

PHYSOCHEMICAL AND RHEOLOGICAL CHARACTERIZATION OF THE PASSION FRUIT OIL AND ITS POLYOL

Roseany de Vasconcelos Vieira Lopes, roseany@unb.br

Luis Felipe Baumotte Osorio, luisosorio@terra.com.br

Universidade de Brasília, Instituto de Química, Campus Universitário Darcy Ribeiro, Laboratório de Pesquisa em Físico-Química de Polímeros, Caixa Postal 4478, CEP: 70904-970, Asa Norte, Brasília - DF

Maria José Araújo Sales, mjsales@unb.br

Universidade de Brasília, Instituto de Química, Campus Universitário Darcy Ribeiro, Laboratório de Pesquisa em Físico-Química de Polímeros, Caixa Postal 4478, CEP: 70904-970, Asa Norte, Brasília - DF

Francisco Ricardo Cunha, frcunha@uol.com.br

Universidade de Brasília, Faculdade de Tecnologia, Departamento de Engenharia Mecânica, Campus Darcy Ribeiro, CEP: 70910-900, Asa Norte, Brasília - DF

Abstract. *In recent times, the use of renewable resources is growing and is attracting great attention of the academic and industrial worlds. In particular, vegetable oils have attracted a special attention because of their potential to replace petrochemical derivatives and also because their use contribute to minimize environmental impacts. In this context, there is a current interest in the development of materials such as polyols that can be obtained from renewable resources such as passion fruit (*Passiflora edulis Sims f. flavicarpa Degener*) seeds. In fact, vegetable oils are excellent renewable sources for chemical and oleochemistry industries, since they can be functionalized to adapt to many applications such as paintings, lubricants, hydraulic fluids and polymeric materials for general use. In this work, we determine some physical and physicochemical properties of passion fruit oil and polyols obtained from this oil. The polyols were obtained by hydroxylation with generation "in situ" of formic acid. Physicochemical properties, such as, chromatographic analysis, iodine value, index of acidity, peroxid index, saponification index and hydroxyl index were determined according to standard methods and furthermore were determined physical properties as density and rheometry. The results revealed a wide variation of the physicochemical characteristics among the oils and polyols. The shear viscosity measurements of the oils and the polyols were carried out at 28°C with a Programmable Couette Viscometer flow. The shear viscosity is determined for several shear rates. The rheological analysis showed that the viscosity of polyols is at least two order of magnitude larger than the viscosity of the original oil, confirming that the hydroxylation reaction occurred with success. The shear viscosity of the polyols does not show any dependence on the shear rate or significant time dependence for the examined samples. In particular, the hydroxylation reactions have produced very viscous Newtonian liquids with viscosities of $O(10^6)$ cP, as opposed to original viscosities of $O(10)$ cP before the reaction. Moreover, we have found that the polyol viscosity decreases with increasing the drying time, following the law $\mu / \mu_{\max} = \mu_{\min} / \mu_{\max} + (1 - \mu_{\min} / \mu_{\max}) (t/t_{\max})^n$, with $n=15/2$ and $\mu_{\min} / \mu_{\max} = 0.0312$.*

1. INTRODUCTION

The growing environmental protection and energy conservation have driven technologists to substitute sustainable resources to petro-based feed stocks. The use of renewable sources in the manufacturing of industrial products received special attention after the petroleum shortages in the 1970s. Today, oils obtained from vegetable seeds present as an excellent raw material of a readily available sustainable resource (Ahmad *et al.* 2005). Results from oleochemistry show that the use of vegetable fats and oils allows the development of competitive, powerful products, which are both consumer-friendly and environment-friendly (Hill, 2000).

Vegetable oils are one of the cheapest and most abundant biological sources available in large quantities and presented numerous advantages, such as, low toxicity, good lubricity, low volatility, high viscosity index, inherent biodegradability, solvency for lubricant additives and easy miscibility with other fluids, and their use is unlimited, including making paints, varnishes, enamels, besides, skin care and countless health. They are considered to be one of the most important classes of renewable resources for utilization in the industry (Adhvaryu and Erhan, 2002; Hill 2000). In some application areas, such as chain saw oil, gearbox oils, hydraulic oils and lubricants for crude oil production, these oleochemical products are already well established. Current developments refer to the use of tailor-made fatty acid esters with specific lubricant properties (Hill, 2000).

Vegetable oils are triglycerides of predominantly unsaturated fatty acids. The fatty acid composition of triglycerides varies not only from oil to oil but also within the same oil, are chemically relatively unreactive and can be functionalized to serve as components for polymeric materials. Several groups are usually introduced in the double-bond position to enhance their reactivity; for example, hydroxyl groups make it possible to prepare polyols for

polyurethanes. Epoxidation is one of the most important addition reactions that can be applied to a triglyceride, and opening up the epoxide ring leads to a large number of products (Lligadas, 2005).

Passion fruit oil (*Passiflora edulis Sims f. flavicarpa Degener*) it is originated from Tropical America and cultivated mainly in Brazil, Peru and Colombia, it is rich in vitamin C, calcium and phosphor is a popular tropical fruit throughout the world (Ferrari *et al.* 2004; Chau and Huang, 2004). The passion fruit juice is an aroma product and acidity accentuated and the aroma is due to an insoluble oil in water that constitutes about 36ppm of the juice. In the juice industry, the passion fruit produces many thousand tons of seeds as agricultural byproducts during juice extraction. These seeds, containing large amounts of fibre and oil, are generally discarded after being crushed (Chau and Huang, 2004). The peels and passion fruit seeds (50 and 13%, respectively, of the mass of the fruit of the species *edulis*) they have market potential. The seeds contribute with about 6 to 12% of the total weight of the fruit and they can be oil source, carbohydrates, proteins and minerals. The oil presents pleasant flavor and is compared to the cotton oil in nutritional value, and your chemical composition there is presence of ascorbic acid, flavonoids, β -carotene and potassium. In the passion fruit oil the fatty acids are presented in larger amount, mainly linoleic acid with about 60%. Due this, the passion fruit oil is considered a drying oil (Ferrari *et al.* 2004; Sant'anna *et al.* 2001).

For natural oils to be used as raw materials for polyol production, multiple hydroxyl functionality is required. Two main ways of preparing vegetable oil-based polyols have been successfully developed and wide used. In the first, polyols are formed by reaction at the double bond of the unsaturated fatty oil. For example, the epoxidation and further oxirane ring opening leads to polyols with secondary hydroxyl groups, while the hydroformylation and the ozonolysis lead to polyols with primary hydroxyl groups. In the second, a combined reaction at the double bonds and subsequent reduction of the carboxyl group yields the hydroxyl moieties (Puig, 2006).

The present work focus the use of passion fruit oil seeds (a byproduct broadly wasted in the industry of juices) and and that has great potential on the preparation of polyols from passion fruit oil through hydroxylation with generation "in situ" of formic acid and determination of some physicochemical properties, such as, chromatographic analysis, iodine index, acidity index, peroxid index, saponification index and hydroxyl index also physical properties as density and shear viscosity of vegetable oil and polyol obtained from this oil.

2. EXPERIMENTAL PROCEDURES

2.1 Materials

Passion fruit oil was obtained Naturais da Amazônia with purity of 99%. It was still used formic acid (85%) from Isofar, hydrogen peroxide (30%) from Dinâmica, sodium bisulphite, ethyl ether, sodium carbonate and anhydrous sodium sulphate was purchase from Vetec.

2.2 Polyols synthesis

The synthesis of the polyol was accomplished in agreement with the procedure described for Monteavaro *et al.* (2005). Then, it was mixed 25 grams (9,08 mmol of double bonds) of degummed passion fruit oil with 17 mL de formic acid. Hydrogen peroxide (19 mL) was slowly added to mixture at room temperature for 30 minutes under strong mechanical stirring. After addition of hydrogen peroxide, the mixture was heated to 65°C and stayed for 5 hours. After that time, heating was removed and 10% wt/vol sodium bisulphate solution was added and the organic layer was washed with 10% wt/vol sodium carbonate solution until neutralized. The organic layer was dried with sodium sulfate and the solvent was removed under vacuum.

2.3 Characterization of oils and polyols

Physicochemical analyses

GC analysis of passion fruit oil was performed on a Varian CP 3800 gas chromatograph equipped with a flame ionization detector and a capillary column (CPwax 52 CB, 30 m x 0.32 mm x 0,25 μ m film). Helium was the carrier gas to a flow of 2mL min⁻¹. The column temperature was programmed it began in 80 °C and it stayed for 1 minute, following by a ramp of 10 °C min⁻¹ up to 250 °C, staying in this temperature for more 7 minutes. Each analysis happened in 25 minutes. Esters of the sample were identified by retention times and by comparing them with authentic standards analyzed under the same conditions. The quantification was measured in agreement in the relative area of each constituent peak of the chromatogram, considering that the total area was of 100 %.

The iodine index, peroxide index and saponification index were determined according to AOCS Official Method Cd 1c-85, Cd 8-53 and Cd 3-25 (AOCS, 1990), respectively.

Acidity index was determined by ASTM Official Method D 1980-87 (ASTM, 1998). Hydroxyl index was determined by ASTM D 1957-86 (ASTM, 1995).

Rheological analyse

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The liquid densities were determined in the Agência Nacional do Petróleo (ANP) by using a digital densimeter Anton Paar DMA 4500. The measures were performed in triplicate. The experimental setup used to measure the liquid viscosities was a Couette device measured depicted in the Figure 1. This consisted of a Brookfield viscometer, model Programmable DV-II + Viscometer, standard cylinder rotary viscometer. All experiments were conducted at a constant operating temperature ($28^{\circ}\text{C} \pm 1^{\circ}\text{C}$). Even in the case of the liquid higher viscosity (i.e. the polyol) which has stronger viscosity dependence on temperature, the temperature control using circulating water from a thermal bath was sufficient. The volume of liquid in the gap between the cylinders was typically about 8ml. The experiment consisted of establishing an unidirectional laminar flow between two concentric cylinders, an internal of radius R_1 and an outer of radius R_2 with $(R_2 - R_1) \ll R_2$. Under this condition the liquid enclosed in the gap experience an almost constant shear rate. Specifically, the angular velocity of the inner cylinder is Ω the shear rate $d\gamma/dt = R_1 \Omega / (R_2 - R_1)$. Now, if the couple on the cylinders is C we see that the viscosity is given by $\mu = (2\pi R_1^3)^{-1} C (R_2 - R_1) \Omega^{-1}/L$, where L is the effective immersed length of the liquid being shared. Thus, the shear viscosities of the layer of fluid between the cylinders were measured according to standard methods of viscometry. The torque C to shear the tested liquids was measured between the cylinders. In addition, the measurements of the passion fruit polyol viscosities were also made as a function of the water volume fraction in the polyol. Basically, for each shear rate examined the shear viscosity was measured as a function of time. The measurement were considered once the viscosity of the liquid appeared to have reached the steady state for a given specific shear rate. That means, when only small fluctuations inside the accuracy of the own viscometer are observed. We calculate the average viscosity by means of a time average and its associated errobars for each shear rate tested. This procedure was repeated for several shear rate.

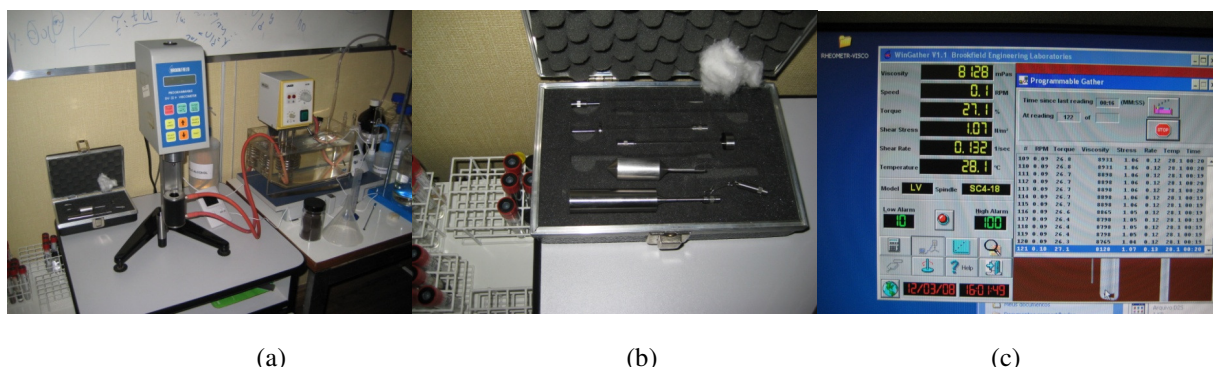


Figure 1. Experimental setup used in the rheological characterization of samples. (a) Viscosimeter (Couette device) and the system to temperature control, (b) the internal cylinder and (c) A typical image of the viscosimeter processing software.

3. RESULTS AND DISCUSSION

Knowledge of the composition of fats and oils is very important in nearly every phase of fats chemistry and technology. The natural oils are triglycerides that comprise three fatty acids linked by a glycerol center, this molecule triglyceride oil can have from 94-96% of weight of fatty acids (Guner *et al.* 2006; Lligadas *et al.* 2006). This fatty acids are identify by of gas chromatography technique that is essential for this determination. So in the gas chromatography the fatty acid esters exit in the order of saturation, separation of the fatty acids is based on chain length, degree of saturation, as well as the geometry and position of the double bonds (O'Brien, 2009). In the Table 1 is presented fatty acids composition of the vegetable oil in study, determined by Lopes (2009) in comparison with fatty acids compositions of the others works (Kobori and Jorge, 2005; Sant'anna *et al.* 2001 and Ferrari *et al.* 2004).

Table 1. Fatty acid composition (% p/p of esters methyl) of passion fruit oil this study compared with others works.

Fatty acid (C _x :y)	Lopes, 2009	Kobori and Jorge, 2005	Sant'anna <i>et al.</i> 2001	Ferrari <i>et al.</i> 2004
Miristic acid, C _{14:0}	-	-	0.08	0.08
Palmitic acid, C _{16:0}	10.5	10-14	11.24	12.04
Palmitoleic acid, C _{16:1}	-	-	0.38	-
Stearic acid, C _{18:0}	1.6	-	-	-
Oleic acid, C _{18:1}	13.9	18-20	15.35	18.06
Linoleic acid, C _{18:2}	72.8	55-66	68.68	68.79
Linolenic acid, C _{18:3}	0.5	0.8-1.1	0.39	0,69

C_{number of carbon atoms}: number of double bonds

Through the table, it is observed that the passion fruit oil in study present high unsaturated index, with predominance of the linoleic acid. The equivalent compositions are observed in others works, some differences presented are justified by depend on climatic conditions, soil type, maturity of plant, microbial conditions, genetic variation of the plant and also the method of extraction of each oil (O'Brien, 2009). The unsaturated degree is an important parameter in the choice of oil because plays an important role on materials properties obtained, so fatty acids unsaturated can be chemically modified with success to obtaining useful products from renewable feedstocks.

The iodine value is a chemical constant for a fat or oil. It is a valuable characteristic in fat analysis that measures unsaturation of fats and oils. Iodine value is a useful tool for process control and product specification. The average degree of unsaturation is measured by iodine value (O'Brien, 2009). Due to that, triglyceride oils are divided into three groups depending on their iodine values, such as, drying (iodine value is higher than 130), semi-drying (iodine value is between 90 and 130) and nondrying oils (iodine value is smaller than 90) [Guner *et al.* 2006]. According to the Table 2, the passion fruit oil can be classified as drying and suitable for chemical modifications, such as processes of hydroxylation.

Peroxide index is important to be measured, since it determines the state of oxidation of oils and fats. When fatty acids are oxidized lead peroxide and similar products. According with literature in the vegetable oil this index should not exceed 10 meq/1000 of sample, because this value indicates a low possibility of damage oxidative. Table 2 shows peroxide index for the oil in study is according to the expected. The oxidative unstable of oils indicates that they have fewer active sites, therefore, less prone to chemical changes as the reaction of hydroxylation (O'Brien, 2009).

Saponification value, a measure of the alkali-reactive groups in fats and oils, was used to predict the type of glycerides in a sample. Glycerides containing short-chain fatty acids have higher saponification values (up to 265 or higher on this) than those with longer chain fatty acids. The saponification value, along with the iodine value determination, were useful screening tests both for quality control and for characterizing types of fats and oils. So as the passion fruit oil contain in its composition the predominantly linoleic acid, which has a chain of 18 carbons, the saponification index shows considerable chemical changes, otherwise if the oil present high saponification index, it would be an indication that the presence of there reaction of alkali reagent formation of soaps.

Acidity index is a measure that quantifier the fatty acids free contained in the oil. The acidity of fatty acids occurs by partial hydrolysis of glycerides, reason which is not constant or characteristic but rather a variable closely related to the nature and quality of raw material, with the quality, purity, processing and the storage conditions of oil. The high level of acidity of a crude oil increases the loss of neutralization, is also an indicator of low seed qualities of improper handling and storage (O'Brien, 2009). In this study, the passion fruit oil presented high acidity (Table 2) that may be related to one of the factors previously cited. Although this index is high, is not a determining factor for not using the oil in the synthesis of polyols, the value found for the passion fruit oil is acceptable for this purpose. Moreover, the index for food is not acceptable because it is directly related to the hydrolytic rancidity of the oil and its conservation. The acidity index for polyol was 12.8 mg KOH/g and, although increased, may be considered acceptable because it does not compromise the properties of the polyol.

Table 2. Physicochemical properties of passion fruit oil this study compared with others works.

Index	Lopes, 2009	Kobori and Jorge, 2005	Ferrari <i>et al.</i> 2004
Iodine (g I ₂ /100g)	139.4	124.36	136.5
Peroxide (mEq/kg)	9,1	0.59	4,7
Saponification (mg KOH/g)	189,4	174.97	-
Acidity (mg KOH/g)	12,1	-	1,34

Hydroxyl percentage (%OH) is another form of expressing the concentration of hydroxyl groups in any polyol. The hydroxyl number is defined as the quantitative value of the amount of hydroxyl groups present in the sample and that are available for the reaction with isocyanates. This determination occurs where terminal hydroxyl groups reacts with organic anhydrides and the acidic carboxyl groups resulting from this reaction are neutralized with the equimolecular quantity of potassium hydroxide. It means also that as larger the hydroxyl index more groups OH is present in the sample. Polyols for lubricants, for example, the most important oils are with high percentage of monounsaturated and polyunsaturated fatty acid and low amount of saturated fatty acid by using various chemical reactions, the double bonds are transformed into hydroxyl groups (Ionescu, 2005).

The hydroxyl index obtained this study was 115 mg KOH/g that compared to soy polyol obtained by the same mechanism of reaction and molar proportions presented hydroxyl index of 150 mg KOH/g. This comparison is due the fact passion fruit oil present composition in fatty acids similar to soybean oil. The difference observed into the hydroxyl index can be attributing to the high level of acidity encountered in passion fruit oil that unchained undesirable parallel reactions.

Density data are important in unit operations in the fatty acid industry. Representative examples include reactors for splitting of fatty acids or conversion of fatty acids to their derivatives, for designing storage and process piping. Also, the pure component data for fatty acids may be used to ascertain mixture property values and to estimate oil density (Noureddini, 1992). Before the conversion of double bonds of the fatty acids in polyols, the high concentration of hydroxyl groups leads to a high density of hydrogen bonds formed between these hydroxyl groups and as an immediate consequence to a strong interaction between the oligomeric chains that strongly increase the oligo-polyol viscosity (O'Brien, 2009).

The Table 3 shows the data of passion fruit oil density and polyol obtained from this oil, it is can observe the increase in density of the polyol in relation to the oil due to the increase density of hydrogen bonds. It is indicate that the greater the amount of hydroxyl groups, the greater the density of the polyol in relation to the oil. The data of specific mass of the passion fruit oil and polyol obtained this oil are in agreement with the data obtained in the literature. For passion fruit oil the density found by Ferrari (2004) was 0.905 g/cm³. Besides comparing the polyol to passion fruit oil with soybean polyol due fact the similar composition of these oils, Zlatanovic *et al.* (2004) found density of 1.006 g/cm³.

Table 3. Data of passion fruit oil and polyol densities.

Density of passion fruit oil at 20°C (g/mL)	0.905
Density of polyol at 20°C (g/mL)	0.988

The viscosity is an important fluid property in order to study the rheological behaviour of the vegetable oils and polyols. The characteristic that many of the polyols can be viscous liquids at room temperature and even at higher temperatures (e.g. 40-60 °C) gives an indication of the processability of an oils and polyols. As described in section 2 polyol shear viscosity is normally determined using a Couette device viscosimeter. In this work the polyol shear viscosities were determined using the same sample of the liquid for four amount of humidity retreat in the polyol samples. Details of the experimental setup have been discussed in section 2.

Table 4 presents shear viscosity measurements of passion fruit oil and its polyol for different amount of humidity. It should be important to note that in the present context the % of humidity used in table 4 is not calculated in terms of the total mass of the mixture (polyol + water). Instead of this, we have considered that before the drying process there is an initial mass of water M_i (g). The drying process is the withdrawal of water by reduction of pressure through a vacuum pump.

Now, if after the drying process a water quantity of mass M_c is extracted from the polyol, then the relative fraction of water that persists in the polyol with respect to initial water mass M_i (i.e. before the drying process) is precisely quantified as being: (%) humidity = $100 (M_i - M_c) / M_i$. So, in absolute terms the resident mass of water in the polyol after drying process is simply, (%) humidity $\cdot M_i / 100$.

Through the table it is seen that the viscosity of the polyol is always greater than the viscosity of the oil, although the polyol having some volume fraction water in its composition. In particular, we can see that the shear viscosity of the polyol free of humidity is about 200 times bigger than the oil viscosity. The observed high viscosity may be interpreted as a direct consequence of the hydroxylation reaction of the oil which modifies its chemical and physical properties (O'Brien, 2009). At the same time, this can be explained by the presence of the more polar molecules that leads to stronger attractive forces between molecules and gives rise to a higher cohesive energy. Consequently, the viscosity may be increased by several orders of magnitude as observed from our shear viscosity measurements.

Table 4. Experimental results of the passion fruit oil shear viscosity (cP) and polyol shear viscosity (cP) for different amounts of humidity.

Passion fruit oil at 28°C	43.78 ± 0.15
Polyol with 100 % of humidity	311.93 ± 2,28
Polyol with 70 % of humidity	552.82 ± 4.33
Polyol with 17 % of humidity	627.83 ± 3.49
Polyol with 0 % of humidity	8278 ± 552.47

The rheological experiments have shown that the sample of liquids all tested were Newtonian fluids in the full range of shear rates investigated in the present work. As mentioned before the shear viscosity measurements of the oils as well as the polyol viscosities were carried out at 28°C in a Couette device viscometer flow. The shear viscosities were also determined for several shear rates in order to investigate any shear rate viscosity dependence.

Figure 2 shows the typical Newtonian behavior of the passion fruit oil shear viscosity. It is seen that the shear viscosity of the oil is quite independent of the shear rate. The values of the shear viscosities all presented in this plot were obtained for a sufficient long time of the experiment so that the viscosimeter system reached the steady state and the shear viscosity saturated for the constant valued (43.78 ± 0.15) cP at 28C for all shear rate tested.

In Figure 3 we have plotted the polyol shear viscosity versus the shear rate at constant temperature (28C). The results are shown for the condition in which the polyol is free of humidity. Again, it is seen that the shear viscosity of the polyol does not vary with the shear rate. We have also observed that the shear viscosity for this high viscosity liquid is also constant with respect to the time of shearing and the stress in the liquid falls to zero immediately the shearing is stopped (i.e. this liquid does not have memory, that means it is instantaneous). Thus, the polyol did not have presented any appreciable deviation from the behavior of Newtonian fluids. It is seen however that the shear viscosity of the polyol free of humidity is approximately 200 times (i.e. 8278 ± 552.47) cP greater than its oil viscosity. This result indicates that the reaction of hydroxylation may produce substantial changes in the molecular packing by the increasing of the molecule-molecule attractive forces. Under this condition the polyol will resist to the tangential stress much more than its oil, that explains the great increasing in viscosity. In addition, figure 4 shows the same plot as presented in Figure 3 for three different fraction of humidity in the polyol. The behavior are typically Newtonian with the shear viscosity constant. We can see that even for higher values of the humidity the polyol shear viscosity is still bigger than the viscosity of its oil, say about seven times the viscosity of the oil. The variation of the dimensionless viscosity of the polyol with the dimensionless drying time is shown in Figure 5. This plot suggests that the dimensionless viscosity is much less affected by the drying time until $t < 0.7 t_{max}$. The best curve to fit the experimental points is also proposed as being $\mu / \mu_{max} = \mu_{min} / \mu_{max} + (1 - \mu_{min} / \mu_{max}) (t/t_{max})^n$, with $n=15/2$, $t_{max} = 30\text{min}$, $\mu_{max}=10460\text{cP}$ and $\mu_{min} / \mu_{max} = 0.0312$. The observed error is less than 1%. This theoretical prediction is able to estimate the polyol shear viscosity for any value of the drying time of the mixture at the interval $[0, t_{max}]$. The observations in Figure 5 pointed out that in order to produce polyols with viscosity much bigger than the viscosity of the original oil the drying process should take a time superior to $0.8 t_{max}$.

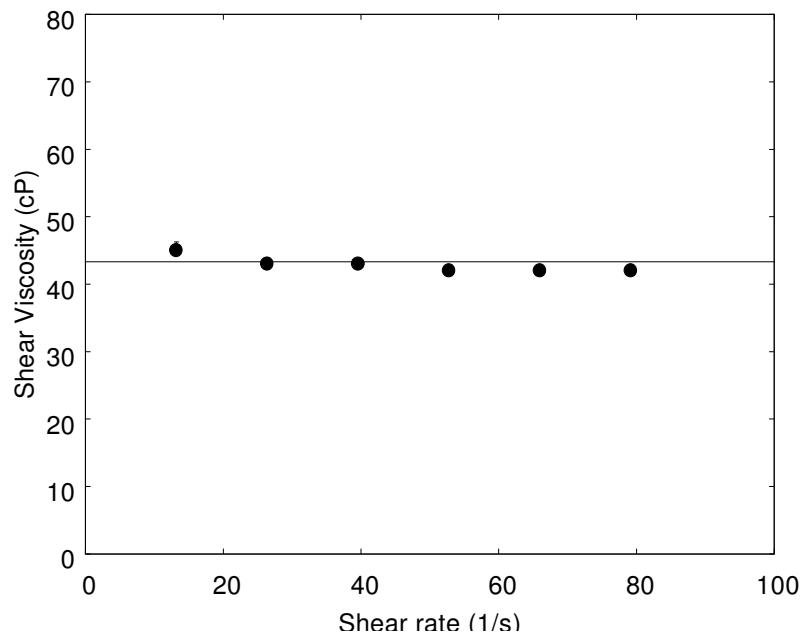


Figure 2. Passion fruit oil shear viscosity as a function of the shear rate for 28C. The horizontal solid line denotes the mean value of the shear viscosity $\mu \cong 44$ cP. The associated error bars of the experimental measurements are also shown in the plot.

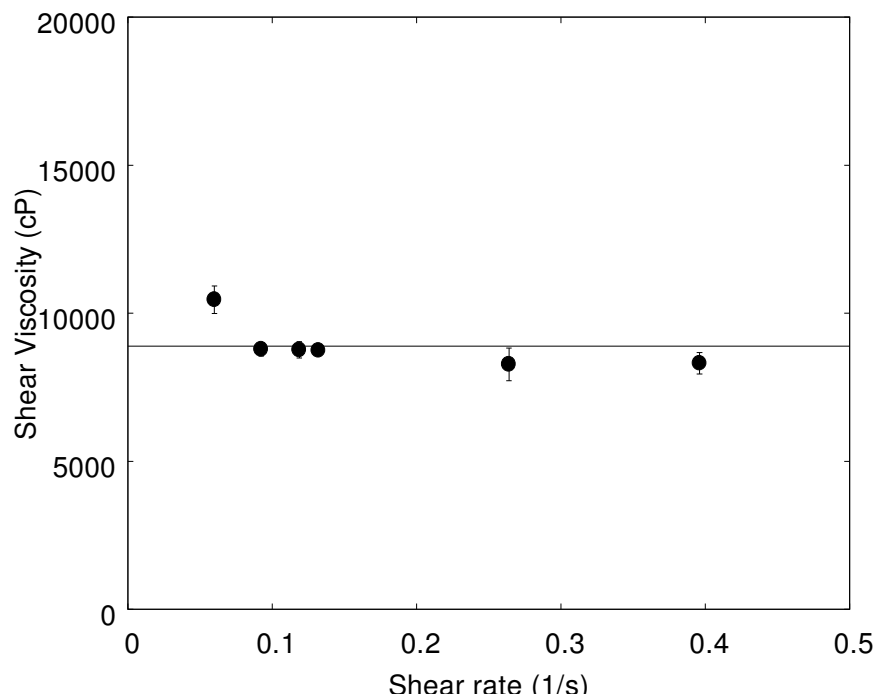


Figure 3. Polyol shear viscosity as a function of the shear rate. The polyol is free of humidity and temperature of the tests was kept constant at 28C. The horizontal solid line denotes the mean value of the shear viscosity, $\mu \cong 8280$ CP. The associated error bars of the experimental measurements are also shown in the plot.

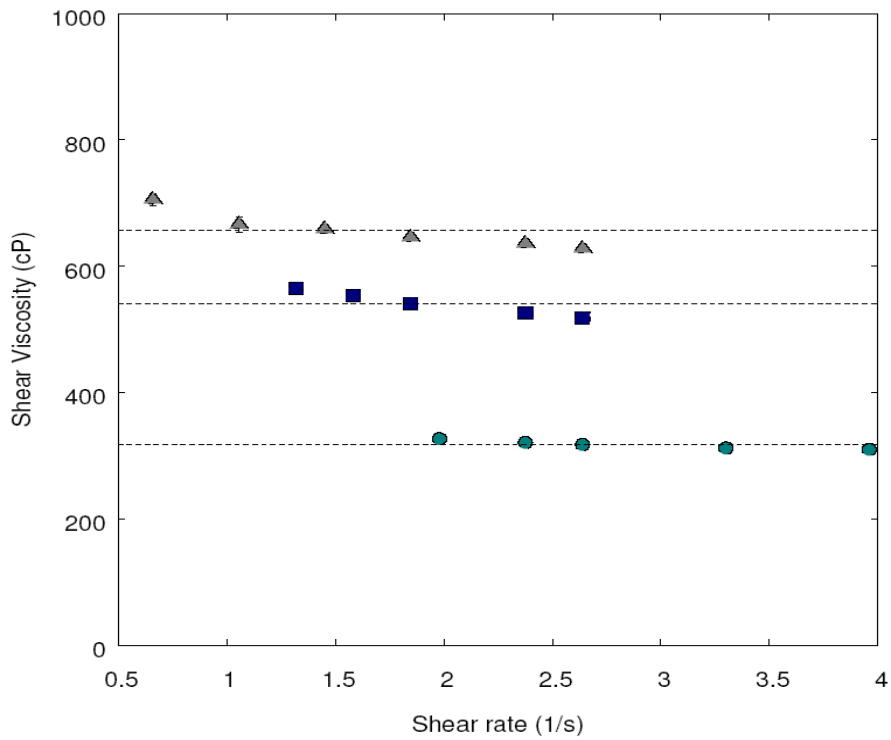


Figure 4. Polyol shear viscosity as a function of the shear rate for three different amounts of humidity: (circles) 100%, (squares) 70% and (triangles) 17%. The horizontal dashed lines represent the mean values of the shear viscosities, $\mu \cong 312$ cP (circles); $\mu \cong 553$ cP (square); $\mu \cong 628$ cP (triangle). The temperature of the tests was kept constant at 28C.

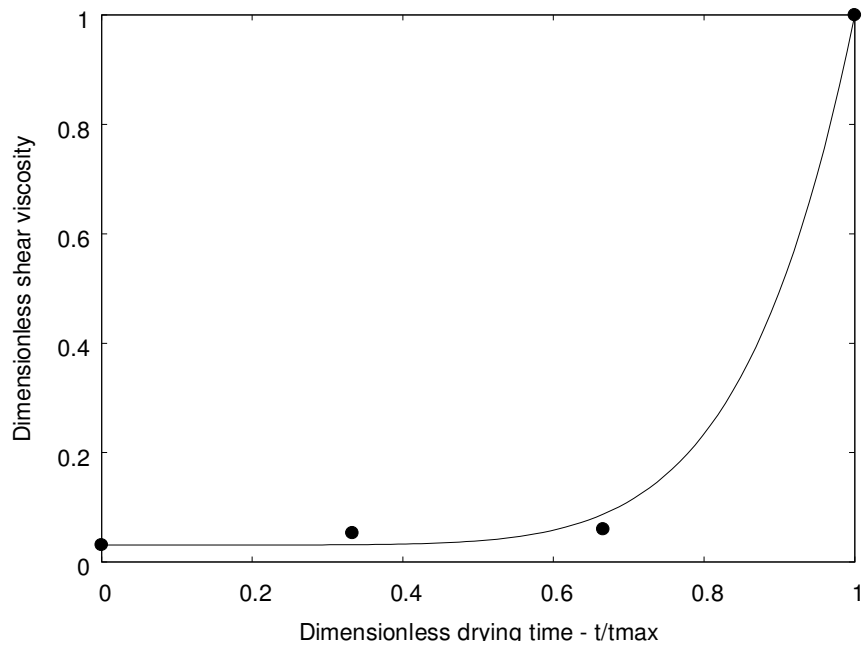


Figure 5. Polyol dimensionless shear viscosity as a function of the dimensionless drying time. The temperature of the all tests was kept constant at 28 °C.

4. CONCLUSION

In this paper we have carried some experiments in order to make a rheological characterization of the passion fruit oil shear viscosity and its polyol for different shear rate and different conditions humidity presented in the polyol. The physicochemical properties of oil, were compatible, indicating that the passion fruit oil shows promising potential for synthesis of polyols. The shear viscosity of the polyols did not show any dependence on the shear rate or significant time dependence of the shear viscosity for the examined samples. So, the rheological behavior of polyol did not presented any deviation from the behavior of a Newtonian fluid. From a rheological point of view the interesting finding of this work was that the hydroxylation reactions may produce very viscous Newtonian liquids with viscosities $O(10^4)$ cP, in contrast to the original pure oil viscosity of $O(10)$ cP before the reaction. The higher values of the viscosities are obtained when the time of the drying process is greater than $0.8 t_{max}$. The extreme increase in the viscosity of the liquid from its original value to the polyol high viscosity value has suggested that the hydroxylation process was very successful. The systematic data gathered here have constituted an essential starting point for subsequent studies. It is related to better assessment of the rheological properties especially in lubricants area. We plan for a future work to examine the rheological behavior of polyols at larger shear rates.

5. ACKNOWLEDGEMENTS

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