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INVESTIGATION OF HEAT TRANSFER FOR SPHERICAL PERISHABLE FRUITS

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Abstract Food products of perishable nature need to be preserved from spoilage using some precooling techniques. Precooling is the process of cooling fruits and vegetables after harvest and prior to transportations over long distance to a cold storage for distribution. The present work is an attempt to investigate experimentally the heat transfer behaviour during precooling of fruits and vegetables in rectangular duct under forced convection. In the experimental study done on rectangular duct, the items being investigated are apple and sapodilla. Forced air cooling is achieved by suspending the food inside a 4 meter long rectangular air duct of 0.3×3 meter section of Galvanized Iron Sheet which is insulated with 1 cm thick puff sheet. The humidity inside the duct is to be maintained constant. The temperatures of the cold air outside package and of the food product at different location inside the package are to be measured at regular time intervals. The air is circulated through the duct by means of a blower powered by 1.5 H.P. Electric motor. The air is then made to pass through a coil. This coil is the evaporator coil of 5 ton capacity vapour compression plant. The test programs were performed on two types of fruits, apple and sapodilla. The air velocity, V=2.5 m/s was selected to examine the effects of cool air velocity on the cooling process. The temperature was monitor at three locations (surface, middle and centre) for apple and sapodilla. In the present study a heat transfer coefficient has been obtained based on the transient temperature measurement techniques. Two instances are used for determining the surface heat transfer coefficient for low Biot Number and large Biot number respectively. It has been shown that the dimensionless temperature of apple and sapodilla decreases exponentially with the time. High reduction in temperature happened during the first 30 minutes followed by lower rate of temperature drop for the remaining time.

Index terms: Physiological, Spoilage , Perishable , Galvanized Iron sheet.

1. Introduction

Fruits and vegetables are highly perishable products. In developing countries, like India, each year up to 25 to 30% of the most perishable fruits and vegetables are(1)(2) lost due to spoilage, physiological decay, water loss, and mechanical damage during harvesting, packaging and transporting, or due to transportation.(3) These losses have been estimated to be more than 40 to 50% in the tropics and subtropics. Post-harvest losses of fruits and vegetables in developing countries is therefore of serious concern. (4) Moreover, in many developing countries only a limited quantity of fruit and vegetable products are produced for local markets or for exportation due to lack of machinery and infrastructure. Reduction of high wastage of fruits and vegetables requires various measures to be adopted to minimize these post-harvest losses.(5) Proper handling, storage, packaging and processing of fresh produce (fruits and vegetables) improves storage characteristics and shelf life.(6)(7) For many decades, refrigeration industry has found its significant application in the preservation of food and perishable products(8) like fruits and vegetables, meat, canned products through storage at lower temperature. (9) Harvested agricultural products are subjected to ‘precooling’ before packaging and transportation.(10) Precooling involves placing field temperature (warm) containers of produce in a cold room before packaging and processing to reduce bacteria and delay enzymatic activities. (11)

Precooling is the procedure of quick cooling of an item after harvesting, previously or in the wake of packaging before it is put away or moved to avoid deterioration of the more perishable vegetables.(12) Fruits and vegetables are precooled preceding transport, stockpiling, or further handling so as to expel the underlying field heat from the fresh produce(13) and furthermore to lessen the refrigeration load on ensuing stockpiling and transport.(14)

In the present study, to investigate experimentally the heat transfer behaviour during precooling of fruits and vegetables in rectangular duct under forced convection. In the experimental study done on rectangular duct, the items being investigated are apple and sapodilla.

Most of the work available in literature concerns with meat products.(15) Thermal properties of a very few fruits and vegetables are available in literature. The objective of this work is to device a simple method to determine the thermal diffusivity of selected food products as a function of surface temperature of the product.

2. Material and method

2.1Experimental setup

The present work is an attempt to investigate experimentally the heat transfer behaviour during precooling of fruits and vegetables in rectangular duct under forced convection. In the experimental study done on rectangular duct, the items being investigated are apple and sapodilla

Experimental set up consist of Air Duct, Blower, Electric Motor, Pully-Belt Arrangement, R-134 Evaporator Cooling Coil, Chilled Water Cooling Coil, Compressor, Air-Cooled Condenser, Water – Cooled Condenser, Receiver, Sight Glass, Expansion Valves, 13. Chillers, Cooling Tower, Condenser Pump, Chiller Pump, Test Section, Food Package, Thermocouples, Anemometer, Digital Multimeter, Dampers.

2.2. Methodology

2.2.1. Measurement of Temperature

The temperature at the centre, middle and surface temperature of the fruits were measure with the help of 28 SWG copper- constant thermocouples. The lead wires of all the thermocouples were connected with a selector switch and the temperature indicator. The temperature and humidity of air circulating in the duct surrounding the fruits were measured with the help of digital multimeter and in the same time temperature for cold air measured by thermometer and compared with the temperature data from multimeter.

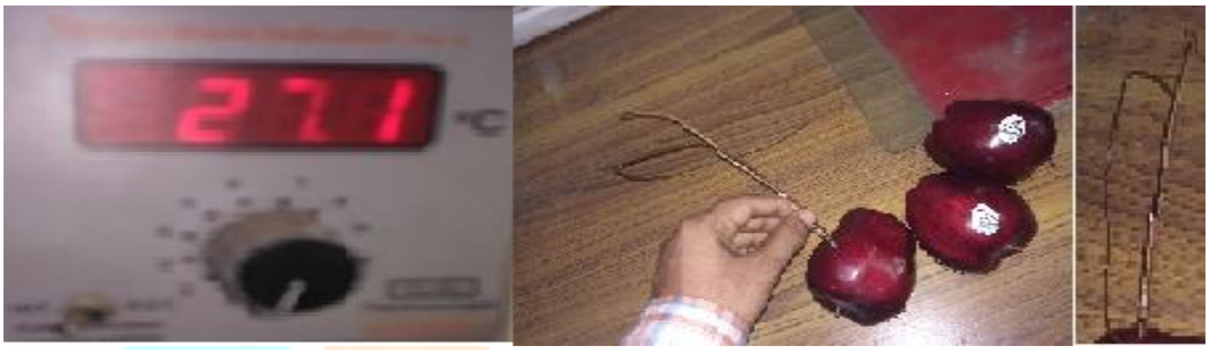

Fig 1. Measurement of temperature

2.2.2. Measurement of Air Stream Velocity

The air-stream velocity in the cooling duct was measured with an anemometer.

2.2.3. Measurement of Relative Humidity of Air

Relative humidity of air was measured by using Hygrometer and multimeter.

2.2.4. Measurement of Refrigeration System Pressure

The suction and discharge pressure of compressor measured by Borden Gauge.

2.2.5. Experimental Procedure for Apples and sapodilla

The cooling plant along with air blower was run for about 2 hours so that the temperature and relative humidity of the circulating air were changed, and the rate of change temperature and humidity of the air circulating depend on the velocity of blower, and the velocity was changed by using different size pulley arrangement, when the pulley diameter 10 cm gives air velocity 2.5 m/s. The approach air velocity inside the duct was measured with the help of anemometer. The apples and sapodilla used for cooling were placed in the wire mesh test chamber in the duct separately. The temperature inside the fruits were measured with the help of thermocouples were used three thermocouples for apples and sapodilla the probes were fixed in different place on the distance(R=0) were measured surface temperature at apples, when thermocouples probes were fixed on the distance (R=d/2) were measured centre temperature of apples and sapodilla when the thermocouples probes were fixed on the distance (R=d/4) were measured middle temperature of apples and sapodilla separately. At the same time surrounding air temperature was measured with the help of multimeter and thermometer interval of 5 minutes during cooling process. The temperature values at different air flow rates were recorded. Cooling curves were drawn for apples based upon the temperature data obtained.

Determination of heat transfer coefficient

Initial and boundary condition

Nusselt-reynolds correlation

3. Result and discussion

The results of the studies on the precooling of perishable food viz. apples and sapodillas are discussed below:

3.1. Cooling curves

Fig. 1. to 11. are drawn, taking time in X- direction and the dimensionless temperature in Y direction. These curves are drawn with the help of SIGMA PLOT. Cooling curves are drawn for apple and sapodilla for three radial positions i.e. geometric centre, half radius and surface. The air velocity blown over apple and sapodilla was 2.5 m/s. It has been observed that the temperature of apple and sapodilla was exponentially with cooling time. The initial rate of fall in the centre, middle and surface temperatures of apples and sapodilla is high.

3.2. Cooling of Apples

Fig. 2. represents the variation of dimensionless temperature (at Centre, middle and surface) with time under air velocity of 2.5 m/s. It has been observed from this graph that the centre, middle and surface temperature of apple decrease with exponentially with time.

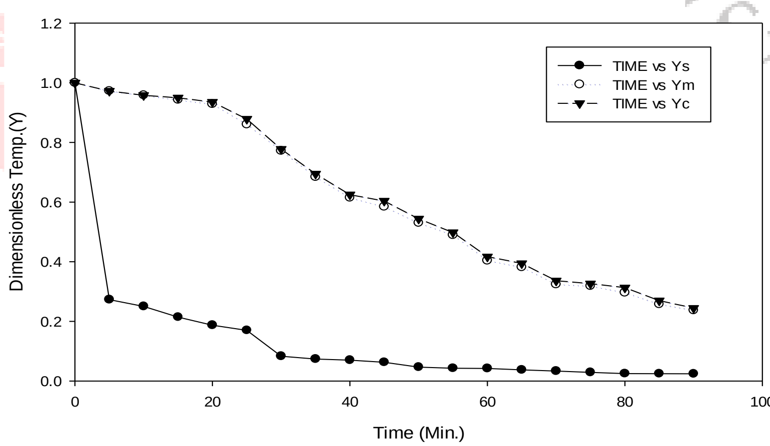

Fig2. Dimensionless Temperature-Time Graph for Apple

(k=0.531 W/m.K, $\alpha=1.295\times10^{-7}$ m^2/s, d=0.07 m. Ti=19^0C, Ta=-5.9^0C)

Fig. 2. It is clear that surface of apple cools faster than middle and centre. During first 30 minutes of time the drop in dimensionless temperature, at surface middle and centre are 0.80, 0.76 and 0.77 respectively. For the next 30 minutes i.e. during 30 to 60 minutes, the drop observed are 0.50,0.4 and 0.42 which are 62.5 %, 52.63 % and 54.55% of the initial drops, respectively and during 60 to 90 minutes, the drops observed are 0.02, 0.23 and 0.25 which are 25 %, 30.26 and 32.5 % of the initial drops, respectively.

Fig.3. Represents the variation of dimensionless temperature at centre with time under air velocity of 2.5 m/s. From fig. 6.2 during first 30 minutes of time the drop in dimensionless centre temperature is 0.77. For the next 30 minutes i.e. during 30 to 60 minutes, the drop observed is 0.42, which is 55% of initial drop as said above and during 60 to 90 minutes drop observed is only 0.25, which is 33 % of initial drop.

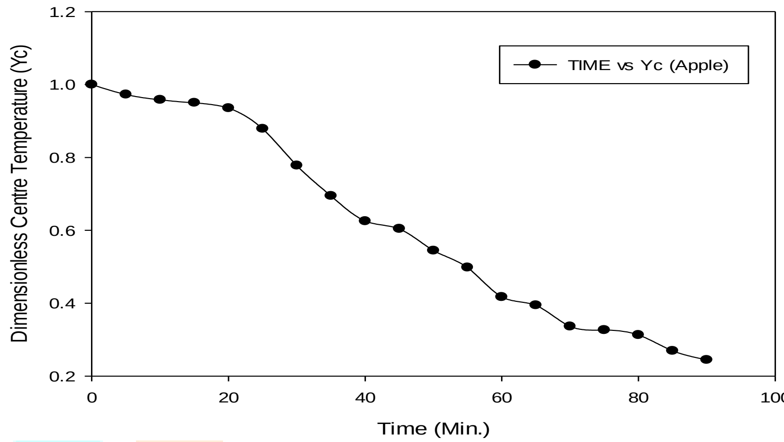

fig. 3. dimensionless centre temperature-time graph for apple

(k=0.531 w/m.k, $\alpha=1.295\times10^{-7}$ m^2/s, d=0.07 m. ti=19^0c, ta=-5.9^0c)

From fig. 4. it is observed that during first 30 minutes of time the drop in dimensionless temperature at surface, middle and centre are 0.05, 0.7 and 0.73 respectively. For the next which are 60 %, 60 % and 61.5% of the initial drop respectively. And during 60 to 70 minutes, the drop observed, are 0.015, 0.38 and 0.40 which are 30%, 54% and 55% of the initial drop respectively.

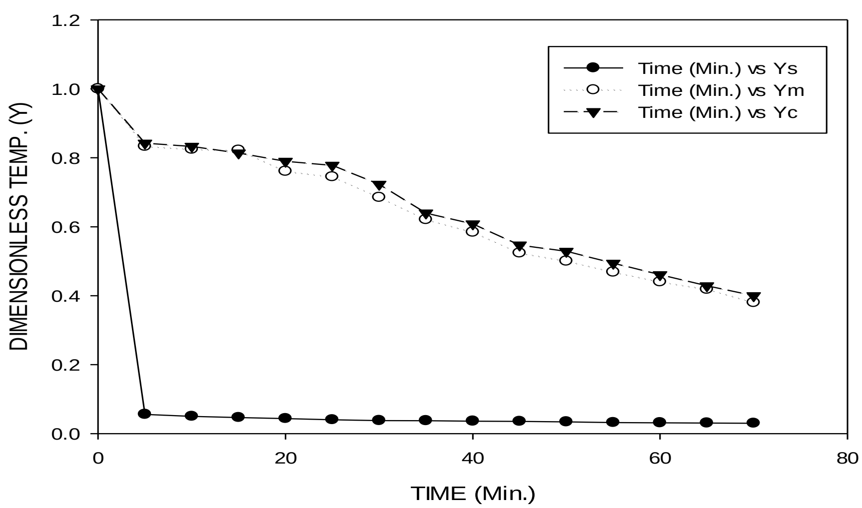

fig. 4. dimensionless temperature-time graph for apple

(k=0.5618 w/m.k, $\alpha=1.309\times10^{-7}$ m^2/s, d=0.07 m. ti=17^0c, ta=-3^0c)

Fig. 5. during first 30 minutes of time the drop in dimensionless centre temperature is 0.73. For the next 30 minutes i.e. during 30 to 60 minutes the drop observed is 0.45, which is 62% of initial drop as said above during 60 to 70 minutes drop observed is only 0.40, which is 56% of initial drop.

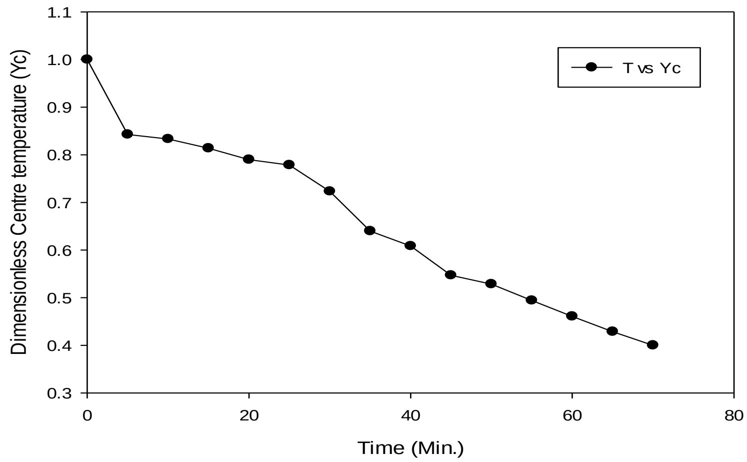

Fig. 5. Dimensionless centre temperature-time graph for apple

(k=0.5618 w/m.k, α=1.309×10^{-7} m^2/s, d=0.07 m. ti=17^{0}c, ta=-3^{0}c)

After 90 minutes there is no significant drop in dimensionless temperature. So, it can be concluded that initial rate of drop in temperature is significantly high because of large temperature difference between food item and cooling medium.

3.3. Cooling of Sapodilla

Fig. 6. Represents the variation of dimensionless temperature (at Centre, middle and surface) with time under air velocity of 2.5 m/s. It has been observed from this graph that the centre, middle and surface temperature of apple decrease with exponentially with time.

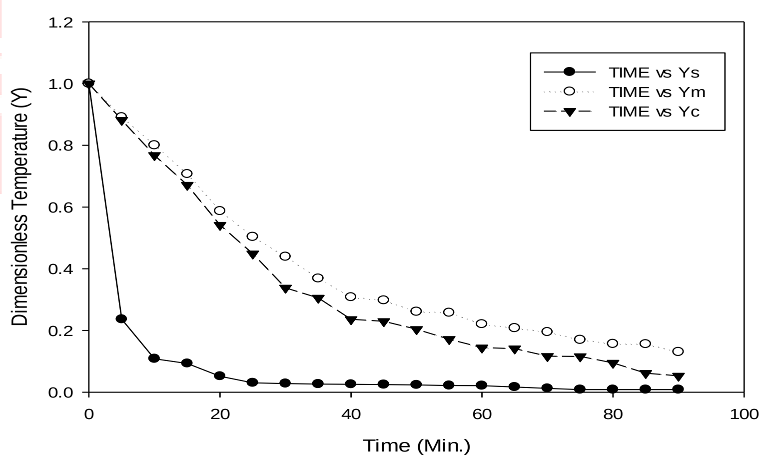

fig. 6. Dimensionless temperature-time graph for sapodilla

(k=0.5047 w/m.k, α=1.2283×10^{-7} m^2/s, d=0.045 m. ti=19^{0}c, ta=-5.6^{0}c)

fig. 6. It is observed that during first 30 minutes of time the drop in dimensionless temperature, at surface middle and centre are 0.028, 0.439 and 0.378 respectively. For the next 30 minutes i.e. during 30 to 60 minutes, the drop observed are 0.021, 0.22 and 0.144 which are 75 %, 50 % and 38% of the initial drops, respectively and during 60 to 90 minutes, the drops observed are 0.008, 0.13 and 0.053 which are 29%, 30% and 14% of the initial drops, respectively.

fig. 7. during first 30 minutes of time the drop in dimensionless centre temperature is 0.378. For the next 30 minutes i.e. during 30 to 60 minutes, the drop observed is 0.144, which is 38% of initial drop as said above and during 60 to 90 minutes drop observed is only 0.053, which is 14 % of initial drop.

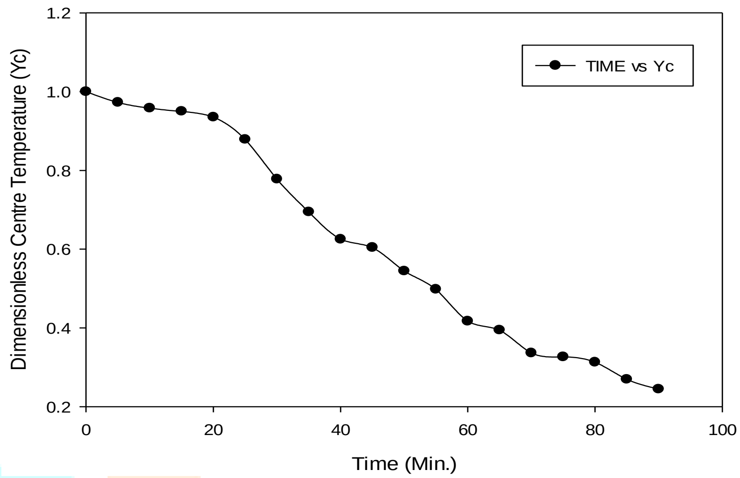

fig. 7. Dimensionless centre temperature-time graph for sapodilla

(k=0.5047 w/m.k, α=1.2283×10^{-7} m^2/s, d=0.045 m. ti=19^{0}c, ta=-5.6^{0}c)

From fig. 8. it is observed that during first 30 minutes of time the drop in dimensionless temperature at surface, middle and centre are 0.025, 0.403 and 0.315 respectively. For the next which are 84%, 55% and 46% of the initial drop respectively. And during 60 to 70 minutes, the drop observed, are 0.01, 0.24 and 0.135 which are 40%, 60% and 43% of the initial drop respectively.

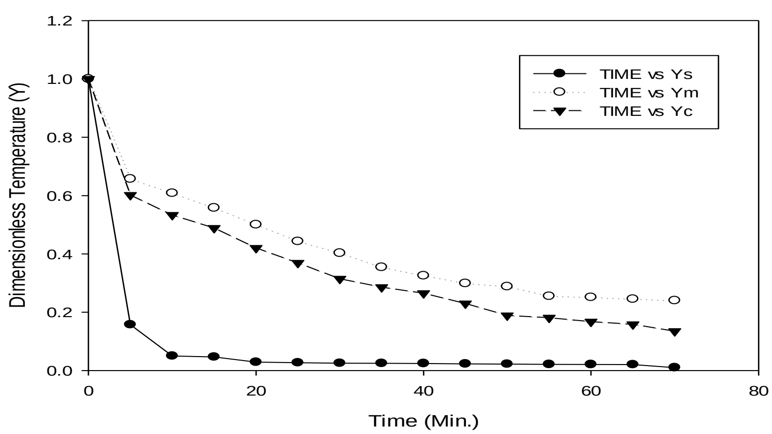

fig. 8. Dimensionless temperature-time graph for sapodilla

(k=0.5618 w/m.k, α=1.309×10^{-7} m^2/s, d=0.07 m. ti=17^{0}c, ta=-3^{0}c)

From Fig. 9.during first 30 minutes of time the drop in dimensionless centre temperature is 0.315. For the next 30 minutes i.e. during 30 to 60 minutes the drop observed is 0.168, which is 53% of initial drop as said above during 60 to 70 minutes drop observed is only 0.135, which is 43% of initial drop.

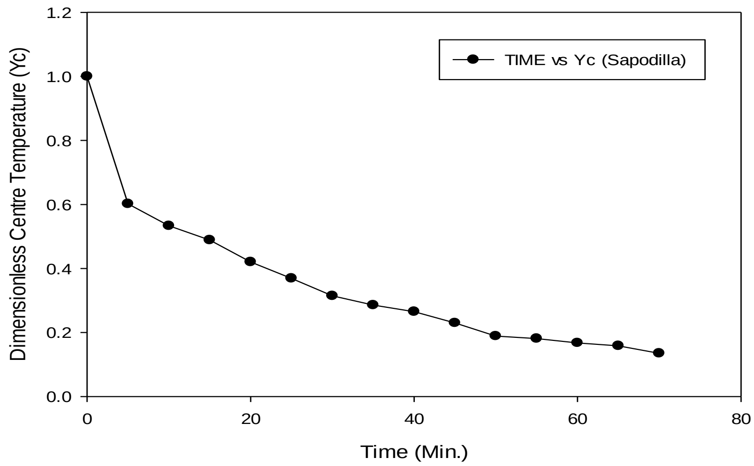

fig. 9. Dimensionless centre temperature-time graph for sapodilla

(k=0.5618 w/m.k, $\alpha=1.309\times10^{-7}$ m^2/s, d=0.07 m. ti=17^0c, ta=-3^0c)

After 90 minutes there is no significant drop in dimensionless temperature. So, it can be concluded that initial rate of drop in temperature is significantly high because of large temperature difference between food item and cooling medium.

3.4. Comparison of Time-Temperature Graph of Apple and Sapodilla

From Fig.10. During first 30 minutes of time the drop in dimensionless centre temperature of apple and sapodilla were found 0.778 and 0.378, respectively. For the next 30 minutes i.e. during 30 to 60 minutes, the drops observed were 0.417 and 0.144. Which are 54% and 38% of initial drop respective ely. During 60 to 90 minutes drop observed were 0.245 and 0.053, which 32% and 14% of initial drop. The initial temperatures of both fruits were same but final temperatures were 0.2 and -4.3 for apple and sapodilla respectively. It shows that sapodilla cools faster than apple.

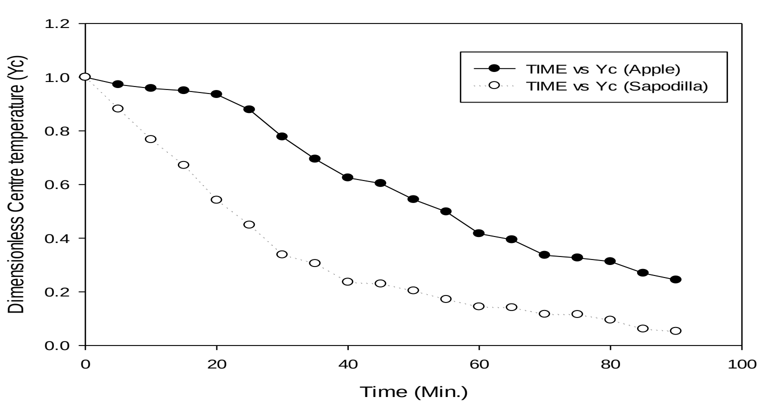

fig. 10. Combined time-temperature graph for apple and sapodilla

Fig.11. during first 30 minutes of time the drop in dimensionless centre temperature of apple and sapodilla were found 0.723 and 0.315, respectively. For the next 30 minutes i.e. during 30 to 60 minutes, the drops observed were 0.461 and 0.168, which are 64% and 53% of initial drop respectively. During 60 to 70 minutes drop observed were 0.4 and 0.135, which 55% and 43% of initial drop. The initial temperatures of both fruits were same but final temperatures were -3 and -0.3 for apple and sapodilla respectively. It shows that sapodilla cools faster than apple.

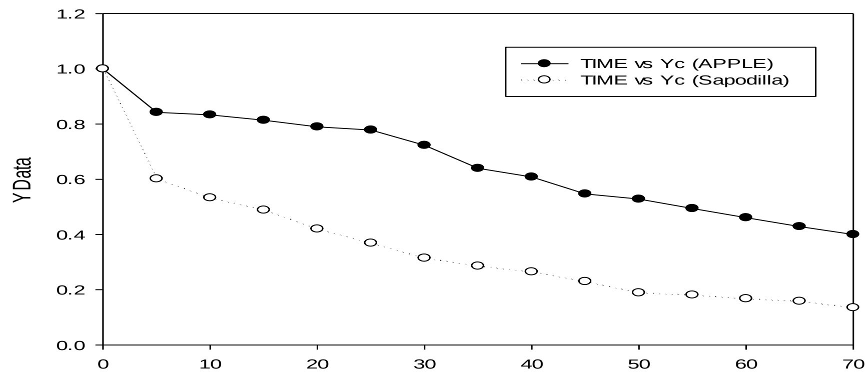

fig. 11. Combined time-temperature graph for apple and sapodilla

3.5. Heat transfer Coefficient

Dimensionless centre temperature Y and cooling time t can be defined as,

$$Y = \frac{T - T_a}{T_i - T_a} = \frac{T_a - T}{T_a - T_i} = j * e^{-Ct}$$

The slope of liner portion of logarithmic dimensionless centre temperature-time graph gives the cooling 5.10 and 5.1, the value of heat transfer coefficient at a particular air flow rate for apple and sapodilla are shown in table 2.1.3.1 and 2.1.3.2.

Table1. Values of convective heat transfer coefficient (1st run)

S. N.	Air Flow Velocity V (m/s)	Diameter d (meter)	Cooling Coefficient C (sec^{-1})	Thermal Conductivity of Air K_{air}(w/m.K)	h (w/m^2K)	Bi	Nu	Re
1.	2.5	0.07 (apple)	0.0023	0.026	45.70	0.95	123	52982
2.	2.5	0.045 (sapodilla)	0.0065	0.026	77.2	1.14	133	55061

Table 2. Values of convective heat transfer coefficient (2nd run)

S. N.	Air Flow Velocity V (m/s)	Diameter d (meter)	Cooling Coefficient C (sec^{-1})	Thermal Conductivity of Air K_{air} (w/m.K)	h (w/m^2K)	Bi	Nu	Re
1.	2.5	0.07 (apple)	0.0023	0.026	46.65	0.97	131	65010
2.	2.5	0.045 (sapodilla)	0.0065	0.026	58.81	0.87	102	53420

Table 1. and Table 2. it is observed that the values of Biot number for apples are higher than sapodilla at the same air flow rate, this is because of the lesser values of the convective heat transfer coefficient (h) and dimensions of sapodillas, as compare to apple.

The cooling coefficient (C), varies with air flow velocity, and air found to be highly sensitive to the size of the products and their surfaces exposed to the cooling medium. The surface heat transfer coefficients, for the individual products are found to be strongly dependent on the cooling coefficients.

From Table 1. and Table 2. it is observed that the value of convective heat transfer coefficient of sapodilla is higher than the value of convective heat transfer coefficient of apple, i.e. sapodilla cools faster than apple.

Table 3. Values of heat transfer for apple and sapodilla.

S. N.	Food Iteam	Velocity (m/s)	Heat transfer Coefficient h (W/m^2K	Surface Area (m^2)	Initial Temperature T_i(^0C)	Final Temperature T_f(^0C)	Heat Transfer Q (Jule)
1	Apple (1st Run)	2.5 m/s	45.71	0.01539	19	0.2	13.225
2	Apple (2nd Run)	2.5 m/s	46.65	0.01539	17	5	8.616
3	Sapodilla (1st Run)	2.5 m/s	77.2	0.006362	19	-4.3	11.444
4	Sapodilla (2nd Run)	2.5 m/s	58.81	0.006362	17	-0.3	6.473

These studies was initiated to resolves deficiencies in transient cooling and find heat transfer co-efficient for precooling of perishable food products. The drawn on the basis of above study are as follows:

Convective heat transfer co-efficient have been found for apples and sapodillas during forced air cooling process at a particular air flow rate (V=2.5 m/s).

The value of heat transfer co-efficient of sapodilla is greater than apple, only because of greater value of cooling co-efficient(C).

After 30 minutes of cooling (in 1st run) the values of dimensionless centre temperatures of apple and sapodilla are 0.77 and 0.378 respectively. The value of dimensionless centre temperature of sapodilla is 49% of apple. Hence, sapodilla cools faster than apple.

After 30 minutes of cooling (in 2nd run) the values of dimensionless centre temperatures of apple and sapodilla are 0.72 and 0.32 respectively. The value of dimensionless centre temperature of sapodilla is 44% of apple. Hence, sapodilla cools faster than apple.

Besides having lower value of convective heat transfer coefficient, heat transfer rate of apple is greater than sapodilla because of greater surface area exposed to the cooling medium.

High dropping in the temperature was occurred during the first 30 minutes of cooling which follows a lower rate of reduction in temperature.

Nusselt numbers for apples and sapodillas are ranging from 100 to 150.

Conclusion

In this study investigated the heat transfer for spherical shape of perishable fruits such as apple and sapodillas. We have found that during forced air cooling process the value of heat transfer coefficient of sapodilla is greater than apple only because of greater value of cooling coefficient. And hence sapodilla cools faster than apple. The above study correlation obtained from this research will be used by future research and design of precooling system for food products. This data will help to find a more accurate determination of cooling rates and corresponding refrigeration loads. The similar correlation can also be used other perishable fruits like apricots, pears, bananas, guavas, mangos and some vegetables

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