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Advances in Wettability Modification for Enhanced Oil Recovery using Nanomaterials Assisted by Electromagnetic Waves

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Abstract

Nanotechnology has emerged as a significant method for improving oil recovery, primarily by altering reservoir rock surface wettability. Integrating nanomaterials with electromagnetic (EM) waves has demonstrated a potential effect in modifying reservoir rock-wetting conditions. Consequently, additional crude oil was noticed to be recovered. EM waves significantly enhance the adsorption process through dipole interactions and polarization effects, thereby improving the effectiveness of surface modification. Recent research indicated that employing nanomaterials with a hybrid of magnetic and dielectric attributes enhances the ions' redistributions, making the fluids highly electrified when exposed to EM waves, and surface wettability can easily be altered effectively. This study reviews recent advancements in wettability modification using nanomaterials under EM wave exposure. Challenges and future research opportunities were also highlighted.

Keywords: Nanomaterials, Interfacial tension (IFT), EM waves

Introduction

Enhanced Oil Recovery (EOR) techniques seek to optimize the extraction of remaining oil from reservoirs following primary and secondary recovery phases.[1,2] The rapid growth in the demand for energy utilization globally is unprecedented.[1,3-6] Crude oil extraction is one of the significant sources of energy derivation; therefore, substantial reform in oil extraction is urgently needed.[7] Wettability alteration is a crucial approach in enhanced oil recovery, affecting the interactions among oil, water, and rock surfaces.[8,9] Wettability refers to the disposition of a fluid to spread across a solid surface when another immiscible fluid is present.[10] The reservoir rock is typically observed to be in an oil-wet condition, presenting specific challenges for effectively transporting fluids. Restoring the reservoir rock from oil-wet to water-wet conditions will significantly enhance the release of trapped oil within the rock pores.[11] Recent studies have shown that EM waves, when exposed to nanoparticles during wettability analysis, can drastically reduce interfacial tension, and surface wettability which in turn enhances oil mobility.[10,12-15]

Forming hybrid nanomaterials is an effective method to improve the nanomaterials' thermal, magnetic, chemical, and electrical properties.[16,17] It has been reported that the nanoparticles with dielectric or magnetic attributes are the most suitable candidates for enhancing the fluids' conductivity and magnetic behavior under EM wave endorsement, making the fluids more electrified. Hence, the moving charges of the particles can be operated by the energy released from EM waves at the fluid/rock surface interface, resulting in a subsequent drop in wettability.[18]

Literature Review

The unique properties of different nanomaterials concerning electrical conductivity influenced by EM waves make them exceptional candidates for surface modification to attain EOR. The

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wettability alteration in this regard is attributed to the increasing movement of the polarized moving ions upon EM wave endorsement. The nanoparticles with dielectric or magnetic attributes are the determinant factor considering their effective reaction under the influence of EM waves. Furthermore, Recent experiments verified that preparing hybrid fluids incorporating magnetic and dielectric nanoparticles makes particles polarized more significantly and enhances the moving ions, which helps to modify the solid substrate subsurface from oil-wet to water-wet.[10,12] Table 1 summarizes some experimental results for the effect of different nanoparticles on wettability change endorsed by EM waves.

Table 1: An overview of nanomaterial's effect on surface wettability change subjected to EM waves exposure

Nanoparticles (NPs)	Base-fluids	Contact angle (degree)		References
		NPs without an EM wave	NPs with EM wave	
Fe_2O_3	brine	98	96	[10]
ZnO	brine	139	121	[10]
$ZnOFe_2O_3$-SiO_2	brine	124	73	[10]
ZnO	brine	54	50	[19]
ZnO-SiO_2	brine	132	58	[12]
ZnO	brine	132	121	[12]

Mechanism of Wettability Change Using Nanomaterials-Assisted EM Waves

The primary mechanisms of the change provided involve nanoparticle adsorption and surface energy modification upon EM wave propagation during wettability experiments. Interfacial energy alteration and charge redistribution also played a significant role. Nanoparticles like graphene oxide (GO), silicon oxide (SiO_2), and metal oxides (like ZnO, Fe_3O_4) modify wettability by influencing the solid-liquid interfacial energy.[19-21] The EM waves significantly enhance the adsorption process through dipole interactions and polarization effects, thereby improving the effectiveness of surface modification.[8,11] Dielectric or semi-conducting nanomaterials create electric dipoles in an EM field, which modifies solid surface free energy, affecting wettability change resulting in hydrophilicity or hydrophobicity in the system. EM waves induce a redistribution of surface charges on nanoparticles, resulting in alterations in zeta potential and surface electrostatic forces, which may result in the separation of oil from rock surfaces, facilitating changes in wettability.

Challenges and Limitations

Notwithstanding the available encouraging outcomes concerning nanomaterials employment for surface wettability change activated by EM waves, numerous difficulties persist:

- EM wave penetration: Efficient transmission of EM waves and exert frequency required
- Nanoparticle stability: Guaranteeing the prolonged stability and dispersion of nanoparticles in reservoirs.
- Cost-effectiveness: Expanding the technology for industrial use while ensuring economic viability.
- Environmental hazard: Possible ecological ramifications of nanoparticles in oil fields.

Potential Research Opportunities

- Formulating hybrid nanoparticles with enhanced dielectric characteristics for superior electromagnetic absorption.
- Investigating low-frequency EM waves for deep reservoir applications.
- Improving surface modification approaches of nanoparticles to optimize alterations in wettability.
- Utilizing machine learning models to enhance nanoparticle-EM interactions in enhanced oil recovery procedures.

Conclusion

The nanotechnology influenced by EM waves for enhanced oil recovery offers an attractive approach for enhancing reservoir wettability. Recent findings show that nanoparticles, especially dielectric and magnetic nanomaterials, can notably change wettability when subjected to EM waves, leading to enhanced oil displacement. Future advancements in material science and EM wave optimization will significantly improve this technology's feasibility and industrial applicability.

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Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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