Effects of imidazolium-based ionic liquids on the viscosity of Mexican heavy crude oil: experimental and modeling study

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Efecto de líquidos iónicos base imidazol en la viscosidad de un crudo pesado mexicano: estudio experimental y de modelado

Efecte de líquids iònics base imidazole en la viscositat d'un cru pesat mexicà: estudi experimental i de modelatge

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ABSTRACT

Ionic liquids (IL) are compounds designed according to the application of interest; in this study, the transport properties of heavy crude oil were modified. This is because of the interaction at the molecular level with the asphalts, which are responsible for viscosity. Potential factors affecting viscosity and IL-crude interactions are diverse (temperature, emulsion phenomena, concentration and structure of the ion liquid). In this study, a statistical analysis of dependent and independent variables (simple mathematical model) is presented, generated from experimental temperature viscosity data (25, 50 and 80°C), type of functionalized molecule with different alkyl chain size (C12, C14, C16 and C18) and IL concentration (0.01, 0.1, 1.0 and 10.0 %w). Viscosity decreases 80.51% to 80°C, using a IL decreases by 70% for C14 and C16 and decreases above 80% by the effect of IL concentration. All these phenomena are observed and ratified in the main effects graph of the built mathematical model, allowing to generate a series of five equations, one for each categorical variable of this study (Heavy crude oil, C12, C14, C16 and C18): the use and application of the Simple mathematics allows to know the trend of dependent variable behavior (viscosity) based on independent and categorical.

Keywords: Heavy oil, ionic liquid, rheology, variance analysis.

RESUMEN

Los líquidos iónicos (LI) son compuestos diseñados según la aplicación de interés, en este estudio se utilizaron para modificar las propiedades de transporte de crudos pesados. Dicho efecto se produce por la interacción a nivel molecular con los asfáltenos, que son los responsables de la viscosidad. Los factores que afectan la viscosidad y las interacciones LI-crudo pesado son diversos (temperatura, fenómenos de emulsionado, concentración y estructura del líquido iónico). En este estudio, se presenta un análisis estadístico de variables dependientes e independientes (modelo matemático simple), generado a partir de datos experimentales de viscosidad en función de la temperatura (25, 50 y 80°C), tipo de molécula funcionalizada con diferente tamaño de cadena alquílica (C12, C14, C16 y C18) y concentración de LI (0.01, 0.1, 1.0 y 10.0 %w). Se reporta la disminución de la viscosidad por efecto de la temperatura (80.51% a 80°C), y al utilizar un LI también se presenta un decremento siendo un 70% para C14 y C16. Y por encima de 80% por efecto de la concentración de LI. Todos estos fenómenos se observan y ratifican con la gráfica de efectos principales del modelo matemático construido, permitiendo generar una serie de cinco ecuaciones; una por cada variable categórica de este estudio (crudo pesado, C12, C14, C16 y C18), el uso y aplicación de las matemáticas simples permite conocer la tendencia y comportamiento de la variable dependiente (viscosidad) en función de las independientes y categóricas.

Palabras clave: Crudo pesado, líquido iónico, Reología, Análisis de varianza

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RESUM

Els líquids iònics (LI) són compostos dissenyats segons l'aplicació d'interès, en aquest estudi es van utilitzar per modificar les propietats de transport de crus pesats. Aquest efecte es produeix per la interacció a nivell molecular amb els asfaltens, que són els responsables de la viscositat. Els factors que afecten la viscositat i les interaccions LI-cru pesat són diversos (temperatura, fenòmens de emulsionat, concentració i estructura del líquid iònic). En aquest estudi, es presenta una anàlisi estadística de variables dependents i independents (model matemàtic simple), generat a partir de dades experimentals de viscositat en funció de la temperatura (25, 50 i 80 °C), tipus de molècula funcionalitzada amb diferent grandària de cadena alquílica (C12, C14, C16 i C18) i concentració de LI (0.01, 0.1, 1.0 i 10.0%w). Es reporta la disminució de la viscositat per efecte de la temperatura (80.51% a 80 °C), i a l'utilitzar un LI també es presenta un decrement sent un 70% per C14 i C16. I per sobre de 80% per efecte de la concentració de LI. Tots aquests fenòmens s'observen i ratifiquen amb la gràfica d'efectes principals del model matemàtic construït, permetent generar una sèrie de cinc equacions; una per cada variable categòrica d'aquest estudi (cru pesat, C12, C14, C16 i C18), l'ús i aplicació de les matemàtiques simples permet conèixer la tendència i comportament de la variable dependent (viscositat) en funció de les independents i categòriques.

Paraules clau: Cru pesat, líquid iònic, Reologia, Anàlisi de variància

INTRODUCTION

In recent years, the demand for energy resources such as crude oil has increased worldwide even with the development of new energy sources. Crude oil still ranks first as a non-renewable energy source. The global reserves of this non-renewable resource are currently expected to be sustainable over the next 50 years.[1] Generating the need to develop technologies that need a better use of these resources, and contemplating the environmental aspect.

Studies have been carried out to improve heavy and extra heavy oils with the purpose of improving the aspects mentioned above.[2-4] Petroleum and heavy oil fractions have become very valuable energy resources, but they also contain great technological challenges, because oil has densities between 0.92 - 1 gcm^{-3} that correspond to viscosities of the order of 10 - 22.3 °API , with difficulties in transport and handling.[5,6]

The viscoelastic behavior of heavy and extra heavy crudes has been attributed to the ratio of organic compounds (SARA, Saturated, Aromatic, Resins and Asphaltenes) present in the composition. Specifically, asphaltenes and the relationship of asphaltenes with resins contained in crude oil[7-10] influence the viscoelastic behavior of different types of oil. Some authors[4,11] establish that below 10% of asphaltene content in crude oil is present the behavior of a diluted system, where viscosity is a function of the amount of resins, while above this value is present a concentrated system with a drastic increase in the viscosity values attributed to the agglomeration of asphaltenes in the systems studied.

The alternatives to work with this type of systems have led to innovate and / or complement the methodologies known as heating[12,13] or dilution with light crudes,[14,15] the use of modifiers of viscoelastic properties,[16,17] surfactants,[18-20] ionic liquids[6,21,22] and / or dispersants.[4,23,24] Because they are chemically stable[25,26] or because of the low concentrations used, ionic liquids do not affect the chemical structure of oil. [27]

The application of modifiers has allowed the production of stable emulsions and the study for the purpose of extraction and / or transport.[28-31] These methodologies seek that the mixture of modifier and crude produce small spheres (micelles) that are stabilized by the different electrostatic forces (interfacial and superficial).[21,22,28] In addition, the separation is possible once the transport is completed, producing the W / O type emulsions.[28,29,32] The main purpose is to generate changes in viscosity values by modifying potential study parameters. The objective of this study is to determine the rheological behavior due to the effect of temperature, concentration and the length of the hydrocarbon chain of ionic liquids, applied to a Mexican crude (alone and emulsified). As well as, use these parameters to propose a mathematical model that describes the physicochemical phenomena that hydrocarbons present when using ionic liquids, where mathematical equations of the viscosity parameter will be proposed as a dependent variable.

MATERIAL AND METHODS

Materials

The imidazolium salts used were previously synthesized by working group through simple organic synthesis procedures reported by various authors[33-36] for the application of this type of ionic liquids, with various sizes of hydrocarbon chains associated with the imidazolium ring. Table 1 shows the structures of the ionic liquids studied.

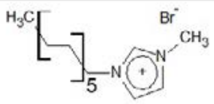
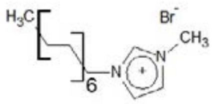
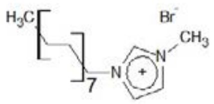
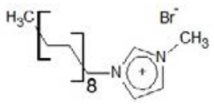
Heavy crude oil (AG-1) used has a density 0.9696 g cm^{-3} at a temperature of 25°C, SARA composition 27.48% saturated W, 36.92% aromatic W, 14.50% W resins, 21.08% W asphaltenes, determined with ASTM-D2007-11 method, 0.69 resin/asphaltenes.

EXPERIMENTAL METHODS

Determination of viscosity. Effect of temperature, concentration of the ionic liquid and length of the hydrocarbon chain.

Viscosity and shear stress were determined by a Brookfield DV-II + Pro rotational viscometer with a thermostatted chamber, Brookfield Thermosel type. In order to prepare the emulsion to be evaluated, four

Table 1. *Chemical name and structure of ionic liquids (IL)*

No	Structure	Chemical name	Key and abbreviation
1		1-methyl, 3-dodecylimidazolium bromide	[1M3DDIM][Br] $[C_{12}H_{25}(N_2C_3H_3)CH_3]$ [Br]
2		1-methyl, 3-tetradecylimidazolium bromide	[1M3TDIM][Br] $[C_{14}H_{29}(N_2C_3H_3)CH_3]$ [Br]
3		1-methyl, 3-hexadecylimidazolium bromide	[1M3HDIM][Br] $[C_{16}H_{29}(N_2C_3H_3)CH_3]$ [Br]
4		1-methyl, 3-octadecylimidazolium bromide	[1M3ODIM][Br] $[C_{18}H_{33}(N_2C_3H_3)CH_3]$ [Br]

different ionic liquids were dissolved in deionized water, then crude oil was gradually added to the solution. The emulsion was homogenized for 10 min at 1000 rpm. The concentrations of ionic liquid were varied from 0.01, 0.1, 1.0 and 10.0% w, and temperatures from 25, 50 and 80°C.

Mathematical modeling and statistical analysis of rheological behavior.

Currently there are tools that allow analyzing and predicting the behavior of a rheological system through the construction and simulation of a mathematical model.[37,38] The Anova variance analysis is a tool used to know the variance that exists in one or more factors with respect to a quantitative dependent variable (viscosity). The mathematical model that describes a process and the correlation with the independent variables (temperature, shear rate, concentration) and the qualitative categorical variables are implicit in the regression process (chain length) are determined by a linear estimation.[38]

RESULTS AND DISCUSSION

Evaluation of viscosity in emulsions. Temperature effect.

Viscosity measurements provide information on the structure, time dependence, stability and characteristic parameters of visco-elastic systems. Viscosity characterizes flow resistance, while elasticity shows how the system responds to stress. These properties provide information on the development of stress gradients at the interfaces.[39]

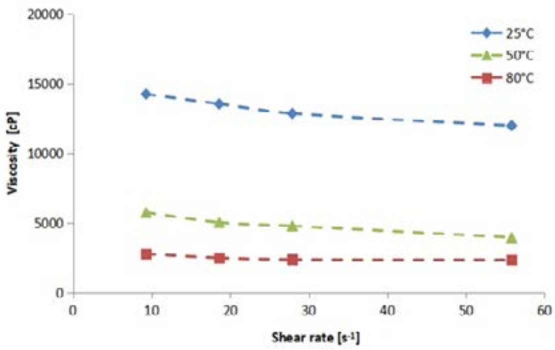


Figure 1. *Effect of temperature on the rheological behavior of AG-1 heavy crude oil.*

Figure 1 shows the viscosity of heavy oil (standard) as a function of the velocity gradient. The initial parameter was 14258 cP at 25°C ($\gamma = 10\ s^{-1}$). The rheological behavior of crude oil is of a non-Newtonian fluid at low shear rate. Viscosity is variable depending on the shear rate; the viscosity changes observed for the speed gradient are of the order of 59.67% at 50°C and 80.51% at 80°C. This same behavior is observed for the rest of the study speeds the viscosity is reduced with the increase of this parameter.

Table 2. *Crude oil viscosity data (AG-1) as a function of temperature.*

	25°C		50°C		80°C	
Shear rate [s^{-1}]	Viscosity [cP]	% Reduction	Viscosity [cP]	% Reduction	Viscosity [cP]	% Reduction
9.3	14258	----	5751	59.66	2780	80.50
18.6	13547	4.98	5040	64.65	2490	82.54
27.9	12865	9.77	4784	66.44	2370	83.38
55.8	11978	15.99	3951	72.29	2340	83.59

Table 2 shows the viscosity values (Figure 1). In addition to viscosity reduction percentages, due to the effect of the analyzed shear rate (9.3, 18.6, 27.9 and 55.8 $s^{-1)}$. A progressive decrease is observed with viscosity decreases as a function of temperature and shear rate. The most important decrease in viscosity at 80°C with reductions exceeding 80% at low shear rate. Viscosity reduction phenomena are being governed firstly by the variation of the temperature and subsequently by the mechanical mobilization of crude oil (for example, agitation, pumping, etc.). Some authors state that this occurs due to the phenomena of dispersion or disintegration of heavy oil components (resins and asphaltenes),[4,6,12] and it is due to this property that crude oil heating has been used as a method for reducing viscosity and therefore pipe transport.[9,13,40,41] However, the disadvantage is that some elements of crude oil are volatilized at high temperatures (between 65 and 85°C, depending on the type of oil and the extraction area), and chemical characteristics are lost or modified.[42]

Evaluation of viscosity in emulsions. Effect of ionic liquids in reducing viscosity of heavy crude oils.

The addition of ionic liquids to modify the viscosity has a favorable effect on the formation of stable emulsions,

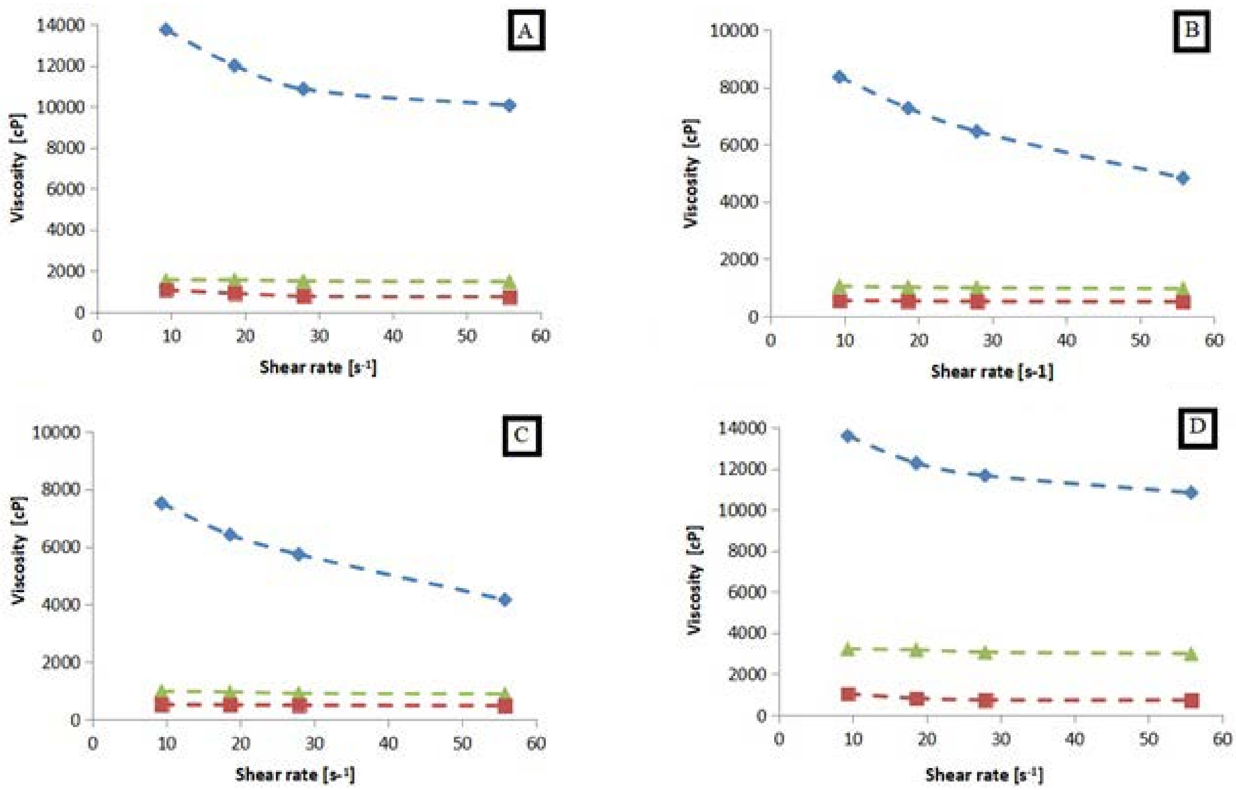


Figure 2. *Rheological behavior of crude / ionic liquid emulsion 10.0% w/w A) [1M3DDIM][Br], B) [1M3TDIM][Br], C) [1M3HDIM][Br] and D) [1M3ODIM][Br] and three different temperatures 25, 50 and 80°C.*

with low viscosity and a rheological behavior that has a tendency of Newtonian.[43]

Figure 2 A-D shows the results of viscosity analysis for four different ionic liquids at a concentration of 10% w / w and study temperatures, 25, 50 and 80°C, with the shear rates of the previous section. In general, the viscosity is reduced by the application of the different ionic liquids. The average reductions are in order of 50 to 70%. The combination of temperature and ionic liquids offers a synergistic result, since the temperature allows viscosity to decrease and the use of ionic liquids increases the fall.[6]

Figure 3 shows the effect of the length of the hydrocarbon chain of the ionic liquid. Increasing a unit of carbon in the hydrocarbon chain generates a decrease in crude oil viscosity, with sequential decreases with respect to the target of the order of 2000 cP for [1M3DDIM][Br], 7200 cP for [1M3TDIM][Br], 7800 cP for [1M3HDIM][Br]. In the case of the 18-carbon chain [1M3ODIM][Br], a setback with variations in viscosity of the order of 1100 cP is observed, below the shortest chain (14 carbons). This result could be attributed to the fact that the 18-carbon, ionic liquid has a crystalline structure at room temperature, that is, in the working conditions, ionic liquid [1M3ODIM][Br] is not liquid at 25°C, over time and the behavior is the bromooctadecane that is the precursor and solidifies at 25°C. This solidification process prevents the asphaltenes of the crude oil from dispersing, preventing a decrease in viscosity. The viscosity of ionic liquids decreases with temperature (Figure 1) but not in the same proportion for all ionic liquids used.

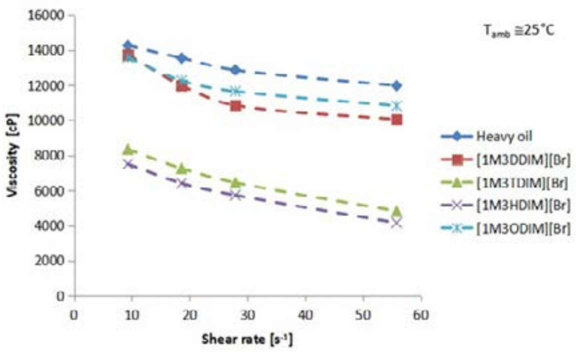


Figure 3. *Effect of the length of the hydrocarbon chain of the ionic liquid on the rheological behavior of the crude / ionic liquid emulsion at a concentration of 10% w/w and T ≅ 25°C.*

Evaluation of viscosity in emulsions. Effect of ionic liquid concentration [1M3TDIM][Br].

The previous results showed that the application of ionic liquids favors the decrease in crude oil viscosity, a study of the variation in the concentration of an ionic liquid studied is presented. Figure 4 shows the effect of the concentration. Study for ionic liquid [1M3TDIM][Br] is presented, which offers better results in terms of rheological stability, at four different percentage concentrations (0.01, 0.1, 1.0 and 10.0%) .

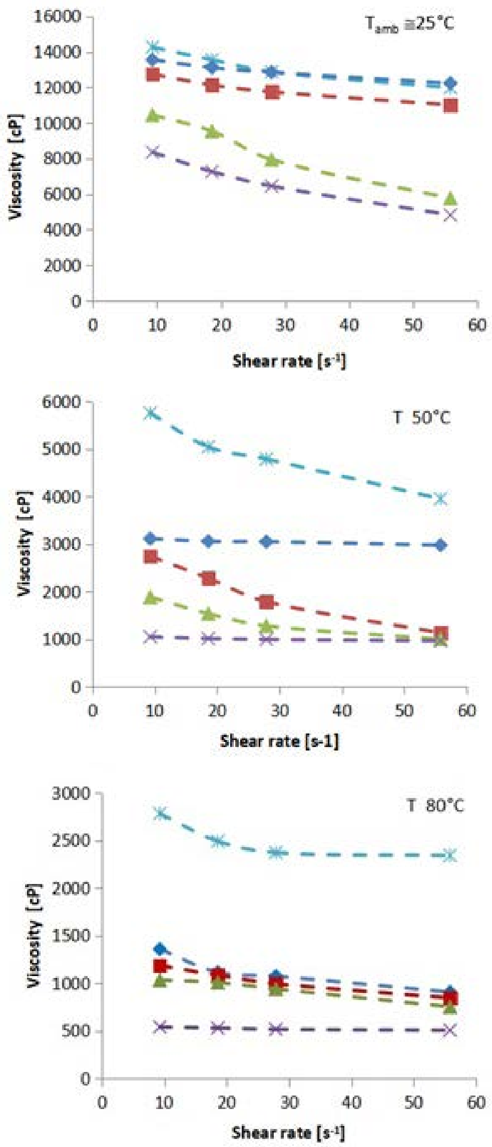


Figure 4. *Effect of the concentration of [1M3TDIM][Br] on the rheological behavior of the crude / ionic liquid emulsion at 25, 50 and 80°C.*

With reference to the previous results (Figure 2), application of ionic liquids favors the reduction of viscosity and with temperature the effect is increased. Nevertheless, the costs of using the temperature are high and it is necessary to look for the role of ionic liquids offset these expenses. Figure 4a shows the results obtained by the application of ionic liquid at four different concentrations, at room temperature. The drop in viscosity due to the increase of an order of magnitude of the concentration of the modifier, obtaining reduction percentages of 10 to 20%. This result was improved with the application of temperature, at 50°C with reductions of the order of 50 to 72% (figure 4b), and at 80°C with reductions of 70 to 83% (figure 4c), however, the potential applications are considered necessary to find the best combination and synergistic effect, between efficiency and economy of the process.

The scientific-basic study of variables of the rheological system crude / ionic liquid allows the generation of a large amount of data. This makes possible the statistical study of the system variables, making it possible to generate the equations that govern the rheology of the systems. And there by propose the best working conditions that lead to the decrease in viscosity (experimental objective of the process) and the low cost of ionic liquid applications (economic objective depending on the potential applications).

The rheological properties of crude oils and their emulsions are closely linked to the suspended droplets and their distribution. The presence of ionic liquids in a crude oil emulsion can contribute to an increase in the diameter of the droplets, due to the surface tension gradients that are generated from the zone of high concentration to the zone of low ionic liquid concentration.

Larger droplet formation usually indicates greater instability, resulting in lower viscosity.[44] According to the above, an increase in the average drop size of the crude oil emulsions modified by ionic liquids is observed (Figure 5).[28]

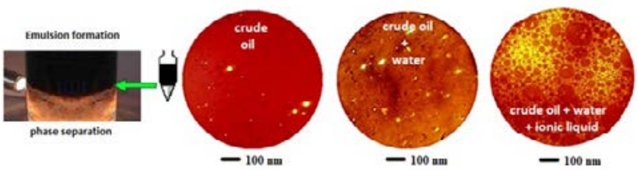


Figure 5. *Micrographs of crude oil, emulsified crude and ionic liquid modified emulsified crude [1M3TDIM][Br].*

Mathematical study of rheological behavior. Evaluation of the main effects in the response variable.

Depending on the rheological behavior previously determined, a statistical analysis was performed of the variables that affect viscosity. All the rheological results obtained from the samples modified with the different ionic liquids were statistically evaluated using the Minitab 17 software. Through a graph of main effects (Figure 6) where the effect of the independent variables vs. dependent variable (viscosity). Through this graph, differences between the level means for each study parameter (factor) and how it affects the variable of interest are examined. When a characteristic line of a factor has a horizontal tendency, that is, the slope tends to zero (m = 0), has no effect on the response variable (dependent) and when the trend line has a greater slope or less than zero (m ≠ 0) has a significant effect on the response variable.

Figure 6a shows that the increase in temperature causes decrease in viscosity with negative slopes (-m) of the order of -157.3. This behavior confirms that the temperature variable has an important effect on the viscoelastic behavior of crude oil, reducing the viscosity of the external phase and the rigidity of the interfacial film.[6,42] Figure 6b shows the effect of the application of four different types of ionic liquids. The additives have a main characteristic that is the increase in the hydrocarbon chain of the heterocycle substitution. The decrease of the values of dependent variable (viscosity) with the increase in the number of carbons of 12, 14 and 16 ([1M3DDIM][Br], [1M3TDIM][Br], [1M3HDIM][Br]) in the variable independent is observed. With a negative average slope of the order on -556, this behavior is attributed to the increase in the affinity of the additives to the aqueous phase, which generates a Newtonian behavior previously observed in the rheological study.[39,43] by increasing the number of carbons to 18 ([1M3ODIM][Br]) the system is reversed, that is, an increase in viscosity is presented and also modification in slope to positive (m = 1438.5), which mathematically establishes a behavior opposite to the initial trend. Finally, in Figure 6c effect of the shear rate is shown, although this variable is not studied precisely, it is presented implicitly in rheological studies. Viscosity changes are observed, although decreases are not significant compared to other variables. The slope value of a trend line that is of the order of -25.4. This value is significantly lower than those observed for other variables of the study, this behavior is presented in Newtonian type fluids.[42,43]

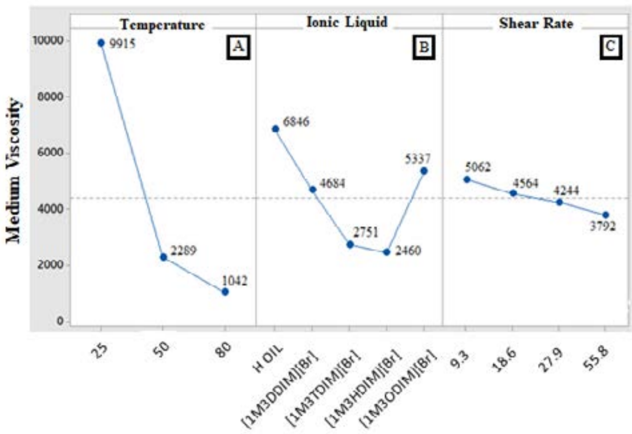


Figure 6. *Main effects chart.*

Finally, according to the main effects graph (figure 6c), temperature of 80°C causes an average viscosity reduction of 83.59%, the most effective ionic liquid is [1M3TDIM][Br] and [1M3HDIM][Br]. [1M3TDIM][Br] is selected for the following analyzes because the comparative effect of both shows no substantial differences in viscosity and chain length of 1M3TDIM and is mathematically efficient to significantly affect the viscosity of the system. The shear rate has no significant effect on viscosity. Figure 7 shows the study of the effects corresponding to the [1M3TDIM][Br] ionic liquid.

Figure 7a shows the effect of temperature on viscosity (m = -157.3). At 80°C, the greatest effect on the dependent variable is presented. Shear rate has an insignificant effect on the variable of interest (Figure 7b). Finally, the effect of ionic liquid concentration with variations of the order of 0.1, 0.1, 1.0 and 10.0% W is analyzed. The decrease of the dependent variable (viscosity) is observed as a function of the increase in concentration (m = -222.49). This behavior is attributed to the surfactant characteristics of the molecules, capable of modifying the viscoelastic properties by electrostatic interactions with the components of the crude oil.[4] The highest concentration (10.0% W) was the most effective for viscosity reduction.

Table 4. *Mathematical models obtained by categorical variable, μ = Viscosity (cP); T = Temperature (°C); C = Concentration (%W); V = shear rate (s^{-1}) and reliability results.*

Categorical variable	Regression model	S	% R^2	% R (Ajust.)	% R (Pred.)	
Heavy crude oil	$\mu = 29557 - 673.9\,T - 155.5\,V + 4.325\,T^2 + 2.61\,V^2 + 0.271\,T\,V - 0.0173\,V^3 + 0.00899\,T^2\,V - 0.00741\,T\,V^2$	85.3219	99.99	99.97	99.76	Ecn.1
[1M3DDIM][Br]	$\mu = 38973 - 1153\,T - 432\,V + 8.471\,T^2 + 3.41\,V^2 + 9.69\,T\,V - 0.0019\,V^3 - 0.0535\,T^2\,V - 0.0426\,T\,V^2$	338.374	99.89	99.58	86.13	Ecn.2
[1M3TDIM][Br]	$\mu = 34566 - 950.5\,T - 191\,V - 13542\,C + 6.696\,T^2 + 0.41\,V^2 + 7672\,C^2 + 4.68\,T\,V + 104\,T\,C - 0.063\,V\,C + 0.0061\,V^3 - 645\,C^3$	494.650	99.16	98.77	97.93	Ecn.3
[1M3HDIM][Br]	$\mu = 21789 - 299.8\,V - 643.7\,T + 2.21\,V^2 + 4.734\,T^2 + 7.357\,V\,T - 0.0117\,V^3 - 0.01591\,V^2\,T - 0.04801\,V\,T^2$	106.271	99.96	99.84	96.04	Ecn.4
[1M3ODIM][Br]	$\mu = 33451 - 891.7\,T - 328\,V + 6.130\,T^2 + 3.97\,V^2 + 6.19\,T\,V - 0.0222\,V^3 - 0.0354\,T^2\,V - 0.0235\,T\,V^2$	223.614	99.95	99.81	94.78	Ecn.5

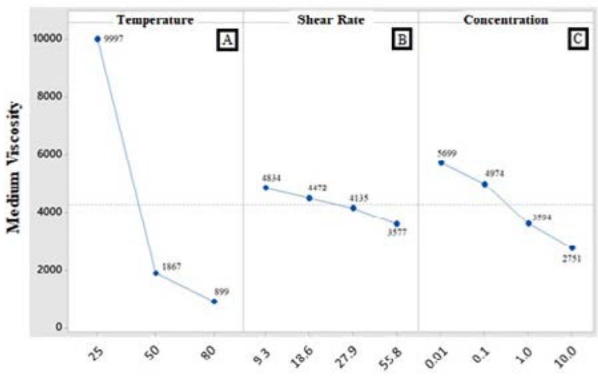


Figure 7. *Graph of main effects for ionic liquid [1M3TDIM][Br].*

Mathematical study of rheological behavior. Correlation between independent variables vs. viscosity.

To analyze the correlation between each independent variable (factor) and the response variable (viscosity), Pareto chart was analyzed. This is a tool that allows to evaluate which variables or combination of them directly affect viscosity.[45-47]

Table 3 shows the maximum effect parameters obtained from Pareto chart for each variable or set of independent variables, the temperature (A) which is the independent variable that has the greatest effect on the response variable (viscosity) with 8876.12. Subsequent by the concentration of ionic liquid (B) with 3452.27 and finally the cutting speed (C) with 1340.97. This behavior has already been confirmed by the experimental results (Figures 1 and 4) and by various authors.[4,6,12] Mathematically, it is possible to establish what are the effects of each variable and the combinations that are generated.[37,48]

Table 3. *Maximum effect parameters in the response variable or variables.*

Key	Variable or independent variables	Magnitude of the effect of the response variable	Level of significance
A	Temperature (Temp.)	8876.12	1.10764
B	Concentration (Conc.)	3452.27	2.50580
AB	Temp./Conc.	2851.64	3.51678
C	Shear rate (S. rate)	1340.97	4.50624
AC	Temp./S. rate	1086.16	5.47420
ABC	Temp./Conc./ S. rate	649.337	6.48518
BC	Conc./ S. rate	430.927	7.47464

The values are analyzed observing that the combination of independent variables, according to the mathematical model developed. The combination of independent variables does not offer improvement over the response variable, and the levels of significance are increased with the combinations which means that the effect is reduced. When the parameters are considered in the analysis of the quality and adjustment of the model with an efficiency of 80%[38] that has been established bibliographically for systems of this type, the effective value of the model that is 6839.

Mathematical study of rheological behavior. Analysis of multiple linear regression between dependent variables vs viscosity.

From the experimental data obtained from the rheological study and the effect of each parameter on the response variable (viscosity), theoretical mathematical models that describe the rheological behavior as a function of temperature, ionic liquid concentration and shear rate are determined. For each categorical variable of this study (length of the hydrocarbon chain of the ionic liquid) that is obtained by means of an analysis of variance and the linear estimation of the set of data collected (Table 4).

The results obtained from the linear estimation indicate the reliability of the adjustment of the mathematical models in Table 4 For this analysis, the parameter % R^2 was determined, which evaluates the mathematical adjustment made, also allows establishing whether sufficient or alternative models should be sought (higher order polynomials). If the values obtained are greater than 99% for all the categorical variables (ionic liquids) and if it is closer, the value is 100%, the model is more reliable.

Based on the results obtained and the designed models, it is possible to establish that multiple linear regression analysis is a simple method and allows the estimation and generation of representative models that combine the application of several variables and the consequent effect they generate on a dependent variable. From the results obtained and the models designed, it is possible to establish that multiple linear regression analysis is a simple method and allows the estimation and generation of representative models that combine the application of several variables and the consequent effectiveness that is generated on a dependent variable.

CONCLUSION

The combination of temperature and ionic liquids offers a synergistic result since the temperature allows viscosity to decrease and the use of ionic liquids increases the drop; attributed to a process that prevents crude asphaltenes from dispersing. This decreasing rates as a whole of the order of 10 to 20% for 25°C, 50 to 72% for 50°C and 70 to 83% for 80°C.

The addition of ion liquids modifies the viscosity favoring the formation of stable emulsions, with low viscosity and rheological behavior with a Newtonian fluid behavior. The size of the molecule also influences the rheological behavior having a decrease in viscosity, depending on the increase in the number of carbon atoms in the cation (16.10% for [1M3DDIM][Br], 59.72% for [1M3TDIM][Br], and 65.28% for [1M3HDIM][Br]), the effect is reversed with an 18-carbon chain (9.64% for [1M3ODIM][Br]). This is attributed to the chemical behavior of the precursor that tends to solidify.

Models that describe the rheological behavior as a function of temperature, ionic liquid concentration, and shear rate are determined. Linear regression analysis is a simple method and allows the estimation and generation of representative models that combine the application of several variables and the consequent effectiveness that is generated on a dependent variable, with correlation coefficients greater than 99%.

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