BIO Web of Conferences **97**, 00033 (2024) https://doi.org/10.1051/bioconf/20249700033
*ISCKU 2024*

# Review of Electrical methods for Enhancing crude oil Viscosity and Flowability

*Taqi S.* Aneed* and *Sarmad T.* Najim

Department of Chemical Engineering, College of Engineering, University of Al-Nahrain, Baghdad, Iraq

**Abstract.** This review is aimed to explain a comparative survey on the most applicable techniques and methods for increasing the flowability (viscosity reduction) of crude oil since it has defects on transportation, processing, and production due to high power consumption for pumping and corrosion as well as depositing in the pipeline and facilities it is related to the troubles that may occur in processing stream lines in addition to the financial cost associated with transporting crude oil. In this review several techniques have been surveyed including heating, dilution, additives, emulsification, shearing, ultrasonic, and electrical treatment. Based on the present survey electrical methods were reported to be very effective and efficient.

## 1 Introduction

The property of viscosity creates a sort of hindrance to the movement of fluid by generating a force of friction or shear between the particles of the fluid and the walls that surround it. In the context of transporting oil via pipelines, the viscosity of thick crude oil plays a vital role. This is because it influences the pumping, corrosion, and overall transportation process. When the oil travels through the pipeline, its inherent abrasive characteristics tend to intensify and speed up the corrosion mechanism. Consequently, this gradually and increasingly weakens and impairs the integrity and effectiveness of the pipeline walls. Furthermore, it is of utmost importance to highlight the fact that the existence of impurities and sediments in heavy crude oil worsens and amplifies this corrosive occurrence, thereby posing a substantial difficulty and formidable hindrance for those responsible for operating pipelines. Surprisingly, heavy crude oil showed a higher rate of corrosion compared to light crude oil in corrosion loops where CO2-brine solution was present. This surprising finding was not previously mentioned in any existing literature [1]. Considering this, it is of utmost importance to conduct regular inspections, perform thorough maintenance, and implement corrosion prevention methods like applying protective coatings. These measures are essential to effectively reduce and alleviate the negative impacts caused by corrosion. It is crucial to comprehend that the heightened thickness of heavy crude oil could potentially disrupt the flow and impede efficient transmission through pipelines. The transportation of heavy crude oil via pipelines poses considerable difficulties due to its high viscosity and flow restrictions, especially in cold regions or offshore settings. In reality, the thickness of crude oil is a noteworthy characteristic that governs and manages the movement of crude oil in pipelines. Due to its high thickness, a considerable amount of power is needed to pump crude oil through long pipelines in order to overcome the growing forces of shear and friction. Consequently, the thickness of these sticky oils must be lessened to make pumping easier and decrease both operational expenses and the harmful consequences of pressure decreases during the movement and treatment process. Different techniques are employed to enhance the efficiency of pumping and the flow of crude oil through pipelines. However, these techniques can give rise to logistical, technical, or economic difficulties in specific situations [2]. The transportation of heavy and extra-heavy crude oil poses challenges due to factors like high viscosities, the formation of asphaltene and paraffin deposits, increased water and salt content, as well as corrosion issues [3]. The thick consistency and viscosity of the oil contribute to the formation of sludge and deposits on the walls of the pipeline. This greatly hampers the smooth and efficient movement of the oil, reducing its flow capacity significantly. Consequently, regular cleaning operations and the appropriate use of additives such as flow enhancers and drag-reducing agents become crucial in order to facilitate the transportation of heavy crude oil and prevent any disruptions in flow..

## 2 Viscosity improving methods

There are several methods for improving viscosity of crude oil in order to enhance flowability some of these methods are:

* Corresponding author: taqi.s.aneed@cde.nahrainuniv.edu.iq

### 2.1 Thermal treatment

This method involves heating the crude oil to high temperatures. This process reduces the viscosity of the oil and makes it easier to transport. Refineries frequently employ mild thermal cracking to lower the viscosity of fuel oils. thermal cracking techniques have received more attention because of the growing demand for pipeline transportation of heavy crude oils without the use of diluent. These procedures use little energy, are straightforward, and are inexpensive, but the level of conversion is constrained by the equipment fouling and the increased instability of the asphaltene component[4].

### 2.2 Solvent addition

In this method, a solvent is added to the crude oil to break down the high viscosity components. The solvent dissolves the heavy components into smaller, less viscous components. Ionic liquids (ILs), for example, as a diluted salt solution, ionic liquids should be able to be injected through the reservoir without mechanically clogging the porous medium. As the polar heavy oil constituents, such as asphaltene and resins, diffused in the ILs, the viscosity of the heavy oil decreased, the sulfur and asphaltene contents decreased, and as a result, the crude heavy oil's °API gravity increased. In addition, ILs' catalytic abilities in reactions involving crude oil oxidation, cracking, and hydrocracking, which play a role in the upgrading of heavy oil, have recently been reported. Although ILs are seen as environmentally friendly alternatives to volatile solvents in many electrochemical, synthetic, analytical, and engineering processes due to their distinct properties, they are typically viewed as being too expensive for industrial applications [5].

### 2.3 Chemical additives

Chemical additives are added to the crude oil to reduce its viscosity. These additives may include polymers or surfactants that help to break up the oil and reduce its resistance to flow. High molecular weight polymers are utilized to pump crude oil more effectively. From an economic perspective, this method is crucial, and it works by injecting crude oil with polymers in a turbulent flow environment. It also performs well when pumping crude oil over long distances without pressure loss. The optimum polymer with a concentric ratio that lowers viscosity has been determined through a number of laboratory studies. As a result, the flow rate of crude oil increases without changing the substance's chemical composition. To raise the rate of flow via pipelines, several researchers conducted practical experiments to make crude oil less viscous. As a result of these studies, researchers utilized polymer, surfactant, chemical additives, and emulsification in the petroleum sector to increase pump efficiency by making crude oil less viscous. Other researchers employed triethanolamine (TEA) to make crude oil flow better and make it less viscous. While others looked into how polyacrylamide (PAM) increased the flow rate of crude oil, they came to the conclusion that the concentration of the additive and the pipe's diameter affected whether the flow rate of crude oil increased or decreased [6].

### 2.4 Dilution

Another method to improve the viscosity of crude oil is dilution with lighter hydrocarbons such as light crude oil or natural gas. This process reduces the viscosity and makes it easier to flow.

Up until the end of the 1980s, almost all of the crude production was transported utilizing condensates. Condensates have some drawbacks when used for heavy oil dilution. The demand for natural gas affects these components' supply. Additionally, these products are poor asphaltene solvents and may cause flocculation. This may result in the lines partially plugging. Using a light crude with an API gravity range of 35 to 42 is another option for dilution of heavy oils. Condensates are more effective at reducing the viscosity of heavy oils than light oils, but light oils have the same availability and compatibility issues with asphaltenes. The use of naphtha appears to be an intriguing substitute for condensates. It is very effective at dilution of heavy oils due to its high API density. Naphtha is readily reusable and exhibits good compatibility with asphaltenes. Generally speaking, the viscosity of the diluted crude is inversely correlated to the viscosity of the diluent. Simple mixing rules do not apply, though, because the viscosity ratio between the heavy oil and the light oil is crucial [7].

### 2.5 Emulsification

This method involves mixing the crude oil with water and an emulsifying agent. This process creates an emulsion that reduces the viscosity of the crude oil, making it easier to transport. Typical emulsification devices are depicted in Fig.1

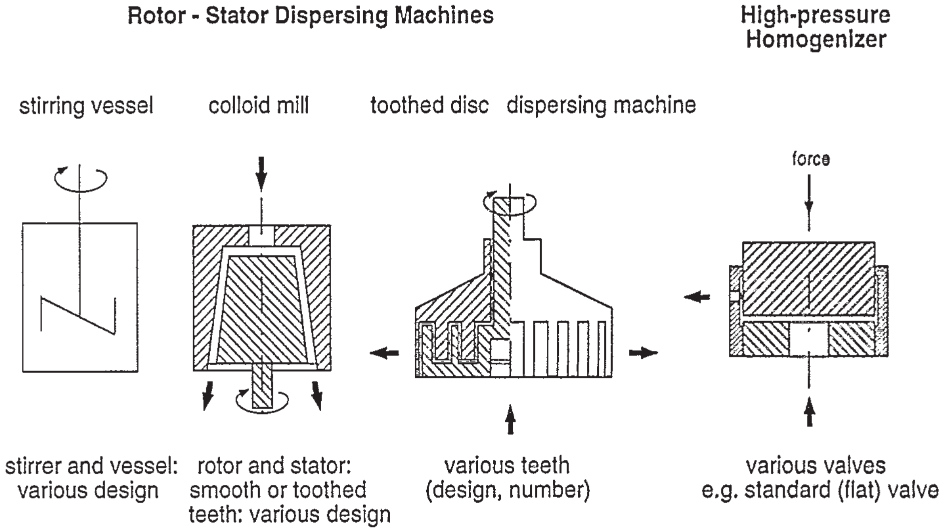


**Fig. 1.** Typical emulsification device [8].

The energy consumption in the mixing vessel is quite low when considering the volume. As a result, this particular mixer is best suited for creating unique emulsions. In a colloid mill, the smooth or uneven droplets are processed by grinding them in the conical area that exists between the rotor and stator. The tooth designs can differ from one mill to another. The width of the gap, the radius of the rotor, the speed at which it rotates, and the flow of materials are all important factors that determine the intensity of destruction caused. Typically, gap sizes fall within the range of 100 to 3000 µm, while peripheral speeds span from 5 to 40 m/s. The toothed disc spreader consists of a set of cutting discs that are arranged in concentric pairs and rotate at a maximum speed of 40 m/s. The premix is then pushed through a narrow opening into a high-pressure homogenizer, where it can reach pressures of up to 1000 bar. The emulsion flows rapidly, reaching speeds of up to 200 m/s, as it passes through the homogenizer valve. It is important to note that cavitation may occur during this process. There are various designs available for the valve used in the homogenizer. Continuous production of emulsions can be achieved using colloid mills, toothed disc dispersers, and high-pressure homogenizers, while stirred tanks are commonly employed for batch processing. [8].

### 2.6 Mechanical shearing

This method involves passing the crude oil through mechanical shearing devices, such as pumps or blades, to break down the viscosity of the oil. Shearing reduces the size of the oil droplets and makes it easier to flow. With increasing homogenizing time and rotation speed in rpm, the density, specific gravity, viscosity, flash point, and pour point of crude oil drop after treatment in the Rotary-Pulsation-Apparatus (RPA). With increasing homogenizing time and rotation speed rpm, API and The Total Percent Yield of Light and Intermediate Fraction for Crude Oil after Treatment in RPA rise [9].

### 2.7 Ultrasonic

Ultrasonic viscosity reduction technique is a novel physical approach for reducing crude oil viscosity. The main principle of this technology is to generate local high temperature, high pressure, and significant physical disturbance in the fluid instantaneously via cavitation, heat, physical agitation, and ultrasonic wave thixotropy, thus lowering viscosity and enhancing the fluidity of heavy oil. This technology has advantages such as great efficiency, low cost, and little pollutants [10].

### 2.8 Electrical treatment

When an electrical field is applied in the direction of flowing oil, it has the ability to decrease the viscosity of crude oil significantly. Research has shown that a remarkable reduction of up to 82.1% in viscosity can be achieved with an electrical field strength of 1.6 kV/mm, while maintaining a treatment temperature of -3.1 C° [11]. The concept of liquid suspensions suggests that crude oil is composed of various intricate components such as diesel, gasoline, and kerosene. Due to the presence of these tiny hydrocarbon molecules, the viscosity of such a liquid is exceptionally low. Crude oil, in its raw form, is a liquid mixture that does not contain large molecules or particles of paraffin and asphalt. It has a low viscosity and is comprised of gasoline, kerosene, and diesel. These suspended particles are typically very small in size, often on the nanoscale [12].

Viscosity reduction is responsible for three mechanisms occurring as a crude oil passes through a strong local electrical field.

1- Create chains of streamlined nanoscale particles in the direction of flow.

2- The polydispersity needs to be raised.

3- Increase the overall dimensions of particles that are hanging in the air.

In Fig.2 below the electrical treatment mechanism is shown

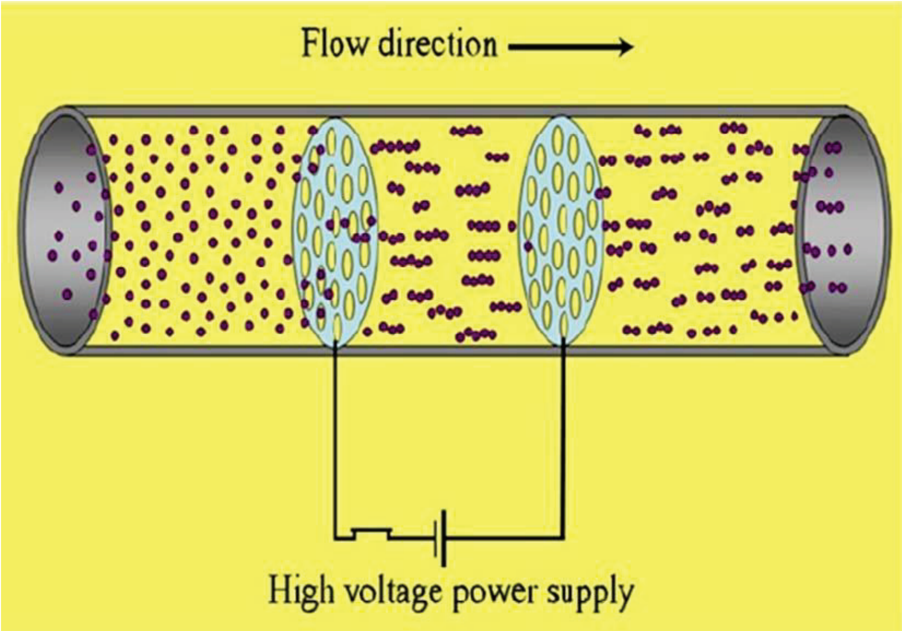


**Fig 2.** Electrical treatment of crude oil [13].

## 3 Tao theory

In his early research, Einstein discovered that a liquid suspension of relatively uniform spherical particles in a diluted solution had an apparent viscosity of

$$\frac{\eta}{\eta_{\circ}} = 1 + 2.5\phi \quad (1)$$

In this equation, the apparent viscosity of the suspension (η) is determined by the viscosity of the base liquid ($\eta_{\circ}$) and the volume fraction of spheres in the suspension ($\phi = \frac{4}{3}\pi a^3 n$), where the volume fraction is calculated using the radius of a sphere (a) and the particle number density (n). The accuracy of Einstein's formula is limited to cases where ϕ is less than 0.01. According to Einstein's formula, if two suspensions containing spheres of different sizes are dispersed in the same base liquid and have the same volume fractions, they should have equal values for η. However, this conclusion does not hold true when $\phi \geq 0.01$ is greater than or equal to 0.01. In reality, the value of η increases when the size of the sphere decreases for a particular ϕ. This observation is based on the estimated mean free path of the suspended spheres, which is calculated by dividing a by ($\frac{a}{(3\phi)}$). As the mean free path gets shorter due to a decrease in size, it leads to an increase in η. The Mooney equation can be utilized to carry out a thorough calculation.

$$\frac{\eta}{\eta_{\circ}} = \exp\left[\frac{2.5\phi}{1-k\phi}\right] \quad (2)$$

The crowding factor, denoted as 'k', plays a significant role in the Mooney equation. This equation is formulated by considering the volume that is left after multiple stepwise particle additions. An experimental estimation reveals that...

$$k = 1.079 + \exp\left(\frac{0.01008}{D}\right) + \exp\left(\frac{0.00290}{D^2}\right) \quad (3)$$

In the realm of particle studies, we often find ourselves exploring the relationship between the particle diameter, represented by the symbol D, and a parameter called k. To be more specific, D is denoted as 2a and is measured in micrometers. As we delve into this subject matter further, an interesting observation emerges: as the value of D decreases, there is a corresponding increase in the magnitude of k.

As a consequence, when the value of $\phi$ is given, $\eta$ increases if D decreases. As the size of the particles decreases, the viscosity appears to rise significantly. Taking this understanding into consideration, we will now illustrate how to decrease the viscosity of suspensions by utilizing either an electric field or a magnetic field. In a magnetic field, the particles become polarized in alignment with the direction of the field and the dipoles gather and orient themselves in that same direction. While maintaining a constant volume fraction $\phi$, the average particle size in the suspension increases. Due to the decreasing crowding factor k, the apparent viscosity decreases [14]..

## 4 High voltage electrical treatment

In a study conducted by Tao and Xu in 2006, it was discovered that using pulsed electrical or magnetic fields can effectively decrease the viscosity of crude oil. This method requires significantly less power compared to conventional heating methods, using only about 1% of the power. What's more, it does not alter the initial temperature of the crude oil. The researchers carried out their experiments on samples of paraffine and asphaltene base oil. For the paraffine-based oil, they applied a strong pulsed magnetic field for a short duration at temperatures below the Wax Appearing Temperature (17 °C). Initially, the viscosity was recorded to be 40.97 cp at 10 °C, but after applying a magnetic field of 1.33 T (Tesla or WB/m2) for 50 seconds, the viscosity decreased to 33.1 cp. After the passage of time, the viscosity gradually returned to its original value, which took approximately 8 hours. When it comes to asphalt base crude oil, the magnetic field has a lesser impact on this particular type of oil due to the asphalt particles being less responsive to magnetic fields. However, it is worth noting that asphaltene particles possess a dielectric constant of 2.7, making them more susceptible to the influence of electrical fields. At a temperature of 23.5 °C, the kinematic viscosity was measured at 773.8 cSt. In order to examine the effects further, a capacitor comprising two metallic meshes was carefully constructed and subsequently connected to a direct current power supply. Following the application of an electrical field with a strength of 1000 V/mm for a duration of 8 seconds, the viscosity experienced a notable reduction and settled at 669.5 cSt. After 90 minutes, the kinetic viscosity of the oil decreased by 67 cSt and remained lower than the initial value of 706.8 cSt. It took approximately 8 hours for the oil sample to regain its original viscosity [15].

In a study conducted by Tao et al. in 2009, they implemented electrostatic atomization with a high electrical field in fuel injection engines. The objective was to decrease the viscosity of the fuel, resulting in smaller fuel droplets and ultimately leading to cleaner and more efficient combustion. To achieve this, the researchers designed a device consisting of two metallic meshes. This device was then subjected to a strong electrical field of 1 kV/mm for a duration of 5 seconds, in the opposite direction of the flow. As a result of this process, the viscosity of the fuel decreased due to the charging of droplets with negative charges and the aggregation of nanoscale particles into larger ones. Additionally, it was found that the number of droplets increased from 5.3% to 15.3%. The introduction of an electric field with a strength of 1 kV/mm for a duration of about 2 seconds has resulted in a significant decrease in the viscosity of the diesel oil, approximately by 9%. The initial viscosity value of 4.6 cP has been reduced to 4.18 cP. However, it is important to note that following this decrease, the viscosity of the diesel fuel starts to increase again. It does not quickly return to its original level, presenting an opportunity to improve fuel atomization. Additionally, this reduction in viscosity has also led to a decrease in brake-specific fuel consumption (BSFC). At a speed of 1900 rpm, the BSFC value was initially measured at 220.1 g kW-1 h-1, but it has now been reduced to 208.7 g $kW^{-1}$ $h\text{-}^{1}$. The efficiency of the engine experienced a notable improvement, rising from 38.0 to 40.1%, which accounts for a noteworthy boost of 5.5% thanks to the implementation of new technology. This advancement can be attributed to the higher heating value of diesel fuel, which amounts to 0.119 531 kW h $g^{-1}$. In an experiment involving gasoline, an electric field of magnitude 1.2 kV/mm was applied for a duration of 1 second. It is worth noting that fuel played a crucial role in these observations as well. Specifically, when the device was switched off, the average power output stood at 0.3677 horsepower; however, once it was activated, the power output ascended to 0.4428 horsepower. This empirical evidence demonstrates that with the same rate of fuel consumption, there was an approximate increase of 20.4% in power output [16].

Researchers (Tang et al., 2011) have developed a system capable of replicating the movement of oil through pipelines. This innovative system is designed to evaluate the flow rate of oil under two different conditions: with and without the presence of an electrical field. The experiment begins by storing crude oil in a cylindrical reservoir positioned at the highest point. This reservoir boasts a diameter of 20 cm and a height of 15 cm, providing ample space for the oil to be tested. Connected to this reservoir is a transparent glass tube, which serves as the central component of the system. This tube possesses an inner diameter measuring approximately 2.26 cm and extends for a length of about 50 cm. Situated near the bottom section of this middle tube are two brass meshes, diligently attached using adhesive materials, guaranteeing their stability throughout the experiment. The glass spacer, which is sandwiched between the two meshes, is joined together using epoxy glue. It has the same diameter as the center glass tube and stands at a height of 2.5 cm. In order to prevent electric discharge, the exteriors of both the meshes and spacer are bonded with thermo-molten plastic glue. The meshes themselves feature holes with an average open area ratio of 48% and a diameter of 0.26 cm. When a high voltage is applied to the mesh electrodes, a powerful local electric field is generated, running parallel to the direction of flow. The lower part of the primary tube is connected to a delicate tube. The inner width of the minuscule tube measures approximately 0.37 cm. The slender tube has an approximate length of 27 cm. In the first trial, the electric field was not utilized. However, in the subsequent experiment, a direct current (DC) of 30 kV was supplied to the mesh electrodes for a duration of 400 seconds, coinciding with the introduction of roughly 50 g of unrefined oil into the container. This resulted in an applied electric field strength of 1200 V/mm between the two electrodes, which were separated by a distance of 2.5 cm. The journey begins with a steady zero-field flow rate of 0.107 g/s, remaining constant throughout. As the pressure decreases and the crude oil flows downward, the flow rate starts to gradually decline. However, once the electric field is brought into play, a remarkable improvement is observed as the flow rate jumps to 0.135 g/s, eventually stabilizing at 0.13 g/s. This signifies a significant 26.2% enhancement. Interestingly, when the electric field comes into action, not only does the level of the crude oil decrease faster, but also the pressure is reduced at an accelerated pace [17].

In their study, Homayuni et al. (2011) explored the use of pulsed electric field application to decrease the viscosity of heavy crude oil, specifically for undersea pipelines. Through experimentation, they found that a short burst of electric field was particularly effective in reducing the viscosity of crude oils with an asphalt base. This can be attributed to the differing dielectric constant of the asphalt particles compared to the rest of the oil. The researchers specifically utilized Iranian Soroosh field heavy crude oil, which has an API value of 19 and contains 10% asphalt content, for their experiments. During the trials, different electric field strengths were used, ranging from 0.5 to 1.8 kV/mm. The pulse durations varied from as short as 5 seconds to as long as 900 seconds. It was interesting to note that the viscosity of the substance being tested decreased by up to 7% during these experiments.

When the electric field intensity was relatively low, between 0.5 and 1 kV/mm, increasing the pulse duration from 5 to 20 seconds resulted in an increase in viscosity reduction from approximately 5.5% to about 8%. On the other hand, when a very high electric field of 1.8 kV/mm was used, increasing the pulse duration from 5 to 900 seconds actually led to a decrease in viscosity reduction from approximately 9.5% to about 7.8%. This information can be found in reference [18].

In a study conducted by Tao and Tang in 2014, they developed a system that included an oil reservoir. The crude oil passes through two capacitors, which are made up of three mesh electrodes, as it steadily trickles downwards. By applying a powerful electric field in the same direction as the flow, the researchers were able to subject the oil to high voltage. The viscosity of the oil can be determined by considering both the flow rate and the capillary tube located at the bottom. To track the gathered mass of oil over time, a microbalance is initiated and starts recording as soon as the experiment commences. The change in flow rates when the electric field is turned on or off indicates the effect of reducing viscosity. The Rocky Mountain Oilfield Testing Center, which is a part of the US Department of Energy, provided a sample of crude oil with an API value of 34. At normal room temperature, the viscosity of the oil is relatively low. However, as the temperature drops, the viscosity increases rapidly. Below a certain temperature called the wax appearance temperature (WAT), which is approximately 12.5 °C, the viscosity rises even more quickly. It has been determined that the pour point of this oil sample is around -4 °C. Hence, as the temperature drops below -3 °C, just above the pour point, the viscosity experiences a significant rise. It is worth noting that at -3.1 °C, the oil flow rate sans an electric field was merely 2.08 mg/s, owing to the combination of low temperatures and a narrow capillary tube that results in high viscosity. The initial viscosity of the oil was approximately 261.3cp, as established by this reference point. Once the untreated oil made its way out of the capillary tube, an electric field of 1.6 kV/mm was introduced, resulting in an immediate surge in flow rate. Remarkably, under this applied electric field, the steady flow rate experienced a staggering increase of more than 460.6%, reaching 11.66 mg/s. Consequently, there was a substantial reduction of 82.1% in the viscosity in the direction of flow, approximately amounting to 46.7cp. The current measured was 0.63 μA, indicating that a mere 0.1025 kW h of power is sufficient to treat one barrel of crude oil. When the electric field is deactivated, the flow rate reverts back to its original state after the treated oil is discharged from the capacitor and capillary tube. In the absence of an electric field, at a temperature of -1.4 °C, the flow rate stood at 3.633 mg/s in response to a viscosity value of 149.9cp. When an electric field of 1.6 KV/mm was applied, the flow rate increased to 9.71 mg/s, showing a whopping 167% boost. The viscosity also went down to 56.7cp, a significant reduction of 62.2%. Under the chilly temperature of 1.5 °C, which mirrors the depths of the ocean, the flow rate without any electric field stands at 4.95 mg/s, corresponding to a viscosity of 105.4cp. However, with the addition of an electric field measuring 1.6 KV/mm, the flow rate jumps up to 10.1 mg/s, indicating a staggering increase of 104%. Consequently, this suggests that the viscosity has decreased by approximately 48.9% to reach a value of 53.9cp. During a recent field test on a pipeline, it was found that the viscosity decrease, which occurs when the short chains that have formed together are separated, does not stay for long. The study revealed that this decrease in viscosity lasts approximately 11 hours [19].

According to a study by Tao and Gu in 2015, when a powerful electric field is applied along the flow direction in a small section of pipeline, the particles suspended in the liquid base come together to form short chains. This aggregation disrupts the rotational symmetry and creates an uneven distribution of viscosity in the fluid. Specifically, the viscosity increases significantly in directions perpendicular to the flow, which effectively reduces turbulence. On the other hand, the viscosity decreases considerably in the flow direction, leading to improved flow through the pipeline. The results from recent field tests on a crude oil pipeline have provided solid evidence in support of the theoretical predictions. When the temperature was at 25 °C, the viscosity of the asphalt-based crude oil sample was measured to be 210.1 cP. However, after undergoing an electric-field treatment in the direction of the pipeline, its viscosity decreased by 32.2% and reached 142.5 cP at the same temperature. To monitor any changes over time, the treated oil sample was stored in a container at

25 °C and its viscosity was periodically examined thereafter. The impact of decreased thickness extended for multiple hours, as the thicknesses only increased to 164.3 cP after two hours, 170.0 cP after four hours, 176.1 cP after eight hours, 179.8 cP after fourteen hours, and 181.1 cP after twenty-four hours. Similar results are observed in the case of crude oil with a paraffin base. For example, the untreated Daqing crude oil exhibited a thickness of 911 cP at a temperature of 35.1 °C. We commenced by subjecting it to an electric field of 8 kV/cm. Subsequently, we maintained the treated oil sample at a temperature of 35.1 °C for several hours. After the treatment, the viscosity of the sample increased to 390 centipoise (cP). Over time, the viscosity continued to rise, reaching 421 cP after 4 hours, 441 cP after 12 hours, 480 cP after 23 hours, and finally settling at 487 cP after 26 hours.

In a separate experiment using a Positive Displacement pump, the viscosity of untreated oil was measured at 118.06 cP. However, when subjected to an electric field, the viscosity in the direction of flow decreased by 56.12% to a value of 51.8 cP. Remarkably, the treated oil maintained this reduced viscosity for approximately 11 hours while experiencing no changes in pressure loss or pump power [20].

The study conducted by Ma et al. in 2017 shed light on an interesting finding regarding the flow of waxy crude oil in cold conditions. According to their research, the application of electrical treatment significantly enhances the oil's ability to flow smoothly. In order to measure its rheological properties, the researchers subjected the waxy crude oil to electrical treatment and employed a device for analysis. The results indicated that viscosity reduction was more prominent at lower treatment temperatures, stronger electric field strengths, and slower shear speeds. Notably, when the oil was electrically treated close to its pour point for a duration of 90 seconds, with an electric field strength of 800 V/mm at a temperature of 18 °C, an impressive viscosity decrease of 70% was achieved. After closely examining the tiny details, it seems that the viscosity decrease observed in the treated oil could possibly be attributed to the wax particles having a broader range of sizes. Moreover, calculations indicate that the electrical treatment requires just 1% less energy compared to the traditional heating method in order to achieve equivalent viscosity reduction results [21].

In their study, Du, Zhao, et al. (2018) conducted an experiment on asphaltene base crude oil to investigate the behavior of the suspended particles in the liquid when an intense electric field was applied in a specific section of the pipeline. The results showed that these particles, known as asphaltene particles, formed short chains along the flow direction due to the aggregation process induced by the electric field. This aggregation disrupted the rotational symmetry of the fluid and caused anisotropy in its viscosity. Specifically, the viscosity increased significantly in directions perpendicular to the flow, effectively suppressing turbulence. On the other hand, the viscosity decreased substantially in the flow direction, leading to improved fluid flow along the pipeline. The thickness of the crude oil made from asphaltenes decreased from 715.8 to 383.4 cP when an electric field of 1.612 kV/mm was applied at a temperature of 23 °C. When the temperature dropped to 16 °C, an electric field of 1.704 kV/mm caused the viscosity to decrease from 1821.2 to 1022.0 cP. Similarly, at a temperature of 12 °C, the viscosity went down from 2750.5 to 1559.2 cP when an electric field of 1.704 kV/mm was applied. Finally, when the temperature dropped to a chilly 6 °C, the viscosity dropped from a high value of 6003.7 to a lower value of 3594.0 cP when an electric field of 1.612 kV/mm was applied [12].

In a study conducted by Ma et al. in 2019, it was found that the viscosity of waxy oils without asphaltenes decreased by a significant 31.0%. They also discovered that applying electrical treatment to these waxy oils improved their cold flowability. However, the effectiveness of the electrical treatment was greatly diminished when asphaltenes were added to the waxy model oils. As the concentration of asphaltenes in the model oil increased from zero to three parts per thousand, the reduction in viscosity dropped from 31.0% to 22.4%. Furthermore, when the asphaltene concentration was further raised to ten parts per thousand, the viscosity reduction plummeted to a mere 1.82%. It was found that the way asphaltenes come together doesn't really affect the negative outcomes. Surprisingly, when the polarity of asphaltenes is increased, it actually decreases their harmful impact during electrical treatment. In an experiment using model oil, when the asphaltenes were changed from being least polar to most polar, there was a significant increase in the reduction of viscosity - going from 3.8% to 24.8% [22].

In a recent study conducted by Huang et al. (2021), it was proposed that by introducing a high-voltage electric field in alignment with the flow of oil or to waxy crude oil, the viscosity of the oil can be effectively reduced. To investigate this phenomenon further, a flowing waxy crude oil was subjected to an electric field perpendicular to the direction of flow within a rheometer that allowed for manipulation of the electric field during the experiment. Surprisingly, it was discovered that similar viscosity reduction could be achieved even with an electric field perpendicular to the flow direction, akin to the results obtained with an electric field parallel to the flow direction. This shows that, unlike the way the oil flows, the effectiveness of the treatment is not affected by the direction of the electric field. Furthermore, the unique properties of the treated crude oil become less important, and there is a greater decrease in viscosity at higher electric fields and lower oil temperatures. The viscosity starts to increase again once the electric field is switched off, and after approximately two days, it returns to its original state. The main reason for the decrease in viscosity is likely due to the decreased interaction between wax particles caused by exposure to an electric field. This is despite the fact that the electric treatment actually leads to larger wax crystals and some degree of particle clustering. As the strength of the electric field increases, the drop in viscosity becomes even more significant. For example, when the electric field is increased from 1 kV/mm to 5 kV/mm, the viscosity reduction goes from 30% to over 80%. Additionally, it can be observed that at lower rates of shear, the impact of the electric treatment becomes slightly more noticeable [23].

## 5 Addition combined with electrical treatment

In their study, Ibrahim and his colleagues from 2017 made use of nanomaterials and an electrical field to lessen the thickness of dense crude oil that originated from Iraq. They accomplished this by constructing a unique capacitor which was then utilized to introduce an electrical field into the pipes transporting the oil. The researchers explored various configurations involving the distance between electrodes, the voltage applied, the concentration of nano silica, and the duration of treatment. During the experiment, a type of crude oil with an API measurement of 31.2 was utilized. To study its viscosity, the oil's initial value of 32.5 cSt was compared to a reduced value of 20.479 cSt. This reduction amounted to 37% when specific voltages (measuring 188V) were applied for a duration of 32 seconds. The experiment took place at a temperature of 10 °C, with the distance between the electrodes measuring 6.11 cm. It is worth noting that no Nano silica was added during this process. As a result of these modifications, the flow rate increased by an impressive 45.6%. The thickness of the liquid was made thinner, dropping from 32.5 centistokes to 12.8 centistokes, resulting in a significant reduction of 60.6%. This occurred when an electrical charge of 188 volts was applied for a period of 32 seconds at a chilly temperature of 10 degrees Celsius. The electrodes were positioned 6.11 centimeters apart and the liquid was supplemented with 100 parts per million of Nano silica. As a consequence, the speed at which the liquid flowed increased by an impressive 77.8% [24].

In a study conducted by Xie et al. in 2020, they examined the effects of different treatments on waxy oil. The researchers applied a 0.8 kV/mm electric field, 100 ppm ethylene-vinyl acetate copolymer (EVA), as well as a combination of both the electric field and EVA to the oil. Prior to any treatment, the viscosity of the oil was measured at 105.40 mPa.s when subjected to a shear rate of 10 s-1.

Interestingly, when an electric field was applied to the oil, its viscosity decreased by approximately 37.1% to a value of 66.27 mPa.s. Similarly, after being treated with EVA, the viscosity reduced by about 40.9%. However, it is worth noting that the impact of EVA treatment on viscosity reduction seems to be more significant compared to the electrical treatment in this particular experimental setting. After undergoing treatment with the electric field and EVA, the viscosity of the oil decreased by a substantial 59.1% and now stands at an absolute viscosity of 43.97 mPa. In comparison to the individual electrical and EVA treatments, the combined treatment is capable of achieving an additional reduction in viscosity by 22.0% and 18.2%, respectively. However, it is important to note that the impact of the combined treatment is not as pronounced as the sum of the effects produced by separate electrical and EVA treatments. For example, at a shear rate of 10 s1, the combination treatment reduces viscosity by 59.1%, which is actually 18.9% less than what would be expected from combining a solitary electrical treatment with a solitary EVA treatment [25].

In their recent study, researchers (Jalal et al., 2022) put forth an innovative idea of utilizing graphene supercapacitors as a means to decrease the viscosity of crude oil. To investigate the potential effects of dilution, they conducted an initial analysis using a sample of crude oil with a 31 °API. Multiple concentrations of acetone were employed as a diluent in this experiment. Notably, the addition of acetone at a concentration of 20 wt% resulted in a significant reduction in viscosity, amounting to approximately 21.98%. Furthermore, the researchers delved into the impact of an electric field on the viscosity of the crude oil. Intriguingly, when an electric field with an intensity of 36.67 (v/cm) was applied, it led to a substantial decrease in viscosity by about 35.6%. Finally, the researchers employed combined treatment involving both dilution and electric field to comprehensively examine their effects on crude oil viscosity. The most optimal decrease in viscosity happens when the solution contains 11% acetone by weight and is subjected to an electric field strength of 36.67 (v/cm), which accounts for approximately 61.856%. This favorable condition persists for a duration of roughly 11 hours before the viscosity begins to rise once more [26].

## 6 Conclusions and recommendations

The present review had surveyed the ultimate techniques and methods of reducing the crude oil viscosity. Based on electrical treatment method it seems very efficient compared to other methods because the heating method needs to heat source and cannot be feasible along pipelines, additives are expensive and requires huge quantities and skid facility, other methods like shearing and ultrasonic are power consuming methods, and dilution method also needs other crude oil cuts or lighter crude oils to dilute the heavy oil ,in the other hand the electrical method is inexpensive and can be employed in pumping stations, under sea pipelines, and whenever that pump is exist.

**Table 1.** Nomenclature

| | |
|---|---|
| AC | Alternative current |
| API | American petroleum institute |
| BSFC | Brake-specific fuel consumption |
| DC | Direct current |
| EVA | Ethylene-vinyl acetate polymer |
| PAM | polyacrylamide |
| RPA | Rotary pulsation apparatus |
| TEA | triethanolamine |
| WAT | Wax appearance temperature |

## References

1. C. Alberto da Silva, D. Filho, T. Pimentel, and Z. Panossian, “Analysis of crude oil effect for CO2 corrosion of carbon steel - A rotating cylinder electrode approach,” *Geoenergy Science and Engineering*, vol. 229, p. 212085, Oct. 2023, doi: 10.1016/j.geoen.2023.212085.
2. F. Souas, A. Safri, and A. Benmounah, “A review on the rheology of heavy crude oil for pipeline transportation,” *Petroleum Research*, vol. 6, no. 2. KeAi Publishing Communications Ltd., pp. 116–136, Jun. 01, 2021. doi: 10.1016/j.ptlrs.2020.11.001.
3. R. Martínez-Palou *et al.*, “Transportation of heavy and extra-heavy crude oil by pipeline: A review,” *J Pet Sci Eng*, vol. 75, no. 3–4, pp. 274–282, Jan. 2011, doi: 10.1016/j.petrol.2010.11.020.
4. R. I. Rueda-Velásquez and M. R. Gray, “A viscosity-conversion model for thermal cracking of heavy oils,” *Fuel*, vol. 197, pp. 82–90, Jun. 2017, doi: 10.1016/j.fuel.2017.02.020.
5. A. Mohsenzadeh, Y. Al-Wahaibi, A. Jibril, R. Al-Hajri, and S. Shuwa, “The novel use of Deep Eutectic Solvents for enhancing heavy oil recovery,” *J Pet Sci Eng*, vol. 130, pp. 6–15, Jun. 2015, doi: 10.1016/j.petrol.2015.03.018.
6. I. N. Sulaiman, A. H. Abdulla, and A. H. Hattab, “A study of the effectiveness of chemical additives on the characteristic flow of crude oils,” *Periodicals of Engineering and Natural Sciences (PEN)*, vol. 10, no. 1, p. 397, Feb. 2022, doi: 10.21533/pen.v10i1.2671.
7. P. Gateau, I. Hénaut, L. Barré, and J. F. Argillier, “Heavy Oil Dilution,” *Oil & Gas Science and Technology*, vol. 59, no. 5, pp. 503–509, Sep. 2004, doi: 10.2516/ogst:2004035.
8. H. Karbstein and H. Schubert, “Developments in the continuous mechanical production of oil-in-water macro-emulsions,” *Chemical Engineering and Processing: Process Intensification*, vol. 34, no. 3, pp. 205–211, Jun. 1995, doi: 10.1016/0255-2701(94)04005-2.
9. D. Sharif Hamadi, G. Raheem, and S. Hussain, “Upgrading of Basrah-Kirkuk Blend Crude Oil Through Mechanical-Acoustical Effect and (LABS) as Surfactant,” 2012. [Online]. Available: www.pdffactory.com
10. J. Liu, F. Yang, J. Xia, F. Wu, and C. Pu, “Mechanism of Ultrasonic Physical–Chemical Viscosity Reduction for Different Heavy Oils,” *ACS Omega*, vol. 6, no. 3, pp. 2276–2283, Jan. 2021, doi: 10.1021/acsomega.0c05585.
11. X. Chen, L. Hou, W. Li, and S. Li, “Influence of electric field on the viscosity of waxy crude oil and micro property of paraffin: A molecular dynamics simulation study,” *J Mol Liq*, vol. 272, pp. 973–981, Dec. 2018, doi: 10.1016/j.molliq.2018.10.097.
12. E. Du, Q. Zhao, Y. Xiao, L. Cai, and R. Tao, “Electric field suppressed turbulence and reduced viscosity of asphaltene base crude oil sample,” *Fuel*, vol. 220, pp. 358–362, May 2018, doi: 10.1016/j.fuel.2018.01.098.
13. E. Du, X. Xu, K. Huang, H. Tang, and R. Tao, “Bunker diesel viscosity is dramatically reduced by electrorheological treatment,” *Int J Mod Phys B*, vol. 32, no. 2, Jan. 2018, doi: 10.1142/S0217979218500121.
14. R. TAO and X. XU, “VISCOSITY REDUCTION IN LIQUID SUSPENSIONS BY ELECTRIC OR MAGNETIC FIELDS,” in *Electrorheological Fluids and Magnetorheological Suspensions (ERMR 2004)*, WORLD SCIENTIFIC, Jun. 2005, pp. 299–305. doi: 10.1142/9789812702197_0045.
15. R. Tao and X. Xu, “Reducing the Viscosity of Crude Oil by Pulsed Electric or Magnetic Field,” *Energy & Fuels*, vol. 20, no. 5, pp. 2046–2051, Sep. 2006, doi: 10.1021/ef060072x.
16. R. Tao, K. Huang, H. Tang, and D. Bell, “Electrorheology improves engine efficiency,” *J Phys Conf Ser*, vol. 149, p. 012030, Feb. 2009, doi: 10.1088/1742-6596/149/1/012030.
17. H. Tang, K. Huang, and R. Tao, “Electrorheology Improves Transportation of Crude Oil,” *J Intell Mater Syst Struct*, vol. 22, no. 15, pp. 1673–1676, Oct. 2011, doi: 10.1177/1045389X11421816.
18. F. Homayuni, A. A. Hamidi, A. Vatani, A. A. Shaygani, and R. Faraji Dana, “The Viscosity Reduction of Heavy and Extra Heavy Crude Oils by a Pulsed Magnetic Field,” *Pet Sci Technol*, vol. 29, no. 23, pp. 2407–2415, Oct. 2011, doi: 10.1080/10916461003645443.
19. R. Tao and H. Tang, “Reducing viscosity of paraffin base crude oil with electric field for oil production and transportation,” *Fuel*, vol. 118, pp. 69–72, Feb. 2014, doi: 10.1016/j.fuel.2013.10.056.
20. R. Tao and G. Q. Gu, “Suppressing turbulence and enhancing liquid suspension flow in pipelines with electrorheology,” *Phys Rev E Stat Nonlin Soft Matter Phys*, vol. 91, no. 1, Jan. 2015, doi: 10.1103/PhysRevE.91.012304.
21. C. Ma *et al.*, “Electrical Treatment of Waxy Crude Oil To Improve Its Cold Flowability,” *Ind Eng Chem Res*, vol. 56, no. 38, pp. 10920–10928, Sep. 2017, doi: 10.1021/acs.iecr.7b02140.
22. C. Ma *et al.*, “Influence of asphaltenes on the performance of electrical treatment of waxy oils,” *J Pet Sci Eng*, vol. 180, pp. 31–40, Sep. 2019, doi: 10.1016/j.petrol.2019.05.020.

23. Q. Huang *et al.*, "Reducing viscosity of waxy crude oil with electric field perpendicular to oil's flow direction," *Fuel*, vol. 283, p. 119345, Jan. 2021, doi: 10.1016/j.fuel.2020.119345.
24. R. I. Ibrahim, M. K. Oudah, and A. F. Hassan, "Viscosity reduction for flowability enhancement in Iraqi crude oil pipelines using novel capacitor and locally prepared nanosilica," *J Pet Sci Eng*, vol. 156, pp. 356–365, Jul. 2017, doi: 10.1016/j.petrol.2017.05.028.
25. Y. Xie *et al.*, "Combined treatment of electrical and ethylene-vinyl acetate copolymer (EVA) to improve the cold flowability of waxy crude oils," *Fuel*, vol. 267, p. 117161, May 2020, doi: 10.1016/j.fuel.2020.117161.
26. N. Jalal, R. Ibrahim, and M. Oudah, "Flow Improvement and Viscosity Reduction for Crude Oil Pipelines Transportation Using Dilution and Electrical Field," *Engineering and Technology Journal*, vol. 40, no. 1, pp. 66–75, Jan. 2022, doi: 10.30684/etj.v40i1.2192.