INFLUENCE OF TEMPERATURE AND CONCENTRATION ON THERMOPHYSICAL PROPERTIES OF CAJA JUICE (*Spondia mombin*, L)

Tadini, C. C.[*], Telis, V. R. N.[°], Telis-Romero, J.[°]

[*]Food Eng. Lab. Chemical Eng. Dept., Escola Politécnica, São Paulo University, Brazil,
P. O. Box 61548, 05424-970, SP, Brazil, Phone: + 551130912258, Fax: + 551130912255, catadini@usp.br
°Food Engineering and Technology Department, Universidade Estadual Paulista, Brazil, P.O. Box 136, 15054-000, São José do Rio Preto, Brazil, Phone: + 55172212251, Fax: + 55172212299, javier@eta.ibilce.unesp.br

ABSTRACT

The thermophysical properties of caja juice were determined between 8.8 and 49.4 ° Brix and from 0.4 ºC to 77.1 ºC. Caja Juice was produced from caja fruit (8.0 ± 0.4 ºBrix, 43.3 ± 1.1 % pulp content, pH, 2.45 ± 0.02, 0.94 ± 0.01 % citric acid, density, 1.0442 ± 0.0032 gcm^{-3}). The concentration process was performed using a roto evaporator, under vacuum, to obtain concentrate juice at about 49 ºBrix. All the experimental measurements were conducted in samples from the same batch of concentrate juice. In order to obtain different concentrations, concentrate juice was diluted with distilled water. Thermal conductivity, thermal diffusivity and density of caja juice at 8.8, 17.6, 22.0, 27.4, 32.9, 38.9, 44.7 and 49.4 ºBrix were determined, in triplicate, at 0.4, 9.3, 22.1, 31.8, 42.3, 54.0, 66.3 and 77.1 ºC. Polynomial regression was performed to fit experimental data obtaining good fit. Both temperature and concentration showed strong influence on thermophysical properties of caja juice. Calculated apparent specific heat values varied from 2.364 kJ/kgºC to 4.515 kJ/kgºC in the studied interval.

INTRODUCTION

Caja is a small fruit, elliptical in shape with 3-4 cm length, cultivated in the Northeast region of Brazil mainly during the rainy season. As with most regional fruit, caja is available during a short period of the year, and it does not reach other regions of the country, nor foreign countries. In fact, the consumption of commercial products of regional fruits has increased in the last few years in Brazil, due their accessibility, year-round availability, and easy preparation. However, one way to improve its commercialization and being possible its consumption in other countries, is to concentrate juice extracted from fruit [1]. Beyond its aromatic characteristics caja fruit is among the good sources of pro-vitamin A. According Rodriguez-Amaya & Kimura (1989) [2], the caja fruit (*Spondias lutea* L.) pulp together with the edible peel present a total carotenoid content higher than cashew, guava and some varieties of papaya. Usual values of physico chemical parameters of fruit are: pH 2.50 – 2.99; soluble solids 7.5 – 8.8 ºBrix; acidity as citric acid 0.39 – 1.09%; reducing sugars 2.70 – 4.53%; ascorbic acid 5.24 – 8.87 mg/100g [3][4].

Thermophysical properties of caja juice are inexistent in literature and to get these data is quite important for adequate equipment design. The objective of this work was to measure thermophysical properties (thermal conductivity, thermal diffusivity and density) of Brazilian caja juice as a function of temperature and concentration, and to obtain simple equations to correlate experimental data.

MATERIALS AND METHODS

All the experimental measurements were conducted in samples from the same batch of concentrate caja juice (49.4 ºBrix). The concentration process was performed using a roto evaporator, under vacuum, to obtain concentrate juice. In order to obtain different concentrations, concentrate juice was diluted with distilled water. Caja juice was extracted from caja fruit (8.0 ± 0.4 ºBrix, 43.3 ± 1.1 % pulp content, pH, 2.45 ± 0.02, 0.94 ± 0.01 % citric acid, density, 1.0442 ± 0.0032 gcm^{-3}).

Thermal conductivity

Thermal conductivity at various temperatures and water contents, was measured using the method described by Bellet *et al.* (1975) [5], based on a cylindrical cell, where the liquid whose properties are being determined fills the annular space between two concentric cylinders. The physical characteristics is specified in Telis-Romero *et al.* (1998) [6] and presented the following physical characteristics: two coaxial copper cylinders, 180mm in length, separated by 2 mm annular space, which was filled with the sample; 50 mm thick covers made of a low thermal conductivity material (0.225 W/mºC) to prevent axial heat transfer; a heater made with a constantan wire (resistance 15 W), electrically insulated by a varnish and coiled around a copper stick; two thermocouples type T to measure temperature differences between the two cylinders, located at half-length of the cell, with wires placed inside 0.5 mm gaps, parallel to the cell axis. The external diameters of the outer and inner copper cylinders were, respectively, 34 mm and 20 mm, while the internal diameters were 24 mm and 10 mm for the outer and inner cylinders, respectively.

To keep the external temperature constant, the cell was immersed in a thermostatic bath (model MA-184, Marconi, São Paulo, Brazil) containing ethyl alcohol. The power input to the heater resistance was from a laboratory DC power supply (model MPS-3006D, Minipa, São Paulo, Brazil), which permitted the adjustment of the current with a stability of 0.05%. An HP data logger, model 75.000-B, an HP-IB interface and an HP PC running a data acquisition program written in IBASIC, monitored the temperatures with an accuracy of 0.6°C. In order to measure the temperature, one and three copper-constantan thermocouples were embedded in the surfaces of the inner and outer cylinders, respectively. The cell was calibrated with distilled water.

Thermal diffusivity

Thermal diffusivity was determined using the method proposed by Dickerson (1965) [7]. The experimental apparatus consisted of a cylindrical cell (24.75 x 10^{-3} m internal radius and 248.5 x 10^{-3} m length) made of chromium plated brass with two nylon covers with thermal diffusivity of 1.09 x 10^{-7} m^2/s, which is similar to the most of liquid food products. Two thermocouples type T were fixed at the center and on the external surface of the cell. The cell was immersed in a well-agitated thermostatic bath (MK70, MLW, Dresden, Germany) heated at a constant rate, and the evolution of temperatures at the wall and at the center of the cell was monitored. Temperatures were monitored employing the same data acquisition system used in thermal conductivity measurements.

Density

Density of caja juice at different temperatures and concentrations was determined in triplicate by weighing, in an analytical balance, the juice contained in a standard volumetric pycnometer [8]. Sample temperature was varied by equilibration on a thermostatic bath. The pycnometer of 25 ml was previously calibrated with distilled water at each temperature.

Specific heat

Specific heat was directly calculated from following equation:

$$C_p = \frac{k}{r \times a} \tag{1}$$

Data analysis

Fitted models were obtained by using estimation procedures from statistical program Statgraphics v. 4.0 (Manigistics). The suitability of the fitted models was evaluated by determination coefficient (r^2), the significance level ($p<0.05$), and residual analysis.

RESULTS AND DISCUSSION

Thermal conductivity, thermal diffusivity and density of Brazilian caja juice at 8.8, 17.6, 22.0, 27.4, 32.9, 38.9, 44.7 and 49.4 ºBrix were determined, in triplicate, at 0.4, 9.3, 22.1, 31.8, 42.3, 54.0, 66.3 and 77.1 ºC, adding up to 192 experimental values for each property. Polynomial regression was performed to fit experimental data ($r^2>0.88$):

$$k = (0.599 + 5.825\times10^{-4} \times T - 5.155\times10^{-3} \times C) \pm 0.017 \tag{2}$$

$$r = (962.6 - 3.1\times10^{-1} \times T + 4.8 \times C) \pm 21.1 \tag{3}$$

$$a = (1.377\times10^{-7} + 2.449\times10^{-7} \times T - 5.533\times10^{-10} \times C) \pm 0.036\times10^{-7} \tag{4}$$

$$0.4^{o}\,C \le T \le 77.1^{o}\,C \qquad 8.8^{o}\,Brix \le C \le 49.4^{o}\,Brix$$

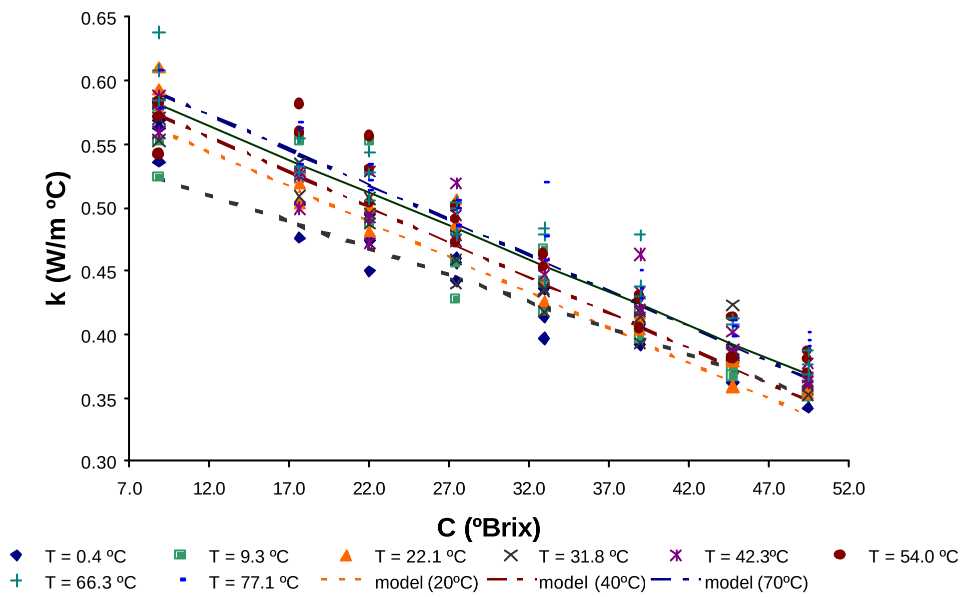

Figure 1: Experimental data of caja juice thermal conductivity as a function of soluble solids C (ºBrix) and temperature T (ºC). Predictions for orange juice at 40ºC (—) [6] and for juices (----) [9].

Figure 1 presents experimental data of caja juice thermal conductivity and compares them those predicted values by eq. 2, at 20ºC, 40ºC and 70ºC (r^2 = 0.94). Multiple regression analysis indicated a strong dependence of thermal conductivity of caja juice related to concentration and temperature ($p<0.01$). Telis-Romero *et al.* (1998) [6] found similar values for orange juice. It can be observed that it has good agreement between experimental data and the predictions of eq. 2. Comparison with correlations proposed for orange juice at 40 ºC [6] and for juices [9], indicated the similarity between orange juice and caja juice.

Figure 2 presents experimental data of caja juice density and compares them those predicted values by eq. 3, at 20ºC, 40ºC and 70ºC (r^2 = 0.90). Multiple regression analysis indicated a strong dependence of density of caja juice related to concentration and temperature ($p<0.01$).

Figure 3 presents experimental data of caja juice thermal diffusivity and compares them those predicted values by eq. 4, at 20ºC, 40ºC and 70ºC (r^2 = 0.88). Multiple regression analysis indicated a strong dependence of density of caja juice related to concentration and temperature ($p<0.01$). It can be observed that the experimental data of thermal diffusivity did not fit as well than others properties, mainly to 17, 22 and 32 ºBrix concentrations. Again predictive model for orange juice proposed by Telis-Romero *et al.* (1998) [6] presents good agreement.

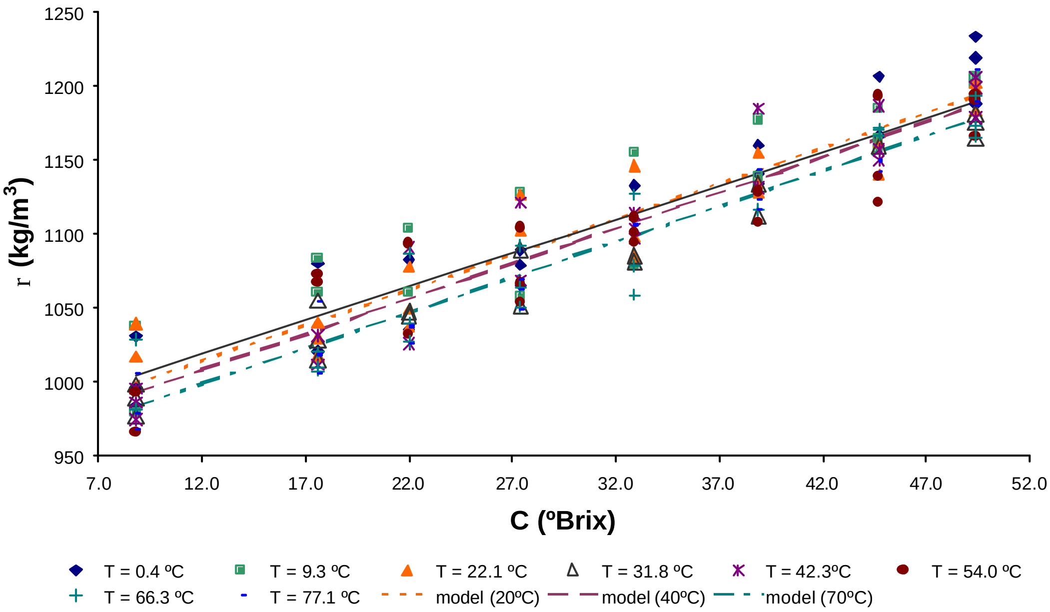

Figure 2: Experimental data of caja juice density as a function of soluble solids C (ºBrix) and temperature T (ºC). Predictions for orange juice at 40ºC (—) [6].

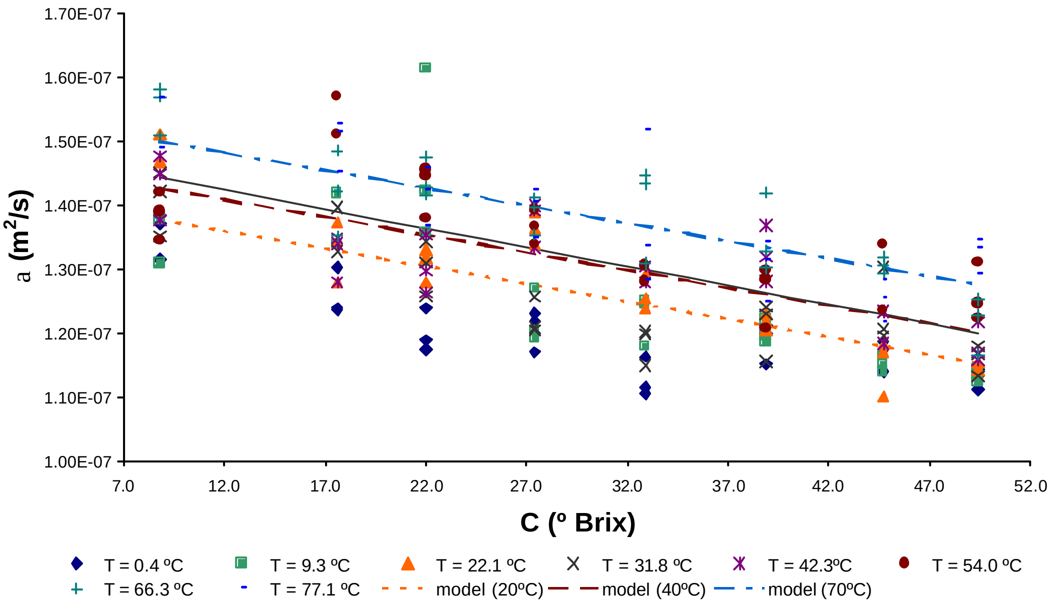

Figure 3: Experimental data of caja juice thermal diffusivity as a function of soluble solids C (ºBrix) and temperature T (ºC). Predictions for orange juice at 40ºC (—) [6].

Specific heat

Specific heat was calculated according to eq. 1, using 192 experimental data for each thermophysical property. Table 1 shows the average data obtained in the experimental assays for thermal conductivity, density, thermal diffusivity and calculated specific heat, as a function of temperature and concentration of caja juice.

Table 1: Thermal conductivity, density and thermal diffusivity experimental data and calculated specific heat from eq. 1, as a function of temperature and concentration of caja juice.

Property	T (ºC)	C (ºBrix)			
		8.8	22.0	32.9	44.7
k (W/mºC)	0.4	0.556	0.473	0.416	0.373
	22.1	0.593	0.496	0.442	0.373
	42.3	0.574	0.497	0.453	0.391
	66.3	0.610	0.526	0.468	0.411
ρ (kg/m^3)	0.4	1003.1	1058.8	1107.7	1177.4
	22.1	1028.0	1054.6	1109.8	1151.2
	42.3	985.1	1058.2	1104.7	1164.4
	66.3	1005.0	1051.2	1087.7	1169.4
$\alpha \times 10^{-7}$ (m^2/s)	0.4	1.356	1.200	1.127	1.166
	22.1	1.496	1.309	1.261	1.151
	42.3	1.434	1.304	1.295	1.217
	66.3	1.553	1.440	1.396	1.306
Cp (J/kgºC)	0.4	4087.5	3719.3	3329.8	2720.2
	22.1	3855.1	3592.9	3160.7	2817.5
	42.3	4066.5	3603.4	3165.7	2762.2
	66.3	3909.2	3472.8	3084.3	2688.9

CONCLUSION

In this paper, some thermophysical properties, such as thermal conductivity, density and thermal diffusivity, of caja juice were determined between 8.8 ºBrix and 49.4 ºBrix and from 0ºC and 77.1 ºC, common conditions applied during evaporation processes. These results could be used to model heat and mass transfer during concentration of caja juice. It is important to emphasize that if these properties were not adequately determined, this could result in under-processing or an incorrect calculation of equipments dimensions.

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NOMENCLATURE

Symbol	Quantity	SI Unit
C	soluble solids content	ºBrix
C_P	specific heat	J/kg.ºC
k	thermal conductivity of the sample at the average temperature $(T_1 + T_2)/2$	W/m.ºC
T	temperature	ºC
α	thermal diffusivity	m^2/s
ρ	density	kg/m^3

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