Experimental investigation on thermal conductivity of muskmelon (cucumis melo) as a function of moisture content and density by transient analysis

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***Abstract*----Food is the main source of energy for all living organisms on earth. All food sources need some sort of preservation in order to reduce or to stop spoilage, to maintain the desired nutritional values. Muskmelon is one such fruit with high nutritional properties. In order to design equipment and facilities for drying, preservation and processing of muskmelon. The knowledge of its thermal properties is very essential. Therefore in this study the effective thermal conductivity of Muskmelon (Cucumis melo) cultivator Ballari area, Karnataka, India were analyzed by Transient line heat source method at different moisture content (40% to 90%)wb for two different densities. The analysis reveals that the thermal conductivity of Musk melon increased with increase in Moisture content in the range of 0.4403W/m^{0}C&0.5955W/m^{0}C .The Experimental values obtained were statistically analyzed &compared with Sweat & Anderson equations .These values were found in good agreement with the predicted models. The analyzed data will help to develop preservation techniques, enhance shelf life and better control on both process and product of food industry and researchers.**

***Key words*---Musk Melon, Drying, Moisture content, Density, thermal Conductivity, Line heat source.**

I. INTRODUCTION

All living organisms on earth need food in order to get energy. There are two main sources of food plants and animals. These food sources are categorized as perishable (which spoils very fast), non-perishable (relatively slower spoilage), harvested food, raw food, and fresh food, formulated food, synthetic food and recently popularized functional food. These sources of foods in our day to day needs some way of preservation in order to reduce spoilage. Nearly 1.3 billion tons of food is lost annually due to lack of proper processing which is one third of global food production. [17]

Some commonly effective methods for food preservation are Freezing, Vacuum Packing, Canning, Dehydration or Drying. Drying or Dehydration is the oldest method of food preservation practiced by man. Drying involves elimination of water by application of heat. 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 to minimize 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.[18].

Muskmelon (Cucumismelo) is a species of melon that has been developed into many cultivated varieties. These include smooth- skinned varieties such as honeydew, Crenshaw, casaba& different netted cultivators (Cantaloupe, Persian melon, & Santa Claus or Christmas melon).Musk melon is a warm season crop it is very sensitive to cold temperatures & requires a fairly long growing season from seed to marketable fruit. Muskmelon is low in calories and high in skin-boosting, eye-strengthening Vitamin A, Soothes the digestive system, Muskmelons also help relieve symptoms of acidity, indigestion and other stomach ailments, Helps relieve constipation Controls your blood pressure Muskmelon acts as a powerful diuretic agent it helps to combat kidney diseases and also keeps the kidneys in good health, is storehouse of antioxidants beta-carotene, folic acid, potassium and vitamin C and vitamin A .
Methods of measuring thermal conductivity can be classified in to two broad categories. [15]
(1) Steady state heat transfer method.
(2) Unsteady state (transient) heat transfer method

The steady state heat transfer requires very long time to complete & significant measurement errors are induced due to moisture migration. [16]
The transient method of measurement is most suitable for biological materials which are generally heterogeneous & contain high moisture content. The most widely used transient analysis is line heat source method. This method uses either a thermal conductivity probe or a bare wire as a heating source and estimates thermal conductivity based on relationship between sample core temperature and the heating time.

The heat generated in a hot wire is expressed in terms of q in watts

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

Where,
I= Electric current in amperes
R=Electric resistance in ohms (Ω)

The modified equation for finding thermal conductivity including the time correction values is

$$K = \frac{q}{4\pi(T2-T1)}\, x\, ln\left[\frac{t2-t0}{t1-t0}\right] \text{------------------------} (2)$$

Where,
K = thermal conductivity of sample in (W/m^{0}c)
q = Heat input (W/m)
T_1& T_2 = Temperature in ^{0}C at t_1& t_2 in seconds
t_0 = Time correction factor for finite diameter probe (8.2 sec)
t_1& t_2 = Time in seconds corresponding to temperatures T_1 and T2

The data on Thermal conductivity have been reported in literature under different conditions of temperature and moisture content by L. E. Kurozawaet.al [2] ,Shiva Kumar Modi et.al (2013) [3], Akbar Akbarnejad et.al (2015) [11].No much data were found on fruits /vegetables especially for tropical fruits such as Musk melon. Hence this study was made to investigate the thermal conductivity of fresh and dried fruit in the moisture range of 40 – 90% (wb) grown in local area (Ballari,KA, India).

II. MATERIALS

i) Sample Preparation and Moisture Content

The samples for testing purpose were prepared from fresh and well ripened Musk melon fruit*(CUCUMIS MELO*) procured from local markets, special care was taken to procure musk melon fruit of uniform shape & size, with no or minimum defects. The fruit was washed in clean potable water. After cleaning the fruit the external layer of the fruit was peeled off by a knife. Then the fruit was cut into halves, then into small pieces, and then the muskmelon pieces were mashed into paste form (pulp as sample). In order to suit to the testing conditions, all fruit samples were equilibrated to the initial condition before testing. The moisture content of the samples was found to be 90 %(wb), the moisture was determined by using a standard method AOAC (Association of official analysts &Chemist) in a vacuum oven at a temperature of 70^{0}Cfor 24 hours with 05 replicates. To obtain samples with a wide range of moisture contents 40 -90 %(wb) the samples were dried in experimental hot air dryer at 55and 65^{0}C.The partly dried samples were sealed in polythene film & stored for 24 hrs at a constant temperature 30^{0}C to ensure uniform moisture content throughout the sample. After drying of samples in a dryer the thermal conductivity of the samples were tested by hot wire probe method.

III. EXPERIMENTAL SET UP

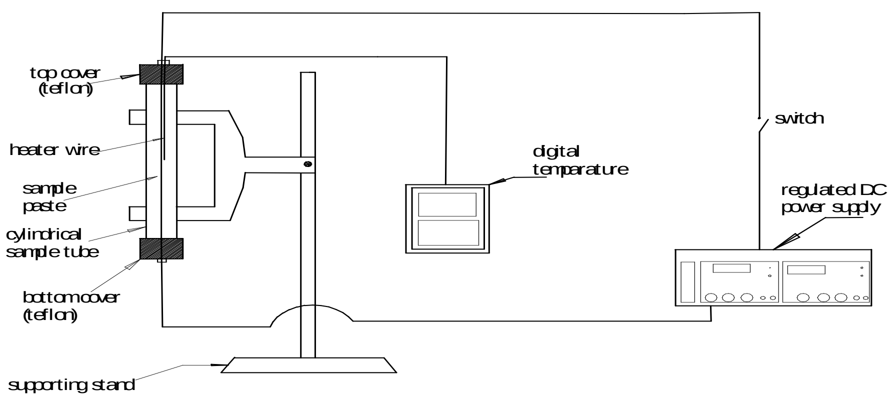


Fig.1 Schematic diagram of apparatus used for measurement of thermal conductivity.

The set up consists of a Aluminum cylinder being held in a supporting stand, A display to show the digital temperature readings, A regulated power supply, An ignition switch & suitable wiring connections. The Samples were held in a long Aluminum cylinder of 28.4mm diameter .A 33 gauge chromel wire of 200 long is stretched between copper leads along the axis of the cylinder is used as a line heat source. A constant DC power supply was used for all tests. 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 28 gauge copper constantan thermocouple is used to measure the temperature rise of heat source.

IV. METHODOLOGY

A known mass & size of sample of define moisture content was filled in the cylinder. To prevent moisture evaporation the open end of the cylinder was sealed with a polyethylene foil after that a Teflon cover is placed to hold the polyethylene foil tightly.

The temperature of the sample and the ambient temperature were noted. When the sample reached the uniform ambient temperature the current was switched 'ON 'and the stop watch started simultaneously. The temperature absorbed by the thermocouple was noted at an interval of 30seconds. The readings were up to 20 minutes. The current was determined to an accuracy of 0.01 amps by measuring a voltage across a standard resistor using a digital voltmeter. The moisture content of the sample was determined before & 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:

1) Sweat (1974) [19] proposed modeling of thermal conductivity to calculate the thermal conductivity of unknown food product.

$$K = 0.148 + 0.00493\ M \text{------------ (3)}$$

2) Anderson S A (1950) [20] proposed the following equation to calculate thermal conductivity of unknown food product.

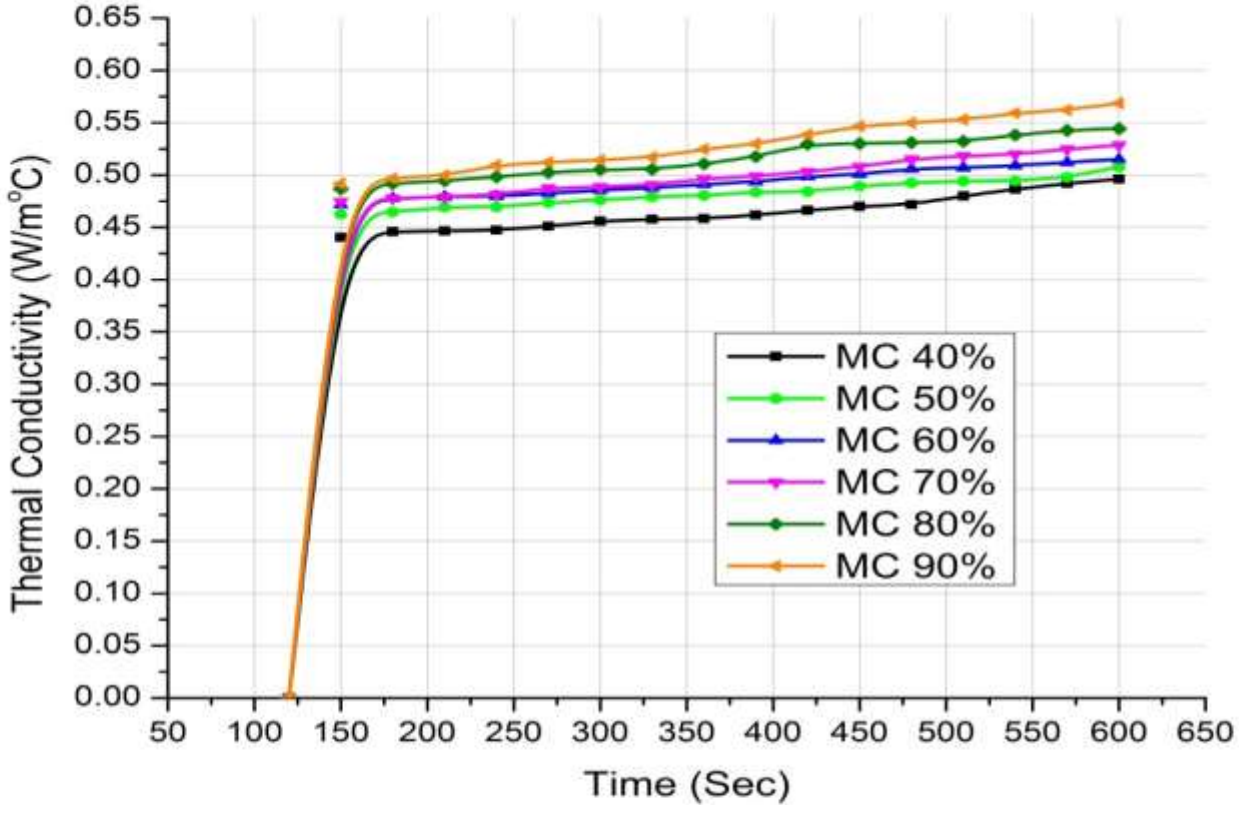
$$K = M\ K_W + (1\text{-}M)\ K_s \text{-------------- (4)}$$

Where,
K= thermal conductivity of unknown material (W/m^{0}c)
K_W = thermal conductivity of water, 0.614 W/m^{0}c
K_s = thermal conductivity of solids, 0.2597 W/m^{0}c
M = Moisture content of material in decimal

V. RESULTS AND DISCUSSION

Experiments were conducted to determine the thermal conductivity of Musk melon fruit (Cucumis melo) at a different instant of time, temperature, density and moisture content ranging from 40% to 90% (wb) .

1. Variation of Thermal conductivity at different instances of time for various Moisture content for a density of 911kg/m^3

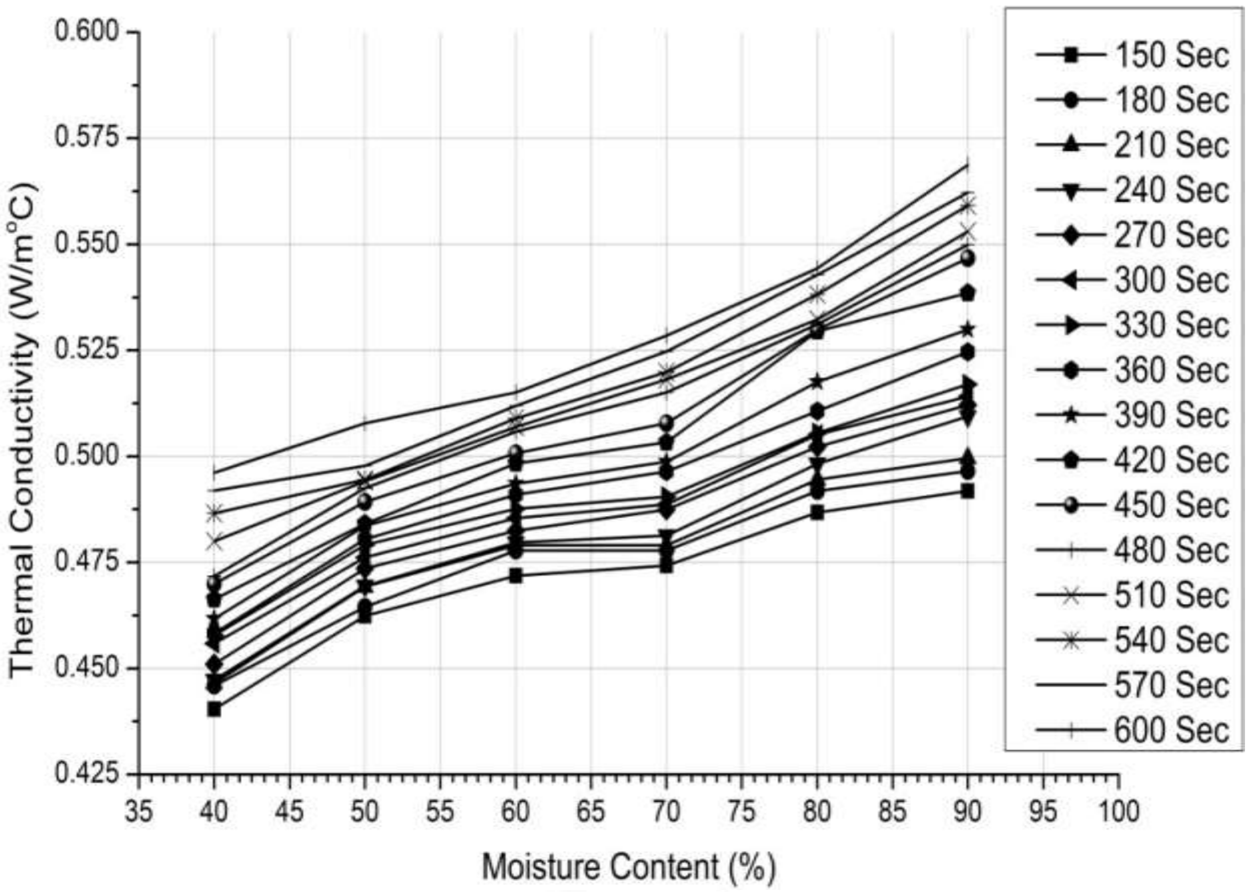


Graph 1. Variation of Thermal conductivity Vs Time for various Moisture content
(For a density of 911kg/m^3)

Moisture content below 60% wb is considered as lower moisture samples and above 60% wb are considered as higher moisture samples. Since readings are taken at fixed time higher time means higher temperature and lower time means lower temperature. From Graph1 it is observed that at all moisture contents the thermal conductivity of muskmelon fruit increases with time/temperature. In case of lower moisture samples the increase in thermal conductivity with time is when compared with higher moisture samples, this may be due to low amount of moisture present.

It is also observed that the thermal conductivity value increases with increase in moisture content this is due to high moisture content. At a particular point of time it is observed that the thermal conductivity increases with increase in Moisture content during the initial stage this is because the surface of sample is wet, then thermal conductivity increases gradually & reaches almost steady state at the final stage.

2. Variation of Thermal conductivity in the moisture range of 40% to 90% wb at different timings for a density of 911kg/m^3

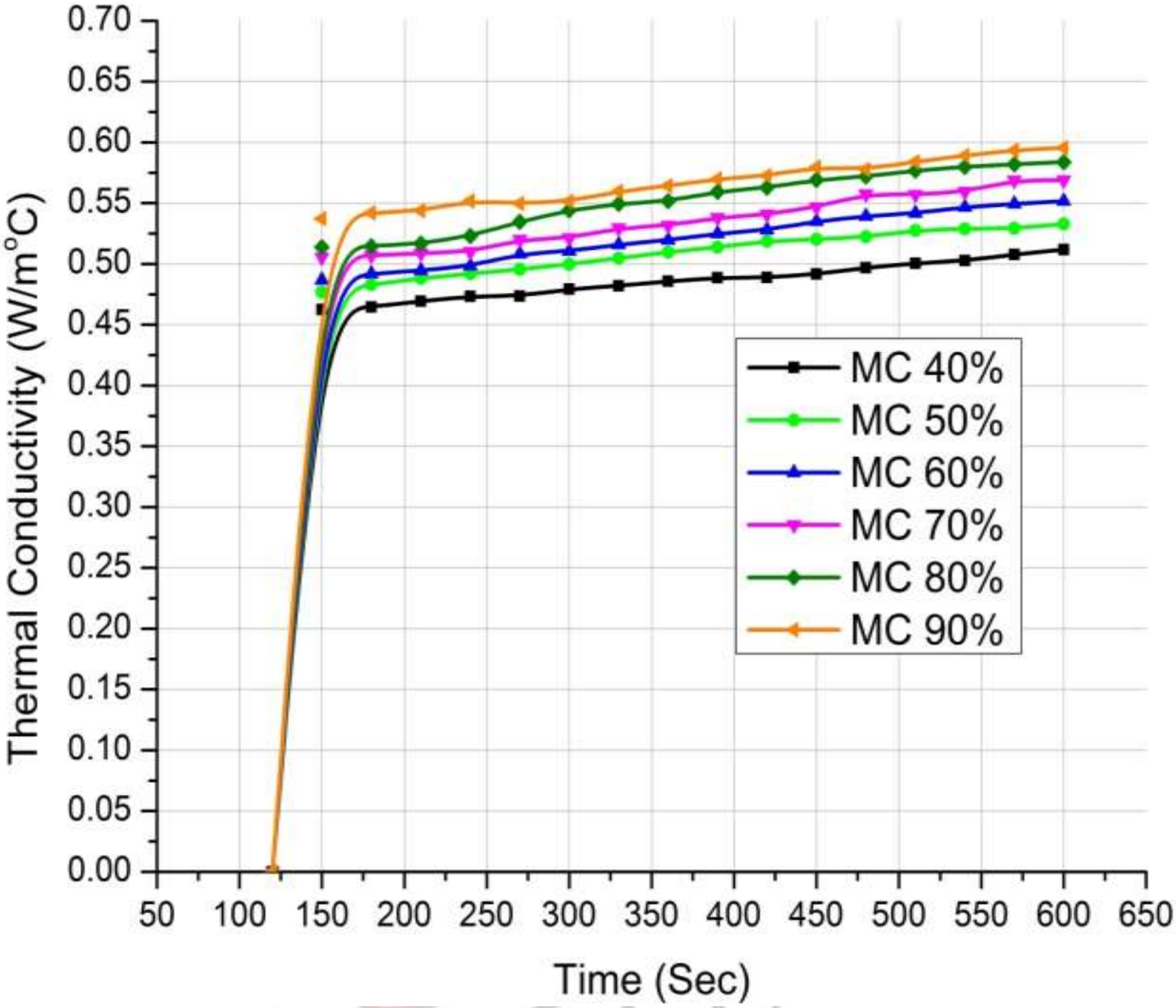


Graph 2. Variation of Thermal conductivity Vs moisture range at different timings
(For a density of 911kg/m^3)

It can be observed from graph 2 that the Thermal conductivity is high at high moisture content and the Thermal conductivity values decreases slightly at 70% wb moisture content towards lower range of moisture content. This may be due non- homogeneity and composition of the sample as the moisture on the surface of sample has evaporated causing case hardening of the surface, with effect of temperature at 70% wb on Thermal conductivity values . Hence the lines are parallel at different temperature showing that the Thermal conductivity varies independently with temperature and moisture content, at particular point.

The reduction in thermal conductivity values may be due surface moisture being evaporated faster causing case hardening of the surface which is a bad conductor. Therefore reduces the heat transfer and Thermal conductivity values.

3. Variation of Thermal conductivity at different instances of time for various Moisture content for a density of 1062kg/m^3



Graph 3. Variation of Thermal conductivity Vs Time for various Moisture content
(For a density of 1062kg/m^3)

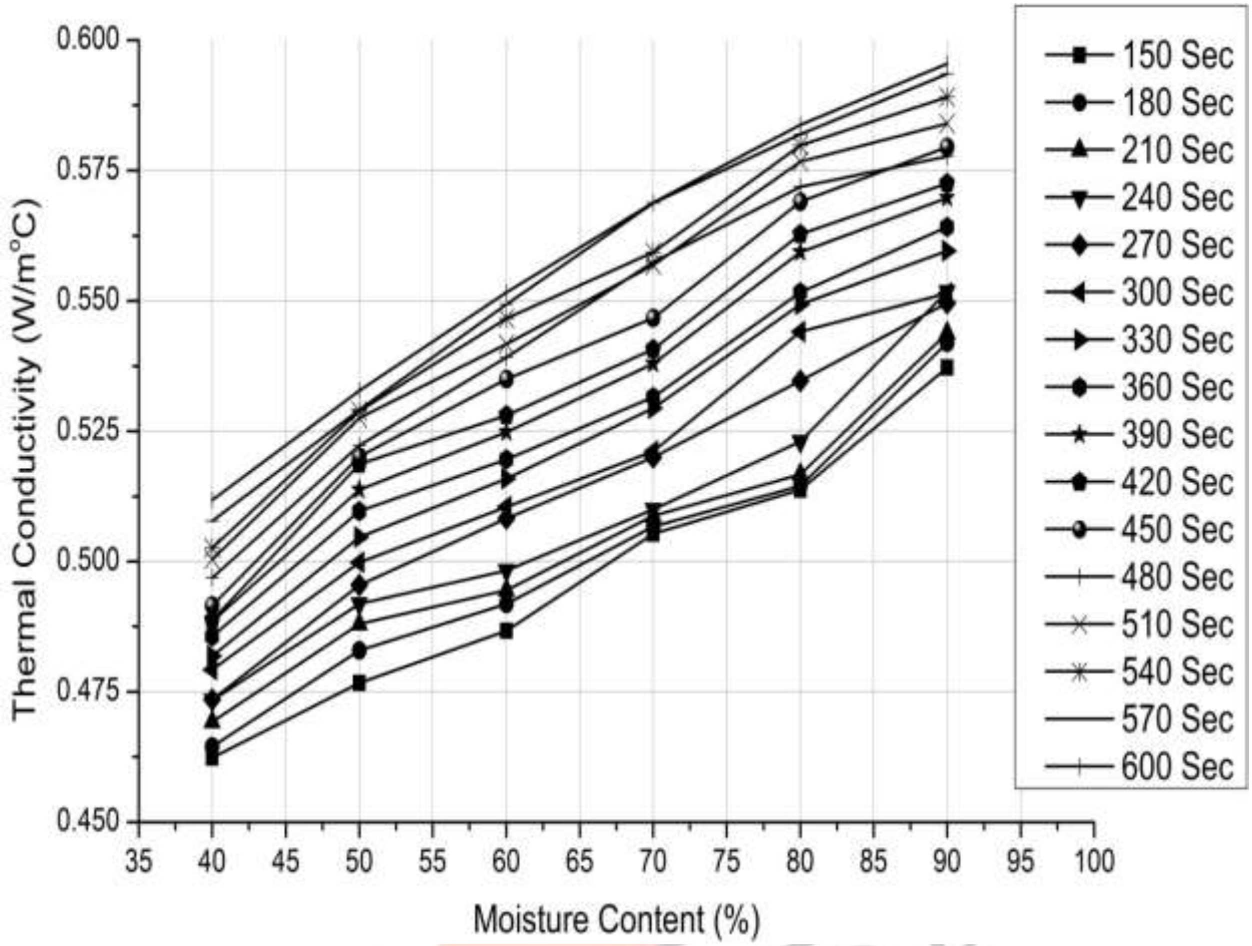
It is observed that at a higher moisture content 80% to 90% wb the Thermal conductivity values are in the range of 0.51379 to 0.58375 W/m^{0}C and 0.53723 to 0.5955 W/m^{0}C, resulting in increase in thermal conductivity values. This may be due to high density and moisture content present in the sample plays a significant role in increasing thermal conductor values.

Correspondingly at a lower MC say 40% the thermal conductivity values lies in the range of 0.46241 to 0.5118 W/m^{0}C. This may be due to low density which reduces the thermal conductivity due void spaces present due to non-homogeneity of material.

By comparing the graph 1 and graph 3, it can be observed that for a particular time and for all moisture content the thermal conductivity increases with increase in density of sample.

The curves show that increase in thermal conductivity with moisture content due to heat conduction of moisture present in sample. Also the lines are almost parallel this shows the independent variation thermal Conductivity with moisture content & temperature.

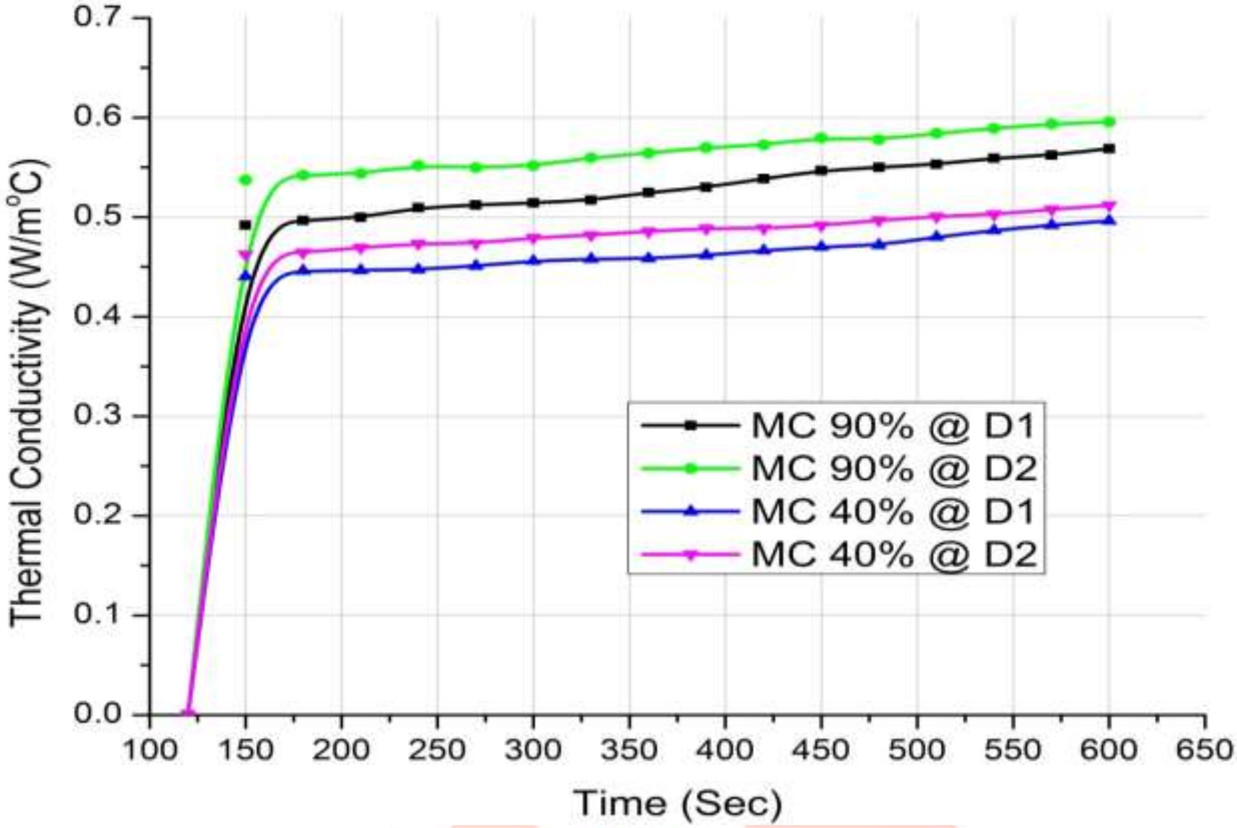
4. Variation of Thermal conductivity in the moisture range of 40% to 90% wb at different timings for a density of 1062kg/m^3



Graph 4. Variation of Thermal conductivity Vs moisture range at different timings
(For a density of 1062kg/m^3)

From the nature of graph 5.5 it is observed that the thermal conductivity increases with increase in Moisture content. This may be due to wet surface of sample during initial period of drying which facilitates transfer of heat. The thermal conductivity value is also more for higher density i.e. 0.5955W/m^{0}C . This may be due to higher thermal contact between particles structure and non-porosity of structure.

5. Variation of Thermal conductivity of Musk melon Vs time for different densities (i.e. 961 kg/m^3 & 1062 kg/m^3) at moisture content of 40% and 90% wb



Graph 5. Variation of Thermal conductivity of Musk melon Vs time for different densities (i.e. 961 kg/m^3 &1062 kg/m^3) and moisture content of 40% and 90% wb

It is observed from graph 5.7 the Thermal conductivity value is higher for sample of higher moisture content and high density (i.e. MC 90% wb& density (D2) 1062kg/m^3). Next the thermal conductivity value decreases for the sample of same 90% wb moisture but low density (D1) 961kg/m^3. By this we can tell that density has more effect on thermal conductivity than moisture content, this may be due to dense structure of sample i.e. sample structure is non-porous with smaller amount of void.

VI. CONCLUSION

Experiment is carried out to determine the thermal conductivity of Musk melon (Cucumis melo) at various Moisture contents (40% to 90% wb), densities and at different instances of time. The technique adopted for the test is Transient line heat source method. The following conclusions can be drawn from this project work

i) It is observed that the thermal conductivity value is higher for samples of higher moisture content as shown in graph 1 and 3

Thermal conductivity value for 90% Moisture content = 0.567W/m^{0}C

Thermal conductivity value for 40% Moisture content =0.49617 W/m^{0}C

By this we can conclude that thermal conductivity increase with increase in moisture content, because higher the Moisture content greater the water particles & hence conduction heat transfer occurs in the sample.

ii) It is also observed that at same moisture content the thermal conductivity Value is higher for sample of higher density as shown in graph 5

Thermal conductivity value for moisture content of 90% & density (D2) 1062kg/m^3= 0.5955 W/m^{0}C

Thermal conductivity value for moisture content of 90% & density (D1) 961kg/m^3 = 0.5687 W/m^{0}C

Hence we can conclude that with increase in density, thermal conductivity also increases, this is due to higher thermal contact between particles structure of the sample and also due to non-porosity of structure.

Therefore the above conclusions indicates that thermal conductivity is not merely a function of physical properties like density , temperature , Moisture content , but it is also a function physical structure of food sample.

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