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ANALYSIS 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*— Cooling of Fruits, Transient heat transfer, unsteady state heat transfer, cooling time etc.**

I. INTRODUCTION

The preservation of food by refrigeration depends on a general rule of physical chemistry. Molecular mobility is depressed and thus chemical responses and biological procedures are slowed at low temperature as against heat treatment. Low temperature for all intents and purposes does not destroy microorganisms or enzymes but rather only discourages their activity in this way:

- Refrigeration hinders decay however it can't improve the initial quality of the item, subsequently the significance of assuring especially high microbial quality in the beginning material.
- Unlike thermal sterilization, refrigeration isn't a strategy for lasting preservation. Refrigerated and even solidified foods have a distinct life of realistic usability, the length of which relies upon the storage temperature.
- The saving activity of cold exists just insofar as low temperature is kept , consequently the significance of keeping up a reliable cold chain up and down the business life of the item.
- Refrigeration should regularly be used along with other preservation forms (the 'hurdle' principle).
- Food preservation at low temperature involves two distinct procedures - chilling and freezing. Chilling is the use of temperatures in the scope of 00C to 180C, i.e. over the point of solidification of the food, while freezing utilizes temperatures well beneath the point of solidification, routinely underneath - 180C.

A. Need for Food Preservation

Food processing and conservation, is the change of raw animal, vegetable, or marine materials into delectable, nutritious, and safe sustenance items. The business has its underlying foundations in ancient times, as people have constantly expected to acquire nourishment and store a bit for later use. Ancient people may have dried natural products in the sun and put away meat in called regions, for example, caves. With the rapid population growth in all around interest for food items, the significance of conservation of perishable food items during cataclysms and crises uncovered the shrewdness of protection during the time. Sources - one is of plant origin and the other originates from animals.

The yield from these ceaseless because of lacking preservation facility, overabundance in market happens during the pinnacle harvest period and the cost of perishable items tumbles to uneconomic levels and in the meantime the items are accessible only during short collecting season. Excess amount of consumable product, which isn't used on gather is ruined. Statistics have uncovered the stunning truth that absence of preservation facility has prompted the deterioration of more than Rs. 50 million worth of edibles every year in India.

B. Precooling and Storage Requirements

1) Precooling

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. Fruits and vegetables are precooled preceding transport, stockpiling, or further handling so as to expel the underlying field heat from the fresh produce and furthermore to lessen the refrigeration load on ensuing stockpiling and transport.

2) Precooling Characteristics

By and large, a segment of cooling curve for foods grown from the ground on semi log plot is linear. The accompanying equation represents the cooling curve:

Where CR = cooling rate

T = products temperature at given time ($°C$)

Ti = initial temperature ($°C$)

Ta = temperature of surrounding medium ($°C$)

t = time in sec.

j = lag factor

This relationship is fundamentally an exponential sort of cooling called the Newtonian type was equivalent to unity. The estimation of j is a pointer of the error in accepting the Newton cooling.

II. PRECOOLING METHODS

A. Tunnel Cooling

High speed of air is utilized to precool the food produced in tunnel cooling. In this method, high speed air is constrained past generally light slow packages in precooling tunnel. This framework furnishes quicker cooling rates with an air speed of 5m/s and consistently dispersed air gaps between the packages.

It has some disadvantages: one is the prerequisite of more precise fan control and the other is the loss of considerable measure of moisture from the items. Tunnel coolers are utilized in South Africa and have been tried in the northwest by Sainsbury (1961).

B. Forced Air Cooling

Forced air cooling is of two types:

1) Pressure Cooling

Pressure cooling is a special strategy for constraining the cooling air through the packages by building up pressure gradients. It has been created by Guillou (1956) in the Agriculture Engineering Department, University of California. Pressure cooling includes distinct stacking designs and the confounding of stacks, so the cooling air is constrained through the individual compartment with assistance of pressure differential. For high effectiveness, a compartment with vent openings set toward air movement and least of bundling materials that would interfere with the free development of air in the holder, are fundamental.

2) Velocity Cooling

Velocity cooling includes constraining high speed air in huge volumes through the voids of bulk food items travelling through a cooling tunnel on continuous conveyors. The heat transfer rates can be improved by exposing the food item to a stream of cold air of high speed.

For the cooling of fresh produce, a distinct gas pressure is made on opposite faces of stacks or vented holders. This guarantees the progression of air around individual fruit or vegetable influencing quick cooling. Velocity cooling is very viable however is restricted in application because of staggering expense of circulating enormous volumes of air at high speed.

C. Hydro cooling

Hydro cooling, or cold water submersion cooling, was first utilized in U.S.A. around forty years ago, and lately it is as a rule generally utilized in that nation for pre-cooling vegetables, for example, lettuce, celery, peas, asparagus, sweet corn, and Brussels sprouts, and fruits such peaches, fruits and pears. Cooling rate for above foods items are accounted for by Sadato Ishibashi, 1967.

The hydro cooling is of two types:

1) pray Type

Spray cooling is one of the several methods for chilling poultry carcasses. Veerkamp and Hofmans (1974) have studied spray cooling of poultry carcasses and they developed an empirical relation for calculating the cooling time.

2) Flood Type

In this technique, chilled water flows past the product submerging it in water. Stewart and Lipton (1960) have studied cooling process of cantaloupes using a pilot model flood type hydro cooler. They observed that the water flow rate should at least be 6.8kg/s.m2 of cooler area and that flow rates in excess of 8.168kg/s.m2 do not improve cooling rate appreciably.

D. Vacuum Cooling

Vacuum cooling is the act of precooling new items, for the most part vegetables, having a high proportion of surface area to volume, by fast evaporation of water from the item. Verdant vegetables like cabbage and lettuce are the most appropriate for vacuum cooling. It creates fast uniform cooling, however is very costly because of the high initial expense of the hardware. Thevenot (1962) reports, that the vacuum cooling is only economical with enormous working limits of around 30 tons for each hour and a moderately long transporting season.

E. Hydraircooling

Hydraircooling is an ongoing precooling method. Hydraircooling is a compelling technique for precooling sustenance items for which moistue loss is inconvenient. It has the positives of both air cooling and hydraircooling. Henry and Bennett (1973), introduced aftereffect of hydraircooling unit loads (1 unit load=40 containers) of sweet corn with a water stream rate of

6.3 kg/s and utilizing little spray nozzles. They revealed that the cooling rate is superior to a regular hydrocooler circulating water at 25.2 kg/s. They have likewise revealed that for a given water flow rate, increment in air flow rate diminishes the cooling time.

Bennett and Wells (1976) have announced the aftereffects of hydraircooling of waxed peaches. At the point when the cold air is passed over food items that are consistently wetted by a slender film of water, there will be increasingly powerful cooling without much lack of hydration from the item contrasted with other ordinary strategies.

F. Package Icings

Package icing is utilized to cool some products that is field packed into shipping containers. The ice may be finely crushed. Flake ice, or a slurry of ice and water called liquid-ice. Liquid ice is injected in the container and has better contact with the products than the other forms.

More expensive water-tolerant containers are required, and the added weight of the ice decreases the weight of actual produce that can be shipped.

G. Evaporative Cooling

Evaporation cooling is an inexpensive and effective method of lowering product temperature. It is most effective in areas where humidity is low. Dry air is drawn through moist padding or fine mist water, then through vented containers of products. Water changes from liquid to vapour; it absorbs heat from the air, thereby lowering its temperature.

The incoming air should be less than 65 percent relative humidity for effective evaporative cooling. It will only reduce temperature from 9 to -120C. This method is more suitable for warm-season cops requiring warmer storage temperature (7.5-12.50C), such as tomatoes, peppers, cucumbers or eggplant.

III. LITERATURE REVIEW

F.A. Ansari et al. (1987), An empirical connection has been created for Biot number, which empowers the estimation of surface film conductance during the transient cooling of round bodies by estimating temperature at any area inside the body and the all out passed time. The technique was utilized to quantify heat transfer coefficient of apples, oranges and potatoes through precooling tests. The outcomes have been examined and those gotten by the Nu-Re relationship accessible in the literature. The qualities controlled by the present strategy yield the phenomenal time-temperature calculations.

Bryan R. Becker et al. (2004), to augment the proficiency of cooling and freezing activities for foods, it is important to ideally plan the refrigeration gear to fit to explicit prerequisites of specific cooling or freezing application. The design of food refrigeration gear requires estimation of cooling and freezing times of products,and also corresponding refrigeration loads. The precision of these assessments thusly, relies upon the exact estimates of heat transfer coefficient for the cooling or freezing activity.

This Project looked into the heat transfer information for the cooling or potentially solidifying of food otems. An aggregate of 777 cooling curvess for 295 sustenance things were acquired from a industrial study and a one of a kind iterative calculation, using the idea of 'equal heat transfer dimensionality', was created to get heat transfer coefficients from these cooling curves. Nine Nusselt-Reynolds-Prandtl correlations were created from a choice 777 heat transfer coefficients coming about because of this algorithm, just as 144 warmth move coefficients for 13 sustenance items, gathered from the literature. The information and correlations coming about because of this task will be utilized by the designers of cooling and solidifying of sustenances. This data will make conceivable an increasingly exact calculation of cooling and solidifying times and comparing refrigeration loads. Such data is significant in the plan and task of cooling and solidifying plants and will be of prompt handiness to engineers involved in the designing and operations of such systems.

IV. RESULT AND PROCEDURE

This chapter gives the information regarding the description, specifications and fabrication of components of the experimental setup. The Procedure adapted, to carryout experimental runs, is also being discussed in this chapter.

A. Description of Experimental Setup

The experimental setup is represented by the sketch shown in fig. 4.2.1, it consists of rectangular air duct (1) cross section made up of Galvanized Iron Sheet insulated with 10 mm thick puff sheet. The air is circulated inside the duct by means of centrifugal blower (2) The blower is driven by means of an electric motor (3) connected with a belt and pulley arrangement

(4) The air velocity in the duct is regulated by controlling the speed of blower by using pulleys of different sizes. Two dampers are also provided to further control the circulation rates and temperature of air in the test and return ducts, by adjusting the damper opening.

The air is cooled by passing the air over the two sets of cooling coil, one is evaporator coil of R-134a evaporator coil of vapor compression cycle (5) and the other is water cooling coil (6) cooling by first set of coil is known as direct cooling technique and is done by placing R-134a evaporator coil of the vapour compression cycle in the path of air, i.e. in the duct.

Heat of the air is absorbed by the refrigerant R-134a flowing inside the evaporator cooling coil. Cooling by second set of coil is called as indirect cooling technique is achieved by placing he coil carrying the chilled water inside the duct. Heat of air is first absorbed by the chilled water coil and then this heat is rejected inside the chiller by the means of another R-134a evaporator cooling coil. The two coils are never run simultaneously but only one coil used at a time, owing to the limitation of the cooling capacity of the existing R-134a vapour compression refrigeration cycle.

The refrigerant R-134a changes its state from liquid phase to vapour phase. These vapours are then sucked by compressor (7), compressor activates the refrigerant by compressing it to the higher pressure and higher temperature level after it has produced its refrigeration effect in te evaporator coils.

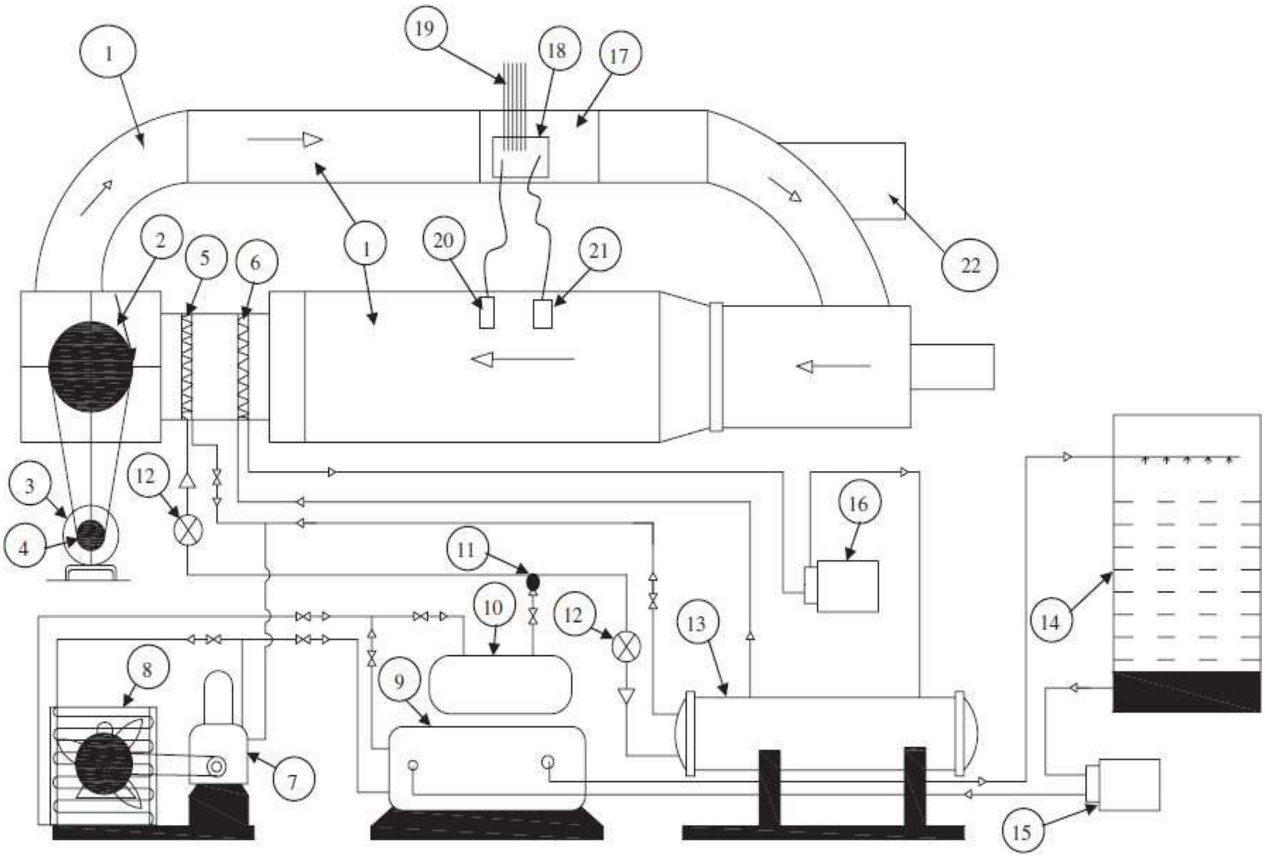

Fig.4.2.1. Schematic Diagram of experimental setup

1. Air Duct, 2. Blower, 3. Electric Motor, 4. Pully-Belt Arrangement, 5. R-134 Evaporator Cooling Coil, 6. Chilled Water Cooling Coil, 7. Compressor, 8. Air-Cooled Condenser, 9. Water – Cooled Condenser, 10. Receiver, 11. Sight Glass, 12. Expansion Valves, 13. Chiller, 14. Cooling Tower, 15. Condenser Pump, 16. Chiller Pump, 17. Test Section, 18. Food Package, 19. Thermocouples, 20. Anemometer, 21. Digital Multimeter,22. Dampers.

The compressed refrigerant transfers its heat to the condenser and is condensed to liquid form. Here the two condensers, one is air-cooler (8) and other water cooled condenser (9) are used. However, only one is used at a time. Refrigerant leaves the condenser as saturated liquids and enters the receiver (10). A sight glass (11) is also placed after the receiver to see the liquid phase of the refrigerant. This liquid refrigerant is then throttled to a low pressure.

Low temperature vapour by means of hand operated expansion valves (12) of produce a refrigeration effect during evaporation inside the first set of evaporator coil and inside the chillier (13). The condenser cooling water is cooled by induced draft cooling tower (14) and is circulated by means of centrifugal pump1 (15). The chilled water on the other hand is circulated by another pump namely, centrifugal pump #2 (16). The test section (17) is made inside the air duct with an arrangement having tray to hold food commodities known as food package (18). The temperature at various locations inside the test section and the food is measured by thermocouples (19). The air velocity is measured by digital anemometer (20). Air temperature and humidity is measured by digital multimeter (21).

Fig.4.2.2. Air refrigeration Setup at IIT, Roorkee

B. Setup SpecificationS

The specifications of different components of the experimental setup are :

1) Air Duct

Air duct is made up of Galvanized Iron sheet having 4 m length and a cross section of 300×300 mm. The duct is insulated by 12 mm thick sheet.

Blower

Type	-	Centrifugal
Drive	-	V-belt
Motor voltage	-	3 ph 400/400 AC
Speed	-	1420rpm

Cooling Coils

Make	-	Bareo
No. of turns	-	6
Material of fin	-	Aluminium

Compressor

Make	-	Bitzer, Germany
Type	-	Open type, reciprocating (Two cylinder)
Cooling capacity	-	5 ton
Speed	-	550 rpm

Compressor Motor

Make	-	Crompton and Parkinson
Rated speed	-	1440 rpm
Rated power	-	7.5 hp
Motor voltage	-	3 ph/400 volts

Air-Cooled Condenser

Type	-	Forced
Tube	-	Copper tube of '3/8' diameter
Fin	-	Aluminium
Capacity	-	5 ton

Expansion Valves

The two manual expansion valves have been used in present experimental facility. The first expansion valve is used with R-134a evaporator cooling coil (5) and the second with the chiller (13).

V. EXPERIMENTAL PROCEDURE

A. Experimental Procedure for Apples

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 used for cooling were placed in the wire mesh test chamber in the duct. The temperature inside the fruits were measured with the help of thermocouples were used three thermocouples for apples 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 when the thermocouples probes were fixed on the distance (R=d/4) were measured middle temperature of apples.

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.

B. Experimental Procedure for Sapodilla

In these experiments the same procedure as mentioned above was followed for sapodilla.

VI. RESULT AND DISCUSSION

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

A. Cooling Curves

Fig. 6.1.1.1. to 6.1.3.2. 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.

Cooling of Apples

Fig. 6.1.1.1. 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.

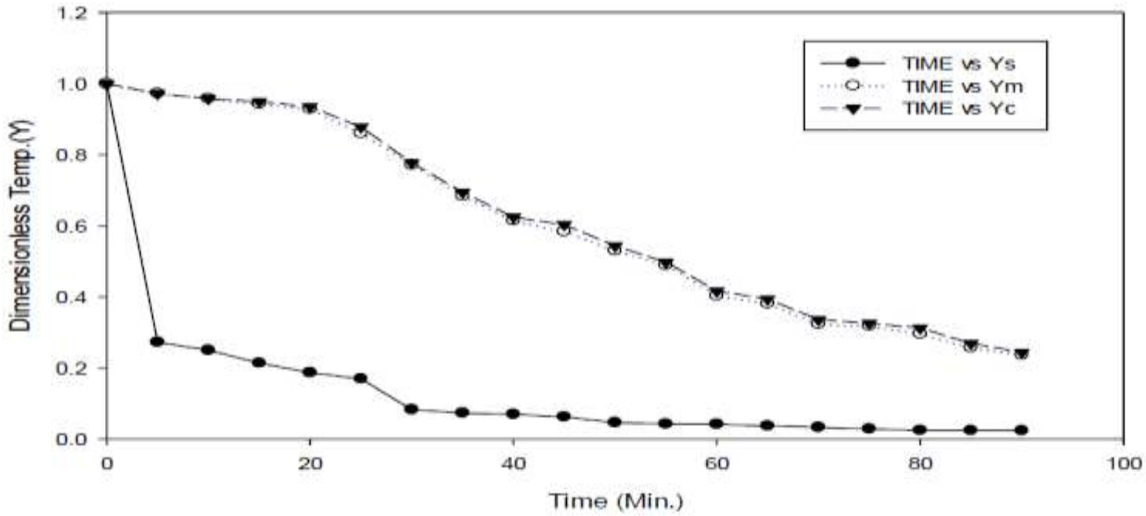

Fig. 6.1.1.1. Dimensionless Temperature-Time Graph for Apple
(k=0.531 W/m.K, $\alpha=1.295\times10^{-7}$ m^2/s, d=0.07 m, Ti=19^{0}C, Ta=-5.9^{0}C)

Fig. 6.1.1.1. 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. 6.1.1.2. 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.

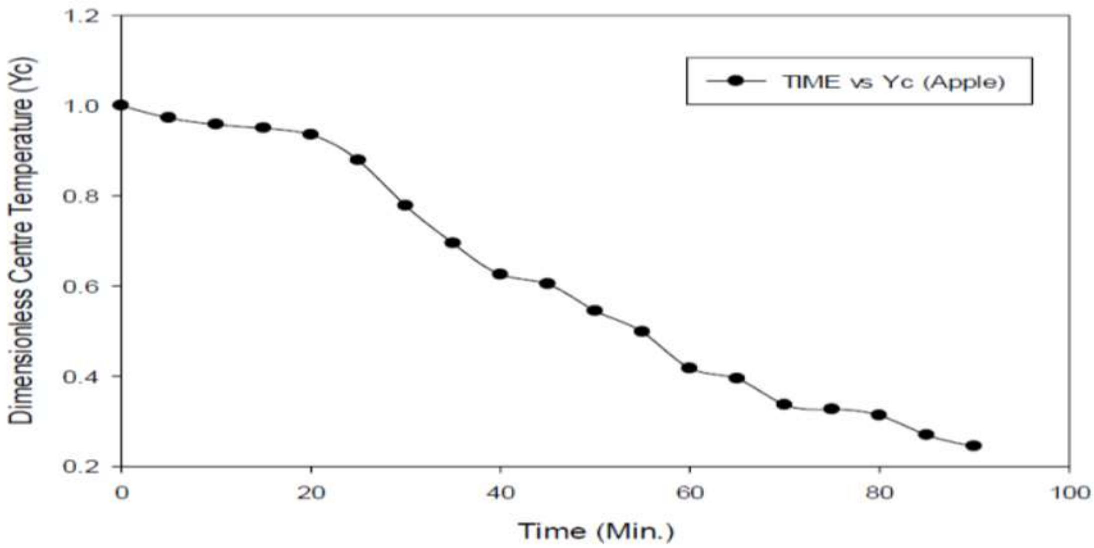

Fig. 6.1.1.2. Dimensionless Centre Temperature-Time graph for Apple
(k=0.531 W/m.K, α=1.295×10^{-7} m^2/s, d=0.07 m. Ti=19^{0}C, Ta=-5.9^{0}C)

From fig. 6.1.1.3, 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.

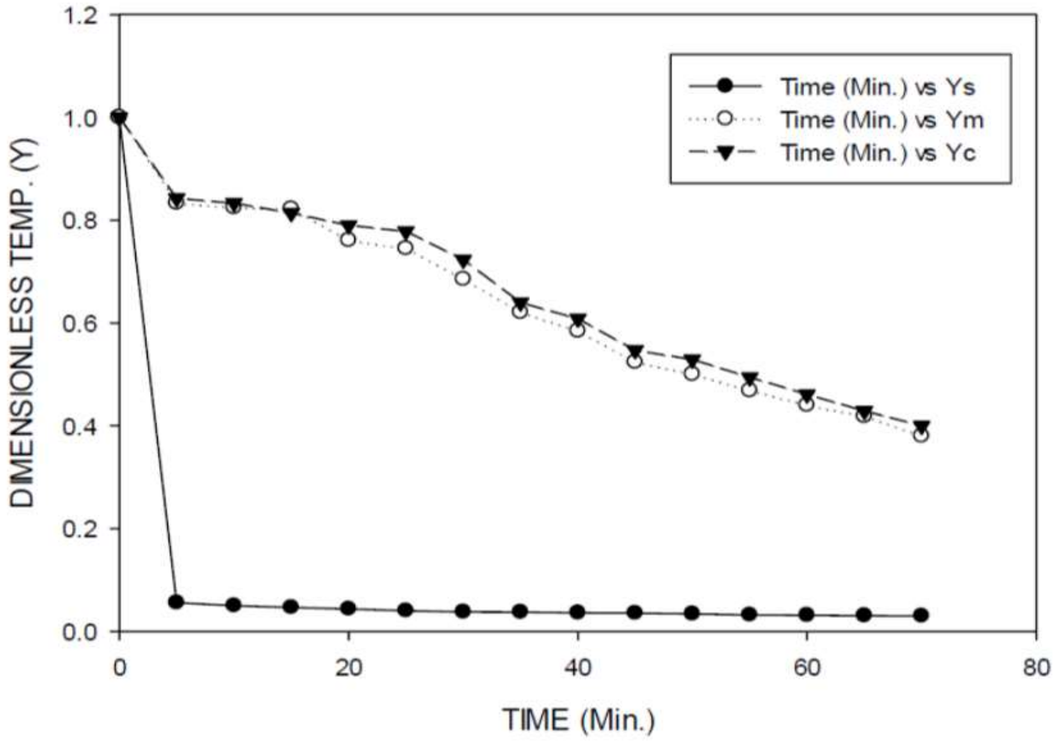

Fig. 6.1.1.3. Dimensionless Temperature-Time graph for Apple
(k=0.5618 W/m.K, α=1.309×10^{-7} m^2/s, d=0.07 m. Ti=17^{0}C, Ta=-3^{0}C)

From Fig. 6.1.1.4 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.

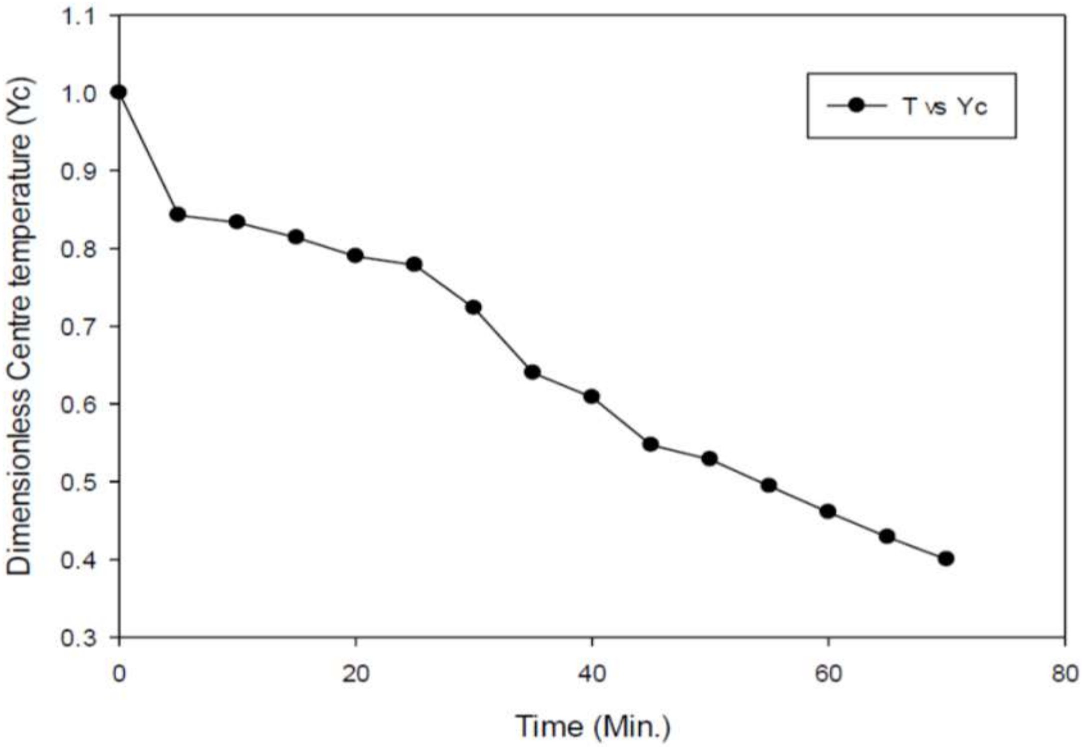

Fig. 6.1.1.4. Dimensionless Centre Temperature-Time graph for Apple

(k=0.5618 W/m.K, α=1.309×10^{-7} m^2/s, d=0.07 m, Ti=17^{o}C, Ta=-3^{o}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.

B. 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 6.1.3.1 and 6.1.3.2.

Table 6.1.3.1 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 Conductivit y of Air Kair(w/m.K)	h (w/m^{2}K)	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 6.1.3.2 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 Kair (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

From Table 6.1.3.1 and Table 6.1.3.2, 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 6.1.3.1 and Table 6.1.3.2, 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 6.1.3.3. 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 Ti(^{0}C)	Final Temperature Tf(^{0}C)	Heat Transfer Q (Jule)
1	Apple (1^{st} Run)	2.5 m/s	45.71	0.01539	19	0.2	13.225
2	Apple (2^{nd} Run)	2.5 m/s	46.65	0.01539	17	5	8.616
3	Sapodilla (1^{st} Run)	2.5 m/s	77.2	0.006362	19	-4.3	11.444
4	Sapodilla (2^{nd} Run)	2.5 m/s	58.81	0.006362	17	-0.3	6.473

VII. CONCLUSIONS

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.

The data and correlations resulting from this thesis could be used by designers of precooling systems for food products. This information will make possible a more accurate determination of cooling times and corresponding refrigeration loads. Similar correlations could also be developed in future with other perishable fruits like apricots, pears, bananas, mangoes etc.

REFERENCES

[1] Abbas, K.A., Ahmad, M.M.H.M., Sapuan, Wan, S.M., M.A., (2006).- Numerical Analysis of heat in cooling of fish packages, International Communications in Heat and Mass Transfer 33 (2006) 889-897.

[2] Abdul Majeed, P.M., (1979). Studies on Heat Transfer during Hydraircooling of Food Products, PhD, Thesis, IIT, Madras, India.

[3] Allan, D.Karus. Abdul, Aziz and James Welty, (2001). Extended Surface Heat Transfer WILEY, pp.770.

[4] Ansari, F.A., Abbas, K.A. Bakar, J., Ashraf, A.O., Mokhtar, A.S., Sapuan, S.M. (2004).Further Improvements in Temperature calculation during cooling of fish packages, American Journal of Applied Science 1 (2) 95-99.

[5] Ansari F.A.,(1987). A Simple and Accurate Method of Measuring Surface Film Conductance for Spherical Bodies, Pergarron Journals Lt, vol. 14, pp. 229-236

[6] Ansari F.A., Abbas K.A., (2004). Correlation between Thermal diffusivity Variation and Quality of cold preserved fish, AJSTD, Vol. 21 Issue 1 pp.1-10

[7] Ansari, F.A. Khan, S.Y. ,(1999). Application Concept of Variables Effective surface Film Conductance for simultaneous Heat and Mass Transfer Analysis during Air blast cooling of food, Energy Conversion & Management 40: 567-574.

[8] Becker B.R., Fricke B.A., (2004). Heat transfer coefficients for Forced-air cooling and freezing of Selected foods, International Journals of refrigeration27: 540-551

[9] Bennett A.H. and Wells J.M., (1976). A New Precooling Method with Special Application for Waxed Peaches, JI. Amer Soc.Hort.Sci, Vol. 101, pp. 428-431

[10] Brody A.L., and Marsh K.S., "Encyclopedia of Packaging Technology ", John Wiley & Sons, 1997, ISBN 0-471-06397-5

[11] Carlisle, Rodney (2004). Scientific American Invention and Discoveries p-357 John Wiley & Sons, Inc,, New Jersey, ISBN 0471244104

[12] Chevalier D., Bail A.L., Ghoul M.,(2000). Freezing and Ice crystals Formed in a Cylindrical Food Model: part 2.Comparison Between Freezing at Atmospheric Pressure and Pressure Shift Freezing, Journal of Food Engineering 46: 287-293

[13] Cleland, A.C., (1990). Food Refrigeration Process: Analysis Design and Simulation. Elsevier Science, Londan.

[14] Dincer I., (1993), Heat transfer Coefficients in Hydro cooling of Cylindrical and Spherical Food Products, Energy Vol. 18, No. 4, pp. 335-340

[15] Dirar, H., (1993). The Indigenous Fermented Foods of the sudan: A study in African Food and Nutrition, CAB International, U.K.

[16] Encarta References Library (2005). (C) 1993-2001 MicrosoftCorporation, www.Microsoft_Encarta_2005_Encyclopedia_Standard.html.

[17] Guillou, R., and Parks, R.R., (1956), Forced Air for Cooling. University of California. Agr. pp. 7-10

[18] Hall, E.G., (1974). Techniques of precooling, the Long Term Storage, Controlled Atmosphoric Storage and the Freezing of fruits and vegetables: Part 1: precooling of fruits and vegetables, int. Short Term cources, Durgapur, India Jan. 14-24. A.A.o.I.I.R., pp. 75- 90.

[19] Henry F.E., Benett A.H.,(1973), Hydraircooling Vegetable in Unit Loads Trans. ASAE, Vol. 16, pp. 731-733

[20] Hornsey Ian Spencer (2003). History of Beer and Brewing. Royal Society of Chemistry. ISBN 0854046305. http://www.cse.iitk.ac.in/users/amit/books/horsney-2003-hisory-of- beer.html. on p.30