THERMOPHYSICAL PROPERTIES OF CASHEW JUICE AT DIFFERENT CONCENTRATIONS AND TEMPERATURES

Renata Cristina Ferreira Bonomo¹, Rafael da Costa Ilhéu Fontan², Tatiana Sant’Anna de Souza³, Cristiane Martins Veloso², Maycon Fagundes Teixeira Reis⁴, Sérgio de Souza Castro²

ABSTRACT

Density and viscosity of commercial cashew juice were studied at a temperature range from (5 to 80) °C and soluble solids contents between (0.8 to 11.2) ºBrix. Polynomial models fitted the experimental data very well, showing a linear relationship between temperature, soluble solids content and the thermophysical properties. The thermal expansion coefficient was computed from its thermodynamic definition at constant pressure. The effect of temperature was very well correlated with the Arrhenius-Guzman equation (R² > 0.96). The values of activation energy (Ea) increased with soluble solids contents from (12.512 to 18.673) kJ.mol⁻¹.

Keywords: density, viscosity, thermal expansion coefficient, activation energy.

PROPRIEDADES TERMOFÍSICAS DO SUCO DE CAJÚ EM DIFERENTES CONCENTRAÇÕES E TEMPERATURAS

RESUMO

Densidade e viscosidade de suco de caju comercial foram avaliadas na faixa de temperatura de (5 a 80) °C e teor de sólidos solúveis entre (0,8 e 11,2) ºBrix. Modelos polinomiais ajustaram-se satisfatoriamente aos resultados experimentais, sendo verificada uma relação linear entre a temperatura, sólidos solúveis e as propriedades termofísicas. O coeficiente de expansão térmica foi determinado a partir de sua definição termodinâmica em pressão constante. O efeito da temperatura na viscosidade foi bem descrito pela equação de Arrhenius-Guzman (R² > 0.96). Os valores da Energia de ativação (Ea) aumentou com o aumento da concentração de sólidos solúveis a partir de (12,512 até 18,673) kJ.mol⁻¹.

Palavras-chave: densidade, viscosidade, coeficiente de expansão térmica, energia de ativação.
INTRODUCTION

Cashew juice is widely available in the Brazilian market. This juice, which is a complex mixture of vitamins, polyphenols, sugar, mineral salts, organic acids and amino acids is an excellent source of vitamin C and contains around six times more vitamin C than orange juice (da Silva et al., 2000; Azoubel et al., 2005).

Generally, food composition and temperature are the important factors which affect thermal properties and the knowledge of these properties is necessary for effective design of food processing equipment such as heat exchangers and other equipments which require pumping of the products (Tansakul & Chaisawang, 2006; Azoubel et al., 2005; Zainal et al., 2000). According to Zuritz et al. (2005) an adequate manufacturing process, a correct design of the concentrate plants and an appropriate evaluation of their performance will facilitate optimization of the concentrated juice quality parameters.

The thermophysical properties of several juices have been reported, such as pink guava (Zainal et al., 2000), orange (Telis-Romero et al., 1998), grape (Zuritz et al., 2005), pomegranate and pear (Magerramov et al., 2007), cashew (Azoubel et al., 2005) and Malus floribunda (Cepeda & Villarán, 1999). Empirical models of thermal properties have been developed for each specific food material, in spite of the general models developed by Choi & Okos (1983) so that they would give a more accurate prediction. The thermal expansion coefficient is a physical property that represents density change in the material, due to an increase in its temperature at constant pressure.

In spite of thermophysical properties of fruit juice as well as mathematical models for their calculation have been published, the majority of the available data for fruits are for sub-tropical ones. In an attempt to fill this gap, the objective of this work was to measure the density, viscosity and thermal expansion coefficient of cashew juice as a function of temperature and soluble solute content and to obtain simple equations to correlate experimental data.

MATERIAL AND METHODS

Materials

Cashew juice with 11.2 °Brix of soluble solids content was obtained at a local market in Itapetinga, Brazil. Dilutions from this juice were made with distilled water until obtain samples with (0.8, 1.4 and 2.6) °Brix. All the juices prepared were filtered to remove particles in suspension using a 50 mesh sieve. The total soluble solids were measured using a portable refractometer (Atago, Brazil).

Density and thermal expansion coefficient

Cashew juice density was determined by applying the picnometric method (Constenla et al., 1989). The sample kept in a 25 mL standard volumetric picnometer was weighed using an analytical balance (precision of ±0.0001 g, Gehaka). The picnometer was previously calibrated with distilled water at each temperature studied, (5, 20, 35, 50, 65 and 80 °C), and kept constant through a thermostatic water bath (Quimis, Brazil). All of these determinations were carried out by three repetitions.

The thermal expansion coefficient was calculated from the thermodynamic expression (Equation 1), at constant pressure, using the best fitting polynomial to represent density (Zuritz et al., 2005).

\[
\beta = \rho \times \frac{\frac{\partial (1/\rho)}{\partial T}}{\rho} = -\frac{1}{\rho} \times \left( \frac{\partial \rho}{\partial T} \right)_p 
\] (1)

Viscosity

Some authors have considered that the fruit juices present Newtonian behavior when pulp content is low, soluble solids content is lower than 30 °Brix, or if the juices have been depectinised (Cepeda & Villarán, 1999; Saravacos, 1970; Zuritz et al., 2005).
In order to determine the apparent viscosity, at first the kinematic viscosity was obtained in the studied temperatures. It was used a 75 capillary Cannon-Fenske viscosimeter, immersed in a cinematic bath for temperature control. The kinematic viscosity value for each temperature was calculated by Equation 2.

\[ \nu = n \cdot t \]  

(2)

Once the density and cinematic viscosity was known, the apparent viscosity could be calculated by Equation 3 (Bird et al., 1960).

\[ \eta = \nu \times \rho \]  

(3)

From viscosity values (\( \eta \)) as function of temperature, flow Activation Energy values for each studied concentration were calculated using the Arrhenius-Guzman equation (Cepeda & Villarán, 1999):

\[ \eta = \eta_0 \times \exp \left( \frac{E_a}{RT} \right) \]  

(4)

Experimental design

The experiments were carried out at 4 levels of soluble solute content, (0.8, 1.4, 2.6 and 11.2) °Brix, and 6 levels of temperature, (5, 20, 35, 50, 65 and 80) °C, in a factorial design. All statistical analysis was performed using the SAEG statistical package (Ribeiro Junior, 2001). The suitability of the fitted functions was evaluated by the determination coefficient (\( R^2 \)), the level of significance and residual analysis.

RESULTS AND DISCUSSION

Effect of temperature and concentration on density and thermal expansion coefficient

In Table 1 values of density of clarified cashew juices are shown with different soluble solids content (concentration) measured at different temperatures. The statistical analysis showed that the concentration and temperature had a significant effect on density at a 95% confidence level.

It was found from these results that density of cashew juice decreased linearly with the temperature increase and concentration decrease. This result is in agreement with depectined and clarified peach juice and orange juice (Ramos & Ibarz, 1998), guava juice (Shamsudin et al., 2005), Malus floribunda juice (Cepeda & Villarán, 1999) and Brazilian orange juice (Telis-Romero et al., 1998). The multiple regression of density as a function of concentration, \( C_s \) (°Brix), and temperature, \( T \) (°C), in the range studied is shown in Eq. (5). Figure 1 shows the response surface obtained from Eq. (5).

Table 1. Density of cashew juices

<table>
<thead>
<tr>
<th>° Brix</th>
<th>5</th>
<th>20</th>
<th>35</th>
<th>50</th>
<th>65</th>
<th>80</th>
</tr>
</thead>
<tbody>
<tr>
<td>11.2</td>
<td>1040.16</td>
<td>1039.29</td>
<td>1035.05</td>
<td>1025.27</td>
<td>1014.48</td>
<td>1010.93</td>
</tr>
<tr>
<td>2.4</td>
<td>1004.94</td>
<td>1004.12</td>
<td>997.62</td>
<td>990.31</td>
<td>985.52</td>
<td>972.28</td>
</tr>
<tr>
<td>1.2</td>
<td>1000.23</td>
<td>998.47</td>
<td>992.63</td>
<td>983.07</td>
<td>979.09</td>
<td>969.08</td>
</tr>
<tr>
<td>0.8</td>
<td>996.22</td>
<td>996.76</td>
<td>993.92</td>
<td>983.31</td>
<td>979.17</td>
<td>967.89</td>
</tr>
</tbody>
</table>

\[ \rho = 996.49 - 0.096T - 0.0038T^2 + 4.03C_s \]  

\[ R^2 = 0.974 \]  

(5)
Thermo physical properties of cashew juice at different concentrations and temperatures

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Figure 1. Density as function of temperature and concentration.

Calculated data from the equations of Constenla et al. (1989), Alvarado and Romero (1989) and the adjusted ones in this work are nearly coincident with the experimental data (Figure 2). For all equations the error was lower than 2%.

Equation 3 was used in Eq. (1) to obtain the thermal expansion coefficient ($\beta$). In Table 2, values of thermal expansion are shown for different concentrations at different temperatures. From these results was verified that thermal expansion coefficient of cashew juice increased linearly with the temperature increase and concentration decrease.

Effect of temperature on viscosity

Values of viscosity are shown in Table 3. It was observed that its values increase with concentration and decrease with temperature elevation. This decrease in apparent viscosity with increase in temperature and decrease in concentration has also been reported by Vitali and Rao (1984) (orange juice), Hernandez et al. (1995) (orange juice) and Shamsudin et al. (2005) (guava juice).

According to Constenla et al. (1989) the solution viscosity is a function of the intermolecular forces and water-solute interactions that restrict the molecular motion. These forces depend upon intermolecular spacings and the strength of the hydrogen bonds, and are affected by changes in both concentration and temperature (Azoubel et. al., 2005).

The model that best fitted with the experimental values was a polynomial type, where the viscosity varies with the square of the temperature and linearly with concentration. The equation obtained by the least squares method, with determination coefficient of 0.949, significant at a probability level of 99%, is presented in the Equation 6. Figure 3 shows the response surface obtained from Eq. (6).
Figure 2. Density of cashew juice at 5 °C.

Table 2. Thermal expansion coefficient of cashew juices

<table>
<thead>
<tr>
<th>°Brix</th>
<th>Temperature (°C)</th>
<th>5</th>
<th>20</th>
<th>35</th>
<th>50</th>
<th>65</th>
<th>80</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.8</td>
<td></td>
<td>1.34 x10⁻⁰⁴</td>
<td>2.49X10⁻⁰⁴</td>
<td>3.65X10⁻⁰⁴</td>
<td>4.83X10⁻⁰⁴</td>
<td>6.04X10⁻⁰⁴</td>
<td>7.27X10⁻⁰⁴</td>
</tr>
<tr>
<td>1.2</td>
<td></td>
<td>1.34 x10⁻⁰⁴</td>
<td>2.49X10⁻⁰⁴</td>
<td>3.64X10⁻⁰⁴</td>
<td>4.82X10⁻⁰⁴</td>
<td>6.03X10⁻⁰⁴</td>
<td>7.26X10⁻⁰⁴</td>
</tr>
<tr>
<td>2.4</td>
<td></td>
<td>1.33 x10⁻⁰⁴</td>
<td>2.47X10⁻⁰⁴</td>
<td>3.63X10⁻⁰⁴</td>
<td>4.80X10⁻⁰⁴</td>
<td>6.00X10⁻⁰⁴</td>
<td>7.23X10⁻⁰⁴</td>
</tr>
<tr>
<td>11.2</td>
<td></td>
<td>1.29X10⁻⁰⁴</td>
<td>2.39X10⁻⁰⁴</td>
<td>3.50X10⁻⁰⁴</td>
<td>4.63X10⁻⁰⁴</td>
<td>5.79X10⁻⁰⁴</td>
<td>6.97X10⁻⁰⁴</td>
</tr>
</tbody>
</table>

Table 3. Viscosity of cashew juices

<table>
<thead>
<tr>
<th>°Brix</th>
<th>Temperature (°C)</th>
<th>5</th>
<th>20</th>
<th>35</th>
<th>50</th>
<th>65</th>
<th>80</th>
</tr>
</thead>
<tbody>
<tr>
<td>11.2</td>
<td></td>
<td>3.420</td>
<td>2.180</td>
<td>1.530</td>
<td>1.120</td>
<td>0.851</td>
<td>0.611</td>
</tr>
<tr>
<td>2.4</td>
<td></td>
<td>1.270</td>
<td>0.801</td>
<td>0.565</td>
<td>0.421</td>
<td>0.325</td>
<td>0.243</td>
</tr>
<tr>
<td>1.2</td>
<td></td>
<td>1.180</td>
<td>0.927</td>
<td>0.645</td>
<td>0.767</td>
<td>0.620</td>
<td>0.295</td>
</tr>
<tr>
<td>0.8</td>
<td></td>
<td>1.080</td>
<td>0.864</td>
<td>0.621</td>
<td>0.464</td>
<td>0.364</td>
<td>0.302</td>
</tr>
</tbody>
</table>

\[ \eta = 1.32 - 3.39 \times 10^{-2} T + 2.78 \times 10^{-4} T^2 + 1.84 \times 10^{-1} C_y - 2.17 \times 10^{-3} T C_y \]  \( (6) \)
Figure 3. Viscosity as function of temperature and concentration.

The effect of temperature on the viscosity follows the Arrhenius-Guzman equation with $R^2$ values greater than 0.96. Magnitudes of activation energy for flow related to apparent viscosity and temperature ranged from (12.512 to 18.673) kJ.mol$^{-1}$, while the corresponding magnitudes of constant $\eta_\infty$ ranged from (5.337x10$^{-6}$ to 1.057x10$^{-3}$) mPa.s (Table 4). The $R^2$ for all cases were greater than 0.96. This increase in activation energy with increase in concentration has also been reported by Nindo et al. (2007) (blueberry puree), Cepeda & Villarán (1999) (Malus floribunda juice).

<table>
<thead>
<tr>
<th>°Brix</th>
<th>$\eta_\infty$(mPa.s)</th>
<th>$E_a$ (kJ.mol$^{-1}$)</th>
<th>$E_a/R$ (K)</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.8</td>
<td>5.337x10$^{-6}$</td>
<td>12.512</td>
<td>1505.0</td>
<td>0.991</td>
</tr>
<tr>
<td>1.2</td>
<td>2.669x10$^{-6}$</td>
<td>13.942</td>
<td>1677.0</td>
<td>0.963</td>
</tr>
<tr>
<td>2.4</td>
<td>5.150x10$^{-4}$</td>
<td>17.600</td>
<td>2117.0</td>
<td>0.992</td>
</tr>
<tr>
<td>11.2</td>
<td>1.057x10$^{-3}$</td>
<td>18.673</td>
<td>2246.0</td>
<td>0.998</td>
</tr>
</tbody>
</table>

**CONCLUSIONS**

From this study, it was found that the physical properties of cashew juice were concentration and temperature dependent. The effect of temperature and concentration on density and viscosity can be described by a linear equation that could be useful for preliminary equipment design. The activation energy $E_a$ increased with total solids content. These results can be applied in process with cashew juice which involves flow and heat transfer.
BIBLIOGRAPHIC REFERENCES


Nomenclature

$E_a$  activation energy (kJ.mol$^{-1}$)

$P$  pressure (Pa)

$T$  temperature (°C)

$t$  the flow off time of the sample (s)

$n$  viscosimeter characteristic constant (m$^2$.s$^{-2}$)

$R$  gas constant (kJ.mol$^{-1}$.K$^{-1}$)

Greek letters

$\beta$  thermal expansion coefficient

$\rho$  density (kg.m$^{-3}$)

$\nu$  cinematic viscosity (m$^2$.s$^{-1}$)

$\eta$  apparent viscosity (mPa.s)

$\eta_\infty$  constant (mPa.s)