Enhancement of Oil Recovery Using Titanium Nano Structures: An Overview

Zainab Mohammad Mahdy, Abdulwahid A. Al-Hajjaj, Shaima Albazzaz
Basra University, College of Engineering, Basra, Iraq

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ABSTRACT

The limited availability of new conventional oil reservoirs and growing energy needs have prompted the development of Enhanced Oil Recovery (EOR) methods to enhance oil extraction From existing resources. Nanomaterials, which are composed of very small particles measuring between 1 nm and 100 nm, have been used to address issues related to traditional EOR methods. These include decreasing interfacial tension, altering wettability, and enhancing the rheology of formation fluids. Silicon dioxide, titanium dioxide, and aluminum oxide, which are non-polar compounds, are effective in limiting chemical absorption in porous materials, especially in tightly or moderately packed oil reservoirs. Recent studies have shown that nanofluids and nanoparticles are very efficient in EOR techniques. This paper provides an updated Review, Exploratory evidence, and Reinterpretation of previous research data and applications regarding the use of titanium dioxide nanoparticles in industrial applications, specifically in EOR Applications. Additionally, it explores use of titanium dioxide nanotubes in industrial applications. It is worth noting that there is a lack of existing reviews on the use of titanium dioxide nanoparticles in EOR applications.

Keywords: *Enhanced Oil Recovery; Titanium dioxide; Nanoparticles; Rheology; wettability; Interfacial tension.*

INTRODUCTION

Global energy demand is rising due to rapid economic growth, with crude oil being a crucial resource for national growth[1-5]. The growing demand for crude oil leads to an escalating exploitation and production of crude oil resources[6]. Traditional recovery methods typically remove around 33.33% of the initial oil reserves, leaving the remaining oil trapped in Rock pores and throats[1]. Research on EOR is essential for developing methods to achieve high recovery factors from oil reservoirs. Several EOR systems have significantly improved oil extraction, including thermal, miscible, and chemical techniques and emerging technologies like microbial and low salinity floods. Recently, nanoparticles and Nanotechnology has been proposed as a possible option. for EOR, as they can infiltrate narrow openings in rock formations, resulting in increased oil recovery[7-10]. Nanoparticles (NPs) are minuscule particles with sizes ranging from 1 nm to 100 nm., providing enhanced oil recovery agents. They are smaller than pores and throats, allowing them to traverse porous media easily without significant permeability. NPs like SiO_2, TiO_2, and Al_2O_3 have diameters ranging from 1 nm to 100 nm, making them ideal for preventing chemical entrapment in porous media[11]. Experimental studies on EOR have shown that various nanoparticles, including Aluminum oxide(AL2O3), Magnesium oxide (MgO), zirconium oxide (ZrO), Zinc Oxide (ZnO),Titanium oxide (TiO_2), Iron oxide(Fe_2O_3), Nickel oxide (NiO), Hydrophobic Silicon Oxide, and Silane-treated Silicon Oxide, have improved recovery and hydrocarbon production[12]. Sara et al [13] look over current studies on the impact of (TiO_2) nanoparticles on reducing the viscosity . The presence of TiO2 nanoparticles has an impact on the viscosity of the Reynolds Colloidal Ratchet (RCR) system, resulting in a maximum percentage deviation of around 1.6%. in other study examines the impact of nanoparticles on steam injection (aqua thermolysis) by Ronal et al , three distinct nanoparticles $Al2O_3$ and NiO, and MgO on the viscosity and composition of the crude oil. The findings indicated that the inclusion of TiO_2 nanoparticles during aqua thermolysis may enhance the oil's quality by decreasing the heavy components and lowering its viscosity by up to 13.4% [14].Fortheremore Goshtasp [15] was Identificat of the potential of TiO2 as a suitable agent for enhancing the effectiveness of surfactant flooding in five-spot glass micromodels.The results of research demonstrated a 51.0% enhancement in heavy oil recovery in micromodel tests using TiO_2. The objective of this study is to examine prior research on the impacts of titanite nanoparticles TiO_2, as well as the

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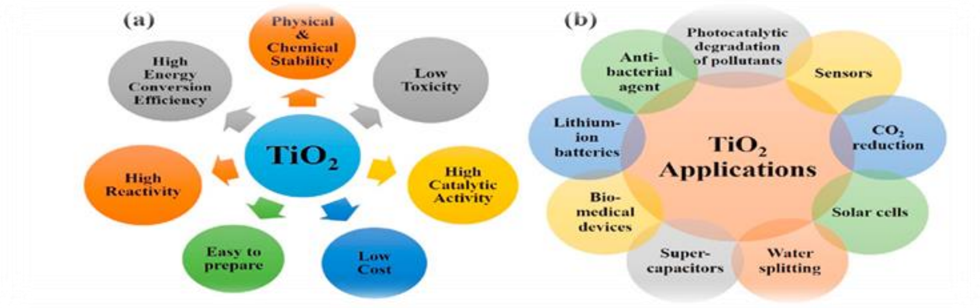
characteristics and industrial uses of TiO2. However, there is a lack of previous research on EOR via the utilization of titanite nanotube.

IMPORTANCE OF TITANIUM DIOXIDE (TiO_2) NANOPARTICLES AND NANOTUBES

Nanoparticles typically have a size that is between the range of 1 to 100 nm[16]. Nanoparticles are categorized based on morphology, size, and form[17]. Nanoparticles such as fullerenes, Graphene ,ceramic NPs, metal and metal oxide nanoparticles (NPs),and polymeric NPs benefit the oil and gas business.[18]. Titanium dioxide. It is extensively used in several industrial sectors such as paints, coatings, varnishes, paper, plastics, printing inks, rubber, cosmetics, and other areas. Due to its distinctive optical, structural, electrical, and photocatalytic capabilities, this material is widely recognized as a very promising semiconductor nanomaterial. TiO_2 is well recognized Regarding its exceptional Stability in terms of physical and chemical properties, little Poisonousness, elevated Refractive Index, remarkable Reactivity, ease of Synthesis, affordability, superior catalytic activity, and extraordinary energy conversion efficiency. Hence, it is highly suitable for many important technological applications such as solar cells, fuel cells, different sensors, wastewater treatment, self-cleaning coatings, and disinfection agents. [19,20].and also The first research motives for titanate nanotubes stem from the extensive range of uses for TiO2. After creating titanate tubes, extensive research revealed that the titanate nanostructures have various applications. These include photocatalysis, catalysis, ion exchange, Hydrogen storage, lithium-ion battery, and maybe serving as a tool for nanoscale Isolation or response environments. This is due to their unique low-dimensional properties, with nanotubes having two dimensions[21,22]. TINT has gained significant interest for its photocatalytic applications. This is because of their distinctive physicochemical Properties, including a nanotubular structure with layered walls, a large surface area, ion exchange capability, and photocatalytic activity[23]. Are shown in Figure (1).



Figure(1) (A) Diverse characteristics and (B)many uses of TiO_2 nanostructures.

TiO_2 exists in three primary forms: Anatase, Rutile, and Brookite (orthorhombic, Pbca). the arrangement of TiO_6 Octahedra plays a vital function in deciding the crystallinity of these forms [23]. Typically, rutile TiO_2 is the most stable form from a thermodynamic perspective. Nevertheless, anatase TiO_2 is extensively researched in photocatalytic applications because Of its superior charge carrier mobility compared to rutile. In recent decades, the rate of photocatalytic H2 development on TiO_2 has been significantly improved using techniques such as bandgap engineering and surface modification, including doping, defect engineering, and co-catalyst collaboration[24]. The distinguishing feature of NPs is their high surface-to-volume ratio, which sets them apart from the bulk medium. These nanoparticles decrease the IFT, modify Wettability, enhance Fine fixing, And function Given that particular agents for EOR. The literature study also discusses the use of nanotechnology in shale stability, high-temperature resistance, and viscosity modification. The discussion also emphasized the issues and potential problems associated with acquiring and using commercial "Nano" items in the context of health and safety, particularly in their uses within the petroleum sector, namely in polymer and surfactant chemical flooding for EOR [18].

MECHANISM OF (TiO_2) NANOPARTICLES IN EOR

Titanium nanoparticles enhance the overall efficiency of crude oil Recovery in both low and high API oil and tight reservoirs. This is accomplished by augmenting the capillary number, diminishing viscous forces, and lowering interfacial tension by a range of 70-90%.As a result, oil recovery is greatly improved[9]. Nanoparticles (NPs) can improve oil recovery efficiency by altering wettability, reducing interfacial tension, blocking pores, diverting flow, dispersing and stabilizing, and improving viscosity. These NPs enhance multiphase flow characteristics, recovering trapped and bypassed oil and improving flooding processes. EOR remains unclear, but methods include reducing interfacial tension, controlling viscosity, applying pressure, sealing pore channels, and emulsifying. The interaction between NPs and pore surfaces is influenced by five types of energy, with adsorption occurring when attraction surpasses repulsion and desorption occurring when repulsion outweighs attractive force[25,7].AS Shown in Figure (2)[26].

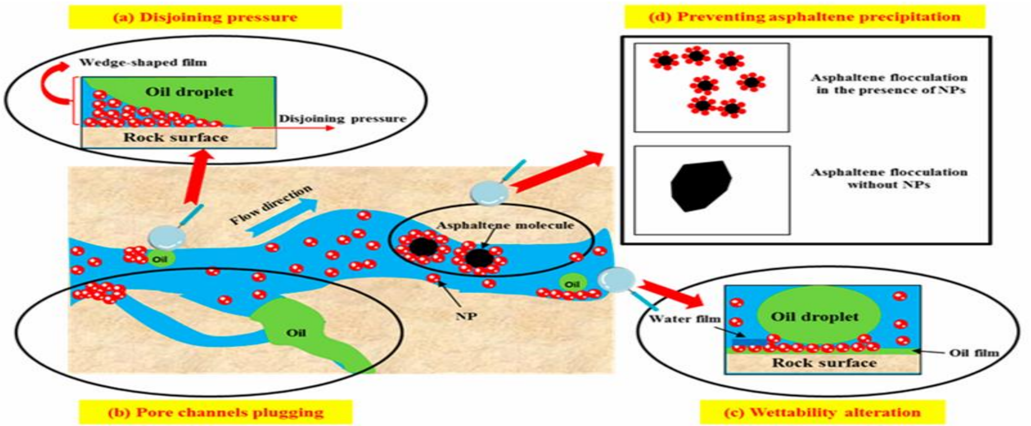


Figure (2) displays the schematic representation of the systems involved in (EOR).

EFFECT OF TITANIUM DIOXIDE(TiO_2) NANOPARTICLES ON RHEOLOGY

Rheological measurements are crucial for evaluating the viscoelastic properties of fluids and polymeric materials. Comprehending the flow characteristics and movement patterns of the individual particles in a nanocolloid solution is essential for analyzing the arrangement and qualities of Nanofluids (NFs). The process of migration and transportation of particles in NFs substantially impact the rheological properties of the suspension, therefore greatly influencing the potential applications of NFs. Hence, a comprehensive comprehension of the Rheological properties of NFs for EOR objectives is very significant in the petroleum sector. Rheological measurements Are crucial for planning and establishing the most effective concentrations of injection fluids for EOR applications. The mobility ratio is mathematically expressed as $kw\mu/ko\mu w$, where k, μ represent permeability & viscosity permeability respectively. The subscript "w" is used to indicate the displacement of the water phase. The letter "o" represents the displaced phase, namely oil.

A mobility ratio below one is advantageous to prevent viscous fingering. Viscous fingering happens when there is a larger mobility ratio, which is caused by the greater mobility of water. Rheology is a crucial method for measuring the Injection fluids' viscosity. Only a limited number of scientific studies publications Explain the rheological properties of non-Newtonian fluids (NFs) used in EOR operations. The utilise of NFs to alleviate the detrimental impact induced by salinity has garnered significant attention in EOR procedures[27]. Analyzing viscoelastic qualities of a polymer involves studying the flow behaviour and deformation features of fluids. It is necessary to improve the rheological behaviour to avoid the occurrence of viscous fingering and provide an appropriate mobility ratio in the reservoir. An injectant is essential for enhanced oil recovery EOR applications. nanoparticles and Polymers degrade in the presence of Brine in a reservoir in the environment. Viscosity reduction happens when the positively charged ions in the brine come into touch with the molecules containing Amide and carboxylate groups of a polymer. The polymer's interaction with nanoparticles is a synergistic impact. It enhances the flow characteristics of the polymer. The presence of brine enhances the electrostatic attraction of nanoparticles, leading to their accumulation and aggregation. This suggests a deficiency in surface functioning, which Itis vital for the EOR process[28]. Nanomaterials significantly impact the study of rheology, particularly titanium dioxide. As Shown As part in Table (1)[27].

Table (1) Evaluation of nanoparticle properties for EOR [27].

Nanoparticles	The Property
SiO_2 Nanoclay Polysilicon Al_2O_3 TiO_2	Rheology
TiO_2 SiO_2	IFT

Al_2O_3 Al_2O_3 MWCNT-SiO_2	
Al_2O_3 Fe_2O_3 Ni_2O_3 SnO	Core flooding
MWCNTa-SiO_2 TiO_2 SiO_2 Al_2O_3 Fe_2O_3 ZrO_2	Wettability alterations

The impacts of pressure, Composition of gases and temperature on the viscosity Regarding Viscous crude oil from the Tatarstan field using the rheometer MCR 302 was studied by Kazan et al. [29]. Results showed that increasing temperature by 125°C reduced viscosity eight times while increasing pressure by 10 MPa increased it by 38% at low temperatures. The study also examined the effects of various gases on crude oil's viscosity. The results showed that the viscosity of crude oil depends on the composition of the gas present, and variations in gas phase composition did not affect The rheological qualities of crude oil.

Danial et al. examined rheological properties of viscous crude oils when ultrasonic cavitation is combined with NiO-functionalized SiO_2 nanoparticles. Experiments were conducted on viscous crude oils with a 17.0% asphaltene mass percentage. Results showed significant changes in viscous crude oils viscosity. The viscosity decreased by The percentage ranges from 50 to 60%, depending on the shear rate. applied. The power density dissipated during a hysteresis cycle was reduced by approximately 70%, power per unit volume, and elasticity, with the initial viscoelastic microstructure disrupted by the combined treatments. The study suggests that asphaltenes stably attach to the nanoparticles [30]. In contrast, Goshtasp's study on TiO_2 nanoparticles' impact on polymer viscosity and its ability to enhance heavy oil recovery was presented. The results showed that nanopolymer injection significantly improved oil recovery performance in core flood displacement experiments, with a 4% increase in oil recovery[31].

EFFECT OF (TiO_2) NANOPARTICLES ON WETTABILITY ALTERATION

Wettability refers to a tendency of a solid to come into contact with one fluid before another, specifically, the fluid that wets it against the fluid that does not wet it. If The solid does not exhibit any discernible Preference for one particular fluids over another, that state is referred to as intermediate-wet and neutral-wet,or mixed-wet. Wettability in the upstream Oil and gas sector refers to a tendency of fluid to adhere to reservoir rock, which consists of oil, water, and rock as its primary components. In this scenario, water is considered a wet fluid, whereas oil is considered a non-wet fluid. A rock is classified as water-wet when it exhibits a strong affinity for water ($0^o<q<90^o$); conversely, it is called oil-wet (ow) when it shows a strong preference for oil ($90^o<q<180^o$), and it is classified as mixed-wet when it exhibits a choice for both oil and water. Oil mainly accumulates in a rock saturated with water in the pores' central region.

Meanwhile, oil mostly adhered to the rock when oil was moist. In the case of mixed-wettability, the rock surface exhibits equal affinity towards both oil and water, resulting in water displacement from some surface areas. Figure 1 depicts the schematic of these three scenarios. The capillary pressure (Pc) is the differential between the non-wet and wet fluid at the interface. Water-wet surface forces result in the upward movement of water, displacing oil. Under oil-wet conditions, the oil displaces the water downwards, as seen in The Figure 2 [32].

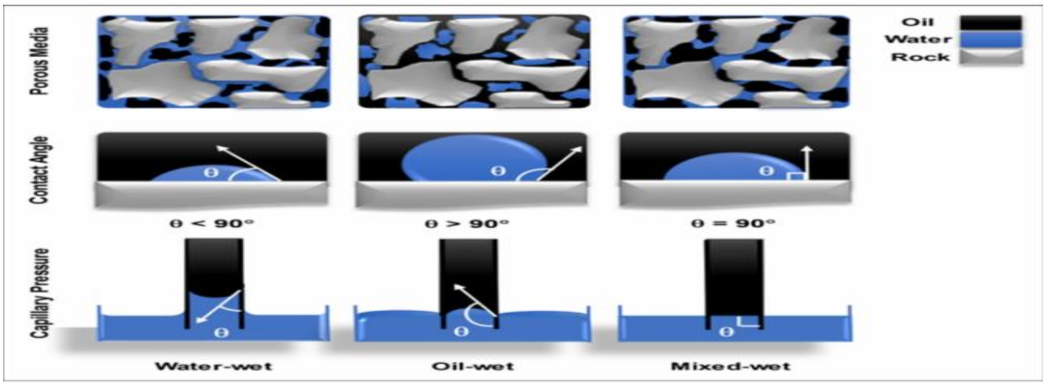


Figure 2. depicts a diagrammatic depiction of wettability in porous media using an oil/water/rock system. It illustrates the conditions of water-wet,mixed-wet and oil-wet, based on the contact angle and capillary pressure.

Wettability change plays a crucial role in oil recovery applications. Recently, nanoparticles have been essential in enhancing oil output by transforming the wetting system from oil-wet to significantly water-wet. Some active substances and strategies exist that may be used to alter the wettability on the surfaces of rocks. Nevertheless, it is essential to consider the economic and environmental concerns. Recently, several experts have acknowledged that nanoparticles have a distinct influence on the modification of wettability and may enhance the oil production rate. To comprehend the process of altering the reservoir's wettability from oil-wet to water-wet, it is essential to consider the idea Regarding the disjoining pressure phenomenon seen during nanofluid flooding.With the increasing use of nanoparticles in the oil industry, numerous Empirical research has demonstrated their ability to change the wetting properties of reservoirs to become more water-wet. This has motivated researchers to investigate The impact of various nanoparticles on altering wettability further through experimentation. Essentially, the wettability conditions are assessed by measuring the contact angle before and after modifying the surface with various additives while a displacing fluid is present[33]. The tight criteria for surface wettability might limit the progress and implementation of technology in several domains. Therefore, altering wettability is crucial for overcoming these problems. The rock surface's hydrophilic and moderately wettable nature is advantageous for improving oil recovery through EOR techniques, as elucidated by the process of wettability modification. The material's lyophobicity is favourable for purifying and adsorbing pollutants in the effluent, while a super-wetting surface is essential for effective oil/water separation[34]. The oil and gas sector is currently studying Nanoparticle and Nanofluids utilisation in various applications. These investigations examine how these substances Impact drilling operations, enhance production development, mitigate formation damage, optimise oil recovery, improve heat transfer, and address wastewater management. The nanoparticles most often used in EOR applications are Fe_2O_3, CeO_2, TiO_2, ZnO, Al_2O_3, MgO, and SiO_2, as shown in Table(2) [33]. In particular, TiO_2 nanoparticles are essential to change wettability in enhanced oil recovery.

In 2022,surface-modified TiO2 nanoparticles were produced using N-(2-Aminoethyl)-3 Amino propyl trimethoxy silane (AEAPTMS). Subsequently, the nanoparticles that were obtained were utilized to create Nanofluids. The findings indicated that the optimal qu-antity of AEAPTMS is 5ml for every 10ml of TTIP, and the stability of Nanofluids is not affected by the concentration of nanoparticles. At a temperature of 90°C and salinities exceeding 30wt%, the Nanofluids were stable when the quantity of AEAPTMS was 5ml. Adding Nanofluids at a concentration of 0.5% by weight may change the wettability of carbonate rock surfaces from highly oil-wet to water-wet. Overall, the generated Nano fluids showed Outstanding stability under Under conditions of elevated salinity and temperature, and they achieved success in modifying the wettability of carbonate rocks. Therefore, this Nanofluid is a superb choice for injecting carbonated reservoirs EOR by Marzieh et al. [35].In contrast, Ghasem et al. [2] used A green approach to create titanium oxide nanoparticles from ecstasy condylocarpa extract and attach them to quartz for improved oil recovery applications. The Nanofluids were dispersed in Deionized water, ocean water, and water with reduced salt content. Adding TiO2/Quartz-Nano fluid (DWN1000) at a concentration of 1000ppm in distilled water led to a 21% Enhancement of oil extraction compared to the original oil in place (OOIP). This was due to decreased interfacial tension and enhanced rheological behaviour and wettability alteration, resulting in a shift towards a more water-wet system with a contact angle reduced from 103° to 48°.

Furthermore, Iman et al. investigated the impact of MgO, γ-Al2O_3 and TiO_2, nanoparticles on wettability in carbonated water. It aimed to increase oil production through imbibition. The lowest contact angle values for carbonated TiO_2, MgO and γ-Al_2O_3 Nano fluids decreased by 55%, 26%, and 17% compared to carbonated water

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without nanoparticles. The Nanofluids with TiO_2 nanoparticles recovered 75.33%, 71.25%, and 64.98% of primary oil, indicating a 30%, 25%, and 18% increase in oil production[36].

Also, Rasoul et al. presented The impact of several Nanofluids, such as Calcium carbonate Zirconium dioxide, Silicon dioxide ,Titanium dioxide, Aluminum oxide ,Magnesium oxide, Carbon nanotube,and Cerium oxide, on the ability of carbonate rocks to be wetted. Initial contact angle assessments were performed to evaluate the nanoparticles, and their effectiveness was assessed using spontaneous imbibition and core flooding experiments[37]. The findings have shown that using $CaCO_3$ and SiO_2 nanoparticles leads to a substantial improvement in oil extraction. The research also evaluated The impact of infusing Nanofluid on the rock surface by quantifying drainage capillary pressure. The variation in structural disjoining pressure was shown to modify the surface's wetting capacity, perhaps removing oil.

The researcher also was created a new Nano composite combining and titanium oxide copper nanoparticles with polyacrylamide polymer for en EOR processes. The Nanocomposite will produce a Nanofluid that can change The oil-wetting condition of carbonate and sandstone reservoirs is transformed into a water-wetting condition. and reduce the interfacial tension between water and oil. The Nanocomposite was synthesized using an extract from the fruit of Cassytha filiformis L. and underwent characterization tests using Field-Emission Scanning Electron Microscopes, X-ray diffraction energy-dispersive X-ray spectroscopy, and thermo gravimetric analysis. The Nanocomposite significantly decreased the interfacial tension between water and oil by about 46% when used at 200 parts per million, and the wettability changed [38].

Table (2) An overview of prior research on the impact of nanoparticles on changes in wettability. [33].

Nanoparticle	Nanoparticle Concentration %	Core Tybe	Disoersied Medium	CONCLUSION
Fe_3O_4	0.1–0.5	Carbonate Rock	HAp/DW and PVA/DW	The most effective concentrations of the Fe3O4/Hap/DW and Fe3O4/PVA/DW nanofluids were found to be 0.4 wt% and 0.5 wt%, respectively. The introduction of Fe3O4 nanoparticles coated with HAp had a substantial impact on the wettability of the carbonate rock, shifting it from an oil-wet state to a very gas-wet one.
ZrO_2	0.05–0.1	Carbonate Rock	distilled water	The contact angle was reduced from 180° to 30° using ZrO2 nanofluid.
NiO ,ZrO_2	0.004–0.05	limestone	brine	The NP_S adhered to the outer layer of the calcite plate and significantly changed its ability to be wetted, transitioning it from being oil-wet state to water-wet state in a very efficient manner. Introducing NF_S into oil-wet limestone formations can significantly enhance oil recovery efficiency by altering wettability.
γ-Al_2O_3,MgO,TiO_2	0.05–0.1	Carbonate rock	Carbonate Water	The combination of nanoparticles with carbonated water, known as carbonated nanofluids, effectively alters the wettability of rocks to become very water-wet. The contact angle decreases achieved by utilizing TiO2-, γ-Al2O3-, and MgO-carbonated NF_S were around 55%, 26%, and 17%, respectively. Similarly, the oil recovery values obtained were 75.93%, 71.25%, and 64.98%, respectively.
SiO_2	0.05–0.15	limestone and dolomite Surfaces	Distilled water, brine, and saline brine	The use of SiO2 nanofluid may greatly enhance wettability alteration. The Huff-n-Puff technique enhanced oil output and reduced the water production rate. Using a Nanofluid containing 50,000 mg/L NaCl resulted in an oil recovery rate of 18%.
SiO_2	0.1–0.6	Carbonate Rock	distilled water	The adsorption of nanoparticles altered the wettability of the rock surface. The findings indicated that using a concentration of 4 g/L of Nanofluid had a notable impact on the rock's wettability, transforming it into highly water-wet by reducing the contact angle from 146.3° to 45°.
Al_2O_3	0.01–0.1	Sandstone	distilled water	Adding nanoparticles in quantities equal to or lower than 0.05% may enhance the wettability modification of rock surfaces to become water-wet. Superior performance was attained at a concentration of 0.01%; the contact angle transitioned from 142° to 0°.
Al_2O_3, ZrO	0.05	Dolomite Rock	distilled water (Including Different Surfactants such as TX-100CTAB, SDS)	The nanoparticles modified the ability of oil-wet dolomite limestone to become substantially water-wet. Al2O3 outperformed ZrO2 in decreasing the contact angle.

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Fe_3O_4 coated with EDTA	0.1–0.9	Carbonate Rock	Distilled water	Coating nanoparticles may significantly enhance the hydrophilicity of surfaces and alter their wettability to become more water-wet. The oil recovery rate was around 20% for the Fe3O4 nanoparticles coated with SLS and 13.5% for those coated with EDTA.
SiO_2	0.5–2	Sand Pack	Polyacrylamide PAM	At high temperatures, the nanofluids can potentially modify the wetting properties of rock.
Al_2O_3, TiO_2, and SiO_2	0.05	quartz plate	Brine (3 wt% NaCl)	The presence of Al2O3, TiO2, and SiO2 nanoparticles significantly alters the wettability of a quartz plate, making it water-wet. This is achieved by lowering the contact angle from 131.2° to 38.82°, 21.64°, and 28.6°, respectively. TiO2 nanofluid reduces contact angle more than SiO2 nanofluid, but SiO2 nanofluid is more effective in oil-wet environments than Al2O3-based Nanofluid.
SiO_2	0.1–5	Glass plate	Distilled water	The introduction of SiO2 nanoparticles modified the hydrophilicity of the plate, resulting in a decrease in the contact angle from 100° to 0°.
SiO_2	10 g/200 Ml	Reservoir rock	Distilled water/ethanol	The study established a clear correlation between the concentration of nanoparticles and their capacity to modify the rock's wettability to become water-wet. Adding amine-functionalized SiO2 nanoparticles decreased the contact angle from 134.4° to 54.5°.
ZrO_2, TiO_2, SiO_2, MgO, Al_2O_3	0.03–0.5	Carbonate rock	Tween80/Span 85, LA3 + Tween80/ Span83, ethylene/glycol + LA3EO, LA7EO, brine (5 wt% NaCl), SDS	The contact angle of decane reduced when exposed to ZrO2, TiO2, SiO2, MgO, and Al2O3 nanofluids, with values of 59.7°, 51.2°, 68.5°, 98.2°, and 103.2°, respectively, compared to the initial value of 140.2°.
Al_2O_3, TiO_2, and SiO	0.005	Limestone rock	Distilled water	The limestone's wettability was changed to become water-wet by nanoparticle adsorption. The addition of Al2O3, TiO2, and SiO2 nanofluids resulted in a decrease in the contact angle from 90° to 71°, 57°, and 26°, respectively. The findings indicated that the Al2O3 and TiO2 nanofluids exhibited superior performance in enhanced oil recovery (EOR) compared to the SiO2 nanofluid across all tested temperatures.

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THE IMPACT OF TITANIUM DIOXIDE (TiO2) NANOPARTICLES ON INTERFACIAL TENSION.

The simultaneous existence of Crude oil and water are immiscible fluids found in oil reserves. generates an interfacial tension force (IFT), as seen in Figure 5. Interfacial tension is the force per unit area that propels the molecule towards the surface from the bulk phase . It is typically measured in dynes/cm (milli-Newtons/meter).IFT,or Interfacial Tension, is a critical metric that may be used to assess The allocation and displacement of fluids in porous media. Therefore, the influence of IFT on the efficiency of the reservoir in generating hydrocarbons is significant. Hence, it is essential to ascertain the IFT between oil and brine or oil and injected fluids to assess the effectiveness of improved methods for extracting oil. A spinning drop method measures the IFT between brine and oil phases. A tensiometer can be utilized. If a micro-emulsion is seen as a third phase in any scenario, the oil phase might be considered as an intermediate phase. to produce more accurate IFT measurements. To decrease residual oil saturation, having a high capillary number and a low IFT between oil and water [39].

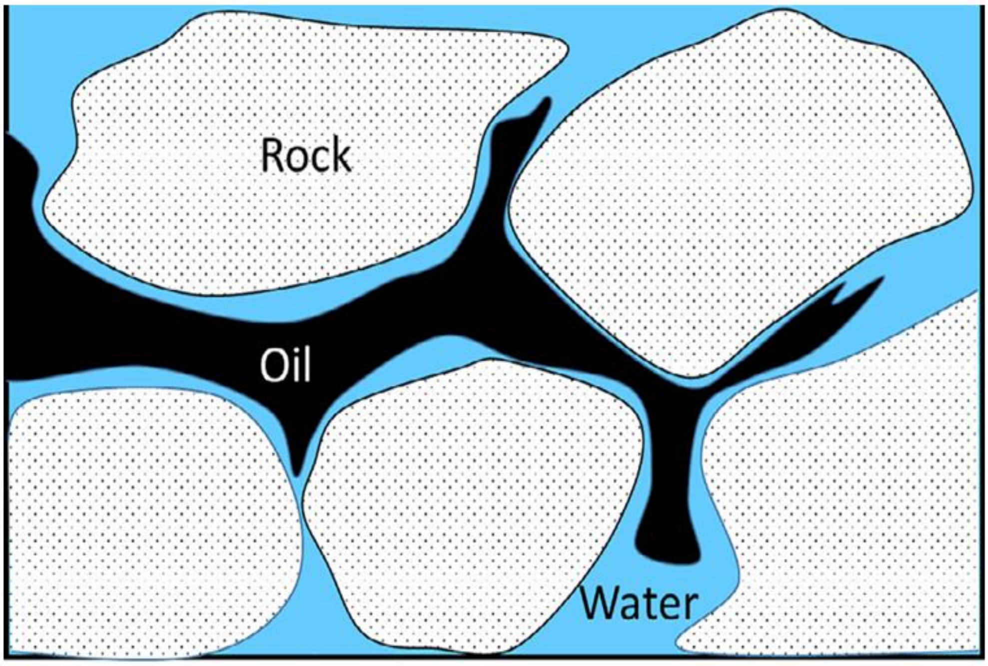

Figure 5 depicts an interaction between water and oil inside porous media.

Research has shown that including nanoparticles may decrease IFT. Still, none have documented that the decrease in IFT is the only mechanism for EOR by nanofluids. Wettability often changed when the IFT was decreased, but not vice versa[40]. There are many nanoparticles used to reduce interfacial tension; in particular, TiO_2 is Shown in Table (3) [39],Table(4) For instance,

Rima et al.[41]present search, This research aims to quantify the alterations in IFT and wettability resulting from the introduction of TiO_2 NP_S (at concentrations of 0, 100, 250, and 500 ppm) into an alkyl ethoxy carboxylic surfactant. The IFT of the crude oil-water (surfactant) system drops by almost two orders of magnitude with an increasing titanium dioxide content, reaching a minimum value of 5.85×10^-5 m/m. By mixing the surfactant with titanium dioxide, The contact angle of the Berea sandstone surface reduces, achieving a minimum contact angle of 8.8°.

The other study explores using SiO_2 and TiO_2 nanoparticles to enhance water injection efficiency and maximize oil recovery by M. Noor et al. [42]. Nano saline solutions were created using NaCl, $CaSO_4$, or $MgSO_4$ at concentrations of 1000 ppm, with varying percentages of SiO_2 and TiO_2 nanoparticles. The IFT between oil and saline solutions were tested at various pressures. The results showed that SiO_2 and TiO_2 nanoparticles effectively decreased IFT, achieving the highest decreases at 507.5 Psi. The NaCl-H_2O-TiO_2 solution had the highest IFT reduction at 58.13%, followed by the NaCl-H_2O-SiO_2 solution at 49.65%.

Furthermore, Pouya et al. used Henna extract may be used as a natural surfactant and in the production of NP_S. like Graphene, TiO_2, SiO_2, and a composite of Graphene -TiO_2 to reduce oil-water IFT. The findings indicate that increasing the extract concentration decreases the interfacial tension between kerosene and water from 0 to 10 wt%,

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while adding TiO_2 nanoparticles reduces IFT from 18.43 to 14.57 mN/m, potentially improving the oil recovery factor during operations. The TiO_2 nano-surfactant showed comparable efficacy to conventional industrial surfactants[43].

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Table 3 An overview of prior research on the impact of nanoparticles on interfacial tension (IFT) [1].

Nanoparticles	Nanoparticles Concentration.	Nano Particles size(nm)	IFT(mN/m)	IFT(mN/m)	Porous Media	Dispersion media
			Without Nanoparticles	With Nanoparticles		
TiO_2	0.05wt%	21	19.2	n.a.	Quartz plates	Brine(3wt%NaCl)
TiO_2	50mg/L	10–30	26.5	17.5	Limestone rocks	DIW (26 ^{0}C)
TiO_2	50mg/L	10–30	21.1	12.4	Limestone rocks	DIW(60 ^{0}C)
ZrO_2	0.05wt%	40	8.46	1.85	Carbonate dolomite	CTAB
ZrO_2	0.05wt%	40	9.88	2.78	Carbonat edolomite	SDS
ZrO_2	0.05wt%	40	9.13	2.64	Carbonat edolomite	TX-100
ZrO_2	10–500mg/L	5–15	48	18	Bidentate carbonates	Surfactant
SiO_2	1.0wt%	7–12	20	1.87	Sandstone cores	SDS
SiO_2	5wt%	20–30	35	10.9	Sandstone cores	Surfactant
SiO_2	0.05wt%	40	19.2	17.5	Quartz plates	Brine(3wt%NaCl)
SiO_2	10gr/200ml	10–15	37.5	22.1	Glass micromodel	Ethanol
SiO_2	50mg/L	20	26.5	17	Limestone rocks	DIW(26 ^{0}C)
SiO_2	50mg/L	20	21.1	11.2	Limestone rocks	DIW(26 ^{0}C)
SiO_2	0.5–3g/L	10–30	38.5	1.45	Sandstone cores	Propanol
SiO_2	1–4g/L	12	26.5	1.95	Sandstone cores	Propanol
Al_2O_3	0.05wt%	17	19.2	12.8	Quartz plates	Brine(3wt%NaCl)
Al_2O_3	0.05wt%	20	8.46	1.65	Carbonate dolomite	CTAB
Al_2O_3	0.05wt%	20	9.88	2.75	Carbonate dolomite	SDS
Al_2O_3	0.05wt%	20	9.13	2.55	Carbonate dolomite	TX-100
Al_2O_3	50mg/L	40	26.5	18	Limestone rocks	DIW(26 ^{0}C)
Al_2O_3	50mg/L	40	21.1	13.2	Limestone rocks	DIW(26 ^{0}C)
Al_2O_3	0.5–3g/L	~60	38.5	2.25	Sandstone cores	Propanol
Fe_2O_3	0.5–3g/L	40–60	38.5	2.75	Sandstone cores	Propanol
FNP	0.05wt%	7–16	16.41	12.61	Sandstone cores	DIW
CNP	0.05wt%	8–75	16.41	12.15	Sandstone cores	DIW
HLP	0.05wt%	N/A	18.4	5.4	Quartz plate	Surfactant
HLP	4g/L	10–40	26.3	1.75	Sandstone rocks	Ethanol

FSPNs	10g/200ml	10–15	37.5	13	Glass micromodel	Ethanol
NWP	4g/L	10–20	26.3	2.55	Sandstone cores	Ethanol

Table 4 A summary of previous works on the effects of TiO_2nanoparticles on interfacial tension (IFT)

Nanoparticles	NP Cons.	Porous media	IFT mN/m Clear	IFT mN/m With NP	Reference
TiO2,CuO, PAM NC.	200ppm	carbonate rocks	28	15	[34]
TiO2, graphene oxide NC.	0.05wt%	carbonate rocks	39	23.8	[38]
TiO2 ,PAM, SiO2 NC.	500 PPM	Carbonate rock	12.83	6.1	[32]
TiO2	0.05 wt%	Limestone rock	17.5	12.5	[44]
TiO2,SiO2 NC	0.1g	Carbonate rock	39	13.2	[45]
Green TiO2, Quartz NC.	1000ppm	Carbonate rock	36.4	3.5	[46]
TiO2	0.005 wt %	Limestone rock		27.8% reduction	[15]
TiO2	1 wt%	Carbonate rock	24.5	10.8	[41]

CONCLUSION

Nanoparticles have played a significant role in advancing the fields of nanoscience and nanotechnology, particularly in the oil business, where they have garnered considerable attention from researchers. This study provides an updated overview and presents the current research development on titanium dioxide nanoparticles in various environments, including surfactants, polymers, polymer-surfactant systems, and low salinity enhanced oil recovery (EOR) processes. This is attributed to the enhanced foam stability and improved viscoelastic properties observed in both homogeneous and heterogeneous reservoirs, when compared to using the surfactant alone. Furthermore, the study revealed that hydrophilic and slightly hydrophobic silica nanoparticles prevent the surfactant from being absorbed into the rock surface. As a result, this decreases the interfacial tension (IFT) and impacts the rheology of the formation fluids, leading to improved economic recovery. Moreover, titanium dioxide nanoparticles have been widely used in tertiary oil recovery processes for many decades after the main and secondary stages of production.It has been shown that the inverse Fourier transform (IFT) of a titanium nano solution cannot consistently yield reliable findings unless an emulsion stabiliser is used. Additionally, it has been shown that the functionalized nano TiO2 solution demonstrates a rapid mechanism for reversing wettability, in comparison to its impact on Viscosity and interfacial tension (IFT). The literature study also discovered that the chemistry and engineering disciplines were examined.The engineering constraints related to metallic nanoparticles should be given high emphasis while screening for nano EOR applications. Nevertheless, it is crucial to prioritise the management of the agglomeration and adsorption of nanoparticles (NPs) at high temperatures in order to provide smooth transit and facilitate favorable oil recovery.Nanotechnology offers a viable and innovative option to augment the existing Enhanced Oil Recovery (EOR) method with advanced technology. This has the potential to revolutionize the whole oil and gas sector and make a big contribution to improving the economics of oil fields.

REFERENCES

1. Kong, X., & Ohadi, M. M. (2010, November). Applications of micro and nano technologies in the oil and gas industry-an overview of the recent progress. In Abu Dhabi international petroleum exhibition and conference (pp. SPE-138241). SPE. https://doi.org/10.2118/138241-MS
2. Zargar, G., Arabpour, T., Manshad, A. K., Ali, J. A., Sajadi, S. M., Keshavarz, A., & Mohammadi, A. H. (2020). Experimental investigation of the effect of green TiO2/Quartz nanocomposite on interfacial tension reduction, wettability alteration, and oil recovery improvement. Fuel, 263, 116599. https://doi.org/10.1016/j.fuel.2019.116599
3. Ali, J. A., Kolo, K., Manshad, A. K., & Stephen, K. D. (2021). Emerging applications of TiO2/SiO2/poly (acrylamide) nanocomposites within the engineered water EOR in carbonate reservoirs. Journal of Molecular Liquids, 322, 114943. https://doi.org/10.1016/j.molliq.2020.114943
4. Anto, R., Deshmukh, S., Sanyal, S., & Bhui, U. K. (2020). Nanoparticles as flow improver of petroleum crudes: Study on temperature-dependent steady-state and dynamic rheological behavior of crude oils. Fuel, 275, 117873. https://doi.org/10.1016/j.fuel.2020.117873
5. Abdurahman, N. H., Rosli, Y. M., Azhari, N. H., & Hayder, B. A. (2012). Pipeline transportation of viscous crudes as concentrated oil-in-water emulsions. Journal of Petroleum Science and Engineering, 90, 139-144. https://doi.org/10.1016/j.petrol.2012.04.025
6. Zapivalov, N. P. (2015). Improved oil recovery vs. enhanced oil recovery. Enhanced oil recovery: Methods, economic benefits and impacts on the environment, 81-94.

7. Agista, M. N. (2017). A Literature review and transport modelling of nanoparticles for enhanced oil recovery.
8. Navas Guzman, J. A. (2020). Chemical enhanced oil recovery simulation in highly stratified heterogeneous reservoir: a field case study (Doctoral dissertation). https://doi.org/10.37394/232015.2020.16.3
9. Agista, M. N., Guo, K., & Yu, Z. (2018). A state-of-the-art review of nanoparticles application in petroleum with a focus on enhanced oil recovery. Applied sciences, 8(6), 871. https://doi.org/10.3390/app8060871
10. Rellegadla, S., Bairwa, H. K., Kumari, M. R., Prajapat, G., Nimesh, S., Pareek, N., ... & Agrawal, A. (2018). An effective approach for enhanced oil recovery using nickel nanoparticles assisted polymer flooding. Energy & fuels, 32(11), 11212-11221. https://doi.org/10.3390/app8060871
11. Hu, Z. (2017). Nanoparticle-assisted enhanced oil recovery (Doctoral dissertation, University of Leeds).
12. Sun, X., Zhang, Y., Chen, G., & Gai, Z. (2017). Application of nanoparticles in enhanced oil recovery: a critical review of recent progress. Energies, 10(3), 345. https://doi.org/10.3390/en10030345
13. Shakir, S. T., Mohammed, A. T. H., Saasa, A. A., Flaih, H. D., & Abbas, U. A. (2020, June). Effect of Titanium Oxide (TiO2) Nanoparticles on Reduced Crude Oil Residue. In IOP Conference Series: Materials Science and Engineering (Vol. 870, No. 1, p. 012058). IOP Publishing. https://doi.org/10.1088/1757-899X/870/1/012058
14. de la Cruz Parejas, R., Moura, F. J., de Avillez, R. R., & de Souza Mendes, P. R. (2021). Effects of Al2O3-NiO, TiO2 and (Mg, Ni) O particles on the viscosity of heavy oil during aquathermolysis. Colloids and Surfaces A: Physicochemical and Engineering Aspects, 625, 126863. https://doi.org/10.1016/j.colsurfa.2021.126863
15. Cheraghian, G. (2016). Effects of titanium dioxide nanoparticles on the efficiency of surfactant flooding of heavy oil in a glass micromodel. Petroleum Science and Technology, 34(3), 260-267. https://doi.org/10.1080/10916466.2015.1132233
16. Sircar, A., Rayavarapu, K., Bist, N., Yadav, K., & Singh, S. (2022). Applications of nanoparticles in enhanced oil recovery. Petroleum Research, 7(1), 77-90. https://doi.org/10.1016/j.ptlrs.2021.08.004
17. Ijaz, I., Gilani, E., Nazir, A., & Bukhari, A. (2020). Detail review on chemical, physical and green synthesis, classification, characterizations and applications of nanoparticles. Green Chemistry Letters and Reviews, 13(3), 223-245. https://doi.org/10.1080/17518253.2020.1802517
18. Negi, G. S., Anirbid, S., & Sivakumar, P. (2021). Applications of silica and titanium dioxide nanoparticles in enhanced oil recovery: Promises and challenges. Petroleum Research, 6(3), 224-246. https://doi.org/10.1016/j.ptlrs.2021.03.001
19. Gupta, T., Cho, J., & Prakash, J. (2021). Hydrothermal synthesis of TiO2 nanorods: formation chemistry, growth mechanism, and tailoring of surface properties for photocatalytic activities. Materials Today Chemistry, 20, 100428. https://doi.org/10.1016/j.mtchem.2021.100428
20. Zavala, M. Á. L., Morales, S. A. L., & Ávila-Santos, M. (2017). Synthesis of stable TiO2 nanotubes: effect of hydrothermal treatment, acid washing and annealing temperature. Heliyon, 3(11). https://doi.org/10.1016/j.heliyon.2017.e00456
21. Chen, Q., & Peng, L. M. (2007). Structure and applications of titanate and related nanostructures. International journal of nanotechnology, 4(1-2), 44-65. https://doi.org/10.1504/IJNT.2007.012314
22. Bavykin, D. V., & Walsh, F. C. (2010). Titanate and titania nanotubes: synthesis, properties and applications (Vol. 12). Royal Society of Chemistry.
23. Liu, N., Chen, X., Zhang, J., & Schwank, J. W. (2014). A review on TiO2-based nanotubes synthesized via hydrothermal method: Formation mechanism, structure modification, and photocatalytic applications. Catalysis Today, 225, 34-51. https://doi.org/10.1016/j.cattod.2013.10.090
24. Cha, G. (2021). TiO 2 Nanotubes: a Study of Their Optical and Photocatalytic Properties, and Related Applications. Friedrich-Alexander-Universitaet Erlangen-Nuernberg (Germany).
25. Foroozesh, J., & Kumar, S. (2020). Nanoparticles behaviors in porous media: Application to enhanced oil recovery. *Journal of Molecular Liquids*, *316*, 113876. https://doi.org/10.1016/j.molliq.2020.113876
26. Sun, X., Zhang, Y., Chen, G., & Gai, Z. (2017). Application of nanoparticles in enhanced oil recovery: a critical review of recent progress. Energies, 10(3), 345. https://doi.org/10.3390/en10030345
27. Liu, N., Chen, X., Zhang, J., & Schwank, J. W. (2014). A review on TiO2-based nanotubes synthesized via hydrothermal method: Formation mechanism, structure modification, and photocatalytic applications. Catalysis Today, 225, 34-51. https://doi.org/10.1016/j.cattod.2013.10.090
28. Sircar, A., Rayavarapu, K., Bist, N., Yadav, K., & Singh, S. (2022). Applications of nanoparticles in enhanced oil recovery. Petroleum Research, 7(1), 77-90. https://doi.org/10.1016/j.ptlrs.2021.08.004
29. Akhmadiyarov, A. A., Petrov, A. A., Rakipov, I. T., & Varfolomeev, M. A. (2019, June). Effect of pressure, temperature and gas phase composition on the rheological properties of heavy crude oil. In IOP Conference Series: Earth and Environmental Science (Vol. 282, No. 1, p. 012021). IOP Publishing. https://doi.org/10.1088/1755-1315/282/1/012021

30. Montes, D., Taborda, E. A., Minale, M., Cortés, F. B., & Franco, C. A. (2019). Effect of the NiO/SiO2 nanoparticles-assisted ultrasound cavitation process on the rheological properties of heavy crude oil: steady state rheometry and oscillatory tests. Energy & fuels, 33(10), 9671-9680. https://doi.org/10.1021/acs.energyfuels.9b02288
31. Cheraghian, G. (2016). Effect of nano titanium dioxide on heavy oil recovery during polymer flooding. Petroleum Science and Technology, 34(7), 633-641. https://doi.org/10.1080/10916466.2016.1156125
32. Mousavi Moghadam, A., & Baghban Salehi, M. (2019). Enhancing hydrocarbon productivity via wettability alteration: a review on the application of nanoparticles. *Reviews in Chemical Engineering*, *35*(4), 531-563. https://doi.org/10.1515/revce-2017-0105
33. Eltoum, H., Yang, Y. L., & Hou, J. R. (2021). The effect of nanoparticles on reservoir wettability alteration: a critical review. *Petroleum Science*, *18*, 136-153. https://doi.org/10.1007/s12182-020-00496-0
34. Eltoum, H., Yang, Y. L., & Hou, J. R. (2021). The effect of nanoparticles on reservoir wettability alteration: a critical review. *Petroleum Science*, *18*, 136-153. https://doi.org/10.1007/s12182-020-00496-0
35. Hosseini, M. S., Khazaei, M., Misaghi, M., & Koosheshi, M. H. (2022). Improving the stability of nanofluids via surface-modified titanium dioxide nanoparticles for wettability alteration of oil-wet carbonate reservoirs. *Materials Research Express*, *9*(3), 035005. https://doi.org/10.1088/2053-1591/ac4fdf
36. Nowrouzi, I., Manshad, A. K., & Mohammadi, A. H. (2020). Effects of TiO2, MgO and γ-Al2O3 nano-particles on wettability alteration and oil production under carbonated nano-fluid imbibition in carbonate oil reservoirs. *Fuel*, *259*, 116110. https://doi.org/10.1016/j.fuel.2019.116110
37. Nazari Moghaddam, R., Bahramian, A., Fakhroueian, Z., Karimi, A., & Arya, S. (2015). Comparative study of using nanoparticles for enhanced oil recovery: wettability alteration of carbonate rocks. *Energy & Fuels*, *29*(4), 2111-2119. https://doi.org/10.1021/ef5024719
38. Bahraminejad, H., Khaksar Manshad, A., Riazi, M., Ali, J. A., Sajadi, S. M., & Keshavarz, A. (2019). CuO/TiO2/PAM as a novel introduced hybrid agent for water—oil interfacial tension and wettability optimization in chemical enhanced oil recovery. *Energy & Fuels*, *33*(11), 10547-10560. https://doi.org/10.1021/acs.energyfuels.9b02109
39. Ali, J. A., Kolo, K., Manshad, A. K., & Mohammadi, A. H. (2018). Recent advances in application of nanotechnology in chemical enhanced oil recovery: Effects of nanoparticles on wettability alteration, interfacial tension reduction, and flooding. *Egyptian journal of petroleum*, *27*(4), 1371-1383. https://doi.org/10.1016/j.ejpe.2018.09.006
40. Li, K., Wang, D., & Jiang, S. (2018). Review on enhanced oil recovery by nanofluids. *Oil & Gas Science and Technology–Revue d'IFP Energies nouvelles*, *73*, 37. https://doi.org/10.2516/ogst/2018025
41. Megayanti, R., Hidayat, M., Cahyaningtyas, N., Sanmurjana, M., Nur Muhammad Yahya, Z., Sagita, F., ... & Marhaendrajana, T. (2023). Effect of Titanium Dioxide Nanoparticles on Surfactants and Their Impact on the Interfacial Properties of the Oil–Water–Rock System. *ACS omega*, *8*(41), 38539-38545. https://doi.org/10.1021/acsomega.3c05365
42. Ghasemi, M. N., Heidari, S., Ramezanzadeh, S., Vakili-Nezhaad, G. R., & Esmaelizadeh, F. (2022). Measuring interfacial tension between oil and nano-saline solutions in the presence of SiO2 or TiO2 at low and intermediate pressures. *Physical Chemistry Research*, *10*(2), 163-171.
43. Tavakoli, P., Shadizadeh, S. R., Hayati, F., & Fattahi, M. (2020). Effects of synthesized nanoparticles and Henna-Tragacanth solutions on oil/water interfacial tension: nanofluids stability considerations. *Petroleum*, *6*(3), 293-303. https://doi.org/10.1016/j.petlm.2020.03.001
44. Patel, H., Shah, S., Ahmed, R., & Ucan, S. (2018). Effects of nanoparticles and temperature on heavy oil viscosity. *Journal of Petroleum Science and Engineering*, *167*, 819-828. https://doi.org/10.1016/j.petrol.2018.04.069
45. Kazemzadeh, Y., Sharifi, M., Riazi, M., Rezvani, H., & Tabaei, M. (2018). Potential effects of metal oxide/SiO2 nanocomposites in EOR processes at different pressures. Colloids and Surfaces A: Physicochemical and Engineering Aspects, 559, 372-384. https://doi.org/10.1016/j.colsurfa.2018.09.068
46. Zargar, G., Arabpour, T., Manshad, A. K., Ali, J. A., Sajadi, S. M., Keshavarz, A., & Mohammadi, A. H. (2020). Experimental investigation of the effect of green TiO2/Quartz nanocomposite on interfacial tension reduction, wettability alteration, and oil recovery improvement. Fuel, 263, 116599. https://doi.org/10.1016/j.fuel.2019.116599