Ceylon Journal of Science: Physical Sciences, 4(1), 61-72 (1997)

STUDY OF SOME PHYSICAL CHANGES IN SELECTED FOODS DURING OHMIC HEATING

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ABSTRACT

Physical property changes are one of the important effects caused by thermal processing of foods. Some of the undesirable effects caused by thermal processing can be reduced by using HTST (High temperature-short time) techniques. Ohmic heating is a recently developed food processing technique. It falls into the category of HTST (High-temperature-short-time) processing techniques due to quick heating. In ohmic heating, the passage of an alternating electric current courses internal generation of heat due to resistance afford by the food material. The process being a HTST technique, ohmic heating should demonstrate higher quality retention.

In this study temperature variation of three different food materials, carrot, beetroot and potatoes, was studied during ohmic heating using a heating medium and an indirect heating method, (250ml of 2.12 g/l Sodium Chloride (NaCl), electrical conductivity = 4.98×10^{-3} Scm^{-1}). Structural changes of carrot was studied during both processes. 3cm x cm x 3cm cubic food particles were heated ohmically using two stainless steel electrodes and an alternating current (240V, 50 Hz) and the results show that the increasing of temperature inside the cube was faster than the medium. Also in the indirect heating method, less damage was caused to the material than in the direct heating method.

NOMENCLATURE

C_P - Specific heat capacity (kJ kg^{-1} K^{-1})
d - Density (kg m^{-3})
E - Electrical field gradient (V m^{-1})
I - Current (A)
M - Weight (kg)
m - Temperature coefficient
P - Power (W)
R - Resistance (Ω)
T - Temperature (^{0}C)
t - time (Sec)

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U - Heat generation rate (JS-1)
σ - Electrical Conductivity (Scm-1)

1. INTRODUCTION

Heat treatment is one of the important methods used in food processing as a preservation technique and a means of changing eating quality of a food. Many changes happen in foods when they are subjected to thermal processing. Among these changes physical property changes such as changes in structure, density, colour, state of aggregation (melting, dissolution, crystallization) are very important[6,9]. These changes mainly depends on the time and temperature of the process and when time and temperature are high they cause an increase in these changes. To minimize heat-induced quality, the heat treatment is often designed as a HTST (High Temperature-Short Time) process [1]. Conventional high temperature processing is well suited to liquid and mixtures of liquids and small particles (up to ~2mm in size) where forced convection occurs rapidly in equipment such as scraped surface or plate heat exchangers, so that heat transfer is limited for particles of any size grater than ~2mm; core temperatures will lag behind that of liquid, causing overcooking of both the food surfaces and the liquid[2,3].

To overcome this limitations, novel technologies have been developed. Volumetric heating techniques, where heat is generated within the food, can be used. Ohmic heating is a heat generating method where heat is internally generated within the food by passing an alternating electric current. Most foods contain electrolytic species such as salts and acids, therefore electric current can be passed through them. Heating by this method has been reported to be rapid and uniform. In conventional processes, heating rates are controlled by thermal properties such as thermal conductivity and specific heat. In ohmic heating, the heating rates are critically dependent in a number of ways on the electrical conductivity of the medium. The heat generation rate of a food is given by[4]

$$U = \sigma E^2$$

Where E is local electric field strength and σ is specific electric conductivity of food. Commercially the ohmic process requires a high heating rate in the region of $1\text{-}5\,^0CS^{-1}$ for a desired product out put. The amount of electrical power required (P) can be estimated using[4,8]

$$P = M\,C_p d\,(T_{out} - T_{in})$$

The current and the voltage required to deliver that power can be expressed as

$$I = (P/R)^{1/2} \quad V = (PR)^{1/2}$$

The process enables solid particles to heat as fast as liquid. If the electrical conductivities of the liquid and solid phases are comparable then the mixture can be heated quickly and uniformly to a high temperature without the problems associated with particle size. The advantages of electrical heating processes are obvious, and many attempts have been tried to use them [2,5]. For an efficient process it is vital that both solid and liquid phases should heat at the same rate. Solid heating rates vary in a complex way with particle and liquid conductivities, particle shape and orientation to the electric field [3,4,7]. The present study looks at the temperature variation of three food materials, carrot, beetroot and potatoes, compared to the heating method and the structural changes of carrot during ohmic heating.

2. MATERIALS AND METHODS

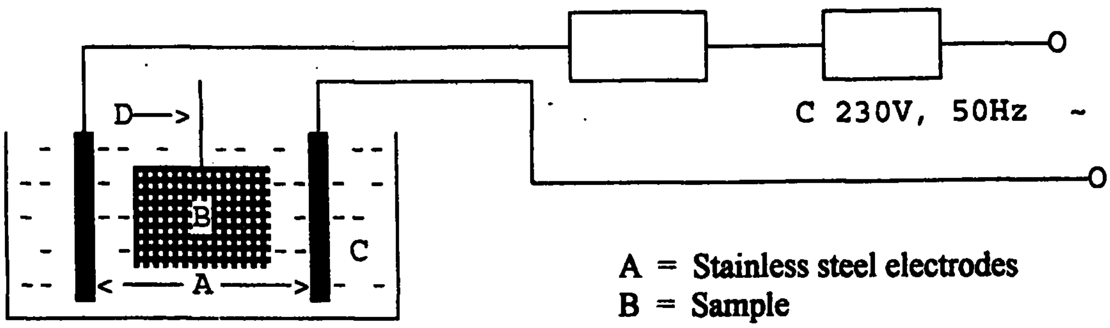
Preparation of samples

The food materials Carrot, Beetroot and Potatoes, were obtained from the local market, Colombo, Sri Lanka. Two stainless steel electrodes, Multimeter (Universal Avometer), Photographic Microscope (Vickers Instrument Co.), Sodium Chloride (NaCl, BDH chemical, UK) were used in this experiment. The set of 3cm x 3cm x 3cm cube of carrot, beet and potatoes were prepared and the axis of the cubes was marked for identification.

Preparation of heating medium

250ml of 2.12g/L Sodium Chloride (NaCl) solution was prepared by dissolving 0.53g in distilled water. The solution has conductivity of 4.985×10^{-3} Scm^{-1}.

Heating of samples

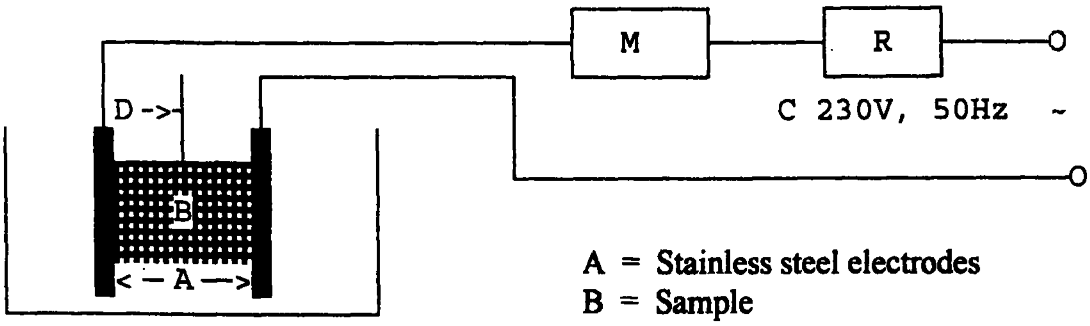


A = Stainless steel electrodes
B = Sample
C = Electrolytic solution
D = Thermometer
M = Multimeter (to measure the current)
R = External resistor (to control the current)

Fig. 2.1. Indirect heating of food sample

The heating medium was introduced to the container and the two stainless steel electrodes were placed at a distance of 4.5cm. 3cm x 3cm x 3cm cube was placed at the centre between the two electrodes (indirect heating method, figure-2.1) and the axis of the cube was set parallel to the electric field. Then an alternating electric current (230V, 50Hz) was supplied to the medium and the temperature of the middle of the cube (T_1) and the solution (T_2) was measured with time until the solution boiled. This procedure was repeated with changing the direction of the axis of the cube to the electric field. During this experiment, six carrot samples, four beetroot and four potato samples were tested.

3cm x 3cm x 3cm carrot cubes were also heated as in procedure 2.2, but distance between electrodes was adjusted to 3.0cm and in contact heating (direct heating method, figure-2.2), the two electrodes were arranged to directly touch the opposite sides of the cube (two electrodes were placed in 3.0cm distance) and the cube was heated, until its temperature became maximum, without using a heating medium. The cross section of carrot samples were prepared and examined microscopically.



A = Stainless steel electrodes
B = Sample
D = Thermometer
M = Multimeter (to measure the current)
R = External resistor (to control the current)

Fig. 2.2. Direct heating of food sample

3. RESULTS AND DISCUSSION

Study of the temperature variation

Variation of the temperature T_2 (inside) and T_1 (outside : heating medium) of the cubic particles of carrot, beetroot potatoes are shown in figure-3.1, 3.2 and 3.3 respectively.

As seen there are some variations in these curves and T1 clearly separate from the T2. When considering the single heating, T1 and T2 are increased with time in nearly equal heating rates. But when the time increases, T2 rapidly increases with time in non linear manor ($d^2T/dt^2 > 0$), and particles were heated up to its maximum before the solution (heating medium) came to boiled. Actually heating rate is depended on the conductivity of the medium. According to these results the conductivity of the solid particle is higher than the medium and also the conductivity increases with increasing of

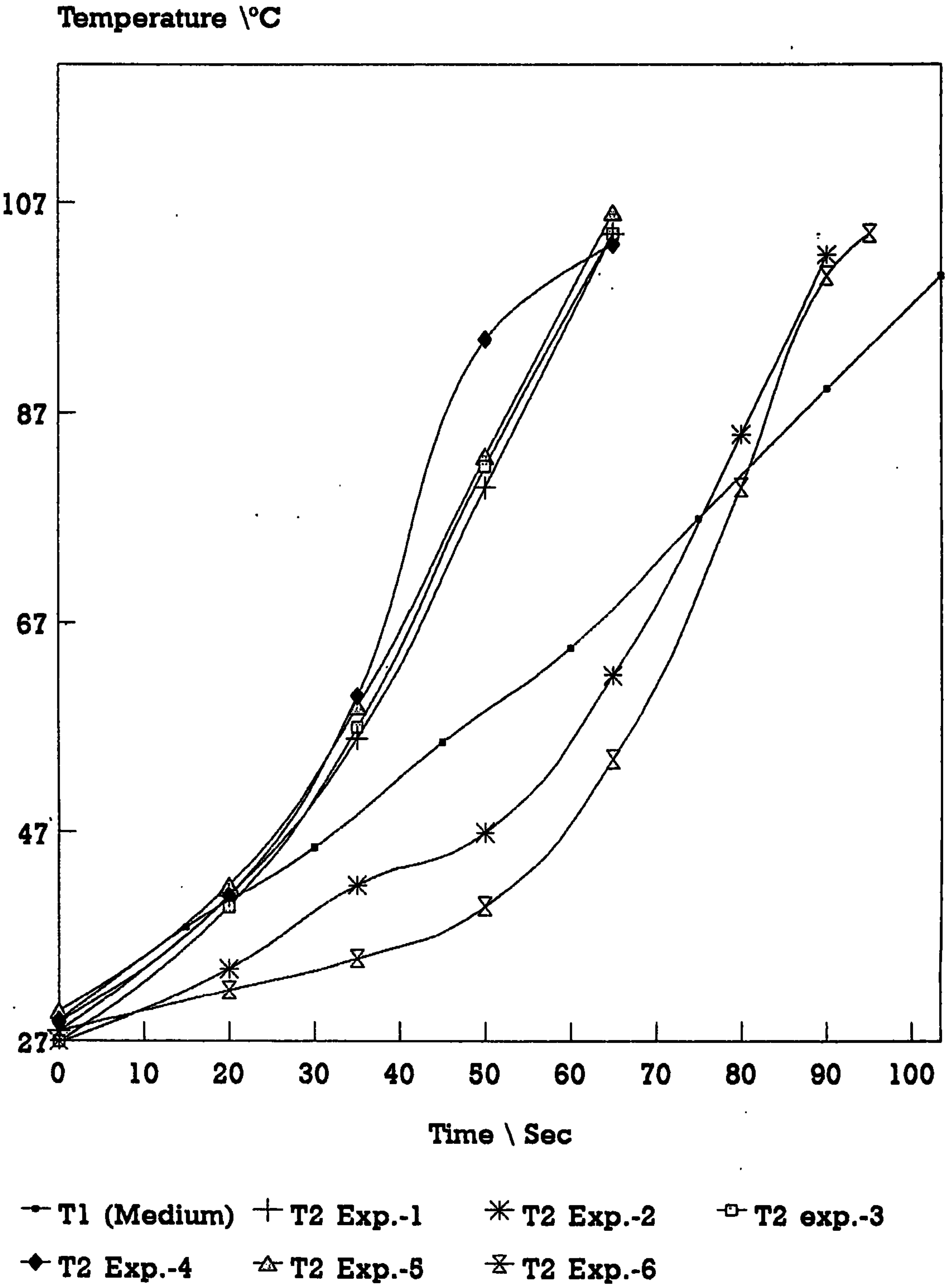


Fig. 3.1. Temperature variation in carrot

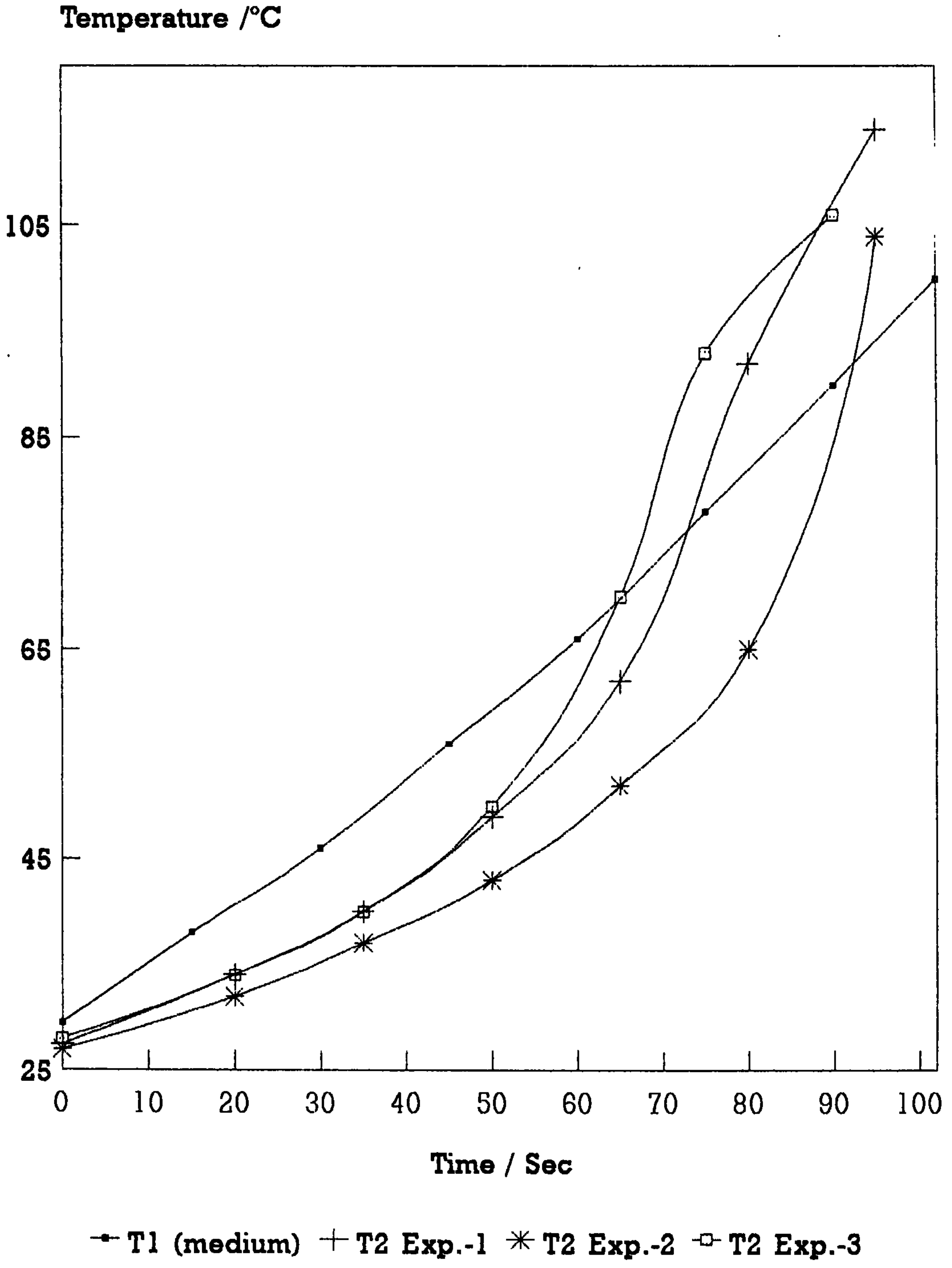


Fig. 3.2. Temperature variation in beetroot

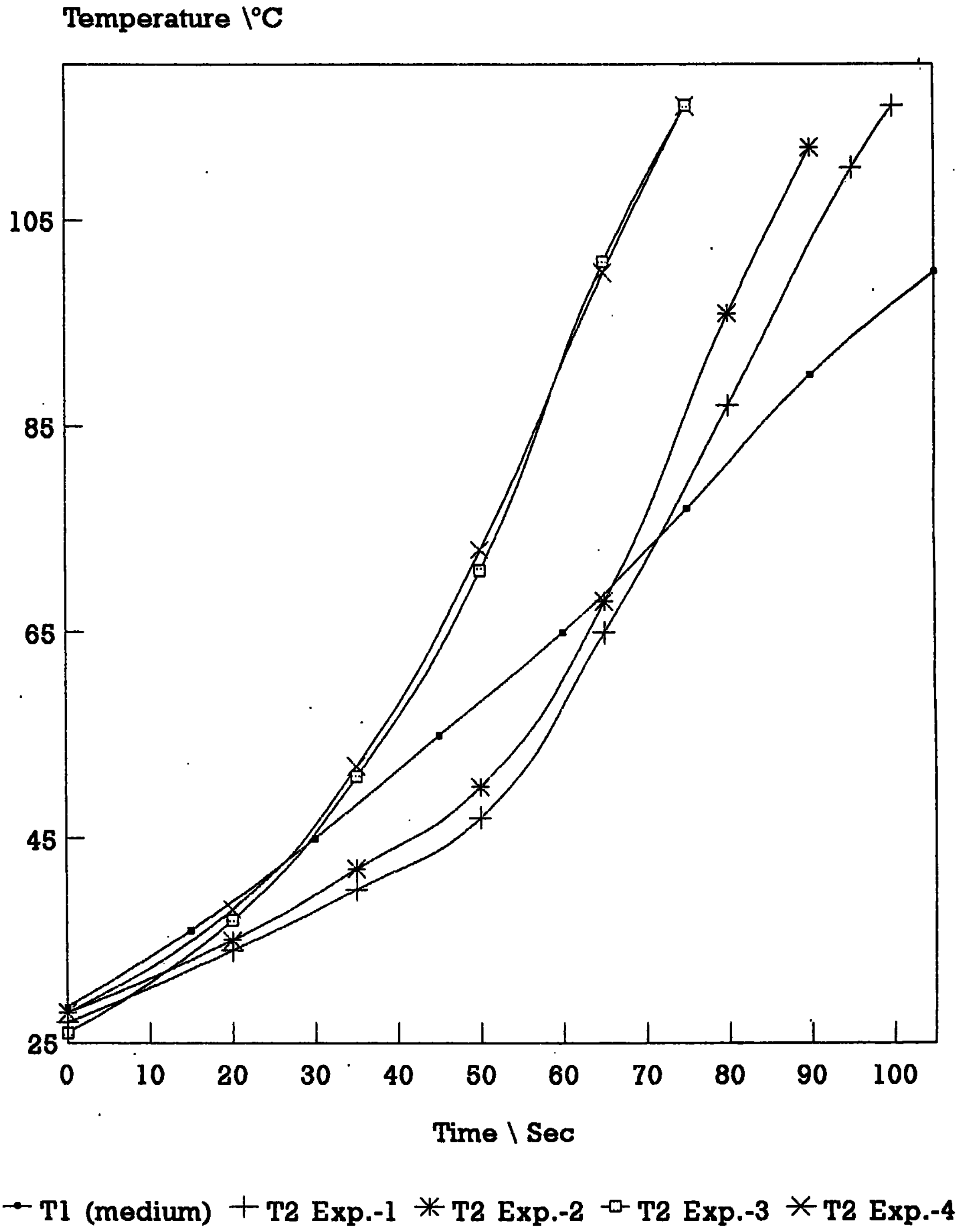


Fig. 3.3. Temperature variation in potatoes

temperature. This is due to conductivity being temperature dependent [8] and this is indicated by the following equation.

$$\sigma_T = \sigma_{ref} [1 + m (T - T_{ref})]$$

Therefore the pattern of the graph was $d^2T/dt^2 > 0$.

When considering the particular food material there are some variations in heating rates with changing the direction of axis of the cube to the electrodes (i.e. to the electric field). The shape of the carrot tuber is more cylindrical, and therefor the cell orientation of the material with respect to the ionic movement is changed with the axis. Further the tissue over layering of carrot is also not similar to potatoes and beetroot. The orientation of the tissues to the electric field has an effect on the heating rate. The grouping of the temperature curves may due to these effects. Also the heating rate was observed to change with the variety of the sample. Different varieties have different cell structures in nature and also shape of the tubers of beetroot and potatoes are more spherical than carrot. These structural variations affect heating rate, also with the contained ions.

Study of the structural changes

In these experiments two different observations were made from two heat application methods when compared to the control (unheated cube). Indirect heating method required more time (45 seconds) than direct heating method (20 seconds) to reach its (inside the particle) maximum temperature. This is caused by high electrical conductivity of the solid particle than the solution. The cross section of the control cube and the cubes heated by these two methods are shown in Fig. 3.4 (a), (b) and (c) respectively. There are clear visible variations between these figures. The cross section of indirectly heated cube indicate that an applied heat was uniformly spread, but directly heated particle is not so. Centres in directly heated one shows overheating than cones and also the sample looks like being heat damaged.

The microscopic structures of the directly heated sample (Fig. 3.7) shows some cell walls damage and carotene pigments (reddish yellow pigments) have been spread to some extent. However during indirect heating (Fig. 3.6) there were no observable damage or such spread.

4. CONCLUSION

Ohmic heating is a rapid heat generating method which can be used as a HTST technique. Increasing of temperature inside the particle is higher than in the solution used in the experiment. The conductivity, original nature of the cells and the orientation of material to the electric field affected heating. Direct heating method, without using any heating medium, was rapid compared to the indirect method which used a heating medium. But the final product was of better quality when a heating medium is used.

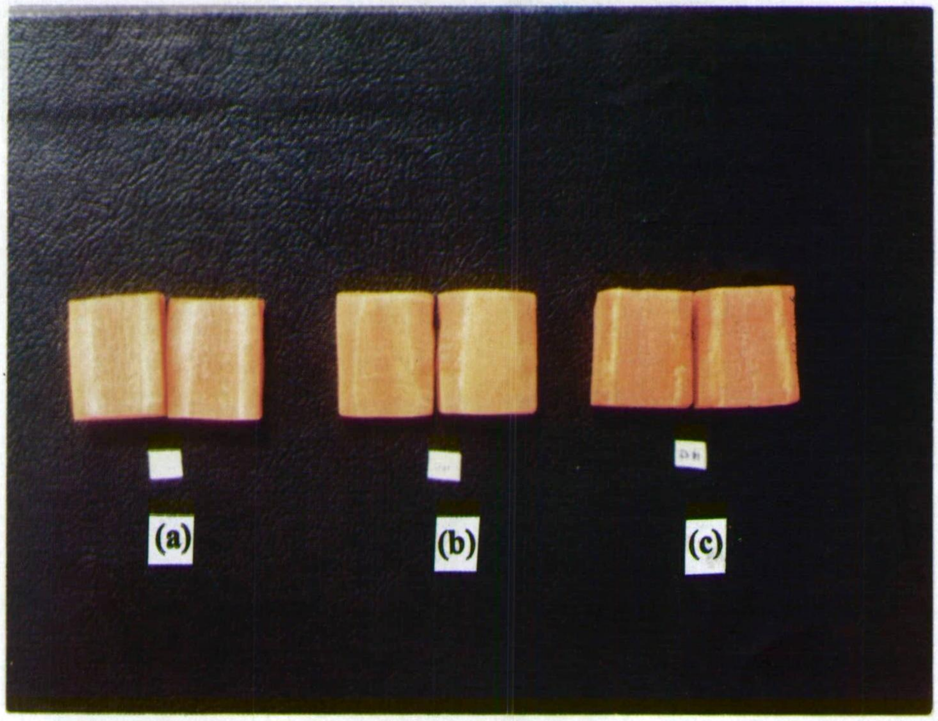


Fig.3.4. (a) Cross-section of an unheated carrot particle, (b) Cross-section of an indirectly heated carrot particle, and (c) Cross-section of a directly heated carrot particle.

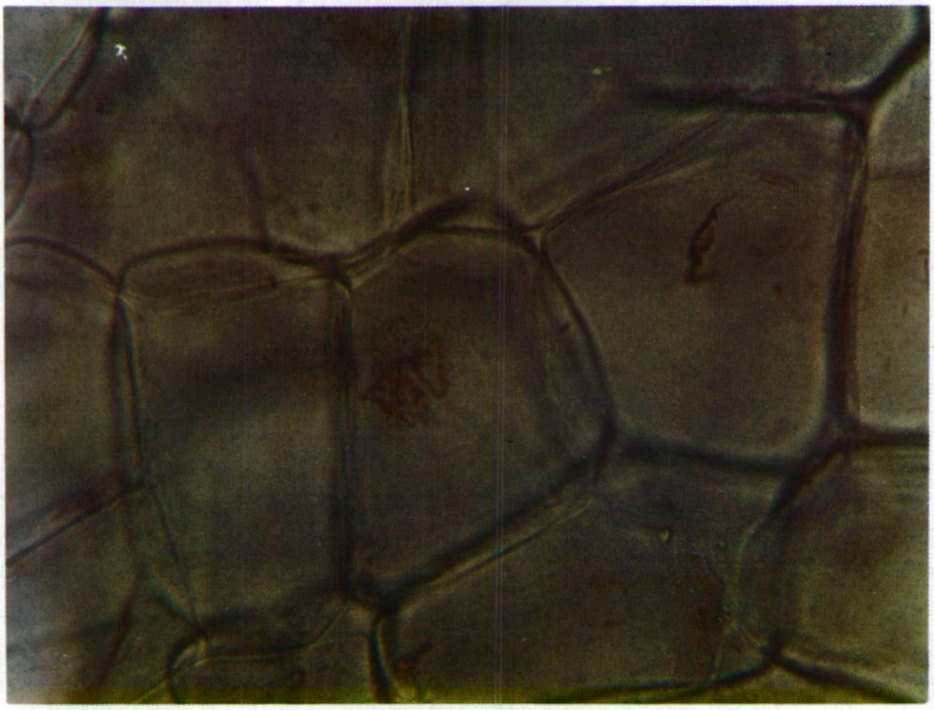


Fig. 3.5. Cell structure of an unheated carrot particle

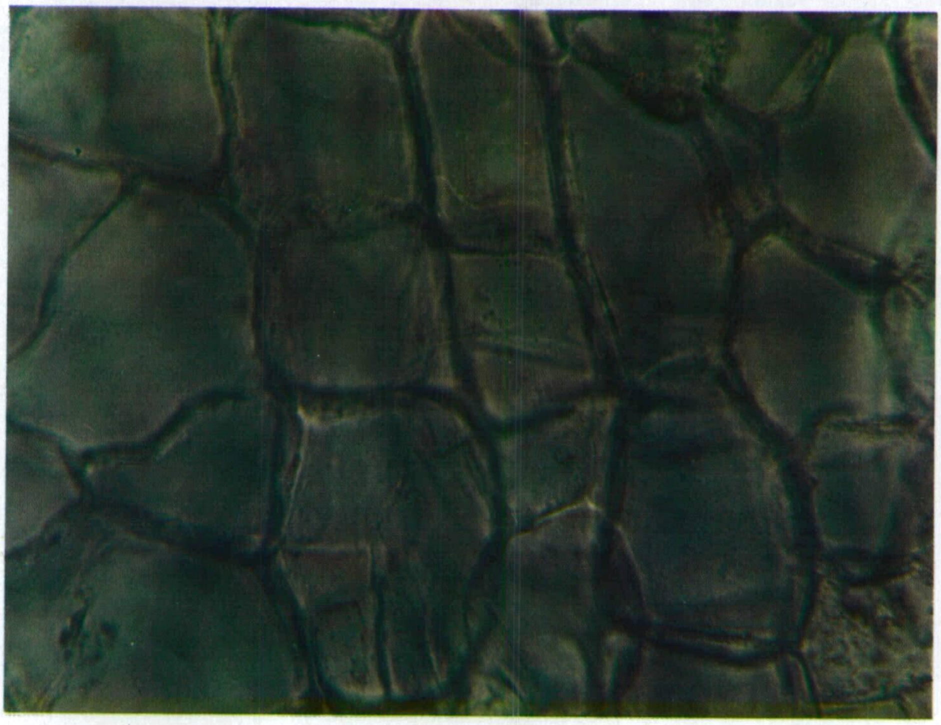


Fig. 3.6. Cell structure of an indirectly heated carrot particle

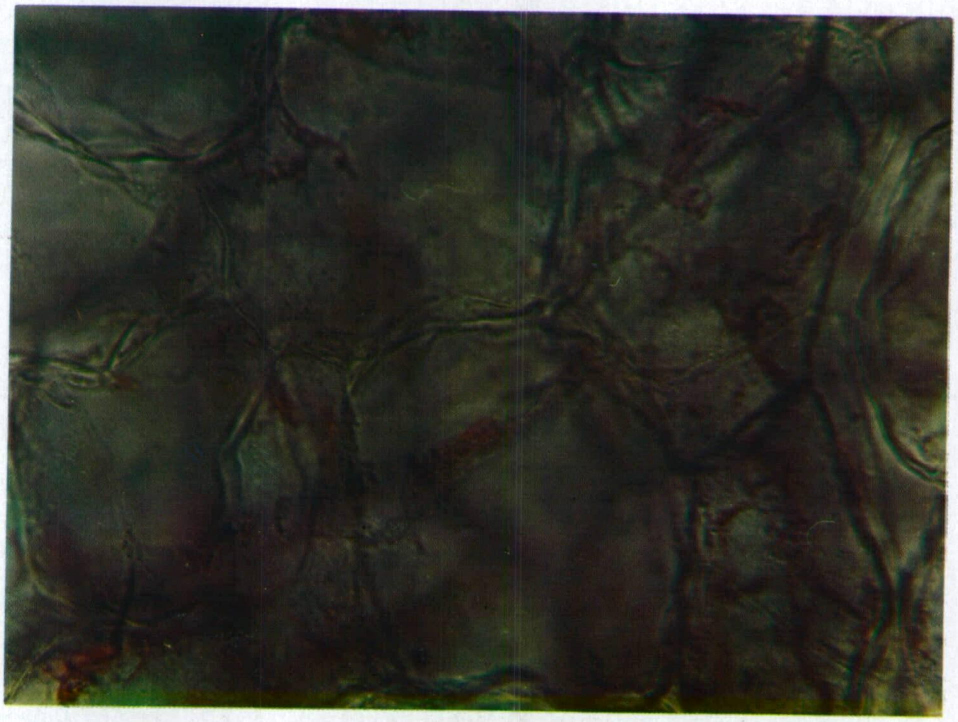


Fig.3.7. Cell structure of a directly heated carrot particle

ACKNOWLEDGEMENTS.

Authors wish to thank the Head and other staff members of the Chemistry department, University of Sri Jayawardenepura for their valuable assistance through out the project.

REFERENCES.

1. Biss, C.H., Coombes, S.A. & Skudder,P.J.(1989). *Process Engineering in the Food Industry.*
2. de Alwis, A.A.P. and Fryer, P.J.(1989). *Journal of Food Engineering*, 11,3-27.
3. de Alwis, A.A.P. Halden. K, Fryer.P.J.(1989). *Chem. Eng.Res.Des*, 67, 159-168.
4. de Alwis, A.A.P. and Fryer,P.J.(1992). *Journal of Food Engineering*, 15,21-48.
5. de Alwis, A.A.P.(1990). *Ohmic Heating of Foods*, PhD Thesis, Cambridge University.
6. Fellows, P. (1988). Food Processing Technology.
7. Palaniappan, S. and Sastry. S.K. (1991). *Journal of Food Presavation and Engineering*, 14, 221-236.
8. Sastry, S.K.(1992). *Indian food Industry*, 11(4), 28-41.
9. Tore Hoyem and Oskar Kvale. (1977). *Physical Chemical and Biological changes in foods by Thermal processing.*