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An Overview of Oil Recovery Techniques: From Primary to Enhanced Oil Recovery Methods

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ABSTRACT

As we all know, numerous methods have been invented for better managing of the reservoirs to recover the trapped oil from them as much as possible. These techniques included primary techniques that were implemented primarily at the beginning of this industry. As these techniques were not effective enough, secondary techniques, like; *water flooding* and *gas injection* methods were created and the amount of recovered oil were increased, as well. On the contrary, the demand for more oil was raised up and it was felt that much more effective techniques are necessary. It resulted to creation of *Enhanced Oil Recovery Techniques* and these techniques are included; thermal methods (steam injection, steam assisted gravity drainage and in-situ combustion), Chemical methods (alkali flooding, surfactant flooding, polymer flooding, foam flooding, and combination of alkali-surfactant-polymer flooding), and microbial EOR. The most promising technique is microbial EOR because of being cost-effective and ecofriendly. GEMEOR (Genetically Engineered MEOR) and EEOR (Enzyme Enhanced Oil Recovery) are two new trends of MEOR that own potential hopes in petroleum industry.

Keywords- waterflooding, enhanced oil recovery (eor), gas injection, thermal eor, interfacial tension, wettability, surfactant injection, polymer injection, alkali injection, foam injection, microbial enhanced oil recovery.

I. INTRODUCTION

Oil recovery technology is an extremely important part of petroleum industry, that includes a large group of techniques designed for extracting the optimal amount of oil from reservoirs beneath the Earth's surface. As global energy demands raised up, optimizing the recovery of oil became paramount for sustainable resource utilization. The oil extraction from any reservoirs passes through three stages. The initial step, is the extraction of oil from the reservoir by utilizing reservoir pressure naturally, the next phase is pumping saline water to maintaining the pressure of the well after falling down of the pressure [1]. As a result, it pushes the

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oil up from the well and enhanced the oil recovery process. During the primary and secondary stages of oil recovery approximately 20-30% of the OOIP from the well is extracted. Although around 70% of the oil are left over the reservoir is called depleted. For recovering the left amount of the oil, the third stage is implied and it is called the *Enhanced Oil Recovery (EOR)* or tertiary recovery [2]. Whereas the secondary oil recovery techniques only sweep the oil through the reservoir by injecting of the water or gas, without altering the properties of the hydrocarbons, enhanced oil recovery methods get involved by changing the reservoirs [3]. In other word, EOR methods change the natural or actual properties of the wells like; density and viscosity of the crude oil that make the disposition process easier. By applying EOR techniques, oil recovery can rise up to 75% depending on the employed technique [2]. We will discuss all these three stages with details in upcoming parts.

II. PRIMARY OIL RECOVERY

This technique is named as the begging step of the oil extraction, that just imply the natural potential energy of the reservoirs, like; pressure and some mechanical ways to pull the oil up to the surface. This method is dependent only on natural pressure of the reservoirs, which is the only and main factor of oil production or extraction from the reservoirs. But this driving force or the natural pressure energy depletes or decreases in early producing life of the reservoir, so it needs to re-pressurize the reservoir for prolonging the production life of the reservoir. That is the reason that secondary oil recovery techniques are used for extending the production life of the reservoir and recovering more oil [3]. Primary recovery methods include; (i) Natural reservoir pressure; the natural pressure within the reservoir itself is sufficient to force oil to the surface, allowing for oil recovery without additional artificial methods. (ii) Mechanical lifts; When the natural pressure is insufficient, mechanical lifts such as pumps or other artificial lift mechanisms are employed to bring oil to the surface. However, primary recovery techniques usually recover only a small portion of the total oil presents in the reservoir, leaving a substantial amount unrecovered. The followings are some examples of primary oil recovery techniques; natural flow, pumping systems, gas lift, rod pumping, and plunger lift.

III. SECONDARY OIL RECOVERY

Secondary recovery methods aim to enhance oil recovery beyond what primary methods can achieve. These techniques involve the injection of external fluids into the reservoir to disposition oil and improve recovery rates. Key secondary recovery techniques include:

3.1. Water Flooding

Water-flooding is a viable alternative to bring back the wells to production by the maintenance of pressure [1], [4]. After recovery some oil from the reserves the pressure decreased and it causes to declining the recovery process. By injecting the water into the reserve, we can control the pressure of the reservoirs and govern the displacement of oil to the producing wells [5]. Water injection is cost-effective because of abundance of water resources and desired characteristics like; viscosity, density and wetting properties. There are two factors that determine the time and schemes to implanting the water flooding; (i) the amount of producible oil reserves, and (ii) nature of drive mechanisms of the reservoirs. One of the considerable potential candidate for water-flooding can be solution-gas drive reservoirs.

Water-flooding technique was used around the world in the 1960s in the majority of the fields regarding to recover much more oil. The success of utilizing this technique depends on the properties and characteristics of the crude oil and the rock formation like; the residual oil saturation, initial gas saturation rate of injection and arrangement of the injectors and producers [3].

Water-flooding technique is not applicable and effective enough in all types of reservoirs. For example; it does not displace all the oil from pore spaces in carbonate reservoirs, because of the capillary pressure difference and nature of wettability of the reservoir rock [6], [7]. Because carbonate reservoirs are fractured reservoirs that contain lots of cracks and fractures that water cannot flow through such fractures. These reservoirs characterized by vugs, multiple porosity and extremely less homogeneity which lead to poor sweep efficiency of oil [8]. For overcoming this challenge, the new technique of water-flooding came to view, that is called *low salinity water injection (LSWI).* Utilizing low salinity water, in water-flooding process shifts the wettability of the rock towards more water-wet nature and releases the oil trapped in the pores [9], [10]. Low salinity water injection is an emerging and improved oil recovery technique, and several aspects of design to identify its suitability have been analyzed [11], [12]. Low salinity water injection is utilized in light crude oil reservoirs that there should be some amount of clay, and clay content must not be high. It is proved that high temperature, low acid number and the presence of Ca^{++}, Mg^{++} or SO_4^{2-} are favorable for low salinity injection in carbonate reservoirs [3].

3.2. Gas Injection

Gas injection method in oil recovery process, have played an essential role in maximizing hydrocarbon recovery from reservoirs. This technique started in 1864 and it is one of the oldest techniques that applied for fluid injection process to support the pressure of the reservoir in a way that is cost-effective. Gas injection in the reservoirs can be implemented before starting the recovery process or during the recovery process that the pressure declines. There are two schemes that are used for applying this technique; ***(i) Crestal Gas Injection;*** also known as top-down gas injection, it means this is a

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method of injecting gases into the upper sections or crest of the reservoir. The advantages of applying this technique can be as following; its ability to target bypassed oil zones and minimizing the risk of early gas breakthrough so it improves the overall sweep efficiency of the injected gas. ***(ii) Pattern Gas Injection;*** it involves distributing the gas injection wells throughout the oil reservoir in a particular pattern and the injection wells are deployed into the oil column [13]. The typical or usual gases that are applied in gas injection are; methane, nitrogen, carbon dioxide, associated petroleum gases, glue gases and air [14]. There are some parameters that should be considered while applying gas injection, like; (i) the gas injection rate and the time period should be sufficient enough, (ii) continuous monitoring and measurement are vital, (iii) enough waiting time before and after injection, and (iv) conducting pilot test in the early life of the developed field [3]. Several factors are significant when determining the application of gas injection techniques. These include the thickness of the net pay in the reservoir, the dimensions and relative thickness of the gas cap, the pressure and temperature conditions within the reservoir, as well as the dissolved gas content and shrinkage factor [15].

IV. ENHANCED OIL RECOVERY (EOR) TECHNIQUES

Enhanced Oil Recovery (EOR) techniques stand as a transformative frontier in the oil and gas industry, representing innovative methods deployed to extract additional hydrocarbons from reservoirs beyond the capabilities of conventional extraction techniques. As global energy demands surge and easily recoverable oil reservoirs diminish, the significance of EOR techniques intensifies in maximizing oil production.

Primary and secondary oil recovery techniques may not work effectively for recovery more oil after a while. Because of capillary force that is able to hold oil in the reservoir rock. In this case, EOR techniques are applicable because these techniques are able to decrease capillary force and reduce interfacial tension between the phases. These techniques are such methods that shift the properties and interactions of reservoir formation; crude oil and rock [3].

The primary objective of EOR is to increase the ultimate recovery factor, extracting a higher percentage of oil from reservoirs than conventional methods alone could achieve. EOR methods are broadly classified as thermal EOR, chemical EOR, gas EOR and microbial EOR methods [16], [17].

The afore-mentioned methods of EOR are selected to apply based on the reservoir rock characteristics like; porosity, permeability, crude oil saturation, pay zone thickness, and formation depth and fluid properties like; crude oil density and viscosity [3].

4.1. Classification of Enhanced Oil Recovery (EOR) Techniques

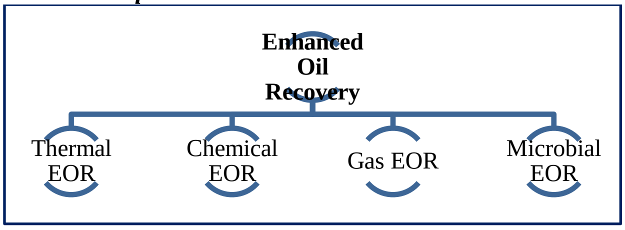

Figure 1: Schematic illustration of EOR classification [18]

1. Thermal EOR Methods

Thermal methods or techniques are the processes that heat is transferred to the reservoirs in different forms, like; in the form of steam or hot air. As a result, it changes the reservoir rock and fluid characteristics [19]. These techniques are more effective and suitable for recovering heavy oil from reservoirs that their viscosity and density are really high and usually own an API number of less than 22 [20]. The thermal energy that applied into the reservoirs uplift the temperature that reversely, decreases the viscosity and displaces the crude oil towards the production well [21]. It includes several different techniques that categorized into two groups: (i) aqueous, like; steam flooding, hot water injection, cyclic steam injection, in situ combustion and steam-assisted gravity drainage (SAGD) [3]. And (ii) non-aqueous methods, such as; electric heating and electromagnetic heating [2]. Thermal EOR techniques are more effective in heterogeneous reservoirs with high porosity sandstone [22]. Thermal techniques are broadly applied globally and there are numerous ongoing projects in the United States of America, Canada, Brazil, China, and Venezuela. We should notice that thermal EOR methods are inappropriate for reservoirs with high depth and thin pay zone [23].

a. Continuous Steam Injection

Also known as steam drive, this technique involves the continuous injection of steam from an injection well into the reservoir. During this process, the characteristics of the crude oil, such as thermal expansion, viscosity reduction, and thermal cracking, undergo changes. These changes lead to a modification in the wettability of the reservoir rock and trigger a dissolved gas drive. As the temperature decreases, the steam transforms into hot water. The water then exerts pressure on the crude oil, causing it to move towards the production well, due to the pressure gradient. This method can result in the recovery of up to 50% of the oil. However, one drawback of the steam drive is the disparity in density between the crude oil and steam, which leads to steam override [3].

b. Cyclic Steam Injection

This method was discovered by Shell Oil Company in 1959 in Venezuela [24]. Even after it is broadly applied by other countries like Brazil, Canada, and Venezuela to manage their heavy oil reserves [25]. In

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this techniques single well is used for both; injection the steam and production the oil. Steam injection takes place regularly in regular time intervals through the injection well, into the reservoir. Each cycle contains three fundamental phases; steam injection phase, soaking period that take a couple of weeks and oil production phase.

c. Steam-Assisted Gravity Drainage

This method is very famous and a widely used technique to recover viscous and highly viscous crude oil. This technique was applied in horizontal wells and two wells are used that are somehow distant from each other but in the same plant. One well that located upper serves as steam injector and another one that is located lower serves as a producer [3]. The steam is continually injected into the top well to supply thermal energy in the well for reducing the oil viscosity. Then this heated well is drained into the lower well that acts as producer and oil is pumped out from the producer [2]. It was reported by Hosseini and his colleagues in 2017, that this method is best suited and effective for heavy oil extraction in carbonate reservoirs. As SAGD is rated, the most well-known in the oil sands and extra-heavy crudes, the application of a hybrid version of SAGD like; its integration with injection of solvent with steam is at its pilot stage [2]. Crude oil recovery is considerably high (up to 60-80%) in comparison with other EOR techniques [26]. Regardless of the mentioned advantages the steam generation cost is significantly higher in this technique that can be a disadvantage of the method because it requires a large amount of natural gas and water [27]. Figure 3 shows a schematic illustration of SAGD process.

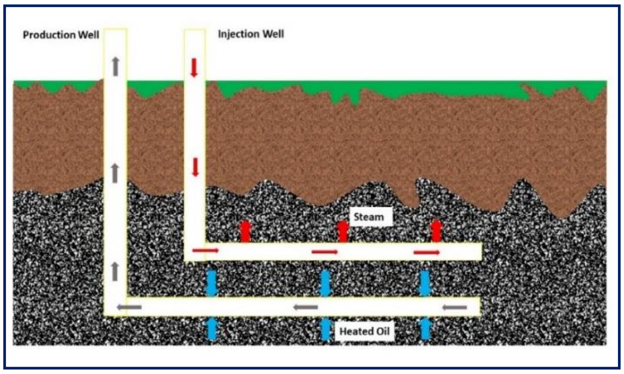

Figure 3. A schematic illustration of SAGD process (by permission of Mokheimer et al. [2])

d. In Situ Combustion

This technique is known as "fire flooding" as well, and it was incepted in the 1950s in Pennsylvania, USA [25]. In this method the adequate amount of compressed oxygen enriched air is injected into the well at pressures equivalent to the reservoir pressure. This injected enriched air interacts with the crude oil in the reservoir and causes to combustion of some amount of crude oil in the well that may be around 10% of OOIP [3]. This combustion or burning process of a portion of crude oil, heat the rock and the fluid up to 500 ºC-900 ˚C which continues till the temperature reaches the ignition temperature [28]. Consequently, the mixture will be ignited and causes a combustion that releases thermal energy and combustion gases like CO_2, CO, and H_2O which dissolves and pushes the reservoir fluids toward the production well [2]. Numerous successes and some inconclusive examples of in situ projects have been recorded and reviewed by Alvarado and Manrique [16]. There has been shown a steady growth of ISC method in carbonate formation since the end of the 1990s. This technique has successfully been applied in countries like Canada, India, Romania, and the USA. In addition, ISC is more energy-effective, it means that lower amount of energy consumed to produce a barrel of oil because the High Temperature Oxidation (HTO) process occurs directly in the reservoir [2].

2. Chemical EOR Techniques

Chemical EOR also renowned as a non-thermal EOR and it is one of the most applicable techniques that incepted in 1980s while the price of the crude oil grew extremely [23]. This technique is really effective in heavy oil reservoirs that own a thin pay zone [29]. In this technique a combination of chemicals like alkali, surfactant, and/or polymers are used to change the physicochemical characteristics of reservoir rock and contained fluids, like; interfacial tension, wettability and relative permeability. Altering of the mentioned properties causes to recover residual oil that trapped within capillaries of the reservoir rocks [30]. In chronological order, chemical EOR methods are divided into two groups; (i) conventional techniques like alkaline flooding, polymer flooding, and surfactant flooding, and (ii) modern techniques like alkaline-surfactant-polymer (ASP) flooding, smart polymers and nanotechnology.

A. Alkali Flooding

Alkali flooding is one of the most conventional methods of chemical EOR, in this technique by flooding alkali compounds in the reservoirs oil displacement efficiency can be expanded, consequently much more oil can be recovered. The core of this process is on the reaction between basic compounds, like; NaOH, Na_2CO_3 and $NaBO_2$ with organic acids that are naturally existed in the reservoirs (see figure 5). This reaction causes to produce soup like compounds that act as surfactants and decrease oil/water IFT [31]. Selection of alkali flooding as a potential candidate depends on the reservoir rock properties, crude oil characteristics and injected fluid features. For instance; the reservoirs with high total acid number and low mobility ratio (approximately or less than 1) can be the potential candidates for alkali flooding technique [32], [33].

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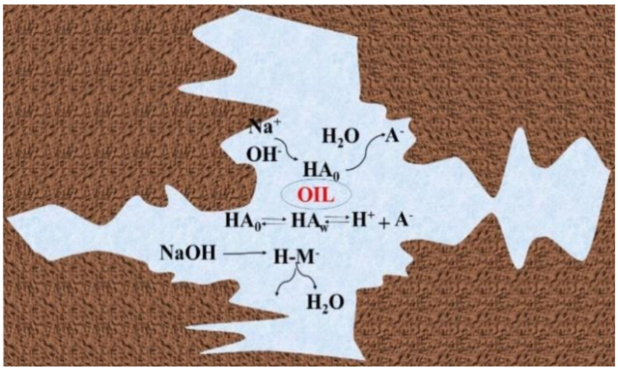

Figure 5: An illustration of alkaline flooding EOR technique (by permission of Mandal [30]*)*

Alkali injection process begins with injection of softened water (water that contain less amount of minerals), followed by the injection of a dose of alkaline solution, like; NaOH or other alkalis, as illustrated in figure 4. There is limitation regarding the alkaline dose volume that can varies from 10% to 30% of the available reservoir pore volume. Injected alkali solution leads to enhance oil recovery by three following mechanisms; (i) reduce oil/water IFT by *in-situ* production of surfactants, (ii) increase the capillary number by producing soap like components, & (iii) decrease mobility ratio of water/oil [34]. As alkaline agents are inexpensive, therefore this technique is really cost-effective than other chemical methods. We can mention western Canada clastic reservoir as successful field project of this method [35].

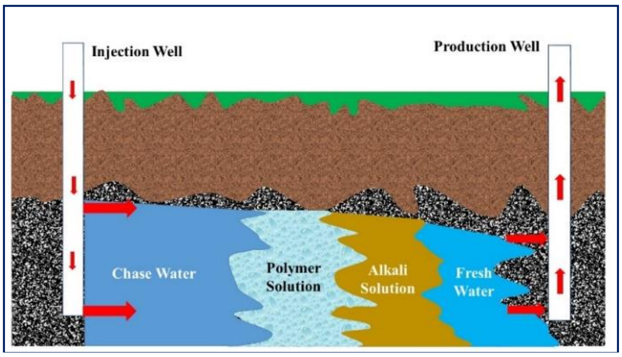

Figure 4: A schematic illustration of alkali flooding

B. Surfactant Injection

Surfactants or surface-active agents, are the chemical compounds that lower the surface tension between two phases, like; liquid/liquid, gas/liquid, liquid/solid [36]. Surfactants are the amphiphilic molecules with a hydrophilic (polar) head and hydrophobic (non-polar) tail [37]. Surfactant injection is one of the most popular way for accessing the oil that is left after primary and secondary recovery processes. The main function of adding surfactants to reservoir is to adapt different fluid interaction by minimizing the interfacial tension between oil and water. Furthermore, it targets to modify the properties of the fluid-rock system by altering the wettability of the porous medium.

Surfactant injection is a technique with greatest potential application among other recovery methods. Due to its potential it has been applied in numerous countries, like; China, the US, France, Austria, Oman and Canada [38]. It was found out, that up to 60% of the original oil in place recovered by surfactant injection [39].

There are two following mechanisms that surfactant injection enhances oil recovery process; (i) reduction of interfacial tension; based on the amphiphilic structure that surfactants own, they interact with two phases simultaneously (with water phase by its polar head and with oleos phase by their hydrophobic or nan-polar head). By this interaction they create an interfacial layer between two phases (water-oil phases as shown in *figure 6)* and decrease water-oil interfacial tension (IFT). Reducing the interfacial tension leads to increase mobilization of the oil and improves oil recovery process [40], [23]. (ii) wettability variation; wettability is defined as the tendency of one liquid to come to contact with a solid surface in the presence of another immiscible liquid. Surfactant shift the wettability of the reservoirs rock from oil-wet to water-wet. Alteration of the wettability of the reservoir to water-wet leads to decreasing capillary number, increasing oil permeability and emulsification process and, as a result; oil recovery enhancement (see *figure 7*) [41].

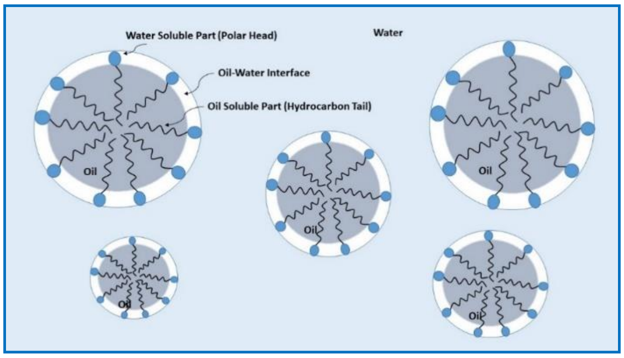

Figure 6: A schematic illustration of adsorption of surfactant at oil/water interface (by permission of Olajire [42])

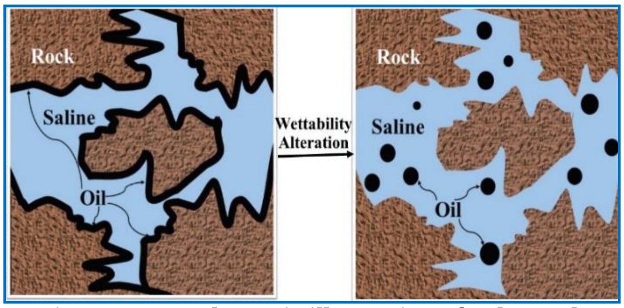

Figure 7: An schematic illustration of enhanced permeability of reservoirs by surfactant flooding, because of wettability alteration of rock from oil-wet to water-wet (by permission of Shamsi Jazey et al. [43])

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Surfactants are recently categorized into six groups based on their hydrophilic groups and hydrophobic tails; 1- anionic surfactants that own negatively charged hydrophilic group containing of a sulfate, a sulfonate or … these surfactants are used in EOR process widely used, specially; in sandstone reservoirs. 2- cationic surfactants have positively charged ion on their polar region, and these surfactants are usually implemented in carbonate reservoirs for enhancing oil recovery process. 3- non-ionic surfactants they do not have electric charge. 4- amphoteric or zwitterionic surfactants that have both negative and positive charges. It depends on the pH of the formation that either they act as anionic or cationic surfactants. 5- Gemini surfactants that have at least two hydrocarbon chains and two polar groups. 6- biosurfactants that are produced by organisms, like; plants, animal, and microorganisms.

A typical surfactant flooding is consisting of several following fluid stages; 1- pre-flush or flooding of fresh water for reducing the salinity of the reservoir. 2- injection of surfactant formulation containing surfactants that are able to place themselves between oil and water to reduce IFT. 3- injection of polymer solution for increasing the viscosity of water phase to enhance sweep efficiency. And 4- again water is injected to displace the already injected fluids (see *figure 8*) [41].

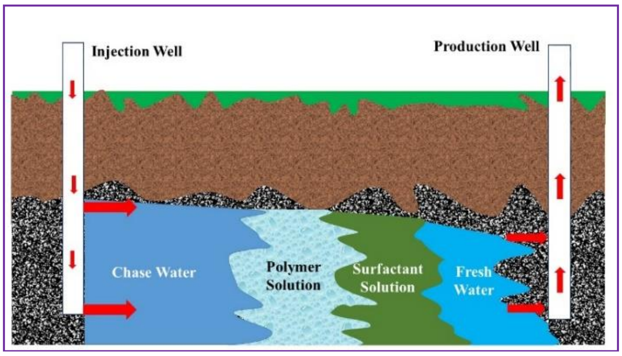

Figure 8: An illustration of typical surfactant injection process

C. Polymer injection

It is the process of injecting water-soluble polymers with high molecular weight along with water for expanding the viscosity of the injected water to boost the mobility of water results to remove viscous fingering phenomena leading to improved oil recovery [44]. This is a successful technique that has been implemented in numerous oilfield around the world, like; Daqing, East Bodo and Pelican and lake, Marmul, & Tambaredjo in countries, like; China, Canada, Oman and Suriname respectively [45].

Polymer injection technique improves oil recovery by; 1- mobility control of injected water; injecting the polymers increase the viscosity of the water leads to lower the mobility of the water. And make more stable the front part of the water phase and eliminate the viscous finger in the formation. By eliminating the viscous finger more oil displaced and the process enhanced [46]. 2- Polymers reduce disproportionate permeability in the reservoirs. As in the reservoirs there are different phases that own unequal permeability distribution, polymers reduce sweep efficiency unevenly. Disproportionate permeability reduction (DPR) means to change the permeability or reduction the permeability of one part or layer of the reservoirs like water phase and no considerable change on permeability of another phase of the reservoir (oil). DPR occurs by several different mechanisms, such as; controlled water channeling, enhanced sweep efficiency and so on. Increasing the viscosity and sweep efficiency of injected fluid (water) alter the flowing direction of water to regions with poor permeability [47]. 3- the third hypothesized mechanism of enhancing oil recovery process due to polymer injection is viscoelasticity of polymeric molecules [48]. As polymeric molecules undergo a series of extending and refolding while flowing in porous media, hence their elasticity and viscosity expanded and effects on their role for stabilization of front phase of water and minimizes viscous finger that improves sweep efficiency leads to less residual oil saturation and enhanced oil recovery. Polymers are classified into two general groups according to the sources that they are obtained. The first group is synthetic polymers that are synthesized and produced industrially. The most common ones are; xanthan, welan and guar gums, scleroglucan, cellulose, hydroxyethylcellulose, hydrolyzed polyacrylamide (HPAM), etc. The most usable are xanthan gum and HPAM among the aforementioned polymers [36].

D. Foam Injection

Foam injection is the method of injecting a stable foam into reservoirs for maximizing oil extraction. The foams, impact oil extraction process in following ways; (i) they raise up the viscosity of the injected water and lead to decrease water/oil mobility ratio, as a result; help oil extraction process. (ii) bubbles that are created by foam redirect the injected water to poor permeability regions that oil has been un-swept. This redirection of water flowing causes to increase sweep efficiency and improved oil extraction [49]. Chronologically, foam flooding methods can be categorized into two following groups; (i) conventional or traditional methods, like; CO_2 foams, nitrogen foams, and air foams. (ii) modern techniques that take advantage of chemical compounds, like; surfactants and polymers for stabilizing foams and boosting their half-life [50].

E. Fusion of conventional CEOR

The combination of chemicals, like; surfactants, polymers and/or alkalis, recently has come into view and tested on both pilot and field scales, for getting better result by complementing the weakness of individual chemical. These consortiums are included binary fusion (alkali-surfactant, alkali-polymer, polymer-surfactant) and ternary combination (fusion of alkali-surfactant-polymer). Therefore, (i) consortium of alkali-surfactant (AS) flooding is a method that, firstly; a dose of alkaline

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mixture is injected, and then, it is followed by a dose of surfactant mixture. In this method, alkali plays two important roles; firstly, it creates *in-situ* soap by interacting with naphthenic contents of the crude oil, and secondly, by presence of alkali, the reservoir rocks surface charged, because of interacting with alkali, and it causes to lower the adsorption of surfactant. At the same time, surfactants lead to IFT reduction and alkali support the action of surfactants, ultimately, oil extraction improved [51]. (ii) consortium of alkali-polymer injection is another method of CEOR. In this technique a fusion of both chemicals are used for compensating the defects of each other. For instance, alkali is not capable of mobility control. So, utilizing the alkali alone is not able to control the water/oil mobility ratio and cannot improve sweep efficiency. Hence, combining polymers with alkali compensate this defect and control mobility ratio by increasing the water viscosity. Correlatively, the presence of alkali prevents the adsorption of polymers on rock pores and increase the efficiency of the process [52]. (iii) the third type of binary combination is injection of surfactant-polymer (SP). In this technique, the order of injecting the chemicals relies on the aim of the process. Either can be injected firstly or behind. The SP injection showed a 14-20% of incremental oil recovery in sandpack reservoirs [53]. The studies have shown that consortium flooding of both chemicals, leads to a higher oil extraction in comparison with injection of individuals [54]. (iv) The ternary mixture within conventional chemical EOR is called alkali-surfactant-polymer (ASP) flooding which is made by injecting alkali, surfactant and polymer solutions for the purpose of enhanced oil recovery (EOR). Such compatibility of the mentioned fragments in the introduced slug ensured this method as the universally accepted most productive chemical EOR method [55]. The first step in this process is adding alkali and surfactant solution into formation that will help in cleaning up and getting rid of the residual oil trapped in pore spaces. Next, the procedure of polymer injection increases mobility ratio so that the volumetric sweep efficiency can be enhanced [56]. The last activities involve adding a provision of freshwater and circulating water in order to more effectively achieve the CEOR (see Figure 9).

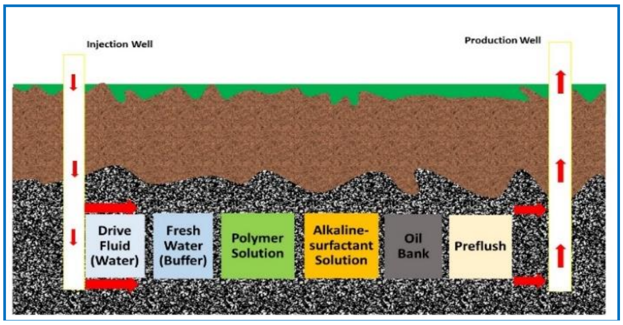

Figure 9: A diagrammatic representation of multi-step ASP flooding (by permission of Olajire [42])

3. Gas Injection EOR Methods

Gas injection is the second EOR method, that is broadly implemented, after thermal EOR processes in heavy oil fields. This process involves the displacement of oil by lean hydrocarbon gases or pressurized non-hydrocarbon gases. There are two types of gases that are used for displacing residual oil in the reservoirs; (i) miscible gases like carbon dioxide (CO_2), and (ii) immiscible gases like hydrocarbon gases. Miscible gases displace oil by altering its viscosity after mixing with the oil in the reservoir and immiscible gases pressurize the reservoir. Consequently, displace the oil toward the production well in the field. Utilizing either miscible or immiscible gases depends on prevailing conditions in the reservoir, pressure and temperature of the formation, and the combinations of the crude oil. Implementing of hydrocarbon gases, liquefied petroleum gas (LPG), CO_2, and N_2 are usual for displacing the oil, during this process [57].

Among all afore-mentioned gases and flue gases, field and research experience do not recommend LPG injection for oil recovery because they are not cost-effective and involve some risks and dangers in practical application. Instead, hydrocarbon gases are implemented, but they have some challenges, like; requiring high minimum miscibility pressure (MMP) to get miscible, as well. On the contrary, according to practical experiences CO_2 is the most effective and productive one, because of possessing the following properties; low cost, higher density, and sequestration of anthropogenic CO_2 in the reservoirs that has a considerable effect on environment besides higher oil recovery. Implementing CO_2 in gas injection method, returns to 1930 and its significant development occurred after 1970s [58]. Injection of CO_2 is applicable and efficient in light to medium oil reservoirs. CO_2 flooding enhances oil recovery process around 15-25% of original oil in place (OOIP) [59]. This method has been implemented in numerous oil recovery projects in different countries like Brazil, Canada, Croatia, Hungary and USA [15].

4. Microbial Enhanced Oil Recovery (MEOR)

Microbial enhanced oil recovery is one the most significant approaches of tertiary oil recovery techniques, that microorganisms or their metabolites, like; biosurfactants, biopolymers, biogenic acids, enzymes, solvents and biogases are used to recover residual oil trapped in the capillaries of reservoir rocks. Microorganisms that are utilized in this technique enhance oil extraction by the following mechanisms; (i) modification of the distributed porosity and permeability of the reservoir, (ii) the rock wettability alteration, (iii) solubilization of the oil, (iv) reducing interfacial tension (IFT), (v) increasing emulsification process, and (x) decreasing water/oil mobility ration [17].

MEOR could be carried out via two primary methods: in-situ and ex-situ. According to Greetha et al., [60], the in-situ technique consists of injecting bacteria and their nutrients into the reservoir through an injection well. The injected microorganisms are then given a few

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months for adaptation to the reservoir's environment, a period termed as the shut-in phase. The microorganisms generate certain metabolites during the shut-in phase after adapting, which ultimately assist in the oil recovery process. Conversely, the ex-situ approach includes growing the microorganisms and harvesting their metabolites before introducing them into the reservoir. Each approach offers positive and negative aspects of its own. As an example, the in-situ approach is cost-efficient, but it is inadequately profitable since it creates an unsuitable environment for the development and reproduction of the appropriate microorganisms. Instead, the ex-situ procedure provides better outcomes and tends to be more productive than the in-situ process, but it comes at a considerably greater budget since there is the need for additional supplies and reagents in order to generate and purify the microbe-derived compounds that are harvested from the reservoir.

There are many positive points of MEOR technique, that made it a dominant method in EOR process. Some of them are as following; (i) this method is inexpensive than others, because microbes are inexpensive and their metabolites are produced inexpensively by feeding them with agricultural wastes and other cheap nutrients, (ii) MEOR is ecofriendly, because all the additives and products that are implemented in this technique are biodegradable. So, it does not create any danger or risk for the environment. Based on the afore-mentioned reasons, this technique is widely used around the world and scientists are investigating to find new ways of implementing this method. Two new trends of microbial enhanced oil recovery are GEMEOR or Genetically engineered microbial enhanced oil recovery and EEOR or enzyme enhanced oil recovery which bring new potential hopes and ideas to the petroleum industry [61].

V. CONCLUSION

In conclusion, we can say that oil extraction is a very vital and fundamental aspect of the oil industry, which, by using different methods and techniques, causes a larger amount of hydrocarbons trapped in oil reserves to be extracted. The developed form of oil extraction plays an extremely crucial role, in optimizing the extraction process, especially since the effectiveness of conventional methods has decreased. The effectiveness of EOR techniques in extracting trapped oil in reserves is clear and obvious, otherwise; These high amounts of trapped oil remained untapped. As we checked out; there are several types of enhanced oil recovery methods with unique approaches to enhance oil extraction. Among all existing techniques, MEOR is a leading and important method because of its great potential for the future. Different types of microorganisms are used in this technique, and especially bacteria have shown a high ability to alter the characteristics of oil reserves and make the extraction process easier. In addition; Two new types of MEOR, which are GEMEOR and EEOR, are new and innovative approaches in this technique that clearly can be leading methods in the future. Inventing of these innovative techniques not only shows the commitment of this industry towards innovation, but it also expresses the potential of this industry to invent sustainable and environmentally friendly methods. As we have seen, with the rapid growth of technology and the integration of different types of technology, new methods are emerging that try to provide a significant amount of the world's energy demand while minimizing the environmental impacts.

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