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Laboratory Investigation of the Water Trapping Phase Phenomenon in Powdered Cores Based on Reservoir Rock Cuttings and Remediation by a New Alcoholic-Treated Water Mixture

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Abstract

Water trapping typically occurs during the drilling process when a sizable volume of drilling fluid is exposed to the area around the wellbore. This phenomenon, which is poorly studied and investigated by few studies, represents the gap in this work. The trapped water causes a reduction in the flow of oil. By lowering the interfacial tension, products such as alcohols and cationic surfactants have been used to reverse the rock's wettability through adsorption, thereby reducing the trapped water saturation. Samples based on reservoir rock cuttings with a determined porosity of 12.72°C and permeability of 12.54 md were used to simulate low-porosity and low-permeability sandstone reservoirs. In this work, an alcoholic-treated water mixture is injected into samples that were initially saturated with simulated oil under experimental conditions. The interfacial tension reduction, which was less than 1 mN/m, was evaluated using Tate's method. Additionally, the results obtained demonstrated that butanol exceeds laboratory experiences at a mere 20% concentration and enables maximum water recovery. The results of this work can be used to improve understanding of the trapped water phenomenon in water mixtures treated with alcohol and fractured reservoirs.

Keywords: *Trapped water; Alcohol; Surfactant; Relative permeability; Interfacial tension; Oil recovery.*

1. Introduction

Water removed following a drilling operation in a low permeability reservoir that reduces relative permeability is referred to as trapped water [1-2]. Ultimately, tight reservoir recovery will be cooperative in order to prevent an energy crisis in the future [3]. Water-based drilling fluids are most commonly used when wellbore fluid loss is a common problem during drilling operations [4]. Drilling fluid filtration has a major impact on formation damage, and different additives have been used to address this problem [5]. The near-wellbore drilling fluid invasion causes large losses in the timely recovery of the reservoir [6-7]. The high water saturation near the wellbore prevents oil from flowing from the reservoir to the well [8]. The efficacy of surfactant injection and hydraulic fracturing in lowering water retention has been established [9]. Alcohols and surfactants have been used as a solution to reduce water retention in order to maintain lower irreducible water saturation [10]. Various gels and particulates as chemical additives have been used to illustrate fluid loss control techniques [11-13]. Furthermore, emulsion outperformed conventional fluid loss control agents in terms of benefits [14]. Emulsions also have a propensity to occupy the deeper reservoir and undergo deformation, which has a variety of advantageous effects on the management of fluid loss [15]. Biodiesel has become one of the most successful materials for oil well stimulation because it is renewable [16]. Therefore, our work differs from previous research in that it uses a novel experimental simulation of tight reservoir with new powdered samples based on reservoir rock cuttings and a new alcoholic mixture to be injected into powdered cores to prevent water trapping. Cuttings were needed to rebuild the matrix of the sandstone reservoir. The impact of the water trapping phenomenon in low porosity and low permeability sandstone reservoirs on oil recovery after filtration during the aqueous drilling phase and the subsequent injection of an alcoholic treated water mixture for remediation is investigated in this study. The results of the study support better decision-making when it comes to the use of water-based mud circulation during the drilling stage in order to avoid oil retention near the wellbore.

2. Materials and methods

2.1. Reservoir rock cuttings

An oil field in Algeria supplied the reservoir rock cuttings, which functioned as a porous medium for each experiment. The samples' average porosity is 12.72 % and permeability is 12.54 md. We chose to focus on the cuttings because they have characteristics and surface chemistry in common with low porosity and low permeability reservoir rocks.

2.2. Samples preparation

After being cleaned with toluene for 48 hours, the cuttings samples were rinsed with distilled water to remove any leftover fluid. After being cleaned, the samples were dried for two hours at 110°C in a vacuum oven to get rid of the toluene that was used in the procedure. Crushing the cuttings produced samples that were uniformly powdered. Following that, a shaker Control vibratory sieve was used for sieving. After the grain size distributions of the powder were analyzed, a fraction collected between (0.1 – 0.4) mm was used in the experiments.

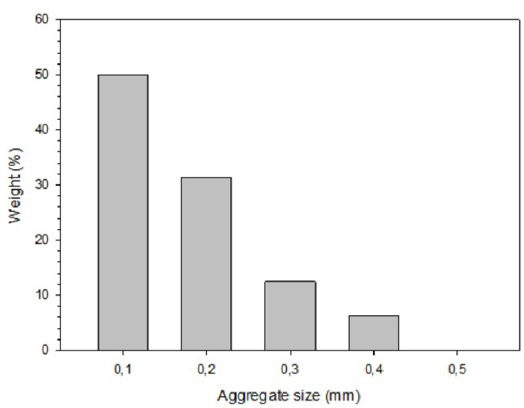

Figure 1. Histogram representation of aggregate size distribution of powdered reservoir cuttings.

Figure 1 displays the findings of the analysis of the powdered drilling cutting's grain size where the weight in terms of percentage. Using a Seifert XRD 3003 TT X-ray diffraction system, samples were analyzed using X-ray technology. In order to determine the samples' mineralogical composition, the XRD pattern was measured for 2θ within the 10° to 60° range. The X-ray diffractometer reveals that quartz makes up 58.29% of the samples, with minor impurities including calcite (1.65%), gypsum (12.63%), and illite (24.10%).

2.3. Gasoil

Gasoil, which is purchased by Naftal Company, is the used oil. Table 1 displays gasoil's characteristics.

Table 1. Properties of gasoil (Bergane and Hammadi, 2020)

Density at 15°C	0.828 g/cm^3
Dynamic viscosity at 20°C	5.6 mPa s
Surface tension at 20°C	30 mN/m
Flash point	88 °C
Pour point	- 14°C
Initial boiling point	152°C
Final boiling point	320°C

2.4. Brine

A saturated synthetic brine solution was used for all experiments, which involved dissolving 320 g of sodium chloride (NaCl) in 1000 mL of distilled water.

2.5. Alcoholic-treated water mixture

A microemulsion was created using water, ammonium chloride, and butanol. We conducted our tests using two different surfactants: quaternary ammonium salt, which is an organic cationic surfactant and a potent oil-wetting agent, and Diacel MS-1 Mutual solvent, which is supplied by Chevron Phillips Company LP.

3. Experimental procedures

An alternative drainage tank, a cylindrical sample holder measuring about 6 cm in length and 3.3 cm in diameter, an inlet/outlet pressure gauge, a microvalve, and a graduated cylinder to receive the recovered fluid was all used in the experiments conducted in the micromodel (Figure 2). Based on a direct reading of the pressure value that indicates the gauge, the differential pressure was determined. The micromodel was cleaned to ensure that no oil was left over from the previous run before each test was conducted.

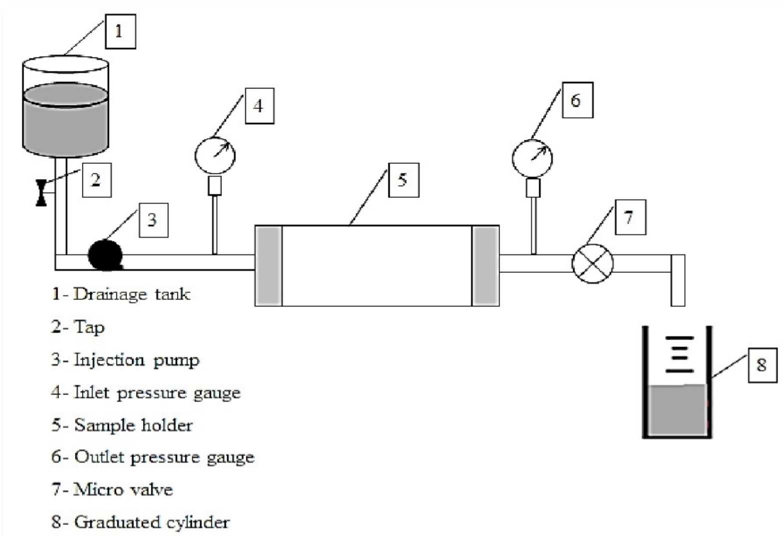

Figure 2. Micromodel of experimental setup for the displacement tests (25ºC).

We suggest using an alcoholic treated water mixture in this work. This mixture was created step-by-step by adding the products listed in Table 2 while being stirred (at 500 rpm) for two hours at room temperature using an AREC magnetic stirrer.

3.1. Porosity and relative permeability measurement

Weighing the dry sample and fully submerging it in brine allowed us to determine the porosity. The measurement of porosity is done by:

$$\phi = (m_s - m_d)/m_s \quad (1)$$

where ϕ is porosity (%), m_s is the saturated mass (g), m_d is the dry mass (g).

The steady state method is employed in the experiments to measure the relative permeability of oil to water. One of the preferred approaches, the steady-state approach is thought to be more precise and dependable.The steps for the relative permeability experiment are as follows.

To measure the absolute permeability, the sample would first need to be completely saturated with brine. After that, oil is injected into the sample to achieve irreducible water saturation by draining the brine out of it. After that, brine and oil are injected at the same time.

Water-oil relative permeability is calculated using generalized Darcy's law once the system reaches a steady state and the data are recorded.
The empirical model of Darcy in horizontal flow is written:

$$Q_o = (k_{ro}*k*A*\Delta P_o)/(\mu_o*L) \quad (2)$$

$$Q_w = (k_{ro}*k*A*\Delta P_o)/(\mu_o*L) \quad (3)$$

where Q_o is the volumetric oil flow rate (cm^3/s); Q_w is the volumetric water flow rate (cm^3/s); K_{ro} is the relative permeability of oil (D); K_{rw} is the relative permeability of water respectively (D); k is absolute permeability (D); L is sample length (cm); μ_o is oil viscosity (cP); μ_w is water viscosity (cP); A is the cross-section area of the sample (cm^2); ΔP_o and ΔP_w are differential pressure of oil and water respectively (atm).

3.2. Trapped water process simulation

In a linear flow micromodel, sample flooding tests were carried out for the simulation of the trapped water process. To achieve the restored state, the mounted sample was first saturated with brine and then desaturated with oil. Subsequently, oil was injected from the inlet end of the sample and injection brine was flooded from the outlet end. The impact of trapped water on oil recovery was assessed by measuring the tested sample's oil recovery at a room temperature of 25˚C using an inlet pressure. After being individually treated with an alcoholic-treated water mixture, the restored sample is submerged in oil.

3.3. Interfacial tension measuring

The drop-weight method is a straightforward and precise way to measure surface tension. Tate (1864) described a procedure that resulted in an equation that is now known as Tate's law:

$$m*g = 2*\pi*r*\gamma \quad (4)$$

where m is the drop weight (kg) (to get a precise measure, this is done for some 22 drops and this number divides the total weight), g is the acceleration of gravity (m/s^2), r is the external radius of the capillary (m), and γ is the interfacial tension of the liquid (N/m). The surface tension with different concentrations of alcohol in the mixture was measured.

4. Results and discussion

4.1. Porosity and permeability experiment results

The sample of powdered rock that was being examined has been cleaned, dried, and removed. The sample measured 4.54 cm in diameter, 11.18 cm in length, and 180.94 cm3 in bulk volume. Next, the liquid intrusion was used to determine the sample's porosity. Table 3 shows that the sample's porosity was 12.720%. In order to ascertain the relative permeability of water and oil, measurements of absolute and effective permeability were made. Table 4 shows that the low permeability of the water indicates that the oil is actually blocked in the reservoir due to its trapping around the near-wellbore (water-wet medium).

4.2. Trapped water effect on oil recovery

The distribution of fluid in the porous medium is equal to the pore volume of the rock. Figure 3 shows that oil recovery decreases with increasing inlet pressures; the incremental oil recovery decreases from 7.889 mL to 0.782 ml. There are two explanations for this phenomenon [17]. The first one relates to the reservoir's geological characteristics, fluid distribution, the interfacial tension between the water and oil phases, and the physical characteristics of the two phases. The second one relates to production and exploitation that is caused by humans. In a tight sandstone reservoir, the initial water saturation is less than the bound water saturation [18]. In actuality, under excessive capillary pressures in the porous medium, oil is readily drawn into the pores during the oil inlet injection process [19]. At first, the sample is wet with water. In order to stop the production of oil, water outlet end injection will trap it in the reservoir.

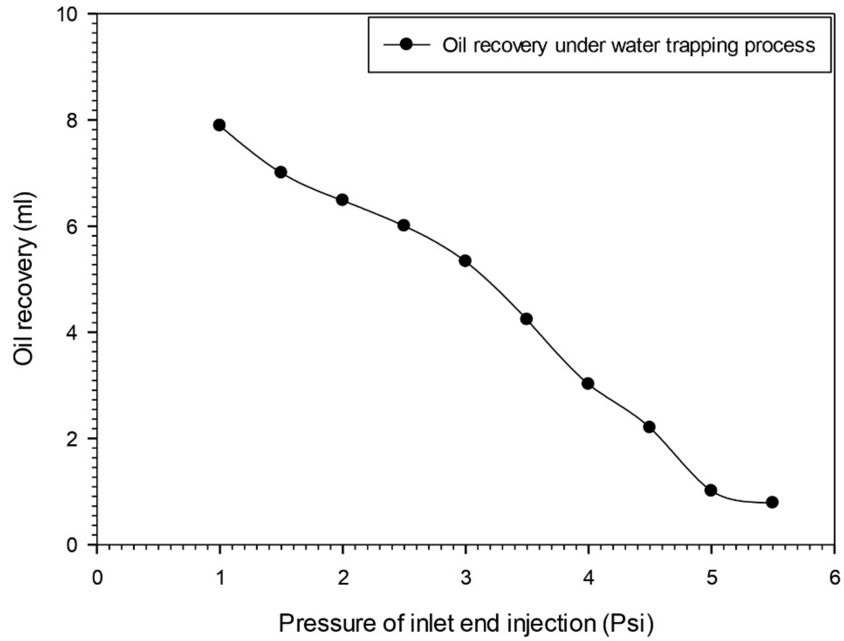

Figure 3. Oil recovery versus pressure inlet end injection.

4.3. Alcoholic treated water mixture injection

To enhance oil recovery, the restored sample was soaked in varying concentrations of the alcoholic treated water mixture. The results of the imbibition tests show that oil recovery rises as the mixture's butanol concentration rises to 7.012 milliliters. Alcohols are thought of as water derivatives where organic residues have taken the place of one or two hydrogen atoms [20]. As seen in Figure 4, the used alcohol dissolves in water and forms a displacement front between the water phase and the oil phase, which is supported by the injected oil inlet pressure. Another element guaranteeing the oil displacement is the cationic surfactant's adsorption. The stone sand has a negative charge. A positively charged material known as a cationic surfactant can adsorb to negatively charged surfaces to create an antistatic and hydrophobic effect [21]. The wetting state and surface tension between the water phase and the grain surface are therefore influenced by the positively charged head groups of quaternary ammonium salt that are drawn to adsorb on the surface of the sandstone, as illustrated in Figure 5.

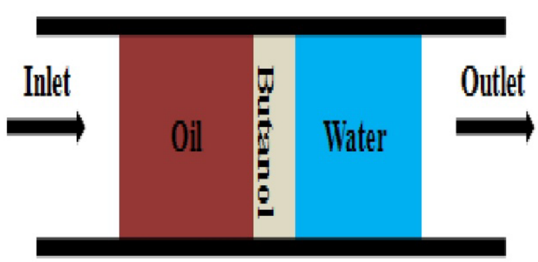

Figure 4. Schematic drawing of oil-water displacement assisted by butanol front.

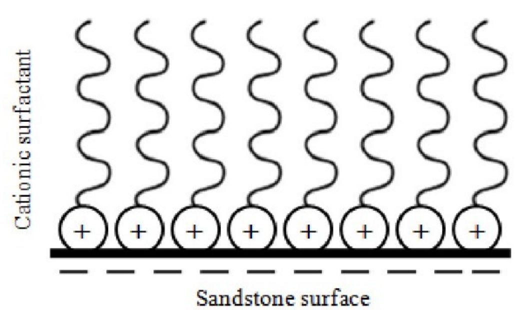

Figure 5. Schematic interaction of sandstone surface with cationic surfactant.

4.4. Interfacial tension measurements results

Gasoil and water have a higher interfacial tension of 47.26 mN/m than any surfactant system. The variation of the interfacial tension with varying surfactant concentrations (quaternary ammonium salt) is depicted in Figure 6. The figure showed that the interfacial tension value decreased as surfactant concentration increased. At a minimal surfactant concentration of 0.5%, quaternary ammonium salt can lower the interfacial tension by up to 0.68 mN/m.

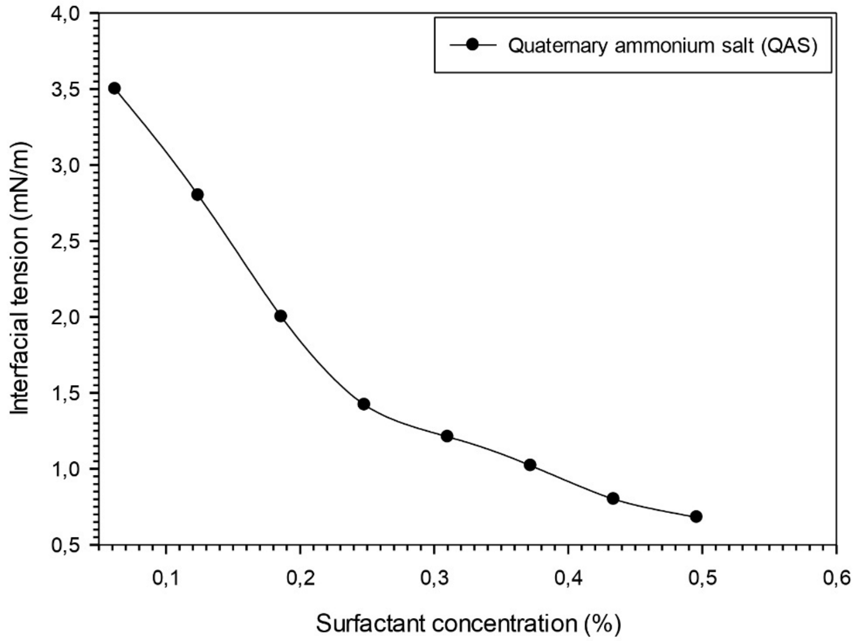

Figure 6. Interfacial tension versus concentration of the quaternary ammonium salt(QAS) at room temperature.

5. Conclusions

This work developed new predictive experimental trapped water based on ground-up sandstone cuttings to predict the effect of drilling fluid filtration-induced water trapping phenomenon in low porosity and low permeability reservoirs. Relative permeability, oil recovery, and interfacial tension were among the various parameters that were used to evaluate the accuracy and performance of the water trapping effect and to compare it with earlier research. The findings showed that, in comparison to previous studies, the experimental work using powdered sandstone cuttings estimates water trapping and its effect on oil recovery under laboratory conditions with the highest accuracy. Moreover, sample flooding experiments were conducted to demonstrate how the suggested treated water mixture affected the samples' oil recovery and interfacial tension. The use of a treated water mixture containing butanol and quaternary ammonium salt at a specific concentration was found to increase oil recovery and decrease the interfacial tension between the rock's oil and water phases.

Nomenclature

ϕ	*porosity (%)*
m_S	*saturated mass (g)*
m_d	*dry mass (g)*
Q_o	*volumetric oil flow rate (cm^3/s)*
Q_w	*volumetric water flow rate (cm^3/s)*
K_{ro}	*relative permeability of oil (Darcy)*
K_{rw}	*relative permeability of water respectively (Darcy)*
L	*sample length (cm)*
μ_o	*oil viscosity (cP)*
μ_w	*water viscosity (cP)*
A	*coss-section area of the sample (cm^2)*
m	*drop weight (kg)*
g	*acceleration of gravity (m/s^2)*
r	*external radius of the capillary (m)*
γ	*interfacial tension of the liquid (N/m)*

Greek letters

ΔP_w differential pressure of water (atm)
ΔP_o differential pressure of oil (atm)

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