Overview and methods in Enhanced Oil Recovery

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Abstract. After the conventional oil recovery system, it was estimated that huge amount of oil reserves is still remaining un-extracted. Because of tremendous demand for oil and established facilities at the oil exploration sites after conventional recovery got significant attention. Since the oil is entrapped in the porous rock structure and is difficult to evacuate, focus was made on tertiary recovery of oils. Many methods have been suggested by various researchers with different techniques to mobilize the entrapped oil in the well. The classification of the techniques will give different methods of recovery. The rheology, surface tension, mobility ratio are the important parameters that were considered during the enhanced recovery. The review that is presented here gives the overall methods for recovery and various materials and important parameters to be considered for the enhanced oil recovery. A new substitute for the sand pack column is suggested to conduct the bench top experimental set up that would ease the work of flooding with alkaline, surfactant and polymers.

1. Introduction
Recovery of oil from underground oil well is the key factor in oil production. The average of recovery factor world wide is to be increased to meet the demand and supply chain. The oil produced from mature and maturing oil fields were not able to meet the pace of the demand for oil. It was known that world’s average recovery factor is near to just 30%. These limitations lead to the enhanced oil recovery (EOR) to meet the present energy demands. EOR methods encompasses the extraction of remaining oil in the well after primary and secondary recoveries. This greatly improves the recovery factor. The cost of EOR method takes the advantage of available facilities, however, becomes economical when compared to the cost of new green field developments. The economical viability of the enhanced oil recovery (EOR) depends on the overall cost of production and it is achieved with enhancement of oil prices[1]. The EOR methods have been broadly classified as thermal and non-thermal as shown in Figure 1.

2. Thermal EOR methods
The technique that is used in the thermal EOR is to increase the temperature of the oil inside the shale which result in the decrease of viscosity of oil. This enables the oil to move in the reservoir[2, 3]. The key feature of the thermal EOR is that it reduces the mobility ratio, which is the ratio of dispensing fluid to the displaced fluid and is known to increase the recovery of oil[4, 5, 6, 7]. It is believed that the in-situ combustion in the shale greatly depends on the production rates, thermal propagation and peak temperature[8]. Understanding the fuel
formation and effect of mineral substrates in in-situ combustion process is important that reveals the clues to perform thermal EOR methods[9]. In this technique, when steam is injected to heat the contents of the reservoir, has a two fold advantage as it not only decreases the viscosity but it also increases the mobility of the oil through the network fractures. It was shown that the steam injection could enhance the oil recovery rates from 25 to 50% with an oil steam ratio of 0.2 to 0.4 cubic meter per tonne of steam[10]. The numerical simulations on steam injection showed that there are possibilities of 0-60% recovery of oil in a limited time period. It was concluded that the flow of oil and steam-oil ratio determines the optimum production time[11]. It is was also shown that 30% of original oil in place (OOIP) can be recovered when the hot water injection is done[11]. Wettability of the rock, enthalpy, specific volume and the latent heat of vaporization of steam that is used for steam flooding are the important parameters that drives the economical status of enhanced oil recovery[12]. In case of hot water injection, it was believed that the thermal effect will begin at 250-270 °C where there will be reduction in the viscosity of the oil[13]. It was shown that the addition of nano particles to low salinity water during the hot water flooding could alter the thermal energy, inter-facial tension and surface energy that could result in higher recovery factors[14]. Recent methods of EOR include electromagnetic wave induced nano particles that alter the parameters like inter-facial tension, viscosity and mobility ratio[15, 16, 17].

3. Non-thermal EOR methods
There is need for low cost non-thermal EOR techniques required to recover the heavy oil. In the tertiary recovery, adverse mobility ratios limit the sweep efficiencies. Non-thermal EOR methods includes physical, chemical and biological methods.

3.1. Physical EOR methods
Original oil in place (OOIP) is an indication of recovery index that lead to the enhanced oil recovery techniques. For unconventional reservoirs, gas injection was considered to be one of the most significant technologies for EOR methods. Since the prices of the oil decides the EOR methods as per the economical viability, the gas injection is most preferable when the oil prices are became less[18]. Various methods of flooding the reservoir with carbon dioxide has been implemented practically to enhance the oil recovery[19]. Injection of CO2 is the most traditional way of technique adopted to improve the recovery of oil in the conventional reservoirs.
This method has been tested for the Bakken tight oil reservoirs as a case study and noted that an improvement is possible in the recovery[20]. During the immiscible injection of CO2, the recovery is mainly due to the oil swelling and reduction of inter-facial tension. However, the miscible injection technique result in the maximum production of light oil[21]. Extensive time is needed to analyse the changes in the properties of reservoir after CO2 injection that might lead to the leakages[22]. Nitrogen is being used as an alternative to the carbon dioxide gas in the EOR methods. The major advantages of the nitrogen gas injection is that nitrogen is abundantly available, non expensive and non corrosive[23]. The numerical simulations on onshore mature field gave promising results for the potential use of nitrogen as an alternative for CO2 injection[24].

3.2. Chemical EOR methods

It is a well known fact that flooding alone cannot mobilize the oil entrapped in the porous rock structures due to the capillary forces. Too much of residual oil remains stagnant in the porous rock structure. Other techniques that were thought of is to alter the inter-facial tension between the water and oil with the addition of certain chemicals such as surfactants or alkaline substances, a method called chemical EOR[25]. Recent studies on EOR is very en-courageous with chemical methods that greatly after the wettability properties and improved recovery rates compared to the traditional thermal methods[26, 27]. Many chemicals have been tried to analyse the chemical EOR methods in the form of alkaline, surfactant, polymer and combined flooding methods. So many micro and macro models have been developed and the improvement of chemicals were suggested in the literature with experimental methods using chemical EOR.

3.2.1. Alkaline flooding

The key mechanism of alkaline flooding is that the alkaline solutions penetrate into the viscous oils with the subsequent formation of water droplets inside the oil phase. This alters the inter-facial properties of oil and water with the formation of water channelling thus improving the sweep efficiency during the chemical EOR method with an alkaline solution. Sodium carbonate and sodium hydroxide were tested for the alkaline flooding analysis and it was seen that the inter-facial tension (IFT) was greatly reduced with the improvement in recovery rate[28]. A laboratory synthesized short-chain sulphobetaine was used as a flooding solution and the results were compared to Sodium meta borate solutions during the alkaline flooding using the sand pack. It was shown that 1% sodium borate could enhance the oil recovery by 27.1%[29]. Sodium hydroxide, dimethylamine, and a mixture of sodium borate and sodium carbonate alkaline solutions were tested for binnon heavy oil in the enhanced oil recovery using sand pack. It was observed that the IFT values have been reduced from 0.1 to 0.01 mN/m with the use of alkaline flooding[30]. The mechanisms of alkaline flooding was extensively studied by various researchers. It is known that the factors like concentration of surfactant, injection rate, oil viscosity would greatly effect the EOR during the surfactant flooding [31]. Another theory on alkaline flooding for EOR suggests that there will be surfactant generation at the oil water interphase in the presence of alkali which lead to the alteration of IFT between oil and water[32]. Important parameters about the surfactant flooding are tabulated as given in Table 1.

3.2.2. Surfactant flooding

Surfactant flooding is an EOR strategy where the phase behaviour can be controlled with the supply of surfactants and co-surfactants. The infusion of surfactant alter the conditions which would be favourable for the alteration of properties of the entrapped oil. Accurately planned surfactant frameworks along with the crude oil can make micro emulsions at the interface between oil and water that drastically alter the inter-facial tension (IFT) to very low values to the order of 0.001 mN/m. This alteration lead to the further development of oil recuperation with self assembly. The major challenge in surfactant flooding is that the
Table 1. The advantages and disadvantages of Malachite Green dye removal methods

| S.No | Materials                                                                 | Injection rate | Interfacial tension (mN/m) | Reference |
|------|---------------------------------------------------------------------------|----------------|----------------------------|-----------|
| 1    | Sodium carbonate and sodium hydroxide                                      | 0.003 ml/min   | 1000 - 0.001               | [28]      |
| 2    | short-chain sulphobetaine and Sodium meta borate                           | 0.5 ml/min     | 0.1 - 0.0001               | [29]      |
| 3    | Sodium hydroxide, dimethylamine, and a mixture of sodium borate and sodium carbonate | 0.5 ml/min     | 0.1 - 0.01                 | [30]      |
| 4    | Sodium hydroxide and sodium carbonate                                      | 0.075 ml/min   | 0.1 - 0.00001              | [31]      |
| 5    | Sodium hydroxide, potassium hydroxide and sodium orthosilicate            | 0.0002 ml/min  | Decreases                  | [32]      |

Surfactants should be resistant to reservoir conditions like high temperatures, pressure and salinities and should perform well. The overall objective of the surfactant flooding is to reduce the interfacial tension (IFT) between water and oil with the direct addition of surfactant solution. This greatly improve the recovery factor of oil when swept using a surfactant slug.

3.2.3. Surfactant polymer flooding It has been seen from the literature studies that the increase in surfactant and polymer concentration increases the incremental recovery of the oil in EOR, which is limited to a particular combination. Beyond certain concentration, the incremental increase is too low such that further increase is inappropriate. To optimize the compositions of surfactants and polymers in the presence of salts, many experiments have been conducted in measuring the incremental recoveries. In the typical experiments conducted with SDS and partially hydrolysed polyacrylamide mixture, the recovery enhancement was observed with a sodium hydroxide concentration of 0.7 to 1 wt%, polymer concentration of 1500 to 2500 ppm and surfactant concentration of 0.2 wt%[33]. More than 60 oil fields at Shengli were tested with surfactant polymer flooding to enhance the oil recovery. The recovery rates were increased and remained for several years with the incremental capacities[34]. It is believed that the experiments could be done on a sandstone device to optimize the incremental oil recovery. Huge amount of literature is piled up in the parametric study of surfactant polymer saline flooding analysis for EOR methods[35, 36, 37].

3.3. Microbial EOR methods

A great amount of Oil in place is still not accessible for the recovery. Biological methods have been adopted to take out the original oil in place, a method called Microbial Enhanced Oil Recovery (MEOR). Various strategies that were used in this method include production of biopolymers, alteration of wettabilities, bio-solvents, bio-surfactants and selective plugging. Various microorganisms have been tested to be used in MEOR, which could sustain the reservoir conditions and perform the biological activity[38].

Microbial Enhanced Oil Recovery (MEOR) is an appropriate selective methodology for oil recuperation among other EOR frameworks. Microorganisms and their accidental impacts are the dependable factor for MEOR measure. Microorganisms in the oil stores and update the recuperation cycle by making different metabolites such as bio-surfactants, biopolymers, acids, gases, biomass. There are theories suggested the MEOR cycle by existing traditional oil recuperation methodologies[39]. It was recognized that the difference in additional oil into vaporous oil (methane) and the in situ making of bio-surfactants are the most encouraging methods for MEOR and thusly base with respect to these issue. A prelude is given to the microbiology of oilfields and show that in situ microorganisms too as embedded social orders can
assist with emptying unrecoverable oil set up. After a major evaluation stage, the further evolved oil recuperation supervisor should pick whether MEOR would be sensible. MEOR by and large further makes oil creation regardless the development may not legitimize the undertaking[40, 41].

4. Surfactant polymer flooding using microporous sandstone device
Sandstone devices are prepared using glass capillaries by incorporating the sand inside the glass capillary column. These columns were saturated with silicone oil as a test standard fluid by colouring the oil.

Figure 2. Image analysis for volume displacement of oil

In the Figure 2 (a), the sand column is saturated with oil. This column is then swept with saline water by using syringe pump at a flow rate. After particular time the column is again photographed and is as shown in Figure 2 (b). A Matlab code is applied that uses image analysis by counting the pixels of the images with white and black after converting the image into grey scale. The portions of the blue colour was considered as black and the rest as white pixels as indicated in Figure 2 (c) and (d). Finally, the difference in the pixels are reported as the area of displacement. This idea could enable us to develop bench top sand pack for displacement studies.

5. Conclusions
Enhanced oil recovery encompasses the various flooding types namely alkaline flooding, surfactant flooding, surfactant polymer flooding. In each of these methods, the parameters like oil water surface tension, wettability, inter-facial tension, viscosity are significant measures to be considered. Recent advancements suggest that modified surfactant polymer slugs loaded with nano particles could be potential materials that could greatly alter the reservoir properties and improve recovery rates. There are possibilities that a transparent glass could could be divined that mimic sand pack to perform flooding experiments with alkali, surfactant and polymer that greatly reduce the pilot plant scale tests.
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