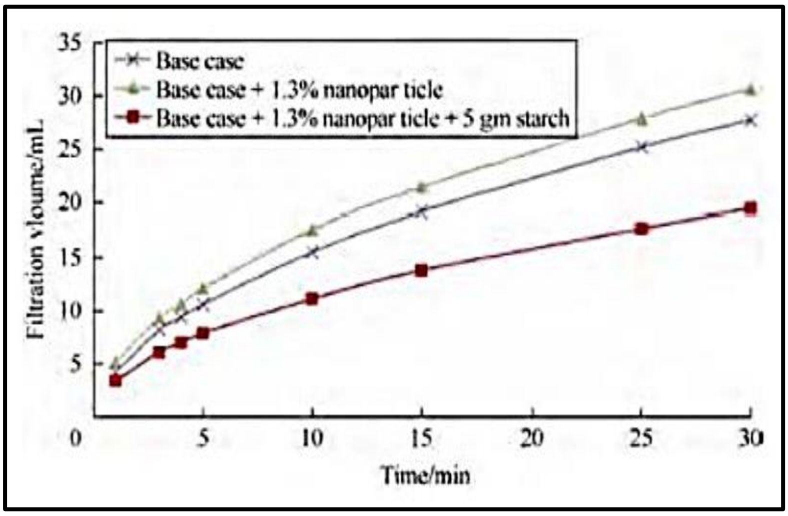


**Fig 5.** Effect of filtration control additive on fluid loss of drilling mud with sepiolite nanoparticles [13].

### 3.2. Experiment 2

The mud features change with the deepening of the well into the formation as it faces a gradual increase in temperature and pressure. (**Fig 6** and **Fig 7**) show the effect on the rheological property of bentonite-based mud with and without sepiolite nanoparticles at a temperature of 50 °C and a pressure of 41.37 ± 3.45 MPa. We note that the rheological property of bentonite-based mud is not stable at increasing temperature and pressure. The plastic viscosity and yield point are also fluctuating and unpredictable. The plastic viscosity and yield point vary from 0 to 135 MPa and 0 to 74.2 Pa, respectively. As shown in (**Fig 6**) and (**Fig 7**), after adding sepiolite nanoparticles to the bentonite-based mud, the plastic viscosity changes from 15 mPa.s to 40 mPa.s and the yield point varies from 0 to 14.2 Pa at any temperature and pressure. This paper demonstrates that sepiolite nanoparticles can stabilize the plastic viscosity and bentonite-based mud's yield point at great temperatures and pressures.

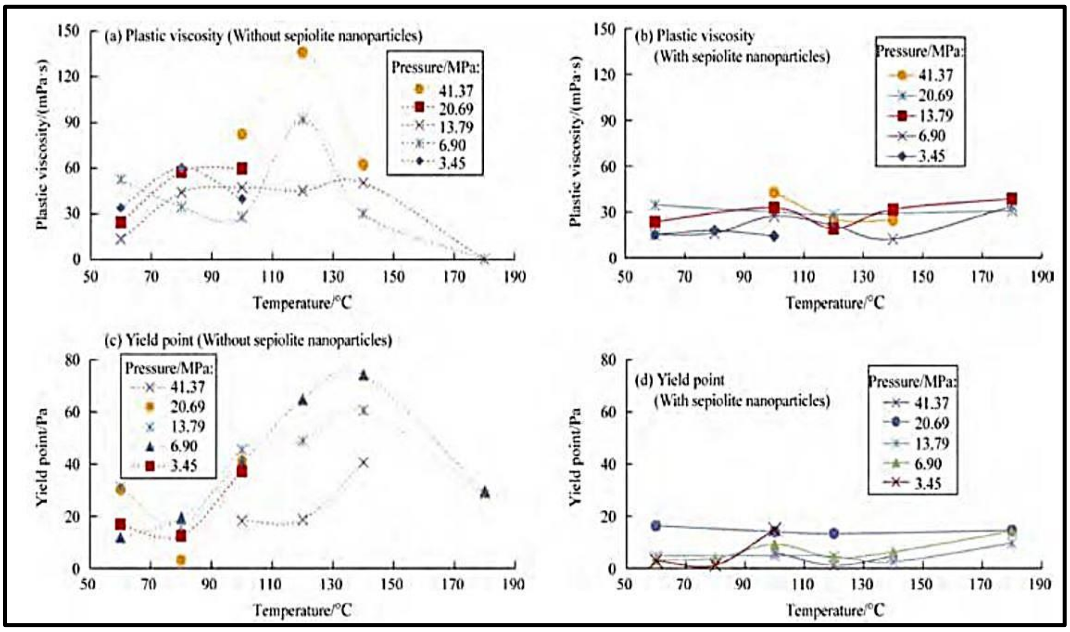


**Fig 6.** Effect of increasing temperature on the rheology of the bentonite-based mud with and without sepiolite nanoparticles [13].

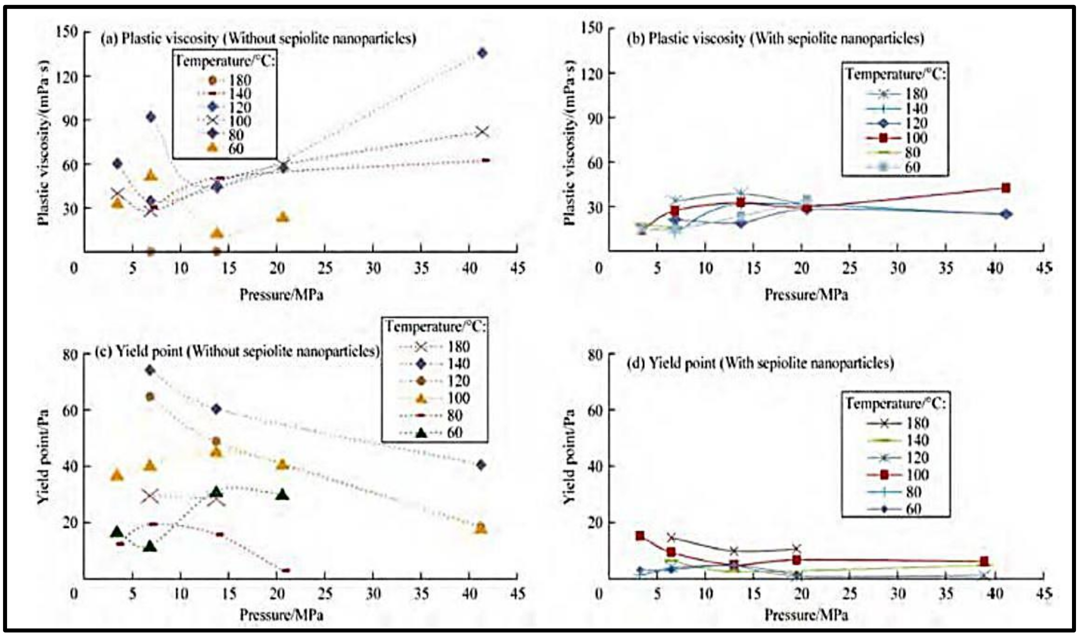


**Fig 7.** Effect of increasing pressure on the rheology of the bentonite-based mud with and without sepiolite nanoparticles [13].

In general, for the field use, the plastic viscosity should be less than 35 mPa.s, and the yield point should be 7.1-14.2 Pa [13].

### 3.3. Experiment 3

As shown in (**Fig 8**), the fluid loss decreases by 15% after adding sepiolite nanoparticles to the bentonite-based mud at a reservoir temperature of 60 °C and a reservoir pressure of 10.35 MPa. They block the sandstone pores and prevent more permeability of bentonite particles into the sandstone formation.

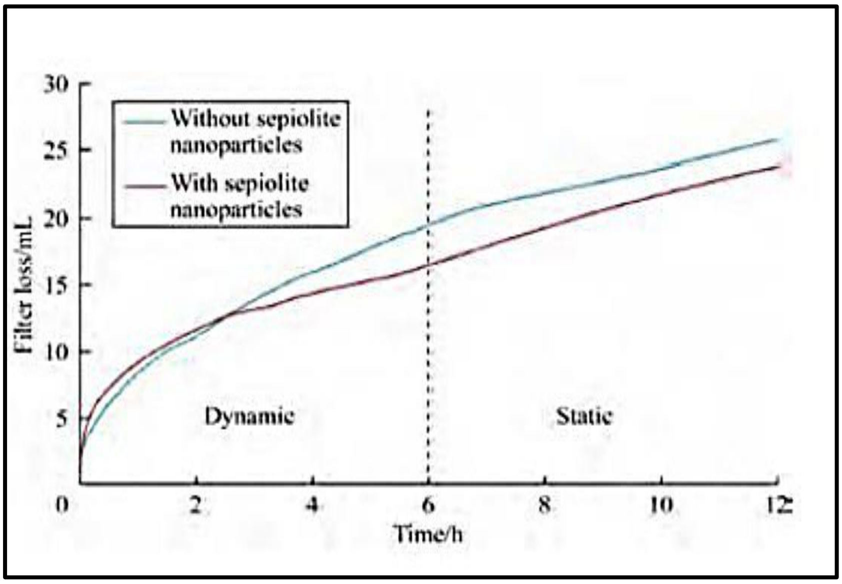


**Fig 8.** Comparison of fluid loss for brine bentonite-based mud with and without sepiolite nanoparticles at reservoir temperature and pressure.

As shown in (**Fig 9**), before permeability into the core, pore space is clean without bentonite or sepiolite nanoparticles. Stains related to bentonite-based mud without sepiolite nanoparticles invaded deep into the formation and according to (**Fig 10**), were observed at the wellbore side (injection side). As shown in (**Fig 11**) bentonite particles were not observed at the wellbore side after the circulation of bentonite-based mud with sepiolite nanoparticles, where the extended particles are sepiolite nanoparticles. Hence, nanoparticles plugged the sandstone pores and reduced the permeability of bentonite particles into the formation. Bentonite clay cumulated at the formation surface and formed the filter cake, which reduced the fluid loss. (**Fig 12**) and (**Fig 13**) show that no bentonite nanoparticles exist at the formation side (exit side) after core flooding by the bentonite-based drilling mud with and without sepiolite nanoparticles.

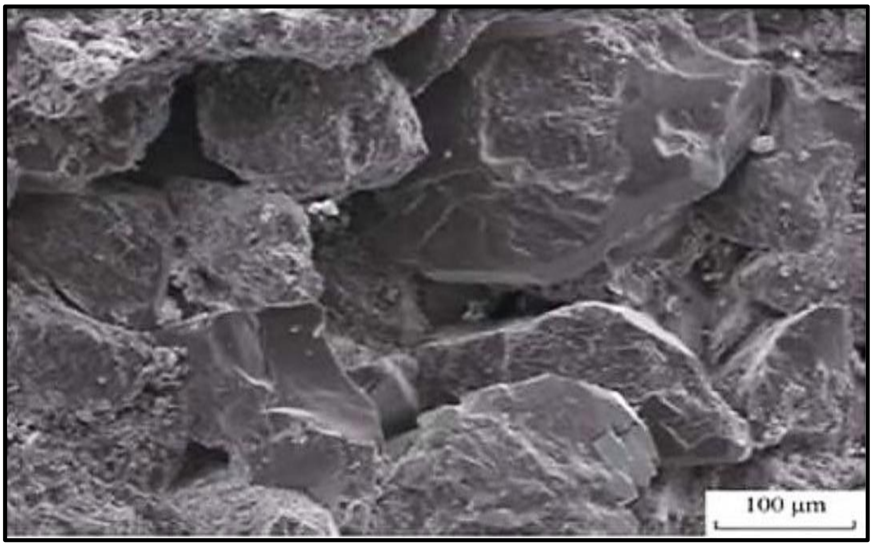


**Fig 9.** SEM images of the core samples before mud circulation [13].

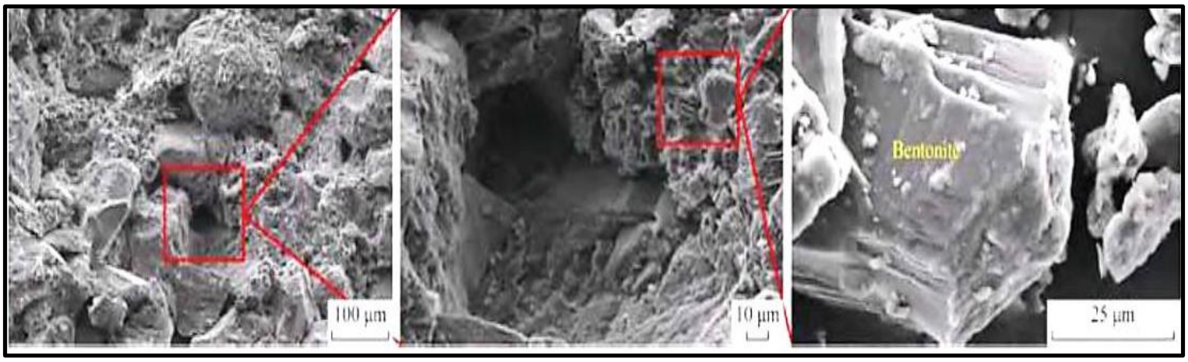


**Fig 10.** SEM images of the cores after the circulation of bentonite-based mud without sepiolite nanoparticles (wellbore side) [13].

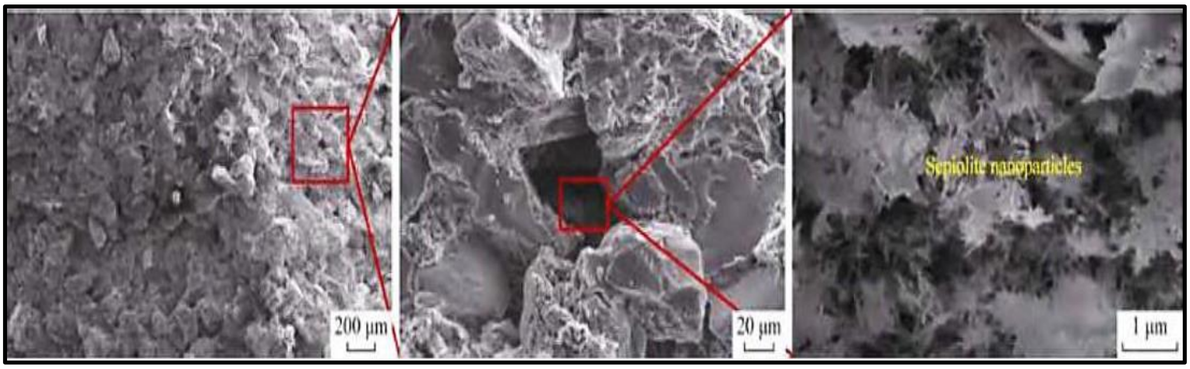


**Fig 11.** SEM images of the core after the circulation of bentonite-based mud with sepiolite nanoparticles (wellbore side) [13].

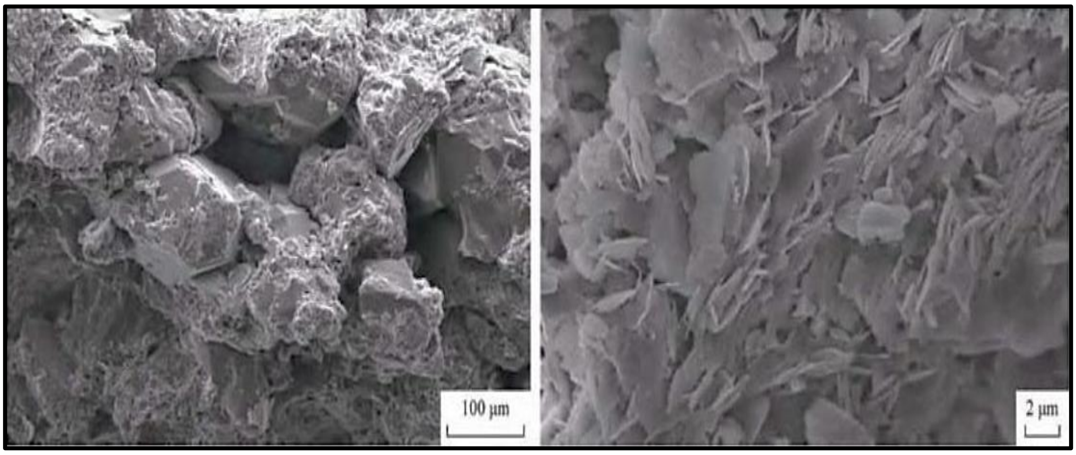


**Fig 12.** SEM images of the core after the circulation of bentonite-based mud without sepiolite nanoparticles (formation side) [13].

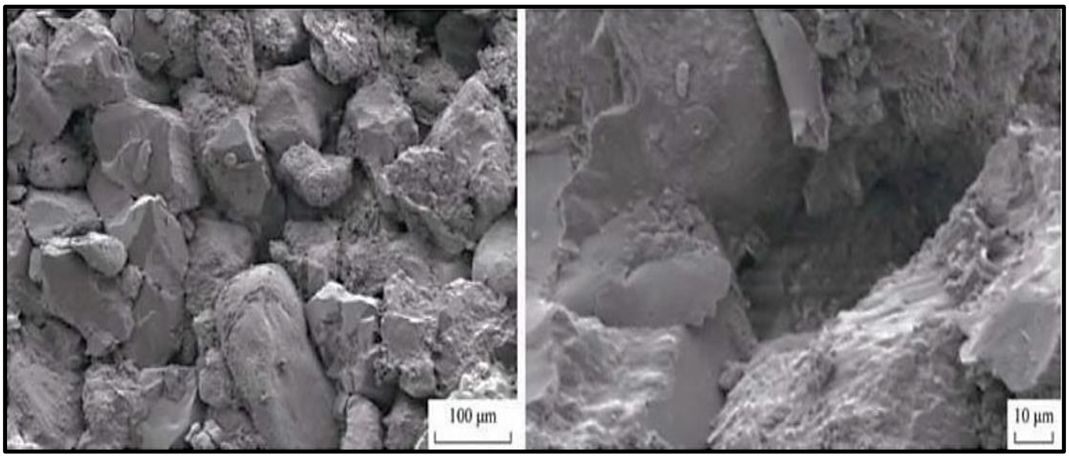


**Fig 13.** SEM images of the core after the circulation of bentonite-based mud with sepiolite nanoparticles (formation side) [13].

**Table 3:** Comparison of permeability reduction due to the bentonite-based mud with and without sepiolite nanoparticles.

| **Mud type** | **Initial permeabilit/$10^{-3}$ µm$^2$** | **Recovery permeability/ µm$^2$** | **$10^{-3}$** | **Permeability reduction/%** |
|---|---|---|---|---|
| Bentonite-based mud without sepiolite nanoparticles | 19.87 | 6.62 | | 66.7 |
| Bentonite-based mud with sepiolite nanoparticles | 27.83 | 15.79 | | 43.3 |

That is due to the hardness of the sandstone core and the formation of the filter cake at the core surface, therefore solid particles won't have a high amount of invasion. As shown in (**Table 3**), the reduction of sandstone permeability due to the bentonite-based mud with silicon chloride nanoparticles is lower than mud without sepiolite nanoparticles by 23.4% (**Table 3**), which shows a significant reduction in the formation damage.

## 4. CONCLUSIONS

The plastic viscosity and yield point of bentonite-based mud have improved through adding sepiolite nanoparticles to freshwater or brine-based mud, which shows that the sepiolite nanoparticles can be viscosifier and shear strength enhancing agent with a more ability of the drilling mud. Sepiolite nanoparticles are not considered as a fluid loss controller at low pressure and low temperature. However, adding starch as a filtration control additive can noticeably cause the reduction of the filtration of nanoparticles without bentonite.

Bentonite-based drilling mud with sepiolite nanoparticles indicated excellent stability in plastic viscosity and yield point over a wide range of temperatures (50–180 °C) and pressure (3.45–41.37 MPa), particularly at high temperatures and pressures. Adding sepiolite nanoparticles could decrease the fluid loss of bentonite-based mud by 15% at reservoir conditions of temperature and pressure. The reduction of sandstone permeability due to the bentonite-based mud with sepiolite nanoparticles was lower than that of mud without sepiolite nanoparticles by 23.4%. As an additive for bentonite-based mud, sepiolite nanoparticles are effective to stabilize the rheological properties of drilling mud and reduce the fluid loss and the formation damage.

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