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The Influence of Moisture Content and Density on Thermal Conductivity of Ficus Carica Linnaus (Fig Fruit) by Transient Line Heat Source Method

Shiva Kumar Modi, Dr B Durga Prasad, Dr. M Basavaraj
R.Y.M.E.C., Bellary-580104, Karnataka., J.N.T.U.C of Engineering, Anantapur-515002, A. P., Ballarpur Institute of Technology, Ballarpur - 442701, Maharashtra

Abstract:* The effective thermal conductivity of Fig fruit (Ficus carica linnaus) cultivar Rayalaseema area Andhra Pradesh, India, were analyzed by Transient Line Heat Source method at different moisture content (30–70%) wb for two densities. The analysis reveals the thermal conductivity of Fig fruit increased with increase in moisture content in the range of 0.1127 to 0.5678 W/m°C. The experimental values were statistically analyzed and compared with Sweat and Anderson equations. These values were found in good agreement with predicted models. The analyzed data will help to enhance shelf life and better control on both process and product of food industry and researchers.

***Keywords*-Fig fruit, Moisture content, density and Thermal conductivity.**

I. INTRODUCTION

Food is the main source of human beings i.e. grains, fruits, vegetables being biological material in its composition, structure and physical characteristics vary due to season, soil, climate and post harvesting differences etc. Food can be preserved by several methods like Drying or Dehydration and is the oldest method of food preservation practiced by man. Today this is a major contributor to the convenience food market. Commonly used techniques include the lowering of its water activity (i.e. Drying or Dehydration), removal of air/oxygen, removal/inhibition/inactivation of micro-organisms. The main objective of drying food is to prolong its shelf-life beyond that of the fresh material. At the same time minimizes undesirable changes in appearance, texture, flavor, and nutritional value during the drying process. Experimental, commercial and large scale operations associated with preservation of foods is by inactivating microorganisms and removal of moisture content (to a optimum level) usually include thermal processing. Fig (Ficus carica Linaus) belongs to the family Moraceae, native of Southern Arabia is an important fruit group of sub tropical countries. Fig is highly perishable in nature even under refrigerated condition thus nearly all the world production is in the dried form. Basically fresh Fig is rich in vitamin-A, calcium, iron and copper. The nutritive index of Fig fruit is 11 as compared 9 of apple, 8 of date palms, and 6 of pears. The fruit helps to maintain acid alkali balance of the human body, used as blood purifier and also in the treatment of skin infection.

Methods of measuring thermal conductivity can be classified in to two broad categories.

(1) Steady state heat transfer method.
(2) Unsteady state(transient) heat transfer method (Mohsenin N N (1980) [1].

The steady state heat transfer methods often require a long time to complete and moisture migration may introduce significant measurement errors (S K Dutta et al (1988) [2]. The transient methods are most suitable for biological materials that are generally heterogeneous and often contain high moisture content. The line heat source method is the mostly wide used Transient analysis. This method uses either a bare wire or thermal conductivity probe as a heating source, and estimates the thermal conductivity based on relationship between the sample core temperature and the heating time. In principle the heat is generated in a hot wire at a rate q in Watts.

$$Q = I^2R \qquad \text{-------- (1)}$$

Where, I = electric current in amperes,
R = Electric resistance in Ωm^{-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)

$$\partial T/\partial t = \alpha\,(\partial^2 T/\partial r^2 + 1/r\;\partial T/\partial r) \qquad \text{-------- (2)}$$

Where,
T = Sample temperature anywhere in the cylinder ^{0}C
t = Time in s.
r = The radial axis in m.
α = Thermal diffusivity in m^2/s.

The solution to the above (2), Transient heat flow method developed by Hopper and Lepper (1950) [3] with time correction factor was employed. Sreenarayanan and Chattopdyaya (1986) [4] have explained theoretical consideration of the equation used. The modified equation for calculating thermal conductivity incorporating the time correction values is shown in the (3).

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

Where,
K = Thermal conductivity of the sample (W/m^0c).

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q = Heat input (W/m).
T_1 & T_2 = Temperatures in ^{0}C at time t_1 and t_2 in s.
t_0 = Time correction for finite diameter probe (8.2 s).
t_1 & t_2 = Time in seconds corresponding to
Temperatures T_1 and T_2.

The data on thermal conductivity have been reported in the literature under different conditions of temperature and moisture content by Kostaropoulos (1971) [5] Sweat et al (1974) [6] and Dickerson and Read (1968) [7]. No much data were found on fruits/vegetables especially for tropical fruits such as Fig fruit. Hence, this study was made to investigate the thermal conductivity of fresh and dried fruit in the moisture range of 30–70% (wb) grown in the local area (Rayalaseema, AP, India).

II. MATERIALS

Sample preparation and moisture content: Fresh and well ripened Fig fruit of local cultivars (Rayalaseema area of AP, India) of uniform shape, size with no or minimum defects were procured, washed in a clean potable water and mashed in to paste form (pulp & peel as sample). All the test samples were well equilibrated to the testing conditions prior to the testing. The moisture content of the fresh samples was found to be 70% (wb) as determined using a standard method AOAC (Association of Official Analysts and Chemists) [8] in a Vacuum oven at 70^{0}C for 24 hrs with 05 replicates. To obtain samples with a range of moisture contents 30-70% (wb), the samples were dried for various periods in an Experimental hot air drier at 55, 65 and 75^{0}C. The partly dried samples were sealed in a polyethylene film and stored at a constant temperature (30^{0}C) for 24 hours to ensure uniform moisture content throughout the sample.

III. EXPERIMENTAL SET UP

The schematic diagram of experimental setup is shown in the Fig.1.[9]

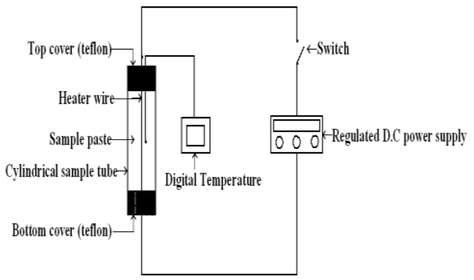

Fig.1 Schematic of the Apparatus used for measuring Thermal Conductivity.

The samples were held in a long aluminum cylinder with 28.4mm diameter. A 200 mm long, 33 gauge chromel wire stretched between copper leads along the axis of the cylinder was used as line heat source. The power input to the line heat source was sufficient to give a measurable temperature difference between the times t_1 and t_2. A constant DC power supply was used for all tests. A 28 gauge copper constantan thermocouple was used to measure the temperature rise of the heat source.

III. METHODOLOGY

A known mass and size of sample of defined moisture content was filled in the test cylinder. The open end of the cylinder was sealed with a polyethylene foil before the cover was placed to prevent moisture evaporation. The temperature of the sample and the ambient temperature were noted. When the sample reached uniform ambient temperature, the current was switched on and stop watch started simultaneously. The temperature observed by the thermocouple was noted at an interval of 30 s upto 20 min. The current was determined to an accuracy of 0.01 amps by measuring the voltage across a standard resistor using the digital volt meter. The thermal conductivity values were determined as per (3). The moisture content of the sample was determined before and after the test to evaluate any change during the test. It was found that there was no considerable change in the moisture content during the test. Predicted Model: Sweat (1974) [10] proposed modeling of thermal conductivity (4) to calculate the thermal conductivity of unknown food product.

$$K = 0.148 + 0.00493\,M \qquad \text{-------- (4)}$$

Where, M = Moisture content of the material in (wb).

Anderson S A (1950) [11] proposed the following empirical relationship to calculate thermal conductivity of unknown food product.

$$K = M\,K_w + (1 - M)K_s \qquad \text{-------- (5)}$$

Where,
K = Thermal conductivity of unknown material (W/m^{o}C)
K_w = Thermal conductivity of Water, 0.614 W/m^{o}C.
K_s = Thermal conductivity of Solids, 0.2597 W/m^{o}C.
M = Moisture content of material in decimal.

IV. RESULTS AND DISCUSSION

Experiments were conducted to determine the thermal conductivity of Fig fruit at a different instant of time, temperature and density with the moisture content ranging from 30 to 70% (wb). The Variation of thermal conductivity of Fig fruit at different instant of time in the range of 30-70% (wb) moisture content for a density of 911 kg/m^3 is shown in Fig.2.

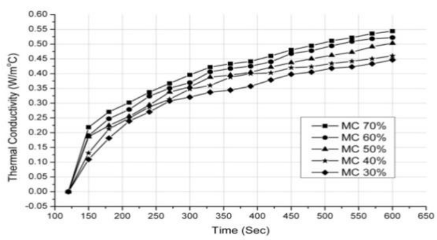

Fig.2 Variation of Thermal conductivity Vs Time for various moisture content (for density of 911 Kg/m^3).

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Moisture content below 50% wb is considered as lower moisture sample and above 50% wb are considered as higher moisture samples. Since readings are taken with fixed time, lower time means low temperature and higher time means high temperature. It is observed that at all the moisture contents the thermal conductivity of Fig fruit increases with time. At lower moisture levels the thermal conductivity relatively decreases with increase in time or temperature. This is because as the moisture evaporates the sample shrinks and the rate of shrinkage in the initial stage of drying is more. It is observed that thermal conductivity values increases with increase in moisture content because of high moisture content. At a particular time the thermal conductivity increases with increase in moisture content in the initial stage because the surface of the sample is wet and gradually increases and almost reaches steady stage at the final stage. Fig.3 shows the variation of thermal conductivity of Fig fruit (Density 911 Kg/m^3) in the moisture range of 30-70% wb at different timings.

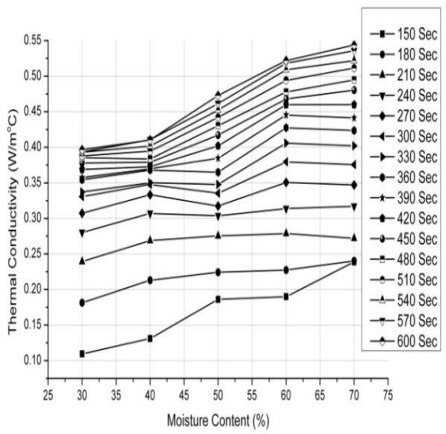

Fig.3 Variation of thermal conductivity Vs Moisture content at different time (for density of 911 Kg/m^3).

It can be observed that Thermal conductivity was high at high moisture content and values decrease slightly at 50% wb moisture content towards lower range of moisture content. This may be due to non homogeneity and composition of the sample and also due to surface moisture evaporated causing the case hardening of the surface with effect of temperature at 50% wb on thermal conductivity values. Therefore the lines were parallel at different temperature indicating the independent variation of thermal conductivity with moisture and temperature at that particular point. The reduction in Thermal conductivity values in the initial stage of drying/heating may be due to surface moisture being evaporated faster causing the case hardening of the surface which is a bad conductor hence reduces the rate of heat transfer and the thermal conductivity values. The Variation of thermal conductivity of Fig fruit at different instant of time in the range of 30-70% wb moisture content for a density of 1062 kg/m3 is shown in the Fig.4.

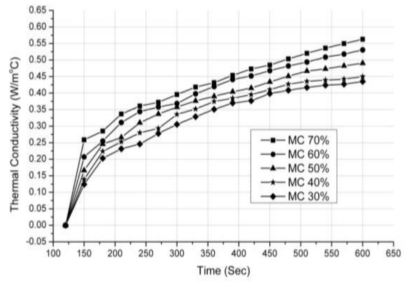

Fig.4 Variation of thermal Conductivity Vs Time for various moisture content (for density of 1062Kg/m^3).

It is observed that at higher moisture content say 50% - 70% wb thermal conductivity values lie in the range of 0.2042 to 0.490 W/moC , and 0.2543 to 0.5678 W/moC resulting in increase in thermal conductivity values. This is because high density and moisture content present in the sample has by far greater influence on the increase of thermal conductivity values [12]. Similarly at lower moisture content 30% wb the thermal conductivity lies in the range of 0.1239 to 0.4352 W/moC. This may be due to low density which apparently reduces the thermal conductivity because of void spaces present due to non homogeneity of the samples. Comparing the Fig.2 and Fig.4 it is observed that for a particular time and for all moisture content the thermal conductivity values increases with increase in density of the sample. The linear characteristic of the curve shows that there is no vapor diffusion and increase of thermal conductivity with moisture content is caused by heat conduction of moisture present in the sample. Therefore the lines are parallel to each other at different time/ temperature indicating the independent variation of thermal conductivity with moisture and temperature Fig.5 shows the variation of thermal conductivity of Fig fruit (Density 1062 Kg/m3) in the moisture range of 30-70% wb at different timings.

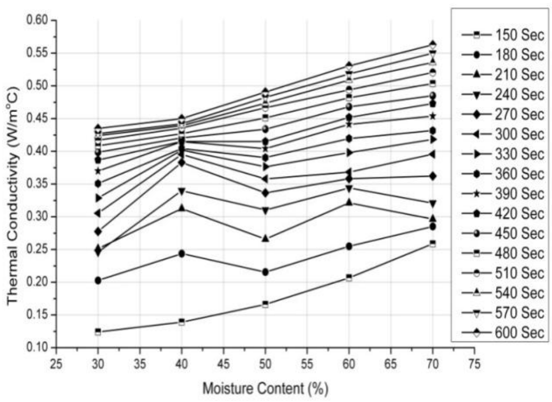

Fig .5 Variation of thermal conductivity Vs Moisture content at different time (for density of 1062 Kg/m^3).

It is observed that thermal conductivity increases with increase in moisture content, and for a particular moisture content in the initial period of drying the thermal conductivity increases because the surface is being wet.

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The value of thermal conductivity is also more for higher density i.e., 0.5678 W/m^{0}C. The variation of thermal conductivity of Fig fruit with time at different densities at 70% moisture content is shown in the Fig.6.

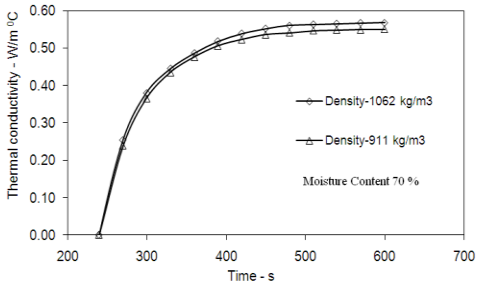

Fig.6 variation of thermal conductivity of Fig fruit Vs time at different densities at 70% moisture content.

It is also observed that at different bulk densities of 70% wb moisture content thermal conductivity values increases with increase in temperature/time and corresponding increase in density as shown in Fig.6.

V. CONCLUSION

It is observed that thermal conductivity increases with increase in moisture content because higher the moisture content greater the water particles and hence conduction heat transfer in the sample. The thermal conductivity also increases with increase in density due to higher thermal contact between particle structures of the sample and also structure is nonporous with fewer voids. This indicates that thermal conductivity is not merely a function of physical properties like density, temperature and moisture content but also is a function of physical structure of food sample [13].

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