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The Role of Nanotechnology in Enhanced Oil Recovery (EOR): Assessing the Impact of Nanoparticles on Oil Displacement Efficiency

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A B S T R A C T

The application of nanotechnology in Enhanced Oil Recovery (EOR) has shown significant potential in improving oil displacement efficiency. Various types of nanoparticles, including silica, carbon nanotubes, polymer, and metal oxide nanoparticles, have been explored for their ability to alter wettability, reduce interfacial tension, and improve oil recovery. This review provides an overview of the mechanisms, applications, and challenges associated with the use of nanoparticles in EOR. The current state of knowledge on the synthesis, functionalization, and transport of nanoparticles in porous media is discussed. Despite the promising results, challenges such as environmental concerns, economic viability, and technical scalability must be addressed to enable the widespread adoption of nanoparticles in EOR. Future research directions are proposed to overcome these challenges and realize the full potential of nanotechnology in EOR.

Keywords: Nanotechnology, Nanoparticles, Synthesis, Wettability, Scalability

1. INTRODUCTION

1.1 Definition and Overview

Enhanced Oil Recovery (EOR) denotes techniques. Oil extraction is increased with the employment of these methods. They are employed in situations where primary and secondary recovery techniques are ineffective (Alvarado & Manrique, 2010). Natural pressure determines primary recovery. It causes the reservoir's oil to be forced out. Secondary recovery, however, uses gas or water injections. This is how it displaces oil.

1.2 History of Enhanced Oil Recovery (EOR)

The concept of EOR has its roots in the 1950s. Around that period, the United States' first commercial EOR project got underway. Taber (1981) emphasises this idea of EOR. Ever since, EOR has changed. It has become a commonly used technique. Additionally, it is currently employed to boost oil output. Many methods have been created and applied all around the world.

1.3 Types of Enhanced Oil Recovery

There are several types of EOR, it includes:

a. **Thermal EOR:** Introducing heat is the subject of thermal EOR. The reservoir is the target of the heat. Reducing the viscosity of oil is the goal and it makes the extraction process more effective.

b. **Chemical EOR:** The goal of chemical EOR is to inject chemicals. could be polymers or surfactants. Their function is to reduce interfacial tension. This is crucial for both water and oil which made the extraction easier (Sheng, 2013).

c. **Gas EOR**: Gas injection is known as gas EOR. Examples are carbon dioxide and nitrogen. Displacement of oil is the goal. This enhances the oil output (Stalkup,1983).

d. **Microbial EOR:** Involves injecting microorganisms into the reservoir to break down the oil and increase production (Lazar *et al.,* 2007).

1.4 Benefits of EOR

EOR offers several benefits, including:

a. Increased oil production: EOR can increase oil production by 10-20% or more, depending on the technique used (Alvarado and Manrique, 2010).

b. Improved oil recovery: EOR can improve oil recovery by 5-15% or more, Increased depending on the technique used (Sheng, 2013).

c. Extended field life: EOR can extend the life of an oil field by 5-10 years or more, depending on the technique used.

2. FUNDAMENTALS OF NANOTECHNOLOGY IN EOR

2.1 Overview of Nanoparticles Used in EOR

Nanoparticles are increasingly being used in enhanced oil recovery, or EOR. This is a result of their distinct qualities. They are tiny and have a large surface area. Rock and oil surfaces can interact with them (Zhang *et al.,* 2018). Several types of nanoparticles have been tested for EOR. These include.

a. **Silica nanoparticles** are frequently used. It has been demonstrated that these nanoparticles increase the effectiveness of oil displacement. They accomplish this by altering the rock surface's wetting characteristics. Additionally, they lessen the tension that exists between water and oil.

b. **Carbon nanotubes** have been employed. Their oil displacement efficiency has increased. This is because the fluid used for displacement has a higher viscosity. Additionally, these particles reduce the permeability of rock (Li *et al.,* 2020).

c. **Polymer nanoparticles** have shown to increase oil displacement efficiency. This is by increasing fluid's viscosity and reducing tension between oil and water.

d. **Metal Oxide Nanoparticles**: These nanoparticles improve displacement of oil. By modifying the wetting nature of the rock surface and lessening tension between oil and water.

2.2 Mechanisms of Oil Displacement with Nanoparticles

a. Wettability Alteration

Nanoparticles can change wettability. It makes the surface of the rock more water-wet. This improves oil displacement. This is done via adsorption of nanoparticles. These are absorbed on the rock surface changing wettability.

b. Viscosity Reduction

Nanoparticles reduce viscosity of oil. The oil flows more easily. This improves oil displacement. It is achieved by dispersing nanoparticles in oil. This dispersion decreases oil's viscosity. It also improves its flowability.

c. **Interfacial Tension Reduction:** Nanoparticles, they can lower interfacial tension. This occurs between oil and water. It enhances oil displacement. It is done by adsorption of nanoparticles at the oil-water boundary. This reduces tension at the interface. Displacement efficiency is thus improved.

d. **Emulsification:** Nanoparticles lead to oil and water emulsification. It aids in enhancing oil displacement. Nanoparticle-stabilized emulsions are formed. They play a role in improving displacement efficiency. This occurs by enhancing the oil and water contact.

e. **Pore-Scale Mechanisms:** Nanoparticles also improve oil displacement. This is achieved through pore-scale mechanisms. For example, pore throat plugging. These mechanisms increase the sweep efficiency and reduce the residual oil saturation.

3. NANOPARTICLES USED IN OIL RECOVERY:

3.1 Silica Nanoparticles.

Among the most popular nanoparticles for oil recovery are silica nanoparticles. Their efficiency in oil displacement is enhanced. By changing the rock surface's wettability, this is accomplished. According to Zhang *et al*. (2018), they also lessen the interfacial tension between water and oil.

3.2 Carbon Nanotubes.

Carbon nanotubes play a vital role in oil recovery. Their use improves oil displacement efficiency. They do so by increasing the viscosity of displacing fluid. It also reduces the permeability of rock (Li *et al*., 2020).

3.3 Polymer Nanoparticles

It has been discovered that oil displacement efficiency is increased by polymer nanoparticles. Increasing the fluid's viscosity does this. Additionally, they lessen the tension that exists between water and oil (Singh *et al*., 2019).

3.4 Metal Oxide Nanoparticles

Increased oil displacement efficiency has been associated with metal oxide nanoparticles. For example, they contain titanium dioxide and zinc oxide. They change the rock surface's wettability. Additionally, they lessen strain at water-oil interfaces (Alomair et al., 2019).

3.5 Magnetic Nanoparticles

Magnetic nanoparticles improve oil displacement efficiency. They do this by increasing viscosity of displacing fluid. Reducing permeability of rock is another thing they do (Wang *et al*., 2020).

3.6 Hybrid Nanoparticles

It appears that hybrid nanoparticles could improve the efficiency of oil displacement. For example, there are opportunities to investigate silica-carbon nanotube hybrids. They can increase the recovery of oil. Utilising various nanoparticle characteristics is how this is accomplished.

3.7 Janus Nanoparticles

Janus nanoparticles show promising results in oil displacement efficiency. They change the wettability of the rock surface. They also reduce interfacial tension between oil and water.

3.8 Core-Shell Nanoparticles

A notable advancement in oil displacement efficiency is provided by core-shell nanoparticles. They accomplish this by using a single substance's core. It forms a shell by being encased in another substance.

3.9 Lipid Nanoparticles

Lipids are used to make lipid nanoparticles. They efficiently increase the efficiency of oil displacement. This is because they have an impact on how wettable a rock's surface is. Additionally, they lessen the tension that exists between water and oil.

4. USES OF NANOPARTICLES IN EOR

Recent research showcases the efficacy of nanoparticles in diverse EOR applications. These conclusions are:

4.1. Application in Fields

Field experiments utilized silica nanoparticles. They recorded an increase of up to 30%. This was in oil recovery rates. It represents a leap compared to traditional approaches (Fang *et al.,* 2023).

4.2. Use in Laboratories

Laboratory tests confirmed the addition of nanoparticles. These were added to water flooding and an up to 50% increase in oil recovery was noted (Sadeghian *et al.,* 2021).

5. SYNTHESIS OF NANOPARTICLES

Various methods can synthesize nanoparticles. These methods include the following techniques.

5.1 Physical Methods:

a. **Laser Ablation**: It involves employing a powerful laser. The laser ablates a target material. The result is the formation of nanoparticles.

b. **Sputtering**: This method employs a high-energy beam. The beam sputters a target material. The end product is the formation of nanoparticles.

5.2 Chemical Methods:

a. **Sol-Gel Method**: is a chemical method. It involves the hydrolysis and condensation of metal alkoxides. This combination results in the creation of nanoparticles.

b. **Colloidal Method**: is another chemical method. It involves the use of a reducing agent. This agent reduces metal ions to form nanoparticles..

5.3Biological Methods:

a. **Microbial Method**: Involves the use of microorganisms. These organisms synthesize nanoparticles.

b. **Plant-Mediated Method**: Uses plant extracts. These extracts synthesize nanoparticles.

6. FUNCTIONALIZATION OF NANOPARTICLES

Functionalization of nanoparticles includes modification of their surface properties. It enhances their stability and dispersibility. It improves their interaction with other materials.

6.1 Surface Modification

a. **Ligand Exchange:** A technique that calls for swapping out current ligands. It takes place on nanoparticle surfaces.

b. **Silanization:** This process uses silane molecules to react. These chemicals interact with the nanoparticle surface. A silane layer is the end product.

6.2 Coating and Encapsulation

a. **Polymer Coating:** This is the method. It involves coating of nanoparticles with polymer layer. This enhances stability and dispersibility of the nanoparticles.

b. **Lipid Encapsulation:** This method involves encapsulating nanoparticles. This is done in a lipid bilayer. The purpose is to enhance biocompatibility and targeting ability of nanoparticles.

7. TRANSPORT AND STABILITY OF NANOPARTICLES IN POROUS MEDIA:

Stability and transport of nanoparticles in porous media is a crucial factor. It is key for several applications. Enhanced oil recovery is one of them. Groundwater remediation is another. The same is true for subsurface energy storage. Understanding this factor is a must, Because this understanding is essential. It's essential for optimizing the use of nanoparticles in these applications.

7.1 Factors Influencing Nanoparticle Conveyance

Various elements influence nanoparticle transit within porous media. These include:

a. **Size and Shape of Particles:** Nanoparticles' size and shape impact their movement through porous media (Kretzschmar *et al.,* 1999).

b. **Surface Charge and Chemistry**: Surface charge and chemistry of nanoparticles affect interaction with porous media. This impacts their transit (Tufenkji *et al.,* 2004).

c. **Properties of Porous Media**: Properties of porous media affect nanoparticle transport. This includes factors like permeability and porosity. It also includes surface roughness.

d. **Fluid Flow Rate and Pressure**: Fluid flow rate and pressure affect nanoparticle transport. They also affect deposition in porous media.

7.2 Mechanisms of Nanoparticle Deposition

Nanoparticles may accumulate in porous media using various methods. These include.

a. **Straining**: Porous media can exert strain on nanoparticles. This results in their accumulation.

b. **The attraction of Nanoparticles**. Nanoparticles tend to be attracted to the porous media using electrostatic forces. This leads to their accumulation.

c. **Hydrophobic Interactions**. Nanoparticles can interact with porous media due to hydrophobic forces. This leads to their accumulation.

7.3 Stability of Nanoparticles in Porous Media

Nanoparticles' stability in porous media is vital. It is required for their movement and application. Elements that have an effect on nanoparticle stability are.

Nanoparticles may aggregate in porous media, which would impact their mobility and stability; they may disperse in porous media, which would impact their mobility and stability; and they may experience chemical reactions in porous media, which would impact their mobility and stability as well.

8. CHALLENGE AND LIMITATIONS

Several obstacles prevent the broad use of nanoparticles in EOR, despite the encouraging results:

8.1 Environmental Factors

More research is required to determine the long-term consequences of nanoparticles on the environment, as their influence is still largely unclear (Kumar *et al.,* 2023).

8.2. Financial Sustainability

In order to make the use of nanoparticles in EOR economically viable, the cost of their production and deployment must be addressed (Mansoori *et al.,* 2024).

8.3 Technical Difficulties

The manufacturing of nanoparticles and their use in large-scale oil fields pose substantial technical obstacles in terms of scalability (Khan *et al.,* 2021).

9. FUTURE DIRECTIONS

Research in the future should concentrate on creating eco-friendly nanoparticles that reduce their negative effects on the environment. Carry out extensive field research to evaluate the practical efficacy of nanoparticles in EOR. To cut expenses and increase scalability, new synthesis techniques are being investigated.

10. Conclusion

Nanotechnology holds significant potential in enhancing oil recovery through improved oil displacement efficiency. While the current research shows promising results, further studies are needed to address the environmental, economic, and technical challenges that currently limit the application of nanoparticles in EOR.

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