Influence of Temperature and Total Soluble Solids on Thermo-Physical Properties of Pomegranate Juice

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Summary

Determination of thermo-physical properties of pomegranate (*Punica granatum* L.) juice is essential for examining, controlling, and developing numerical models of processes such as drying and concentrating. These properties are affected by changing the percentage of soluble solid content (°Brix) and temperature. Thermo-physical properties of pomegranate juice including density, specific heat and thermal conductivity at temperature range from 25 to 70°C and at the three levels of soluble solid content (12, 40 and 65 °Brix) were investigated in this research. Thermal conductivity, density, and specific heat were measured by co-axial cylinder, volumetric pycnometer and differential scanning calorimeter (DSC), respectively. Results from regression analysis of output data showed that both temperature and solid content affected the thermo-physical properties of pomegranate juice; however, the soluble solid content exhibited a greater effect. By increasing soluble solid content and decreasing temperature, thermals conductivity and specific heat have been reduced linearly but density increased during augment of soluble solid content or decrease of temperature.

Key words

thermal conductivity, specific heat, density, pomegranate juice

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Introduction

Determining thermo-physical properties of foods such as specific heat, thermal conductivity and density are essential in food engineering industry. Thermal conductivity is also one of the important factors in heat transfer and operations such as concentration and drying. Generally, modeling of food processes is difficult due to complexity of raw materials that affect thermo-physical properties. In addition, thermo-physical properties of food undergo fundamental changes as temperature and amount of solid materials. Numerous researches have been conducted to identify thermo-physical properties of agricultural products and food materials. Various methods of measuring these properties have been presented by different researchers (Mohsenin, 1980; Reidy and Rippen, 1971; Singh, 1982). Thermal conductivity, diffusivity, specific heat and density of tomato juice were measured in temperature range of 20 to 50°C and solid content of 4.8 to 80%. Also the linear regression models were presented to determine the relation between these properties with temperature and solid content (Choi and Okos, 1983). Constenla et al. (1989) measured thermo-physical properties of clarified apple juice within the temperature range of 20 to 90°C, and soluble solid content of 12 to 70 °Brix. In line with the results, specific heat and thermal conductivity decrease linearly as solid content increase. Shariaty-Niassar et al. (2000) measured thermal conductivity of potato starch gel under pressure in a vast range of temperature, 25 to 80°C, and pressure range of 0.2 to 10 MPa using thermal conductivity probe technique.

According to their results, thermal conductivity increases when temperature and moisture content rise, and also pressure rises up to 1 MPa. Mass and heat transfer in liquids such as toluene was studied by Demirel and Sandler (2002). Results showed coupled equations of mass and heat transfer depend excessively on thermal conductivity and thermal diffusivity. Thermo-physical properties of lime juice were determined in different conditions of temperature and total solid content by Roustapour et al. (2005). Thermal conductivity was measured by co-axial cylinders, specific heat by differential scanning calorimeter, density by pycnometer, and thermal diffusivity was determined by applying the relation among the aforesaid properties. Results indicated that, thermal conductivity, specific heat and thermal diffusivity of lime juice increase linearity when temperature rises and solid content reduces but density decreases in the same conditions. Thermal conductivity and specific heat of coconut milk were measured by hot-wire conductivity method with differential scanning calorimeter in temperature range of 6 to 80°C and fat percent of 20 to 35. In accordance with the results, these properties reduced when the amount of fat increased and the temperature decreased (Tansakul and Chaisawang, 2006).

Jane at al. (2006) determined density, specific heat and thermal conductivity of liquid egg components, including albumin, yolk and mix of them, in temperature range of 273 to 311 K and water content of 51.8 to 88.2%. The linear and polynomial regression models also showed the influence of temperature and water content on these properties. Results showed the density variation from 1023 to 1143.5 kg.m^3, the specific heat variation from 2.6 to 3.7 J g^{-1} K^{-1} and thermal conductivity variation from 0.2 to 0.6 W m^{-1} K^{-1} for pure yolk to pure albumin in the ranges of temperature and water content.

Thermal conductivity of a liquid food, including apple juice, canola oil, honey and high fructose corn syrup was measured at 25°C temperature and 0.1-700 MPa pressure. Based on the results, the augment of pressure caused amplification of thermal conductivity of all materials. Apple juice had the highest thermal conductivity (0.8 W m^{-1} °C^{-1}) and canola oil had the lowest thermal conductivity (0.29 W m^{-1} °C^{-1}) at 700 MPa pressures (Ramaswamy et al., 2007). Bon et al. (2010) determined the density, specific heat and thermal conductivity of mango pulp in the moisture contents of 0.52 and 0.9 kg kg^{-1} and at temperatures of 20 and 80°C. They also provided the linear regression models to illustrate the effect of temperature and humidity on variation of these properties. The results showed that the moisture content had more influence than temperature on the thermo-physical properties of mango pulp. The objectives of this research were:

1. To determine the coefficients of thermal conductivity, specific heat and density of pomegranate juice (Rabab variety) in various temperatures and total soluble solid contents.
2. To establish the correlation between every mentioned coefficient with parameters of temperature and total soluble solid content.

These coefficients are used to define the properties of pomegranate juice in modeling of its drying process in spray dryer or its concentration process in evaporators in different conditions such as medium temperature and different stage of evaporation.

Materials and methods

Materials

To investigate the effects of solid content and temperature on thermo-physical properties of pomegranate juice, they were determined in soluble solid content ranging from 12 to 65 °Brix and temperature ranging from 30 to 70°C. The dominant compositions of pomegranate juice are carbohydrates such as fructose, glucose and organic acids such as malic and citric. Carbohydrates were measured by enzyme method which relies on their ability to catalyze specific reactions. Ion Exclusion Mode is the most commonly used mode for organic acid analysis such as citric acid and malic acid. The ingredients of pomegranate juice (AOAC, 1990) in 100 g of juice are shown in Table 1.

Table 1. Pomegranate juice composition

Parameter	Units	Mean	Std. Dev.
Fructose	g/100g	6.63	0.85
Glucose	g/100g	6.62	0.83
Citric acid	g/100g	1.24	0.33
Malic acid	g/100g	0.053	0.017
Potassium	mg/kg	2476	304
Formol value	meq/100mL	1.04	0.24
Proline	mg/kg	5	3

In the current study, Rabab variety of concentrated pomegranate juice with 65 °Brix soluble solid content was purchased from a local factory and subsequently diluted with distilled water. Two other levels of soluble solid content were obtained, 12 and 40 °Brix. Eventually soluble solid content was observed by a refractometer. The experiment of measuring thermo-physical properties was conducted at three levels of soluble solid content, and mostly at five levels of temperature. The specific heat of pomegranate juice was determined through DSC (Differential Scanning Calorimeter) technique. The technique is extensively applied for measuring thermal capacity and heat transfer rate and measuring thermal energy in temperatures ranging from 170 to 770°C. The above mentioned technique is based on measuring minuscule temperature variation during heat flow in the material. This calorimeter consists of two 2 mm^3 cells, one of which contains sample material and the other one contains base material that is sapphire; the caps are placed and thermal flowed in the material. The recording section of the system determines the changes of thermal energy in base and main materials in the temperature range, and calculates the amount of absorbed or desorbed thermal energy by main material.

Specific Heat Measurement

In order to measure the specific heat of pomegranate juice, calorimeter was calibrated with toluene. Therefore, toluene was poured in sample-holder container and the variation in its specific heat was obtained in a temperature range of 40 to 70°C. This calorimeter cannot be applied for temperatures less than 40°C. By comparing the results obtained by calorimeter and the standardized specific heat of toluene, the amount of deviation was determined from standardized data in each temperature (Rohsenow et al., 1998). The calibration curve of this device is shown in Figure 1.

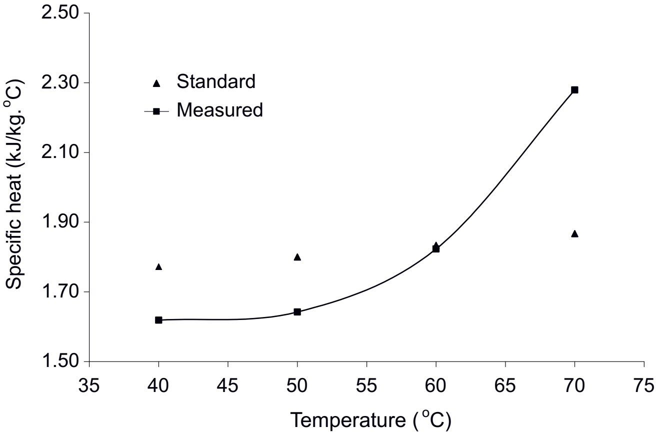

Figure 1. Calibration curve of differential scanning calorimeter

Having calibrated the calorimeter, the specific heat of pomegranate juice was determined at three levels of soluble solid content and four levels of temperature. The actual specific heat at each temperature can be obtained according to calibration curve and measurement error at each temperature.

Thermal conductivity measurement

Thermal conductivity of pomegranate juice was found out by a co-axial cylinders heat conductivity measurement device. This device consists of two pipes made of phosphorus-bronze alloy each of which is 210 mm long and 6 mm thick. The pipes have been assembled co-axially and blocked at their both sides. The liquid is injected in the empty space between the two cylinders and forms a 2 mm thick layer. There is an electric heater that has been assembled in the inner cylinder which produces the initial heat. A temperature sensor (PT100) is in each cylinder wall. The outputs of these sensors are connected to a data logger (A/D card) and heat variations are observed over time.

To begin the experiments, the device needs to be calibrated, so toluene was injected in the closed space between the pipes and after being placed in isothermal bath, the heater was turned on. The temperatures of two sides of the liquid layer were recorded in the steady state condition. Then the amount of consumed thermal energy was calculated by Equation 1 in average recorded temperatures. Calibration was accomplished in four levels of heater temperature between 30 to 60°C. The difference between electrical energy of heater and consumed energy in steady state condition is heat loss of the system (ql). Figure 2 shows the heat loss in different temperatures.

$$K = \frac{q * \ell\left(\frac{r_2}{r_1}\right)}{\left(T_1 - T_2\right) * 2\pi L} \qquad (1)$$

By calibrating the device and determining the heat losses in various temperatures, the thermal conductivity of pomegranate juice was investigated. The experiments of measuring coefficient of thermal conductivity were carried out at three levels of soluble solid content and four levels of temperature of the heater. Finally, this coefficient was determined in three levels of average temperature of liquid layer that was injected in the closed space. Thermal conductivity coefficient was obtained through Equation 1, by having the proportion of consumed heat energy. This proportion was indeed considered the thermal conductivity of pomegranate juice in the average temperature of the liquid layer.

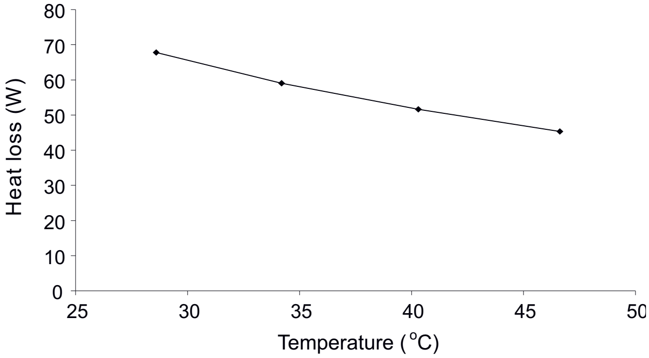

Figure 2. Heat loss at different mean temperature of toluene layer in coaxial cylinder

Density measurement

Density of pomegranate juice was obtained by employing a 50 ml volumetric pycnometer. In order to measure density, the pycnometer was filled with juice, subsequently it was weighed on an accurate scale and the density was calculated. If the pyc-

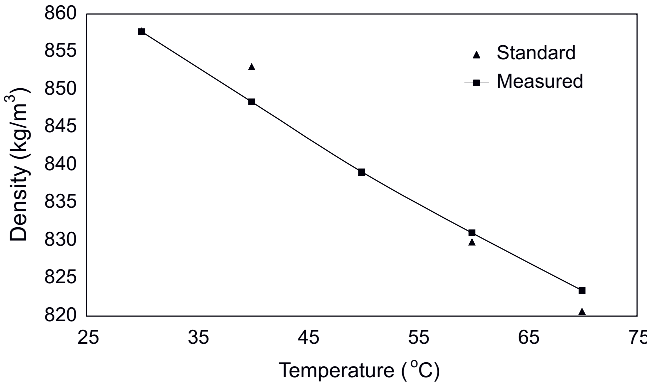

Figure 3. Calibration curve of pycnometer in density measurement of toluene

nometer containing the liquid is placed in isothermal bath and its heater is set on desired temperature, it is possible to determine the density at different temperatures.

Initially, the pycnometer was calibrated with toluene in the thermal range of 30 to 70ºC, and pomegranate juice density was measured subsequently. The error of pycnometer was obtained by determining the difference between measured density of toluene and standardized data of its density in various temperatures (Kothandaraman and Subramanyan, 1989). The results express that the measured density is a little less than the standardized amount, which is due to the pycnometer inaccuracy. Therefore, the standard deviation of density was added to density that we had measured by pycnometer at various temperatures. Calibration curve at various temperatures is portrayed in Figure 3.

Experiments of determining pomegranate juice density were carried out at three levels of soluble solid content and five levels of temperature. Based on the regression analysis, the empirical models were obtained. They illustrated the relationship of each thermo-physical property of pomegranate juice including specific heat, thermal conductivity and density, with soluble solid content and temperature.

Results and discussion

Specific heat reduced when soluble solid content rose from 12 to 65 ºBrix, and increased when temperature moved up from 40 to 60ºC. When the temperature rose, the heat flux that passed through the liquid also augmented and consequently the specific heat goes up. Since the specific heat of water is higher than the other solid ingredients of pomegranate juice, specific heat reduces when soluble solid content increases. The obtained regression model to correlate the relation between the specific heat of pomegranate juice and the factors consisting of soluble solid content and temperature was a two-variable linear model with R^2 equal 0.985 (Equation 2). The standardized coefficient “β” expresses that increasing soluble solid content by one unit concluded in 0.947 unit reductions in specific heat, while a one unit increment in temperature concluded in 0.248 unit increases in specific heat (Table 2).

The soluble solid content had significant impression on specific heat of pomegranate juice (p<0.01), but temperature had less significant impression on specific heat (p<0.05).

$$c = 4.4 - 0.034X_S + 0.023T_m \qquad R^2=0.958 \qquad (2)$$

Figure 4 illustrates the changes in specific heat of pomegranate juice with parameters such as soluble solid content and temperature and the linear model performed on the data.

Table 2. Correlation coefficients of specific heat regression model

	Coefficients		t- test	Sig.
	Unstandardized	Standardized (β)		
Constant	4.400		10.491**	0.000
Soluble solid content	-0.034	-0.947	-11.270**	0.000
Temperature	0.023	0.248	2.954*	0.025

** - Significant effect at the level of α=99%
* - Significant effect at the level of α=95%

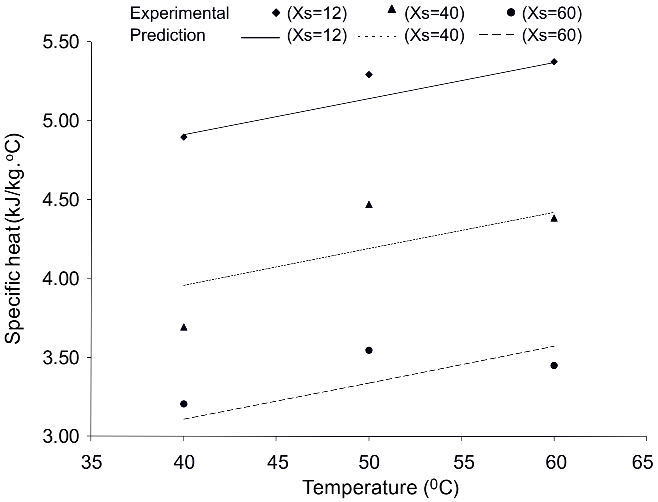

Figure 4. Specific heat of pomegranate juice as a function of TSS content and temperature (SD=0.820)

Results portrayed the variation of specific heat of pomegranate juice with temperature and soluble solid content were similar to the variation of this property for tomato determined by Choi and Okos (1983). The thermal conductivity of pomegranate juice increased with an increment in temperature from 28 to 42ºC, because the heat flux passing through the material rose and thermal conductivity developed consequently. On the other hand, this coefficient declined when the soluble solid content of pomegranate juice rose from 12 to 65 ºBrix. Since the thermal conductivity of water is higher than other solid materials in pomegranate juice, the thermal conductivity of pomegranate juice decreases with a reduction in water content. The regression model to correlate the relationship between thermal conductivity of pomegranate juice and factors such as soluble solid content and temperature is a two-variable linear model with R^2 equal 0.862. The standardized coefficient “β” implies that each one unit increase in soluble solid content resulted in 0.644 unit decline in thermal conductivity, while a one unit increment in temperature caused 0.668 unit augments in thermal conductivity (Table 3).

Table 3. Correlation coefficients of heat conductivity regression model

	Coefficients		t- test	Sig.
	Unstandardized	Standardized (β)		
Constant	0.138		5.504**	0.002
Soluble solid content	-0.001	-0.644	-4.245**	0.005
Temperature	0.003	0.668	4.403**	0.005

** - Significant effect at the level of α=99%

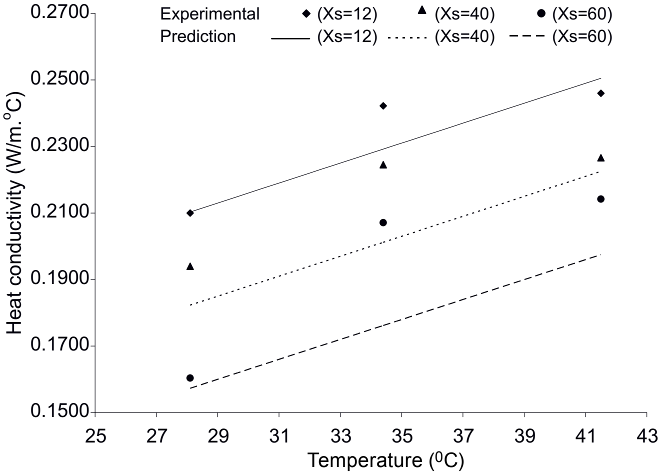

Figure 5. Heat conductivity of pomegranate juice as a function of TSS content and temperature (SD=0.026)

The obtained conclusions from regression analysis of pomegranate juice thermal conductivity indicated that soluble solid content and temperature had a significant effect on thermal conductivity ($p<0.01$). The obtained linear relationship between the independent variable, pomegranate juice thermal conductivity, and dependant variables, soluble solid content and temperature, is shown in Equation 3.

$$k = 0.138-0.001X_s+0.003T_m \quad R^2=0.862 \qquad (3)$$

Figure 5 indicates the changes in thermal conductivity with parameters consisting of soluble solid content and temperature and the linear model performed on the given data. Heat conductivity variation models of pomegranate juice was compared with that models of lime juice determined by Roustapour *et al.* (2005). In accordance with the results, these variations were similar.

According to the obtained results, the density of pomegranate juice augmented when soluble solid content rose from 12 to 65 °Brix and decreased when temperature moved up from 30 to 70°C. The pomegranate juice in the pycnometer overflows when temperature increases, so the final weight of the liquid and pycnometer reduces and consequently density decreases. Increment of solid content causes enhance in concentration per unit of volume and density. The obtained regression model was a two-variable linear model with R^2 equal 0.966. The standardized coefficient "β" expresses that by adding one unit of soluble solid content, density rose by 0.981 units, while one unit enhancement in temperature concluded the minuscule change of 0.066 units in density (Table 4).

Table 4. Correlation coefficients of density regression model

	Coefficients		t- test	Sig.
	Unstandardized	Standardized (β)		
Constant	974/15		36.400**	0.000
Soluble solid content	5.559	0.981	18.399**	0.000
Temperature	-0.576	-0.066	-1.245ns	0.237

** - Significant effect at the level of α=99%
ns - No significant effect at the level of α=95%

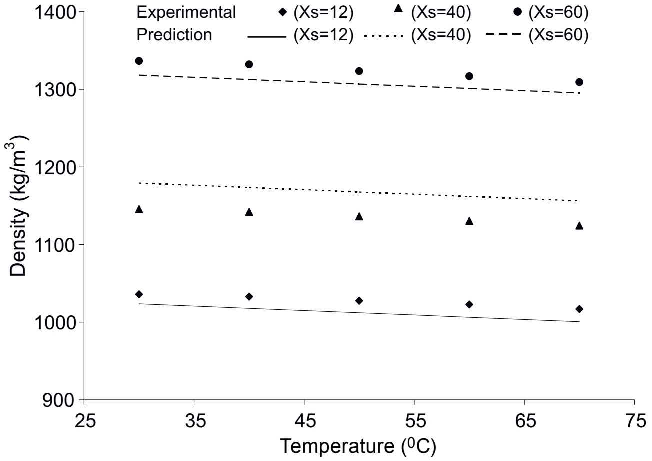

Figure 6. Density of pomegranate juice as a function of TSS content and temperature (SD=12.703)

According to the results, soluble solid content had a significant effect ($p<0.01$) on the density of pomegranate juice, but temperature did not have any significant effect. The obtained relationship between independent variable, density, and dependent variables, soluble solid content and temperature, is as in the Equation 4.

$$\rho = 947.175-5.559X_s+0.567T_m \quad R^2=0.966 \qquad (4)$$

Figure 6 illustrates the variations in pomegranate juice density caused by soluble solid content and temperature changes and also the linear model performed on the data. The linear regression model that indicated the variation of density of pomegranate juice was similar to the one determined for Brazilian orange juice by Telis-Romero et al. (1998)

Conclusion

The obtained results from studying the effects of solid content and temperature on thermo-physical properties of pomegranate juice revealed that the mentioned parameters had a significant effect on these properties. Thermal conductivity and specific heat decreased, but density increased when solid content rose. Thermal conductivity and specific heat also enhanced with an increment in the temperature of liquid layer, while the density of pomegranate juice was reduced. The relationship between thermo-physical properties of pomegranate juice and parameters such as solid content and temperature was presented through two-variable linear regression models. The coefficient (R^2) of presented models for specific heat and density was about 0.96 and for thermal conductivity was about 0.86.

Nomenclature

c	Specific heat, kJ kg^{-1} °C
k	Heat conductivity, W m^{-1} $°C^{-1}$
L	Length of coaxial cylinders, m
q_1	Heat loss, kW
r_1	Inner radius of liquid layer in coaxial cylinders, m
r_2	Outer radius of liquid layer in coaxial cylinders, m
T_1	Inner temperature of liquid layer at coaxial cylinders, °C
T_2	Outer temperature of liquid layer at coaxial cylinders, °C
T_m	Mean temperature of the liquid layer at coaxial cylinders, °C
X_s	Total soluble solid content, kg kg^{-1}
ρ	Pomegranate juice density, kg $(m^3)^{-1}$

References

AOAC. (1990). Official methods of analysis (15th Eds). Association of Official Analytical Chemists. Washington DC, USA.

Bon J., Vaquiro H., Benedito J. Telis-Romero J. (2010). Thermophysical properties of mango pulp (Mangifera indica L. cv. Tommy Atkins). Journal of Food Engineering. 97: 563-568.

Choi Y. Okos M. R. (1983). The thermal properties of tomato juice concentrates. Transactions of the ASAE. 26: 305-311.

Constenla D. T., Lozano J. E. Crapiste G. H. (1989). Thermophysical properties of clarified apple juice as a function of concentration and temperature. Journal of Food Science and Technology. 54: 663-668.

Demirel Y. Sandler S.I. (2002). Effects of concentration and temperature on the coupled heat and mass transport in liquid mixtures. International Journal of Heat Mass Transfer. 45: 75-86.

Jane S.R. Coimbra J.S.R., Gabas A.L., Minim L.A., Garcia Rojas E.E., Telis V.R.N. Telis-Romero J. (2006). Density, heat capacity and thermal conductivity of liquid egg products. Journal of Food Engineering. 74: 186–190.

Kothandaraman C. P. Subramanyan S. (1989). Heat and mass transfer data book.4th Eds. New Delhi, India.

Mohsenin N.N. (1980). Thermal properties of foods and agricultural materials. Gordon and Breach Science Publishers. New York.

Ramaswamy R., Balasubramaniam V.M. Sastry S.K. (2007). Thermal conductivity of selected liquid foods at elevated pressures up to 700 MPa. Journal of Food Engineering. 83: 444-451.

Reidy G.A. Rippen A.L. (1971). Methods for determining thermal conductivity in foods. Transaction of the. ASAE. 14: 248-254.

Rohsenow W. M., Hartnett J. P. Cho Y. I. (1998). Handbook of heat transfer. 3th ed. Newyork, USA.

Roustapour O.R., Ghobadian B., Khoshtaghaza M.H. Fakhrpour Gh. (2005). Determination of Thermophysical Properties of Lime Juice. Iranian Journal of Agricultural Science. 36(4): 833-848. (in Persian).

Shariaty- Niassar, M., Hozawa M., Tsukada T. (2000). Development of probe for thermal conductivity measurement of food materials under heated and pressurized conditions. Journal of Food Engineering. 43: 133-139.

Singh R.P. (1982). Thermal diffusivity in food processing. Food Technology. 36, 87-91.

Tansakul A., Chaisawang P. (2006). Thermophysical properties of coconut milk. Journal of Food Engineering. 73: 276–280.

Telis- Romero J., Telis V.R.N., Gabas A.L. Yamashita F. (1998). Thermophysical properties of Brazilian orange juice as affected by temperature and water content. Journal of Food Engineering. 38: 27-40.

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