International Journal of Heat and Mass Transfer 78 (2014) 354–359

Contents lists available at ScienceDirect

International Journal of Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ijhmt

Effect of moisture content and temperature on thermal conductivity of *Psidium guajava* L. by line heat source method (transient analysis)

Shiva Kumar Modi [a,*], Durga Prasad B. [b], Basavaraj M. [c]

[a] Department of Mechanical Engineering, RYM Engineering College, Bellary, Karnataka, India
[b] Department of Mechanical Engineering, JNTU College of Engineering, Anantapur, AP, India
[c] Principal, Ballarpur Institute of Technology, Ballarpur, Maharastra, India

ARTICLE INFO

Article history:
Received 13 February 2014
Received in revised form 25 May 2014
Accepted 27 June 2014
Available online 23 July 2014

Keywords:
Guava
Moisture content
Food processing
Temperature
Thermal conductivity
Density

ABSTRACT

Thermal conductivity (K) of *Psidium guajava* L. (guava fruit) cultivar (Rayalaseema area, AP, India) is one of the fundamental importance to establish the design of process equipment. A study on effect of moisture content (MC) and temperature on thermal conductivity (K) of guava fruit are presented. The thermal conductivity is evaluated by transient technique using line heat source method for various MC ranging from 80% to 40% (wb) at two different densities. The analysis reveals that the thermal conductivity of guava fruit increased with increase in moisture content and temperature in the range of 0.1526 to 0.6037 W/m °C. The experimental values were compared with standard (Sweat and Anderson) models and were found in good agreement.

1. Introduction

Guava (*Psidium guajava* L.) fruit is generally ovoid or pear shaped native to Mexico and it is available throughout South America, Europe, Africa and Asia. It also grows in all subtropical areas [1].

Guava is often marketed as "super-fruits" which has a considerable nutritional importance in terms of vitamins A and C with seeds that are rich in omega-3, omega-6 poly-unsaturated fatty acids and especially dietary fiber, riboflavin, as well as in proteins, and mineral salts. The vitamin C in guava makes absorption of vitamin E much more effective in reducing the oxidation of the LDL cholesterol and increasing the (good) HDL cholesterol. The fibers in guavas promote digestion and ease bowel movements. The high content of vitamin A in guava plays an important role in maintaining the quality and health of eye-sight, skin, teeth, bones and the mucus membranes [2]. The anti-oxidant virtue in guavas [3] is believed to help reduce the risk of cancers of the stomach, esophagus, larynx, oral cavity and pancreas.

It has been generally recognized that Thermo-physical properties of biological materials such as food stuffs are dependent on temperature, moisture content and composition. Therefore variability in composition and physical characteristics resulting from variations in soil, climatic conditions, irrigation techniques and fertilizer used would manifest themselves in measured thermo-physical properties [4–6]. Fruits and vegetables at different stages of processing are subjected to thermal treatments in the food industry, understanding their behavior to these thermal processes requires good knowledge of thermal and physical properties. These properties are essential for designing and optimization of every process involving heat transfer at unsteady state such as cooking, frying, and drying and post-harvest heat treatments.

Thermal conductivity is an intrinsic property which measures the ability of a substance to conduct heat. The importance of thermal conductivity is to predict or control the heat flux in food material during processing when energy transfer is involved.

2. Theory

The calculation of heat transfer in foods begins with the identification of three major parameters in heat transfer processes:

1. Thermal properties of the food.
2. Geometry of the food.
3. Thermal Processing conditions.

Methods of measuring thermal conductivity are classified into two categories:

* Corresponding author.
E-mail address: modsheev@gmail.com (S.K. Modi).

http://dx.doi.org/10.1016/j.ijheatmasstransfer.2014.06.076
0017-9310/

Nomenclature

D_1	= density (911 Kg/m^3)	T	= sample temperature (°C)
D_2	= density (1062 kg/m^3)	T_1	= temperature (°C) at time 't_1'(s)
HDL	= High Density Lipoprotein	T_2	= temperature (°C) at time 't_2' (s)
I	= Electric Current (AMP(A))	t	= time (s)
K	= thermal conductivity (W/m °C)	t_0	= time correction factor (s)
K_w	= thermal conductivity of water (W/m °C)	t_1	= time (s) corresponding to temperature (T_1)
K_s	= thermal conductivity of solid (W/m °C)	t_2	= time (s) corresponding to temperature (T_2)
LDL	= low density lipoprotein	wb	= wet bulb
MC	= moisture content (%)		
q	= heat input (W/m)	*Greek symbols*	
r	= radial axis (m)	α	= thermal diffusivity (m^2/s)
R	= electric resistance (Ω m^{-1})		

1. Steady state heat transfer method.
2. Unsteady state (transient) heat transfer method [6].

The steady state heat transfer methods often require a long time to complete and moisture migration may introduce significant measurement errors [7]. The transient methods are most suitable for biological materials that are generally heterogeneous and often contain high moisture content, where the line heat source method is one of the most widely used. Here a bare wire method is used as a heating source, and estimates the thermal conductivity based on relationship between the sample core temperature and the heating time. The rate of heat generated in the wire 'q' W/m:

$$Q = I^2R \tag{1}$$

where
I = electric current in amps (A),
R = electric resistance in Ω m^{-1}.

For a long cylindrical sample, where the end effects and the mass of hot wire can be neglected and when the sample is homogeneous and isotropic, heat conduction in the sample is governed by the equation (cylindrical coordinates)

$$\frac{\partial T}{\partial t} = \alpha\left(\frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r}\right) \tag{2}$$

where
T = is the sample temperature anywhere in the cylinder '°C',
t = time in 's',
r = is the radial axis in 'm',
α = thermal diffusivity in 'm^2/s'.

The solution to the above equation, transient heat flow method developed by Hoopper and Lepper [8] with time correction factor was employed. Sreenarayanan and Chattopadhyay [9] have explained theoretical consideration of the equation used. The modified equation for calculating thermal conductivity incorporating the time correction values is shown in the Eq. (3):

$$K = \frac{q}{4\pi(T_2 - T_1)} \times \ln\left[\frac{t_2 - t_0}{(t_1 - t_0)}\right] \tag{3}$$

where
K = thermal conductivity of the sample (W/m °C)
q = heat input (W/m)
T_1 and T_2 = temperatures in °C at time t_1 and t_2 (s)
t_0 = time correction factor (8.2 s).
t_1 and t_2 = time in seconds corresponding to temp. T_1 and T_2.

The data on thermal conductivity for the food products have been reported in the literature under different conditions of temperature and moisture content by Kostaropoulous [10], Sweat [11] and Dickerson and Read [12]. Not much data were found on fruits/vegetables especially for Exotic tropical fruits such as Guava fruit. Hence, this study was made to investigate the thermal conductivity of fresh and dried fruit in the moisture range of 40–80% (wb) grown in the local area (Rayalaseema, AP, India).

3. Materials

3.1. Sample preparation and moisture content

Fresh, Desiree, ripened and well matured fruits of uniform shape size and color with no apparent damage were procured from the local orchard (Rayalaseema area, AP, India) are washed in clean potable water (the flesh of each fruit was observed to be pink and the central pulp contains seeds) and allowed to equilibrate with room temperature prior to testing.

The moisture content of the fresh samples was found to be 80% (wb) as determined using a standard method AOAC (Association of Official Analysts and Chemists) [13] in a Vacuum oven at 70 °C for 24 h with 03 replicates. To obtain samples with a range of moisture contents 80% to 40% (wb), the samples were dried for various periods in an experimental hot air drier at 55, 60 and 65 °C. The partly dried samples were sealed in a polyethylene film and stored at a constant temperature for 24 h to ensure uniform moisture content throughout the sample.

4. Experimental setup and methodology

4.1. Experimental setup

Schematic representation of line heat source apparatus used for measuring K is shown in Fig. 1 [14].

The bare wire thermal conductivity apparatus consisted of an aluminum cylindrical sample tube of 104 mm length and 28.4 mm inner diameter, with a removable Teflon cover and with a fixed bottom base cover. A chromel resistance heating wire of 33 gauge and a length of 200 mm stretched between copper leads along the axis of cylindrical tube used as line heat source, of which the effective length of heating element inside the test cylinder is 104 mm and the remaining length (96 mm) is used to connect the leads on either sides outside the test cylinder. A constant DC Power supply was used for all the tests. A pre-calibrated T-type 28 gauge iron-constantan thermocouple was installed for measuring the core temperature of the sample in the cylinder. The power input to the line heat source was sufficient to give a measurable temperature difference between the time t_1 and t_2.