A comprehensive review on Technical Aspects of Caustic Flooding for the application of Enhanced Oil Recovery

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Abstract
Alkaline flooding is one of the important methods of enhanced oil recovery. This paper mainly highlights the potential of using the alkaline flooding and its effect on various parameters such as wettability alteration, interfacial tension, contact angle etc. It was found that the suitable combination of additives could improve the recovery of heavy oil. It was seen by core flooding experiments that the use of NaOH alone or a mixture of NaOH and Na_2CO_3, could be enhanced the ultimate oil recovery by 10%. The study of contact angle also showed that it could change from 24 degrees to about 160 degrees with the use of alkali. A review of MSEA (Mixed Surfactant Enhanced Alkaline) has also been conducted at various temperatures, whilst taking into consideration various parameters such as physical, interfacial property measurements and phase stability, which has resulted in the substantial recovery of hydrocarbons from the reservoir. Moreover, the effects of adding Silica Nanoparticle in alkaline solution is studied which alters the wettability of the formation from oil-wet to water-wet and the other properties such as viscosity, IFT (Interfacial Tension), permeability which increases the recovery rate from 24 to 27%. Also based on the flooding sequence the effects on the recovery are measured. The effects of Sodium ion, pH and acid content on IFT activity of the crude oil are studied and the increase and decrease in IFT is measured.

Keywords: Caustic Flooding, Wettability Alteration, Silica Nanoparticles, Heavy Oil Reservoir, Enhanced Oil Recovery.

1. Introduction

Alkaline flooding is a chemical method by which the pH of injected water is modified for increasing oil recovery. It is normally achieved by the addition of Sodium Hydroxide or Sodium Orthosilicates to the water. Alkaline flooding has great efficiency to increase the recovery of oil in the heavy oil reservoir. Water-oil emulsions mechanism of alkaline flooding enhances the heavy oil recovery. Increasing the size and number of water droplet present in the W/O emulsions increases the alkaline concentration which rise the oil recovery [27]. There are some criteria for using alkaline flooding like reservoir rock should be clay free sand with minimum carbonate inclusions, reservoir has high acid number, viscosity of oil should be less than 50-100 cP, and salinity of formation water should be less than 20% [31]. The displacement efficiency of alkaline flooding depends upon the concentration of the alkali and the type of alkali and the displacement efficiency increases with the increase of the alkaline concentration and basicity [10].
The alkaline chemical reacts with certain types of oils, forming surfactants inside the reservoir. Eventually, the surfactants reduce the interfacial tension between oil and water and cause an increase in oil production. However, alkaline flooding is not recommended for Carbonate reservoirs because of the abundance of calcium; the mixture between the alkaline chemical and the Calcium ions can produce Hydroxide precipitation that may damage the formation [14]. Acid number is an important factor in alkaline flooding and it positively affects the tertiary oil recovery. The brine salinity and test temperature also affect the performance of alkaline flooding. The brine salinity can change the created emulsion type and it affects those properties which are related to the displacement efficiency [18].
In recent flooding, most commonly used alkaline materials are Sodium Hydroxide and Sodium Orthosilicate. It was claimed that if calcium ions are present in injection fluids, Orthosilicate shows slightly more effective results. S. Kumar et al., studied that other alkali such as Sodium Carbonate, Ammonium Hydroxide, Polyphosphate and Hydroxyl Amine can be used but they do not improve oil recovery in presence of Sodium Hydroxide [21].

2. Selection criteria used for Alkaline Flooding

Generally, the reservoir should not be very heterogeneous, since some zones would be un-approachable also it should not have extensive fractures or thief zones. In case of highly faulted and/or fractured reservoir, alkaline flooding is not recommended. The net pay thickness should not be a small fraction of the gross formation thickness. Also pay zone thickness must be sufficient and the areal extent should be sizable to prevent the wastage. In an aquifer-connected reservoir, water-drive reservoir is not suitable for alkaline flooding especially when a thin pay zone is acted by thick aquifer. A reservoir having a well-developed porosity and permeability is preferable. In case of presence of a gas cap, the reservoir is not a good candidate because the sizable amount of mobilized oil can re-saturate the gas cap and a reservoir having less than 200°F and reservoir depth of 6000 ft are preferable for avoiding the alkaline consumption, and the injection wells should be within oil zones, not in the peripheral aquifer [21]. Also gravity of 20-30 °API, viscosity of 11-200 Cp, temperature of 68-203 °F and average permeability of 10-1500 md are of the basic criteria which should be considered in alkaline flooding [7].

2.1 Factors affecting the Recovery

The acid number is an important factor in alkaline flooding. Adding alkali to injection water can have a beneficial effect on the oil recovery factor only when the oil has a sufficiently high acidity. In comparison to Na_2CO_3, NaOH provides better result in alkaline flooding. In addition, the brine salinity and test temperature also effect the performance of alkaline flooding. Moreover, the relatively low temperature is also a beneficial prominent factor in alkaline flooding. When the temperature increases to a specific value, the displacement efficiency of the hydrocarbon declines strenuously [18].

2.1.1 Test descriptions of the Factors

Jijiang Ge et al. conducted 25 numbers of sand pack-flooding to investigate the effect of oil acid number, alkaline concentration and type, brine salinity, and temperature on alkaline flooding with four types of heavy oils. The reaction between the alkaline reagent and the crude oil is the main mechanism for alkaline flooding to improve oil recovery; therefore, the oil acid number is a prominent factor in alkaline flooding [14].

3. Techniques for Enhancing Oil Recovery using Alkaline Flooding

Li et al. studied that the accurate characterization of the remaining oil is very important for additional improvement of chemical flooding recovery. To improve the recovery rate of ASP flooding, effective methods are needed to improve the oil displacement process and various traditional methods such as chemical tracer method, surface seismic method, cross-well seismic method, surface electromagnetic method, cross-well electro-magnetic method, well-ground electromagnetic method, direct current method, electrical logging method, and gravity logging method are presently used. In some tests area having serious electromagnetic interference, the electromagnetic response differences of the reservoir before and after ASP flooding cannot be acquired for traditional time-lapse electromagnetic method. So, differential wide-field electromagnetic method (WFEM) is used to monitor the reservoir resistivity variations during the ASP flooding by only acquiring the electrical field [23].

Gittler et al. studied that during alkaline flooding the emulsified crude oil can be recovered more competently by the use of alcohol additives. The chemical structure of alcohol directly effects efficiency of the oil recovery. Water miscible alcohols can improve more oil recovery as compared to plain alkaline flood to some degree. The IFT between oil/water interfaces is affected by type of alcohol. The low molecular weight alcohol causes little or no effect but Butanol and Pentanol isomers cause an upgrading of IFT [16].

Cambridge et al. found that composition of crude oil is one of the major interruptions to the use of general alkaline flooding. The in-situ air oxidation in unconsolidated cores can dramatically increase the acid numbers of low acidity crudes. The oxidized crude oil has much lower caustic/crude IFT as compared to the paternal crude oil. The acids generated by oxidation are more inter-facially active than the parent crude and it was observed that the minimum IFT are drastically reduced by a slight degree of oxidation [4]. In a high acidic reservoir where the average TAN is more than 6 mg KOH/g shows potential. The emulsification ability is enhanced and transformed from partial to full emulsification by increasing the acid concentration [30].

3.1 Petroleum Behaviour by the use of Petroleum Sulfonate and Ligno-Sulfonate

Chiwetelu et al. found that the alkaline flooding was the most promising recovery technique as compared to traditional oil recovery surfactants such as petroleum sulfonates in surveying potential non thermal applications because alkalis are cheap and abundant than surfactants. A sufficiently low magnitude of IFT below 0.01 mN/m can be achieved by injecting low concentration alkaline solutions against acidic crude oils to significantly improve oil recovery and it was recognized that IFT is transient in nature and it depends upon the oil type, alkali type, alkali concentration, salinity and temperature. Nearly 40 years ago, the adding of synthetic surfactants to the alkaline solution was introduced to improve the oil recovery but very little work in IFT behaviour of alkaline/surfactant system against crude oil has been observed [7].

3.2 IFT Behaviour of Mixed Surfactant on absence of Alkali

The process When mixtures of Petrostep B-100 (Petroleum Sulfonate) and Ligno-sulfonate, Sodium-based Marasperse N-22 or calcium-based Marasperse C-21 with the Court crude oil at 25 and 65°C is contacted, the transient IFT data are obtained and by analysing the results it was concluded that the C-21 Ligno-sulfonate is perceived to be slightly better than the N-22 in its ability to reduce the IFT. Ligno-sulfonate properties can be adjusted with respect to sulfonate content, molar mass, kind and amount of cation, and surface activities and they are water-soluble, oil-insoluble, anionic surface-active by products of lignin. From experiments the transient behaviour of IFT has been observed, it was found that in case of same molar mass %, the C-21 reduces the more IFT as compared to N-22. Also, C-21 reduces the IFT more preferably when the concentration increases from 0.05 % to 0.10 %. From the results, it can be concluded that C-21 is more preferable as compared to N-22 as an additive to Petrostep B-100 to increase the recovery by decreasing more IFT. From experiment which was done at court crude oil temperature 65° and it was observed that the C-21 was slightly more inter-facially active than the N-22, and both Ligno-sulfonates showed IFT values which were decreasing moderately with increasing temperature. The maximum ratio 1.5:1 of Petroleum Sulfonate/ Ligno-sulfonate was found to be bearable because above it, increasing amounts of liquid crystalline structures in cooperation with a significant concomitant increase in viscosity were observed [7].

3.3 IFT Behavior of the mixtures of Petrostep B-100 and Ligno-Sulfonate C-21 in presence of Alkali

The additive-free NaOH solutions achieves an ultra-flow IFT along with showing a tendency of increasing IFT with increasing contact time and dramatically increased with increasing temperature while the addition of mixtures of Petrostep B-100 and C-21 Ligno-sulfonate to NaOH successfully inverted the trend of increasing IFT. The NaOH is largely excluded from the oleic/aqueous interface which leads to the long-chain surfactant molecules preferentially adsorbed at the interface and hence resulting the reduced NaOH concentration at the interface. The reduced concentration leads to the reduced rate of reaction with the acid in the oil which results very desirable structures of steadily decreasing and continued IFT [7].

3.4 Effects of Silica Nanoparticle in Alkaline Flooding

Elyaderan et al. found that increasing Silica Nanoparticle concentration at a fixed concentration of Sodium Carbonate, increases the IFT and decreases pH of the solution and the lowering of pH terminates the production of in-situ surfactant. Also with increasing Sodium Carbonate concentration leads to the wettability alteration of oil-wet to water-wet [15]. A rise in oil recovery rate from 24 to 27% is obtained when the concentration of the Nanoparticle is increased from 0 to 0.05 wt% at constant concentration of 0.5 wt % alkali. But the further increase in Nanoparticle concentration in the caustic solution from 0.05 to 0.1 wt % leads to the decrease in oil recovery from 27 to 23.2 % due to the mechanism of increasing IFT dominates the other two mechanisms. So it was found that addition of Silica Nanoparticle up-to 0.05 wt % reduces the reduction of permeability due to the absorption of Nanoparticle on the rock and thus preventing the interactions between some of the alkalis and the rock but further high concentration of Silica Nanoparticle becomes unstable in the presence of calcium and magnesium salt, hence leads to the noticeable reduction of permeability [15].

3.5 Role of Synthetic Surfactant in Alkaline Flooding

The role of Synthetic Surfactant in Alkaline Flooding has been discussed based on the following aspects:

Interfacial Tension:

Low pH alkalis frequently fail to attain the ultra-low IFT values required for considerable oil mobilization. In 1985, it was revealed that adding very modest amounts of synthetic surfactant to alkaline solutions improved transient IFT behavior and oil mobilization with weakly alkaline compounds dramatically. Two examples of optimal alkaline systems with and without additional surfactant are provided, both of which display typical IFT behavior [13].

Acidic Crude:

The first is a pH 9.3 mixture of 0.095 N NaHCO3 and 0.095 N Na_2CO_3 that was tested with oil B from the Ranger Zone of Wilmington, at 52°C. Because Wilmington crude oil is acidic and highly reactive to alkali, it produces a quick drop in IFT to 55 μN/m in only 2 minutes. IFT, on the other hand, begins to rise very immediately. IFT increased to 500 μN/m in 32 minutes. The combination of 0.1% Neodol 25-9 alcohol Ethoxylate surfactant and alkali resulted in a quick decrease in IFT followed by a sustained, very modest increase in IFT. The minimal IFT for the combination of surfactant and alkali was 4 μN/m, which was significantly lower than the IFT for either surfactant or alkali alone. After 16 minutes, the IFT with the synthetic surfactant and alkali mixture was still below 50 μN/m. The conclusion reached is that using a mixture of synthetic surfactant and alkali with Wilmington oil results in lower IFT that lasts longer than using either component alone. The natural surfactants formed by interactions with the alkali appear to be the primary cause of the very low IFT in this oil, while the addition of synthetic surfactant appears to be the primary cause of the prolonged low IFT [13].

Low-Acid Crude:

Light oil from the Delaware-Childers field is the second example. A pH of 9.5 i.e., mixtures of 0.049 N $NaHCO_3$, 0.0078 N Na_2CO_3, and 0.0325 N Na_2HPO_4 was utilized as the alkali. The studies were carried out at 52° C, which was the same temperature as the heavier crude. The addition of 0.1 percent Petrostep B-100 anionic surfactant to the alkali resulted in a quick reduction in IFT to a low value that was maintained over time. The combined IFT of 2.9 N/m for synthetic surfactant with alkali was considerably lower than either component alone. The observations with the Delaware-Childers crude found that a combination of alkali and a low percentage of synthetic surfactant can give very low IFT values even for crude oils with very low acid levels [13].

Loss of Surfactant:
Low-pH alkaline flooding compositions require synthetic surfactant, which is an expensive component. As a result, in current field research, only dilute (0.1-0.2 percent) doses of additional surfactant are used. Surfactant concentrations in alkaline solution as low as 0.1 percent are enough to achieve an ultra-low IFT. Because of losses due to precipitation, adsorption, and phase entrapment, the surfactant may not propagate very deep into an oil reservoir at these low levels [13].

Precipitation in Reservoir:
Surfactants utilized in EOR applications can be precipitated by calcium and magnesium ions found in reservoirs. Alkalis are useful at lowering divalent ion levels in petroleum reserves. Hydroxide, Carbonate and Silicate are all useful alkalis for lowering divalent ion levels. An alkaline pre-flush to lower divalent ion levels before injecting a Surfactant containing formulation is likely to be the optimal injection method [13].

Adsorption on Reservoir Rock:
Adsorption onto reservoir rock can also diminish surfactant levels inside an injected solution. The anionic surfactants' adsorption under alkaline circumstances has been studied by a number of researchers. Alkali reduced anionic surfactant adsorption onto pure clay minerals by up to 93 percent when reservoir sandstones were utilized, and reduced adsorption by 7 to 49% when reservoir sandstones have been used [13]. While the production of O/W and/or W/O emulsions was largely determined by the reservoir's and injected fluids' unique qualities, evidence from the literature suggested that W/O emulsions have been more frequently created in heavy oil reservoirs. The goal of this research was to analyse the flow characteristics of a W/O emulsion across porous medium in alkaline flooding and to mimic the process's key flow mechanisms for improved oil recovery [32].
Using four distinct grades of W/O emulsions running through three various permeability sand-packs at four distinct injection flow rates, the effective viscosity of W/O emulsion within porous media was examined experimentally. The following findings were formed based on experimental and simulated results:
1) The emulsion quality had the greatest impact on the effective viscosity of W/O emulsion measured on porous medium. If all other variables were equal, the higher the emulsion quality, the higher the effective viscosity of the emulsion.
2) Though in-situ created high viscosity W/O emulsions, a well-constructed alkaline flood for heavy oil recovery might effectively enhance sweep efficiency.
3) Water-phase relative permeability could be significantly reduced as a result of the production and flow of W/O emulsions [32].
In porous medium, an alkaline solution can permeate heavy oil and create W/O emulsions. Because of the W/O emulsion's high viscosity, the resistance to water flow in the high-water saturation zone can be enhanced, improving sweep efficiency. The oil can be created by the mechanism of O/W emulsion flow when an alkaline/surfactant formula is utilized to make ultralow IFT and O/W emulsion. When compared to the W/O emulsion mechanism, this mechanism has a substantially lower pressure drop along the model [11].

3.6 Mobility Control in Alkaline Flooding
Oil reservoirs are usually never uniform beds with constant properties, despite the fact that they are porous media with specific porosity and permeability. The dispersion of reservoir permeability is important in increasing oil recovery. The majority of the oil left in the lower permeability zone gets bypassed as a result. The injected fluid replaces the oil that is evacuated and supplied from the high permeability zones, reducing the residual oil saturation in such areas. It has been demonstrated that injecting polymer can significantly reduce the negative effects of permeability changes, boosting the volumetric sweep efficiency. The polymer first enters the more permeable zone and builds up a flow resistance. This permits fluid to be injected into the regions that are less permeable, increasing overall oil recovery [1].

3.7 Polymer Selection for Alkaline Flooding
In a reservoir, a variety of chemicals can be employed as polymers. In addition to cost effectiveness, the following are the most significant requirements:
1. Proven tertiary oil recovery with minimal deterioration.
2. During pumping and injection activities mechanical shear that is stable.
3. High-temperature thermal stability.
4. Reservoir conditions, biologically immune.
5. Resistant to a variety of salts and chemical [1,3].

Alkaline flooding of acidic oils with Hydroxides of particular divalent cations boosted production and recovery efficiencies above those achieved by alkaline floods with Hydroxides of univalent ions both with and without high electrolyte concentration, according to dynamic displacement tests. Emulsification and coalescence were responsible for the higher efficiency [5].

3.8 Mechanisms of Alkaline Flooding

The possible mechanisms in the alkaline flooding could be oil dispersion and entrainment, reversal or wettability alteration and oil emulsification and entrapment. The water mobility can be reduced and the sweep efficiency can be improved by moving the residual oil within the alkaline solution. It is recently observed that in sand pack flood test, injection of dilute chemical solution causes the heavy oil drops to break and forms water in oil dispersion phase [17]. In case of water flooding in heavy oil reservoirs, large amounts of oil don't get recovered due to the fingering effect of the water that is injected. Chiwetelu et al., stated in his paper that lowering the values of the interfacial tension between the phase of invading and oil zone nearly to 1mN/m or further less, the residual oil might get mobilized if the capillary forces are overcome and thus oil might be recovered [8].

As a result of the interaction between the alkali in the injected water and acids present in the reservoir, surfactants are formed in in-situ which further helps in the decrease of interfacial tension in the alkaline or caustic flooding. As the residual oil saturation can be determined with the help of the capillary number, the evaluation of the interfacial tension can be made with the help of displacement models [29]. Also, Capillary forces can be reduced with the help of alkalis leading to the increase of capillary number which enhances production of oil [12].

3.9 Model description of Interfacial Tension

It is well known that the generations of surfactants are as a result of the reaction in alkaline flooding in the reservoir. Ramakrishnan et al., stated in their document that several attempts have been made to establish its relation with interfacial tension [29]. Laben et al, conduct an experiment where the interfacial tension between the crude oil and alkali solutions was enhanced from 9.66 to 12.2 m N/m in the presence of 250 ppm alkali. When Alkaline concentration was below 250 ppm, the interfacial tension was increased and when it is more than 250 ppm, the interfacial tension was decline [22].

4. Experimental Results

For correlating the results of theory with the experiments, various IFT data were measured using caustic solution with various concentration of NaCl. It was experimentally seen that at low concentration of NaOH, small effect of NaCl occurred but at higher concentrations, dependence was seen to be more theoretically [29].

4.1 Calculation of Displacement

The general solutions are not willingly evident as the equations governing the displacement of alkali are non-linear, first order and partial differential. de Zabala et al., cited that due to the trivalent nature alkaline flooding is complicated, hence the use of 3-D diagrams are must and evaluation by the computers is also very necessary [9].

4.2 Secondary Alkaline Flooding

The oil has an initial acid concentration of 0.05 molar and is injected with caustic at a pH of 12.75. This translates to an acid number of 2.8 assuming a unity specific gravity for the oil. The adsorption delay parameter is equivalent to 1.5 for an injected pH of 12.75 [9].

4.3 Comparison of IFT in presence and absence of Alkali

Three alkalis were pre-screened for use in the recovery of crude oil e.g. Sodium Hydroxide, Sodium meta-Silicate, and Sodium Orthosilicate. Petrostep B-100 and Petrostep B-110 and Petronate L were used for this work as widely viable synthetic petroleum sulfonate surfactants. Two commercial Ligno-sulfonate surfactants, Sodium-based Marasperse N-22 and calcium-based Marasperse C-21, were also chosen. Petroleum sulfonates are oil-soluble, partially water-soluble compounds made from sulfonic acids derived from specific petroleum fractions. The hydrophobic portion of the sulfonate molecule increases with only an associated increase in surface activity as the molar mass (which is usually in the 400 to 500 Da range) increases [7].

4.4 Interaction of Caustic Reagents with Crude Oil

The exact mechanism is still not certain for the reaction occurring between that of the caustic reagents to that of the crude oil of acids. It is known to us that formation of surface active soap species are the resultant of the reactions between that of the caustic agents of water and acids. IFT is drastically reduced when surface active anions accumulate at oil/ water interface. IFT varies with salinity, alkalinity and crude oil type of the reservoir [8].

4.5 Effects of p^H, Alkali and Salt on Alkaline Flooding

Chan et al. studied that the IFT was recognized by the interaction of alkali in water and acid in oil and the recovery of oil by alkaline flooding which lowers the interfacial tension between water phase and oil phase resulting to formation of oil-water emulsion and hence recovers the trapped oil in the reservoir. Once the pH of the interface reaches the pKa of the acids, by using some salt, the IFT rapidly sharp drops to the range of 10^{-5} N/m and after that further addition of Sodium in the form of NaOH and NaCl leads to the formation of non-dissociated, tight complex of Sodium soap which have higher molecular weight which may precipitate out and resulting to increase in IFT [6].

4.6 Effect of Lower Molecular Weight Alcohol on Alkaline Flooding

Pei et al. presented an experimental study, including IFT measurements, sand-pack flood tests, and microscopic studies, to examine the effect of the addition of low molecular weight alcohols on heavy oil recovery during alkaline flooding. From the results of the IFT tests, the authors found that when lower molecular weight alcohol is added to the alkaline/heavy oil system the partitioning of the alcohol molecules occur at the oil-water interface due to which the interfacial space available for surfactant molecules reduces. Therefore, the authors concluded that the addition of low molecular weight alcohols can be unfavorable to IFT reduction for the alkaline/heavy oil system. However, sand-pack floods conducted with the addition of the low molecular weight alcohols shows an obvious improvement in oil recovery over the alkaline-only flooding. On the other hand, from the results of the microscopic test, the authors found that the alcohol additives accelerate the reaction rate to produce the small discontinuous W/O droplet flow, which strengthen the jamming effect to improve sweep efficiency [27].

4.7 The Microscopic Mechanism of Alkaline Flooding

The microscopic mechanism for alkaline flooding in case of enhanced heavy-oil recovery include the penetration of alkaline solutions into the crude oil and, subsequently, the formation of water drops inside the oil phase that tends to moisture the tendency toward viscous fingering as well as it slows water channeling, and thus it improves sweep efficiency. The reduction of IFT leads to the penetration of alkaline solution into heavy oil, and the non-uniform entrance of in situ surfactants which was generated by the interface inter- action at the oil/water interface [25].

5. Limitations and their Proposed Solutions

The stability and efficiency of mixed surfactant-alkaline preparations are adversely affected by some factors such as preferential adsorption of surfactants onto the reservoir rock, viscous fingering of the lower-viscosity aqueous phase through the higher-viscosity oil phase, changing temperature within the reservoir, reaction of the alkali with the reservoir rock and presence of electrolytes in the reservoir [7]. Limited addition of salt in the form of NaOH and NaCl is bearable for decreasing IFT because after that further addition of Sodium can lead to the formation of non-dissociated soap which precipitate out and hence increase IFT [6]. In case of addition of Silica Nanoparticle in alkaline solution, 0.05 to 0.1 wt% concentration of Silica Nanoparticle leads to the decrease in oil recovery from 27 to 23.2 % also above this concentration the Silica Nanoparticle becomes unstable in the presence of calcium and magnesium salts and hence leads to the noticeable reduction in permeability, so 0 - 0.05 wt% concentration should be maintained [15].

6. Innovative approaches of Alkaline Flooding

A modification to Alkaline Flooding is the addition of surfactant and polymer to the alkali, giving rise to an alkaline-surfactant polymer (ASP). ASP flooding is undoubtedly the most efficient chemical EOR method. However, extremely high recoveries can be achieved at optimum salinity conditions oil recovery method, essentially a less costly form of micellar-polymer flooding [19]. Zhou et al prepare a sand-packed model to investigate the role of alkaline in combination flooding, SP and ASP flooding experiments. They draw the conclusion that as the distance increases, the residual oil saturation did too. The majority of the oil increment originated from the area around the inlet when alkaline was present, and ASP flooding had a higher displacement efficiency than SP flooding [33].

For the purpose of optimizing the use of chemical EOR, a number of studies have been carried out based on IFT, emulsion stability, thermal stability, rheology study, modelling, and simulation. According to laboratory studies and modelling results, using various chemicals as the ASP slug yielded an overall recovery of 33.25% and 47%, respectively [28].

Li et al. A new cold production technique named alkali-cosolvent polymer (ACP) was developed which uses a inexpensive co-solvent instead of a surfactant and the cosolvent generates natural surfactant with acidic components of crude oil which leads to formation of Type III microemulsion with the salt, natural surfactant and heavy oil. Rapid equilibration, the phase behaviour improvement, broadening the optimal salinity range, rheological characteristics, and reducing the viscosity of the microemulsion are influenced by the use of cosolvent. The viscosity of Type III microemulsion is about 10 mPa s which improves the mobility of crude [24].

7. Conclusions

Ali et al. studied that with the by injection of alkali, displacement of volume of oil increased approximately by 24% [2]. Factors that effects the caustic flooding are acid number, salinity, low temperature etc. Moreover, the precipitation of calcium and magnesium ions also effects in oil recovery. Various additives can be used to increase the benefits of alkaline flooding. The addition of petroleum sulfonate and Ligno-sulfonate changes the IFT behavior. Sodium based Marasperse N-22 or Calcium based Marasperse C-21 can reduce the IFT. C-21 is more preferable than N-22, as it reduces the IFT with increasing temperature. Addition of silica

nanoparticle with alkaline solution results in increase in IFT and decrease in pH. It decreases the contact angle and increases the viscosity. Increase in concentration of silica nanoparticle leads to formation damage and also results in decrease in oil recovery. Lower molecular weight alcohols are unfavourable for IFT reduction. Nowadays, MSEA is used which inverted the trend of increasing IFT of additive free NaOH solution with increasing contact time and temperature. The addition of small amount of alkali has a significant effect on the pH of the system and also on the wettability.
Mono-ethanolamine (MEA) and Na_2CO_3 with sulfonate surfactants (SLPS) reduce IFT. It can reduce the IFT to ultra-low (<10-3mN/m) with a temperature under 90^{o}C. The turbulent emulsification and self-emulsification are the main emulsification mechanism of the system, while during the migration of the emulsions coalescence-dispersion and coalescence-entrainment phenomenon are the main displacement mechanism to improve the displacement efficiency of remaining and irreducible oil which results in increase in ultimate recovery.

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CONFLICT OF INTEREST
The authors declare that they have no conflicts of interest.

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