Manuscript Title: A Review on the Feasibility of Chelating Agents for Enhanced Oil Recovery from Sandstone Reservoirs

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Abstract

With the growing world demand for energy, it is challenged to enhance the efficacy of crude oil recovery methods to increase production from oil reservoirs. This review paper evaluates the efficiency of the chelating agents, i.e., Ethylene diamine tetra acetic acid (EDTA) and Diethylenetriamine penta acetic acid (DTPA) as low salinity water flooding (LSWF) performance improvers for enhancing oil recovery of sandstone reservoirs. The efficacy of chelating agents, with metal ions, was appraised with regard to reservoir and fluid properties (interfacial tension, wettability alteration, viscosity, acid number, pour point, API gravity, and capillary pressure). Laboratory experiments on crude-saturated cores infer changes in these properties as a function of EDTA- or DTPA treatment. Past research work show that use of the chelating agents could successfully change the wettability of rocks from oil-wet to water-wet and reduce the interfacial tensions and enhance the mobility of crude oil. Moreover, chelating agents are found effective in inhibiting mineral scales and facilitate better permeability and flow performance. The findings of this review work highlight chelants as a potential strategy for the LSWF for EOR application with better performance along with environmental acceptability.

Keywords: Chelating agent, low salinity water flooding, sandstone reservoir, heavy crude oil, wettability alteration, interfacial tension

A Review on the Feasibility of Chelating Agents for Enhanced Oil Recovery from Sandstone Reservoirs

1 Introduction

Oil is extremely important as the main energy source in the world, and with the growing need for hydrocarbons, it is essential to improve hydrocarbon production using better recovery methods, effective reservoir management, and new technologies. This approach aims to meet global energy demands sustainably while ensuring economic viability and supply security [1]. Conventional oil recovery methods are typically categorized into primary, secondary, and tertiary stages, each progressively enhancing extraction efficacy by employing the natural drive of a formation, water or gas flooding techniques, and enhanced oil recovery (EOR) methods, such as thermal, chemical, or gas processes, to recover additional hydrocarbon volumes, thus augmenting operational efficiency and reservoir performance [2]. The rate of oil recovery from the reservoir is solely a function of the natural energy of the reservoir during the primary period. The second strategy is often to control the reservoir pressure with gas injection or water flooding to drain additional oil to the production wells, thereby increasing the recovery efficiency of the field and extending the productive life of the reservoir through improved reservoir drive mechanism [3]. To aid in extracting additional oil at this stage, tertiary methods — what's known as enhanced oil recovery (EOR) — come into play. As a result, EOR maximizes a field's potential by accessing the remaining oil saturation that exists in the rock, by changing the physical properties of the oil or reservoir rock to allow migration through the rock, to lower the interfacial tension or to release the oils, and enhance the flow or mobility of crude oil in the rock-mass, and to increase/extend the overall yield or productivity of the field, increasing the percentage of the reservoir's Original Oil In Place (OOIP) that can potentially be produced [4].

One essential characteristic that tells us how easily a fluid will flow is its viscosity. The viscosity of crude oil can affect how easily it passes through pipelines and the rocks in the reservoir. The more viscous an oil is, the slower it flows, which complicates oil production and frequently calls for specialized techniques like enhanced oil recovery (EOR) to optimize extraction [5]. Due to its paraffinic character and high wax content, the crude oil has a comparatively high viscosity in comparison to many other crude oils. In addition to affecting the flow characteristics during recovery and transportation, this high viscosity presents problems such as pipeline wax accumulation, elevated pour points, and the need for extra extraction and/or heating procedures to preserve mobility in the face of temperature variations that may occur in the field [6]. The weather in the area makes this greater viscosity even more noticeable: colder ambient temperatures can precipitate waxes in the crude, raising the pour point and making flow even more challenging [6]. Various strategies have been put out to address these issues. One way to reduce viscosity and improve oil flow characteristics is to utilize diluents like surfactants [7]. Additionally, using chelating chemicals like EDTA and DTPA with low-salinity water can promote changes in rock wettability and interfacial tension, which enhances oil mobilization and recovery. The goal of these methods is to make extraction and transportation of crude oil easier by overcoming the challenges posed by its high viscosity.

The American Petroleum Institute developed API gravity as a means of determining if a hydrocarbon liquid is heavier or lighter. It's established using Eq. (1):

$$\text{API gravity} = (141.5 / \text{SG at } 60°\text{F}) - 131.5 \qquad (1)$$

Where, SG is the specific gravity of the crude oil. Crude oils are classified based on their API gravity as follows:

Light crude oil: API gravity > 31.1°
Medium crude oil: API gravity between 22.3° and 31.1°
Heavy crude oil: API gravity < 22.3° . [8]

The crude oil exhibits a wide range of API gravities from indicating the presence of both heavy and light crude oil. Among other factors, the paraffinic nature and wax concentration of the crude oil, which also influence its viscosity and pour point, are responsible for the variation in API's gravity [9]. Furthermore, the interaction between chelating agents and metal ions in crude may impact the latter's density and, thus, its API gravity.

The term "total acid number" (TAN), also known as "acid number" (AN), refers to multiples of the mass of potassium hydroxide (KOH) per thousand barrels of oil. It is computed using milligrams of KOH equivalents per gram of oil. One of the most crucial factors in determining how corrosive crude oils are is their TAN value. A high TAN value may lead to corrosion in pipelines and refinery equipment since it indicates a higher concentration of naphthenic acids and other organic acids. Crude oils with TAN values greater than 0.5 mg KOH/g are regarded as acidic, and those with TAN values greater than 1.0 mg KOH/g are classified as high TAN and challenging to handle [10]. The issue of high TAN crude oils has been addressed by the study of several additions, including chelating agents like ethylenediaminetetraacetic acid (EDTA). These substances can work in tandem with metal ions and acidic groups to counteract the crude oil's acidity and corrosion-causing qualities [11].

The lowest temperature at which crude oil loses its flowability is the pour point temperature. This measure is crucial for evaluating the transferability and flowability of crude, and it becomes even more significant at lower temperatures. It is widely accepted that high pour point crude oil, which primarily originates from sources with high wax content, has a significant impact on storage tanks and pipeline transit [9]. Crude oil having a high paraffinic content, results in much higher pour points. Due to its waxy nature, the crude has a tendency to accumulate wax during transit, which can lead to clogging and increased maintenance expenses [7]. Chelating agents have been explored as a potential solution to this issue. Chelating compounds, such as EDTA and DTPA, can lower the pour point because they can mix with the metal ions in crude oil and alter the waxes' crystallizing properties. According to studies, adding chelating agents can lower the pour point and facilitate the flow of crude oil, both of which are advantageous for the transportation of crude.

One crucial factor in assessing surface wettability, and one that is particularly significant for crude oil recovery, is the contact angle. The contact angle is the angle, expressed in degrees, between the tangent to the droplet and the horizontal that the tangent line makes with the solid surface far inside the droplet [12]. This angle infers how the liquid is interacting with the solid's surface; if the liquid completely wets the surface and makes contact with it, the contact angle is 0°; if the angle is 180°, the solid was not wetted. To evaluate how crude oil behaves in porous reservoir rock, petroleum engineers need to determine the contact angle [13]. Since water can imbibe more effectively and displace the oil, a lower contact angle suggests that the surface is water-wet, which can be advantageous to the EOR. On the other hand, a large contact angle might decrease oil recovery by trapping the oil in the rock pores and become a measure of the oil-wet surface [13]. When the wettability of the reservoir rock shifts from oil-wet to neutral-wet, the compression of capillary forces enables the gravitational forces to play a substantial role in oil recovery [14]. While this wettability change may not lead to instantaneous enhanced extraction, by weakening capillarity, it improves recovery through the influence of gravity [14]. The former involves capillary imbibition, which is facilitated by the combination of capillary and gravity forces to improve oil recovery as the wettability is transformed from neutral to strong water-wet [15]. Such conversion of wettability from oil-wet to water-wet helps to enhance oil recovery efficiently [16]. It can be concluded that altering the contact angle can have a great impact on the success of oil recovery methods, and thus changing the contact angle via any method, including the addition of chelating agents, is useful.

IFT is the force per unit length that two immiscible fluids—such as crude oil and brine—apply at their interface. This tension, which is typically expressed in millinewtons per meter (mN/m), results from molecular interactions that are different on the opposing sides of the interface. High IFT between crude oil and brine in petroleum reservoirs can impede oil recovery by creating capillary tension between pore throats to retain oil [17]. One crucial aspect of EOR is IFT reduction. In order to reduce the IFT between crude oil and brine, chelants, EDTA, and DTPA are used [17]. Studies have demonstrated that DTPA and EDTA can successfully lower the IFT. For instance, decreasing the IFT between crude oil and brine for improved oil recovery has been achieved by adding a 5-weight percent (%wt.) solution of these chelating agents. Divalent cations' chelating alters the interfacial characteristics and reduces the capillary forces holding the oil in the reservoir rock, which results in a decrease in IFT [18].

The present study will make an assessment based on the above understanding of the feasibility of chelating agents on improving flow characteristics in porous media of the upper Assam basin, India. This novel approach in improving flow characteristics based on experimental analysis will be compared with the existing literature reflecting their feasibility. The following is the assessment basis for the selection of chelating agents as EOR chemicals (Fig. 1).

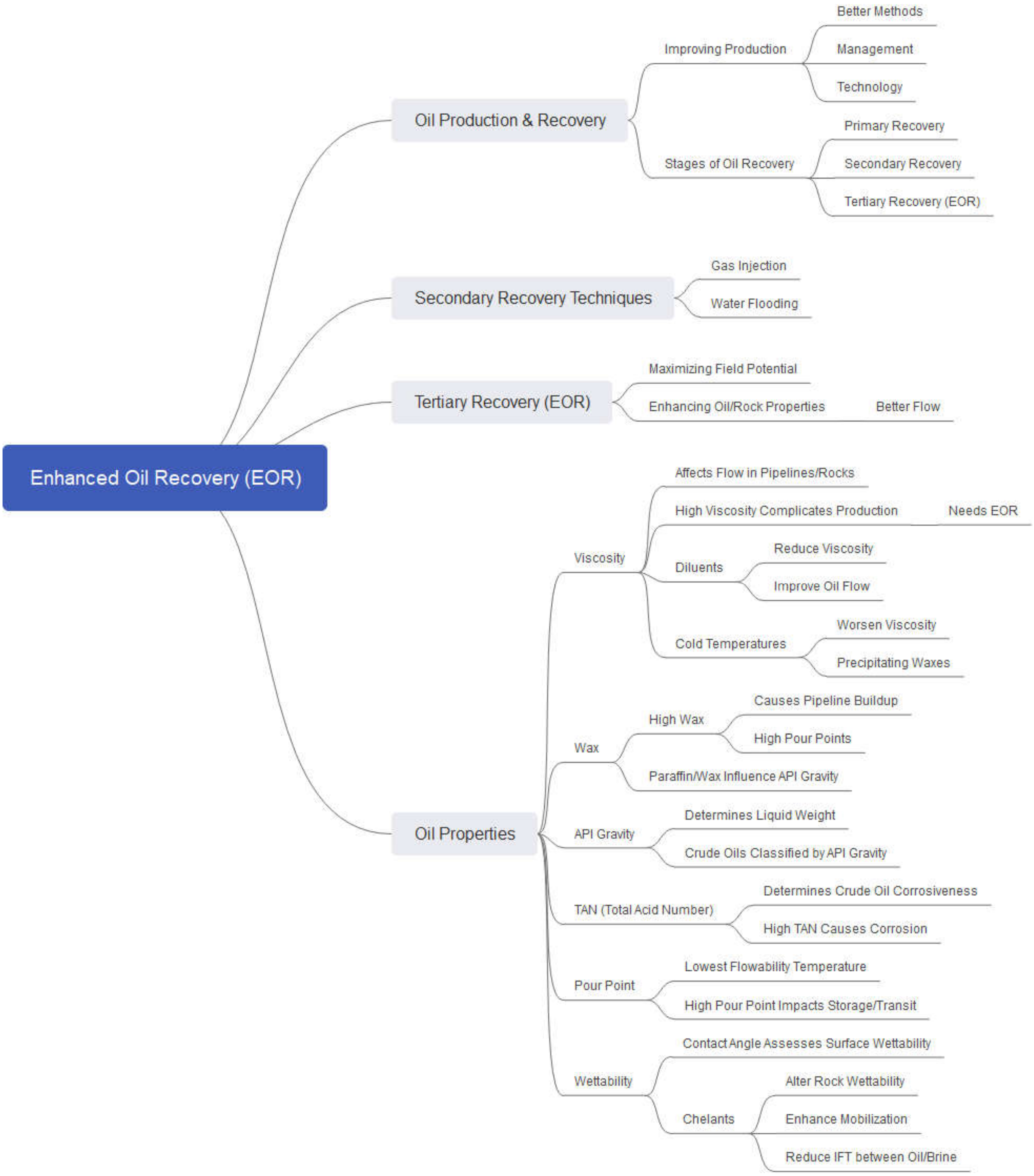

Figure 1: Strategy for chelating agent feasibility study in oil flow through porous media.

2 Methodology

In this study, chelating agent properties will be evaluated to make it compatible with crude oil for achieving flowability through porous media. The properties outlined in different texts will be compared with the evaluated chelating properties in the lab, and based on this assessment, the feasibility behavior will be evaluated.

2.1 Chelating agent

Chelating agents are special compounds that form bonds with metal ions; in the oil and gas sector, this mostly refers to aminopolycarboxylic acids, which feature amine groups that may bind to metals multiple times [18]. Chelating agents have become extremely important in the upstream oil and gas sector because of their ability to form stable complexes with metal ions, which can help with a variety of issues such as acid fracturing, enhanced oil recovery (EOR), and scale removal. Chelating chemicals, like DTPA and EDTA, are chelants that contain aminopolycarboxylic acids (APCAs), which are known to bind metal ions and create comparatively stable chelate rings [19]. Fig. 2 represents chemical coordination with divalent and trivalent ions, which reduces scale and corrosion and improves productivity in oilfield operations. Another appealing EOR technique for sandstone and carbonate reservoirs is low-salinity water flooding, which is proven to improve oil recovery by altering wettability, IFT reduction, and ion exchange [20, 21]. In this context, it has been found that chelating agents work well by retaining formation permeability, which enhances production, and precipitating calcium + (and other ions) to precipitate minerals that are damaging the formation (such as carbonates) [22].

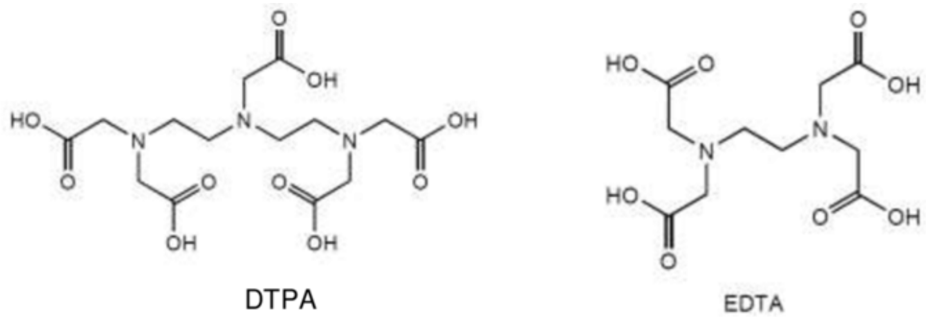

Figure 2: Structure of EDTA and DTPA [23].

Chelating agents such as GLDA (Glutamic Acid Diacetate) dissolve barium sulfate and exhibit low corrosion rates [24]. Nasr-El-Din et al. found that GLDA at 20% concentration reduced corrosion on L-80 steel at 300°F, outperforming other fluids [25]. In tests at high temperatures (300°F) and pressures (1000–1200 psi), GLDA reduced corrosion on (chromium) Cr-13 and duplex steels without inhibitors, proving effective in harsh conditions [25]. Nasr-El-Din's research revealed that oil recovery was greatly increased by using the chelation procedure to sequester ions of iron from clay minerals. However, EDTA's contact with non-clay minerals caused blockage of pores and rock breakdown [26]. Mahmoud, M. A. first investigated EDTA chelating compounds as EOR agents and found that after seawater infusion in sandstone samples, oil recovery improved by up to 30% of the original oil in place [27].

Studies on EDTA and DTPA highlight their effectiveness in improving recovery by improving wettability, reducing interfacial tension, and increasing oil displacement. Furthermore, research shows that GLDA and other biodegradable chelating agents are not only effective but also eco-friendly options [28].

The key benefits of using chelating agents as chemical EOR agents are presented in Table 1 below.

Table 1 Key benefits with chelating agents' application

Benefit of Chelating Agents	Citation
Prevent scale formation	[18]
Alter wettability	[29]
Reduce interfacial tension (IFT)	[30]
Inhibit clay swelling	[31]
Improve low-salinity flooding	[32]
Offer environmental benefits (biodegradable)	[33]
Reduce viscosity	[26]
Enhance API gravity	[34]
Depress pour point	[35]
Reduce acid number	[36]

Chelating agents like EDTA and DTPA effectively bind with divalent and trivalent metal ions (e.g., Ca^{2+}, Ba^{2+}, Fe^{3+}), preventing the formation of mineral scales such as calcium carbonate and barium sulfate. This action helps maintain reservoir permeability and flow efficiency [18].

Particularly in carbonate and sandstone reservoirs, chelating compounds can change the wettability of the rock surface from oil-wet to water-wet, which can enhance spontaneous imbibition and ultimately improve oil recovery [29].

The interfacial tension between crude oil and brine is reduced by chelating agents like EDTA and DTPA. Oil that is trapped can move and displace considerably more easily [30].

Chelating agents mitigate clay swelling by complexing with metal ions in clay minerals, maintaining reservoir rock integrity and permeability [31].

In low-salinity waterflooding, chelating agents help stabilize ion concentrations and prevent mineral precipitation, improving the reliability of enhanced oil recovery processes [32].

Biodegradable alternatives such as GLDA (glutamic acid diacetic acid) offer lower toxicity and environmental impact while maintaining effectiveness in scale inhibition and wettability alteration [33].

Chelating agents can reduce the viscosity of crude oil by complexing with metal ions that contribute to the formation of heavy organometallic compounds. This complexation disrupts the associations between heavy molecules, leading to a decrease in viscosity and improve flow characteristics. For instance, the application of DTPA has been shown to lower the viscosity of heavy oils, facilitating easier extraction and transport [26].

API gravity is inversely related to the density of crude oil; thus, a reduction in density results in an increase in API gravity. By breaking down heavy metal complexes and asphaltenes, chelating agents reduce the overall density of the oil. This alteration leads to an increase in API gravity, indicating a lighter and more valuable crude. Studies have demonstrated that the use of EDTA and DTPA can effectively enhance the API gravity of heavy crude oils [34].

The pour point of crude oil is the lowest temperature at which it remains pourable. High pour points are often due to the presence of waxes and heavy paraffinic compounds. Chelating agents disrupt the crystalline structure of waxes by binding with metal ions that act as nucleation sites for wax formation. This disruption leads to a lower pour point, improving the cold flow properties of the oil. Research indicates that DTPA effectively reduces the pour point of waxy crude oils, enhancing their flow in colder environments [35].

The acid number measures the number of acidic compounds, primarily naphthenic acids, in crude oil. High acid numbers can lead to corrosion and processing challenges. Chelating agents like EDTA and DTPA can neutralize these acidic components by forming stable complexes with the acidic molecules or associated metal ions. This neutralization reduces the acid number, mitigating corrosion risks and improving the quality of the crude oil [36].

3 Mechanism of Chelating Agents in EOR

3.1 Scale Prevention and Removal

Scale formation is a common issue in oilfield operations, typically resulting from the precipitation of divalent and trivalent metal ions such as calcium (Ca^{2+}), barium (Ba^{2+}), strontium (Sr^{2+}), and iron (Fe^{3+}) when incompatible waters—such as formation water and injected water—mix [37]. This precipitation leads to the formation of insoluble compounds like sulfates and carbonates, which can deposit in the reservoir or wellbore. Chelating agents are highly effective in addressing this problem, as they chemically bind with these metal ions to form stable and soluble complexes. This binding prevents the metal ions from reacting with anions like sulfate (SO_4^{2-}) or carbonate (CO_3^{2-}), thereby inhibiting new scale formation [38]. In cases where scale is already present, chelating agents help by dissolving the scale through sequestration of the metal ions, effectively breaking down the scale matrix. As a result, the use of chelating agents mitigates the risk of permeability reduction in the reservoir and prevents blockages in production tubing. This ensures cleaner injection and production pathways, ultimately improving operational efficiency and oil recovery [39]. Fig. 3 presents the chelating working mechanism on scale removal.

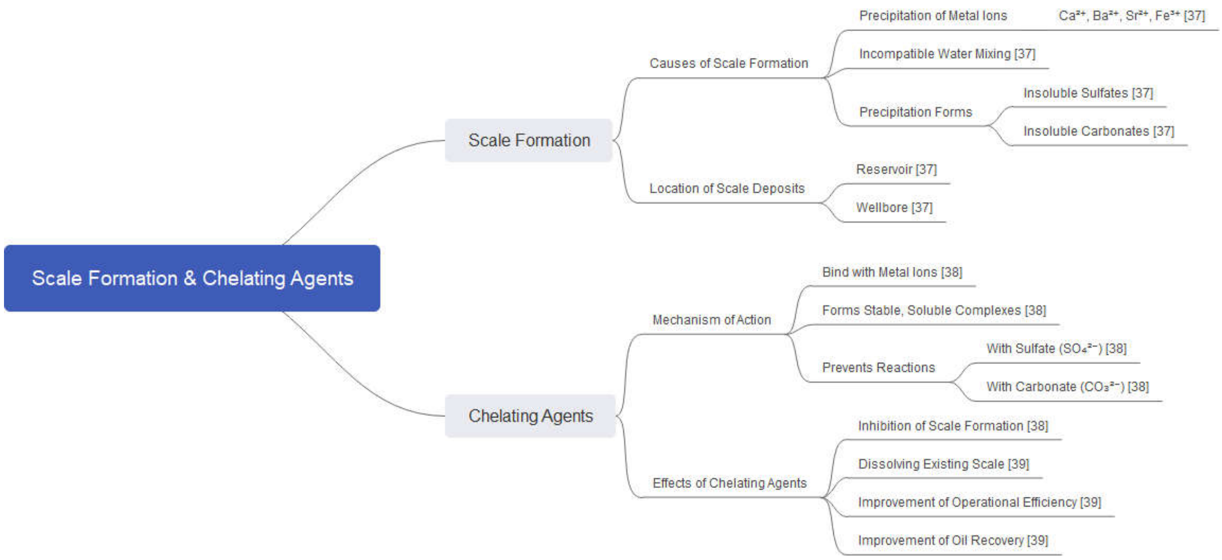

Figure 3: Chelating working mechanism on scale removal.

3.2 Wettability Alteration

Chelating agents play a crucial role in altering the wettability of reservoir rocks, especially those exhibiting oil-wet characteristics. They achieve this by effectively removing metal ions and basic oxides that are adhered to the mineral surface components that often contribute to maintaining oil-wet conditions. Additionally, chelating agents help in cleaning organic deposits such as asphaltenes and acidic compounds, which significantly influence the surface energy of the rock [40]. By eliminating these substances, the rock surface transitions from oil-wet to more water-wet conditions. This change in wettability enhances spontaneous imbibition, a process where water invades the pore spaces, displacing oil more efficiently. The result is a reduction in capillary resistance, which allows the injected brine to more easily mobilize and recover trapped oil, thus significantly improving oil recovery rates [29]. Fig. 4 presents the working mechanism on wettability alteration by chelating agents.

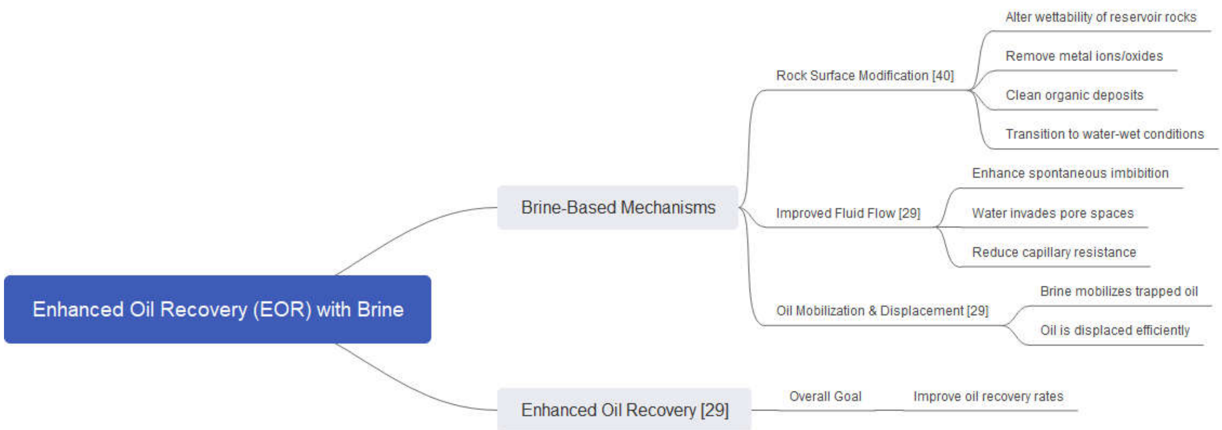

Figure 4: Chelating working mechanism on wettability alteration.

3.3 Reduction of Interfacial Tension (IFT)

Chelating agents significantly influence the interfacial tension (IFT) between crude oil and brine by altering the ionic environment at the oil–water interface. They achieve this by selectively binding and removing multivalent cations such as calcium (Ca^{2+}) and magnesium (Mg^{2+}), which are known to stabilize and rigidify the interfacial film. The removal of these ions destabilizes the interfacial layer, thereby weakening the film and resulting in a noticeable reduction in IFT [41]. This reduction lowers the energy barrier required for oil droplets to detach from the rock surface, enhancing their mobilization. Consequently, the microscopic displacement efficiency of the displacing fluid is improved, contributing to better overall oil recovery [42]. Fig. 5 infer to the relevant mechanism on IFT reduction with chelating agent.

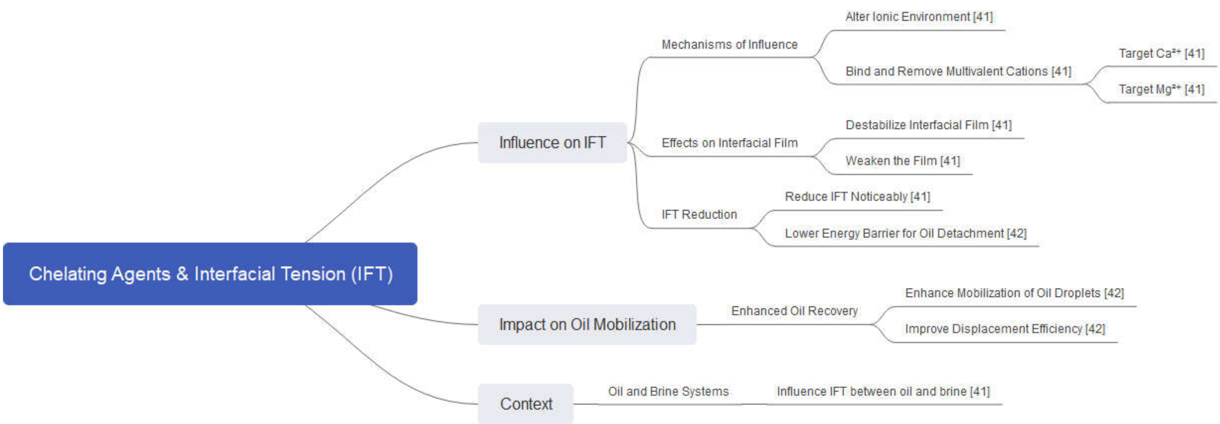

Figure 5: Chelating working mechanism on IFT reduction.

3.4 Clay Swelling Inhibition

In sandstone reservoirs, the exposure of clay minerals to low-salinity water often leads to swelling due to osmotic imbalance, which can cause serious formation damage. Chelating agents mitigate this issue by binding with exchangeable cations such as sodium (Na^{+}), potassium (K^{+}), and calcium (Ca^{2+}), which are primarily responsible for initiating the swelling of clay particles [43]. By sequestering these ions, chelating agents effectively prevent the ion-exchange reactions that destabilize the clay structure. Furthermore, they form stable surface complexes with clay minerals, which enhances the structural stability of the reservoir rock and minimizes expansion. This dual action not only prevents clay migration and pore throat plugging but also ensures the maintenance of reservoir permeability, thereby preserving flow paths for efficient oil production [44].

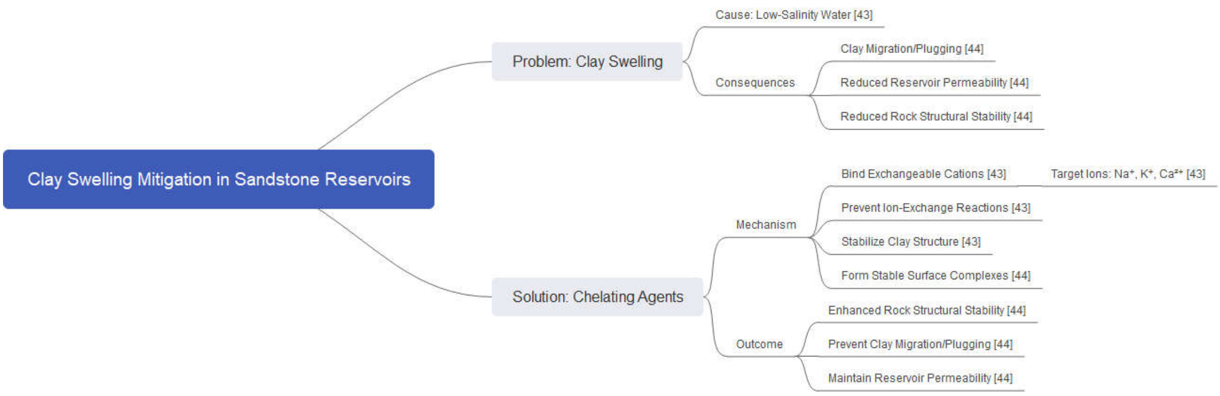

Figure 6: Chelating working mechanism on EOR process.

3.5 Compatibility with Low-Salinity Water Flooding

Low-salinity water flooding (LSWF), while effective in enhancing oil recovery, often triggers undesirable effects such as mineral precipitation—particularly calcium sulfate ($CaSO_4$)—and clay instability due to ionic imbalance. Chelating agents address these challenges by sequestering divalent ions like Ca^{2+} and Mg^{2+}, which are primarily responsible for scale formation and clay swelling [27]. By maintaining ionic balance within the reservoir, these agents prevent scale deposition and minimize structural changes in clay minerals. This stabilizing effect ensures that LSWF can be carried out more efficiently without the common issues of permeability reduction or reservoir damage. Ultimately, the integration of chelating agents provides a synergistic advantage to LSWF by preventing scaling and clay-related complications, leading to improved oil displacement and recovery [45]. The relevant working mechanism is displayed in Fig. 7.

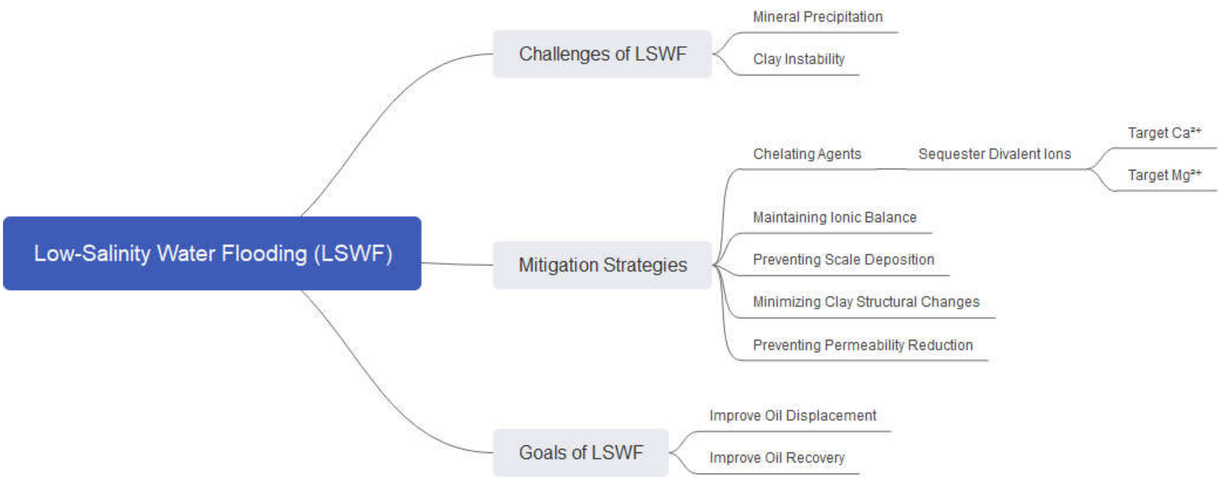

Figure 7: Chelating working mechanism on LSWF process.

3.6 Viscosity Reduction

Heavy fractions in crude oil, such as asphaltenes and resins, are often stabilized by the presence of metal ions like vanadium, nickel, and iron. These ions facilitate strong intermolecular interactions and micellar aggregation, increasing the viscosity and flow resistance of the crude. Chelating agents disrupt this stability by binding with the metal ions, effectively disaggregating the micellar structures and weakening the interactions among heavy molecules. This leads to a reduction in internal resistance to flow. As a result, the mobility of highly viscous crude oils is significantly improved, enhancing their transport through porous reservoir rocks and pipelines, and facilitating more efficient oil recovery [46]. Fig. 8 presents the finding of the mechanism for viscosity reduction with chelating agent.

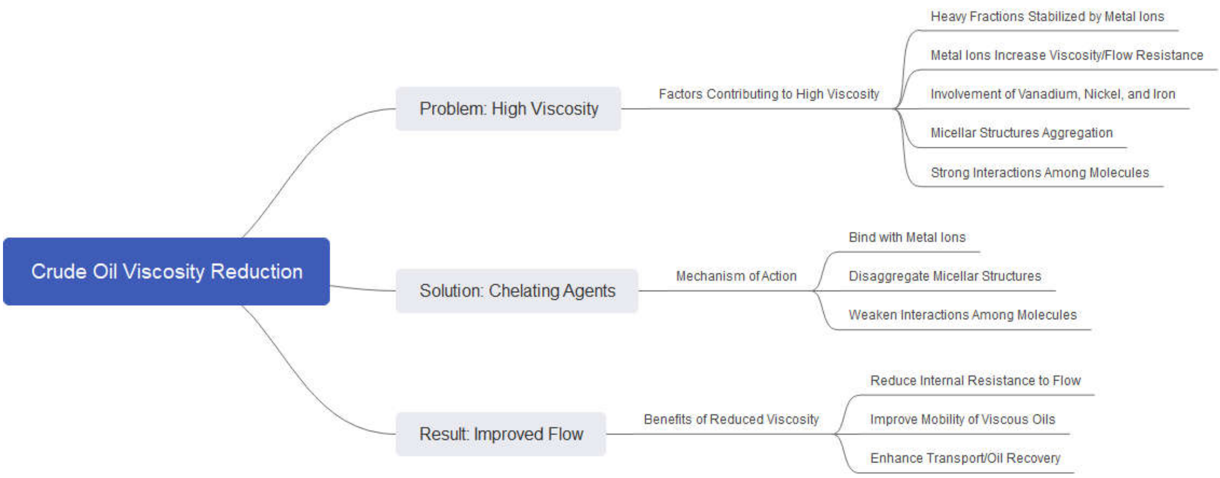

Figure 8: Chelating working mechanism on viscosity reduction.

3.7 API Gravity Enhancement

API gravity, an indicator of crude oil quality and density, tends to increase when heavier molecular components such as asphaltenes and metal complexes are broken down or removed. Chelating agents contribute to this process by binding and extracting metal ions that stabilize these heavy fractions, leading to a reduction in the average molecular weight of the crude. This shift increases the proportion of lighter hydrocarbons, enhancing the API gravity of the oil. Not only does this improve the crude's commercial value and ease of refining, but it also benefits flow behavior through porous media. Lighter, less viscous oil phases exhibit better mobility and reduced flow resistance, thereby improving displacement efficiency during enhanced oil recovery (EOR) operations. Fig. 9 below presents the API gravity improvement mechanism.

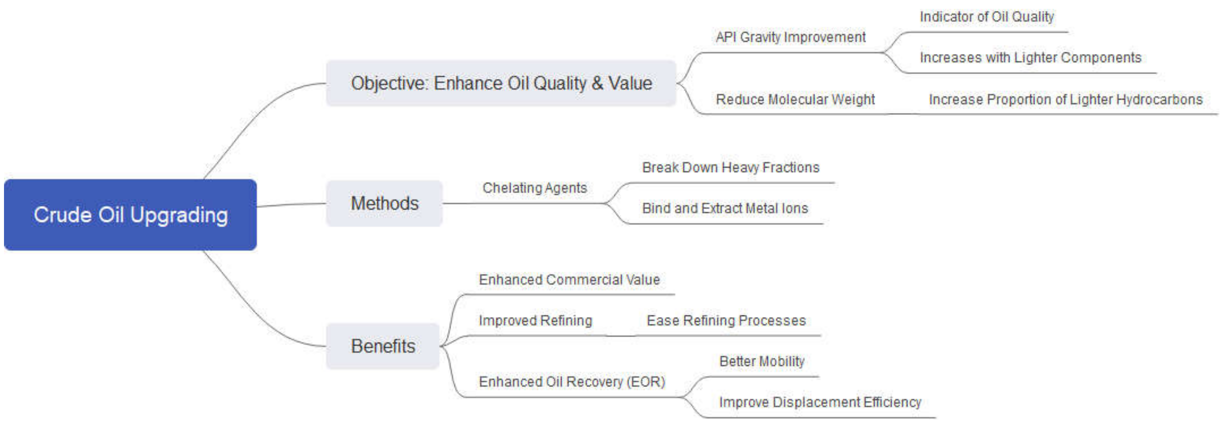

Figure 9: Chelating working mechanism on API gravity improvement.

3.8 Pour Point Depressant

The pour point of crude oil—the lowest temperature at which it remains flowable—is heavily influenced by wax crystallization processes. Nucleating metal ions such as calcium (Ca^{2+}) and iron (Fe^{3+}) facilitate the formation of wax crystals, leading to higher pour points and flow assurance issues. Chelating agents effectively sequester these metal ions, thereby hindering the nucleation and subsequent crystallization of wax. Additionally, by altering the polarity of the surrounding molecular environment, chelating agents reduce the aggregation of wax molecules, further suppressing the formation of large crystalline networks. This dual action ensures that crude oil remains flowable even at lower temperatures, minimizing the risk of wax deposition in pipelines. In the context of porous media, the reduction in wax-related viscosity and blockages significantly enhances crude oil mobility and improves overall recovery efficiency during secondary and tertiary recovery operations. Fig. 10 is the representation of the working mechanism on pour point with application of chelating agent.

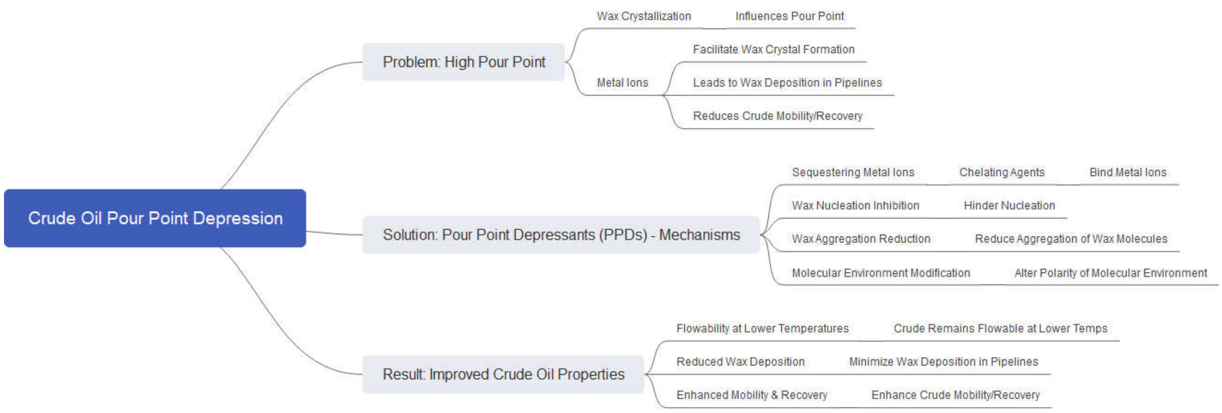

Figure 10: Chelating working mechanism on pour point.

3.9 Acid Number Reduction

High acidity in crude oil, primarily due to naphthenic acids, leads to oil-wet conditions in reservoir rocks by promoting the adsorption of acidic components onto mineral surfaces, which hinders water's ability to displace oil [47,48, 49]. This reduces oil recovery efficiency during secondary and tertiary recovery processes. Chelating agents help lower crude oil acidity by binding metal ions and preventing the formation of metal soaps, which further alters the interaction between crude oil and rock surfaces. As a result, the rock becomes more water-wet, enhancing the effectiveness of spontaneous imbibition and oil displacement, thus improving oil recovery. This process also reduces the corrosive nature of crude oil, making it safer for transport and prolonging the life of pipelines and surface facilities.

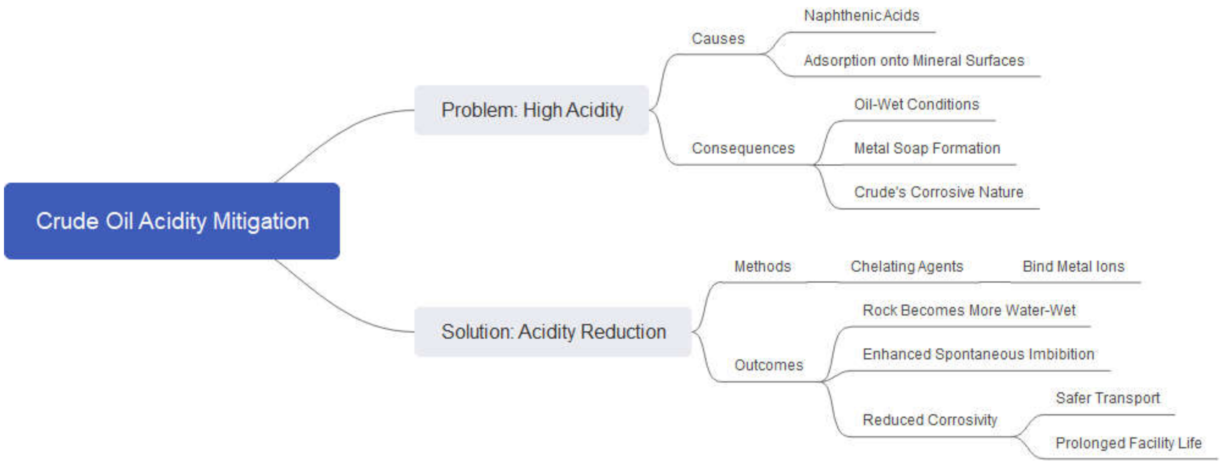

Figure 11: Chelating working mechanism on acid no.

4 Effect of chelating agent interaction with crude oil and brine interaction

Pre- and post-chelating agent treatment on different properties of crude oil-rock-chelating agents have been examined, and evidence is presented in Table 2 below.

Table 2 Comparative analysis for feasibility of chelating agent application

Sl. No.	**Pre treatment**	**Post treatment**
Parameters	**Values**	**Values**
°API	28°	31.04°
Acid no. (mg KOH/g of crude oil)	4.321 mg KOH/g of crude oil	1.10 mg KOH/g of crude oil
Contact Angle (Wettability), °	69.2	52.6
Interfacial Tension (IFT) (mN/m)	53.76	43.65
Pour point, °C	27	15

The above findings with respect to porous media of the upper Assam basin find the feasibility of chelating agent application.

5 Conclusion

Based on the above findings the following conclusions have been drawn in line with the feasibility of chelating agent in oil field EOR operations.

- Chelating agents are critical in the oil and gas sector, especially aminopolycarboxylic acids (APCAs) like EDTA and DTPA, due to their ability to form stable complexes with metal ions. These complexes address issues in acid fracturing, enhanced oil recovery (EOR), and scale removal.
- By binding with divalent and trivalent metal ions (Ca^{2+}, Ba^{2+}, and Fe^{2+}), chelating agents preserve reservoir permeability and flow efficiency by inhibiting the formation of mineral scales such as calcium carbonate and barium sulfate.
- Wettability alteration, which improves imbibition and increases oil recovery, particularly in carbonate and sandstone reservoirs, is accomplished by converting the rock surface from oil-wet to water-wet. The metal ions and basic oxides that cause oil-wet conditions are eliminated by chelating agents.
- Another key benefit is the reduction of interfacial tension (IFT). Chelating agents lower IFT between crude oil and brine by sequestration and precipitation of multivalent cations, breaking the interfacial film, and thus allowing the oil droplet to be mobilized.
- Exchangeable Na^+ and K^+ can be bound by chelating agents, which inhibit the swelling of clay in two ways: by interfering with ion exchange, which disrupts clay structure, and by maintaining reservoir permeability.
- By keeping ion concentrations in limit and reducing mineral precipitation, chelating agents also aid the use of LSWF and ensure more reliable EOR by preventing scaling and clay-related problems.
- Biodegradable chelates, e.g., GLDA, provide reduced toxicity and environmental impact and can be highly effective in scale inhibition and wettability modification. GLDA has also been found to decrease the corrosion rates of steel as well.
- Viscosity reduction is by bonding with metal ions to form heavy organometallic compounds or disrupting bonding of heavy molecules and operates particularly well in heavy crude oil to affect flow.
- Chelating agents disrupt heavy metal complexes and asphaltenes to lower oil density and increase API gravity, resulting in lighter and more valuable crude.
- Pour point depression is achieved by disrupting the crystalline structure of waxes through binding with metal ions that act as nucleation sites, improving the cold flow properties of the oil, particularly in colder environments.

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Statements and Declarations

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Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

Bibliography

[1] Khanghah M.A and Keradeh M.P (2024) Unraveling the Impact of Ethylenediaminetetraacetic Acid Chelating Agents on the Oil Recovery Processes: An Insight into Its Role in Fluid–Fluid and Rock–Fluid Interactions, Langmuir. vol. 40, no. 14, pp. 7532–7549, Apr. 2024, doi: 10.1021/acs.langmuir.4c00042

[2] Moradpour N, Pourafshary P, and Zivar D (2021) Experimental analysis of hybrid low salinity water alternating gas injection and the underlying mechanisms in carbonates, J. Pet. Sci. Eng. vol. 202, p. 108562, Jul. 2021, doi: 10.1016/j.petrol.2021.108562

[3] Daneshfar R, Nouroddin M.K, Mousavi Golsefid S. Z., Mohammadi-Khanaposhtani M., Davoudi E, and Shariati K (2023) Experimental Investigation and Modeling of Fluid and Carbonated Rock Interactions with EDTA Chelating Agent during EOR Process, Energy Fuels. vol. 37, no. 2 pp. 919–934, Jan. 2023, doi: 10.1021/acs.energyfuels.2c02702

[4] Mohammed M and Babadagli T (2015) Wettability alteration: A comprehensive review of materials/methods and testing the selected ones on heavy-oil containing oil-wet systems, Adv. Colloid Interface Sci. vol. 220, pp. 54–77 Jun. 2015, doi: 10.1016/j.cis.2015.02.006

[5] JOUR T.Y et al. (2003) New Compositional Models for Calculating the Viscosity of Crude Oils, Industrial & Engineering Chemistry Research. doi: 10.1021/ie0300631

[6] Kandwal V. C, Agrawal K. M, Nautiyal S. P and Khan H. U (2000) Paraffin deposition and viscosity temperature behaviour of assam crude oil, Pet. Sci. Technol. vol. 18, no. 7–8, pp. 755–769, Aug. 2000, doi: 10.1080/10916460008949871

[7] Baruah S and Neog D (2025) Adsorption analysis of organic and chemical sorbents for oil spill management on land, Results Eng. vol. 26, no. April, p. 105167, 2025, doi: 10.1016/j.rineng.2025.105167

[8] Hassan A. M and Al-Hashim H. S (2019) Oil Recovery Mechanisms During Sequential Injection of Chelating Agent Solutions Into Carbonate Rocks, J. Energy Resour. Technol. vol. 142, no. 012903, Jul. 2019, doi: 10.1115/1.4044226

[9] Dutta S. J. and Neog D (2025) Sustaining heavy crude oil production with chemical EOR: A comparative study, Chem. Thermodyn. Therm. Anal. vol. 18, no. April, p. 100191, 2025, doi: 10.1016/j.ctta.2025.100191

[10] Parisotto G. et al. (2010) Total Acid Number Determination in Residues of Crude Oil Distillation Using ATR-FTIR and Variable Selection by Chemometric Methods Energy Fuels. vol. 24, no. 10, pp. 5474–5478, Oct. 2010, doi: 10.1021/ef1002974

[11] Ramirez-Corredores M. M (2017) Acidity in Crude Oils, The Science and Technology of Unconventional Oils. Elsevier, 2017, pp. 295–385. doi: 10.1016/B978-0-12-801225-3.00004-8

[12] Morrow N. R. (1990) Wettability and Its Effect on Oil Recovery, J. Pet. Technol. vol. 42, no. 12, pp. 1476–1484, Dec. 1990, doi: 10.2118/21621-PA

[13] Jadhunandan P. P and Morrow N. R (1995) Effect of Wettability on Waterflood Recovery for Crude-Oil/Brine/Rock Systems, SPE Reserv. Eng. vol. 10, no. 01, pp. 40–46, Feb. 1995, doi: 10.2118/22597-PA

[14] Deng X et. al. (2024) Wettability Alteration on Carbonate Rock by the Mixture of the Gemini Surfactant and Chelating Agent, Energy & Fuels. Accessed: Nov. 12, 2024. [Online]. Available: https://pubs.acs.org/doi/abs/10.1021/acs.energyfuels.2c03045

[15] Hassan A. et al. (2020) Applications of Chelating Agents in the Upstream Oil and Gas Industry: A Review, Energy Fuels. vol. 34, no. 12, pp. 15593–15613, Dec. 2020, doi: 10.1021/acs.energyfuels.0c03279

[16] Tariq Z, Aljawad M. S, Hassan A, Mahmoud M, and Al-Ramadhan A (2021) Chelating Agents as Acid-Fracturing Fluids: Experimental and Modeling Studies. Energy Fuels. vol. 35, no. 3, pp. 2602–2618, Feb. 2021, doi: 10.1021/acs.energyfuels.0c04045

[17] Hamzeh M. S, arhizgar Keradeh M. P and Tabatabaei-Nezhad S. A (2024) Exploring the Impact of EDTA and DTPA Chelating Agents on Rock-Fluid Interactions, Fluid-Fluid Interactions and Fluid Flow in Carbonate Cores Under HP-HT Reservoir Conditions, Aug. 18, 2024, Social Science Research Network, Rochester. NY: 4926013. Accessed: May 08, 2025. [Online]. Available: https://papers.ssrn.com/abstract=4926013

[18] Mahmoud M. A and Abdelgawad K. Z (2015) Chelating-Agent Enhanced Oil Recovery for Sandstone and Carbonate Reservoirs, SPE J. vol. 20, no. 03, pp. 483–495, Jun. 2015, doi: 10.2118/172183-PA

[19] Almubarak T, Ng J. H, Ramanathan R, and Nasr-El-Din H. A (2021) Chelating agents for oilfield stimulation: Lessons learned and future outlook. J. Pet. Sci. Eng. vol. 205, p. 108832, Oct. 2021, doi: 10.1016/j.petrol.2021.108832

[20] Nash K. L, Brigham D, Shehee T. C, and Martin A (2012) The kinetics of lanthanide complexation by EDTA and DTPA in lactate media, Dalton Trans. vol. 41, no. 48, pp. 14547–14556, Nov. 2012, doi: 10.1039/C2DT31851B

[21] Nasr-El-Din H. A, de Wolf C. A, Bouwman A, Bang E. R, Naylor E, and Alex A (2012) A New, Low Corrosive Fluid to Stimulate Wells with Carbon Steel Tubular and Internals, presented at the SPE Saudi Arabia Section Technical Symposium and Exhibition, OnePetro. Apr. 2012. doi: 10.2118/160849-MS

[22] Mahmoud M and Nasr-El-Din H (2014) Challenges During Shallow and Deep Carbonate Reservoirs Stimulation, J. Energy Resour. Technol. vol. 137, no. 012902, Aug. 2014, doi: 10.1115/1.4028230

[23] Attia M, Mahmoud M. A, Al-Hashim H. S, and Sultan A. S (2014) Shifting to a New EOR Area for Sandstone Reservoirs with High Recovery, No Damage, and Low Cost, presented at the SPE EOR Conference at Oil and Gas West Asia, OnePetro, Mar. 2014. doi: 10.2118/169670-MS

[24] Mahmoud M, Attia M, and Al-Hashim H (2017) EDTA chelating agent/seawater solution as enhanced oil recovery fluid for sandstone reservoirs, J. Pet. Sci. Eng. vol. 152, pp. 275–283, Apr. 2017, doi: 10.1016/j.petrol.2017.03.019

[25] Barri A, Mahmoud M, and Elkatatny S (2016) Evaluation of Rock Mechanical Properties Alteration During

Matrix Stimulation With Chelating Agents, J. Energy Resour. Technol. vol. 138, no. 032907, Feb. 2016, doi: 10.1115/1.4032546

[26] Alarifi S. A, Mahmoud M. A, and Kamal M. S (2018) Interactions of DTPA chelating agent with sandstone rocks during EOR: Rock surface charge study, Fuel. vol. 232, pp. 684–692, Nov. 2018, doi: 10.1016/j.fuel.2018.06.003

[27] Mahmoud M, Elkatatny S, and Abdelgawad K. Z (2017) Using high- and low-salinity seawater injection to maintain the oil reservoir pressure without damage, J. Pet. Explor. Prod. Technol. vol. 7, no. 2, pp. 589–596, Jun. 2017, doi: 10.1007/s13202-016-0279-x

[28] Li N. *et al.* (2023) Research and application of eco-friendly chelating agents in plugging removal systems: A review, Geoenergy Sci. Eng. vol. 229, p. 212135, Oct. 2023, doi: 10.1016/j.geoen.2023.212135

[29] Mahani H, Keya A. L, Berg S, Bartels W.B, Nasralla R, and Rossen W. R (2015) Insights into the Mechanism of Wettability Alteration by Low-Salinity Flooding (LSF) in Carbonates, Energy Fuels. vol. 29, no. 3, pp. 1352–1367, Mar. 2015, doi: 10.1021/ef5023847

[30] Mahmoud M. A, Nasr-El-Din H. A, De Wolf C. A., and Alex A. K (2011) Sandstone Acidizing Using A New Class of Chelating Agents, in SPE International Symposium on Oilfield Chemistry. The Woodlands, Texas, USA: SPE, Apr. 2011, p. SPE-139815-MS. doi: 10.2118/139815-MS

[31] Gens A, Guimarães L. Do N, Olivella S, and Sánchez M (2004) Analysis of the Thmc Behaviour of Compacted Swelling Clay for Radioactive Waste Isolation, in Elsevier Geo-Engineering Book Series. vol. 2, Elsevier, 2004, pp. 317–322. doi: 10.1016/S1571-9960(04)80060-0

[32] Zhang P, Tweheyo M. T, and Austad T (2006) Wettability alteration and improved oil recovery by spontaneous imbibition of seawater into chalk: Impact of the potential determining ions Ca^{2+}, Mg^{2+}, and SO_4^{2-}, Colloids Surf. Physicochem. Eng. Asp. vol. 301, no. 1–3, pp. 199–208, Jul. 2007, doi: 10.1016/j.colsurfa.2006.12.058

[33] Barri A, Hassan A, and Mahmoud M (2022) Carbonate Stimulation Using Chelating Agents: Improving the Treatment Performance by Optimizing the Fluid Properties, ACS Omega. vol. 7, no. 10, pp. 8938–8949, Mar. 2022, doi: 10.1021/acsomega.1c07329

[34] Huang T, McElfresh P. M, and Gabrysch A. D (2003) Carbonate Matrix Acidizing Fluids at High Temperatures: Acetic Acid, Chelating Agents or Long-Chained Carboxylic Acids? in SPE European Formation Damage Conference. The Hague, Netherlands: SPE, May 2003, p. SPE-82268-MS. doi: 10.2118/82268-MS

.[35] JOUR T.Y et al. (2023) Enhanced Oil Recovery from Heavy Oil Sandstone Reservoirs Using DTPA Chelating Agent/SW Solution, Arabian Journal for Science and Engineering. doi: 10.1007/s13369-023-08361-z

[36] JOUR T.Y. et al. (2024) Pore-scale study of the effects of DTPA chelating agent flooding on oil recovery utilizing a clay-coated micromodel, Petroleum Research. doi: 10.1016/j.ptlrs.2023.11.001

[37] Almubarak T, Ng J. H, and Nasr-El-Din H (2017) Oilfield Scale Removal by Chelating Agents: An Aminopolycarboxylic Acids Review, in SPE Western Regional Meeting. Bakersfield, California: SPE, Apr.

2017, p. D041S011R005. doi: 10.2118/185636-MS

[38] Kamal M. S, Hussein I, Mahmoud M, Sultan A. S, and Saad M. A. S (2018) Oilfield scale formation and chemical removal: A review, J. Pet. Sci. Eng. vol. 171, pp. 127–139, Dec. 2018, doi: 10.1016/j.petrol.2018.07.037

[39] Hamza A, I. Hussein A, Jalab R, Saad M, and Mahmoud M (2021) Review of Iron Sulfide Scale Removal and Inhibition in Oil and Gas Wells: Current Status and Perspectives, Energy Fuels. vol. 35, no. 18, pp. 14401–14421, Sep. 2021, doi: 10.1021/acs.energyfuels.1c02177

[40] Mohammed M and Babadagli T (2015) Wettability alteration: A comprehensive review of materials/methods and testing the selected ones on heavy-oil containing oil-wet systems, Adv. Colloid Interface Sci. vol. 220, pp. 54–77, Jun. 2015, doi: 10.1016/j.cis.2015.02.006

[41] Mohammadi Khanghah A and Parhizgar Keradeh M (2024) Unraveling the Impact of Ethylenediaminetetraacetic Acid Chelating Agents on the Oil Recovery Processes: An Insight into Its Role in Fluid–Fluid and Rock–Fluid Interactions, Langmuir. vol. 40, no. 14, pp. 7532–7549, Apr. 2024, doi: 10.1021/acs.langmuir.4c00042

[42] Ahmed M. E, A. Sultan S, Saikia T, Mahmoud M, Patil S, and Kanj M (2023) Investigating Effects of Chelating Agents on Viscoelastic Surfactant Flooding at the Pore Scale Using Micromodels, Energy Fuels. vol. 37, no. 2, pp. 1070–1080, Jan. 2023, doi: 10.1021/acs.energyfuels.2c03777

[43] Anderson R. L, Ratcliffe I, Greenwell H. C, Williams P. A, Cliffe S, and Coveney P. V (2010) Clay swelling — A challenge in the oilfield, Earth-Sci. *Rev.* vol. 98, no. 3–4, pp. 201–216, Feb. 2010, doi: 10.1016/j.earscirev.2009.11.003

[44] Mahmoud El-Din M. A (2018) Effect of Chlorite Clay-Mineral Dissolution on the Improved Oil Recovery From Sandstone Rocks During Diethylenetriaminepentaacetic Acid Chelating-Agent Flooding, SPE J. vol. 23, no. 05, pp. 1880–1898, Oct. 2018, doi: 10.2118/189988-PA

[45] Mahmoud A. A. and Al-Hashim H (2019) Evaluating the integrity of clayey sandstone rocks flooded with high pH EDTA chelating agent solutions, J. Pet. Sci. Eng. vol. 177, pp. 614–623, Jun. 2019, doi: 10.1016/j.petrol.2019.02.074

[46] Almubarak T, Ng J. H, and Nasr-El-Din H (2017) Chelating Agents in Productivity Enhancement: A Review, in SPE Oklahoma City Oil and Gas Symposium. Oklahoma City, Oklahoma, USA: SPE, Mar. 2017, p. D021S002R004. doi: 10.2118/185097-MS

[47] Neog D (2022) Effect of temperature on the pH of water flood effluents and irreducible water saturation: A study with reference to the Barail sandstone outcrop of the upper Assam Basin. J Petrol Explor Prod Technol 12, 1129–1145 (2022). https://doi.org/10.1007/s13202-021-01384-y

[48] Neog D. and Borgohain P (2022) Effect of temperature on sandstone rock wettability behaviour: a study on the Barail sandstone outcrop of the Upper Assam Basin. Arab J Geosci 15, 138 (2022). https://doi.org/10.1007/s12517-022-09429-0

[49] Amte A. and Neog D (2025) Study on thermo-chemical impact on Crude Oil Recovery. Research Journal of Chemistry and Environment. 29. 7-12. 10.25303/293rjce07012