Phase behavior and rheology of drilling fluid o/a with nonionic surfactant and glycerol

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ABSTRACT

The main objective of this work was to formulate drilling fluid obtained from a microemulsified system, using distilled water and water:glycerol solution (40%) in the aqueous phase. The water-in-oil microemulsion regions were precisely determined and the influence of glycerol on the microemulsified area was also examined. All the systems studied showed an isotropic region rich in water (water-in-oil microemulsion area), which was considered highly dependent on the surfactant weight ratio. By means of the integral calculation, the area of the microemulsified region was determined for the studied systems and it was verified that the Water:Glycerol (40%)/TWN 80/Pine oil system presented a larger area of the microemulsion region. In addition to the microemulsified system, the drilling fluids had in their composition the bentonite CMC, HPA and NaCl. The flow curves of both fluids showed a characteristic profile of the Bingham model, corresponding to a fluid with pseudoplastic behavior. This characteristic is very important for drilling fluids, as pseudoplastic fluids show a reduction in viscosity with increasing flow rate (shear rate), thus facilitating flow during drilling.

Keywords: Microemulsion, Nonionic surfactant, Theology, Drilling fluid.

1 INTRODUCTION

Drilling fluids are mixtures of solid additives present as discontinuous phases spread in a continuous liquid phase [1]. These fluids are important because they promote gravel lifting, control pressure, cool and lubricate pipes and drills, stabilize the formation and the well [2], prevent formation fluids from invading the well, and ensure stability by creating a low permeability film on the wall called filtrate cake [3]. Many additives for drilling fluids have been used to alter the density and their chemical properties to improve functionality [4]. Drilling fluids made from microemulsified bases contribute to greater stability of the well, when compared to the same prepared from emulsions, in addition to being thermodynamically stable, spontaneous and easily prepared. [5, 6] studied the application of this base in drilling fluids and concluded: they are stable in a wide range of saline conditions, resistant to corrosion, good lubricity characteristics, gel strength, less permeable and thin plaster formation, and low interfacial stress. According to [7], microemulsified drilling fluids are viable for their lubricity, stability, low cost, and formation of a fine filtrate cake with microemulsion-added characteristics. The rheological properties of the drilling fluid, such as plastic viscosity, yield strength, and gel strength, among others, and fluid loss characteristics must be carefully examined to achieve optimal drilling process performance [8]. During any drilling operation, it is critical to control the rheological and filtration properties of the fluid for smooth and efficient operation. The properties are controlled in such a way that the fluid provides optimum performance. Rheological properties affect (i) the removal of gravel (ii) keeping the gravel and heavy material suspended when not circulating, (iii) releasing the gravel on the surface, (iv) reducing to a minimum any adverse effect on the well, (v) providing information on penetrated formations, among others [9]. In this context, this work aimed to analyze the influence of nonionic surfactant on the formulation of microemulsified drilling fluid of the water-in-oil (A/O) type as well as the rheological properties.

2 MATERIALS AND METHODS

2.1 MATERIALS

The materials used to obtain the microemulsified system and formulation of the fluids were: sodium chloride - NaCl (Synth), ethoxylated ester - TWN 80 (Synth), pine oil - OP (Casa dos Químicas), activated bentonite (commercial), carboxymethylcellulose - CMC (Synth), HP starch (HPA), glycerol (Tech profile) described in Table 1.

Tab 1. Reagents (Own Authorship)

Reagent	Description
Distilled water	Aqueous phase
Glycerol	Aqueous/Dispersing Phase
Pine Oil	Oil Phase
TWN 80	Surfactant
Bentonite	Filtrate Control
CMC	Viscosifier and filtrate reducer
HPA	Filtrate reducer
NaCl	Active Formation Inhibitor

2.2 ANALYTICAL METHODS

The methods and equipment used to determine the microemulsion region, preparation and properties of the fluids are presented in Table 2.

Tab 2. Analytical methods and equipment used in the study. (Own authorship)

Parameter	Apparatus	Belt	Manufacturer/Model
Weighing	Analytical scale	0.01-220g	SHI-AUW 220D
Agitation	Agitador Vortex	50-60Hz	Fisatom/772
Mixture	Mechanical Agitator	1/3 Hp	Hamilton Beach/HMD 2000
Viscosity	Rheometer	115V,60Hz,90W	Fann V. G. Metter/35A

2.3 EXPERIMENTAL METHODS

2.3.1 Phase Diagram

The studied microemulsion was formulated with distilled water (aqueous phase), Glycerol (aqueous phase), TWN 80 (non-ionic surfactant) and pine oil (organic phase). The microemulsion region (Winsor IV) was chosen to compose the formulation of the drilling fluid. A volumetric titration methodology was used to obtain Winsor IV areas [10]. Initially, the maximum solubility point of the surfactant in the aqueous phase was determined. In a glass flask, the surfactant was titrated drop by drop with the aqueous phase until it reached the transition from cloudy to clear or vice versa. The vial was weighed and the amount of aqueous solution added to the system was determined. This point was called the end point of titration. Nine mixtures of organic-surfactant phase (10 to 90% by weight) and nine mixtures of aqueous phase - organic phase (10 to 90% by weight) were titrated with this solution. The end point of titration was determined by the appearance of two phases. The vials containing the systems were weighed and the amount of titrant was determined. The ternary phase diagram was obtained by plotting the amounts (wt%) of aqueous phase, organic phase and surfactant used in each experiment [11].

2.3.2 Calculation of the area of the microemulsified region

To determine the area of the microemulsified region, it is necessary to perform the integral calculation of the curve that delimits the miscibility region, since the region does not have a defined geometric shape. The first step is to turn the ternary diagram into a rectangular diagram. By means of linear regression, the equation representing the curve - f(x) is obtained. The integration limits are the concentrations of the organic phase, as shown in Figure 1. Subtracting the area of the triangle from the area under the curve is equivalent to the microemulsified region (Equation 1) [12].

$$S = S_{triângulo} - \int_a^b f(x)dx \qquad (1)$$

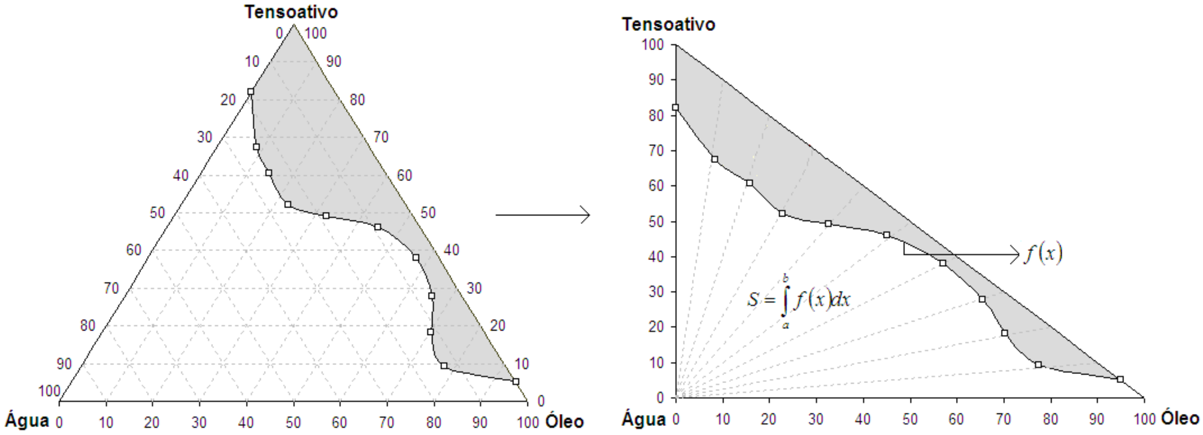
Being:

S: area of the microemulsified region,

Triangle: area of the right triangle;

f(x): function that describes the solubility isotherm.

Fig 1. Representation of the integral calculation of the microemulsified area [12].



2.3.3 Drilling Fluid Preparation

The compounds listed in Table 1 were successively added to the metal cup and mixed with the aid of the Hamilton Beach mechanical agitator, at constant rotation of 16,000 rpm for the cationic fluid (FC) and 18,000 rpm for the bentonite fluid (FB). The addition was made in 5 and 20 minutes of agitation for each addition of components, in the order presented in Table 3. After the preparation of the fluid, it was kept at rest for 24 h and then the rheological parameters were measured [13]. The formulations studied are described in Table 3.

Table 3. Fluid formulation data. (Own authorship)

	Water (mL)	Glycerol (mL)	NaCl (g)	TWN 80 (mL)	ON (mL)	Bentonita (g)	CMC(g)	HPA (g)
Fluid 1	490	0	50	5	5	35	1,8	2,85
Fluid 2	294	196	50	5	5	35	1,8	2,85

2.3.4 Rheological tests

The rheological measurements of the drilling fluids were performed in the Fann V. G. Metter Model 35A viscometer, equipped with coaxial cylinders, at room temperature. Viscosity was measured using the values obtained from the equipment for shear rates (1021.8, 510.9, 340.6, 170.3, 10.2 and 5.1s-1, respectively), according to the API RP 13 B1 standard. From the readings performed on the viscometer it was possible to construct the flow curves. The values of □ and □ were obtained through equations (1) and (2).

$$\tau = 0{,}51 \cdot \theta \qquad (1)$$

$$\gamma = 1{,}703 \cdot N \qquad (2)$$

Where: □ the shear stress (Pa), □ the shear rate (s-1$^{),}$ N the number of revolutions per minute, □ the deflection (degree).

The rheological study of the drilling fluids was performed after a 24-h rest. The fluid was agitated for 5 min in the same mechanical agitator at 17,000 rpm. After agitation, the fluid was transferred to the Fann 35 A viscometer vessel. Six torque readings were taken at shear rates ranging from 5.1 to 1022 $^{s-1}$. The viscometer was activated at 600 rpm for 2 min and the reading was performed. Soon after, the speed was changed to 300 rpm, taking the reading after 15 s. Again, we change the speed to 200 rpm and wait for it to stabilize to take the reading. The same procedure was used for the 100 rpm, 6 rpm and 3 rpm speeds. To obtain the initial gel force, the fluid was kept in the Fann viscometer at 600 rpm for 15 s and then remained at rest for 10 s. Soon after, we put the agitator at a speed of 3 rpm, and the reading is carried out. Then, to obtain the final gel force, the fluid was left to rest for 10 min and, soon after, the reading was performed at a speed of 3 rpm. With the data from the readings obtained in the viscometer we calculated the apparent viscosity (VA), the plastic viscosity (PV) and the yield strength (LE) according to the N-2605 standard, using equations 3, 4 and 5 [2].

$$VA = \frac{(L_{600})}{2} \qquad (3)$$

$$VP = L_{600} - L_{300} \qquad (4)$$

$$LE = L_{300} - VP \qquad (5)$$

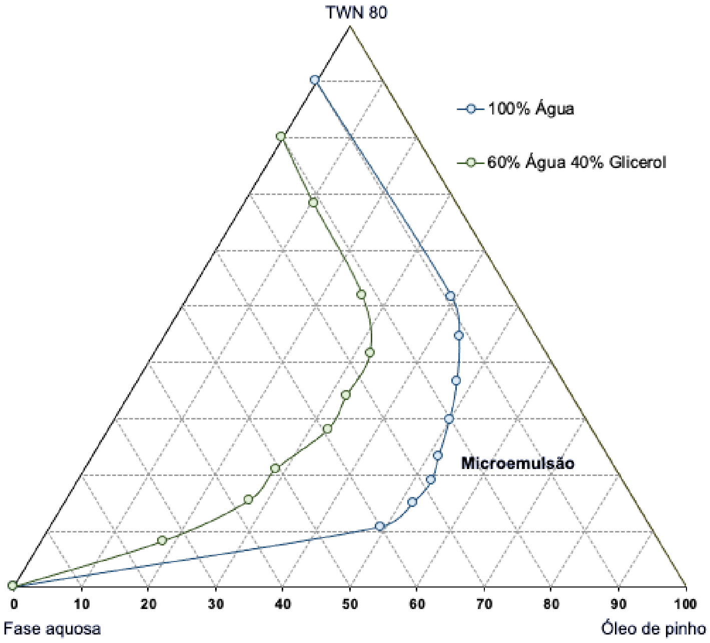
Being: apparent viscosity (cP), plastic viscosity (cP), yield strength (N/m2) (Al-Yasiria, et al., 2019).

3 RESULTS AND DISCUSSIONS

3.1 PHASE DIAGRAMS

Figure 2 shows the ternary phase diagram obtained. The microemulsion region is located below the solubility isotherm, and within the region, the composition chosen for the formulation of the drilling fluid was 1% surfactant, 1% pine oil and 98% aqueous phase. Although the microemulsion region represents a larger area, a composition has been specially selected to reduce drilling fluid costs by reducing the oil and surfactant ratios and increasing the aqueous phase ratio. The difference observed in the microemulsion (Winsor IV) regions of the surfactant in TWN 80 can be explained by the hydrophilic-lipophilic (BHL) equilibrium.

Fig 2. Ternary diagram for the system: TWN 80, pine oil and the aqueous phase, at 28 ºC. (Own authorship)

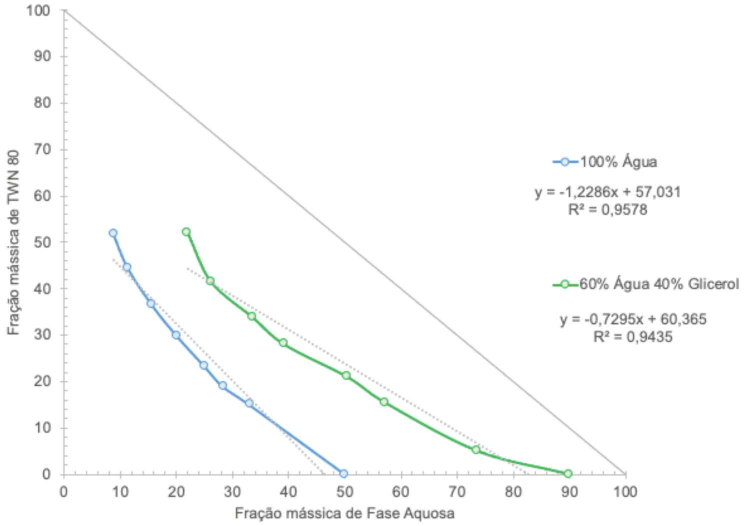


Based on [14] research, BHL is a number that expresses the relationship between the hydrophilic group (affinity for water) and the hydrophobic group (affinity for oil). These values are expressed on a scale of 0-20, indicating that low values on this scale lead to higher solubility in the aqueous phase. TWN 80 is a nonionic surfactant and its main hydrophilic group is polyethers, thus presenting high solubility in the aqueous phase, implying a BHL equal to 15.0 [14]. Thus, it is observed that glycerol, being an aliphatic organic tri-alcohol that has high affinity with water, is responsible for a better stabilization of the microemulsion in surfactants with high BHL, while it has an inverse role with surfactants with low BHL [11].

3.2 CALCULATION OF THE AREA OF THE MICROEMULSIFIED REGION

In order to produce a drilling fluid that uses microemulsion with low concentration of surfactant as a dispersant phase, calculations were performed to determine the microemulsified area of the diagram. Based on this, a range of 0 to 20% surfactant was determined.

Fig. 3. Rectangular diagrams for determination of the microemulsified area of the system: TWN 80; pine oil and the aqueous phase. (Own authorship)



To determine the microemulsified area, the ternary diagrams were converted into rectangular diagrams and, by means of a linear regression, the equations representing the limit lines that indicate the phase change were determined. The difference between the hypotenuse area and the curve corresponds to the myroemulsified region. Figure 3 shows the rectangular diagram and its respective equations of lines referring to the systems studied.

Thus, it is possible to evaluate which combination of surfactant and aqueous phase has the largest area of A/O microemulsion.

Tab 4. Area of the microemulsified region, at 28 ºC, using 0 % to 20 % surfactant as the integration limit. (Own authorship)tag.

Aqueous phase	Microemulsified region area (unit of area)
Proportion	TWN 80
100% Distilled Water	738,6
60% Distilled Water-40%Glycerol	905,1

As observed, the system with the largest microemulsion region is the system composed of TWN 80 in the presence of the aqueous phase with glycerol and pine oil, highlighting that a surfactant with high BHL has a greater tendency to form microemulsion. The presence of glycerol contributes significantly to the increase of the microemulsified area, since it has the characteristic of being soluble in water, favoring the solubility and stability of the mixture.

3.3 RHEOLOGICAL ANALYSIS

From the readings of 6 velocities obtained with the viscometer it was possible to trace the flow curve of the fluids studied. Table 5 shows the results: coefficient of determination, R2, flow behavior index, n (dimensionless) and consistency index, k (cP). Figure 4 shows an increase in shear stress at a higher shear rate for glycerol-containing fluid in the aqueous phase. This fact may be due to the presence of glycerol, as it directly influences the rheological behavior of the drilling fluids.

Fig 4. Flow curve for the fluids studied (Authored by the authors).

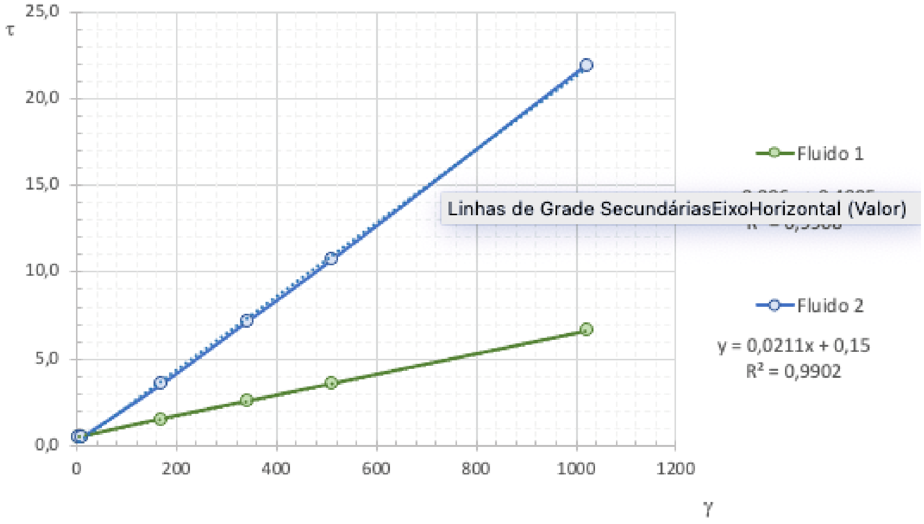
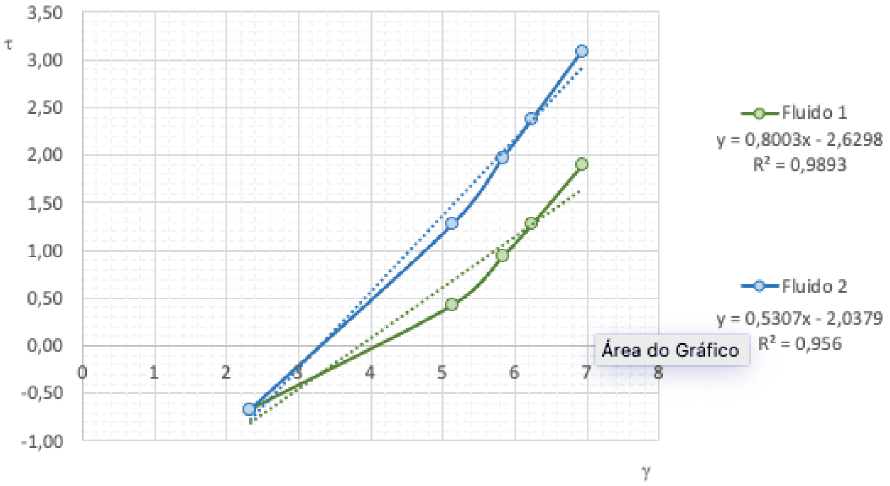


Table 5 shows the rheological parameters for the formulated fluids. The behavior index was performed using linear regression (Figure 5). According to the results, the fluids were classified as pseudoplastics because they have 0<n<1. This is due to the physical characteristics and interactions of the particles. The consistency indices (k) of the fluids formulated with water (Fluid 1) and the water/glycerol mixture (Fluid 2) were similar, indicating that both have similar characteristics to yield strength.

Fig 5. Linearization of the flow curve of the fluids studied (own authorship).



It is possible to observe non-Newtonian pseudoplastic behavior with initial yield strength in the fluids, which is better suited to the Bingham model. Although some researchers claim that Bingham's plastic model is insufficient to explain the rheological behavior of fluids [15], it is a simpler model that can estimate some parameters of fluid behavior with near precision to other more complex models [15].

Tab 5. Rheological parameters and parameters of the Bingham plastic model and the Herschell-Buckley model. (Own authorship)

Fluid			Bingham		Herschell-Buckley	
	VA (cP)	VP (cP)	n	R2	n	R2
Fluid 1	6,5	6	0,006	0,9908	0,800	0,989
Fluid 2	21,5	22	0,0211	0,9902	0,531	0,956

4 CONCLUSIONS

In view of the ternary systems studied and the solubility isotherm curves represented in the ternary diagrams, it was possible to infer that all systems were capable of forming A/O microemulsion. Thus, the study of the microemulsified areas of the systems aims to choose the system that presents the largest region of microemulsion A/O. Among the systems studied, all presented microemulsion area, however the Water:Glycerol (40%)/TWN 80/Pine oil system presented the largest area for a range of 0 to 20% of surfactant. It is possible to apply them as a formulation for microemulsified base drilling fluids. The rheological assays showed that the formulated fluids exhibit non-Newtonian behavior, of the pseudoplastic type. This type of fluid is characterized by reducing its viscosity when subjected to a high shear rate, and increasing its viscosity when at rest (it acquires gel form). By decreasing its viscosity, it improves its flow through the column, by increasing the flow rate and reducing the pressure drop. The drilling fluid, in its most viscous form, is responsible for keeping the gravel suspended in the well, thus preventing the pinning of the drill string or drill bit by wedging, caused by the sedimentation of these on the drill.

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