Effect of concentration on the physical properties of cashew juice

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Abstract

Thermal conductivity, thermal diffusivity, density and viscosity of cashew juice were measured at 30 °C for soluble solids content ranging from 5.5 to 25 °Brix. Thermal conductivity and diffusivity were determined using a linear heat source probe. Both properties were found to decrease with the increase of soluble solids content, while density and viscosity increased. Empirical models were fitted to the experimental data for each property and the accuracy of those models was checked.
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1. Introduction

Cashew juice is widely available on 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, containing approximately six times more vitamin C than orange juice (da Silva, Collares, & Finzer, 2000; Soares & Maia, 1970).

A knowledge of thermal properties is necessary for effective design of food processing equipment, such as heat exchangers and other equipment requiring pumping of the product (de Moura, Germer, Jardim, & Sadahira, 1998).

Over the years both measured values of thermophysical properties of food as well as the mathematical models for their calculation have been published (Bhumbla, Singh, & Singh, 1989; de Moura et al., 1998; Dickerson, 1968; Polley, Synder, & Kotnour, 1980; Riedel, 1949). However, the majority of the available data for fruits are for sub-tropical ones. Little published information is available about the thermal properties of tropical fruit products like juices.

The objective of this work was to determine density, thermal conductivity, thermal diffusivity and the rheological behaviour of cashew juice as a function of soluble solids content and to compare the experimental data and the values obtained from the mathematical models found in the literature.

2. Theory

Several methods are available to measure physical properties of food. The line heat source probe can be employed for the determination of thermal conductivity and thermal diffusivity simultaneously (Choi & Okos, 1983; Nix, Lowery, Vachen, & Tanger, 1967). Advantages of this method are the short duration of the experiments, simplicity, speed and relatively small sample requirement (AbuDagga & Kolbe, 1997; Tocci, Flores, & Mascheroni, 1997).

The theory of this method is presented in detail by many researchers (Blackwell, 1954; Nix et al., 1967) and is based on the fact that the temperature rise at a point close to a line heat source, in a semi-infinite solid, subjected to a step change heat source, is a function of time, the thermal properties of the solid and the source strength (Choi & Okos, 1983). The expression in which the thermal conductivity may be obtained is

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$$k = \frac{Q \ln(t_2 - t_0)/(t_1 - t_0)}{4\pi(T_2 - T_1)}, \qquad (1)$$

where k is the thermal conductivity of the sample ($\mathrm{W\,m^{-1}\,K^{-1}}$), Q is the heat source strength ($\mathrm{W\,m^{-1}}$), t_1 and t_2 are the initial and final times (s), respectively, when $\ln(t)$ versus T plot becomes linear and T_1 and T_2 are the temperature (K) at times t_1 and t_2, respectively.

A time correction factor (t_0) was introduced to correct the effect of finite heat diameter and finite heat resistance between the heat source and the sample (Van der Held & Van Drunen, 1949).

The determination of thermal diffusivity using the line source technique is possible without information of density and specific heat by using the following expression (Choi & Okos, 1983):

$$T = \frac{Q}{2\pi k} \int_\beta^\alpha \frac{\exp(-\beta^2)}{\beta} \,\mathrm{d}\beta, \qquad (2)$$

where β is inversely proportional to $(\alpha)^{0.5}$:

$$\beta = \frac{r}{2\sqrt{\alpha t}}, \qquad (3)$$

where r is the distance from the heat line (m) and α is the thermal diffusivity ($\mathrm{m^2\,s^{-1}}$).

Nix et al. (1967) give the following series expression for evaluation of the above integral:

$$T = \frac{Q}{2\pi k}\left[-\frac{C_e}{2} - \ln\beta + \frac{\beta^2}{2 \times 1!} - \frac{\beta^4}{4 \times 2!} + \cdots \right], \qquad (4)$$

where C_e is Euler constant (0.577).

Nix et al. (1967) found that the first 40 terms of the above equation need to be evaluated to insure convergence. However, for values of $0 < \beta < 0.16$, the residual error occurs if only the first two terms within the brackets are taken. That condition is easily attained if the probe and the point where temperature is measured are closely located and the time is larger (order of minutes; Urbicain & Lozano, 1997).

3. Material and methods

3.1. Materials

Cashew juice at various soluble solids content (5.5–25 °Brix) was made from a 9.6 °Brix pulp obtained in a local market of Campinas, Brazil. The main characteristics of this pulp juice are summarized in Table 1.

The 5.5 °Brix juice was made by reconstituting the original pulp with distilled water. The concentration of cashew juice was carried out in a rotary evaporator, in which the evaporation chamber was rotating at a constant speed in a water bath at 54 °C. The solutions were concentrated to 11.3, 15.5, 17.0, 20.0, 23.4 and 25.0 °Brix. All the obtained juices were filtered to remove

Table 1
Specifications of the 9.6 °Brix cashew juice

Moisture (%)	90.4
Total sugars (%)	10.24
Reducing sugars (%)	9.85
pH	3.88
Fibers (%)	0.24

suspended particles using a 50 mesh sieve with an opening width of 300 μm. The total soluble solids were measured by a bench refractometer (PZO Warszawa).

Each juice sample was placed in 50 ml beakers. Error due to natural convection was avoided by adding 2% agar to the juice.

3.2. Thermophysical properties

The thermophysical properties were determined at 30 °C, accurately controlled with a constant temperature circulation bath. Experiments were conducted in triplicate.

A Pycnometric method was used to determine the density of cashew apple. Pycnometers of 25 ml capacity were used and they were calibrated with water. A water bath was used for controlling temperature.

A probe was used to measure simultaneously thermal conductivity and thermal diffusivity. The probe encloses a heater wire and a thermocouple junction contained in a hypodermical needles ($L = 5$ cm, $D = 0.2$ cm for the thermal conductivity probe and $L = 5$ cm, $D = 0.1$ cm for the thermal diffusivity probe). Construction of the line heat source probe is described by Choi and Okos (1983).

A constant electrical current of 3.6 A was applied to the heater wire. The system was computerized and a Scanlog data aquisition software recorded the thermocouple reading every 4 s for a total duration of 20 min (Fig. 1). A digital multimeter was used to check the voltage during data collection.

The thermal conductivity and the thermal diffusivity probes were positioned in the samples in such a way that
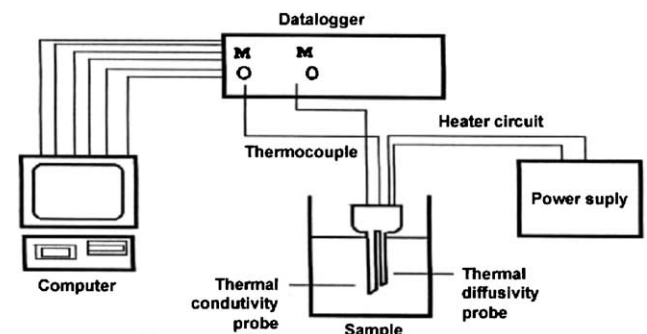

Fig. 1. Thermal conductivity and diffusivity measurement apparatus.

the full length of the probes were covered. Thermal conductivity was calculated on the basis of Eq. (1). The heat input Q in this equation was calculated from the resistance of the constantan heater and the electrical current, according to the equation $Q = I^2R$. The probe was tested by determining thermal conductivity and thermal diffusivity of water (2% agar).

A programmable Brookfield rheometer (LV DV-II+) was used to determine the viscosity and shear rate of juice. The sample was put in the concentric cylinder of the rheometer and heated in a water bath at 30 °C. The power law parameters were determined from the apparent viscosities measured at different shear rates.

4. Results and discussion

4.1. Thermal conductivity and thermal diffusivity

Experimental results of thermal conductivity (k) and thermal diffusivity (α) at eight selected soluble solids levels ranging from 5.5 to 25 °Brix at 30 °C are shown in Figs. 2 and 3, respectively. There was a strong dependence of these properties on concentration and a noticeable decrease was observed as concentration increased. With an increase in water fraction of fruit juices, there is an increase in these thermal properties of fruit juices because compared with thermal conductivity and thermal diffusivity of the solids present in the juice, since water has a higher value of these properties.

Measurements of k and α of cashew juice were not found in the literature. However, the obtained values fall into the range reported for other fruits and their products, like juices and pulps (Constenla, Lozano, & Capriste, 1989; Jaramillo-Flores & Hernandez-Sanchez, 2000; Singh, 1982; Zainal, Rahman, Ariff, Saari, & Asbi, 2000).
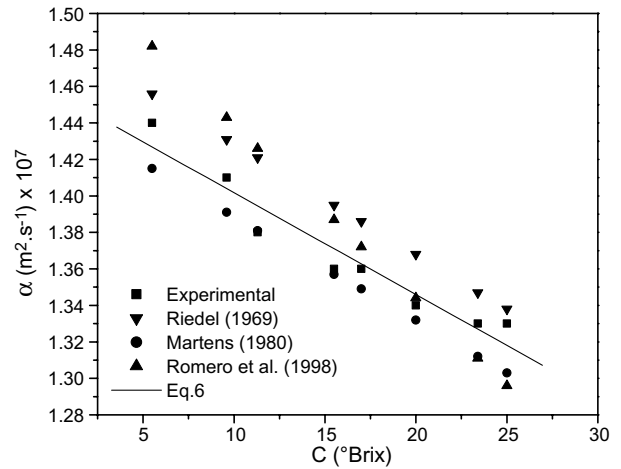

Fig. 3. Thermal diffusivity of cashew juice at 30 °C.

Values of k and α predicted by different models are shown in Figs. 2 and 3, respectively. It is seen that the proposed models are more accurate, with $R^2 > 0.93$:

$$k = 0.5994 - 6.0527 \times 10^{-3}C \quad (R^2 = 0.974), \tag{5}$$

$$\alpha = 1.45751 \times 10^{-7} - 0.00558 \times 10^{-7}C \quad (R^2 = 0.932), \tag{6}$$

where C is the concentration (°Brix).

4.2. Density

The relationship between the density of cashew juice and soluble solids can be presented as a straight line (Fig. 4) and given as

$$\rho = 0.99562 + 0.00412C \quad (R^2 = 0.996). \tag{7}$$

The density of cashew juice increased with increasing soluble solids concentration. This result is in agreement with depectined and clarified peach juice and orange
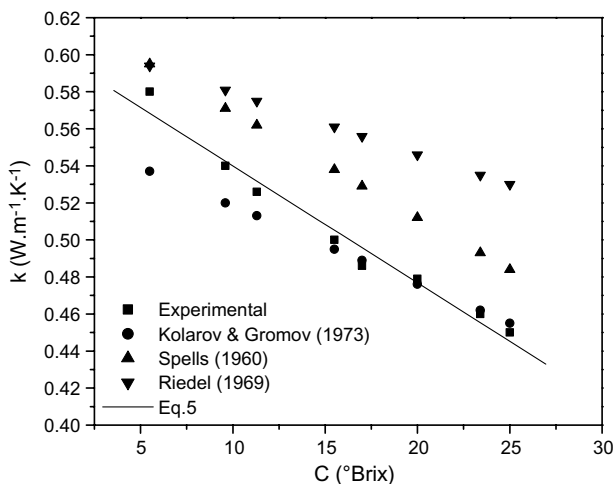

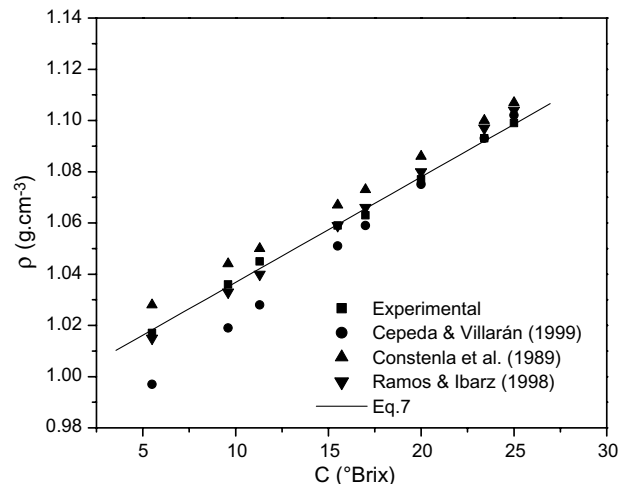Fig. 2. Thermal conductivity of cashew juice at 30 °C.

Fig. 4. Density of cashew apple at 30 °C.

juice (Ramos & Ibarz, 1998), cloudy and depectinised *Malus floribunda* juice (Cepeda & Villarán, 1999), clarified apple juice (Constenla et al., 1989) and pink guava juice (Zainal et al., 2000).

Calculated data from the equation of Ramos and Ibarz (1998) are nearly coincident with the experimental data (Fig. 3), while the data predicted with the equation of Constenla et al. (1989) are different. Calculated data from the equation of Cepeda and Villarán (1999) are nearly coincident with experimental data at higher concentration values.

4.3. Rheological measurements

The experimental data showed a non-Newtonian behaviour for the cashew juice (Fig. 5), that retained its pseudoplastic characteristic, indicated by the value of the flow behaviour index (*n*), being less than 1 (Table 2). Similar behaviour was found by Zainal et al. (2000) for pink guava juice and by Rao, Cooley, and Vitali (1994), who reported that the effect of concentration on viscosity of fruit juices at constant temperature could be
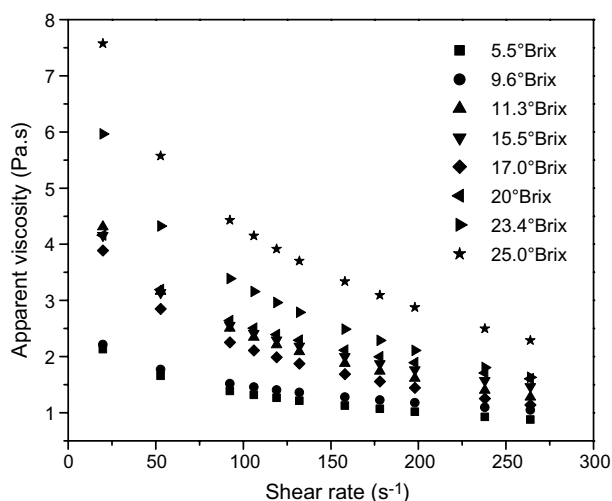
represented by either an exponential-type or a power-type relationship.

Viscosity of cashew juice increased with soluble solids, as expected. Constenla et al. (1989) reported that, as in the case of density, the viscosity of a solution 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. When more solutes such as sugars are dissolved in the solution, the viscosity increases because of the increase in hydrogen bonding with hydroxyl groups and the distortion in the velocity pattern of the liquid by hydrated molecules of the solute.

5. Conclusions

From this study, it was found that the physical properties were concentration dependent. Thermal conductivity and thermal diffusivity decreased with an increase in soluble solids concentration, while density and viscosity increased. The regression equations obtained in this study are capable of simulating the physical properties of cashew juice. The results of this work have direct application to fruit juice processes involving fluid flow and heat transfer.

Acknowledgements

Fig. 5. Apparent viscosity of cashew juice versus shear rate.

Table 2
Values of consistency coefficient (*K*) and flow behaviour index (*n*) for cashew juice at different soluble solids concentration

C (°Brix)	K	n	R^2
5.5	0.0058	0.7337	0.985
9.6	0.0039	0.8207	0.995
11.3	0.0092	0.7256	0.988
15.5	0.0076	0.7485	0.995
17.0	0.0081	0.7230	0.996
20.0	0.0113	0.6748	0.983
23.4	0.0087	0.7979	0.995
25.0	0.0121	0.7526	0.985

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