

## Obtaining and characterizing microemulsion systems containing Alkali-Surfactant-Polymer (ASP) for advanced oil recovery application

Obtenção e caracterização de sistemas microemulsionados contendo Álcali-Surfactante-Polímero (ASP) para aplicação em recuperação avançada de óleo

Obtención y caracterización de sistemas microemulsificados que contienen Alkali-Surfactant-Polymer (ASP) para su aplicación en recuperación avanzada de aceite

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### Abstract

Fluids in terms of rheological behavior can be classified into Newtonians and non-Newtonians. Newtonians are fluids that have unique and absolute viscosities, because the ratio between shear stress and shear rate is constant. In the oil industry, most fluids, such as microemulsions, oil and polymeric solutions, do not exhibit Newtonian behavior. To understand the behavior of chemical fluids, it is necessary to analyze some parameters to interpret their properties and applicability. In this context, the present work aims to obtain and characterize microemulsion systems containing Alkali, Surfactant, and Polymer, and verify their applicability in advanced oil recovery. Thus, we obtained five microemulsion systems consisting of saponified coconut oil (surfactant), Butan-1-ol (co-surfactant), kerosene (oil phase),  $\text{Na}_2\text{CO}_3$  (alkali), water and different percentages of the polymer. The systems were characterized by analyzes of particle diameter, surface tension, viscosity and rheological behavior using mathematical models. Droplet sizes showed characteristic values of micellar aggregates. Surface tension presented a slight elevation when the percentage of polymer in the microemulsion increased. Through the rheological study, it was possible to observe that experimental values were better adjusted to the Ostwald-de Waele “power-law” model. As the percentage of polymer in the system increased, we calculated the apparent viscosity of the systems and observed an increasing change in viscosity values, a result of great interest to enhanced oil recovery studies.

**Keywords:** Microemulsion systems; ASP; Fluid rheology.

### Resumo

Os fluidos quanto ao comportamento reológico podem ser classificados em Newtonianos e não Newtonianos. São denominados Newtonianos os fluidos que apresentam viscosidade única e absoluta, pois a razão entre a tensão cisalhante e a taxa de cisalhamento é constante. Na indústria de petróleo a maior parte dos fluidos não exibe comportamento Newtoniano, como por exemplo as microemulsões, o petróleo e as soluções poliméricas. Para entender o comportamento dos fluidos químicos faz-se necessário analisar alguns parâmetros para interpretar suas

propriedades e aplicabilidade. Neste contexto, o presente trabalho tem como objetivo a obtenção e a caracterização de sistemas microemulsionados contendo Álcali, Surfactante e Polímero (ASP) visando a sua aplicabilidade na recuperação avançada de óleo. Assim, foram obtidos cinco sistemas microemulsionados constituídos de óleo de coco saponificado (surfactante), Butan-1-ol (co-surfactante), querosene (fase oleosa),  $\text{Na}_2\text{CO}_3$  (Álcali), água e diferentes porcentagens do polímero. Os sistemas foram caracterizados por análises de diâmetro de partícula, tensão superficial, viscosidade e comportamento reológico utilizando modelos matemáticos. Os tamanhos de gotículas apresentaram valores característicos de agregados micelares. A tensão superficial apresentou uma pequena elevação ao aumentar a porcentagem de polímero. Através do estudo reológico foi possível observar que os valores experimentais se ajustaram melhor ao modelo de Ostwald de Waele, denominado modelo de potência. Foi possível calcular a viscosidade aparente dos sistemas e observar uma alteração crescente dos valores de viscosidade conforme o aumento do percentual de polímero no sistema, resultado de grande interesse no que diz respeito à recuperação avançada de petróleo.

**Palavras-chave:** Sistemas microemulsionados; ASP; Reologia de fluidos.

### Resumen

Los fluidos en términos de comportamiento reológico se pueden clasificar en newtonianos y newtonianos. Se llaman newtonianos, los fluidos que tienen una viscosidad única y absoluta, por lo que se encuentran entre la vanguardia y las tasas impositivas constantes. En la industria petrolera, la mayoría de los fluidos no presentan un comportamiento newtoniano, como microemulsiones, petróleo y soluciones poliméricas. Para comprender el comportamiento de los fluidos químicos, es necesario analizar algunos parámetros para interpretar sus propiedades y aplicabilidad. En este contexto, el presente trabajo tiene como objetivo obtener y caracterizar sistemas microemulsificados que contienen álcali, tensioactivo y polímero (ASP) con el objetivo de su aplicabilidad en la recuperación avanzada de petróleo. Así, se obtuvieron cinco sistemas microemulsificados constituidos por aceite de coco saponificado (tensioactivo), Butan-1-ol (co- tensioactivo), queroseno (fase aceitosa),  $\text{Na}_2\text{CO}_3$  (álcali), agua y diferentes porcentajes del polímero. Los sistemas se caracterizaron mediante análisis de diámetro de partícula, tensión superficial, viscosidad y comportamiento reológico utilizando modelos matemáticos. Los tamaños de las gotas mostraron valores característicos de agregados micelares. La tensión superficial mostró un pequeño aumento al aumentar el porcentaje de polímero en la microemulsión. A través del estudio reológico se pudo observar que los valores experimentales se ajustaron mejor al modelo de Ostwald de Waele. Fue posible calcular la viscosidad aparente de los sistemas y observar un cambio creciente en los valores de viscosidad a medida que aumentaba el porcentaje de polímero en el sistema, resultado de gran interés con respecto a la recuperación avanzada de aceite.

**Palabras clave:** Sistemas microemulsificados; ASP; Reología de fluidos.

## 1. Introduction

The Enhanced Oil Recovery (EOR) process using ASP (Alkali-Surfactant-Polymer) technology consists of injecting banks, together or separately, of an aqueous solution containing an alkaline agent, a surfactant and a polymer. The method was developed in the early 1980s, due to the good synergy between the three chemical agents, depending on the petrophysical, rheological properties, and the methodology of the procedure adopted, and has been used to recover residual oil (Borges et al., 2007; Viana et al., 2015; Cheng et al., 2018). The process seeks to reduce capillary forces, improve displacement efficiency, increase the contact area between fluids and control the mobility ratio. According to the literature, the increase in the recovery factor (OOIP divided by incremental oil) can reach more than 20% (Chen et al., 2012; Volokitin et al., 2012; Humpphry et al., 2013; Sharma et al., 2015; Aitkulov et al., 2018; Al-Murayri et al., 2017; Viana et al., 2015; Zhong et al., 2018).

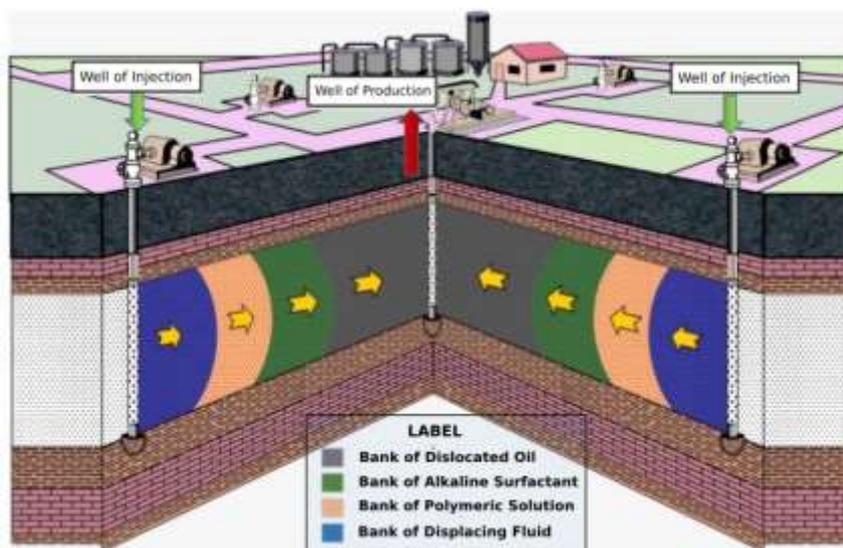
Each chemical agent plays a key role in the reaction. The main function of the polymer is to increase the viscosity of the displacing fluid, contributing to the correction of the mobility ratio between the fluids. Thus, it increases the sweep efficiency of the injected fluid. The surfactant acts in reducing the surface tension and contributing to the stability of the emulsion formed. The alkaline agent promotes the emulsification of the trapped oil, changes the wettability of the rock surface, increases pH and reduces adsorption of surfactant and polymer (Sheng, 2011; Castro Dantas et al., 2017; Huang et al., 2019; Aiolfi & Romero, 2019).

However, the polymer solution and the surfactant/alkali solution may impose restrictions on each other. Huang et al. (2019) pointed out that the viscosity of the polymeric solution is reduced by 30% if added to alkali and surfactant, while the dynamic stress is much lower in the polymer-free A/S-oil-water system without polymer. The injection pressure increases

rapidly when the ASP solution is injected continuously, leading to a decrease in injection and production in the middle and final stages of the process.

In applications of the ASP method, usually before the main ASP bank, there is a pre-bank (“pre-flush”) and then a post-bank (“protection slug” or “polymer drive”) to avoid incompatibility between fluids and favor the flow throughout the reservoir (Sharma et al., 2015). Figure 1 shows a possible ASP injection system configuration.

**Figure 1** - Scheme of a possible injection configuration using ASP system.



Source: Authors.

Figure 1 presents a possible sequence of banks injection in a process using ASP technology. The alkali-surfactant pre-flush has the function of reducing the interfacial tension through the inversion of the rock's wettability. The polymer bank has the objective of forming a uniform advancing front, to increase the sweeping efficiency. The water bank is used as a displacement fluid (Sharma et al., 2015; Viana et al., 2015). However, in the literature, there is no rule as far as establishing the order of injection of the respective banks, making it possible to insert a lower concentration polymer post bank to protect the main polymer bank from possible incompatibility.

### 1.1. Microemulsions

Microemulsions are self-aggregated, spontaneous and dynamic systems, with an oil phase and an aqueous phase, stabilized by a surfactant and, if necessary, a co-surfactant. The co-surfactant consists of a short-chain alcohol, such as butan-1-ol, used to act directly on the packaging factor and its function is to reduce the repulsion of the polar “heads” of the surfactants, stabilizing the micelle (Castro Dantas et al., 2017; Garnica et al., 2020; Curbelo et al., 2021). Microemulsions differ from conventional emulsions because they allow the stabilization of immiscible, thermodynamically stable, translucent, isotropic mixtures and have much smaller structural units (Gurgel, 2004; Gradzielski, 2008; Soares, 2011; Viana et al., 2015; Castro Dantas et al., 2019). According to Rossi et al., (2006), Castro Dantas et al. (2017) and Curbelo et al. (2021), in the microemulsion, with ionic aggregates, the phases are organized similarly to the emulsion. The oil phase is dispersed in the aqueous phase, that is, the hydrophobic part of the molecule is grouped inside the micelle to have a minimum of surface in contact with water, while the polar ends are directed towards the aqueous medium, forming direct microdroplets. However, when the opposite phenomenon occurs, the inverse microdroplet originates, as can be seen in Figure 2.

**Figure 2** – Schematic representation of types of micelles.(a) Direct microdroplet and(b) Inverse microdroplet.



Source: Rossi et al (2006)

Due to these characteristics, microemulsion systems have a great potential for application in the oil industry. They are used, in the solubilization of oil sludge (Viana, 2013; Silva et al., 2019), and the treatment of produced water (Castro Dantas et al., 2018; Silva et al., 2020). They also work as, fracturing fluids (Ribeiro et al., 2016) and in advanced oil recovery (Hendraningrat et al., 2013; Castro Dantas, 2014; Shafiee et al., 2017; Sharma et al., 2017; Oliveira et al. 2017, Castro Dantas et al., 2017; Dantas et al., 2019).

## 1.2. Rheology

Fluids in terms of rheological behavior can be classified, according to Newton's Law, into two types: Newtonian and non-Newtonian (time independent or time dependent), relating shear stress and shear rate, as shown in Equation (01).

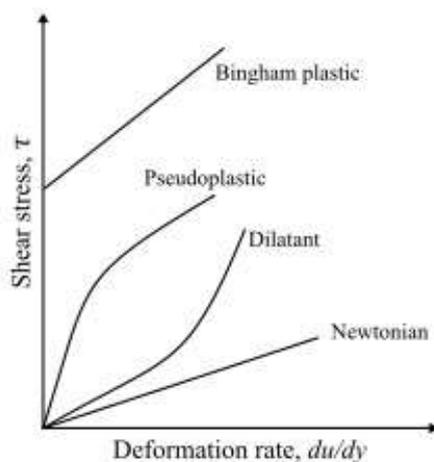
$$\tau = \eta \cdot \left( \frac{dv}{dy} \right)^n = \eta \cdot \gamma^n \quad (01)$$

where “ $\tau$ ” is the shear stress (Pa), “ $\eta$ ” it is the viscosity (mPa.s), “ $\frac{dv}{dy} = \gamma$ ” the shear rate (s<sup>-1</sup>) and “n” the behavior index.

Newtonian fluids are influenced by temperature and pressure. Viscosity is unique and absolute, as the ratio between shear stress and shear rate is constant (Castro Dantas et al., 2017).

In the oil industry, most fluids, such as microemulsions, petroleum and polymer solutions, do not exhibit Newtonian behavior (Gomes et al., 2007; Castro Dantas et al., 2017). In these non-Newtonian fluids, the relationship between the shear rate and the stress is not constant (Machado, 2002). These fluids are classified according to the aspect of the flow curve and the correlations with some equation or mathematical model. Figure 3 shows different types of rheological behaviors for non-Newtonian fluids, regardless of time.

**Figure 3** – Fluid flow curves.



Source: Fox and McDonald (1998)

To understand the behavior of chemical fluids, it is necessary to analyze some parameters to interpret their properties and applicability. Among these parameters are particle diameter size, surface tension, and rheological behavior of fluids (Viana et al., 2015). Therefore, the present work aims to obtain and characterize ASP microemulsion (Alkali-Surfactant-Polymer) systems in view of their applicability in oil recovery.

## 2. Methodology

### 2.1 Synthesis of anionic surfactant SCO

The saponified coconut oil surfactant (SCO) was synthesized at the Surfactant Technology Laboratory (LTT) of the Federal University of Rio Grande do Norte - UFRN, through the saponification reaction using a well known methodology (Mendham et al., 1992; Lucena Neto, 2005; Rossi et al., 2006; Viana et al., 2015).

### 2.2. Obtaining microemulsion systems

The formulation of the microemulsion point was carried out through an appropriate order of weighing of the components, methodology used by Viana et al. (2015). The four stages of preparing the microemulsions are as follows: 1 – initially, surfactant, co-surfactant, oil phase (OP), part of the aqueous phase (AP), and distilled water (without alkali and polymer) are weighed; 2 – with the aid of a magnetic stirrer, the mixture is homogenized quickly forming the microemulsion (transparent aspect); 3 – following, the polymer is added and is left stirring for at least 6 hours, under around 700 rpm, to ensure total solubilization; 4- At last, the alkali mass is added and, within a few minutes of stirring, the microemulsion preparation is completed. Table 1 shows the composition of the chemical fluids, the polymer-free microemulsion systems (SM-AS), and the microemulsion systems with alkali-surfactant-polymer (SM-ASP) described in this paper.

**Table 1** – Composition of microemulsion systems.

Microemulsion systems	Co-Surfactant/ Surfactant (C/T = 0.5)15%	Oil phase 0.5%	Aqueous phase 84.5%
SM-AS	Butan-1-ol /SCO	Kerosene	84.5% solution of 1.5% de Na <sub>2</sub> CO <sub>3</sub>
SM-ASP <sub>1</sub>	Butan-1-ol /SCO	Kerosene	0.01% polymer AH 912 SH + 84.49% solution of 1.5% Na <sub>2</sub> CO <sub>3</sub>
SM-ASP <sub>2</sub>	Butan-1-ol /SCO	Kerosene	0.02% polymer AH 912 SH + 84.48% solution of 1.5% Na <sub>2</sub> CO <sub>3</sub>
SM-ASP <sub>3</sub>	Butan-1-ol /SCO	Kerosene	0.03% polymer AH 912 SH + 84.47% solution of 1.5% Na <sub>2</sub> CO <sub>3</sub>
SM-ASP <sub>4</sub>	Butan-1-ol /SCO	Kerosene	0.04% polymer AH 912 SH + 84.46% solution of 1.5% Na <sub>2</sub> CO <sub>3</sub>

Source: Authors.

### 2.3 Characterization of microemulsion systems

The characterization step of microemulsion systems aims to identify the physical-chemical properties of the system, to ensure the formation of alkaline microemulsions with polymer, to check if the systems under study are suitable for application, and to assist in the interpretation of the results of special oil recovery. The systems were characterized by droplet diameter analysis, superficial tension, rheological behavior through mathematical models and viscosity analyses.

#### 2.3.1 Particle diameter

To determine the size of the particle diameter, we used a Nanotrak (Microtrac) equipment, Model 252. This equipment uses the principle of dynamic light scattering (DLS). The incident laser had a wavelength of 780 nm, the software used was the Microtrac Flex11, and the equipment measured diameters of 0.8 - 6540 nm, presenting 52 channels, and the distribution was according to the intensity of the light.

#### 2.3.2 Superficial tension

Surface tension analyses were determined using the tensiometer Sensadyne (QC6000–Sensadyne Instruments). Measurements were obtained using the maximum bubble pressure method, without being affected by surface contamination or foaming. Two capillaries of different diameters were immersed in the solution, and the bubbles were formed by injecting nitrogen gas. The average volume required for this analysis is about 20 mL. Distilled water and ethyl alcohol (99.5%) were used for high calibration (71.4 mN/m) and low superficial tension (21.6 mN/m), respectively. The temperature was set at 86°F and the bubble frequency was equal to 2s<sup>-1</sup> (Castro Dantas et al., 2017).

#### 2.3.3 Rheological behavior

The rheological study of the points of the microemulsion systems was based on the coaxial cylinder method. The temperature of 122 °F was regulated by thermostatic bath, with the acquisition of data per second, for a period of 120 seconds, through the Compact Modular Rheometer MCR 92 produced by Anton Paar. Each sample rate, with a volume ranging from 12 to 17 mL, was inserted into the coaxial cylinder (Z43). The broken/sensor (Z41) was immersed in the sample to apply the shear

rate, generating their respective tensions in response, in the shear rate of 0 until reaching  $1000 \text{ s}^{-1}$ . As a result of these analyses, flow curves were generated and mathematical models were applied to determine the behavior of colloidal systems and their respective viscosities.

### 3. Results and Discussion

Microemulsion systems (SM-AS, SM-ASP1, SM-ASP2, SM-ASP3, and SM-ASP4) were characterized by particle diameter analyses, superficial tension, and rheology of fluids to provide data to interpret application results in advanced medium oil recovery. As for the macroscopic aspect, the systems showed a clear and stable appearance for a certain time. Stability over time was compromised by the presence of precipitates. Viana et al. (2015) reported that these precipitates are possibly constituents of the surfactant (SCO) which had reduced solubility in alkaline environments. According Castro Dantas et al. (2017) and Garnica et al. (2020) the stability of the systems is directly related to the constituents of the microemulsion.

Results show that different percentages of AH 912 SH polymer have been added in relation to the system. The value corresponds to this mass percentage being taken from the amount of water, to maintain the percentage of other components. The polymer AH 912 SH belongs to the class of the commercial-type polyacrylamides (SNF of Brazil Ltd.). It features a white color, a granulated solid physical state, a molecular weight  $8 \times 10^6 \text{ g/mol}$ , and it has an anionic character. Table 2 shows the compositions of microemulsion systems with different percentages of polymer, macroscopic aspect, superficial tension, and particle diameter.

**Table 2** – Influence of AH 912 SH polymer percentage in the systems studied.

Microemulsion Systems	Polymer Concentration (%)	Macroscopic appearance	Superficial tension (mN/m)	Diameter (nm)
SM-AS	0	Transparent	$27.6 \pm 0.14$	$1.170 \pm 0.002$
SM-ASP <sub>1</sub>	0.01	Transparent	$28.8 \pm 0.06$	$1.175 \pm 0.002$
SM-ASP <sub>2</sub>	0.02	Transparent	$28.9 \pm 0.07$	$1.231 \pm 0.006$
SM-ASP <sub>3</sub>	0.03	Transparent	$28.9 \pm 0.06$	$1.910 \pm 0.004$
SM-ASP <sub>4</sub>	0.04	Transparent	$28.9 \pm 0.04$	$2.630 \pm 0.003$

Source: Authors.

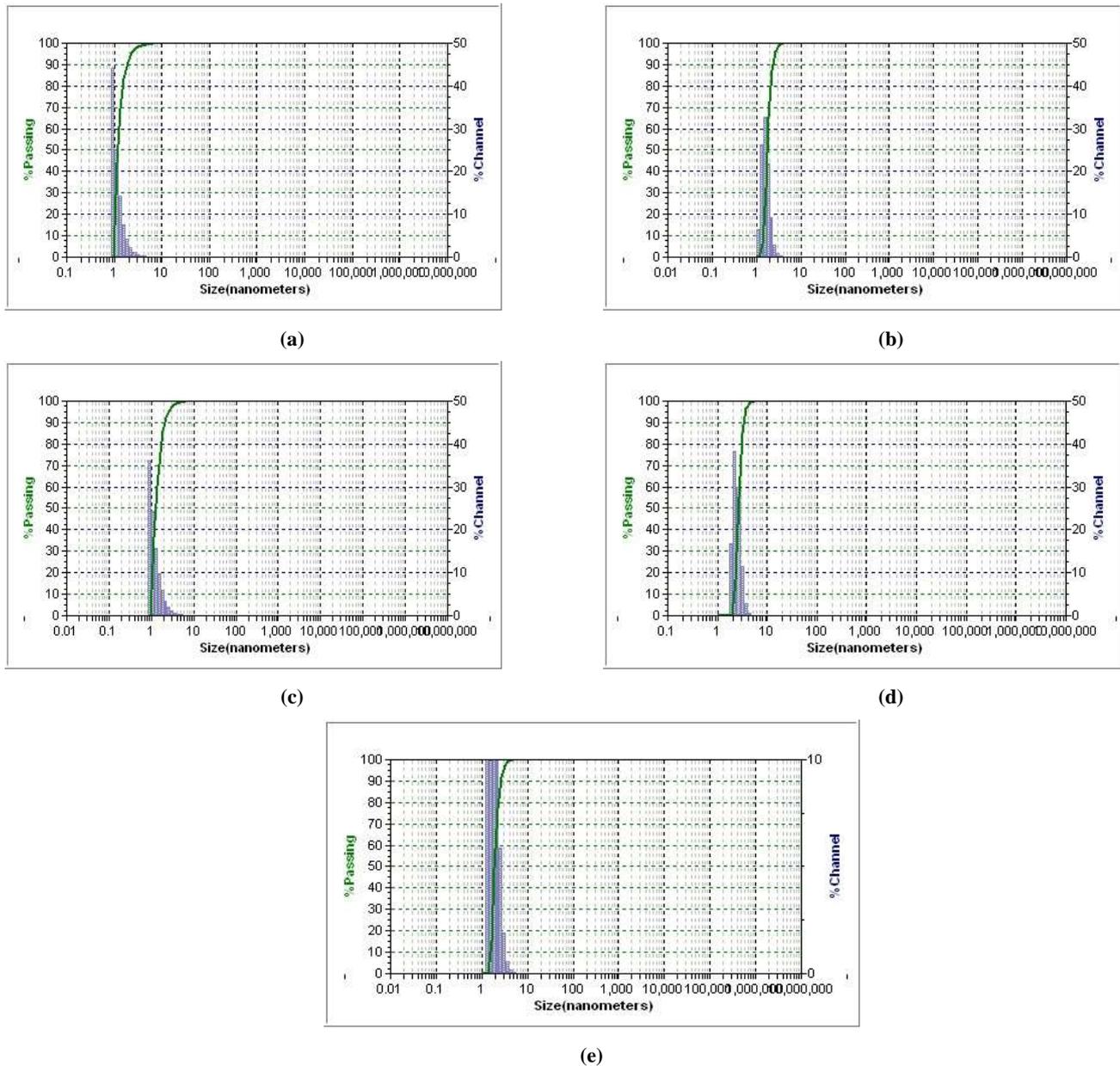
The surface tension of all systems showed similar values, around 28 mN/m. However, upon the addition of the polymer, we could observe an increase in surface tension in the order of 1,3 mN/m. This, result justified by the increase in viscosity, which makes it difficult for the surfactants to migrate to act on the surface (Castro Dantas et al., 2014). Although, in general, the systems presented a reduction in surface tension of more than 50% when compared to water (71,4 mN/m, at 86°F).

Droplet diameters were determined, in triplicate, with the objective of evaluating whether the particle size of the systems is within the indicated range of a microemulsion. Also, according to the data presented in Table 2, it is possible to notice that there is a greater variation in particle size as the percentage of the polymer in the system increases. This result is related to the size of polymer molecules and of the polydispersion of the system. In this case, the increase in polymer concentration tends to form a more polydispersed system. However, all systems presented a diameter below 5 nm, maintaining the systems in the microemulsion range, characteristic of micellar aggregates. Figures 4.a, 4.b, 4.c, 4.d and 4.e present the particle diameter distributions of the systems studied.

According to the results observed in Figure 4, all microemulsions presented the narrow Gaussian base. However, as noted on Table 2, for the higher polymer concentration system (SM-ASP4), a larger diameter distribution was observed with

the mean value of 2.630 nm. These measurements were performed in triplicate to determine the mean deviation of the analyses.

**Figure 4** – Particle size distribution of the systems under study:(a) SM-AS; (b) SM-ASP<sub>1</sub>; (c) SM-ASP<sub>2</sub> ; (d) SM-ASP<sub>3</sub> ;e (e) SM-ASP<sub>4</sub>.



Source: Authors.

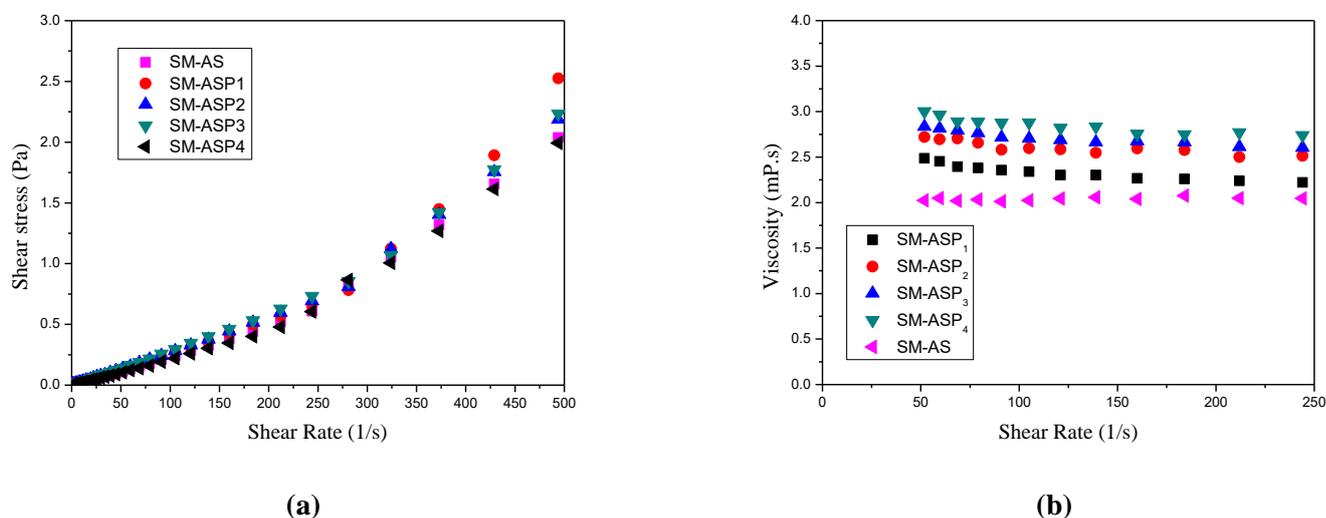
According to Almeida (2015) and Green (1998), in the EOR process, the increase in oil production occurs through five mechanisms: (1) reduction in oil viscosity, (2) reduction of rock/fluid and fluid/fluid interfacial tensions, (3) change in rock wettability, (4) correction of the mobility ratio between the displacing fluid and the trapped oil (5) or promotion of the relative permeability of a phase.

Some parameters are used to evaluate the production of hydrocarbons obtained by an EOR project quantitatively. Such parameters are: horizontal and vertical scanning efficiency, which measures the fraction of the porous volume reached by

the displacing fluid; and the efficiency of displacement, which measures the oil's ability to mobilize in regions washed by the displacing fluid (Costa et al., 2017). The increase in sweeping efficiency occurs via reduction of mobility ratio by increasing the viscosity of the displacing fluid or by decreasing the viscosity of the displacing fluid. Thus, the lower the mobility ratio is, the greater the recovery efficiency will be. The use of microemulsion ASP systems, among other features, acts in changing the viscosity of the displaced fluid. In this context, it is of utmost importance to evaluate the rheological behavior of the systems under study, in view of its applicability in advanced recovery.

The microemulsion systems were subjected to shear rates varying from 0 until 1000s<sup>-1</sup>, at 122°F, to generate flow curves (shear stress as a function of shear rate) and to gather data to analyze the influence of the shear rate on viscosity, as shown in Figure 5.

**Figure 5** – Influence of the shear rate on the shear stress (a) and viscosity (b).



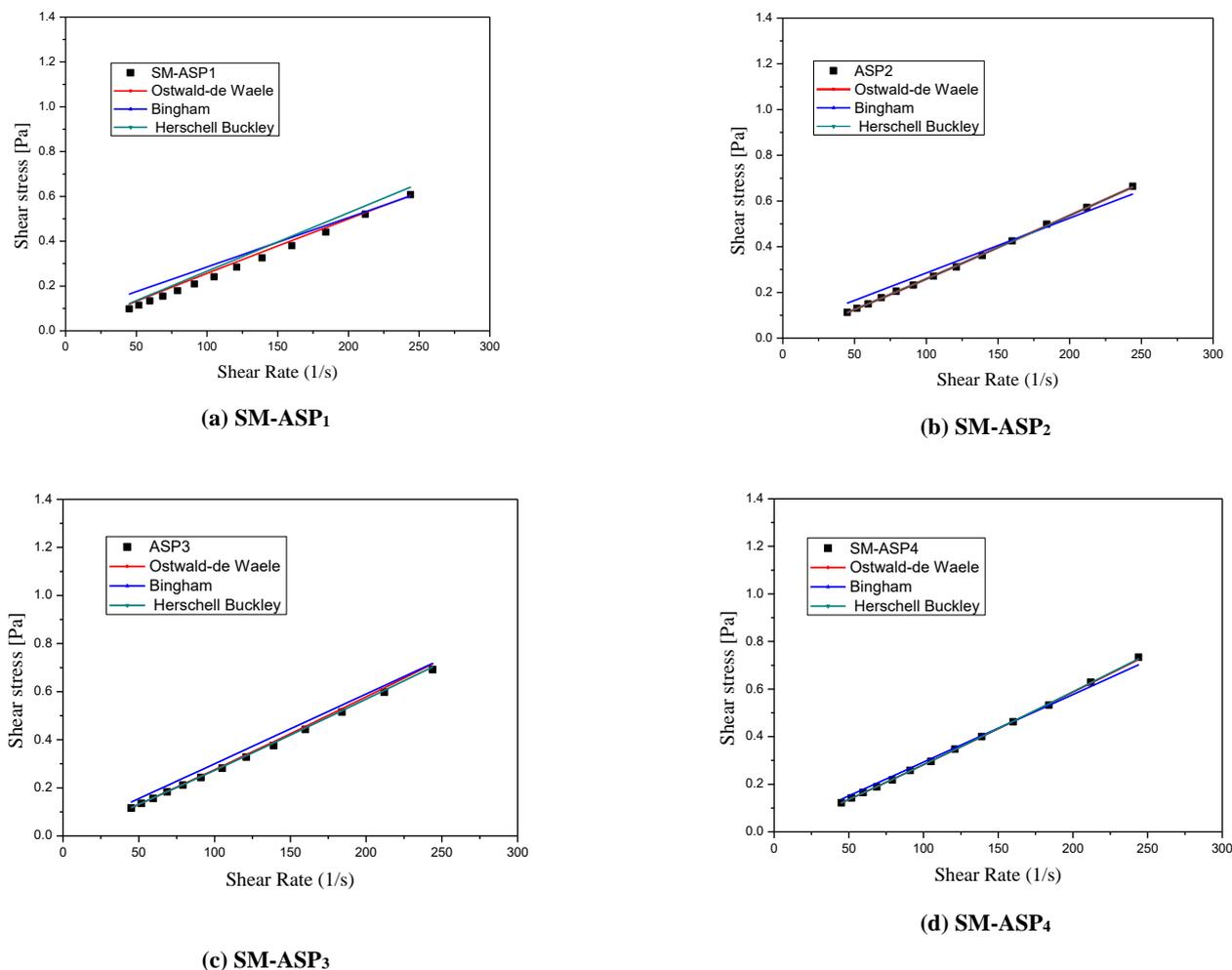
Source: Authors.

Looking at Figure 5.a, one can observe that, in the microemulsion systems studied, the influence of shear rate on shear stress, behaves very similarly. Figure 5.a shows two well-defined regime regions, which show a change from laminar to turbulent regime for rates above 250 s<sup>-1</sup>. When analyzing Figure 5.b, one can infer that, for the system with no polymer (SM-AS), viscosity values tend to remain constant, being classified by Machado (2002) as Newtonian fluid. However, for polymer systems, there is a decrease in viscosity with an increase in the shear rate, behavior characteristic of non-Newtonian fluids of the pseudoplastic type.

The rheological behavior of fluids used as displacers in EOR projects are analyzed through mathematical models applied to laminar flow, due to the predominance of the flow regime of fluids in the porous medium. Therefore, for comparative effect of all systems, rheological behavior tests were carried out at a shear rate of 50 until 250 s<sup>-1</sup>. The tests started in 50 s<sup>-1</sup> to neglect the initial stresses related to the expiration of static friction generated for the equipment to start moving.

Figure 5 presents flow curves of systems with polymers at a shear rate of 50 a 250s<sup>-1</sup>, at 122°F. Non-Newtonian fluid models Bingham, Ostwal-de Waele, and Herschel-Bulkley were applied.

**Figure 6** – Rheological models and flow curves of polymer systems: (a) SM-ASP<sub>1</sub>; (b) SM-ASP<sub>2</sub>; (c) SM-ASP<sub>3</sub>; (e) SM-ASP<sub>4</sub>.



Source: Authors.

Table 3 presents both rheological and correlation parameters ( $R^2$ ) analysis by all mathematical models used in the study.

Analyzing the rheological behavior of microemulsion systems with polymer, Figures 6.a; 6.b; 6.c; and 6.d, it is possible to observe that the experimental values fit the Ostwald-de Waele “Power Law” model best. This result can be confirmed by the values of the correlation parameter ( $R^2$ ) observed in Table 2, which show variation solely in the fourth decimal place. According to the literature (Veerabhadrapa et al., 2011; Teixeira, 2012, Viana et al., 2015; Huang et al., 2019) microemulsion systems with the addition of polymers usually present this type of behavior. It is noteworthy that, in the Power Law (Ostwald-de Waele) model, when subjected to shear rate, ‘n’ represents the fluid behavior index. Thus, the values of Table 2 indicate the fluid’s departure from Newtonian behavior ( $n=1$ ), increasing the pseudoplasticity of these systems. The values of ‘K,’ for the Power Law, indicate the degree of resistance of the fluid to the flow, being the system SM-ASP<sub>4</sub> the one to present the greatest value, which was already expected because it is the system with the highest concentration of polymer.

Therefore, the parameters of the Ostwald-de Waele model were used to determine the apparent viscosities of the systems with polymer and the absolute viscosity of the system SM-AS (values presented in Table 4). Consequently, these values were used to evaluate the effect of viscosity in a possible application to be used in the advanced recovery process.

**Table 3** – Parameters of mathematical models in polymeric mathematical systems.

Microemulsion Systems	Bingham parameters	Ostwald-de Waele parameters	Herschell-Buckley Parameters
SM-ASP <sub>1</sub>	$\tau_L = 0.0651$	$n = 0.9591$	$\tau_0 = 0.0025$
	$\mu_p = 0.0022$	$K = 0.0020$	$K = 0.00272$
	$R^2 = 0.9954$	$R^2 = 0.9997$	$R^2 = 0.9976$
			$n = 1.0809$
SM-ASP <sub>2</sub>	$\tau_L = 0.0450$	$n = 0.8952$	$\tau_0 = 0.0028$
	$\mu_p = 0.0024$	$K = 0.0021$	$K = 0.0019$
	$R^2 = 0.9978$	$R^2 = 0.9996$	$R^2 = 0.9985$
			$n = 0.0615$
SM-ASP <sub>3</sub>	$\tau_L = 0.0210$	$n = 0.7852$	$\tau_0 = 0.0028$
	$\mu_p = 0.0029$	$K = 0.0022$	$K = 0.0019$
	$R^2 = 0.9979$	$R^2 = 0.9999$	$R^2 = 0.9989$
			$n = 0.0651$
SM-ASP <sub>4</sub>	$\tau_L = 0.0090$	$n = 0.7655$	$\tau_0 = 0.0030$
	$\mu_p = 0.00284$	$K = 0.0031$	$K = 0.0021$
	$R^2 = 0.9986$	$R^2 = 0.9998$	$R^2 = 0.9982$
			$n = 0.0682$

Source: Authors.

**Table 4** – Influence of polymer AH 912 SH percentage in the systems studied (122°F).

Systems	Viscosity (cP)	Classification
SM-AS	2.0357	Newtonian
SM-ASP <sub>1</sub>	2.3330	Pseudoplastic
SM-ASP <sub>2</sub>	2.6890	Pseudoplastic
SM-ASP <sub>3</sub>	2.8382	Pseudoplastic
SM-ASP <sub>4</sub>	3.2881	Pseudoplastic

Source: Authors.

By means of the values presented in the Table 4, it is possible to observe an increasing change in viscosity values as the percentage of polymer increases in the system. The systems presented low viscosity values, however, polymer systems showed higher viscosity than water and brine used in EOR processes (KCl 2%). In this case, these systems are expected to have greater mechanical displacement power, avoiding preferred paths, “fingers,” and, consequently, the increase in the oil displacement efficiency (Teixeira, 2012; Viana et al., 2015; Castro Dantas et al., 2017; Dantas et al., 2019).

#### 4. Conclusion

The microemulsion systems obtained, analyzing the macroscopic aspect, presented a transparent appearance and stability for a certain amount of time. The surface tension increased slightly when adding polymers to the systems. We verified that the Bingham, Ostwald-de Waele and Herschel-Bulkley rheological models presented good adjustments to experimental data. The polymer-free system presented a Newtonian behavior while other systems presented a pseudoplastic rheological behavior. Polymer microemulsion systems have viscosities higher than those containing water and brine (KCl 2%)

that are used in EOR processes. Thus, we can estimate that microemulsion systems with polymers increase the efficiency of oil displacement in the EOR.

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