Chapter

Methods for Enhancing Recovery of Heavy Crude Oil

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Abstract

The methods of enhancing recovery of heavy crude oil explore the importance of enhanced oil recovery and how it has grown in recent years due to the increased needs to locate unconventional resources such as heavy oil, shale, and bitumen. Unfortunately, petroleum engineers and managers are not always well-versed in the enhancement methods available when needed or the most economically viable solution to maximize their reservoir's productivity. Various recovery methods have been explored to extract heavy oil from deep reservoirs or oil spills. This chapter summarizes the details of methods, namely nanoparticle technology, carbon dioxide injection, thermal recovery and chemical injection, which include the methodology as well as the findings.

Keywords: enhancing oil recovery, nanoparticle, carbon dioxide injection, thermal recovery, gas injection

1. Introduction

The production of oil is classified into three phases; primary, secondary, and tertiary. First, the primary recovery involves the extraction of hydrocarbon which naturally rises to the surface. Then, for the second phase, water and gas are injected into the well to push oil to the surface [1]. After the second phase is done, there is still about 60–80% of oil left inside the well [2]. Thus, the implementation of enhanced oil recovery (EOR) during the last phase which is the tertiary phase can contribute up to 30% of original oil in place (OOIP) that can be extracted. Therefore, EOR can be represented by a few techniques namely nanoparticle technology, carbon dioxide injection, thermal recovery and chemical injection.

Heavy oils have the American Petroleum Institute (API) gravity of between 10 and 20 API and a viscosity greater than 100 cP with the characteristics of being asphaltic, dense and viscous. More energy demands are required for the elevated viscosity and the density of these crude oils in their production, and upgraded as well for transportation. Recovery of heavy oil is expected to make an important contribution towards environmental protection as well as energy and resource conservation.

2. Nanoparticle technology

Nanotechnology is one of the methods which attracts great attention nowadays in enhancing oil recovery because it is cost-effective and environmentally friendly [3].

Commonly, the size of nanoparticles for oil recovery is in a range of 1 to 100 nm. The size may slightly differ from any other international organization. First and foremost, the metallic oxide nanoparticles explaining the nature of the metal element which has low ionization potential and low electronegativity shows that it is a reactive and unstable element. The metal element can easily lose an electron, and form a stable state when in contact or react with oxygen. There are a few examples of metal oxide nanoparticles that have been studied lately such as aluminum oxide, copper(II) oxide, iron oxide, nickel oxide, magnesium oxide, tin oxide, titanium oxide and zinc oxide [4].

In enhancing oil recovery (EOR) with nanoparticles, the most influential factor is the interfacial tension (IFT). This parameter contributes to decreasing the capillary force, thereby increasing the oil recovery. Several studies show that IFT reduction between the oil and aqueous phase when mixed with nanofluids increase oil recoveries [5–7]. The trapped oil droplets may have deformed whilst the IFT between the oil and aqueous phase reduced, and it may pass the pore throats easily [5, 8]. Another parameter is the wettability, as it is measured by the complex interface boundary conditions acting within the pore space of sedimentary rocks [9, 10]. The alteration via wettability happens if nanoparticles are absorbed on the surface of grains. The most recommended metal oxide nanoparticles as enhancing oil recovery agent for heavy oil reservoirs is aluminum oxide (Al_2O_3) nanofluid. It can decrease the oil-brine IFT and oil viscosity. Spontaneous imbibition recovery in sandstone cores shows the highest recovery when the Al_2O_3 nanoparticles are dispersed in diesel [11]. Other than that, an experiment conducted by researchers found that Al_2O_3 nanoparticles can de-stabilize water drops which reduce the water in oil emulsion. This case indicates that Al_2O_3 may decrease the emulsion viscosity [12, 13]. However, it concludes that higher concentration of nanoparticles can block pore throats due to the aggregation of particles around the pores, and this may lead to prevention of oil recovery. This proves that in the study by Alomair et al., [12] the lowest concentration of 38.5% of oil recovery is obtained due to the IFT reduction and emulsion viscosity. Since iron oxide has a unique magnetism nature and low toxicity, iron oxide particles can reduce the viscosity of crude oil [14]. As iron oxide spreads in brine, it can be a good oil recovery agent in sandstone reservoirs. For unprompted imbibition in sandstone rocks, it shows that when diesel is selected as a dispersing agent, iron oxide can act as a better oil recovery candidate with instances of 82.5% of total oil recovery. Researchers have experimented with iron oxide to coat polymer in the separation of water and oil [15]. Polyvinylpyrrolidone (PVP) is the polymer used and coated with this nanoparticle, and results in near 100% of oil recovery due to the PVP that has the tendency to absorb both aliphatic and aromatic components of oil component, and the iron oxide acts as a structural support which allows magnetic separation from aqueous phase easily.

On the other hand, nickel oxide (Ni_2O_3) nanoparticles also show the same nature as Al_2O_3 nanoparticles. The effects of dispersed nanoparticles in heavy oil show the recovery of up to 85% of the asphaltenes in the original solution. According to Ogolo et al. [4], spontaneous imbibition and core flood experiments are seen on sandstone rock samples at room condition. The observation for spontaneous imbibition experiments which result in aluminum, nickel, and iron oxides are best found in oil recovery agents especially when diesel is selected as the dispersing agent. In the case of the core flooding experiments, nickel oxide nanoparticles are found to increase oil recovery when injected into sandstone cores after waterflooding. The recovery factor is found to be higher particularly when brine is used as the dispersant for nickel oxide particles. The study claims that the nickel oxide nanoparticles can increase the viscosity of the displacing fluid, and decrease the viscosity of the displaced oil.

Furthermore, magnesium oxide (MgO) and zinc oxide (ZnO) nanoparticles are used during core flood tests which spread in brine or ethanol. It can cause permeability impairment in sandstone rocks. It is found that soaking the rock samples in ethanol and magnesium oxide nanoparticle solution could significantly reduce the oil viscosity. For ZnO, the investigation of the applications of this inorganic compound in enhancing oil recovery processes are very limited. As stated by Ogolo et al. [4], similar to magnesium oxide, when ZnO is used as an enhancing oil recovery agent in sandstone, it shows a negative effect on the permeability of the samples used. The study claims that the problem initiated by agglomeration of the zinc oxide nanoparticles at the injection point can block the pores.

Other than that, Zirconium oxide (ZrO_2) nanoparticles are rarely used in the oil and gas industry and in enhancing the oil recovery process. Ogolo et al. [4] inject metal oxide as an enhancing oil recovery agent at room temperature into a sandstone core sample. It results in a small increase in oil recovery compared to the injection of distilled water alone. When brine or ethanol is used as dispersing agents, it reduces the recovery factor to less than that achieved in the absence of nanoparticles [4]. Tin oxide (SnO_2) nanoparticles are investigated by Naje et al. [16]. SnO_2 nanoparticles have recently attracted a lot of attention from researchers in various fields. Generally, SnO_2 is not used in oil recovery processes extensively. Studies are done by Ogolo et al. [4] on the potential of SnO_2 as oil recovery agent. The results obtained by these researchers show that SnO_2 performs like zirconium oxide and increases oil recovery in sandstone cores while spread in distilled water [16].

For TiO_2 nanoparticles, an analysis using these nanoparticles for water flooding are done, and 80% of oil recovery from oil-wet Berea sandstone in the EOR process comes out. After that, the test is done again, but with the absence of nanoparticles which show a result of 49% in amount [17]. However, the tendency of these particles to aggregate and precipitate results in a milky solution and impossible to measure the IFT [11]. They also conduct a coreflood experiment with TiO_2 and achieve 76% points of original oil in place (OOIP) with 0.05%wt of concentration by using povidone as dispersant since it reduces the particles plugged at inlet points [11].

Instead of the use of metal oxide nanoparticles, researchers also found organic and inorganic nanoparticles that may contribute to the EOR system. For organic nanoparticles, a study found the use of Multiwall Carbon Nano-tubes (MWNT) potential fluid for EOR agent in a high-temperature condition and high-pressure reservoirs [18]. There are two results which are in the absence and presence of electromagnetic waves. For the absence of electromagnetic waves, it shows 36% of oil recovery after the injection of the MWNT nanofluids, while in assistance of electromagnetic fields, it shows almost double the recovery. The higher results have been directly related to the oil viscosity reduction associated with the electromagnetic field. Also, the application of these nanotubes has been reported to increase the efficiency of drilling fluids [19].

In inorganic nanoparticles, the prominent element used is silica. The SiO_2 nanoparticles as proposed by Ogolo et al., [4] shows that the application of SiO_2 in water-wet sandstone reservoirs with this type of nanoparticles can be considered as a suitable EOR agent for this type of rock. Researches reveal that the specific surface area of the SiO_2 powders almost have no change even when it is heated to various temperature of up to 65°C, and proven with good thermal stability [20]. It also does not need a stabilizer compared to metal oxide by forming a more stable emulsion in 3%wt NaCl brine, and achieving higher oil-brine IFT compared to a mixture of brine and stabilizer on its own, resulting in higher oil recovery from Berea sandstone [9].

Researchers investigate that SiO_2 nanoparticles on the bubble surface enhance the foam stability against film rupture and Ostwald ripening [21]. The bubbles

Nanoparticles	Findings	References
Aluminum oxide (Al_2O_3) nanofluid	• Mostly used nanoparticles in enhancing oil recovery (EOR) process. • Al_2O_3 decreases oil brine interfacial tension (IFT). • Total recovery due to nanoparticles (distilled water as dispersing agent) is 12.5%. • Total recovery due to nanoparticles (brine as dispersing agent) is 5.0%. • Al_2O_3 decreases oil viscosity.	[4, 11, 12]
Iron oxide	• Has a unique magnetism characteristic. • Can reduce oil viscosity. • Total recovery due to nanoparticles (distilled water as dispersing agent) is 9.2%. • Diesel as a dispersing agent reached 82.5% of oil recovery.	[4, 14, 15]
Nickle oxide (Ni_2O_3)	• Has the same characteristics as Al_2O_3. • Total recovery due to nanoparticles (distilled water as dispersing agent) is 2.0%. • Total recovery due to nanoparticles (brine as dispersing agent) is 1.7%. • The oil recovery reached up to 85%.	[3, 4]
Magnesium oxide (MgO)	• Cause permeability impairment in sandstone rocks. • Reduce oil viscosity when soaking the rock sample in ethanol with MgO. • Total recovery due to nanoparticles (distilled water as dispersing agent) is 1.7%.	[3, 4]
Zinc oxide (ZnO)	• Very limited use in EOR. • These nanoparticles can block the pores, showed a negative result. • Total recovery due to nanoparticles (distilled water as dispersing agent) is 3.3%.	[3, 4]
Zirconium oxide (ZrO_2)	• Rarely used in EOR. • Show small recovery of oil compared to distilled water alone. • Total recovery due to nanoparticles (distilled water as dispersing agent) is 4.2%.	[4, 16]
Tin oxide (SnO_2)	• Same characteristics as zirconium oxide. • Increases oil recovery while spreading in distilled water. • Total recovery due to nanoparticles (distilled water as dispersing agent) is 3.3%.	[4, 16]
Titanium dioxide (TiO_2)	• Recover 80% of the oil from oil wet Berea sandstone. • Reduce the oil brine IFT. • Achieved higher oil recovery in wet formation compared to SiO_2.	[11, 17,]
Multiwall carbon nanotubes (MWNT)	• Absence of electromagnetic (EM) wave shows 36% of oil recovery. • The presence of EM waves shows 72% of recoveries.	[18, 19]
SiO_2	• Less oil recovery at room temperature. • Considered as suitable EOR agent in all different wettability conditions. • Forming stable foam, more stable bubbles penetrate further inside the pore which can displace more oil.	[4, 9, 20–22]

Nanoparticles	Findings	References
Hydrophobic silicon oxide (SiO_2)	• The small size of these particles in the range of several to tens of nanometres reduces the risk of blocking the pore in an EOR process.	[3, 4]
Inorganic silica core or polymer-shell nanocomposite	• Can reduce IFT. • Increasing the viscosity at critical concentrations. • Can be an excellent EOR agent for sandstone reservoirs, especially when dispersed in ethanol.	[23, 24]

Table 1.
Summary of nanotechnology method in EOR process.

are more stable than foam when they meet the residual oil due to bigger bubbles being flushed and squeezed into smaller ones towards the dead-end. The more stable bubbles penetrate further inside the pore which can displace more oil. When the stable bubbles invade the dead-end pore, the microforces acting on the oil droplet also help to recover more oil. The attached nanoparticles on the bubbles reduce the surface area available for interbubble gas diffusion, which stabilize foam against Ostwald ripening [22]. Other than that, the use of SiO_2 nanoparticles during core-floods conducted at room temperature result in less recovery, and it is still considered as a suitable EOR agent in all different wettability conditions from water-wet to intermediate and oil-wet. Researchers explain that alumina coated silica nanoparticles on the SiO_2 nanoparticles entirely alter their properties.

The coating creates a positive charge on the surface of a nanoparticle. The study proves that alumina coated with SiO_2 possesses higher surface area compared to those without coating, and when disposed into the environment, it shows lower toxicity. The study also comes out with fascinating results in which alumina coated silica nanoparticles with modified surface form a more stable foam and result in good oil recovery from sandstone cores compared to the bare nanoparticle or any surfactant flooding. For hydrophobic silicon oxide nanoparticles, it is demonstrated with addition of silanol (Si-OH) group into the silica nanoparticles surface, and completed with a satisfying result, showing that it is a better EOR agent in sandstone reservoir compared to the metal oxide nanoparticles [4].

Other than that, most researchers use the spherical fumed silica nanoparticles as a stabilizing agent for oil/water emulsion [23]. In EOR studies, it has limited direct use in flooding experiment and has not been studied yet. However, the size of the nanoparticles is suitable for EOR activities which can reduce the risk of blocking the pores. After that, as for inorganic silica core or polymer-shell nanocomposite, its build is illustrated as SiO_2 nanoparticles in the core covered with a shell of synthetic polyacrylamide polymer. The composite nature of the nanoparticles is suitable to be applied for higher temperature and salinity with the presence of hard ion that can be found in offshore reservoir [24]. **Table 1** show the summary of nanotechnology method in EOR process.

3. Carbon dioxide injection

Another effort in increasing the production of oil from the reservoir is the type of method in the EOR process. In secondary production including water flooding and gas injection, it is employed to increase production by boosting depleted pressure in formation. After the oil and natural gas in a formation is produced, the remaining trapped hydrocarbon in the reservoir due to the pressure in the formation is reduced. Therefore, the production is either slow dramatically or stop altogether [25]. In the secondary phase, gas injection is used on a reservoir in enhancing waning pressure within the formation. It will systematically spread throughout the field, and the gas-injection reservoir is used to inject gas and effectively sweeps the formation for remaining petroleum and boosts production [26].

The gas injection, also known as miscible flooding, maintains the reservoir pressure and improves the oil displacement due to the reducing interfacial tension between water and oil. The techniques remove the interface between the two interacting fluids, and this allows for total displacement efficiency [27]. The gasses used are carbon dioxide (CO_2) and natural gas or nitrogen, but CO_2 is commonly used for miscible displacement because it reduces the oil viscosity and cheaper [28]. Oil displacement by CO_2 injection depends on the mixtures of the gas and the crude phase behavior, which are strongly dependent on reservoir temperature, pressure and crude oil composition.

The use of CO_2 as an injection fluid in oil reservoirs has been widely investigated [29]. The characteristics of CO_2 include ease to dissolve oil, can reduce the viscosity of the oil, use moderate pressure to extract the oil's light component, and can form heterogeneously with oil at relatively small pressure [30]. Besides, CO_2 has minimum miscibility pressure (MMP) compared to other gasses. From the study, oil recovery has been improved by manipulating injection pressure (3000, 3144 and 3400 psi) for both horizontal and 450 down dip displacement processes. It can also be said that oil recovery and displacement efficiency increase with the increase of injection pressure. Thus, high pressure can produce maximum displacement efficiency and oil recovery.

The solvent-based process such as cyclic solvent injection has shown a significant contribution in enhancing heavy oil recovery. The examples of solvent are CO_2, flue gas, and light hydrocarbon gases such as natural gas, methane, ethane, propane, and butane. The cyclic solvent injection is an initiative for cyclic steam injection for heavy oil. This is done by injecting the gas into a well (huff cycle), followed by a short shut-in time and then the well is returned to production after a soaking time to allow solvent interaction with oil formation (puff cycle) [31]. Firouz and Torabi [31] investigate the efficiency of the huff-and-puff recovery technique through eight sets of cyclic injection experiments at different operating pressure, utilizing pure CO_2 and pure methane to enhance heavy oil recovery. 71% of oil recovery is obtained by injecting pure CO_2 at the near supercritical condition of 7239 kPa and 28°C, while 50% of oil recovery is obtained by using pure methane at the highest operating pressure of 6895 kPa. The production is contributed by several governing mechanisms such as solution gas drive, viscosity reduction, extraction of lighter components, the formation of foamy oil and to a lesser degree of diffusion process.

Consequently, a study is also done via a long core in the CO_2 huff "n" puff process. When the CO_2 is injected into the core, diffusion occurs to prove viscosity reduction and oil swelling. The IFT between the CO_2 and heavy oil declines [32, 33]. The mobility then increases, and oil recovery enhances significantly. The ultimate heavy oil recovery factors are as high as 32.75%, which is a very good production performance for a cold heavy oil production process [34]. Another study is done in which the CO_2 injection is compared with the injection of nitrogen gas. Both gases show a positive result in oil recoveries and the recoveries are led with the injection of CO_2 gas with 15.8% based on OOIP.

When CO_2 is in the soaking stage, it can also lower the viscosity, and alter the relative permeability hysteresis of higher oil recovery. Then, by using this gas injection, the recovery obtained is ultimately higher at 85.9% based on OOIP compared to the injection of nitrogen gas at 64.7%. In 2017, further study was done and the team investigated the probability of improving oil recoveries for 21 samples at reservoir conditions. The oil transportability in the small pores improves, then the CO_2 can extract oil from the unconventional core samples by diffusion. The result proves that by injecting this gas, it is able to recover up to 99% of oil samples in 24 hours under reservoir condition exposure, and it summarizes that the CO_2 could be injected to highly fractured tight reservoirs through fractures to recover oil [35, 36].

Particularly, injecting the CO_2 in a supercritical state is effective in reservoirs with depth of about 2000 feet. It can be applied in high pressure with lighter oil, as a result of oil swelling, in reducing the viscosity and possible in reducing IFT with the reservoir rock. For low pressure or heavy oils case, CO_2 will form an immiscible fluid, or it can only partially mix with the oil. Some oil may be swelling and significantly the oil viscosity still can be reduced [37]. In this application, there is about one-half and two-third of injected CO_2 return with the produced oil. Usually, it is reinjected into the reservoir to minimize the cost. Thus, the use of CO_2 as a solvent is beneficial for being more economical than other similar miscible fluids such as propane and butane [38].

Besides that, water-alternating-gas (WAG) is another method implemented in the EOR process. As water mixing with CO_2 is used, the saline solution is used to not disturb the carbonate formation in the reservoir. Water mixed with CO_2 is injected into the reservoir for a larger recovery as the mixture has lower miscibility with oil. The use of both water and CO_2 also lowers the mobility of CO_2 gas, for instance, making the gas more effective at displacing the oil in the reservoir [39]. The researcher states that using a small slug of both CO_2 and water allows for a quick recovery of the oil. Additionally, in a study done by Saxena K. [40], using water

Findings	References
• CO_2 can easily dissolve in oil. • Injecting CO_2 can reduce the oil viscosity in the reservoir. • Only requires moderate pressure to be applied for oil recovery. • CO_2 can form heterogenous when mixing with oil in the reservoir.	[30]
• The diffusion occurs when CO_2 injected into the reservoir and this leads reduction of viscosity and oil swelling.	[32, 33]
• The mobility of oil increases after the injection of CO_2. • Heavy oil recovery achieved as high as 32.75% when CO_2 is injected.	[34]
• The injection of CO_2 gas able to recover up to 99% of oil samples. • The CO_2 could be injected on to highly fractured tight reservoirs through fractures to recover oil.	[35, 36]
• CO_2 gas will form an immiscible fluid for low pressure or heavy oils case. • The gas only partially mixes with the oil then some oil may be swelling, and the oil viscosity still can be reduced.	[37]
• CO_2 gas is more economical than other miscible gas such as propane and butane.	[38]
• Water-alternating-gas (WAG) making the gas more effective at displacing the oil in the reservoir.	[39]
• Using water allows for greater oil removal and greater geochemical interactions in WAG.	[40]

Table 2.
Summary of carbon dioxide injection method in EOR process.

with lower salinity allows for greater oil removal, and greater geochemical interactions [40]. **Table 2** show the summary of CO_2 injection method in EOR process.

4. Thermal recovery

Thermal EOR is another technique used for more than 50% in the EOR process. Steam injection is the most common method in thermal EOR including the in-situ combustion [41]. This process involved by heating the reservoir and then the injected high-oxygen gas mixture was burnt to create the combustion front. Basically, for the steam injection, it is applied in a shallow reservoir containing high viscosity oil usually for heavy crude oil, for example, the reservoir in the San Joaquin Valley of California or the oil sands of Alberta, Canada [42]. In the 1960s, steam injection is commercially used and well understood by the researchers in EOR. Steam injecting heats the crude oil in the formation whilst lowering the oil viscosity and at the same time the steam will vaporize some of the oil to increase its mobility.

Besides, when the crude oil viscosity decreases the surface tension also reduces. It increases the permeability of oil and improves the reservoir seepage condition. When oil vaporizes, it allows the oil flowing freely through the reservoir and forms a better quality of oil once it has been condensed. The steam injection EOR varies with two distinct categories: cyclic steam stimulation and steam flooding [43]. For cyclic steam stimulation, the same reservoir is used for steam injection and oil production. Firstly, the steam is injected for a period from a couple of weeks to a couple of months. The introduction of the steam into the reservoir immediately allows the oil to heat up through convective heating, and at the same time it is lowering the oil viscosity. After the targeted oil viscosity is achieved, the steam injection stops to allow the heat to redistribute evenly in the formation. By doing that, it can contribute by increasing the amount of oil recovered after this stage. These steps are repeated when the reservoir temperature drops and the viscosity of oil increases again.

Other than that, steam flooding injection and production wells vary from each other. Steam is introduced through the injection wells and move towards the oil by physically displace while heating the oil to reduce its viscosity. The steam flooding is in the continuous form which allows the steam to drive the oil towards the production wells. Compared to cyclic steaming, this steam flooding is more costly due to this method which requires more steam during the process. Nonetheless, this method usually recovers a big portion of oil. In some cases, both methods can be implemented together for cyclic stimulation followed by steam flooding [44].

Thermal Oil Recovery is by far the most popular method used in the world during the tertiary stage of oil recovery. Steam injection is the most common method

Findings	References
• Using steam injection to heat the crude oil in lowering the oil viscosity.	[41]
• The steam injection was applied in a shallow reservoir containing high viscosity oil which usually suitable for heavy crude oil.	[42]
• Thermal recovery method used to recover a big portion of oil. • Both methods can be implemented in cyclic stimulation followed by steam flooding in EOR.	[44]

Table 3.
Summary of thermal recovery method in EOR process.

used in thermal EOR. It helps produce up to 30% of OOIP. Steam injection does not pose as many environmental risks as other EOR methods might have. This helps implement this technology in different countries, even with strict regulations. The economy is the main factor that determines if this technology should be implemented in one field or the other. **Table 3** shows the summary of thermal recovery method in EOR process.

5. Chemical injection

Usually, the injection of any type of chemical as a dilute solution is used in mobility aid and the reduction of IFT. The injection of an alkaline or caustic solution into the reservoir with oil which consists of organic acids that occur in the oil naturally will produce a soap that may reduce the IFT, and sufficient to increase the production of oil [45]. Other than that, water-soluble polymer diluted solution is injected to increase the viscosity of injected water in the reservoir which can improve the amount of oil recovered in some formations. For example, the use of petroleum sulfonates as surfactant or biosurfactant such as rhamnolipids in dilute solutions can lower the IFT or capillary pressure that impedes oil droplets from moving through the reservoir. So then, this is analyzed in terms of the number of the bond, relating the capillary forces to gravitational ones.

Special formulations of oil, water, surfactant and microemulsions can be particularly effective in reducing interfacial tension. Concerning this application of these methods, they are usually limited by the cost of the chemicals and their adsorption and loss onto the rock of the oil-containing formation. All the chemicals are injected into several reservoirs and the production occurs in other nearby wells. These methods include the polymer flooding, microbial injection, and plasma pulse.

For polymer flooding, it consists of long-chain polymer molecules mixed with the injected water to improve the water viscosity. It also implements the vertical and areal sweep efficiency to improve the water/oil mobility ratio [46]. The surfactant may be used in conjunction with polymer, it decreases the IFT between oil and water. This reduces the residual oil saturation and improves the macroscopic efficiency of the process [47]. Primary surfactants usually need the addition of co-surfactant, activity booster and co-solvent in fixing the stability of the formulation. As caustic flooding is the addition of sodium hydroxide into the injection of water, therefore, it lowers the IFT, reversing the rock wettability, oil emulsification, the oil mobility and aids in drawing the oil out of the rock.

Other than that, the microbial injection which is part of microbial EOR is a method rarely used due to the higher cost and not preferable. These microbes help in EOR by generating biosurfactant in partially digesting long hydrocarbon molecules or by emitting CO_2 gas. There are a few studies in achieving this microbial injection. Bacterial cultures are mixed with food source such as molasses injected into the reservoir. Then, the second approach is where the nutrients are injected into the ground to nurture the existing microbial bodies. The bacteria tend to help in increasing the production of natural surfactants which they normally used to metabolize the underground crude oil [48]. After the injected nutrients are utilized, the microbes will be terminated where their exterior surface will become more hydrophilic. At the same time, the microbes will migrate to the oil-water interface area where it will cause the oil droplets to form a larger oil mass. Thus, making the droplets to be more likely to migrate to the wellhead. **Table 4** shows the chemical injection method in the EOR process.

Findings	References
• The injection of an alkaline or caustic solution into the reservoir with oil produces a soap that can reduce the IFT. • Water-soluble polymer diluted solution also can be used in reducing the IFT. • This may lead in increasing the production of oil.	[45]
• Polymer flooding consists of long-chain polymer molecules mixed with the injected water can improve the water viscosity. • It implements the vertical and areal sweep efficiency due to improving the water/oil mobility ratio in the reservoir.	[46]
• The surfactants may be used in conjunction with polymer, it decreases the IFT between oil and water. • This will reduce the residual oil saturation and improves the macroscopic efficiency of the process.	[47]
• Using microbial injection in generating the biosurfactant or emitting CO_2 in decreasing the IFT of oil. • Nutrients are injected into the ground to nurture the existing microbial bodies and these nutrients cause the bacteria to help increase the production of natural surfactant which they normally used to metabolize crude oil underground. • Causing the oil droplets to form from the larger oil mass and making the oil move to the reservoir surface.	[48]

Table 4.
Summary of chemical injection method in EOR process.

6. Conclusion

Most studies show that nanoparticles can be used in increasing the oil recovery from an oil reservoir in which this nanotechnology in displacement fluid can lower the interfacial tension, change the wettability of rock to a more water-water state. It also lowers the adsorption of surfactant on reservoir rock, but the stability of nanoparticles is the most challenging problem as well as the aggregation of nanoparticles. Besides, there is a nanoparticle technology that has not been discovered and needs further investigation in EOR. The most concerning problem in nanoparticle technology is costly in the application and its effects on the environment. Nevertheless, using the recommended nanofluid to flush a depleted reservoir or using ethanol itself may boost or improve the oil recovery.

After that, the CO_2 injection has the potential in the application for enhancing heavy oil recovery with CO_2 injection, and it is increasing in reservoir pressure and driving higher forces to produce more oil. Sometimes injected gas mixes and dissolves in oil. Thus, the oil viscosity decreases because oil moves easier than before and oil production improves. Therefore, the prominent benefits using CO_2 gas is the miscibility of gas in crude oil, less expensive and is an excellent method in EOR where the injection may improve oil recovery at the same time, the greenhouse gas profile is improved as well.

Besides, thermal EOR is a commonly used method in the world during the tertiary stage which helps improve the production of oil about 30% of OOIP. It also does not contribute to any environmental risk or pollution as another method in EOR might have. For the chemical injection, this method uses many types of chemicals including polymers and surfactants. It can reduce the IFT and increase the flooded water viscosity. This method is used followed by the waterflood where it captures residual oil then the production of oil is up to 15% incremental. In a nutshell, both nanoparticles, CO_2 injection, thermal recovery and chemical injection in enhancing oil recovery are reviewed. The results are promising and there is still a chance for these methods to become better.

Acknowledgements

The authors would like to acknowledge the Centre for Biofuel and Biochemical Research (CBBR) and Chemical Engineering Department, Universiti Teknologi PETRONAS for the support.

Conflict of interest

The authors declare no conflict of interest.

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