MICROEMULSIONS AND NANOEMULSIONS APPLIED TO WELL STIMULATION AND ENHANCED OIL RECOVERY (EOR)

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ABSTRACT

Well stimulation and enhanced oil recovery (EOR) plays an important role in oil production. Microemulsions and nanoemulsions fluids have been studied as a fluid to enhance the efficiency of these processes. In EOR, the chemical methods act on the alteration of physicochemical rock/fluid properties reducing the residual oil saturation and increasing the displacement of oil in the porous medium. Several authors have investigated the use of acid micro and nanoemulsions as systems of production enhancement. The study, under different conditions, indicated that acid nanoemulsion systems present a potential to be used as a retarded acid system, stimulating carbonate formation using a low concentration of surfactant and oil phase, offering an alternative fluid system to stimulate production in carbonate formations, especially in environmentally sensitive areas. Overall, this paper presents a review of laboratory studies of production improvements and enhanced oil recovery using microemulsion and nanoemulsion systems.

KEYWORDS

microemulsion; nanoemulsion; interfacial tension; production enhancement; enhanced oil recovery

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1. INTRODUCTION

The discovery and exploitation of new types of reservoirs, such as those located below the salt layer in deep waters, tar sands and shale gas, require the application of innovative and adequate systems to these new environments. The application of nanotechnology has been a strong alternative to overcome the difficulties of the oil industry. Therefore, some work has been developed regarding the phenomena associated with the movement of nanofluids in porous media (Sheikholeslami, 2018a; Sheikholeslami, 2018b; Sheikholeslami, 2018c; Kasaeian et al., 2017; Isfahani & Afrand, 2017; Sheikholeslami et al., 2017; Mohite & Umavathi, 2016; Mahdi et al., 2015).

Among all the information to be obtained about an accumulation of oil after its discovery, the amount of hydrocarbons that can be processed from this reservoir and the time in which this production will occur are, without doubt, the most important. For economic viability in petroleum accumulation, the volume of recoverable oil must be economically attractive. Also, the rock must have porosity and permeability that are feasible, and enough energy for hydrocarbon production from the reservoir to the well and from the well to the surface.

The increasing use of petroleum products, considering its importance as main energy source of the world, requires a greater production of it. To satisfy this demand, companies seek to create new technologies and different methods to improve oil production with lower operating costs. Based on this need to increase production, there are some operations that have been used to stimulate wells. These techniques, widely used in production improvement and enhanced oil recovery (EOR), aim to increase reservoir productivity through different aspects: oil temperature increase, improvement of the interaction between the injected fluid and the oil, decrease of viscosity difference between the injected fluid and the oil, among others (Green et al., 1998; Hagoort, 1988; Khan et al., 2007; Latil, 1980; Rosa et al., 2006).

The application of surfactants and related systems, such as micro and nanoemulsions, on wells stimulation and EOR has shown good results in experimental studies (Zengying & Guocheng,

2010; Liu et al., 2010; Castro Dantas et al., 2014; Sofla et al., 2016; El Batanoney et al., 1999; Hosseini-Nasab et al., 2016; Nandwani et al., 2017). These systems allow the preparation of less toxic formulations, with low interfacial tension and specific properties to the application.

This article focuses on the application of microemulsions to nanoemulsions for EOR and production improvement. It also includes a review of basic concepts related to the topics. Although the present research demonstrates technical benefits of micro and nanoemulsion systems, there is a strong resistance of the industry to its application. A major limitation of microemulsion systems has been the high amount of active matter necessary for its preparation, raising the cost of these systems and making it economically unfeasible in many scenarios. In this context, coupled to the need for environmentally friendlier systems, several works have proposed the use of nanoemulsion systems using smaller quantities of surfactant than the microemulsion systems. This path needs to be further explored, especially in researches that could increase efficiency and reduce the formulation costs.

2. SURFACTANTS, MICROEMULSIONS AND NANOEMULSIONS

Surfactants are amphiphilic molecules composed by a polar part and non-polar part. As a result of its dual characteristic, these molecules possess in part of the structure affinity to non-polar, while the other has attraction to polar substances, placing the surfactant between them. Figure 1 illustrates the structure of a surfactant molecule, the hydrophilic part is called "head", while the lipophilic part is dominated "tail", usually constituted by a chain of hydrocarbons.

Figure 1. Representation of a surfactant molecule.

Figure 2. Process of micelle formation in aqueous phase.

The hydrophilicity, "head" of the surfactant, occurs due to the presence of polar functional groups, such as alcohols, ethers, esters, acids, and salts of carboxylic acids, among others. The surfactants can be classified as cationic, anionic, non-ionic, and zwitterionic, according to the nature of the charges of these groups.

The amphiphilic nature of the surfactant induces the alignment of the molecule to the interfaces, illustrated in Figure 2. This conformation is favored, since it is the most stable condition for the non-polar group of the molecule. The effect of this alignment phenomenon on the interface is the reduction of the liquid interfacial tension, being one of the most important properties on the study of surfactants and related systems (Aum, 2016b).

However, the increase in surfactant concentration saturates the liquid-air interface, promoting the migration of the surfactant molecules to the solution's inner part. Initially, this concentration is in the form of monomers (Figure 2b) and, then, forming aggregates, known as micelles, with the increase of concentration, Figure 2c. The concentration of surfactants that promote micelle occurrence is denominated C.M.C. (critical micellar concentration).

The C.M.C. depends mainly on temperature, surfactant nature, molecular structure, as well as the medium in which the surfactant is being dispersed. Above the C.M.C., there is a dynamic migration process of surfactant molecules, moving from micelle to interface and interface to micelle.

Microemulsions (ME) are semi self-organized, isotropic, transparent, thermodynamically stable systems composed by two immiscible phases, one disperse and another continuous, stabilized by a

surfactant film and, in some systems, a cosurfactant. Cosurfactants are usually alcohols or short-chain amines that reduce the repulsion of the polar "heads", stabilizing the droplet.

It is important to notice that microemulsions are not only different from conventional emulsions by the smallest particle size, but mainly by its thermodynamic stability and spontaneous formation systems of the self-organized type. The peculiar characteristics of the microemulsion systems give them a vast field of application.

Several self-organized structures can be formed depending on the type and concentration of the surfactant, cosurfactant, oil phase and aqueous phase. The structures formed in microemulsion systems have a size up to 100 nm. One of the most common structure models is described as one phase dispersed in another, being stabilized by a monolayer of surfactant and cosurfactant in the interfaces of the droplets, forming spherical structures (Sastri et al., 1982). Figure 3 illustrates the spherical structure. It is observed that, when the disperse phase is the oil phase and the continuous phase is the aqueous phase, the dispersion is called a ME O/W, Figure 3 (a). In this type of structure, the hydrophilic part of the surfactant is directed to the outward of the dispersed droplet, while the surfactant's tail is facing the center of the droplet.

In the systems where the continuous phase is the oil and the dispersed phase is the aqueous component, there is a W/O microemulsion (ME W/O). In this type of structure, Figure 3 (b), the polar part of the surfactant is facing the inner part of the droplet and the hydrophobic "tail" is facing the outer part of the structure (Aum, 2016b).

Figure 3. Microemulsion droplet arrangements: (a) ME O/W; (b) ME W/O.

An adequate amount of components must be mixed together to form a microemulsion system. To obtain the correct composition of a microemulsion system, it is necessary to prepare mixtures with different formulations, verify the type of equilibrium, and the number of phases for each formulation. In order to do this, one must construct a phase diagram to delimitate the balances associated with each specific composition, as illustrated in Figure 4 (Myers, 2005; Tadros, 2006).

The use of surfactants reduces the interfacial tension between fluids involved that disperse immiscible liquids. The microemulsion droplet size, in general, it has a diameter of less than 100 nm. The use of alcohol molecules in the formulation of these systems reduces the droplet size and, generally, reduces interfacial tension values in addition to minimizing the interaction between the polar heads of the surfactant's micelle. If the

interfacial tension reaches very low values, the diameter of the droplet can be reduced to about 10 nm. These dispersions usually are obtained with medium to high quantities of surfactant (Goodwin, 2009).

Unlike microemulsions, nanoemulsions have no spontaneous formation, requiring a power source to form them. This energy source can originate chemical potential of molecules or a mechanical source such as an ultrasound (Jafari & McClements, 2018). Another method of nanoemulsion formation consists of performing a microemulsion dilution until the concentration of surfactant reaches the critical micelle point (CMC).

Nanoemulsions have a particle size between 1 nm and 100 nm, promoting transparency and translucency with the naked eye (Chiesa et al., 2008). Because the size of the particles is so minuscule, the droplets are not subjected to the

Figure 4. Pseudoternary diagram illustrating the characteristics of microemulsion types.

gravity force. However, they are subject to Brownian motion (Klang et al., 2012). The nanoemulsion does not provide thermodynamic stability, but has kinetic thermodynamic stability and a low production cost, considering that most parts of the system are composed by aqueous phase.

The approaches to obtain nanoemulsions can be divided into two groups: high and low energy emulsification methods. Among the methods of high-energy emulsification are high-pressure homogenizers and ultrasound generators. However, these methods require a lot of energy, making the process economically unfeasible for industrial purposes.

To form an emulsion using the high-pressure homogenization method, it is necessary to perform two steps. The first step is to preheat the aqueous and oil phases separately and, then, carry out the hot mixture in a high rotation homogenizer. After cooling the mixture, it is necessary to use a high-pressure homogenizer that forces the mixture through small holes at a high flow rate, so that shear forces are sufficient to break the droplets and form smaller droplets. The ultrasound method has its efficiency restricted to small volumes, making it unfeasible for industrial operations (Leal-Calderon et al., 2007). One type of low energy method of emulsification is the phase inversion method. This method consists in changing the system's physical property, where the oil phase becomes the dispersed phase. The most widely used method of phase inversion is the PIT (Phase Inversion Temperature). This method consists in the preparation of a water-in-oil emulsion (W/O) at a high temperature followed by a drastic reduction of temperature to below the PIT value. The interfacial tension of the surfactant is reduced dramatically, providing droplet fragmentation, inverting the emulsion phase (Xu, 2016).

3. FLOW IN POROUS MEDIUM

Due to its properties, micro and nanoemulsions have been used in various applications of the petroleum industry, such as: clean up fluids, fracturing fluids, carbonate acidizing, and enhanced oil recovery (Xu, 2016; Rosen et al., 2005; Curbelo et al., 2018; Liu et al., 2010; Hoefner & Fogler, 1985).

The flow in porous medium, also known as Darcy flow, is one of the most relevant topics in the oil industry. This is because oil usually is located in the pores of rock formations confined thousands of feet deep. The study of the flow helps one to understand how to remove oil from the reservoir rock and produce it. Another important aspect of the hydrocarbon exploration is related to the presence of water and gas in the porous medium. It turns the medium into a multiphase problem, since the pores of the rock contain the three fluids simultaneously. The volumetric fraction of each fluid is known as saturation. These saturations are S_w , S_o , and S_g , the water, oil and gas, respectively. For each saturation ratio, there is a relative permeability. In this case, the flow of each component is affected by the presence of the other component. It is important to understand that the relative permeability curve is a reflex of the rock-fluid and fluid-fluid interaction effect. Micellar systems of low and ultralow interfacial tension ($<10^{-2}$ mN m⁻¹) have been studied to improve enhanced oil recovery processes. Several studies show that oil recovery is more efficient when the displacement fluid is quasi-miscible with the oil. Therefore, microemulsions have been studied because of their ability to generate ultralow interfacial tensions.

Another important aspect of microemulsion systems is that they are capable of changing the wettability of rock surface. The wettability is related to the effects of capillarity, and is a key factor in determining the affinity that the oil will have with the reservoir rock and how easily the oil will be displaced.

4. MICRO AND NANOEMULSIONS IN PRODUCTION ENHANCEMENT

The stimulation of wells is composed by a set of techniques that aim to increase or restore the permeability of the region near the well, improving its production. Stimulation operations can be classified into hydraulic fracturing, acid fracturing, and matrix acidification. In fracturing operations, the fluids are pumped above the fracture pressure of the rock formation to open and propagate fractures into the formation. These fractures are filled with proppant materials that support them, allowing a high flow through these channels. In the

Figure 5. Gel viscosity as a function of temperature (Castro Dantas et al., 2003).

acid fracturing, in general, they are not used as prostatic due to the heterogeneity of carbonate formations, creating channels on the faces of the fractures due to their reaction with the acid, so the conductivity is maintained even after the accommodation process of the rock formation. In matrix acidification operations, acidic systems are pumped into the well, at a pressure below the fracture pressure, so the acid permeates into the porous medium region near the well. In the case of carbonate formations, the HCl reacts with the rock matrix and forms conductivity channels. In sandstone formations, the acid dissolves and disperses acid-soluble components, obstructing the pores of the rock matrix. Several studies have reported the use of micro and nanoemulsion systems for well stimulation operations. In addition to the properties similar to emulsified fluids, the micro and nanoemulsion systems have the advantage of being obtained with lower oil concentrations, being environmentally friendlier.

4.1 Hydraulic fracturing

Surfactant-based fracturing gels (microemulsions), also known as Viscoelastic Surfactant (VES) fluids, are considered clean gels due to the absence of insoluble residues in their composition. This kind of fluid has been developed to minimize or eliminate damages to fractures.

Castro Dantas et al. (2003) studied the rheological properties of a new anionic surfactant-based gel (microemulsion). Steady and oscillatory shear experiments were carried out to evaluate the structure of the gel. The oscillatory shear experiments showed that the viscoelastic gels are characterized by loss and storage modulus slightly

dependent on the frequency. Steady shear experiments showed that gel viscosity depends on cosurfactant/surfactant (C/S) ratio and temperature (Figure 5).

Castro Dantas et al. (2006) developed an experimental methodology to break surfactant-based fracturing gel (microemulsion). According to authors, these gels brake when exposed to hydrocarbons or brine. Therefore, conventional breakers, commonly used in polymer-based gels, are not required, and the oil or gas production can break the surfactant-based gels by itself. The gel break test consisted, basically, on the injection of fluids into a sandstone core sample (Figure 6). One could observe that the gel studied presented optimum break results, with a decrease in viscosity to 10 mPa in the first 6 hours of the test.

Khair et al. (2011) developed a new anionic surfactant fracturing fluid – D3F-AS05. It has temperature stability above 90 °C. The fluid handles the shortcoming of zwitterionic and cationic VES fluid that allows it to be used in deep well with a high injection rate. The viscoelastic properties of D3F-AS05 make it capable of suspending and transporting proppant at viscosities lower than conventional ones. It has the ability of gel breaking at low temperatures and obtaining high permeability after breaking. The performance of the fluids is sensitive to temperature; therefore, surfactant and other component concentrations must be adjusted accordingly.

Liang et al. (2017) presented an experimental investigation based on a core-flood sequence that simulates fluid invasion, flowback, and

Figure 6. Experimental apparatus developed for the break tests of the surfactant-based gels (Castro Dantas et al., 2006).

hydrocarbon production within the rock near the fracture face. Real-time CT scans were applied to visualize the change of water saturation profile, which were, then, compared to the regaining of rock permeability. Different surfactants were used to test the effect of IFT reductions and microemulsions formation. They were compared to explore the best conditions for maximizing permeability enhancement. Results showed that surfactant additives that form in-situ microemulsions, in particular W-I and W-III, are promising candidates to mediate the water block after hydraulic fracturing.

Das et al. (2018) studied the combination of single phase viscoelastic surfactant fluid (sodium oleate - an anionic surfactant) and polymer gel system (carboxy methyl hydroxyl propyl guar CMHPG), prepared in the microemulsion gel region, with enhanced synergistic effects and reduced surface tension between broken fracturing fluid and formation. The prepared gel showed an improved rheology with higher thermal stability, better cleaning properties, and less residues when compared to the individual one.

Liang et al. (2018) evaluated the properties of a well-screened LNF – forming a nanofluid and comparing it with a commercial flowback surfactant (CFS) that is widely used by the industry. The results showed that LNF used as a fracturing fluid additive invades the formation during the fracturing, possibly promoting spontaneous imbibition and, thus, enhancing oil production. LNF is a promising candidate for the fracturing fluid additive to enhance oil production from shales or other tight oil reservoirs.

Kuang et al. (2018) evaluated nanofluid mixtures as EOR agents or additives to fracturing fluids through a detailed investigation of their interfacial properties and impacts on oil recovery. The nanofluids were prepared by dispersing nanoparticles (SiO_x , Al_2O_3 , and TiO_2) in brine solutions with different concentration of chemical agents (oleic acid, polyacrylic acid, a cationic, an anionic, and a nonionic surfactant). The interfacial tension between crude oil, aqueous phases, and the wettability of reservoir rock samples in the presence of nanofluids were studied. The effects of nanofluids on oil recovery were investigated using spontaneous imbibition experiments at room conditions, and core-flooding tests at high pressures and temperatures. Results show that the studied nanofluids were capable of reducing the interfacial tension between oil and brine phases. Nanofluids formulated with the cationic surfactant and oleic acid changed the wettability of the rock's surface towards less water-wet, or even oil-wet; and nanofluids formulated with the anionic surfactant made the surface slightly more water-wet. When observing the results from spontaneous imbibition experiments with nanofluids as additives to hydraulic fracturing fluids and as enhanced oil recovery agents, it was found that pure and anionic nanofluids enhanced oil production from both sandstone and carbonate core samples. The nonionic nanofluids were the most effective colloidal solutions for oil recovery. The SiO_x + nonionic surfactant nanofluid was tested in core-flooding experiments on sandstone and carbonate rock samples. The results in sandstone were promising with a recovery of 6.2%. In carbonate samples, the presence of the calcium ion was a hampering factor for its successful application.

Figure 7. Plug after nanoemulsion injection, lateral view (A), bottom view (B), and cut view (C) (Sousa, 2015).

4.2 Matrix acidification

In matrix acidification, nanofluids are capable to delay reactions by decreasing the diffusion of the acid in the medium, enabling acidification in reservoirs with low permeability. **Hoefner and Fogler (1985)** studied a microemulsion system formed by cetylpyridinium chloride as surfactant, butanol as cosurfactant, dodecane as oil phase, and aqueous hydrochloric acid for in the acidification of carbonate rocks. In 1987, they concluded that the system was successful in reducing the acid diffusion coefficient by half (**Hoefner & Fogler, 1987**).

Zengying and Guocheng (2010) investigated a new divergent acid, varying temperature, pH, and amount of viscoelastic surfactant. The results showed that the acid system containing viscoelastic surfactant has a non-Newtonian fluid behavior and is a power-law fluid at low temperatures, however, when subjected to high temperatures it behaves as a Newtonian fluid. One could observe that the system had viscosity and elasticity properties at the same time, and that this viscoelastic tendency grew proportionally along with the increase of the viscoelastic surfactant concentration.

Liu et al. (2013) studied the divergence mechanisms of acid systems with viscoelastic surfactants through experimental analysis and developed a numerical model that describes the divergence of these systems to perform simulations. They concluded that the divergence is dependent on the viscosity of the spent acid and zone of spent acid. These two factors grow according to the addition of auto-divergent acidic systems with viscoelastic surfactants, which results in a continuous increase of the differential pressure. However, for low permeability areas, this zone of spent acid is lower when compared to high

permeability areas. In addition, the non-uniform distribution of the viscosity does not generate a sharp decline of pressure in breakthrough boundaries. Through the simulations, the results resembled the experimental ones, proving that the model is effective.

Al-Ghamdi et al. (2014) studied an auto-divergent system based on viscoelastic surfactants, varying the flow and initial permeability of the plugs. The injection of auto-divergent and aqueous HCl systems was performed in calcite plugs. The results showed that the systems were not diverging effectively. However, the results contributed to the understanding of wormholes formation and divergence process.

Sousa (2015) studied the formulation of acid nanoemulsions for matrix acidification. A study of the superficial stresses, reaction kinetics, and evaluation of the injection in carbonate rock, as well as a test of asphaltic sludge removal were performed. Results showed that the nanoemulsions were efficient to create artificial drainage canals (wormholes) in carbonate core plugs with low natural permeability. The wormholes increased permeability, reaching values up to 390 mD (Figure 7). The acid microemulsion system showed a good result of asphalt sludge removal, indicating the potential of nanoemulsions in the removal of this type of damage.

Acid microemulsions of the type O/W systems were obtained by **Aum (2016a)**, the experiments demonstrate that the dissolution reaction of HCl is retarded in microemulsion media. Coreflood experiments were performed on carbonate plugs using two stimulation fluids (**Aum 2016**). The first stimulation base used hydrochloric acid (HCl) and the second ethylenediamine tetra-acetic acid (EDTA) in microemulsion media. EDTA is a chelating

Table 1. Permeability assays of EDTA systems at 1 mL/min.

Assay	Pore volume	Flow rate (mL/min)	Initial permeability	Final permeability	Increment %
1	1	1	496	746	50%
3	1	1	793	822	4%
5	1	1	744	991	33%
13	1	1	675	962	43%
15	1	1	760	930	22%
17	1	1	511	950	86%

Table 2. Permeability assays of HCl systems at 1 mL/min.

Assay	Pore volume	Flow rate (mL/min)	Initial permeability	Final permeability	Increment %
7	1	1	505	774	53%
9	1	1	674	1052	56%
11	1	1	561	726	29%
19	1	1	704	785	11%
21	1	1	463	773	67%
23	1	1	487	742	52%

agent that reacts with calcium carbonate and has the capacity of stimulating carbonate formations. The experiments performed by [Aum \(2016a\)](#) and [Aum et al. \(2016\)](#) consist of the injecting of 1 pore volume of the reactive system at different flow rates and verifying the permeability enhancement promoted.

The results, presented in Tables 1 and 2, show that microemulsion systems were efficient in stimulating the plugs, reaching permeability increments up to 86% for the EDTA and 67% for the HCl. Furthermore, corrosion experiments demonstrated that both acids in the microemulsion media have the potential to reduce corrosiveness by 80%.

Through the experiments, the authors demonstrated that microemulsion systems obtained are suitable to serve, potentially, as alternative fluids in carbonate stimulation.

5. ENHANCED OIL RECOVERY

Enhanced oil recovery methods (EOR) are used to increase the productivity of reservoirs where conventional methods are inefficient, or even as an initial alternative for production. Among these

methods, there are the thermal, miscible, and chemical methods. The use of the chemical methods for enhanced oil recovery acts in the alteration of the rock/fluid physical and chemical properties, decreasing the oil residual saturation and increasing the oil displacement in the porous medium. The injection of chemical fluids, such as polymer, surfactant, and microemulsion (nanofluid) solutions seek to increase the viscosity of the injected fluid, decrease the interfacial tension, and increase the miscibility between the injected fluid and oil. Studies in this area show that chemical fluids are considered an effective approach to oil production after the use of water or gas as injected fluid.

Microemulsion systems are transparent dispersions, thermodynamically stable, capable of solubilizing polar and non-polar substances and have droplet size in nanometric scale ([Holmberg, 1994](#); [Lindman & Shinoda, 1987](#)). These characteristics draw attention to the application of nanotechnology in EOR ([Castro Dantas et al., 2014](#); [Bera et al., 2014](#); [Jeirani et al., 2013](#); [Kumar et al., 2016](#)).

[Bera et al. \(2011\)](#) studied the effects of salinity on a sodium dodecyl sulfate/brine/propanol/heptane-based microemulsion on the results from interfacial

Figure 8. Efficiency of displacement versus injected porous volume by conventional and EOR methods (Santanna et al., 2013).

tension between crude oil and microemulsion as a determinant factor to select the microemulsion for enhanced oil recovery tests. Results and efficiency of oil recovery by this method were above 25%.

Santanna et al. (2013) used a microemulsion system in enhanced oil recovery tests to evaluate the mobility and oil displacement in the porous medium. The microemulsion system reached an OOIP recovery of 21.5% and total recovery (conventional + special) of 62.5% (Figure 8).

Hendraningrat et al. (2013) verified the possibility of using nanofluids in enhanced oil recovery tests in sandstone rock of high and low permeability. The nanoparticle used 99.8% silicon dioxide added to brine (NaCl 3% by weight) at different concentrations (0.01%, 0.05% and 0.1%). The fluids obtained were used in the enhanced oil recovery assay after injecting the NaCl solution. Interfacial tension studies were also performed among the fluids involved, obtaining lower interfacial tension results for the higher nanofluid concentrations. The silica nanoparticles solution showed potential in the capacity of enhanced oil recovery in sandstone at certain concentration. In this study, the system with a concentration of 0.05% presented the best result of final oil recovery (68.75%) for both low and high permeability. The efficiency result for the higher nanoparticle concentration (0.1%) was lower probably due to obstruction of the porous spaces.

Jeirani et al. (2013) evaluated the ideal composition of a microemulsion using triglyceride (palm oil) as oily phase. The experimental results

indicated that the ideal microemulsion was obtained when mixing equal masses of palm oil and aqueous phase containing 3% of sodium chloride, 1% of alkyl-polyglycosides, 3% of glyceryl mono-oleate, and 93% in deionized water by weight. Interfacial tension measurements showed very low results in the system performed, and the system obtained in the special recovery was applied. It was possible to recover about 4.3% of the residual oil using the optimum microemulsion, resulting in a total recovery of 87%.

Bera et al. (2014) investigated the effects of salinity on the formation of microemulsions with non-ionic surfactant. The microemulsion (20% cosurfactant/surfactant; 53% of oil and 27% of brine) used in EOR tests was more efficient in reducing the interfacial tension when compared with the surfactant solution and brine. The particle size was between 2.5 – 10 nm, varying the microemulsion salinity from 2% to 9% NaCl. The microemulsion injection recovery was 25% above the conventional method (brine).

Castro Dantas et al. (2017) used nanofluids in enhanced oil recovery (EOR). The experiments were carried out in core flood equipment capable of simulating oil reservoir conditions if a sandstone rock from the Botucatu formation. The ME systems were obtained from a microemulsion composed by RNX95 as surfactant, isopropyl alcohol as cosurfactant, kerosene as oil phase, and distilled water as aqueous phase. Different percentages of polyacrylamide were added to the systems obtained to evaluate the influence of viscosity on

Figure 9. Illustration of microemulsion and brine bank injections (Souza, 2017).

the EOR results. The parameters droplet size, surface tension, and interfacial tension were evaluated. A system with 2.5% surfactant was used for EOR assays. Oil recovery was directly proportional to the percentage of polymer in the nanoemulsion, varying from 39.6 to 76.8%. Total oil recovery ranged from 74.5 to 90%.

Souza (2017) evaluated the use of chemical fluids (surfactant solution and microemulsion) in Enhanced Oil Recovery (EOR) with Ultramina NP200 as surfactant. The EOR tests evaluated the concentration influence of injected surfactant and how the surface, interfacial tension, and viscosity in oil recovery. The use of Ultramina NP200 solution was capable of increasing the oil displacement capacity in relation to brine injection. However, the surfactant solution, despite the high concentration (25% m/m), obtained a lower recovery factor when compared to the microemulsion, even when the concentration of active matter was low (1.0%-M/m). The recovery factor increased as the surfactant concentration increased in the microemulsion. It was also observed that it is possible to achieve satisfactory recovery results by injecting smaller amounts of microemulsion, followed by brine (Figure 9), with oil in place recovery of 24.1% (%OOIPA) and total recovery of 77.2% (%OOIPT).

Viana (2018) studied micro and nanoemulsion multicomponent systems with ASP constituents for inversion of reservoir rock wettability and EOR. All the systems formulated were capable of changing it to water-wet rock, being efficient in wettability inversion and favoring oil displacement. The recovery results proved the swept efficiency and displacement of micro and nanoemulsions, since the total oil recoveries were high, ranging from 65% to 97%.

6. CONCLUSIONS

In this paper, the authors analyzed the use of micro and nanoemulsions, their application in EOR and in Production Enhancement, defining the basic concepts to obtain micro and nanoemulsions systems. They discussed the phenomena related to flooding process in the porous media and effects caused by surfactants, micro and nanoemulsions.

This work studied Microemulsions (ME) as alternative fluid to enhance production. As fracturing fluid, the ME presented satisfactory results and achieved viscosities compatible with a successful break process, necessary to the flowback. Carbonate acidizing microemulsions can delay the diffusional process of the acid in the medium. The results presented in this research show that microemulsions are effective in increasing permeability of the carbonates. Oil-in-water nanoemulsions (O/W) were also tested and achieved results that were similar to those found with microemulsions systems, however, using a lower surfactant concentration. These results demonstrate the potential of these systems to enhance production.

Experiments demonstrated the effectiveness of micro and nanoemulsions in promoting enhanced oil recovery. Results indicate that the displacement of these systems in the porous medium promotes improvements in oil recovery by using different mechanisms, including wettability inversion and miscibility of the reservoir oil with displacement fluids.

In general, microemulsions are a technical alternative to applications in enhanced oil recovery and production enhancement. Although, literature reports and technical references in this field are

limited, they indicate that the industry still has some resistance to its application, especially due to the high concentrations of surfactant and additives. Therefore, research on this topic should focus on the development of formulations with low surfactant concentration and on the increase of cost-effectiveness. Furthermore, micro and nanoemulsion could be an effective alternative to environmental sensitive areas.

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CONFLICT OF INTEREST

The authors declare no conflict of interests.

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