A comprehensive review of improving the heavy crude oil transportation process using additives

Abstract:

Transporting heavy crude oil from the wellhead to the oil refineries.is extremely important because worldwide oil production is on the rise. These oils are characterized by high viscosity and low API gravity. Due to these specifications, the flow of oil through pipelines is difficult, and to facilitate its transportation must be treated. In this paper, the additives that reduce the viscosity and density of crude oil and reduce the asphalt materials in it, which, if their percentage increases, are deposited in the transport pipelines. Additives are not only to reduce the viscosity and density of heavy oils, but their use aims to reduce the content of asphalt and sulfur materials and as a result of all this friction and pressure losses between crude oil and pipes will be reduced during transportation, with a decrease in viscosity and density of crude oil will increase its movement, and with a decrease in sulfur content will reduce corrosion that causes serious damage to pipes. Solvents (such as naphtha, toluene, gasoline, and kerosene) surfactants (such as petroleum sulfonates, and polymeric surfactant), and nanoparticles (such as Al_2O_3, and Fe_2O_3) are the most important additions that achieve this enhancement and optimization for the transport of crude oil through pipelines. One of the important additions that in turn improve heavy crude oil is the addition of solvents that have low viscosity and low density; these solvents reduce the viscosity of heavy crude oil and reduce the proportions of metals such as nickel and vanadium, as well as reduce the percentage of sulfur in crude oil.

Keywords: improving, heavy crude oil, transportation, upgrading, nanoparticle.

INTRODUCTION

The growth of the world's population, with the limited industrialization of developed countries and the significant increase in energy consumption, has led to an increase in global demand for crude oil. However, one of the big challenges is the significant decline in light crude oil reserves, which would make major international companies turn their attention towards exploiting heavy and extra-heavy oils in order to meet energy requirements due to the extractable oil capacity. Heavy crude oil and bitumen are defined as crude with an API gravity of less than or equal to 22 and equal to or less than 10 (denser than water), respectively [1] .Despite the importance of reserves for heavy crude oil, which is large in size for light oil, one of the great challenges is in its development, production, and refining because this is very difficult as a result of its chemical and physical properties and in particular it's high density and high viscosity, so its attractiveness is low API, and the high hydrocarbon content It usually contains HO and EHO with a high and high percentage of compounds and components that are Heavy as resins and asphalt compounds which reduce the attractiveness of the API and significantly increase the raw viscosity [2]. API gravity is a qualitative gravimetric that defines the quality of crude oil in terms of being light or heavy. By the American Institute specialized in the oil industry (API) in order to measure the relative density of all different petroleum liquids, whether crude oil or petroleum products, and express them in degrees. The lower the API number, the heavier the crude oil or oil product, and the greater its specific gravity. The important and distinctive heavy crude oil properties are that it has a high viscosity, a high specific gravity, a high molecular structure, a low hydrogen-to-carbon ratio, a high carbon residue is high and a high asphaltin, heavy metal, sulfur, and nitrogen content [3]. For the optimization required to transport heavy crude oil to the surface, heating stations and pumping pipes consider the conventional techniques used, emulsifying and diluting with less viscous solvents, and reducing friction [4,5]. And with all this, all these techniques are considered remarkably expensive. Due to the high global demand for raw materials and the urgent need for them, and the great need to transport them over long distances through large pipelines, the need for additional operations to transport crude oil has become crucial[6,7]. Therefore, many papers have been presented that will highlight all the available and different techniques in order to improve the movement and movement of heavy crude oil with its advantages and limitations[8]. The search for new technologies to improve the process of heavy crude oil flow is of great importance, so nanomaterials appeared as a new and alternative technology in order to reduce the viscosity of heavy crude oil and improve its other specifications, because of the specifications and features of nanomaterials, nanoparticle, and flood parts, which made them very useful [9,10]. The usual techniques for transporting heavy and very heavy oil are expensive and expensive in addition to being dangerous, so nanotechnology has emerged as a complementary technology that can strongly compete technically and economically because it shows high and distinctive potential, which leads to improving the movement of oil due to the reduction of viscosity, which occurs through the interaction of fine particles with the asphaltene in the crude[11]. When particles are added to the size of nano, they are characterized by their high absorbency due to the fact that the ratio of the mass of adsorbent to the volume of solution (A/V) is very high[12]. In addition, the nanoscale is not a problem in blocking the porous grooves of conventional crude oil deposits, because its surface is known to have a significant affinity with the asphaltene found in crude oils, which is much greater than the affinity of crude oil it is significantly larger than the convergence of asphaltene aggregates of crude oil, so it is expected that when this happens, the molecular weight of these aggregates will also decrease, so a significant decrease in viscosity is obtained [13]. Petroleum is the most important consumer material worldwide[14]. Because the oil product not only provides raw materials for the petrochemical industry and other products, it also provides fuel for energy, heating, and transportation, and enters all industries [15]. Petroleum consists of many organic compounds, in particular hydrocarbons, trapped in special geological formations with a trace of water and minerals [16]. The composition of crude oil covers a wide variety of hydrocarbons in a wide range of organic functions, sizes and molecular weight [17]. This configuration varies depending on the age of the field, the depth and location of the tank [18]. The following is a brief description of the diverse chemical families identified in crude oil [19]. Kinds of paraffin are saturated hydrocarbons (ordinary and isoparaffin, respectively) and these compounds (paraffin) are considered to have branched chains or straight . These chains connect carbon atoms by single covalent bonds. Paraffinic oils are white oils. Naphthene is a cycloparaffin. They are molecules with a saturated ring structure, and the saturated ring contains 5, 6, or 7 carbon atoms. Most naphthenes have paraffinic side chains with more than one ring in the molecule. Mononaphthene, di-naphthene, and tri-naphthene. Also, the rings can be merged or unintegrated[20]. Compounds containing at least one benzene ring are aromatic hydrocarbons, such as mono, di, and triphoxy. Crude oil fragrances usually contain paraffin side chains and may include naphtha rings[21]. The non-molten and molten rings are aromatic and naphthenic rings in this group of hydrocarbon compounds. Aromatic compounds increase significantly with the increase in the number of rings due to the large number of possible formations of naphthalic and aromatic rings and side chains[22]. All heterogeneous compounds are considered hydrocarbon compounds of the classes mentioned above where one or more heterogeneous atoms (N, S, O, V, NI, FE) are part of the molecule. The presence and elasticity of these heterogeneous atoms contribute to the complexities of hydrocarbon structural structures. Heterogeneous compounds are usually part of the fractions of the high molecular weight of petroleum liquids [23]. Heavy and very heavy oil and bitumen make up 70% of the world's oil reserves, as shown in Figure1 .

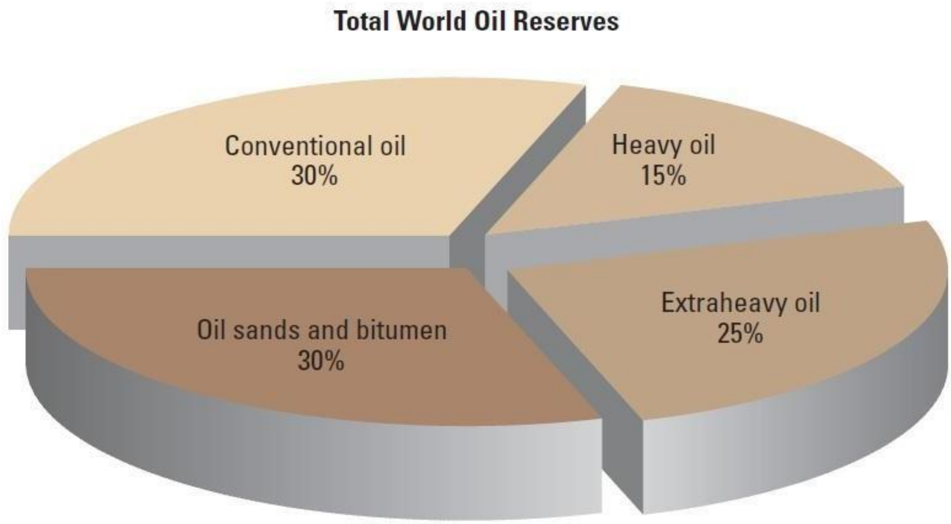


Figure 1. Shows the total distribution of oil reserves in the world by classification [24]

HO and EHO. It is known that the unnatural oil reserve has a very high resistance to flow and transfer, and its density is very high when compared to conventional oils. Figure 2 [25]

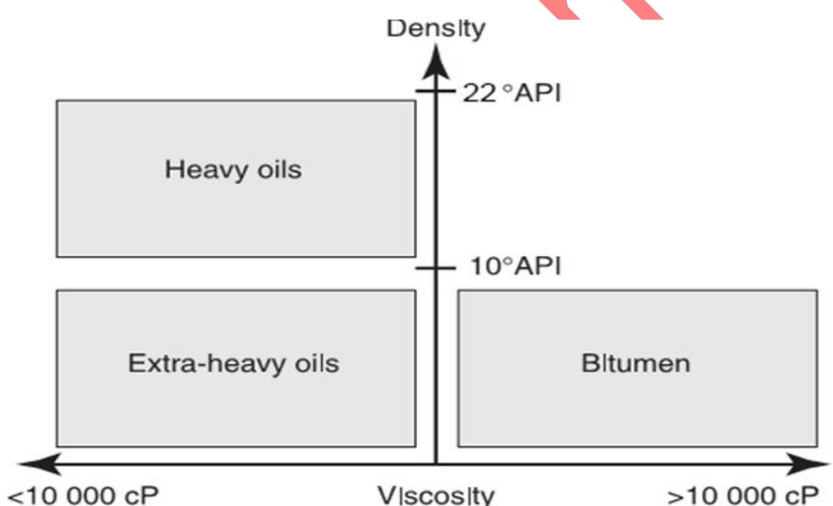


Figure 2. Values for API different oils[26]

Figure 3 illustrates the very popular oil split. The knowledge of the type of oil and the determination of its physical properties is done through the most famous and prominent chemical sections in the liquid [27]. In general, paraffin oils have a lower boiling point, viscosity, and density than naphthene oils. The greatest boiling point, viscosity, and density have been found in oils with a high content of heterogeneous and aromatic compounds. This classification clearly shows that conventional oils are the most common and most common naphthenic and paraffinic liquids, while heavy, very perforated, and bitumen oils contain a high and high percentage of hydrocarbons, polar, and aromatic heterogeneous compounds[28,29].

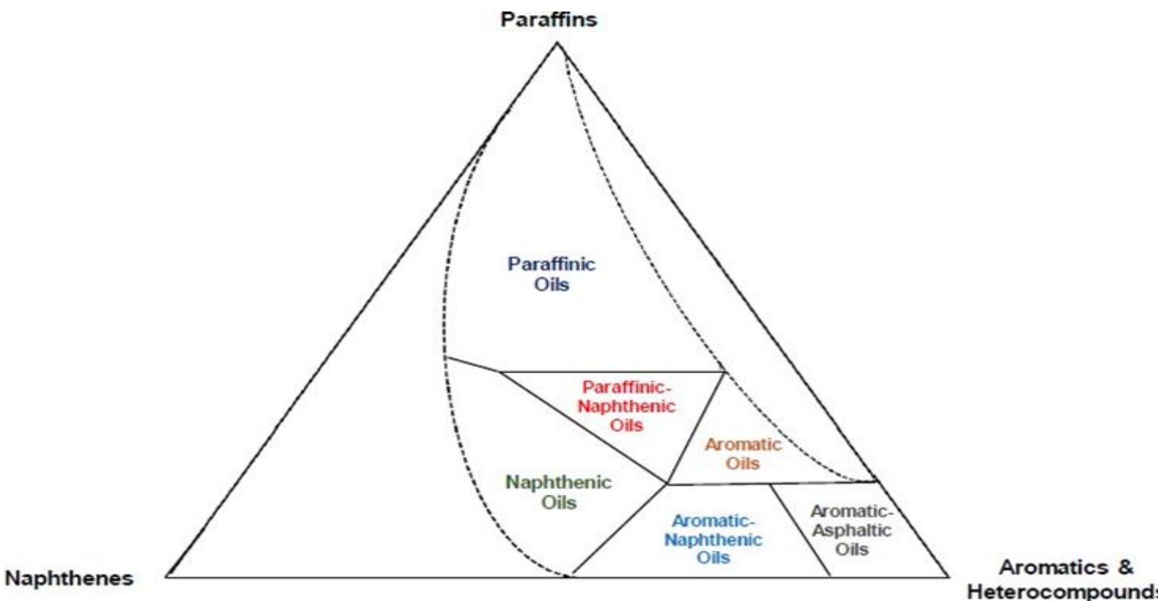


Figure 3. The types of crude oil in different regions.[30].

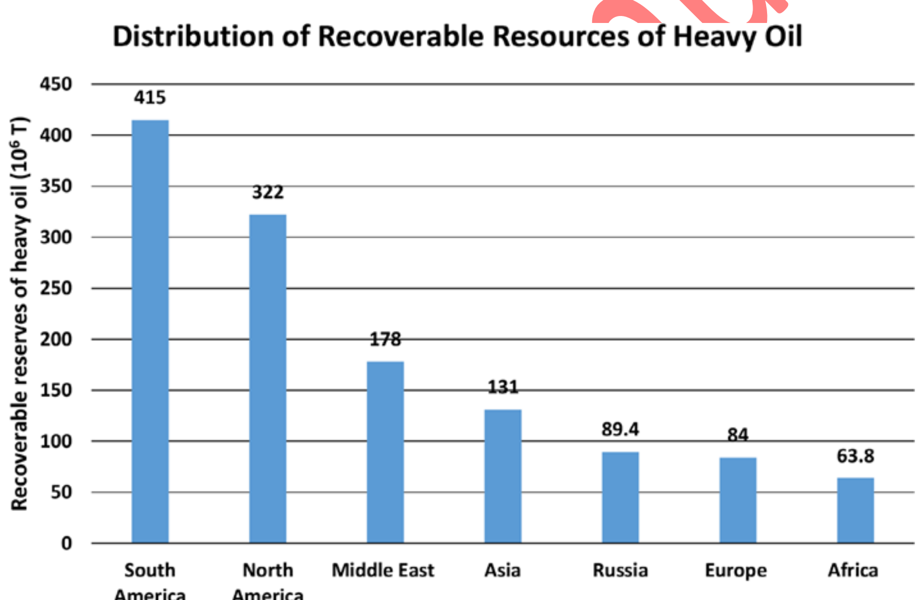


Figure 4. Distribution of recoverable oil in different regions[31].

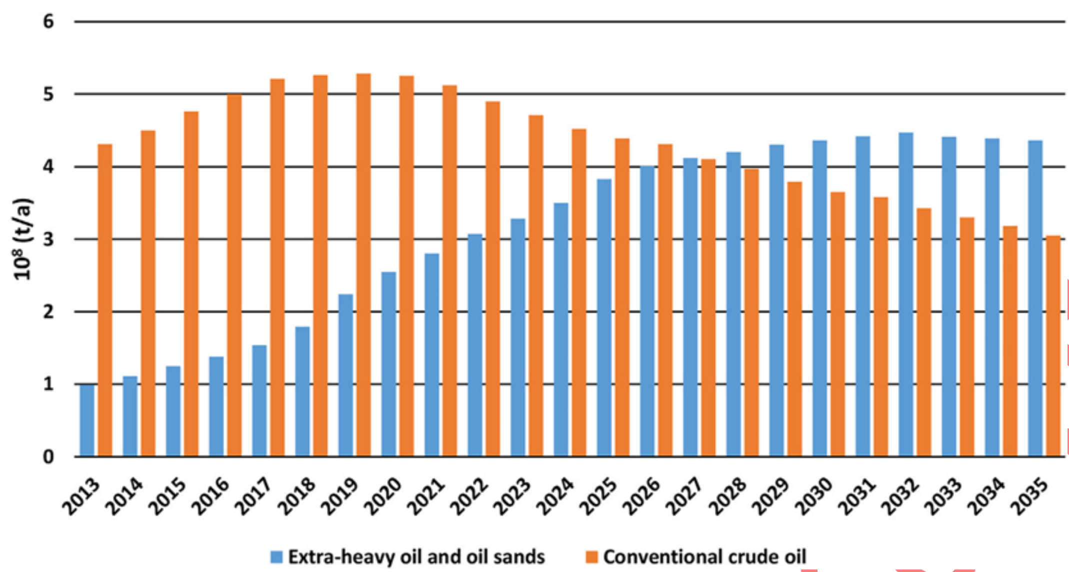


Figure 5. Oil production forecasts over the next twenty years[32].

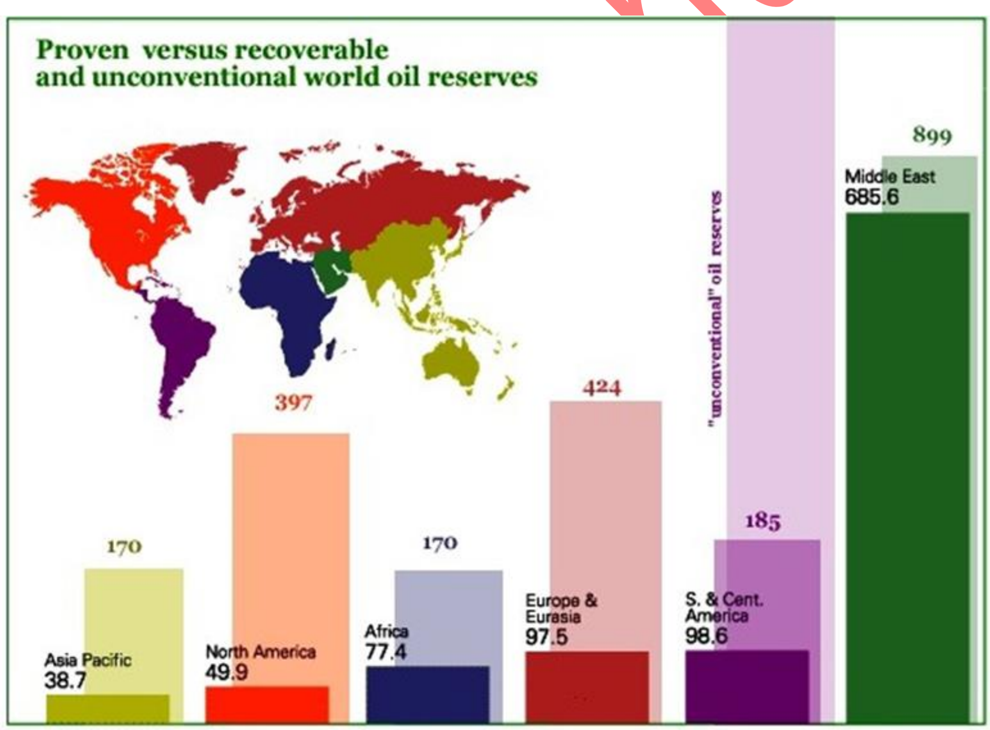


Figure 6: Distribution of proven oil reserves that can be extracted in billions of barrels[33,34]

1. Crude Oil Characterization

Characterization of crude oil in terms of composition is the first step to determining and measuring its chemical and physical properties, predicting and identifying its thermodynamic behavior, whether in oil reservoirs [35], oil wells, surface equipment, installations, or refineries for refining. For example, the nature and type of products obtained at refineries when refining operations depend to a very large extent on the specifications and characteristics of crude oil entering the refinery for refining [34,36]. According to his concept of continuity [37], the distribution of the properties of the components of crude oil is through a wide range of molecular weights, ranging from the lowest to the largest components. As boiling point and molecular weight increase, other properties such as odors and heteroatom content increase, as shown in Figure(4)[38]

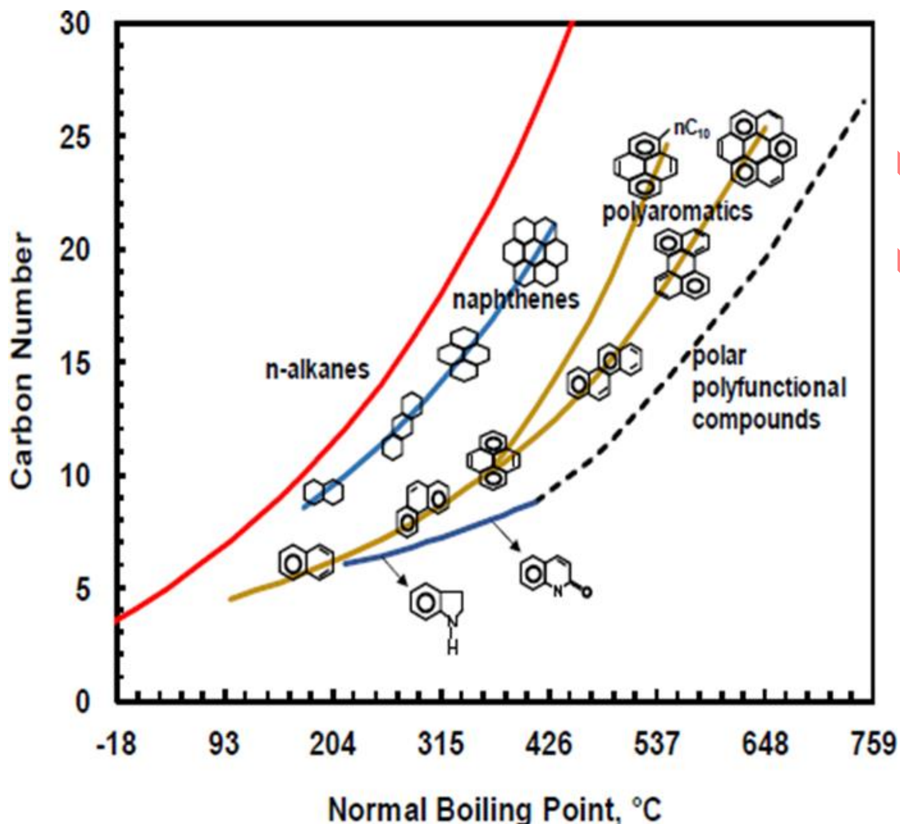
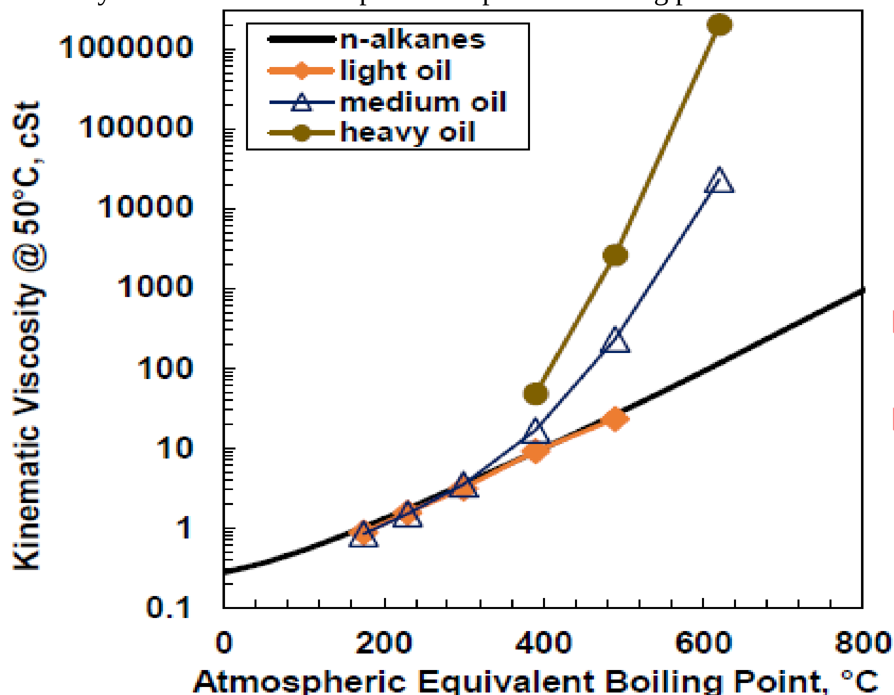


Figure 7. The effect of boiling point on the various chemical components present in crude oil.[39].

Figure 8. Shows that the properties of transporting oils, such as viscosity, also systematically vary with the boiling point. The viscosity and boiling point of light oil are almost very close to that of n-alkanes. However, the viscosity of medium and heavy oil pieces is trending and tends to have high viscosity. Deviation arises from an excess of naphthene and aromatics of oils. The exponential increase in the viscosity of the heaviest wounds is due to the presence of a large and different group of multinucleated aromatics and heterogeneous polar compounds [40].

Figure 8. Kinematic viscosity at 50°C in the atmosphere compared to boiling points of normal alkanes and distillate



fractions of light, medium, and heavy crude oils.[19,41].

What we need to characterize this wide distribution of properties is a starting point test. Many types of crude oil analysis methods have been developed, each capable of providing valuable information about the nature of the crude oil. However, not all methods provide the same information, so the choice of characterization depends on the nature of the information required to analyze the process in question. For example, distillation is the preferred method for characterizing crude oil in an oil refinery, as it provides comprehensive information about products such as cooking gas, gasoline, kerosene, lubricants, and basic stocks.[42]. In contrast, the choice is made for soluble-based characterization to ensure flow because the solubility data would provide more information about the components that can be deposited under specific conditions. A variety of techniques for the characterization of crude oil have been described in detail elsewhere [42] [18]. Often, the analysis of SARA (saturated, aromatics, resins, and asphaltic) is used for the characterization of heavy and very heavy crude oil.

1.2 Density, API gravity

API is an acronym for American Petroleum Institute, where the American Petroleum Institute uses API to determine the specific gravity (SG) of crude oil. Specific gravity, density, and API gravity are the most important physical properties that are essential in the characterization of each oil part[43]. Each of these three characteristics mentioned above is measurable and closely related to each other. We do not necessarily need to calculate all these properties separately; but some of them can be calculated and others are defined by the mathematical relationships that link these properties to each other, where if the general gravity of crude oil or any oil product is calculated, the density and API attractiveness of this oil or product can be determined[44]. One of the characteristics of heavy crude oils is that they are more viscous, have a higher boiling point, and have higher densities, so they have less attraction to API. Specific gravity is defined as the ratio of crude oil density to water density at 15.6 °C (60 °F). By calculating the API, crude oil can be classified, where the gravitational value of very heavy oil is less than 10, and if it is between 10 and 22, the oil is heavy, and the average is between 22 and 32, while light if the value of gravity is greater than 32 and to more than 40[44][44]. The density and specific gravity have been determined at 20 ° C according to ASTM 1217.[45]

Heavy crude oils are usually rich in aromatics and tend to contain more residual substances, such as asphaltene, heterocyclic, such as sulfur, nitrogen, and oxygen-containing hydrocarbon isotopes [46].

Table 2: Crude oil classification by the National Petroleum Agency of Brazil [47].

Oil Class	°API
Light	°API ≥ 31
Medium	22 ≤ °API < 31
Heavy	10 ≤ °API < 22
Extra-heavy	°API ≤ 10

1.3 Crude Oil Viscosity

Viscosity can be defined as the measure of fluid flow resistance necessary for tank studies. The viscosity of oils is an important physical property that controls the flow of crude oil and affects transportation through porous media and pipes[48]. heavy oil viscosity is a decisive factor that has a significant impact on the production of crude oil, upstream, surface transportation, and refining of crude oil[49]l.. A better understanding of how high viscosity forms greatly helps to find more and better approaches and methods in terms of reliability and sustainability for the recovery of heavy oil and for reducing related capital and/or operating costs [50]. Forecasting regarding the viscosity of crude oil is made by means of a variety of theoretical models and empirical comparisons[51]. However, due to its rather complex composition, accurately designed models cannot be applied to the viscosity estimation of a sample of heavy crude oil. Heavy crude oil has the ability to significantly change its physical and chemical properties from one reservoir to another [52,53]. The measurement of the results of Mexican asphalt viscosity is evidence of a noticeable increase in viscosity with asphalt material. When measuring the viscosity of the reconstituted oil at room temperature, its value was 367 times higher with a 20 percent volume of the of the deasphalted crude oil (maltine). He also concluded that the large amount of increase in viscosity with asphalt content is most likely due to the accumulation of strong asphalt particles. Note that he had done another test [54] 5 wt., percent of asphalt on a model of Athabasca bitumen with 16 initial weight and then found that the viscosity of bitumen had increased from 300,000 to 1,000,000 MPa. [55]

1.3.1 Effects of various solvents on the viscosity of heavy oils

It is clearly demonstrated by the adjustment of the asphalt concentration in the malting[56] , where a decisive density was observed, and the entanglement of colloidal particles was observed. It increases the amount of structural change significantly . It is more likely that viscosity will be reduced by reducing interference[57]. The interactions between the polar compounds and the solvent of the crude oil (mostly asphalt) and the fraction lead to improved reactions. These interactions are between asphalt and asphalt. The parameter δt is considered a representation of molecular interactions, according to the theory of "Hildebrand and Scott" [58]. The solubility parameter is determined by:

$$6t = \sqrt{\frac{ELv}{VM}} \qquad \ldots\ldots 1$$

Where $E_{LV} = \frac{\Delta H - RT}{VM}$

of VM (mol/L) as molar volume ΔH is the heat of evaporation and ELV (kW) as cohesion energy. For the ability to differentiate and distinguish between polar reactions dispersion forces and hydrogen bonding, Van Hansen [59] divided this solubility factor into three parts, i.e. the polar part, the dispersion part, the hydrogen bonding part, and the polar component called the cohesion force parameters.

$$\text{б}t = \text{б}d^2 + \text{б}p^2 + \text{б}H^2 \qquad \ldots\ldots 2$$

2 Pipeline Transport

Heavy oil would pass into the pipeline network type. In addition, the specifications and properties of HO have problems with flow control due to their very high viscosity, and these problems are not present in lighter hydrocarbon currents[60]. It is known that heavy crude oils cannot be transported by conventional pipelines, they can only be transported by additional processing operations[49]. These additional treatments are used to reduce viscosity (dilution, upgrade, heating, emulsion, and oil in water). Or in reducing friction in the pipe's basic annular flow [61]. Since time immemorial, clouds have been diagnosed and identified as the main cause of energy loss in conveyor channels, pipelines, and pipelines. The contribution of this drag is mainly due to the viscosity of the flow as well as the friction against the walls of the transmission pipes[62]. These energy losses can be determined by the decrease in the amount of pressure, which will inevitably lead to a rise in pumping energy consumption. Very high viscosity makes its transportation very difficult and complex, so additional processing procedures must be carried out.[49,63].

2.1 Drag reduction

The phenomenon of drag reduction is to reduce as much as possible the friction of the flowing fluid. The airway in turbulent flow is reduced by using a small amount of added material[64]. This is beneficial because pumping power requirements can be reduced[65,66]. In general, much research has been conducted in order to reduce turbulent drag in pipelines used to transport crude oil as an answer to energy saving and flow improvements[67,68]. When reducing drag using surfactants found through his experimental work on pipe flow using a dilute solution of cetyl trimentol ammonium bromide (CTAB) with 508 ppm, it was observed that the drag reduction in the large diameter pipe was greater than the diameter[69]. The smallest, at a finite value of the flow, the Reynolds number ends due to the deterioration that occurred as a result of oxidation after a period of several days[70]. Dioctates in their investigation used aluminum in toluene as a drag reducer. They showed that the method of preparing a disoap solution has a severe effect on the flow behavior[71]. They found that the structure of the solution is temporarily split by a very high shear. They noted that the losses due to friction would be lower as the concentration of aluminum dioctates increased[72]. Where he conducted his investigation using a number of non-ionic surfactants for linear primary alcohol in aqueous solution. The effects of surface actor structure, temperature, concentration and mechanical degradation have been studied on drag reduction. The most effective surfactants were additives that reduced drag. All surfactants used have been found to be possible for repair, i.e. after mechanical decomposition they can regain their ability to reduce drag when they reach an area with low shear forces[73]. The towing effects on drag reduction are similar to those observed in high polymer solutions (% increases Dr by reducing pipe diameter) [74]. Different types of cationic surfactants are used as cloud reduction agents (ammonium chloride trimethyl ethyl (CTAC), trimethyl ammonium lipolysalicylate (TTAS), aero ethyl triethylammonium salicylate (ETAS), and trimethyl ammonium chloride (STAC) [75]. The closed-loop flow and heat transfer device has been used to measure clouds and to reduce heat transfer in turbulent pipe flow [76]. They concluded that the variety of different types of surfactants used was effective. High in reducing both drag and heat transfer in turbulent pipe flow. It has been proven that surfactants simultaneously reduce the friction of pipe flow and the individual heat transfer coefficient from pure water and that surfactants have a critical temperature and have a Reynolds number above which the heat transfer coefficient and friction of pipe flow return to water [77]. The percentage of cloud reduction increased by increasing the concentrations of surfactants from 50 to 500 ppm.[78,79]**.** The surfactant effect (Habon G 530 ppm aqueous solution) on the wall disturbance structure has been experimentally investigated [80]. In order to prove that the drag reduction in their work exceeds the predictions of the maximum drag reduction Virk using the surfactant Habon G [C16H33N (CH3) 2C2H4OH] + consists of 53.5% active surfactant, 10.2% isopropanol, and 36.3% water [81]. The average speed of the flexible sublayer was the sharpest of Virk's proposed features of near-maximum drag reduction solutions. They concluded that surfactant solutions could reduce turbulent friction loss more than the Virk maximum drag reduction approach suggested in the use of polymers. It was also shown that the turbulence intensity of the surfactant system to reduce drag decreases by 25% to 35% from that of pure water. [82] When studied shear and drag reduction and studied the measurement of expansion rheometers in cationic aqueous surfactants. Cryo-TEM has been used to show the image and size of the surfactant solvency [83]. Argued 16-50, with three similar concentrations, 2-, 3, or 4-chlorobenzoate at 12.5 molar has been used as a withdrawal reducer. Each isomer showed a variety of different types of rheological and different micelle structures. 2 [84]. The chlorine system has shown no low drag reduction, low outward existential viscosity, and only spherical microlar. The 3-chloro system has shown excellent drag reduction ability by a maximum of 50% Dr. The 4-chloro system explained an excellent withdrawal reducer with a maximum of %Dr up to 70% [85]. High-definition elongated viscosity has been obtained, and a thread-like Meckler mesh has been obtained[86]. The effects of positive surfactant mixtures on reducing streamlined behavior and drag have been experimentally proven[87]. Cationic alkaline trimethylammonium (IV) surfactants have been blended with an alkyl chain length from C12 to C22 in varying molar ratios [88,89]. A variety of surfactants, three anionic surfactants, and non-ionic surfactants have been tested as drag attenuators in the flow of turbulent oil pipelines in Iraq within three pipe diameters ranging from 0.5, 1, and 3 inches [90][62].The researcher was able to reach the fact that the withdrawal rate decreases with high concentration of the active substance on the surface (within certain limits) and the flow rate of the solution. and the diameter of the crude oil transport pipeline. The maximum extraction rate was achieved using SDBS, which was 56.5% at a concentration of 200 ppm. Experiments were conducted to verify and confirm that four different types of anionic surfactants (SDBS, SLS, SLES, SS), all of which reduce drag agents with refining products such as gas oil and kerosene, in different concentrations (50-300 ppm [91]. Three closed flow loop systems (1.91, 2.54, and 5.08 cm) tube diameters were used in his experimental work. The researcher found that the process of reducing drag increases by increasing the surfactant concentration and flow rate (Reynolds number) and by decreasing the diameter of the oil transport pipe. The maximum of 53% of the Dr was reached using 300 (ppm) of (SDBS), which is dissolved in gas oil flowing through a 1.91 cm defined tube. The maximum of 48% was reached using 300 ppm of SLES, which is dissolved in kerosene flowing through a 1.91 cm knowledge tube. It was observed that the four anionic surfactants used had no clear effect on the apparent physical properties of both gas oil and kerosene. The researcher concluded that the reduction of drag occurs when the molecules of the surfactant form a kind of molecular lattice structure[92]. These structures extend when subjected to high shear, which increases their effective viscosity, leads to the suppression of smaller vortices, and reduces their ability to absorb energy from the average flow[93]. Drag reduction measurements in oil and gas alloy flow are presented in two stages in their study. Two types of oils with different viscosities were clearly examined in horizontal tubes with an inner diameter of 10 cm in order to evaluate the effect of oil viscosity on total pressure loss and the effectiveness of drag reduction factors (DRAs) in reducing pressure drop in slug flow [94][95]. The total pressure drop in 50cp oil was more significant than in 2.5cp oil, in particular when the flow rate of the gas increased. However, they noted that DRA was more effective in reducing the overall pressure drop in 2.5cp oil plus, the higher oil velocity, and therefore the higher oil volume fraction, has increased the DRA effect of both liquids [96] **.**The effect of two surfactants (sodium dodecyl benzene sulfonate (SDBS) and sodium lauryl sulfate (SLS)) in crude oil was studied using a closed-loop system for three pipes of different diameters (0.75, 1, and 1.5 inches) of 2 meters each and three different temperatures (30°C, 40°C and 50°C) was used [62]. The concentrations of each of the surfactants used range from 50 to 300 ppm. The final results showed that the greatest reduction in clouds (% DR) was 23.67% (flow increase was 16%). This value is obtained when 200 ppm of SDBS is added at 30°C. The high viscosity of crude oil as the dominant transport fluid property poses great challenges in the production and refining of crude oil in refineries and before its transport through wells and pipelines [48][97][49] . Friction on the wall, viscous drag, and pressure drop in the pipeline are much greater in heavy crude oil when compared to conventional light crude oil. The drag effect is caused by pressures on the wall due to fluid shear, resulting in low fluid pressure [7][98,99]. This makes it very difficult to pump oil over long distances[100,101]. For this, drag reduction is a basic annular flow-based lubrication technique in order to reduce pressure in transporting heavy crude oil by pipelines[7][99,102]. Commonly used friction reduction techniques include enhanced pipeline transport of heavy crude oil through additives that reduce drag and improve basic loop flow [103].

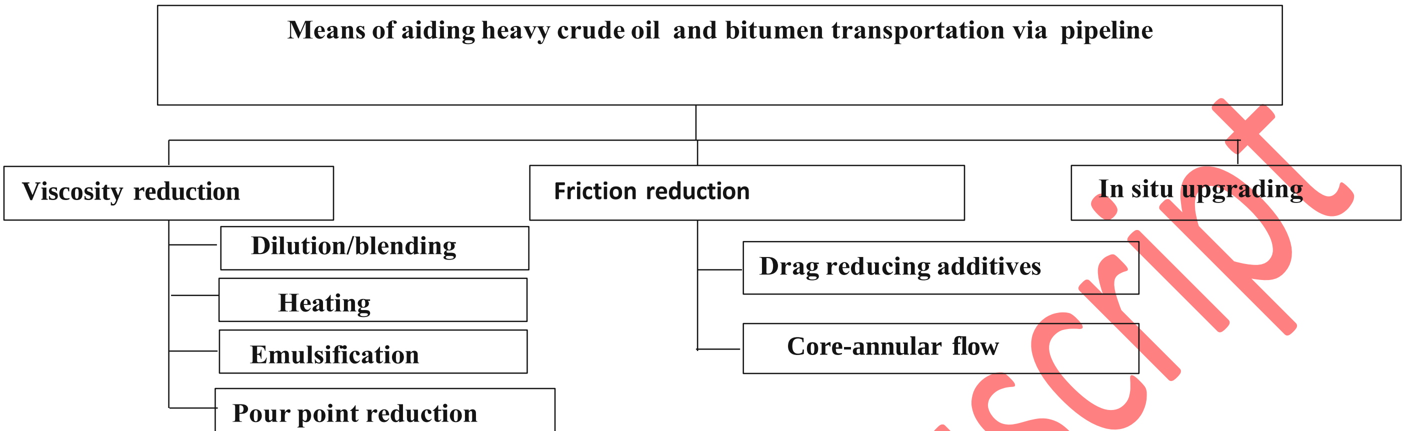


Figure 9. Methods for improving the flow of heavy crude oil through pipelines.[103][7]

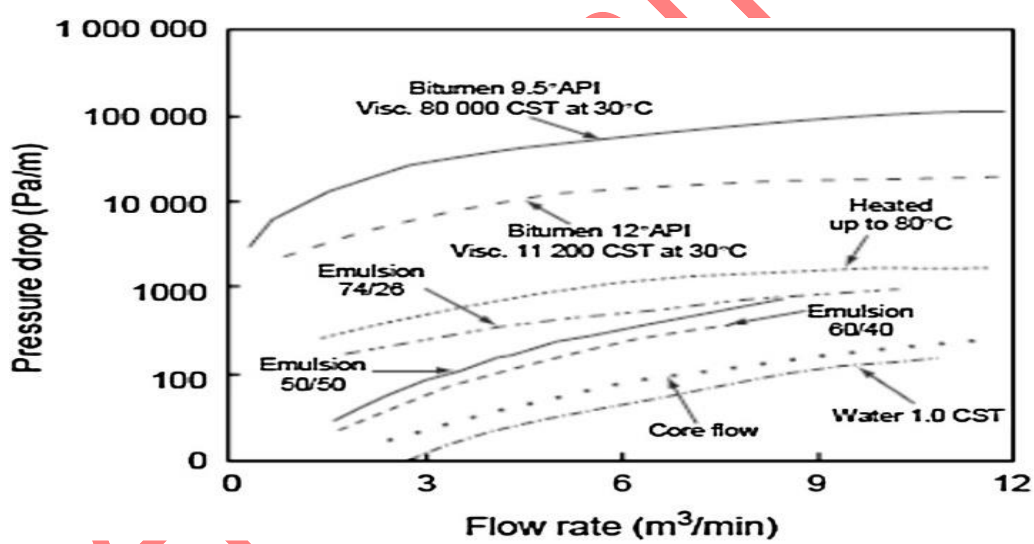


Figure 10. (ΔP Vs Q) of various heavy crude oil transport mechanisms[104]

2.2 Viscosity reduction

One way to reduce the viscosity value of heavy oils is by mixing with hydrocarbons that are less viscous and dense, such as condensate, naphtha, kerosene, or light oil. The process is called dilution[48]. In order to reach acceptable and economical limits for transportation, it is necessary to have up to 30% of the attenuators by volume, which means a large capacity of oil transport pipelines [105]. A problem that may also arise is the availability of diluents [62]. The dilution process may be a suitable solution for transporting heavy oil, but this process requires a significant investment to install an additional return pipeline[106]. that condensate was used until the end of the eighties in order to transport the full production of Canadian crude oils[107]. According to forecasts and calculations made at the end of the eighties and have since been confirmed [108], it has been predicted that condensate production will not be capable of meeting the market demands because demand is definitively linked to the development of heavy oil production [109]. It is important to know that condensate is a poor solvent for asphaltene. One of the influential problems is the formation of asphaltene deposits that partially clog the lines [110], Light oils were used in the range of 35° to 42 API in order to reduce the viscosity of heavy crude oil[48][111]. All this leads to a significant rise in the volume of effluent, leading to additional capacity for crude oil pipelines [112,113]. As for condensate, the supply of light oils may fluctuate, and their use as a diluent may be limited, as this will reduce the light from the oil for the refinery supply. Finally, due to their high saturated content, some light oils are weak asphaltene solvents and, like condensate, can catalyze asphaltene deposits[114,115]. examined alcohols in particular pentanol for reducing heavy oil viscosity at least twice as much as kerosene[116,117,118]. The hydrocarbons selected in the study are nonane and naphtha. It has been noted that for naphtha, the relative viscosity of diluted oil is greater than nonane due to its aromatic content, where naphtha is a good solvent for asphaltene[119]. On the contrary, nonane is known to be a bad solvent for asphaltene [120].

2.2.2 Dilution

It is known that the prices of heavy crude oil are low due to its high viscosity, with the difficulty of transporting and refining it, and all this makes the process of transportation, processing, and refining difficult and expensive[121,122]. Therefore, the dilution method is one of the first and most popular methods for reducing the viscosity of heavy oils.[123,124]. This method (mitigation method) encounters some problems, making it less attractive. Because of the great need to extract crude oil from the ground, it requires large expenses in order to access the oil reservoirs and the expenses of drilling and completion, and then the expenses of surface treatment transportation and refining expenses, and can not benefit from heavy crude oil unless it is refined and converted into useful and precious light products[49]But the process of delivering it to refineries is a great challenge because of the viscosity and high density of heavy oil[117], which requires energy and pumping large and many and thus to the costs economically. Therefore, diluting heavy crude oil by adding a low-viscosity diluent is one of the solutions used [125]. This attenuator is usually a very light gas condenser (C5+ or "Pentane Plus") or any light, low-viscosity hydrocarbon[126,127]. When using thinners to improve transport, there are two main methods that do this: the first is that the diluent is reused, and the second is that it is not reused[128,129]. In both cases, a larger diameter of the transmission pipeline is needed, as a large suspension will be imposed by the attenuator[130,131].

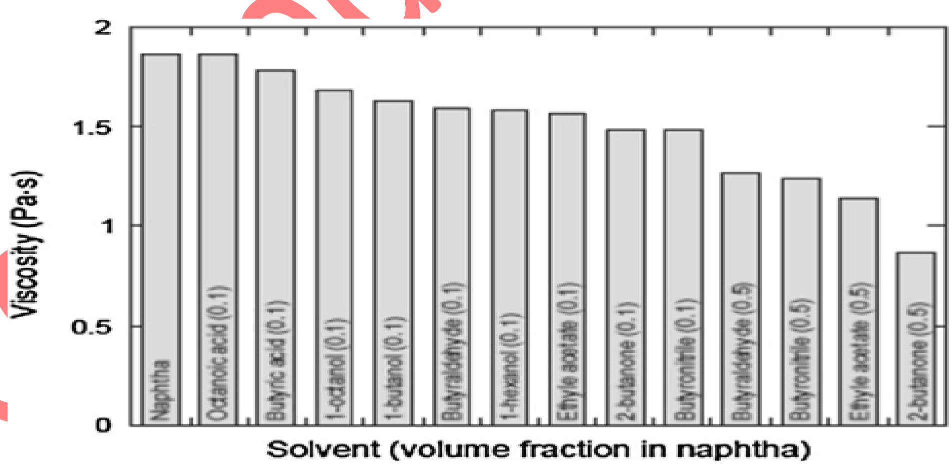


Figure 11. The relationship between the effect of adding solvents to crude oil and viscosity values[132]

2-2-3. Summary of previous experiments

Table 3. Summary of previous studies on the effect of solvents on the flow of heavy crude oil.

Authors	Additives	Objectives	Additives concentrations	Summary of main results
Y. Wen; A. Kantzas (2006)[133]	Kerosene, toluene, naphtha, heptane, hexane, and pentane	Reduce **Viscosity**	Kerosene, toluene, naphtha, heptane, hexane, and pentane were added to the oils in several predefined mass fractions: 100% oil, 99%, 96%, 93%, 90%, 85%, 80%, 70%, 50%, 30%, and 0% (100% solvent)	It is known that if the viscosity is high, it causes great concern in the methods of heavy oil extraction and production. Therefore, the viscosity should be reduced in order to complete the transfer process, and μ can be reduced via mixing bitumen and heavy oil with solvents. This study aimed to reduce viscosity by using multiple solvents, all of which achieved the objectives of the study, with differentiation in results from one solvent to another.
Peng Luo et al. (2007[134])	propane solubilities	upgraded heavy oils	7.0 – 14.0 wt%	In this research study, laboratory experiments were conducted to dissolve improved solvents in heavy crude oil developed in situ. Starting with three types of heavy oils with different asphaltene contents.
Pradeep Ananth Govind et al. (2008)[135]	Solvent SAGD	Enhance oil recovery	1:10 and 1:15	The study presented the results of a simulation. It was done to verify and confirm important aspects of the ES-SAGD process. In the ES-SAGD process, a solvent is added to the injected steam which remains in the steam phase in the SAGD steam room, condensing along the walls of the steam chamber.
Samane Moghadam et al. (2009)[136]	solvent vapour extraction (VAPEX)	heavy oil recovery	16.9 wt.%	In this study, a major development of a model for predicting cumulative heavy oil production was undertaken in the entire VAPEX process. In the study, a total of five VAPEX tests were

				performed to recover a sample of heavy crude oil from a rectangular optophysical model packed with high-pressure sand, measuring cumulative heavy oil production against time data.
Guo Jixiang, et al. (2010)[137]	$C_3H_6O_2$, $C_{22}H_{45}$, CH=CH(O)2O, and styrene	The aim of the study is to reduce the high viscosity of heavy oil.	3:2:2 $C_3H_6O_2$, $C_{22}H_{45}$, CH=CH(O)2O, and styrene respectively	In this paper, the viscosity drop rate was 95.5% at 50°C. The IR spectra and intertensions of heavy crude oil without and with a "viscosity reducer" were examined to understand the mechanism of viscosity reduction.
V. Pathak, et al. (2011)[138]	Butane and propene	Heavy oil and bitumen recovery	1:12 -1:20	In this work, experiments have been done for Study of solvent performance at high temperatures for heavy oil and bitumen recovery.
Mohammad Kariznovi, et al. (2012)[139]	Methane and Ethane	Phase Behavior and Viscosity Measurements of Heavy Crude Oi	15.0 -17.0 wt%	In this study, laboratory results suggest that reductions in saturated density and viscosity with pressure under high-temperature conditions were not as important as those at the lower temperatures of both solvents. However, the balancing time has been significantly reduced, and the application of these processes in the field has become practical.
Hamad Motahhari, et al. (2013)[140]	Solvent-Diluted	Improved and Enhanced Recovery	15 to30 wt%	In this paper, the model is synthesized for data of dead oils, and condensate with average relative deviations of less than 11%.
Hussein Qasim Hussein and Saja Abdul-wahhab Mohammad (2014)[141]	polar solvents (toluene, methanol, mix xylenes and reformate)	The effect of the solvents (toluene, ethanol, mix xylenes and reformate) for transportation of heavy crude oil	12 wt.% solvent and 0.5-1 wt.% dispersant concentration	In this work, it has been studied to transport of oil east of Baghdad by adding polar solvents (toluene, methanol, xylene mixture, and rehabilitation)

				The results showed that the viscosity decreased with increasing solvent concentration, so that the viscosity decreased.
Akbar Mohammadi Doust et al. (2015)[142]	Solvent presence ultrasound advances.	µ reduction	1:3 solvent from fuel oil	The maximum decrease in the value of the wife has been obtained at 133 ° C, in ultrasound irradiation time 5 minutes, Temperature 50°C Loading acetonitrile 5% by volume.
Faris, H.A., Sami, N.A., 2015[143]	Naphtha and toluene	drag reducing	10 wt.% (naphtha) and (toluene).	The effect of additive, its type and concentration, the effect of the inner diameter of the pipe, the effect of the oil flow rate, and the effect of heating, all must be taken into consideration when reducing the draught value (%Dr).
Amir Hossein Saeedi Dehaghani et al (2016)[118]	Naphtha, heptane, methanol, toluene, and gas condensate.	viscosity reduction	Add 4, 8 or 12 vol.% from solvent.	In this work, viscosity values were calculated after using a method of mixing various solvents at different temperatures. The study showed that the effect of solvents is greater as their concentration increases. The study also demonstrated that increasing the concentration of the gas condensate leads to better results in reducing viscosity.
Fuxin Yang et al.(2017)[144]	organic solvents	lowering the viscosity of oil	Add 1:3 solvent	This study has shown that viscosity drops significantly even when there is a small amount of solvent.
Sherif Fakhe et al (2018)[145]	Hydrocarbon Soluble Low Molecular Weight	Improving oil productivity and transportation	added with 5, 10, and 20 wt% to the crude oil.	It has been found that crude oil contains 5.73% by weight of asphaltene, which is a clear indication that the oil is heavy.
Jimoon Kang et al.(2018)[146]	supercritical methanol	Upgrading of heavy oil	1:1 supercritical methanol	In this work, a more saturated, less aromatic cMeOH resin was used in

				the upgrading process. It was found that the higher the temperature, the faster the upgrading process.
G I Volkova et al (2019)[147]	alkaline solution of isobutyl alcohol	Viscosity reduction using high-sonic treatment in the presence of solvent.	1.75% wt alkaline solution of isobutyl alcoho	In this study, it was shown that the introduction of an alkaline solution by weight of 1.75% isobutyl alcohol resulted in a 35%. And that after complex treatment, one-minute sound exposure and the addition of the reagent – the viscosity was reduced by 60%.
Rana Abbas Azeez et al (2020)[148]	Using Organic Solvents	Organic Solvents to reduction µ	solvents with different weight fraction (0, 5, 10 and 15 wt. %) at 298.15 K. The heavy oil.	This study discussed the fact that high viscosity increases the trouble in transporting and producing pipes from the tank; so this study focused on the dilution method to reduce the viscosity of heavy crude oil using toluene, dimethyl ketone (DMK)
Manigandan Sekar et al (2020)[149]	Naphtha, kerosene with (silica nanoparticles)	The effect of the solvent and nanoparticle on reducing the viscosity of oil.	5-15 wt.% solvent and 500, 1000, 2000, and 10000 ppm from silica nanoparticles	This study examines a blending and emulsification method for reducing viscosity. The addition of silica nanoparticles to naphtha and kerosene increases the solvent's performance in the upgrading process by 80%–90%.
Firas K. Al-Zuhairi et al. (2020)[150]	using Different Organic Solvents	Viscosity Reduction of Heavy Crude Oil	5, 10 and 20 wt.% of (nheptane, toluene, and a mixture of different ratio toluene/n-Heptane)	In this work, the reduction of µ predicate was DVR and the optimization accuracy was 98.7%, on the other hand, the µ and DVR factors were closer to the ANN model unit.
Ali Nasir Khalaf et al (2021)[151]	Naphtha and Kerosene additive	Improvement of flow Ability of Heavy Crude Oil	(3-12) wt.%	In this work, experimental results demonstrated that naphtha solvent achieved a 40% reduction in viscosity. This is considered a good result, but for some heavy and high-viscosity types, nanoparticles may be

				required to further improve the performance.
Soleimani, Ali et al (2021)[152]	Dilution (kerosene) using.	Additive kerosene and toluene in order to reduce µ	5-30% v/v in 25°C	In this research paper, a dilution method was studied to reduce the viscosity of one of Iran's oil fields, the Nowruz field, which has a high viscosity and high density. Kerosene, diesel, and toluene were used in this research, with solvent ratios ranging from 5% to 30%. The study demonstrated that the higher the solvent used, the better the improvement results.
Noor I. Jalal et al (2022)[114]	Using Dilution (acetone)	Improve flow and reduce viscosity	20 wt. % of aceton	In this study, the viscosity reduction was about 21.98% when 20% acetone was added by weight. When the effect of the electric field was studied, a decrease in viscosity of 35.6% was observed when applying 36.67 (volume/cm). The effect of the composite treatment – dilution and electric field – was investigated and confirmed according to the factor design. The optimum viscosity reduction was about 61.856% at 11 wt.% of acetone and 36.67 (volume/cm) of the electric field.
Eman M. Saasaa et al (2022)[153]	naphtha & toluene, naphtha & xylene, naphtha & kerosene	Effect additive of of low molecular weight hydrocarbon compounds to heavy crude oil.	Additive : (4, 8, and 12 weight%) and temperatures 15, 25, 35, and 45 °C	In this study, it was found that increasing the concentration of naphtha with xylene from 4% to 12% leads to a clear decrease in viscosity from 48.62 cp at 15 °C to 30.11 cp. The viscosity of the naphtha and kerosene mixture decreases from 50.15 cp at 15 °C to 31.70 cp when the concentration increases from 4% to 12%.

				Adding toluene to kerosene causes viscosity to decrease from 51.76 cp at 15 °C to 33.67 cp when the toluene concentration rises from 4% to 12%. The rise in xylene concentration from 4% to 12% in kerosene this resulted in a significant decrease in viscosity.
Sandeep Badoga, et al. (2023)[154]	toluene, dichloromethane, ethyl acetate, and n-pentane	μ reduction	21.8- 54.3 wt.%	In this study, two diverse technical approaches were explored to upgrade bio-crude oil produced by hydrothermal liquefaction of forest debris, to the level and extent where it becomes compatible with co-processing in an oil refinery.. The first approach consisted of using solvents.
Adan Y. Le´ on et al. (2024)[155]	Using Naphtha	upgrading of heavy crude oil	3–9 wt.% naphtha	The experiments of this study demonstrate the effect of adding naphtha on the viscosity of crude oil, as it decreased at different rates depending on the temperature. The decrease ranged between: (25% and 51%), and between (36% and 58%) at temperatures between: (270 and 300°C, for 66 hours). And at a rate ranging between (20% and 30% at a temperature of 270°C, for 66 hours).
Jafar Qajar et al (2024)[156]	Solvent treatment (Toluene and n-heptane)	Improving poor quality oils	Add 1:5, 1:7, 1:10 solvent to crude oil	In this study, toluene and n-heptane were used, which represent aromatic solvents and paraffinic. Viscosity measurements and infrared spectroscopy tests were performed to convert Fourier to solvent-diluted supersized crude oil and solvent-diluted sonication crude oil. The results for untreated and separately processed crude oil samples have been

				compared. The study showed that the most effective way to reduce viscosity involved mixing monistic oil with toluene under optimal irradiation time and concentration conditions.
Ming Zhang et al. (2025)[157]	SAGD	Improving poor quality oils	3.29 to 35.04 wt.%	Projects using solvent concentrations ≥1% by weight produce more acceptable and realistic results, but in many cases, a higher solvent concentration is required to achieve optimal results. Therefore, balancing optimal treatment results with the appropriate solvent quantity is important.

2.2.4 Emulsions

Emulsions occur naturally in oil production and pipe lining, mainly those in water-in-oil and are more complex than oil-in-water emulsions in oil (O/W/O). Figure 12 [158]. All these emulsions mentioned are harmful to oil production because the μ of oil rises, with the increase in corrosion problems, and also, it is difficult to break them in desalination and drying units before refining. Nevertheless, emulsions can be used as a method of transporting heavy or very heavy crude oil, and dispersion of (O/W) or in "brine" may be a substitute method for transporting highly viscous crude through pipelines in order to reduce viscosity [159].

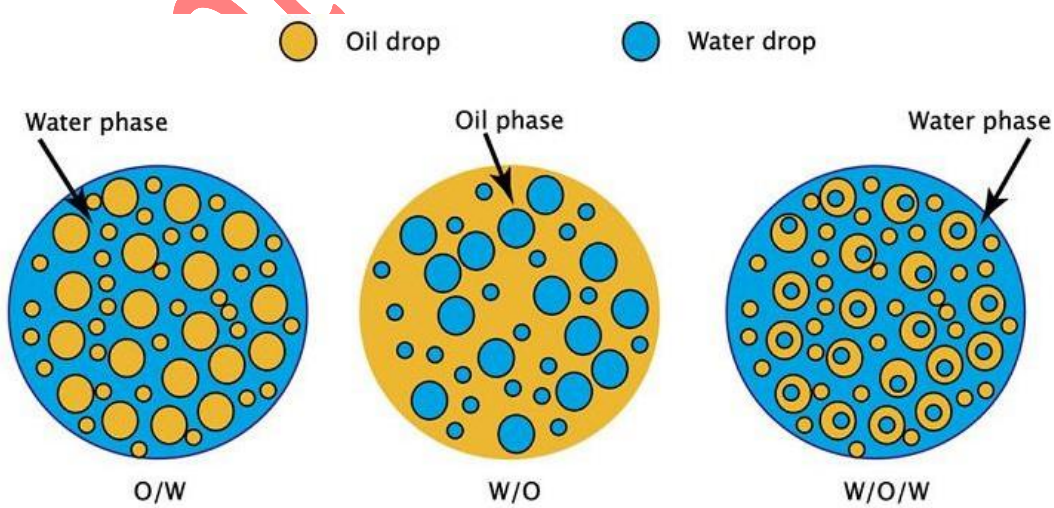


Figure 12: Various emulsions used in the transport of heavy crude oil [160].

O/W dispersion emulsion is a mixture of two miscible fluids where the crude oil phase is dispersed in the continuous phase of water as in Figure 11 [161]. This method may be more suitable for use than the mitigation method in some locations, because hydrocarbon or lighter crude diluents may not be available on-site, while freshwater, seawater, or even formation water may be available to disperse crude oil. O/W Emulsions are often produced intentionally to reduce the viscosity of high-viscosity crude oils so that they can be easily transported through pipelines.[162]. The O/W emulsion reduces the viscosity of heavy crude oils and bitumen and may be a successful alternative to the use of attenuators or heat to reduce viscosity in pipelines [163].

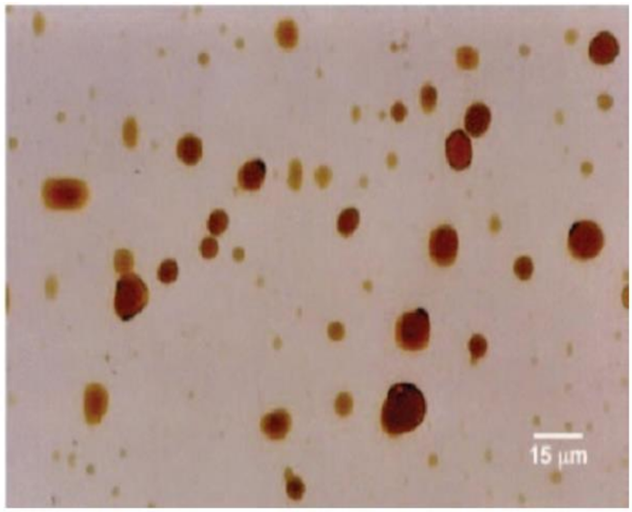


Figure 13 . (O/W) Photomicrograph [164].

O/W emulsions can be formed by adding specific concentrations of surfactants, and it is considered an effective and beneficial method for reducing the viscosity of heavy crude oil.[165]. In the emulsification process, the heavy crude oil is transferred in the form of fine oil droplets in the aqueous phase.[161]. In order to ensure the stability of the emulsion during the transport pipeline, it is necessary to add surfactants in order to reduce the interstitial tension of the oil, and at other times additional substances are added as stabilizers to avoid phase separation. In general, non-ionic surfactants are a useful option because they are not affected by water salinity, are relatively cheap[166,167].

2.2.5 Main Annular flow

In the transmission system the pumping pressure necessary for the current generated by lubrication can be equivalent to the pressure of the liquid alone by means of a liquid layer covering the base of the oil, acting as a lubricant[168,169]. The main problem with some transport designs is that crude oil continues to adhere to the wall of the pipe and thus blocks the flow mechanism[63]. During the shutdown process which stratifies the oil and water phases, requiring a significant restart, it is possible that the pressures exacerbate this type of difficulty . There are other methods available to enable the transport of heavy oils, for example, oxidation and travel reduction[123][170].

2.3 Friction reduction

Blending with hydrocarbons is considered less viscous than condensate, kerosene, naphtha, or light crude, and this process is known as dilution [171]. In order to have acceptable limits for the transportation of crude oil, it is very necessary to have a fraction of up to 30% of the attenuators by volume, which means a large capacity of the transport pipelines[172]. New problems may arise regarding the availability of boosters (Crandall et al, 1984) [53]. Mitigation can be a suitable and good solution for transporting heavy crude oil, but it needs significant investment in order to install an additional return pipeline[49]. Several studies have shown that condensate was used until the end of the eighties to transport almost complete production of Canadian crude oil[173]. The condensate is a type of oil that is considered very light, and obtaining it occurs through the production of natural gas by separating the lighter phase. Condensates are, unfortunately, poor solvents for asphalt; this is because asphalt deposits may form that partially obstruct the pipelines.[174,175]. In addition, condensate is a poor solvent for asphalting. Asphaltene deposits may form so that they partially block the lines[176]. Light oils are used in the 35° to 42°API range to reduce oil viscosity, although up to twice the volume of light oil compared to condensate may be required to provide the same viscosity reduction[48]. This leads to a significant rise in the volume of effluent, causing additional capacity for transport pipelines[177]. As for condensate, light oil supplies may fluctuate, and the use of attenuators may be limited, as this will result in less light oil for refinery supplies. Finally, due to their high saturated content, some light oils are weak solvents for asphaltene and, like condensate, can catalyze asphaltene deposits[113]. It has been proven in research and laboratory experiments that methyl acid (MTBE) and triethyl methyl ether (TAME) can be used as alternative diluents to heavy oils[178]. An exponential relationship has been found between the resulting viscosity of the mixture and the volumetric fraction of the dilution, making dilution a highly effective and efficient method[118]. Alcohols, especially ethanol, have been studied to reduce the viscosity of heavy crude oil by at least twice the amount of kerosene [179]. Simple organic solvents (heptane, toluene,...) are used, which are not descriptive of heavy and complex crude oil (from 0 to 20% by weight)[116]. All these results contribute to the knowledge of the characteristics and specifications of the flow of heavy crude oil and are intended to contribute to and participate in the improvement of its transportation[117]. Many low-viscosity hydrocarbons have been used as dilutors for heavy oils, in particular naphtha and kerosene. For tests containing attenuators, 4 attenuation rates "5, 10, 15, and 20%" weight and 5 temperatures "3, 20, 40, 60, and 80 ° C" were tested for each attenuator[180]. Other hydrocarbons, such as nonane and naphtha, have also been used. For naphtha, the relative viscosity of diluted oil is greater than that of nonane[181]. Due to its aromatic content, naphtha is a good solvent for asphalting. On the contrary, nonane is known to be a bad solvent for asphalt[182]. The pressure drop encountered in transporting heavy oils through transmission pipelines is more severe when transported over long distances. So, reducing the withdrawal by including a chemical addition becomes a suitable option. Heavy crude oil is transported through pipelines, and the system for flow is often turbulent. In addition, high friction loss due to high viscosity causes waste and loss of much energy used for transporting heavy crude oil[183]. High drag in turbulent flow occurs due to radial transmission of flow momentum by fluid vortices[185,186]. The reduction of polymer clouds was discovered a few decades ago by Toms (1948), who observed a decrease in the withdrawal value by 30-40% when the polymer[187,188] (methyl methacrylate) was added to the disturbed chlorobenzene flowing through the transport pipeline[189,190]. In this regard, additives contribute and help reduce friction near the walls of transport pipelines and inside the turbulent liquid core of the moving fluid. Technology has evolved over the years. Even the classification of drag reduction additives into three categories: polymers, fibers, and surfactants[191,192,193]. Hence, drag decrease is an oiling procedure that relies on the main annulated flow in order to decrease the pressure in transporting heavy crude oil through transport pipelines[194]. Widespread and well-known friction reduction technologies aim to augment the transport of dense oil through complete pipelines by means of additives that reduce intake and basic annular flow[195]. Equally, techniques decrease flow drag through changing speed range, for example, inhibiting stormy oscillation in the wall area near the transmission pipeline while the flow in the heavy crude oil pipeline is laminated or slightly turbulent with minimal flow resistance based on the significant viscosity effect on flow drag[196,197].

2.4 Pour point reduction

The collection and precipitation of large Valentine particles in petroleum contribute significantly to its density and great speed, making heavy crude oil extremely difficult to flow in transport pipelines[198]. Then, destroying or preventing this result via the use of pouring point inhibitors will help to enhance the properties and specifications of heavy oil flow[199]. Oil casting is the lowest degree at which it stops flowing due to the loss of flow properties[200]. For example, it is hard to pass through pipelines for heavy crude oil and wax in cold climates. because of the low temperature reasons the growth of crystals prevents oil molecules from flowing. Crystallization depends on the climate, the arrangement of oil, the temperature, and pressure during transport of heavy oils[201]. It is known that there are many ways to reduce the cause of wax and valeting deposition, and the use of polymer inhibitors is an important and appropriate alternative[202,203]. adding together of copolymers, for instance " polyacrylates, polymethacrylate, co-ethylene acetate, methacrylate, etc". all prevent sedimentation and transport stability. It has been found from viscosity measurements that at the temperature at which wax crystals begin to form, the copolymer has shown a significant and very influential effect in reducing viscosity[204,205].

3 Additives to improve heavy oil transportation

There are several methods used to improve the process of transporting heavy oil through pipelines, and one of the important methods used in this is the method of improving transportation by improving the properties of crude oil by adding, where different chemicals are added and from the materials used[206]:

3.1 Nanoparticles

It is scientifically and practically known that a nanoparticle is "a microscopic particle whose size is measured in nanometers, usually limited to so-called nano-sized particles (NSPs; < 100 nanometers in aerodynamic diameter), and their other name: nanoparticles[207][208]. Nanotechnology has been developed in the last and recent years to include applications on the oil industry to inhibit composition damage[209].Upgrading heavy oil and ultra-heavy oil, improving oil recovery processes (IOR)[210], Emproving oil recovery (EOR), due to the fact that particle sizes, between 1 and 100 nm, the large surface area available, the large dispersion and the adjustable chemical and physical qualities and properties[211], the nanoparticles are predisposed and able to selectively absorb asphaltene and inhibit their self-bonding. In a previous research and study[212]. The research group focused on the use of silica, alumina and magnetite nanoparticles to prevent asphaltene accumulation under varying temperatures and solvent ratios with varying asphaltene concentration[213]. Hence, the characterization of nanoparticles is of very great importance to understand the role of particles in reducing the viscosity of heavy crude oil and very heavy oil[214]. The size of the nanoparticles is a key parameter that is important to consider when considering these materials for in situ application[215]. It is important to ensure that the materials available for injection into reservoirs meet size constraints in order to ensure that the nanoparticles do not cause further damage to the reservoir due to pore or throat bridge or blockage[216]. According to the principles of the arc from the third to the seventh, it is possible that the particle size of the bridge/blockage is shared as follows: i) particles larger than 1/3 of the pore size are prone to generating pore blocking, b) particles in the range 1/7 - 1/3 of the pore size will generate a bridge in the throat of the pores that will generate a blockage of the pores and c) particles whose sizes are less than 1/7 of the pore size are able to pass through the pores of the throat. Most nanotechnology publications in the oil and gas industry are reports of laboratory experiments [217]. Therefore, there is a need for more field trials for further advances in nanotechnology in the oil industry. While nanoparticles are not cheap but expensive, the cost would be appropriate if the lowest possible concentrations of nanoparticles were used at an appropriate performance level[218]. More studies are needed to improve nanotechnology research in the near future. In order to obtain less expensive, more efficient and environmentally friendly oil extraction methods, most NPs used are considered environmentally friendly when compared to chemicals, which are usually expensive, with potential damage caused by chemicals in their preparation and use [219] for example, silicon dioxide is the most important component of silicon nanoparticles in short, NP is effective and environmentally friendly . Large-scale nanoparticles such as TiO_2, SiO_2 and Al_2O_3 at 1-100 nm are less than pores, and in other sizes[220]. It is possible to easily flow through porous media until they become trapped without reducing extreme permeability as a result of the small size of the particles, the ratio between surface to size is considered very high. A large area raises the atomic percentage on the surface of the pulp and the nuclear ratio of the core on the nanoparticles is very large[221]. Figure (12) shows the definition of the expanded layer with low particle size. Due to the special and exceptional properties of nanoparticles, such as large surface area and catalytic properties depending on size and shape, nanoparticles can also be used as adsorbents and/or catalysts to dissolve the reservoir[222]. Multiple nanoparticles have been incorporated onto the substrate for the first time by adsorption and eventual catalytic pyrolysis of asphaltene[223]. The kinetics and thermodynamics of asphalt absorption of nanoparticles α-Al_2O_3 have been confirmed and investigated through his previous study [224]. The author explained that adsorption was achieved quickly in less than two hours when adsorption scales were achieved. This was the result of the non-porous nature of the material that dominates the external adsorption. A number of studies have been carried out on the absorption of n-C7 asphalt extracted from Colombian crude oil recently[225] using NiO nanoparticles supported by silica and alumina nanoparticles. The adsorption and equilibrium period of choices was very few. The authors have discovered that nanoparticles are strong in adsorption efficiency[226]. As a result of the small size of the nanoparticles and the large area per unit size of them, which gave them unique properties, and therefore they are more responsive to other molecules, which are the most serious challenges to chemical processes [227].

It is the clogging of pores and also the injection of trapped chemicals into porous media, which leads to a decrease in the permeability of the composition and leads to increased injection costs [228][229].

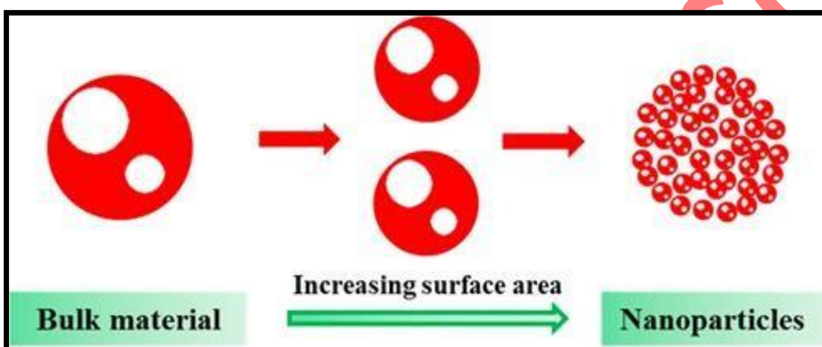


Figure 14: Represents the diagram of the high surface-to-size ratio of nanoparticles (NPs), [230].

The common name for silicon dioxide is silica, and by its nature it is in the form of quartz and sand, silica nanoparticles contain silicon and oxygen, a chemical compound with a SiO_2 composition [231][232]. Laboratory studies have been carried out in oil recovery from light and moderate oil reserves [233] in order to determine and examine the effectiveness of modified silica Nano plastics. The calculation of the optimal concentration of nanofluid for the injection stage has been done for all studies with interfacial stress measurements[234]. They note that Nano silica reduces interfacial stress, then separation is achieved [235].

3-1-1 Summary of previous experiments

Table 4. Summary of previous experiments on the streamlined behavior of heavy crude oil by adding nanoparticle.

Authors	Additives	Objectives	Additives concentrations	Summary of main results
Maher Al-Jabari, et al. (2007)[236]	Fe_3O_4	Separation of Asphaltenes from Heavy Oil	10 g/L	In this study, nanoparticle absorption and magnetic separation were combined in order to remove asphaltene from heavy crude oil by adsorption on colloidal magnetite, Fe_3O_4, with sizes ranging from 20-30 nm. The adsorption was examined by adding nanoparticles to typical

				solutions prepared from heavy crude oil, consisting of heptane-precipitated asphaltene in toluene.
Stanislav R. Stoyanov, et al. (2008)[237]	Zeolite Nanoparticle	Heavy Oil Upgrading	500-1500 ppm	In this study, the results of its zeolite acidity calculations are excellently consistent with experimental data and other available computational studies. The findings of this study could be useful for further modelling and rational design of catalytic zeolite nanoparticles for heavy crude oil upgrade.
Binshan Ju andTailiang Fan (2009)[238]	SiO2	improve oil recovery and enhance water injection	0.1 wt.%	In this work, two types of polysilicon nanoparticles (PN) were used in oil fields to improve oil recovery and to promote water injection respectively in this work.
Xiangling Kong; Michael M. Ohadi (2010)[239]	Micro and Nano Technologies	Applications of Micro and Nano Technologies in the Oil and Gas Industry	Recent developments in research in areas of significance to the oil and gas industry are briefly reviewed and include two case study examples	Micro and nanotechnologies have already contributed significantly too significant technological advances in many industries, including pharmaceuticals, biomedicine, electronics, materials, manufacturing, aerospace, photography and most recently the energy industries. Micro nanotechnologies have the potential to bring about significant and fundamental changes in many areas of the oil and gas industry, such as exploration, drilling operations, production operations, oil recovery enhancement operations, and refining and distribution operations.
Nashaat N. Nassar et al.(2011)[240]	Fe2O3,Co3O4, and NiO	Heavy Oil Upgrading	100,500,1000-10000 ppm from nanoparticle.	In this work, the calculated optimization process at the temperature of the NiO , Co3O, and Fe3O4 nanoparticles is 37%, 32% and 21% respectively. The strength of the interaction between asphaltene and diverse species of nanoparticles.
Belal J, et al. (2012)[241]	NiO nanoparticles	Adsorption of asphaltenes from heavy oil	2.8 g asphaltene/g nanoparticles	This study has demonstrated that removing asphaltene from heavy crude oil

				improves oil quality and facilitates its processing.
Negahdar Hosseinpour , et al. (2013)[242]	Fe2O3 and ZrO2	toward in Situ Upgrading of Reservoir Oils	2.75 and 12.34 mg of KOH/g,	In this study, the effects of surface acidity and basic metal oxide nanoparticles on thermodynamics for asphaltene absorption were investigated and studied. .
Kewen Li et al. (2014)[243]	carbon nanocatalysts	Upgrading Heavy Crude Oil	0.1 w% of nanoparticle	In this study, the proposed technique has the following advantages: (1) a large percentage of viscosity reduction of more than 96%, (2) a low temperature required, (3) a short reaction time (less than 1 hour), and (4) a long viscosity regression time.
Rohallah Hashemi et al. (2014) [244]	Nanoparticle technology	heavy oil in-situ upgrading and recovery enhancement	The study aims to present nanotechnology techniques and their effect on extraction and properties	Recently, nanotechnology has emerged as an alternative technology for the on-site upgrade and recovery of heavy crude oil. Nanocatysts – nanocatalysts – are one of the important examples of applications of nanotechnology Nanocatalysts exhibit unique catalytic and absorbent properties due to the exceptionally high surface-to-volume ratio and active surface locations.
Abdullah Al-arshed et al (2014)[244]	Nanoparticle technology for heavy oil in-situ upgrading	The effect of the Nanoparticle Iron Oxide of Heavy Oil Upgrading	Adding 0.03−0.4 wt. %.	In this work, the appropriate conditions for interaction with iron oxide dispersed nanoparticles (≤50 nm) have been optimized for on-site catalytic upgrade of heavy crude oil in the following ranges; temperature 355-425°C, reaction time 20-80 minutes, agitation 200-900 rpm, initial hydrogen pressure 10-50 bar, and iron metal load 0.03-0.4 wt.%. Then it was found that the optimal combinations for interaction The factors are: temperature 425°C, initial hydrogen pressure 50 bar, reaction time 60 minutes, agitation 400 rpm, iron and metal load 0.1 by weight %.

Mohsen Rahimi Rad et al. (2014)[245]	multi-wall carbon nanotube (MWCNT) supported Co–Mo	Upgrading extra heavy oil	In both of the synthesized nanocatalysts, the Co/Mo weight ratio was 1/3.	The results of this study indicated that both nanocatalysts were able to break down heavy crude oil under moderate operating conditions. However, nanocatalysts manufactured through two-step impregnation showed greater performance, showed better conversion of heavy crude oil to light crude oil, and better desulfurization than other methods. This superiority is due to the nanocatalyst structure and the better distribution of metal clusters on the support.
Osamah A. Alomai et al. (2015)[246]	nanoparticles—silicon oxide, aluminum oxide, nickel oxide, and titanium oxide	**Enhanced-Heavy-Oil Recovery**	Oil phase: paraffin oil, n-octane, or toluene Oil fraction: 50 %(v/v) C(NP): 0.5 wt.%	In this work, the nanofluid mixed from silicon oxides and aluminium at 0.05% by weight has shown the greatest additional crude oil recovery among other nanofluids. It is expected to be the best type of chemical flood due to its performance in reservoir conditions – high pressure, temperature and water salinity – and its ability to resist asphalt rainfall.
Esteban A. Taborda et al (2016)[9]	nanoparticles/nanofluids on the rheology of heavy crude oil	Effect of nanoparticles/nanofluids on the rheology of heavy crude oil and its mobility	1000- up to10,000 ppm of nanoparticles in the mixture.	In this study, the experimental results indicate that the increase in the concentration of nanoparticles in the mixture reaches 10,000 ppm. Acid silica nanoparticles were used to prepare an aqueous nano liquid at different concentrations in Distilled water, also with the addition of 2.0% by weight of non-ionic surfactant.
Ashley R. Brown et al. (2016)[247]	biogenic nanoscale magnetite (BnM; Fe3O4).	Upgrading of heavy oil	0.1-0.5 w% of nanoparticles	In this work, the catalyst activity has been further enhanced by the simple one-step addition of surface-bound PD to achieve loads of 4.3, 7.1 and 9.5% by wt. This has resulted in a clear and significant decrease in viscosity of up to 99.4% for 9.5% loaded BnM by weight Pd. An increase of 9.5% by weight has been achieved:

				7.8 degrees in API attractiveness with respect to feed oil for 9.5% by weight Pd-BnM, compared to thermal cracking alone (5.3 degrees).
Esteban A. Taborda et al. (2017)[13]	SiO_2, Fe_3O_4, and Al_2O_3	Viscosity Reduction in Heavy Crude Oils	0.1- 0.4 w% of nanoparticles	In this paper, the said model linking the concentration of nanoparticles to the viscosity of the liquid mixture has been successfully validated using empirical data, as evidenced by RSME% values below 10%. The significance of these findings lies in the absence of previous empirical and theoretical data in the open literature showing a significant decrease in the viscosity of heavy crude oil in the presence of nanoparticles.
Luqing Qi et al.(2018) [248]	DMAEMA PNPs exceeds that of DMAEMA homopolymer additives	Reversible Emulsification and Recovery of Heavy Oil	il phase: Canadian heavy oil Oil fraction: 50 %(v/v) C(NP): 0.1 wt.%	This study discussed the possibility of DMAEMA PNPs to stabilize Canadian heavy oil emulsions at concentrations as low as 0.1% by weight and at neutral pH. It has been observed that the performance of DMAEMA PNPs exceeds that of homogeneous DMAEMA additives, and we attribute the reason for this to the larger volume and irreversible absorption of DMAEMA PNPs to the oil/water interface.
Jaber Taheri-Shaki et al (2018)[249]	nanomaterials of Fe, titanium oxide (TO) and super activated carbon (CA)	Effect of nanoparticles/nanomaterial the rheology of heavy crude oil.	with 4 wt.% of each nanoparticle in each step.	In this paper, the effects and efficacy of the nanomaterials of iron, titanium oxide (TO), and superactivated carbon (CA) as catalysts in the process of improving heavy crude oil from the Azadeghan oil field in southwestern Iran using microwave radiation (MW) have been investigated. Radiation of 4% by weight of each nanoparticle at each step.
Dong Lin et al.(2018)[250]	synthesize recyclable magnetic	Improving of heavy crude oil	Viscosity reduced by 85.0 %	Not only does synergy favour the dispersion of Fe3O4 nanoparticles over

	Fe3O4/HZSM-5 catalyst			zeolite, but it also effectively breaks the Csingle bondS bond as well as reduces the percentages of resin and asphaltene. In addition, the designed Fe3O4/zeolite catalyst effectively reduces the viscosity of heavy crude oil by 85.0%. This study sheds new light on the design of highly efficient heterogeneous catalysts for catalytic water pyrolysis.
Luisana Cardona et al. (2018)[251]	NiO- and PdO-Functionalized SiO2 Nanoparticulated	Heavy Oil Upgrading and Enhanced Recovery	0.1 wt % of NiO and PdO nanocrystals, respectively, to improve the catalytic activity of the nanoparticles.	This paper showed that the use of 1.0% by weight of NiO and PdO nanocrystals, respectively, is effective and effective in the improvement process. Rheological measurements also showed that the viscosity value decreased by up to 85% after nanofluid processing during the steam injection process.
Sanaz Tajik et al. (2019)[252]	silica-graphene nanohybrid supported molybdenum disulfide (MoS2	Heavy Oil Upgrading and Enhanced Recovery	0.1-0.5 wt.%	In this work, the effect of catalyst quantity (10% by weight and 20% by weight by weight from MoS2) on the booster in hydrogenation reactions was examined. Graphene silica/MoS2 containing 10% by weight of MoS2 can significantly increase the API attractiveness of crude oil (up to 7.7 degrees) and lower its viscosity by up to 81%.
Rincy Anto, et al. (2020)[253]	Silica and alumina nanoparticles	flow improver of petroleum crudes	500-2000 ppm	It is known that with the current energy scenario, oil companies are beginning to be convinced to exploit the resources of heavy crude oil with high viscosity and extreme chemical composition, which makes the process of its production and transportation very complicated. Therefore, the emergence of anotechnical technology in this aspect may provide a better solution for optimizing production from the subsurface tank as well as

				ensuring flow in surface transport.
Luisana Cardona et al. (2021)[254]	The nanofluids AlNi1 and AlNi1Pd1	xtra-Heavy Crude Oil Upgrading and Oil Recover	The nanofluids AlNi1 and AlNi1Pd1 consist of 500 mg·L−1 of alumina doped with 1.0% in mass fraction of Ni (AlNi1) and alumina doped with 1.0% in mass fraction of Ni and Pd (AlNi1Pd1), respectively, and 1000 mg	In this paper, the process of upgrading heavy crude oil is shown significantly for the AlNi1Pd1 system, which reduces the viscosity of crude oil by 99%, increases the amount of American Petroleum Institute (API) ° from 6.9° to 13.3°, and lowers the asphaltene content by 50% with a quality of 0.5. This study is expected to help understand the appropriate conditions under which nanoparticles must be injected into the steam injection process in order to improve its efficiency in terms of oil recovery and crude oil quality.
Zihan Gu et al (2022)[255]	the SiO2 nanoparticle foam system	Effect of nanoparticle the properties of heavy crude oil.	0.2- 0.5 wt.% nanoparticles in solution.	The results of this study showed that nanoparticles are talented Foam with stiffness, increased viscosity, reduced drainage velocity and interfacial energy, and Improve the half-life and viscoelastic modulus of foam. All of these changes made the foam structure denser with better stability and strength and provided it with a higher pore-sealing capacity and displacement mobility ratio, all of which led to improved sweep efficiency, while generating larger displacement pressure differentials.
Alcides Simão et al.(2022)[256]	MgO, CaCO3, Fe2O3, NiO, ZrO2 and WO3	in-situ oil upgrading	500,1000,1500,2000-10000 ppm	In this study, some findings about effectiveness have been highlighted Catalysts for improving heavy crude oil in terms of asphaltene absorption, reducing viscosity, increasing API attractiveness, and coke formation. The literature reviewed indicates the need for further research on this topic; In order to develop more effective and effective catalysts not only to

				increase the recovery factor, but to permanently improve the quality of heavy and very heavy oil as well.
Eynas Muhamad Majeed et al (2023)[257]	Nanoparticles (silica and gamma-alumina)	Effect of nanoparticle silica and gamma-alumina in properties of heavy crude oil.	Add nanoparticles dose:(500, 1000, 1500 and 10000 ppm)	In this study, nanoparticles - silica and gamma lumina - were added as viscosity enhancers or API improvers to Iraqi heavy crude oil. Effect of nanoparticle doses (500, 1000, 1500, 10,000 ppm) and at various temperatures (25°C, 50°C, 75°C) on viscosity reduction efficiency. It has been shown that the use of nano-gamma alumina gives superior results in the process of improving and reducing the viscosity rate at temperatures exceeding 25 degrees Celsius, when a viscosity reduction of 37 % is obtained with 10000 ppm, and at 75 ºC
Jingnan Zhang et al.(2023)[258]	manganese chloride ($MnCl_2$) solution, sodium dodecylbenzene sulfonate (SDBS) solution, and silica (SiO_2) nanofluids	nanofluid enhanced oil recovery and improve oil properties.	0.5 wt.% nanoparticles	This study revealed that silica nanofluid can effectively improve crude oil production in small pores, reducing the surface tension between oil and water, and changing the wettability of rocks.
Vladimir E. Katnov, et al. (2023)[259]	Na nanoparticles	Efficiency of Heavy Oil	concentration of 2 wt.%	This study showed that sodium nanoparticles interact with water to produce hydrogen gas, the concentration of which increases from 0.015 to 0.805 by weight. In addition, the viscosity of the updated heavy crude oil decreased by more than 50% and the low molecular weight heavy oil content. Hydrocarbons in the aromatic and saturated fractions have been increased.
Abdullah Al-Marshed et al. (2024)[260]	Nanoparticulate Iron Oxide	Heavy Oil Upgrading	0.03−0.4 wt. % of nanoparticle	In this work, it was observed that the best combinations of reaction parameters were: temperature 425 degrees Celsius, initial hydrogen pressure 50 bar, reaction time 60 minutes, stirring

				400 rpm, and iron and metal loading. 0.1% by weight. It showed that the characteristics of the developed crude oil in the optimal condition are: API gravity 21.1°, viscosity 105.75 cP, sulfur reduced by 37.54%, metals (Ni+V) decreased by 68.9%
Mohammed T. Naser et al.(2024)[261]	modified silica and magnesium oxide nanoparticles	flow behaviour of heavy crude oil	3% wt of surface-modified silicon dioxide (SiO_2) and magnesium oxide (MgO) nanoparticles	In this paper, the effect of these nanoparticles on rheology, pressure drop, emulsion stability, viscosity, and energy consumption was studied. The rheology study showed that the best results were achieved by adding a modified surface Nano silica at 3%, resulting in obvious viscosity reduction with shear thinning behavior. This addition of 3% Nano silica resulted in a highly stable emulsion Up to 69% reduction in energy consumption for liquid pumping.
Saeed Zeinali Heris et al. (2024)[262]	carbon nanotubes (MWCNTs) and sodium dodecyl sulphate (SDS)	For improving properties of heavy crude oil	1:1 ratio of MWCNTs to SDS	This study revealed The 1:1 ratio of MWCNTs to SDS achieved a significant reduction of 10% Surface tension while affecting viscosity was minimal, which showed promise for practical applications.
Azin Khajeh Kulaki et al. (2024)[263]	nano γ- Al_2O_3/ SiO_2 modiied	Improving oil properties and enhanced oil recovery	Add γ-Al_2O_3 and SiO_2 NPs in 0.1 wt.%	This study showed that the greatest oil recovery for the γ- Al_2O_3/SiO_2 composition modified with GA The dispersion in 2-DSSW has been reported to be 60.34%. It has been verified that NFs modified with GA can enhancing the applicability of LSWF by delaying the penetration time and by improving the scanning efficiency.
Abbas Khaksar Manshad et al. (2024)[264]	SiO_2/bentonite nanocomposites (NCs)	Improving oil properties and enhanced oil recovery	4000 and 2000 ppm of SiO_2	This study confirms that these improvements in enhanced recovery parameters for heavy crude oil, the stability and efficiency of the green

				solution, which was formulated as an active solution for enhanced oil recovery, can extract a high amount of crude oil in an environmentally friendly environment sustainable way.
Rubén H. Castro et al.(2024)[265]	SiO2, Al2O3, and TiO2	Improving oil properties and enhanced oil recovery	100-10000 ppm of nanoparticles	This study showed a discussion of the results of the analysis of variance (ANOVA), and that the preparation method and retention time affect the viscosity of nanofluids, with a statistical significance of 95%. In contrast, the heating temperature and NP type are negligible. Finally, the nanofluid had the best performance if its ratio was: 1000 ppm SG + 100 ppm SiO2_120 NPs prepared by the second method.
Salem J. Alhamd et al (2025)[266]	Nano silica and Nano Molybdenum disulfide	The effect of the of Nano silica and Nano Molybdenum disulfide in Bazargan Oilfield	adding 0.3 wt.% of silica nanoparticles	The results of this study indicate a noticeable reduction in the viscosity of heavy crude oil. As a result of adding nanoparticles and as a result of increasing the concentration of nanoparticles and increasing Operating temperature. It is observed that the viscosity reduced from 57.15 cP at 25°C to 31°C. 27 cP at 55°C after the addition of 0.3 wt.% of impurity silica particles when compared to the decrease in viscosity from 57.15 cP at 25°C to 31.37 cP after the inclusion of 0.3 wt.% nano-molybdenum disulfide at 55°C.
Deja Hebert et al.(2025)[267]	NiO2 and Fe2O3	upgrading of heavy crude oils	0.1-0.5 wt% of nanoparticles	This study discussed and stated that no previous studies have used spICP-MS to trace the nature of NP additions in the asphaltene fraction of hydrocarbons without adulterating the sample. The particle number

3.2 Surfactant:

The term surfactant (short form of surfactant) was first coined by Antara in 1950 [268]. These organic compounds consist of at least two parts, the first of which is the soluble part in a given solvent and the second is the soluble leophyll part. This dual property of surfactant makes him amphibious in nature . If the solvent is water, the term commonly used is hydrophilic and hydrophobic[269]. Mostly and lustrously, the hydrophobic chain is branched or linear with 8-18 carbon atoms of length, and the polar head group may be ionic or non-ionic depending on the charge of the molecule in the solution, the hydrophobic group extends outside the bulk aqueous phase, while the water-soluble head group is found in the aqueous phase[270]. When the surfactant molecule moves to the surface, it leads to the disintegration of the water molecule and because of this the water molecule loses hydrogen bonds with other water molecules, the result is: a decrease in surface tension. Surfactants usually reduce the surface tension of water from 72 to 35 dyne / cm contributing to the formation of the emulsion, which allows easier diffusion between different liquids [271]. When the surfactant is present at low concentration, it is absorbed on the interfaces. Another important property of surfactant is that in solution it tends to form aggregates of a monomer called micelles and this assembly process is called micellization[272]. The concentration at which the micelles composition first appears is kwon as a critical micelle concentration (CMC). At a very low concentration of surfactant, micelle formation occurs, which reduces the free energy of the system[273]. Mecellates are also used to enhance the solubility of substances that are often poorly soluble or insoluble in a dispersed medium, a process known as solubility [274]. It is the spontaneous dissolution of an insoluble substance in an imultaneous soluble solution by means of surfactant [275]. The minimum temperature at which the formation of micelles from the surfactant occurs is called Kraft Point or Kraft Temperature [276]. When the temperature is lower than these, CMC formation does not occur. Therefore, it is the transition point of the phase and above it and above it the solubility of the actor at the surface rises at a very high speed due to the occurrence of the discharge process[277]. Kraft point is obtained as a result of attenuating the forces of attraction between the hydrocarbon chains through the micelle[278]. When the surface reactor solution is heated with an oxyethylene group, it becomes turbid at a certain temperature range resulting in cloudy solution formation [279]. This temperature is called the cloud point. It depends on the length of the polyoxymethylene chain of the surfactant. In the case of increased surface actor concentration, other groups are also formed called liquid crystals with heterotopic inherently heterogeneous [280]. There are many studies, articles and research papers that have been written and published about surfactants, their properties and applications, and some studies have taken care of their classification and application in a different field, simultaneously[281]. Some studies have provided systematic classification, important structural features and different application of surfactant in detail. This type of review article may be useful for researchers involved in the field of surfactant and its application [282].

3.2.1 Classification of Surfactants:

The primary surfactants are divided depending on the charge on the polar head group[283]. If this charge is negative, the surfactant is called anionic. If this charge is positive, the surfactant is called a cation. If the surfactant has a head with two oppositely charged groups, it is called zwitterionic. Depending on this charge, surfactants are classified into categories - anionic, cationic, nonionic and zwitterionic[237].

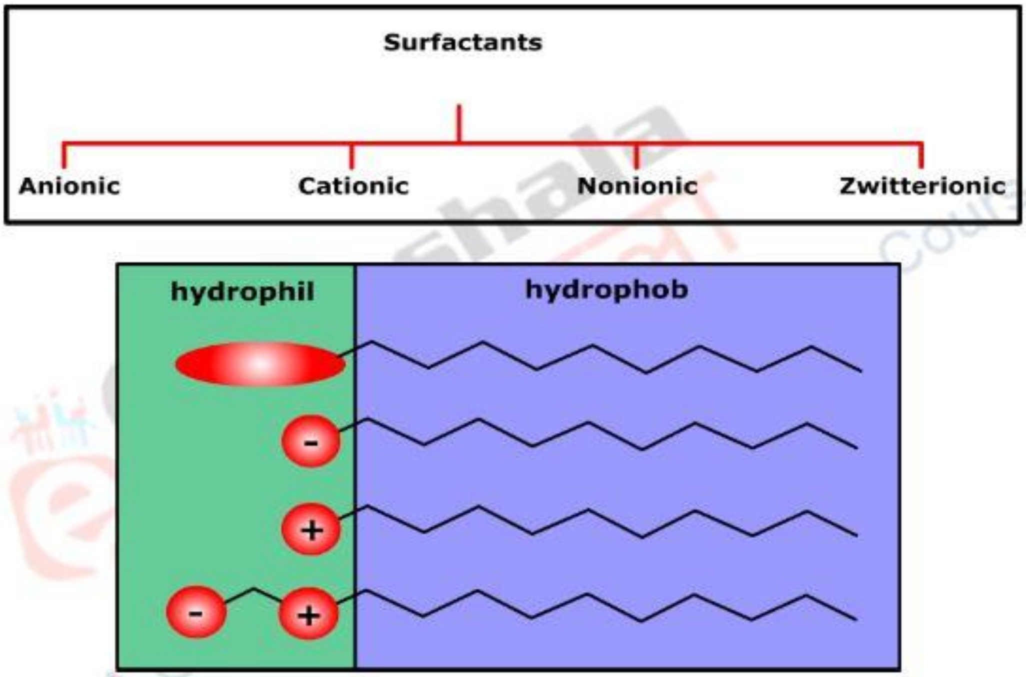


Figure 15. Shows the division of surfactants according to the charges on them [284].

3.2.1.1 Anionic surfactants

Anionic surfactants consist of anionic functional groups on top of them, such as phosphates, sulfates, carboxylates and sulfonates [285]. Anionic surfactants are used in a larger volume than the rest of the classes of surfactants, as they are used in most detergent formulations, where the best resistance to localization is obtained by alkyl and alkyl aryl chains in the C12-C18 range[286]. Soap, as it is known, is the single largest type of surfactant is anionic surfactants, which are obtained through the process of saponification of natural oils and fats. Soap is a genetic name that refers to the mineral salt of alkaline carboxylic acid originating from animal fats or vegetable oils. Soap bars are usually based on fatty acid mixtures produced from coconut, lard and palm oil. For the past fifty years, soap has been replaced by better efficient materials such as alkyl sulfate, alkylbenzene sulfate and alkyl sulfate[287]. Anionic surfactants are highly sensitive to water hardness . The most commonly used anti-ions are potassium, sodium, ammonium and calcium with many alkyl proton amines. Sodium and potassium give solubility in water, while calcium and magnesium give solubility in oil. While amine/alkanolamine salts give oil- and water-soluble products[288].

3.2.1.2 Cationic surfactants

In this species, the hydrophilic part is positively charged. This group does not contain any washing activity effect, but it is fixed on surfaces where it gives other important effects namely softening, antistatic, antibacterial, soil repellent or corrosion inhibitor[289]. The ideal and different applications of this type are their use as softeners (fabric softeners) and anti-static. The anti-cationic surfactant ion is generally methyl sulfate or halide. Primary, secondary and tertiary amines depend on pH: (primary and secondary amines are positively charged with $pH < 10$) [290].

3.2.1.3 Nonionic surfactants

This type of surfactant is a non-ion-charged surfactant. This type of material is suitable for cleaning purposes and is insensitive to water hardness. This type has wide applications in cleaning detergents and includes groups such as: polyglycosides, alcohol, fatty alcohol, ethoxylate, etc. Long-chain alcohols exhibit some surfactant properties[291].

Notable among the most prominent are stearyl alcohols and fatty alcohols, cetosteryl alcohol (consisting mostly of cetyl alcohol and stearyl), cetyl alcohol, and oleyl alcohol [292].

3.2.1.4 Zwitterionic surfactants

The zwitterionic surfactant consists of two groups with opposite charges. Zwitterions are usually known as "amphoteric" but these terms are not the same. An oscillating surfactant is a surfactant that converts into a net cation via zwitterion into a pure anion by going from low to high pH. The acid is not charged and the primary site is not continuously and permanently charged, i.e. the compound is only zwitterionic on a pH limit range[272]. It is noted that at the isoelectric point, the chemical-physical behavior is usually similar to that of non-ionic surfactants[293]. There is a gradual shift above and below the electric isotope point toward the cation and anion character, respectively. Zwitterion is a group with excellent properties that do not affect the skin[294]. So in do not cause eye and skin irritation they are suitable for use in shampoos and various personal care products (cosmetology). Zwitterionic (amphoteric) surfactants are composed of anion and cation centers bonded to the same molecule. The cationic fraction depends on primary, secondary, tertiary and quaternary ammonium cations [295]. Sulfate is the internal sulfonic acid salt of a strong inorganic acid and is often called, such as sulfobutine [296]. It is similar to betaine, which is considered to be an internal carboxylic acid salt for weak organic acids [297]. Both molecules are zwitter-ionic at pH7 where the nitrogen in the hydrophobic tail is quadruple - cationic-[298]. The polar head sets anionic and adds to the hydrophilic properties of the molecule. Quaternary nitrogen is usually considered positive, these molecules at any pH do not get an anionic nature and are not really oscillating, although they are commonly referred to as some common types of zwitterionic surfactants that are N-alkyl derivatives of simple amino acids, such as glycine (NH2CH2COOH), betaine (CH3) (2NCH2COOH) and amino propionic acid (NH2CH2CH2COOH). Petinis, for example cocamidopropyl betaine [285].

3.2.2 Drag reduction by using surfactants

(White, A., 1967). This study demonstrated through experimental work on the flow of conveyor pipes using a dilute solution of cetyl trimentol ammonium bromide (CTAB) with 508 ppm, the study showed that the drag reduction in conveyor pipes with a large diameter was greater than the smaller diameter and ended at a low value of the Reynolds number flow due to the deterioration that occurred due to oxidation after a period of several days.

(Hershey et al., 1971)[5] In their study and research they used aluminum dioctate in toluene as a drag reducer. They found that the method of preparing a disoap solution significantly affects the flow behavior. It appeared to them that the structure of the solution is temporarily split by a very high shear. They found that friction losses would be low the higher the concentration of aluminum dioctates. Some studies conducted using a combination of non-ionic surfactants have shown linear primary alcohol in aqueous solution, where the effects of surfactant structure, concentration, temperature and mechanical degradation on drag reduction have been investigated. Almost all surfactants were effective as additives that reduced drag. It has been confirmed and learned that all the surfactants used are repairable, that is, after being mechanically decomposed, they can restore their ability to reduce drag when they reach an area with low shear forces. The towing effects on reducing drag are similar to those observed in high polymer solutions (% increase Dr by reducing pipe diameter)[299][300]. They have used different types of cationic surfactants, drag reducing agents (ammonium chloride trimethyl ethyl (CTAC), trimethyl ammonium salicylate grease (TTAS), triethyl triethylammonium salicylate (ETAS), and trimethyl ammonium chloride (STAC) [301]. A closed-loop flow and heat transfer device was used to measure drag and reduce heat transfer in turbulent pipe flow. They discovered that the different types of surfactants used were highly effective in reducing all of heat transfer and drag in the flow of turbulent transport pipes[302]. They have proven that surfactants reduce the friction of pipe flow and the single heat transfer coefficient of pure water simultaneously, and surfactants have a critical temperature and a Reynolds number above which the heat transfer coefficient and friction of pipe flow return to water[303]. The percentage of cloud reduction increased by higher concentrations of surfactants (50 to 500 ppm) [304]. There are some studies and research that have examined shear reduction, pulling and radical measurement by dilation in aqueous surfactant solutions[305]. Cryo-TEM (cryo-TEM) electron microscopy technology was used to show the size and image of surfactant solvents. Argued 16-50 was used in three close concentrations, 2-, 3- or 4-chlorobenzoate at 12.5 mmol as a withdrawal reducer[306]. Each isomer showed different types of rheological and different micelle structure. The chlorine system did not show any decrease in clouds, low elongation viscosity and spherical peeling only. The 3-chloro system has shown a very good ability to reduce drag by a maximum of %Dr by 50%. The 4-chloro system showed a very good withdrawal reducer with a maximum of %Dr up to 70%. We have reached and combined high viscosity reduction, interconnected like a Meckler grid [307]. The effects of positive surfactant mixtures on reducing streamlined behavior and clouds have been verified and confirmed experimentally[308]. Positive alkyl trimethylammonium (IV) surfactants were experimentally mixed with an alkyl chain length from C12 to C22 in different molar ratios, and then it was shown that by adding 10% moles of C12, the effective drag reduction temperature range expands to 40-120 °C compared to 80-130 °C with surfactant C22[309]. As a result, mixing cationic surfactants with different alkyl chain lengths is an efficient and convenient way to adjust the drag reduction temperature range[310]. Experimental and experimental results in micrographs showed that the micellar network corresponded to the filaments of surfactant solutions in the cloud reduction temperature range, while vesicles were the dominant microstructures at non-cloud-reducing temperatures, all of which supports the widely believed hypothesis that filament-like micelles are necessary to reduce surfactants[311]. Three anionic surfactants as well as non-ionic surfactants have been studied as drag attenuators in the flow of turbulent Iraqi crude oil transport pipelines and within three specific 0.5, 1 and 3-inch tanker pipeline diameters [312]. The researchers concluded that the percentage of drag reduction (%DR) is increased by the high concentration of the surfactant (within certain limits), the flow rate of the solution and the diameter of the transport pipe[313]. Maximum withdrawal reduction of 56.5% obtained at 200 ppm SDBS concentration. Finally, the mechanism of reducing clouds was demonstrated and clarified through the interaction of surfactant micelles with heavy crude oil, allowing to suppress and prevent turbulence[314]. Four types of anionic surfactants (sodium dodecyl benzene sulfonate (SDBS), sodium lauryl sulfate (SLS), sodium laureth sulfate (SLES) and sodium stearate (SS) have also been experimentally compared as withdrawal reducing agents with refining products such as (gas oil and kerosene), at different concentrations (50-300) ppm[315]. Three closed flow loop systems, with conveyor pipe diameters of diameters (1.91, 2.54 and 5.08 cm) were used in their experimental research. The researcher discovered that drag reduction increases by increasing the flow rate (Reynolds number) and surfactant concentration which reduces the diameter of the pipe[316]. The maximum of 53% of Dr was reached using 300 ppm of surfactant SDBS dissolved in gas oil flowing through the specified 1.91 cm transfer pipe. The maximum of 48% was reached using 300 ppm of SLES dissolved in kerosene flowing through a 1.91 cm cognitive pipe[317]. Drag reduction measurements in the flow of oil and gas alloys have been introduced in two stages. Two types of heavy oils with significantly varying viscosity in horizontal conveyor pipes with an inner diameter of 10 cm were examined to evaluate the effect of oil viscosity on total pressure loss and loss, and the effectiveness of drag reduction agents (DRAs) in reducing pressure drop in slug flow[318]. The drop in total pressure in 50cp oil has always been more significant than in 2.5cp oil, especially when the gas flow rate increases[319]. However, they found that DRA was more effective in reducing the overall pressure drop in 2.5cp oil. Moreover, this increased the speed of the liquid, as a result of which the DRA effectiveness of both oils increased[320]. Some researchers have studied the efficacy and effect of two surfactants (sodium dodecyl benzene sulfonate (SDBS) and sodium lauryl sulfate (SLS)) in heavy crude oil using a closed-loop system for three pipes of different diameters (0.75, 1 and 1.5 inches) and a length of 2 meters each, using three different temperatures :(30°, 40° and 50°C)[321]. The concentrations of each of the surfactants used range from 50 to 300 ppm. It was discovered that the final values of the results showed that the largest decrease in clouds (% DR) was 23.67% (where the flow increase rate was 16%). This value was reached when adding 200 ppm of SDBS at 30°C [322] .

3.2.3 Summary of previous experiments

Table 5. Summary of previous experiments on the streamlined behavior of heavy crude oil by adding surfactant.

Authors	Additives	Objectives	Additives concentrations	Summary of main results
Yousef Al-Roomi et al. (2004) [323]	commercial non-ionic surfactant, and Triton X100	Using surfactant to improv the transportability	Aqueous solution of surfactants having concentration of 1000 ppm	This model showed good data accuracy with a coefficient correlation higher than 93%. It is possible to propose the transport of heavy crude oil as emulsions as an alternative to Mix crude oil with any diluent or natural gas condensate.
T. Babadagli1 (2005)[324]	Surfactant Solution	Oil Recovery Analysis	0.1,0.2.0.3,0.4 and 0.5 w%	This study aims to analyze and identify recovery mechanisms and perform upgrading exercises for the extraction of crude oil from various rock types by capillary (spontaneous) drinking of surfactant solution.
J.R. HOU et al.(2006)[325]	changing the NaOH concentration	Enhanced Oil Recovery	0.3 wt%, NaOH concentration changed from 0 to 1.2 wt%	In this study the results of ASP flood tests were discussed, and their effects on the recovery of grade III oil for sodium hydroxide concentration and the balance between reducing IFT and increasing viscosity were discussed. For heterogeneous models, this study has shown that there is a minimum viscosity The value of the ASP solution for IFT systems is too low to fully optimize the extraction of residual crude oil.
G. A. R. Rassoul and Ati A. A. Hadi (2007)[326]	Anionic sur1actani (ISOBS)	Improving Grude Oil Flow in Pipeline	(50, 100, 150, 200 and 250 ppm	It has been observed in this research paper that the highest value of the draw reduction by 54% in the identity . This was when using 250 ppm of the dissolved SDBS surfactant at the crude oil flow rate used I2 m3/h.
Dennis Denney (2008)[327]	alkali/surfactant (A/S)	flooding in heavy-oil reservoirs.	0.05-0.1 w%	This study presents the results of basic laboratory studies looking at the mechanisms of recovery of alkaline-reducing surfactants (A/S) floods in heavy crude oil reservoirs.
J. BRYAN and A. KANTZAS (2009)[328]	Alkali-Surfactant	Flooding in Heavy Oil Reservoirs	50, 100, 150, 200 , 300and 500 ppm	This study showed that alkaline surfactant flooding is a well-established technique for crude oil recovery in conventional oil reservoirs, as the injected chemical reduces the oil/water intertension, which in turn leads to reduced oil contract retention.
V.S. MILLIOLI1 et al. (2009)[329]	rhamnolipid biosurfactant	Effective of Rhamnolipid addition to crude oil	Addition 1 and 15 mg	In this study it was shown that the addition of biosurfactant leads to improvement of all treatments, except for assays

				with the addition of 1 and 15 mg g-1 where a decrease in bioremediation rates was shown in toxicity tests.
Jinxun Wang; Mingzhe Dong (2010)[330]	**Alkaline/Surfactant**	Flood for Heavy Oil Recovery	0.05-0.1 w%	The flow and composition of emulsions during the alkaline flood process plays a major role in improving the extraction of heavy crude oil. In this paper, alkaline/surfactant (A/S) flood tests were performed in sandbags to demonstrate the effectiveness of improving the sweep efficiency by O/W oil-in-situ emulsion.
Amedea Perfumo et al. (2010)[331]	**Biosurfactants**	Biosurfactants Uses in Petroleum Industry	1-10 g/l surfactant to oil	Surfactants are a group of microbial molecules that are determined by their unique ability to react with hydrocarbons for de-emulsification, coating, hydration, dispersion and foaming. Biotensile materials can also achieve many surface activities when applied within systems.
P. Srivastava; L. Castro (2011)[332]	Thin Film Spreading Agents (TFSA)	surfactant Additives to Enhance Recovery of Heavy Oil	250 ppm of TFSA	17 vertical wells in California of CSS in a sandstone configuration have been treated using TFSA to achieve progressive oil recovery. Of the 17 wells, 14 showed an average progressive oil recovery of 5,411 barrels, which translates into a success rate of 82%.
George J. Hirasaki et al. (2011)[333]	alkaline/surfactant	injecting alkali and synthetic surfactant to EOR	0.1 and 0.3 w%	In this study, recent advances in surfactant-enhancing oil recovery (EOR) were reviewed. The addition of alkali to surfactant flooding in the eighties reduced the amount of surfactant required, and the process became known as alkaline/surfactant/polymer (ASP) flooding.
S. Trabelsi et al.(2012)[334]	Sodium Dodecyl Benzene Sulfonate (SDBS)	Diluted Heavy Crude Oil	200 ppm from surfactant	In this study it was observed that the addition of sodium benzene sulfonate (SDBS) above the critical micellar concentration (CMC ~ 0.002%), to the change and variation of the dynamic IFT behaviors of the fully diluted heavy crude oil as the IFT dropped sharply and finally reached a plateau, amounting to about 1.5 × 10-3 mN/m at a concentration of only 0.02%.

Haihua Pei et al. (2012)[335]	Alkaline− Surfactant	Flooding for Improved Heavy-Oil Recovery	0.1,0.2,0.3-1 w%	This study discusses the results of a laboratory investigation, including sandstorms. Micro flood experiments and studies, in order to evaluate the effectiveness and suitability of alkaline floods and alkaline surfactant floods (AS) for the recovery of heavy crude oil.
Lifeng Chen et al.(2013)[336]	Alkaline/surfactant	enhancing the recovery of heavy oil	only alkyl polyglucoside (0.05%)	The results of this study showed that the recovery of grade III oil can reach 19.4% of the initial oil in place using the appropriate alkaline/hypotensive system.
Mehdi Mohammad Salehi et al. (2013)[337]	surfactant alternating gas (SAG)	improved oil recovery from heavy and semi-heavy oil reservoirs	0.1 – 1.2 w% from SAG	In this paper, an experimental study of injecting immiscible heated SAG into a sandbag has been done. This new method is a combination of SAG and thermal process as it can be used in semi-heavy and heavy crude oil reservoir.
Kumar et al. (2014)[338]	Mineral oil, SDS, CTAB and Brij S-20	Effect of the addition of surfactants on the viscosity and yield stress of a synthetic crude oil	(50e80%) mineral oil and 0.1%wt/v of each surfactants	This study showed that increasing the temperature and adding mineral oil to synthetic oil leads to a reduction in viscosity and stress the required flow yield. Considering both the stress of yielding and the reduction of viscosity, SDS is optimal.
Kwan Min Ko et al. (2014)[339]	dodecyl alkyl sulfate	enhanced oil recovery	0.01 – 0.5 w%	In this paper, the relationship between dodecyl alkyl sulfate and some specific crude oils was examined through phase behavior testing. The branched superficial representative turned out to be more effective and suitable of the linear surfactant.
Tarun Kumar Naiya et al. (2015)[340]	Naturally Extracted Surfactant	Heavy Crude Oil Rheology Improvement	500 to 2000 ppm	In this study, a new surfactant extracted from the tropical Indian plant Madhuca Longifolia was used to enhance the flow properties of heavy crude oil through transport pipelines.
Banerjee et al. (2015)[341]	Sapindus mukorossi (soapnut),water and ethanol	Improving heological properties and comparing results with water and ethanol in crude oil.	1e8% w/w of each additive	This study showed that adding 4% weight/weight to surfactants improves the flowability of heavy crude oil is much better than ethanol and water. The naturally extracted surfactant is best suited for use in petroleum transport operations.
Zhihua Wang et al. (2015) [342]	By enzymatic syntheses were carried out.	The effect of additive surfactant to reduced drag and viscosity.	surfactant additive at a concentration of 100 mg/L. (use of	In this study, the maximum viscosity reduction of 70% and withdrawal reduction of 40% of crude oil flows in transport pipelines were obtained using a

			biobased surfactant obtained by enzymatic syntheses)	surfactant additive with a concentration of 100 mg/L.
Banerjee et al. (2016)[343]	Sapindus mukorossi (soapnut)	The effect of the surfactant on the wax crystal structure, crystal size distribution, pour point and viscosity behavior of three heavy crude oil samples	(1%, 2%, 3%, 4% and 5% w/w)	In this study, a significant decrease in viscosity and casting point as well as a significant decrease in the surface area of the wax crystals and a change in the structure and size of the wax crystals were observed by adding 4% w/w surfactant to all crude oil samples, indicating surfactant effectiveness.
Kumar et al. (2016)[344]	Brij 30, mineral oil and 3-pentanol	Comparison of the surfactant Brij 30 with diluents to improve the transportability of heavy crude oil	5% w/w and 10% w/w of each additive	In this study, all rheological properties of heavy crude oil were improved by increasing the temperature from 25 to 60 °C and improving it through the addition of additives. Brij-30 is much more effective at improving flow behavior than mineral oils and 3-pentanol.
Kumar et al. (2017) [345]	Sapindus mukorossi (soapnut) and Brij-30	Study and compare the usefulness of both surfactants as a flow improver during heavy crude oil transport	1000 ppm, 1500 ppm and 2000 ppm of each surfactant	In this study yield stress, viscosity, inter-tension, complex, volumes and loss were significantly reduced by adding only 2000 ppm surfactants, with Sapindus being more effective. Adding Sapindus mukorossi to heavy crude oil can significantly reduce the cost of heating at very low temperatures.
Kumar et al. (2017)[346]	Madhuca Longifolia (Mahua)	Effect of surfactant on the rheological behavior and microscopic properties of wax crystals	(500e2000 ppm) of surfactant concentration	This study showed that the flow properties at low temperatures can be significantly improved by heating or adding 2000 ppm of the surface actor. The addition of surfactants significantly reduces the size of the wax crystals.
Gudala et al. (2017)[347]	Mahua surfactant and dispersed water	The effect of surfactant concentrations on the viscosity and drag reduction of heavy crude oil-water dispersed flow in 200 -ID, 2.5 m pipeline at different temperatures	(0e1000 ppm) Mahua surfactant for viscosity measurements. (0 e2000 ppm) Mahua surfactant and 0e15% dispersed water for drag reduction measures	It was observed in this study that the viscosity decreased by 60.4% after adding 1000 ppm of mahwa at 50 ° C. A maximum withdrawal reduction of 94.8% was obtained after adding 2000 ppm of Mahua to 85% crude oil × 15% water at 40°C and a flow rate of 50 l/min.
Gudala et al. (2018)[348]	Potato starch and dispersed water	Effect of additives on viscosity reduction, head loss, drag reduction and power saving ability.	(5e15 v/v%) of dispersed water and (0e2000 ppm) of potato starch concentrations	In this study, it was observed that the addition of 2000 ppm of potato starch to an 85% mixture of heavy crude oil and þ15% water at 40°C resulted in a reduction in viscosity by 80.24% and head loss by 7.55 × 10-4 m at 60 l/min.

				Also, the withdrawal was reduced by up to 91% and increased energy savings to 38.24% after adding 2000 ppm of potato starch to the same mixture at 60 litters per minute and 40 °C.
Xuefan Gu et al. (2018)[349]	cetyl trimethyl ammonium chloride (CTAC), cetyl trimethyl ammonium bromide (CTAB), and octadecyl trimethylammonium chloride (OTAC)	Reduce viscosity with these additives	Crude oil has initially been heated to 70°C in a constant and airtight temperature state and kept for about 1 hour. Then the 30 g samples were placed in a container at a certain temperature. Then after about 20 minutes, CTAB, CTAC and OTAC in various and different concentrations were added to the samples and stirred continuously at a certain temperature respectively.	In this study, the viscosity value was reduced to less than 540 MPa seconds under different concentrations at 35 °C by CTAC, and the casting points could be reduced by 7.5 °C at 0.03%. Environmental morphology analysis and DSC analysis, CTAC reaction and saturated hydrocarbons revealed one of the components of crude oil, which in turn can reduce the wax peak temperature and wax deposition point of crude oil.
Hamad Al‐Adwani and Adam Al‐Mulla (2019)[350]	Various polyacrylamide (PAM)	drag reduction of crude oil using surfactants and polyacrylamide	For a surfactant concentration of 70 ppm, PSSS	In this study, it was observed that the concentration of surfactants, when it reaches 70 ppm of PSSS, is produced by the lowest viscosity value of crude oil A, while CHP is produced. At the lowest viscosity value of ore B. An increase in the values of the loss coefficient (G")
Al-Dawery and Al-Shereiqi (2019)[351]	Palm fiber, walnut shell, roasted date kernel and date kernel	The efficacy of using the bio- wastes on the rheological properties and flow time of heavy crudes	(10, 20 and 100 ppm) of each bio-material	This study has shown that particle size and biomaterial concentration are effective factors for reducing the withdrawal of together kinds of oil, but are more active as agents for reducing the viscosity of light crude oil.
Negi et al. (2020)[8]	Chitosan-based cationic surfactant (CBCS)	The impact of the surfactant on viscosity of oil	Concentrations (200, 400 and 600 ppm) of surfactant	In this study, improvement in the viscosity of oil was already observed when The concentration of surfactants enhanced from 0 to 600 ppm due to low agglomeration rate of asphaltene in oil matrix.
Jing Gao et al. (2021)[352]	ex-situ surfactant/solvent	Efficient treatment of crude oil	Brij-58/1,2-dimethylbenzene mixture	This study is intended to investigate absorption efficiency for the regeneration of a catalyst contaminated with crude oil using an ex situ surfactant/solvent washing technique. Six types of surfactants and solvents have been used for improvement, and an optimal mixture of surfactant and solvent has been created to

				remove crude oil from the contaminated catalyst.
Deneb Zamora García Rojas et al. (2021)[353]	non-ionic surfactants	Impact of non-ionic surfactants on the moving and properties of heavy oil	(W/O) evaluated at a ratio of 30/70 (w/w %)	This paper discusses that recent studies focus on emulsion design for the development of techniques that decrease the viscosity and interstitial tension of heavy crude oils, in order to enhance the recovery of heavy crude oil.
Hao Ma et al. (2022)[354]	surfactant-polymer composite system	viscosity reduction for heavy crude oil	0.05 moles of hydrogen hydroxide were placed in the reactor. 0.03 moles of the compounds were slowly added to the homogeneous mixture to react for two hours.	The results of this study showed that the composite system of surfactant polymer consisting of amphibious polymer had a clear benefit in blending stability, where the water separation amount reached 60.6% after 48 hours in the simulated salinity, and viscosity decrease rate was more than 92.1% after improvement.
Yilu Zhao et al. (2022)[355]	surfactant-biopolymer combined system	Increased oil mobility and reduced viscosity.	0.1 wt% anionic surfactant (fatty alcohol polyoxyethylene ether sulfate, SC) and 0.05 wt% biopolymer (xanthan gum, XG)	The results of this study showed that the addition of XG to SC systems can in turn significantly reduce the oil-to-water displacement fraction (lo/ld) to 1.42 and at the same time maintain a high viscosity reduction rate at 94.03%, which is considered beneficial for reducing the water-to-oil (M) transfer ratio.
Mayda Maldonado et al (2023)[356]	Surfactant using a flow enhancer and water at changed temperatures conditions	The impact of the Surfactant on heavy oil viscosity	adding 1.2–2 wt %.	This paper programs the impact of flow enhancer (FE) on the viscosity performance of very heavy crude oil , and in emulsions consisting of 5% and 10% water (W). The results showed the efficiency of 1%, 3% and 5% flow boosters in dropping viscosity and introducing Newton's flow performance, which in turn helps reduce the price of heat treatment through the transportation of oil during the transport pipeline.
Yanping Wang et al. (2023)[357]	synthesized Gemini surfactants CEA	viscosity reductant for heavy oil	The surfactant solution and the simulated oil were injected into a test tube by an oil/water fraction of 7:3	results of this study showed the change in the length of the polyether chain of surfactant molecules with the greatest effect on interfacial tension (IFT), and the best were the surfactants with longer alkyl chains with better interstitial membrane strength.
Ehsan Hajibolouri et al. (2024)[358]	(SDS), (SYW), SYW and (SYG)	the performing of	Combined Annealing Simulation (CSA) values	In this study, the Combined Annealing Simulation way was

		surfactants in decreasing heavy oil viscosity	AARE, R, MAE, MSE and RMSE 8.982, 0.996, 0.004, 0.0002 and 0.0132, respectively.	used to improve all algorithms. With values of AARE, R, MAE, MSE and RMSE 8.982, 0.996, 0.004, 0.0002 and 0.0132 respectively
Wanfen Pu et al. (2024)[359]	surfactants—sodium dodecyl sulfate (SDS), sodium oleate (SO), and APG0810	enhances heavy oil recovery	ombining 0.3% SO with 0.5% n-pentanol	In this study, three (SDS), sodium protolate (SO) and APG0810 – were evaluated for suitability and efficacy in the X reservoir. The properties of the solution of these surfactants have been analyzed and their exact mechanisms investigated and confirmed using MD calculations.
Temurali Kholmurodov et al. (2024)[360]	nonionic surfactants and catalysts	enhance heavy oil	Two main components have been used for the manufacture of precursors: aluminum oxide and sodium hydroxide solution. These components were loaded into a small 2:1 reactor and processed for 4 hours with temperature changes.	This study pioneered an environmentally friendly technology coupled with specially designed non-ionic surfactant co-injection with a heterogeneous nanocatalyst with steam.
Xianwu Zhang et al. (2025)[361]	cationic polymeric surfactant	enhanced crude oil	0.001 wt% Q-g-PN concentration via the proposed temperature-regulated	In this study, bottle tests showed that the DE emulsification performance of Q-g-PN could reach: 94% with Q-g-PN concentration only, and by 0.001% by weight via the temperature-regulating proposal.

4- Comparison table of heavy crude oil transportation improvement technologies:

Through this comprehensive study, we can summarize the basic differences between surfactants, nanoparticles, and solvents in the heavy crude oil transportation process.

Table 6. Comparison table of heavy crude oil transportation improvement technologies

No.	Evaluation Criterion	Surfactants	Solvents	Nanoparticles
1	Mechanism of action	Reduces viscosity by forming a stable emulsion	Direct dilution by blending (dilution method) or by separation of asphalt components (extraction method)	It breaks up asphaltins and adsorbs it because it has a very high surface area
2	Its efficiency in reducing viscosity	Good to very good (depending on the type of surfactant)	Very good and fast	Very good and according to the types used
3	Its thermal stability	Very good to excellent (depending on the type of surfactant)	Medium to weak	Excellent operating at various temperatures and at high pressures

4	Impact on the environment	Low and may increase depending on the type of surfactant	Low to medium	Low
5	Cost	Medium	Sometimes it is low and sometimes high, depending on the type of solvent	Higher than the previous ones
6	Ease of application in the field	Easy and based on the mixing concentration control	very easy	More complicated, because it needs a special technique
7	The extent of its interaction with asphaltins	Effective in breaking up asphaltins	Very effective, especially aromatic solvents	Very effective through adsorption and fragmentation at the nanoscale
8	Reuse	Mostly can't	Possible	Possible through the process of separation and activation
9	Safety (health hazards)	Moderate	High, especially flammable solvents	Low to moderate
10	The extent of its impact on transportation	Improves flow and reduces pressure difference	Improves flow and reduces pressure difference	Improves flow and reduces pressure difference excellently if applied correctly.

Nomenclature list

Symbol	Definition
DRA	Drag reduction agents
EOR	Enhanced oil recovery
IOR	improve oil recovery
MEK	Methyl ethyl ketone
HO	Heavy oil
EHO	Extra heavy oil
SARA	saturates, aromatics, resins, and asphaltenes
E_{LV}	cohesion energy
V_M	molar volume
NPs	Nanoparticles
DME	dimethyl ether
T	Temperature
δ	Hansen parameter
μ	Kinematic viscosity
δp	Polar component
δd	Dispersion component
δh	Hydrogen component

VR	Viscosity reduction

Result and conclusion:

For the optimal utilization of heavy oil and bitumen, it is very important to advance technology to help transport it during pipelines. In this review paper, additives used to improve the transportation of heavy crude oil and bitumen through pipelines were presented. Each of the three kinds of methods used to decrease viscosity to help transport a heavy crude oil pipeline was presented. The technologies used take into account oil characteristics, regional logistics between the wellhead and the refining locate, The operational issue, transportation distance, cost, environmental concerns and legislation. However, the current strategy in the oil industry is to integrate on-site modernization into enhanced oil thermal extraction methods due to the cost, The energy efficiency they provide and the environment. By looking at previous studies that included different methods to enhance the transport of heavy crude oil in pipes, it was found that the best method used for optimization is when using a mixture of solvents with the addition of nanoparticles. The addition of nanostructured silica particles to a solvent such as naphtha or kerosene can reduce the viscosity of heavy crude oil by 80% - 90%. Furthermore, adding surfactants to the mixture of solvents and nanoparticles significantly reduces the viscosity of the oil. In addition to the above studies have also shown that the percentage of surfactant added must be in an appropriate amount, otherwise high percentages of added surfactant lead to the opposite result, as the viscosity of crude oil increases. Therefore, it is necessary to choose an appropriate percentage of the added surfactant in order to achieve the objectives of the addition. The same applies to adding nanomaterials. Adding high and inappropriate percentages of nanoparticles leads to agglomeration and aggregation of the particles, and thus they will lose their properties through which the process of adsorption of metals and impurities in the crude oil takes place. Through the nanoparticles' adsorption of minerals and impurities in the crude oil, the process of upgrading the crude oil occurs. However, if the added percentages increase, agglomeration of the nanomaterials will occur and they will lose their function in improving the properties of the heavy crude oil. Rather, their agglomeration, aggregation, and deposition increase the percentage of impurities in the crude oil, and thus the pulling force will increase, which in turn will increase the viscosity percentage. For all of this, we cannot determine a single ratio for all types of nanoparticles or types of surfactants, so it cannot be said that this ratio is appropriate for all types, but rather the appropriate ratio added is determined through experiments and practical studies, and as the research papers that have been done have shown it. Collect and analyze. As for the solvents used, studies have also shown that the volumetric percentages added vary depending on the type of solvent and its physical properties. Therefore, it is not possible to determine a single volumetric ratio, so it is said that it is the optimal ratio to use for all types of solvents. Rather, each solvent must be studied separately. For some solvents, the optimal volumetric ratios to be added to crude oil are: 1:15, and for others: 1:10, Some of them: 1:8, some of them: 1:5, some of them: 1:4, some of them: 1:3, some of them: 1:2, and some of them: 1:1. With the caveat that the optimal ratio is not the best in improvement, but rather it is the ratio that achieves improvement at the lowest cost. Otherwise, adding high percentages of solvent leads to a higher improvement and upgrade, but this upgrade comes at a high cost, so engineers and scholars in the oil industry are looking to achieve the appropriate and required adjustment. At the lowest cost.

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