Removal of paraffinic compounds from crude oil using magnetite to improve transportation efficiency

Yesenzholova Nadiya, Randy Hazlett

Abstract

Paraffin deposits in crude oil pipelines reduce flow efficiency and increase the risk of blockages and damage. This research investigates the potential of magnetite (Fe_3O_4) to remove paraffin from model oil. A mixture of dodecane and paraffin was used to simulate crude oil. Magnetite (0.5 g and 1.0 g) was added at 80 °C and stirred while the temperature gradually dropped to 60 °C, 50 °C, and 40 °C. The amount of paraffin extracted at each stage was measured. The results showed that magnetite can capture paraffin, with better efficiency at higher temperatures and when using 1 g of magnetite. However, overall performance remains limited, suggesting the need for further optimization or complementary methods.

Introduction

Due to the depletion of old oil fields and increased demand for energy resources, The energy industry has increasingly turned to the extraction of oil from heavier sources.This shift includes the development and extraction of high-paraffin crude oils. High-paraffin crude oils are characterized by a significant content of high-molecular-weight paraffins (alkanes, particularly those with 18 or more carbon atoms)." (More concise, uses "or more" for C18+).These high-molecular-weight alkanes, which exhibit a strong tendency to crystallize at reduced temperatures, forming dense paraffin deposits within pipelines and on equipment. This crystallization significantly increases the viscosity of the oil, especially at low temperatures, and leads to a progressive narrowing of the pipeline lumen.[1] This increases hydraulic resistance, leading to increased pressure in the system, especially in cold weather. In extreme cases, this can cause pipe rupture or oil leakage. [2],[3].

To mitigate these flow assurance challenges, various methods are employed to improve oil transportation, particularly by reducing paraffin deposits through diverse treatments.The primary industrial solution involves the use of chemical additives known as pour point depressants (PPDs) [4,] [5]. Despite their widespread application, pour point depressants (PPDs) often fail to ensure adequate performance with highly waxy crude oils [6]. Moreover, their efficacy is often compromised by mechanical stress and temperature fluctuations during pipeline flow [7]. This highlights the pressing need to develop alternative methods to enhance the low-temperature transportability of crude oils.

One environmentally friendly method for reducing paraffin deposits in pipelines is the use of magnetite—a magnetic mineral that can interact with wax molecules and help remove them from crude oil. Unlike magnetic field treatments, magnetite offers a physical sorbent-based approach, where paraffin molecules are captured by magnetite particles and then removed using a magnet.

Studies suggest that magnetite may influence wax crystallization by disrupting aggregation and weakening intermolecular forces between long-chain alkanes like dodecane ($C_{12}H_{26}$), which are responsible for wax formation in pipelines [8]. This improves oil flowability by lowering viscosity and pour point. However, the practical effectiveness of magnetite in paraffin removal remains insufficiently studied.

The aim of this research is to quantitatively evaluate how well magnetite removes paraffin from model oil at different temperatures. This could offer a low-cost, scalable alternative to chemical additives for flow assurance in high-paraffin crude oil.

Methodology

This study will conduct a controlled experiment to quantify the effect of magnetite on the physical behavior of crude oil containing paraffin. A series of comparative tests will be performed to assess how magnetite influences paraffin removal and wax crystallization. The experiments will be conducted at different cooling stages

without applying chemical additives, ensuring that any observed changes result solely from the interaction between magnetite and paraffin compounds under realistic conditions.

This study uses synthetic paraffin wax (melting point range: 60–80 °C) as the precipitating component to simulate the behavior of high-paraffin crude oil. The base solvent is n-dodecane ($C_{12}H_{26}$, ≥99% purity), representing a light hydrocarbon fraction of crude oil. The aim is to investigate the influence of magnetite (Fe_3O_4) on paraffin precipitation under controlled thermal conditions using a magnetic stirrer–hotplate system. Magnetite is introduced at various cooling stages to evaluate its effectiveness in reducing paraffin content through physical sorption and magnetic separation

.1. Sample Preparation

Oil model samples were prepared by dissolving 39 g of paraffin wax (melting point 60–80 °C) in 100 mL of n-dodecane ($C_{12}H_{26}$, ≥99% purity, ~75 g), corresponding to 34.2 wt% paraffin. Dissolution was carried out at 80 °C on a magnetic stirrer–hotplate with continuous stirring at 600 rpm to ensure complete homogenization. The paraffin concentration was kept constant for all trials to enable direct comparison.

2. Measurement of Paraffin Solubility

Solubility of paraffin in dodecane was evaluated at three temperature points: 40 °C, 60 °C, and 80 °C. At each temperature, the solution was maintained under constant stirring at 600 rpm for 15 minutes using a magnetic stirrer–hotplate to ensure uniform mixing.

Clarity was assessed by visually comparing each sample against a standardized white background under consistent lighting conditions, with photographs taken for documentation.

3. Cooling and Precipitation Stage

After thermal equilibration, the samples were cooled from the dissolution temperature to ambient conditions. The ambient temperature during experiments

was approximately 25 °C.
Photographs of the samples were taken at 40 °C, 60 °C, and 80 °C during the experiment, immediately after each addition of magnetite, to document changes in clarity and the appearance of visible precipitates.
At each stage, magnetite bound with paraffin was removed manually using a strong external magnet and laboratory gloves to ensure safety. The collected material was weighed directly on an analytical balance (±0.1 mg) to determine the mass of paraffin removed.

4. Magnetic Extraction Stage
At each cooling stage (80 → 60 °C, 60 → 50 °C, and 50 → 40 °C), magnetite (0.5 g or 1.0 g, Fe_3O_4 powder, ≥99% purity) was added directly into the paraffin–n-dodecane mixture. The suspension was stirred magnetically at 600 rpm for 5 minutes at the target temperature.
After stirring, magnetite bound with paraffin was removed manually using a neodymium external magnet , handled with nitrile laboratory gloves for safety. The collected magnetite–paraffin mixture was transferred to a pre-weighed glass container and dried in a laboratory oven at 40 °C for 12 h to remove residual solvent. The final mass was recorded on an analytical balance (±0.1 mg).
All experiments were performed in three replicates for each magnetite mass and temperature condition.

5. Data Analysis
The following parameters were compared across all temperature and magnetite mass conditions:

Paraffin solubility at each temperature (g per 100 mL).
Mass of paraffin removed by magnetite at each stage.
Removal efficiency (%)
Visual clarity changes recorded from photographs taken at 40 °C, 60 °C, and 80 °C.
Data are reported as mean ± standard deviation from three replicates per condition.

Materials

Magnetite (Fe_3O_4) – fine powder, purity ≥99% (supplier not specified).

n-Dodecane ($C_{12}H_{26}$) – purity ≥99%, clear liquid hydrocarbon (supplier not specified).
Synthetic paraffin wax – melting point range 60–80 °C, purity ≥99% (supplier not specified).
Heating oven – laboratory oven, temperature set at 40 °C for drying samples.
Laboratory thermometer – accuracy ±1 °C, range 0–100 °C.
Magnetic stirrer–hotplate – used for controlled heating and continuous mixing of samples.
Mastersizer 3000 – laser diffraction particle size analyzer, used to determine the particle size distribution of magnetite.
X-ray Diffractometer (XRD) – used to confirm the crystalline structure and phase purity of magnetite.

Method

1. Paraffin Solubility Test

The solubility of paraffin in dodecane was determined at different temperatures (40 °C, 60 °C, and 80 °C). A weighed amount of paraffin was gradually added to pre-heated dodecane in a glass beaker, stirred until no more paraffin dissolved, and the saturation point was recorded.

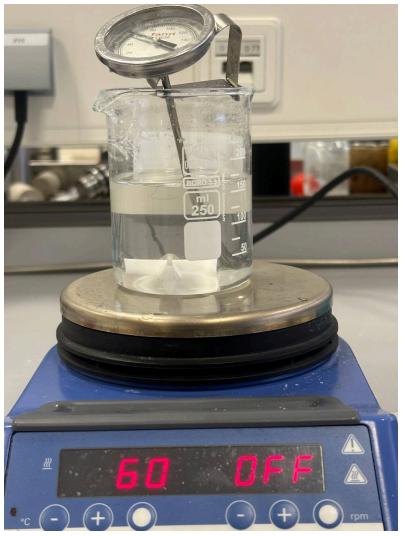


Figure 1. Experimental setup for paraffin solubility determination

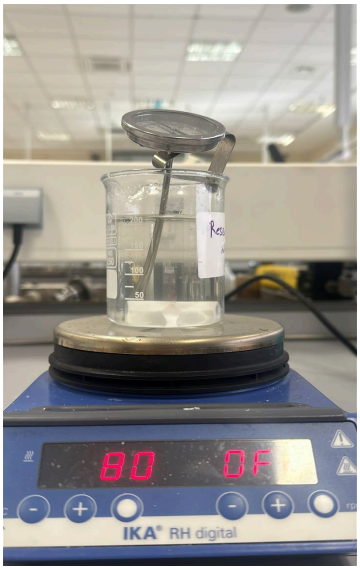


Figure 2. Saturated paraffin–dodecane mixture at 80 °C

2. Paraffin Removal with Magnetite

To investigate paraffin removal efficiency, a model oil (dodecane saturated with paraffin) was first heated to 80 °C. Magnetite was added (0.5 g or 1 g), and the mixture was stirred with a magnetic stirrer until the temperature dropped to 60 °C. At this point, the magnetite was extracted using a magnet, and the recovered paraffin mass was recorded. The same procedure was repeated during further cooling stages—60 °C to 50 °C, and 50 °C to 40 °C—by reintroducing fresh magnetite each time.



Figure 3. Magnetite addition to model oil at 80 °C

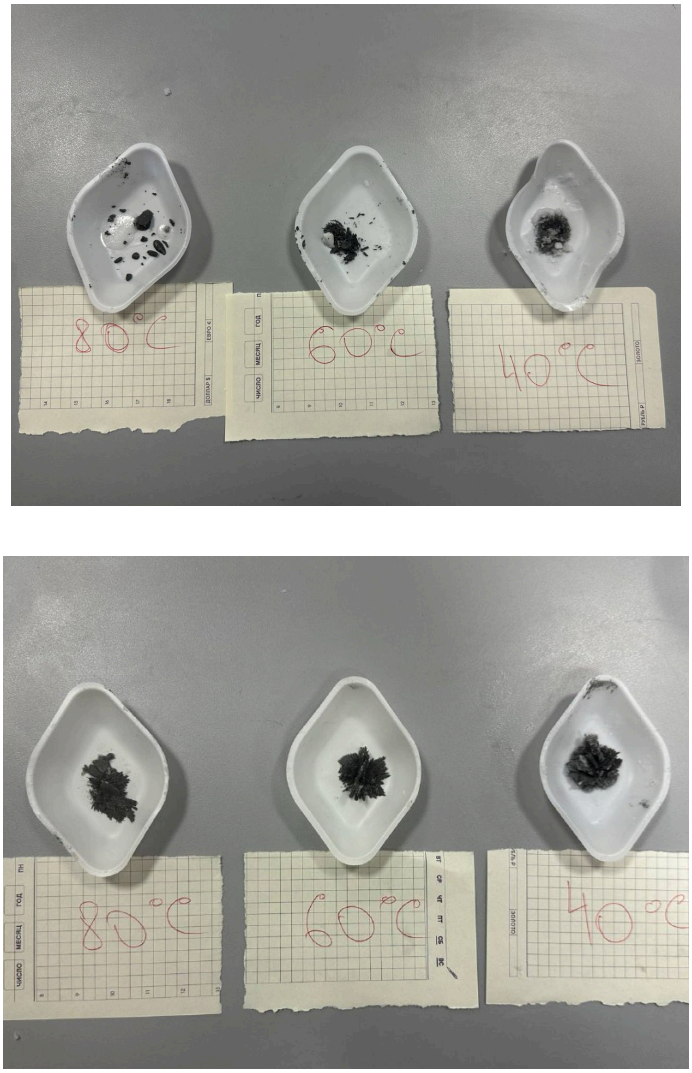


Figure 4. Magnetic extraction of paraffin-coated magnetite(0.5g and 1g)

Results

1. Paraffin Solubility

The solubility of paraffin in dodecane increased with temperature. At 40 °C, only a small amount of paraffin dissolved before reaching saturation, while at 80 °C, the solution could hold significantly more paraffin.

Temperature	Solubility per 100 ml
40°C	38g
60°C	35g
80°C	41g

Figure 5. Maximum paraffin solubility in dodecane at different temperatures

2. Paraffin Removal Efficiency

Magnetite was able to extract paraffin from the model oil at all tested stages. Using 1 g of magnetite consistently showed higher removal efficiency compared to 0.5 g.

Better paraffin removal was observed during higher-temperature cooling stages (80 °C → 60 °C) compared to lower temperatures (50 °C → 40 °C). This trend suggests that paraffin remains more accessible for extraction before it fully solidifies.

Temperature(°C)	**Magnetite amount (g)**	**Extracted paraffin (g)**	**Removal Efficiency (%)**
80->60	0.5	0.355	0.865
80->60	1	0.26	0.634
60->50	0.5	0.325	0.928
60->50	1	0.386	1.103
50->40	0.5	0.325	0.855
50->40	1	1.08	3.08

Figure 6.Effect of Temperature and Magnetite on Paraffin Removal

Conclusion

This study demonstrated that magnetite can remove paraffin from model oil, although the overall efficiency remains limited. Higher magnetite mass (1 g) and higher cooling-stage temperatures improved removal rates, while paraffin solubility tests confirmed that temperature strongly influences wax behavior in oil. These findings suggest that magnetite alone may not be sufficient for practical pipeline applications, and further optimization—such as combining magnetic treatment with mechanical or chemical methods—could be required to achieve effective paraffin control.

References

(1) Ganeeva, Yu. M.; Foss, T. R.; Yusupova, T. N.; Romanov, A. G. Distribution of High-Molecular-Weight n-Alkanes in Paraffinic Crude Oils and Asphaltene-Resin-Paraffin Deposits. *Pet. Chem.* **2010**, *50* (1), 17-22. DOI: 10.1134/S0965544110010020.

(2) Ribeiro, F. S.; Souza Mendes, P. R.; Braga, S. L. Obstruction of Pipelines Due to Paraffin Deposition During the Flow of Crude Oils. *Int. J. Heat Mass Transfer* **1997**, *40* (18), 4319-4328. DOI: 10.1016/S0017-9310(97)00082-3.

(3) Brill, J. P. Paraffin Deposition Phenomena in Crude Oil Pipelines. In *IUTAM Symposium on Lubricated Transport of Viscous Materials*; Springer: Dordrecht, Netherlands, **1997**; Vol. 43, pp 43-64. DOI: 10.1007/978-94-011-5248-8_4.

(4).Ibrahim, R. I.; Oudah, M. K.; Hassan, A. F. Viscosity Reduction for Flowability Enhancement in Iraqi Crude Oil Pipelines Using Novel Capacitor and Locally Prepared Nanosilica. *J. Pet. Sci. Eng.* **2017**, *156*, 356-365. DOI: 10.1016/j.petrol.2017.05.028.

(5)Zhang, J.; Liu, D.; Wang, H.; Wang, R.; Xu, C. Performance and Mechanism of a Novel Electro-Magnetic Treatment for Improving the Cold Flowability of Waxy Crude Oil. *Fuel* **2021**, *285*, 119119. DOI: 10.1016/j.fuel.2020.119119.

(6)Zhang, C.; Zhang, J.; Kang, J.; Xie, Y.; Han, S.; Li, H. Electrorheological Effects of Waxy Crude Oils under High-Voltage AC Electric Field. *Fuel* **2023**, *331*, 127494. DOI: 10.1016/j.fuel.2023.127494.

(7)Xie, Y.; Li, H.; Xu, M.; Su, Y.; Zhang, C.; Han, S.; Zhang, J. Effect of Shear on Durability of Viscosity Reduction of Electrically-Treated Waxy Crude Oils. *Energy* **2023**, *286*, 128605. DOI: 10.1016/j.energy.2023.128605. (Note: Volume 286, not 285, based on DOI check).

(8).Zhang, W. W.; Wang, D. D.; Wang, T. T.; Zhang, S. C. Study on the Mechanism of Magnetic Paraffin Control of Crude Oil Based on the Reorientation of Paraffin Crystals Induced by Magnetic Field. *Appl. Mech. Mater.* **2015**, *743*, 137-141. DOI: 10.4028/www.scientific.net/AMM.743.137.

(9).Marques, L. C. C.; Rocha, N. O.; Machado, A. L. C.; Neves, G. B. M.; Vieira, L. C.; Dittz, C. H. Study of Paraffin Crystallization Process Under the Influence of Magnetic Fields. In *Proceedings of the Latin American and Caribbean Petroleum Engineering Conference (LACPEC)*, Rio de Janeiro, Brazil, August 30-September 3, **1997**; SPE 38990. DOI: 10.2118/38990-MS.