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Magnetic Nanoparticles for Oil Removal from Water: A Short Review of Key Findings

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Abstract:

This mini review provides an overview of the potential use of magnetizable nanoparticles for de-oiling water, drawing on the findings of several studies in the field. Magnetic nanoparticles demonstrate significant promise for oil removal due to their magnetic properties, which enable them to be separated from contaminated water using a magnetic field. Additionally, the surface of these nanoparticles can be modified with oil-attracting agents to enhance their oil-removal efficiency. Our systematic search in Scopus revealed that "oil," "water," "magnetic," "nanoparticles," and "removal" were the most commonly used words in the literature corpus. Through our analysis of four case studies, we gained valuable insights into the practical applications of magnetic nanoparticles for oil removal from water and observed that their unique magnetic properties make them an ideal solution for this purpose. Furthermore, our summary of key findings from the four studies revealed that optimal conditions for oil removal include a nanoparticle size range of 2-10 nm, surface modification with cationic coatings or silica and ammonium, and a concentration range of 0.31 to 5 mg/cm^3 to 30-50 mg/L. The recyclability of these nanoparticles was found to be efficient, with an oil removal efficiency of approximately 97% after ten cycles. However, further research is needed to determine the optimal conditions for oil removal from water using magnetic nanoparticles, as these conditions may vary based on specific applications. In conclusion, magnetic nanoparticles offer a promising avenue for effective water de-oiling and are an area of significant interest in oil removal from water research.

Keywords: Oil-water separation; magnetic nanoparticles; magnetite; maghemite; surface modification

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Introduction

Magnetizable nanoparticles are materials with unique properties for a variety of applications, many of which have been studied by our research group (1–57), such as those ranging from environmental recovery to drug delivery.

Magnetic nanoparticles have been proposed as a promising solution for removing oil from water (58–64). This is due to the magnetic property of these particles, which allows them to be easily separated from the contaminated water using a magnetic field (65–73). The surface of magnetic nanoparticles can also be modified with oil-attracting agents, such as surfactants, to enhance their oil-removal efficiency (74–79). The use of magnetic nanoparticles has been shown to be efficient, environmentally friendly and cost-effective compared to traditional methods of oil removal from water (80–82). However, most of these studies are effective on a laboratory scale. Thus, more research is needed to determine its effectiveness and feasibility on a large scale in real-world scenarios.

Methods:

A systematic search was conducted in Scopus using the TITLE-ABS-KEY search ("Magnetic Nanoparticles" AND "Oil Removal" AND Water) to identify relevant literature on magnetic nanoparticles for oil removal from water. The search results were saved as a CSV file and filtered based on relevance criteria. Titles and abstracts of the remaining documents were then extracted and saved as TXT files for each year. These TXT files were analyzed using Voyant Tools to identify key trends and patterns over time.

Additionally, four relevant case studies were selected and analyzed to gain further insights into the practical applications of magnetic nanoparticles for oil removal from water. These case studies were selected based on their relevance and impact on the field, and their results were integrated into the overall analysis to provide a more comprehensive understanding of the topic.

Results

On February 23, 2023, we conducted a comprehensive search for relevant literature on the topic of "Magnetic Nanoparticles for Oil Removal from Water" in Scopus using the TITLE-ABS-KEY search ("Magnetic Nanoparticles" AND "Oil Removal" AND Water). We retrieved 50 documents that were subsequently analyzed using Voyant Tools. The corpus is publicly available at https://voyant-tools.org/?corpus=5f86f0f9561b87f8584c19b434b39ac0. Voyant Tools is a powerful web-based text analysis tool that enables users to upload text corpora and perform various text analysis tasks, including trend analysis, text visualization, and word frequency analysis. The tool generated a list of the most common words in the corpus and their frequencies, which helped us identify the most important words.

The five most frequently occurring words in the corpus were "oil" (354), "water" (174), "magnetic" (146), "nanoparticles" (145), and "removal" (112). We used this data to analyze the frequency of these top five words over 13 years (2010-2023). The frequency of each word fluctuated over time, with "oil" being the most common word throughout the period, followed by "water," "magnetic," "nanoparticles," and "removal." Interestingly, "oil" was predominant in 2015, likely due to heightened awareness and attention following the Deepwater Horizon oil spill in the Gulf of Mexico on April 20, 2010.

Our analysis highlights the significance of magnetic nanoparticles in de-oiling water. The high frequency and increasing trend of "magnetic nanoparticles" suggest that they are a topic of interest in oil removal from water research. Magnetic nanoparticles possess unique magnetic properties that make them ideal for removing oil from water. They can be separated from water using an external magnetic field, making them a promising tool for treating oil-contaminated water.

To further investigate the effectiveness of magnetic nanoparticles in removing oil from water, we selected and analyzed four relevant studies.

The first study, "Application of Magnetic Nanoparticles for the Removal of Oil from Oil-in-Water Emulsion: Regeneration/Reuse of Spent Particles" by Elmobarak and Almomani (83), explored the use of magnetite nanoparticles for removing oil from water. The authors found that 8 nm particles with a 30-50

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mg/L concentration achieved a 98% or higher demulsification efficiency. Additionally, the authors reported a recovery rate of 83% for the nanoparticles after the seventh reuse cycle.

The second study, "Accelerated Oil Droplet Separation from Produced Water Using Magnetic Nanoparticles," by Ko et al. (84), examined magnetic nanoparticles with cationic coatings for separating oil droplets from produced water. The authors found that cationic coatings were more efficient than anionic coatings, with the best conditions involving surfactants and nanoparticles in specific proportions, resulting in a separation time of 2 hours.

The third study, "Efficient Removal of Enhanced-Oil-Recovery Polymer From Produced Water With Magnetic Nanoparticles and Regeneration/Reuse of Spent Particles" by Ko, Lee, and Huh (85), investigated the use of magnetic nanoparticles modified with silica and ammonium for removing Enhanced-Oil-Recovery Polymer (HPAM) from produced water. The solution delivered a removal efficiency of about 100%.

The fourth study, conducted by Theurer and colleagues (86), investigated the use of magnetic nanoparticles for removing residual oil from produced water. The study found that Fe_3O_4 magnetic nanoparticles require surface modification for effective oil removal, while γ-Fe_2O_3 does not. The researchers achieved an impressive oil removal efficiency of 99.9% for an oil-in-water emulsion of 1,000 ppm, using particles with a critical concentration of 0.625 mg/cm3 and a size of 22.5 nm. The magnetic nanoparticles were also recyclable, with a high oil removal efficiency of 97% after ten cycles.

These findings suggest that magnetic nanoparticles have the potential to be a promising tool for removing residual oil from produced water, with potential applications in industrial and environmental settings.

Conclusions and directions:

This short review examines the use of magnetic nanoparticles for removing oil from water, employing bibliometric analysis based on Voyant Tools data and focusing on four important studies. The analysis indicates that the most frequent words in the corpus were "oil," "water," "magnetic," "nanoparticles," and "removal," with "magnetic nanoparticles" being of particular interest. The optimal conditions for removing oil from water using magnetic nanoparticles were identified, including nanoparticle size, surface modification, concentration, and recyclability. However, these conditions are dependent on the specific type and composition of oil, presence of surfactants, and other factors. Based on the four studies, the recommended optimal conditions are as follows:

- Nanoparticle size: 2-10 nm
- Surface modification: cationic coatings (Accelerated Oil Droplet Separation from Produced Water) or silica and ammonium modification (Efficient Removal of Enhanced-Oil-Recovery Polymer from Produced Water). γ-Fe_2O_3 does not require surface modification (Removal of Residual Oil from Produced Water).
- Concentration: a concentration range of 0.31 to 5 mg/cm^3 with a critical concentration of 0.625 mg/cm^3 (Removal of Residual Oil from Produced Water) or 30-50 mg/L (Application of Magnetic Nanoparticles for the Removal of Oil from Oil-in-Water Emulsion).
- Recyclability: The magnetic nanoparticles are recyclable, with an oil removal efficiency of around 97% after ten cycles (Removal of Residual Oil from Produced Water).

It is important to note that these conditions may vary based on the specific type and composition of oil, presence of surfactants, and other factors. Further research is needed to determine the optimal conditions for removing oil from water using magnetic nanoparticles.

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