

**DEVELOPMENT OF A CONTINUOUS OHMIC HEATING
SYSTEM AND STUDIES ON MANGO PULP,
TOMATO PULP AND PEAS**

Thesis submitted in part fulfilment of the requirements for the
Degree of Master of Engineering (Agriculture) in Agricultural Process Engineering
to the Tamil Nadu Agricultural University, Coimbatore.

By

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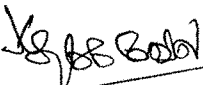
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Acknowledgement

ACKNOWLEDGEMENT

It is my pleasure and privilege to express my deepest sense of gratitude and fervent indebtedness to **Dr. K. Thangavel**, Deputy Registrar (Academic) Chairman of the Advisory Committee, for his guidance and constant encouragement right from the inception of this topic to the successful completion of this report.

I express my sincere thanks to **Dr.N.Varadharaju**, Associate Professor, Department of Agricultural Processing and member of advisory committee for his helpful suggestions and interest shown in this work.

I am thankfully obliged to **Dr. Saraswathy Eswaran**, Assistant Professor, Department of Bio-Energy and member of Advisory Committee for her extreme interest, esteemed help and incomparable wisdom she provided during my entire course work and research work.

I am honest while speaking my admiration towards **Dr.CT.Devadas**, Professor and Head, Department of Agricultural Processing for his spontaneous willingness to provide any help and his warm and caring approach through out the course of this study.

I owe a great deal to **Dr.R.Kailappan**, Professor, department of Agricultural Processing for his special interest and valuable suggestions during the entire period of my research work.

I duly acknowledge artisan **Mr.K.Swaminathan, Mr. Balasundarra**
(Foreman), **Mr.S.Shanmugam** (Store Keeper) and **Mr.Perumalsamy**
(Driver) in Agricultural Processing workshop for their timely help and
constant encouragement during the entire course of this investigation.

On a personal note, I express my gratitude to my friends for their
moral support and cooperation throughout the study.

Last but not the least I thank **KIADEF** (Krishnamurthy International
Agricultural Development Foundation) for providing financial assistance
during the entire period of study.

My thanks are also due to **Sowmiya Communications, TNAU**
Campus, Coimbatore for their neat computer typing of the thesis.


(**SHARMILA GANGULY**)

Abstract

ABSTRACT

DEVELOPMENT OF A CONTINUOUS OHMIC HEATING SYSTEM AND STUDIES ON MANGO PULP, TOMATO PULP AND PEAS

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India is the largest producer of fruits and vegetables. However, with a growing population it is not in a position to meet the recommended per capita norms. Annual losses of 50 per cent occurs in fruits and vegetables due to poor infrastructural post harvest handling and processing facilities. Fruits and vegetables owing to perishable nature deteriorate quickly. This huge extent of losses could be reduced resorting to processed foods. Thermal processing is one of the oldest and most widely adopted method for preservation of fruits and vegetables. Ohmic heating is a novel technique in which food materials get heated when electric current is passed through. Among the advantages claimed for this technology are uniformity of heating, product safety and improvements in quality with minimal structural, nutritional or organoleptic changes.

The objective of this work was to develop a continuous ohmic heating system and perform ohmic heating on mango pulp, tomato pulp and peas which are popular canned products.

A continuous ohmic heating system of 30 kg/h capacity was developed. Ohmic heating of mango pulp and tomato pulp in the developed system was carried out at different voltages *viz.*, 30, 60, 90 and 110 volts and at different flow rates of 0.5 l min⁻¹, 0.75 l min⁻¹ and 1 l min⁻¹. Ohmic heating of peas was carried out in the system at voltages of 30, 60, 90 and 110 volts and at three concentrations *viz.*, 0.001 M, 0.01 M and 0.1 M of conducting solutions.

Heating rate increased with applied voltage. Time taken to attain 100°C temperature at 110 V for mango pulp, tomato pulp and peas in 0.1 M brine solution was 10 minutes, 6 minutes 9 seconds and 5 minutes respectively. Heating was also affected by flow rate, as the flow rate reduced, heating time reduced. Further, heating rate increased with the increase in the concentration of conducting NaCl solution. Time required to heat peas to 100°C at 110 V at 0.001 M concentration was 10 minutes which reduced to 5 minutes when concentration was 0.1 M.

Current and power consumption increased with applied voltage. At a particular voltage, current consumption increased with time and when operated at 110 V maximum current consumption of 20 A for mango pulp, 12 A for tomato pulp and 24 A for peas in 0.1 M brine solution were recorded. Current and power consumption also increased with the increase in the concentration of conducting solution.

Firmness of peas reduced from an initial value of 0.182 kg/mm² to 0.114 kg/mm² after ohmic heating. Viscosity of ohmically heated tomato pulp and mango pulp were found to be 96 poise and 2612.16 poise, which had increased from their initial values of 94.98 poise and 2136.4 poise. Colour of mango pulp, tomato pulp and peas were changed.

β -carotene content of ohmically heated mango pulp was found to be 2047 $\mu\text{g}/100\text{g}$ and lycopene content of ohmically heated tomato pulp was 200 $\mu\text{g}/100\text{g}$. Ascorbic acid content of ohmically heated mango pulp, tomato pulp and peas was found to be 30, 25 and 10 $\text{mg}/100\text{g}$ respectively. Polyphenol oxidase activity of ohmically heated mango pulp, tomato pulp and peas was found to be 250, 376 and 40 unit/mg respectively.

Cost of the developed continuous ohmic heating system was found to be Rs.17,000. Cost of operation was found to be Rs.58.07/h and efficiency of the system was 45.38 per cent.

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SYMBOLS AND ABBREVIATIONS

A	-	Ampere
AC	-	Alternating Current
cm	-	Centimetre
<i>et al.</i>	-	and others
G	-	Green
g	-	gram
g/cc	-	gram per cubic centimetre
h	-	hour
HCl	-	Hydrochloric acid
hp	-	horse power
Hz	-	hertz
kcal	-	kilo calorie
kg	-	kilogram
kJ	-	kilo joule
kW	-	kilo Watt
$l \text{ min}^{-1}$	-	litre per minute
l	-	litre
m	-	metre
M	-	Molar
min	-	minute
MJ	-	Mega Joule
ml	-	millilitre
mm	-	millimetre

NaCl	-	Sodium chloride
nm	-	Nanometre
PP	-	polypropylene
ppm	-	part per million
PPO	-	polyphenol oxidase
s	-	second
SS	-	Stainless Steel
TSS	-	Total Soluble Solids
V	-	Volt
VAW	-	Voltage Ampere Watt
<i>viz.</i> ,	-	namely
w/v	-	weight per volume
YR	-	Yellow Red
R	-	Red
β	-	beta
μ	-	Mu
Δ	-	delta
ρ	-	Rho
$^{\circ}\text{C}$	-	degree celsius
%	-	per cent
η	-	efficiency
ϕ	-	diameter
\$	-	dollar

Introduction

Chapter I

INTRODUCTION

India produces 43 million tonnes of fruits and 73 million tonnes of vegetables annually, which accounts for 10 per cent of world's fruits and vegetable production (Anon, 2000). Despite of the above fact, in India only 0.5 to 1 per cent of total fruits and vegetables are processed as against 83 per cent in Malaysia, 80 per cent in South Africa, 70 per cent in Brazil and 65 per cent in USA (Singhal, 1999). Because of the lack of cold chain and handling by 5-7 intermediaries, about 50 per cent of horticultural produce goes waste. India wastes more fruits and vegetables in a year than consumed in United Kingdom (Saran, 1999). This huge waste costs more than 30,000 million annually (Maini, 1997). According to ICMR recommendations, daily consumption of fruits should be 92 g and vegetables 300 g, but statistics reveal the per capita availability of fruits as 46 g and vegetables as 135 g (Singh, 1991). This low per capita availability can be attributed to poor post harvest handling processing and storage facilities. This clearly indicates that processed food industries have the potential to significantly grow and contribute to foreign exchange earnings by means of export.

Post harvest deterioration of fruits and vegetables can be attributed to three major mechanisms *viz.*, microbial spoilage, enzymtic spoilage and chemical spoilage. To combat these factors and enhance the shelf life, fruits and vegetables are to be subjected to processing. Commercial processing not only improve the marketing of fruits and vegetables but also minimize wastage by organizing proper processing facilities. Preservation helps the food to be available in off season and in any place. The various methods of preservation are by employing high temperature, low temperature, preservatives, dehydration, irradiation etc.

Of the various means of preserving foods the use of heat finds very wide application. It is done mainly to destroy the microorganisms as well as to inactivate the enzymes. Thermal inactivation is the only way to reduce enzymatic spoilage, since other methods have little effect on enzymatic activity. Since the heat resistance of enzymes like peroxidase, pectinesterase, polyphenol oxidase etc. are higher than that of microorganisms, inactivation of these serve a basis of thermal processing (Ramaswamy, 1995). Out of the various thermal processing like sterilization, pasteurization, blanching etc., blanching is most common. This is generally applied to fruits and vegetables primarily to inactivate natural food enzymes. This goes as an important pre treatment prior to dehydration, canning, packaging and when the products are to be frozen.

Conventional thermal processing of fruits and vegetables is usually done by steaming and hot water treatment. But studies reveal that blanching by steam injection is not energy efficient compared to that by using heat exchanger (Thomas *et al.*, 1981). But the product quality resulting from both methods is inferior to fresh product because of the over cooking of the exterior portion and the undercooking of the interior portion of fruits and vegetables. Hot water blanching is the least desirable method, because of dissolution of soluble components in water.

The quality of the product obtained after blanching by microwave heating is quite high compared to previous method, but this is highly capital intensive and less energy efficient. So, the need of a rapid method of energy efficient and uniform heating, energy efficiently leads to the revived attention towards ohmic heating. Concept of ohmic heating dates back to nineteenth century. At that time it

was employed for pasteurization of milk, by passing the milk between parallel electrodes. This technology later disappeared due to lack of suitable inert electrode materials. But during recent years, ohmic heating is being used again for food process applications due to the simplicity of process and high energy saving.

Ohmic heating occurs when an alternating current is passed through a material with resistance R, with the resultant energy generation causing temperature rise. The basic equation for energy generation under ohmic heating is

$$P = I^2 RT \quad \dots\dots 1.1$$

Where, P = heat generated in Watts

I = current in amperes

R = resistance in ohms

T = time in seconds

During ohmic heating, heat generation takes place uniformly throughout the material, avoiding overcooking or undercooking. This results in thermally processed products of high quality compared to conventionally heated products. Efficiency of the system is very high since energy supplied is entirely used for heating of the material employed and no energy is supplied to any device other than the material meant for heating.

The present research work was planned to fabricate a continuous ohmic heating apparatus and perform ohmic heating on tomato pulp, mango pulp and peas as these three processed products find a wide domestic and international market. A detailed study on the parameters affecting ohmic heating as well as the biochemical changes during ohmic heating was also carried out.

Following are the objectives of the study:

1. Fabrication and testing of a laboratory scale continuous ohmic heating apparatus.
2. To conduct studies on tomato pulp, mango pulp and peas and to compare it with conventional blanching method.
3. To study the changes in engineering properties of processed products.
4. To study the biochemical changes occurring in tomato pulp, mango pulp and peas due to ohmic heating.
5. To work out energy efficiency and cost economics of ohmic heating.
6. Simulation and modelling of existing batch type ohmic heating apparatus.

Review of Literature

Chapter II

REVIEW OF LITERATURE

The past decade has seen a tremendous growth in ready prepared food products. Hence, the world's food industry has focused increasing attention on continuous sterilization of liquid particle mixture. This had lead to rapid methods of heating food and has resulted in revived attention towards ohmic heating. When compared to conventional methods, heat penetration in ohmic heating throughout the product is far more rapid and even, resulting in high levels of flavour retention and particle integrity, and above all it is ecofriendly. A number of attempts have been made to exploit this process, some of the works done in this course are described briefly in this chapter. Also there exists a potential of ohmic heating to go as a precursor to aseptic processing. Cost and nutritive loss are two major factors of any thermal processing. Therefore, the literature pertaining to all these works are classified as follows:

1. Principles and techniques of ohmic heating
2. Continuous ohmic heating systems
3. Ohmic heating as a precursor to aseptic processing.
4. Enzyme activity in fruits and vegetables
5. Thermal preservation of fruits and vegetables.
 - (a) Nutrient losses in thermal processing
 - (b) Cost and energy accounting in thermal processing

2.1. Principles and Techniques of Ohmic Heating

Mizrahi *et al.* (1975) stated that the come up time required to reach blanching temperature in ohmic heating can be calculated by:

$$t_c = \frac{\rho \times C_p \times (T_B - T_I)}{(V/L)^2 \times k} \quad \dots\dots 2.1$$

Where,	t_c	=	come up time
	ρ	=	density
	C_p	=	specific heat of the product
	T_B	=	blanching temperature
	T_I	=	initial temperature of the product
	V	=	voltage drop between the electrodes
	L	=	distance between the electrodes
	k	=	specific electrical conductivity of the product

Yadav *et al.* (1986) investigated on the electrical deacidification of milk. Stainless steel, silver and aluminium were tried as electrode material. Aluminium was found to be the most acceptable, as stainless steel electrodes were conducive to pitting and silver electrodes lost their weight rapidly and hence were uneconomical.

Halden *et al.* (1990) investigated the changes in the electrical conductivities of pork meat and potato during ohmic heating. It was found that electrical conductivity of pork slightly lowered at high temperature due to fat melting and for potato, electrical conductivity increased at around 80°C due to starch gelatinization.

DeAlwis and Fryer (1991) reported that electrical conductivity of food material critically determines the local rate of heat generation in ohmic heating.

$$Q = kE^2 \quad \dots\dots 2.2$$

where, Q is the rate of heat generation

k is the electrical conductivity of the product

E is the electric field strength

It was also observed that rate of ohmic heating was same irrespective of size for particles with same electrical conductivity.

Palaniappan and Sastry (1991a) found that the electrical conductivities of tomato and orange juices increased with temperature and decreased with solid content. The effect of temperature was greater for orange juice, whereas effect of solid content was greater for tomato juice. Reducing the particle size of juice solids increased the effective conductivity of the juice.

Palaniappan and Sastry (1991b) studied about the electrical conductivities of selected solid foods during ohmic heating. It was found that electrical conductivity of solid foods increased linearly with temperature during ohmic heating at a voltage gradient of 60 v/cm due to electroosmotic effect. Soaking of vegetable samples in water decreased electrical conductivity by leaching of solutes, whereas infusion of salt solution increased electrical conductivity.

Sastry (1992a) reported that the basic relation for the energy generation of a food under ohmic heating can be given by:

$$U = |\nabla v|^2 \sigma \quad \dots\dots 2.3$$

where, U is the energy generation rate per unit volume

σ is the electrical conductivity

∇v is the voltage gradient

It was observed that for solid materials under going ohmic heating, σ -T relation becomes linear as the electric field strength increased, this was possible due to electro osmotic effects which increased the effective conductivity at low temperatures for solids and for liquids the σ - T relationship was linear regardless of the mode of heating.

Sastry and Palaniappan (1992a) studied the influence of particle orientation on the effective resistance and ohmic heating rate of a liquid particle mixture. It was found that effective resistance of two phase mixture consisting of liquid and cubic particles had only a slight dependence on orientation.

Sastry and Palaniappan (1992b) employed a static ohmic heater to study heating rate of potato cubes in sodium phosphate solutions. It was found that particle liquid mixtures heated at rates which were dependant on the relative conductivities of the phases and the volume of fractions of the respective phases. Solids of low conductivity relative to fluid lagged behind fluid when they were at low concentrations but under high concentration conditions, particles heated faster than liquid.

Sastry and Palaniappan (1992c) reported important design considerations of an ohmic heating process.

1. Close matching of electrical conductivities of phases is desirable.
2. If the solid phase is of lower electrical conductivity than liquid phase the particle concentration plays a critical role, high particle concentration is conducive to faster heating of solid phase but slower overall heating.

3. For cubic and spherical particles, orientation has small effect but for cases in which particle aspect ratios are far from unity, it is important as particle oriented perpendicular to current flow thermally leads the fluid.
4. Particles containing fat must be handled with care, as fat melts and separates from solid phase to form a third phase in mixture, complicating the heating pattern.

Zaror *et al.* (1992) observed that ohmic sterilizer yields higher heating rates than conventional indirect heaters and the temperature at the particle centre in ohmic sterilizer rised faster than in steam sterilizer even in the case of poorly conducting solids.

Imai *et al.* (1995) applied ohmic heating to Japanese white radish at 50Hz - 10 kHz and 40 v/cm to examine the effects of frequency on heat generation. Sharpest initial rise of temperature and shortest time to raise the temperature to 80°C was observed at 50 Hz due to electroporation of tissue membrane, resulting in reduction of its impedance. Heating rates above 60°C were found to be same and linear for all frequencies.

Kim *et al.* (1996a) observed higher lethality of *Bacillus stercorophilus* at the centre of the meat ball rather than near the surface while experimenting with a 5 kW continous ohmic heating system.

Mizrahi (1996) reported that leaching of solutes during blanching followed the same pattern regardless of the heating methods (hot water or ohmic). The extent of solute loss was linearly proportional to the surface volume ratio of the product and the square root of the process time.

Zoltai and Swearingen (1996) studied on product development considerations for ohmic processing and reported that the conductivity differences could be minimized by avoiding fat, oil, nuts, air, alcohol, bone and ice.

Anil (1998) studied on ohmic heating of papaya, tomato and carrot in brine solution. It was observed that heating rate increased with current and power consumption and also with concentration of conducting solution.

Alam and Naik (2000) reviewed ohmic heating and stated that the process had been successfully applied to sterilization of diced and sliced fruit, extraction, pretreatment for drying and expression, fermentation and online detection of starch gelatinization.

2.2. Continuous Ohmic Heating Systems

Malkki and Jussila (1979) employed a continuous resistance heating apparatus for heating sausages. The apparatus consisted of PTFE (Poly Tetra Fluoro Ethylene) tube and cylindrical graphite electrodes and found that temperature increased with increase in power consumption. An uniform heating throughout was observed and the final product was of good colour, taste and consistency.

Sastry (1992b) suggested the following points for safe process design in a continuous flow ohmic heater.

- a. Thermal process calculations must be based on the lowest conductivity particle in the mixture.

- b. The lowest conductivity particle will heat slowly relative to its surroundings if located around fluid or other particles of higher electrical conductivity.
- c. Temperature attained would depend on residence time. Fast moving particles can thermally lag the fluid but to lesser extent than expected for conventional processing systems.

Khalaf and Sastry (1994) studied the effect of fluid viscosity on the ohmic heating rate of solid liquid mixture in static, vibrating and continuous ohmic heaters. For static ohmic heater, heating rate of fluid and particle was independent of viscosity. In vibrating ohmic heater the heating rate of particle and fluid increased with fluid viscosity and in continuous higher viscosity fluid heated faster.

Quarini (1994) analysed the thermohydraulic aspects of ohmic heating process on a continuous flow ohmic heater. It was found that though heating rates were uniform, temperature distribution across the column varied significantly. This was due to the variation in the velocity profile across the column.

Bhat (1996) demonstrated the usefulness of laser in the study of ohmically heated jet. It was reported that the presence of an electric field and low values of flow velocities rule out the use of techniques other than laser doppler technique to obtain the mean velocity and turbulence statistics accurately.

Giese (1996) described a continuous commercial ohmic heating system developed by APV, U.K. It consisted of twin piston pump, ohmic heating column, holding chamber, cooling section and aseptic packaging chamber. It was capable of heating upto 140°C in 90 seconds and the product could be cooled down to ambient conditions within 15 minutes.

Kim *et al.* (1996b) investigated on validation of ohmic heating for quality enhancement of food products and found that sterility of the entire food product could be achieved by ohmic heating if the power level was adjusted to maintain the fluid temperature at the ohmic column exit above 131°C and a flow rate to give a residence time of 1 min. in holding tube and ensure even the fastest moving portion was held for 0.5 minute in the holding tube.

2.3. Ohmic Heating as a Precursor to Aseptic Processing

Ohmic heating is an innovative thermal process technology. A variety of high quality low and high acid products containing particulates have been tried. There is a considerable interest to incorporate ohmic heating with aseptic packaging to process shelf stable meals containing particulates.

Parrot (1992) evaluated ohmic heating system for aseptic packaging of food and stated that ohmic heating will play a major role in aseptic processing, as it had the ability to heat particulates uniformly, without mechanical damage combined with low nutrient and vitamin losses and no fouling of heat transfer surfaces.

Patwardhan (1999) reviewed aseptic packaging of particulate food products and reported that ohmic heating had the ability to provide exceptionally rapid uniform heating of the product and provided a high degree of microbiological safety and thus had been approved by Food and Drug Administration, USA.

Rao *et al.* (1999) described eleven particulate food processing systems for aseptic processing and advocated ohmic system for significantly less processing time besides minimum adverse effect on the quality of the food.

Tewari and Jayas (1999) reported aseptic processing and packaging as a promising technique for food processing industries and said sterilization of the product could be done by (i) direct heating (steam injection or infusion) (ii) indirect heating (plate, tubular or scraped surface heat exchanger) and (iii) ohmic heating.

2.4. Enzyme Activity in Fruits and Vegetables

Enzymes are biocatalysts which accelerate the rate of biological reactions. They are present in all biological substances. Common enzymes present in fruits and vegetables are polyphenol oxidase, peroxidase, catalase and transaminase. These enzymes play a definite role in ripening. If the enzymatic reaction continues the fruit or vegetables gets spoilt.

Hulme (1970) reported that polyphenol oxidase played a vital role in the biochemical processes leading to fruit ripening. The enzyme activity was found to increase during growth phase and subsequently declined as the fruit ripened. Another enzyme protease catalyzed protein catabolism resulting in increase of free amino acids and amides. The enzyme catalase decomposed hydrogen peroxide to water and oxygen. This enzyme together with peroxidase was called the hydroperoxidases. Oxidation of substrates such as phenols, amines, ascorbic acid and indole was catalyzed by the peroxidases.

Ambrosova and Shchutskaya (1973) stated that polyphenol oxidase activity in potato increased with increasing maturity of tubers. Polyphenol oxidase activity of 3.2-6.35 unit/mg of protein was observed for potato.

Bal and Singh (1978) observed a reduction in amount of total phenolics in ber at full ripe stage. It was found that this reduction was due to the enzymatic hydrolysis of phenolic compounds to sugar and other volatiles.

William and Francis (1982) observed that darkening of the total cambial region of sweet potato, during lye peeling was due to the reaction between polyphenol oxidase and dihydroxy phenol.

Jose and Lourenco (1985) extracted and inactivated polyphenol oxidase from potato. The heating of polyphenol oxidase at 65°C revealed that decrease of its activity did not follow first order kinetics. It showed high stability with 40 per cent of its original activity remaining after 10 minutes heating at pH 7.0. It was also observed that lowering of pH decreased the heat resistance of the enzyme.

Chen and Paul (1986) confirmed the occurrence of light brown skin scald due to enzyme activity on papaya subjected to chilling injury. To avoid this, it was suggested not to keep papaya at less than 7°C for more than two weeks.

Errington *et al.* (1997) reported that tomato fruit ripening was accompanied by the degradation of cell wall pectin by the polygalactaronase enzyme.

Lay-Yee *et al.* (1998) reported that polygalacturonase enzyme, which catalyzes the hydrolysis of pectins, a component of cell walls, was destroyed when papaya fruit was subjected to hot water treatment at 46°C and thus delayed softening.

Jiang and Fu (1999) carried out studies on post harvest browning of Litchi. It was found that litchi pericarp browning was due to formation of brown substance which were catalyzed by polyphenol oxidase and peroxidase.

2.5. Thermal Preservation of Fruits and Vegetables

In India, 50% of total fruits and vegetables produced is reported to go waste costing more than Rs.30,000 million annually. Owing to the perishable nature of fruits and vegetables they get easily spoiled, the principal cause being growth of spoilage microorganisms, the action of naturally occurring enzymes in the horticultural produces, chemical reactions structural changes and conditions of storage of fruits and vegetables. This could be prevented by destroying microorganisms in fruits and vegetables and prevent recontamination by microorganisms from outside (Khurdiya, 1995). In this process depending on the severity of heat treatment there would be certain loss in the quality. Yet another important factor was energy consumption of the process which decides the cost which in turn could decide the commercial feasibility of any product to be processed.

2.5.1. Nutrient losses in thermal processing

Shrikhande *et al.* (1976) conducted studies on thermal processing for bulk packaging of mango pulp and found that carotenoid and ascorbic acid content of fresh pulp reduced from 7.9 and 39.24 mg/100g to 4.6 and 15.38 mg/100g after six months of storage after heat sterilization in cans.

Adsule *et al.* (1982) studied the effects of hot water dipping on tomatoes. It was found that a dip at 70°C for 5 minutes not only decreased microbial load but was also safe for seed viability.

Lee *et al.* (1982) studied the effects of post harvest handling and processing in vitamin contents of peas and reported that ascorbic acid, Vit.B6 and niacin contents decreased significantly during blanching and canning processes. Thiamin content decreased significantly as a result of canning. Riboflavin and carotene remained relatively unaffected by heat processing. Also some significant difference in vitamin contents of canned peas among different processing plants was observed.

Ranote and Bains (1982) investigated on preservation of kinnow fruit juice and found that juice heated to 98°C for 1 minute underwent ascorbic acid loss from 18.7 to 10.7 mg/100g after storage for 3 months.

Beerh and Rane (1983) studied on canning of mandarin orange segments. It was found that 23.46% of ascorbic acid was lost during canning and 35 - 40% on storage for 10 months after a heat treatment of 88°C for 13 minutes and sealed cans at 82.5°C for 10 - 12 minutes.

Nanjunda Swamy *et al.* (1983) studied the preparation and preservation of tomato paste. It was found that shelf life was significantly enhanced when tomato paste was heated to 85°C and hot filled in sterilized cans and sealed and further processed in boiling water for 30 minutes.

Teotia *et al.* (1983) studied on quality of canned okra and proposed that to get a firm texture with least mucilage, okra pieces should be blanched in 0.1% citric acid simmering solution for 2 minutes and then steeped in 1% CaCl₂ for 2 hours and then filled in cans and covered with simmering hot line containing 2.5% common salt, 0.4% citric acid and 1.5% sugar and exhausted at 82°C and then sealed and processed in boiling water for 30 minutes.

Ros and Rincon (1993) studied the changes in constituents of pea during commercial canning and formulated a heat treatment index to distinguish raw, blanched and canned peas.

$$\text{HTI} = \frac{\text{NPN} \times \text{AP}}{\text{TS}} \quad \dots\dots 2.4$$

where, HTI stands for heat treatment index

NPN stands for non-protein nitrogen

AP stands for albumin protein

TS stands for total sulphur

NPN, AP and TS showed most regular decreasing trend during commercial canning process.

Sudhakar and Maini (1994) studied stability of carotenoids during storage of heat processed mango pulp at room temperature. Among the various treatments tried ascorbic acid (200 mg/100g) and 0.01% BHA (butylated hydroxy anisole) was found to be best as there was no loss of carotenoids upto four months storage.

Tapadia *et al.* (1995) studied about vitamin C content of processed vegetables and reported that cooking without the use of the lid resulted in maximum loss of vitamin C.

Anil (1998) found that β -carotene, lycopene and ascorbic acid contents decreased with increase in temperature during ohmic heating. The initial beta

carotene content of papaya, carrot and tomato were 628, 6497 and 330 $\mu\text{g}/100\text{g}$ respectively which lowered to 298, 4798, 112 μg respectively, after ohmic heating to 100°C . The lycopene content of papaya carrot and tomato during ohmic heating reduced from initial values of 363, 1018 and 649 $\mu\text{g}/100\text{g}$ to 110, 324 and 195 $\mu\text{g}/100\text{g}$ respectively and the ascorbic acid content lowered during ohmic heating for papaya, carrot and tomato from 55.9, 30.34 and 23.02 to 6.75, 6.9 and 2.1 $\text{mg}/100\text{g}$ respectively.

Ghorai and Khurdiya (1998) conducted studies on storage of heat processed kinnow mandarin juice (90°C for 10 minutes) and reported that TSS, ascorbic acid, carotenoids, free amino acids, soluble proteins and acidity decreased with increase in storage period.

2.5.2. Cost and energy analysis

Chinan *et al.* (1986) measured the energy use by each piece of equipment during spinach processing. The total energy required was 7.3 MJ/kg of raw spinach. The exhaust boxes, blanchers and retort used 49, 34 and 15 per cent of energy respectively.

Classen *et al.* (1992) computed the energy usage of a vegetable processing plant during canning of vegetables. Process energy requirement of spinach, pork, beans and huminy was calculated to be 2.7, 3.9, 4.7 and 6.6 MJ/kg respectively.

Bera *et al.* (1995) performed an energy accounting in fruits and vegetables canning industry and reported that pasturization and sterilization in which thermal energy in the form of coke was employed consumed 72.63 and 27.24% of total energy input in the processing system.

Larson and Cortez (1995) reported that the effect of energy analysis was effective management. The energy analysis was found to be essential for cost effective design and management of process utilizing energy of different quantities.

Allen *et al.* (1996) made an economic engineering study of ohmic food processing and predicted the profitability as \$2.00/lb in whole sale. The profitability analysis suggested that ohmically heated products can command a high price and there exists opportunities for highly profitable investments.

Materials and Methods

Chapter III

MATERIALS AND METHODS

Ohmic heating occurs when electric current is passed through food materials to be heated. This electroresistive heating is volumetric by nature, therefore has potential to significantly reduce over processing. Ohmic heating is carried out using ohmic heating apparatus.

In this chapter various materials and methods employed for the design and operation of laboratory scale continuous ohmic heating apparatus are presented. Also the procedures followed to determine the engineering properties and biochemical characteristics of ohmically heated mango pulp, tomato pulp and peas are included.

3.1. Design of Continuous Ohmic Heating System

The essential components of the continuous ohmic heating apparatus are

1. Heating unit
2. Pumping unit
3. Inlet and outlet tanks
4. Feeding unit for particulates
5. Stainless steel pipes and pipe fittings
6. Measuring instruments

3.1.1. Heating unit

The heating unit of continuous ohmic heating system consists of a polypropylene pipe and two stainless steel tubular electrodes fitted facing each

other along the periphery of the pipe. Stainless steel sheet of 1.5 mm thickness was given a tubular shape and was bolted at three points. When current is applied through the flowing food material, heating takes place.

3.1.1.1. Material of construction

Main criteria for selection of material for the heating chamber are:

- (i) Heating chamber should not conduct electricity.
- (ii) Heating chamber should be capable of withstanding high temperature.
- (iii) Heating chamber should not impart off flavour to the product
- (iv) It should allow a steady continuous flow of particulate food material.

Considering the above points polypropylene pipe was selected for the heating chamber (Halden *et al.*, 1990).

The electrode material should have

- 1) Non porous surface, so that it does not absorb odours and flavours and does not provide breeding ground for bacteria and fungi.
- 2) It should be resistant to acidic or alkaline foods or cleaners.
- 3) It should be capable of withstanding high temperature
- 4) It should have an excellent formability

Keeping the above facts in mind SS316 was chosen as electrode material (Raghavan *et al.*, 1994).

3.1.1.2. Design of heating unit

To get a desirable voltage gradient of 60 v/cm (Palaniappan and Sastry, 1991a), gap between the electrodes, when a voltage of 270 volts is applied should be:

$$\begin{aligned}
 &= \frac{270}{60} \\
 &= 4.5 \text{ cm}
 \end{aligned}$$

Polypropylene pipe of 4 mm thickness with 5.5 cm internal diameter, which is close to the designed gap between the electrodes was selected.

1.5 mm thick stainless steel sheet (SS 316) which could be given a tubular shape and introduced as electrodes within this tube was selected.

Therefore, maximum gap between the electrodes

$$\begin{aligned}
 &= 5.5 - 0.3 \\
 &= 5.2 \text{ cm}
 \end{aligned}$$

$$\begin{aligned}
 \text{Available voltage gradient} &= \frac{270}{5.2} \\
 &= 51.92 \text{ v/cm}
 \end{aligned}$$

For the proper heating of food material and the conducting solution within one pass, flow rate is assumed as 1 l min⁻¹ and residence time as 3 minutes.

Therefore holding capacity of the pipe should be 3 litres.

To facilitate this, length of the pipe should be,

$$\frac{\pi}{4} \times (5.5)^2 \times L = 3000$$

$$L = 126.27 \text{ cm}$$

$$\sim 130 \text{ cm}$$

Therefore, the length of the polypropylene pipe was chosen as 150 cm and within it electrodes of 130 cm length were placed.

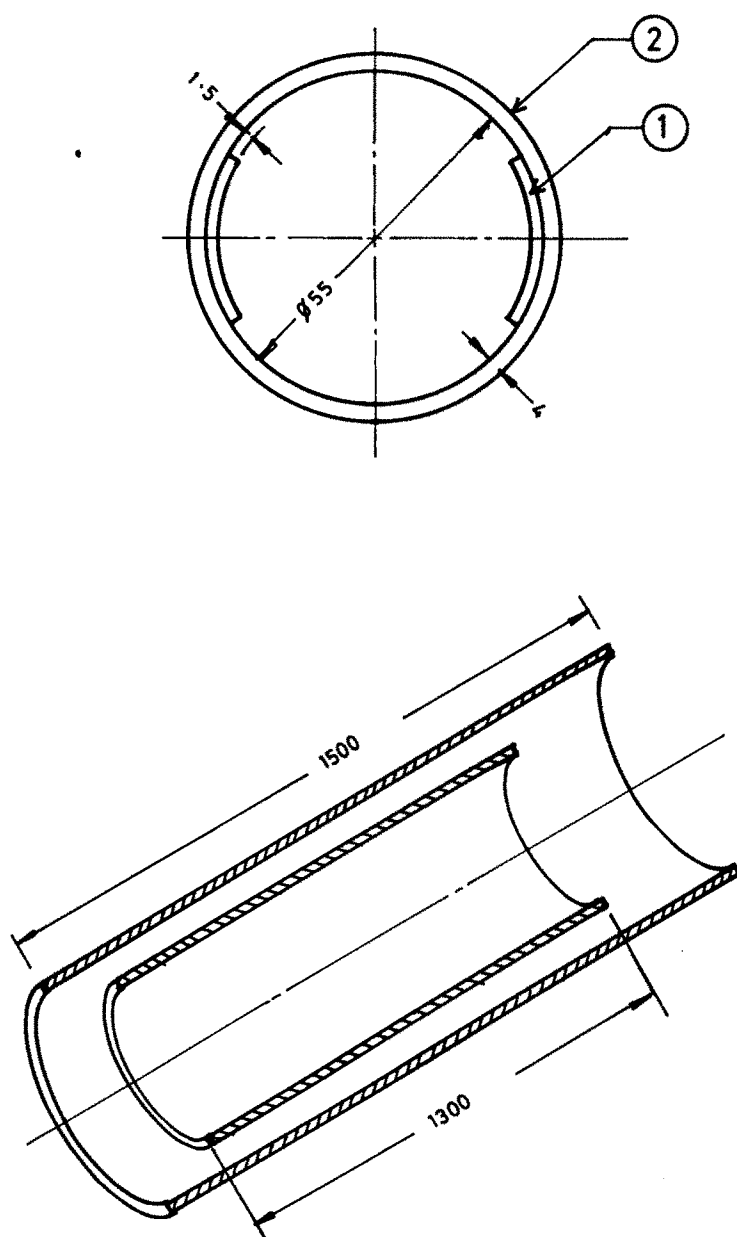
Thus, the heating unit of developed ohmic heating system consisted of polypropylene heating chamber of 150 cm length, 5.5 m internal diameter and within it two SS316 strips of size 130 x 5, 0.15 cm, which were given a tubular shape were introduced centrally and fixed by three nuts and bolts each on two sides facing each other as shown in Fig. 3.1.

3.1.2. Pumping system

A rotary gear stainless steel pump was selected since, the raw material selected for the study were highly viscous in nature. Maximum flow rate required was 1 l min⁻¹. Pump available in the market, with a capacity of 20 l min⁻¹ was selected. A number of ball valves were provided to get a desirable flow rate in the heating unit.

3.1.3. Inlet and outlet tanks

Two aluminium containers of 30 litres and 20 litres were selected for inlet and outlet tanks respectively.



DIMENSIONS IN MM
NOT TO SCALE

1. Stainless steel electrode 2. Polypropylene pipe

FIG. 3-1 CUT SECTION OF HEATING CHAMBER OF CONTINUOUS OHMIC HEATING SYSTEM

3.1.4. Feeding unit for particulates

When pulp or juice is required to be processed, the material can be directly poured into the inlet tank, and can be pumped into the ohmic heating unit continuously. The food material after ohmic heating can be collected in the outlet tank. In case of particulate food like peas in brine solution, the solution can be pumped through the pump from the inlet tank and peas can be introduced separately, between the pump and heating chamber. The fluid coming in high speed can carry peas along with it into the heating unit and after heating peas and brine solution can be collected in the outlet tank.

Feeding unit consists of a 35 cm long 25.4 mm diameter stainless steel pipe with a hopper of 650 cc capacity, which is connected at a distance of 10 cm before the heating element with the help of SS reducer, couplings and tees. A ball valve is provided in the feeding unit to prevent the out flow of fluid when pulp or juices are processed.

3.1.5. Measuring instruments

To carry out the experiments at different voltage gradients, to measure the temperature at different points and to measure the power consumption during processing an auto transformer, thermocouples and power meter were required.

3.1.5.1. Auto transformer

An auto transformer (Hetran Services, Coimbatore) which could vary the voltage in the range of 0-270 V at a current rating of 27.5 amperes was used for the experiment. Electric current from domestic supply with 240 volts and 50 Hz was used.



3.1.5.2. Volt-Amp-Watt meter (VAW meter)

A digital type VAW meter (M/s. Delta Controls, Bombay), which could read upto 500 V, 30 A and 20,000 W was used to measure voltage, current and power consumption simultaneously. Ohmic heating apparatus along with measuring instruments is shown in Fig. 3.2.

3.1.5.3. Thermocouples

To find out the temperature gradient of the flowing food material along the heating chamber, three iron constantan thermocouples were inserted and fixed in the polypropylene pipe. The thermocouples were fixed at a distance of 13 cm, 75 cm and 137 cm from the feed end. A fourth thermocouple was attached at the bottom, centrally opposite to the second thermocouple. If both of these show the same temperature, it assures a full flow through the pipe.

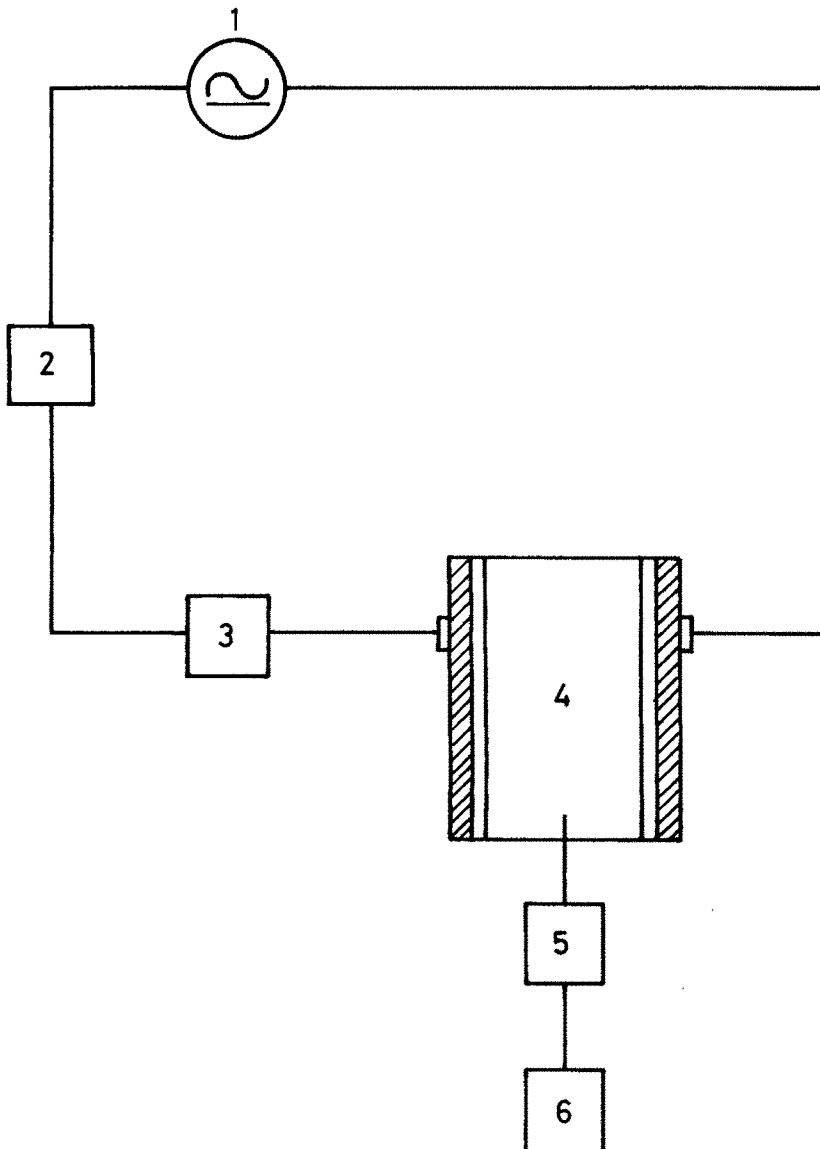
All the thermocouples are attached to a digital temperature indicator through a selector switch. The schematic diagram of the continuous ohmic heating system is shown in Fig. 3.3.

3.2. Ohmic Heating Process

Ohmic heating process involves selection and preparation of fruits and vegetables, filling in the tank and finally applying the required voltage to ohmically heat the fruits and vegetables.

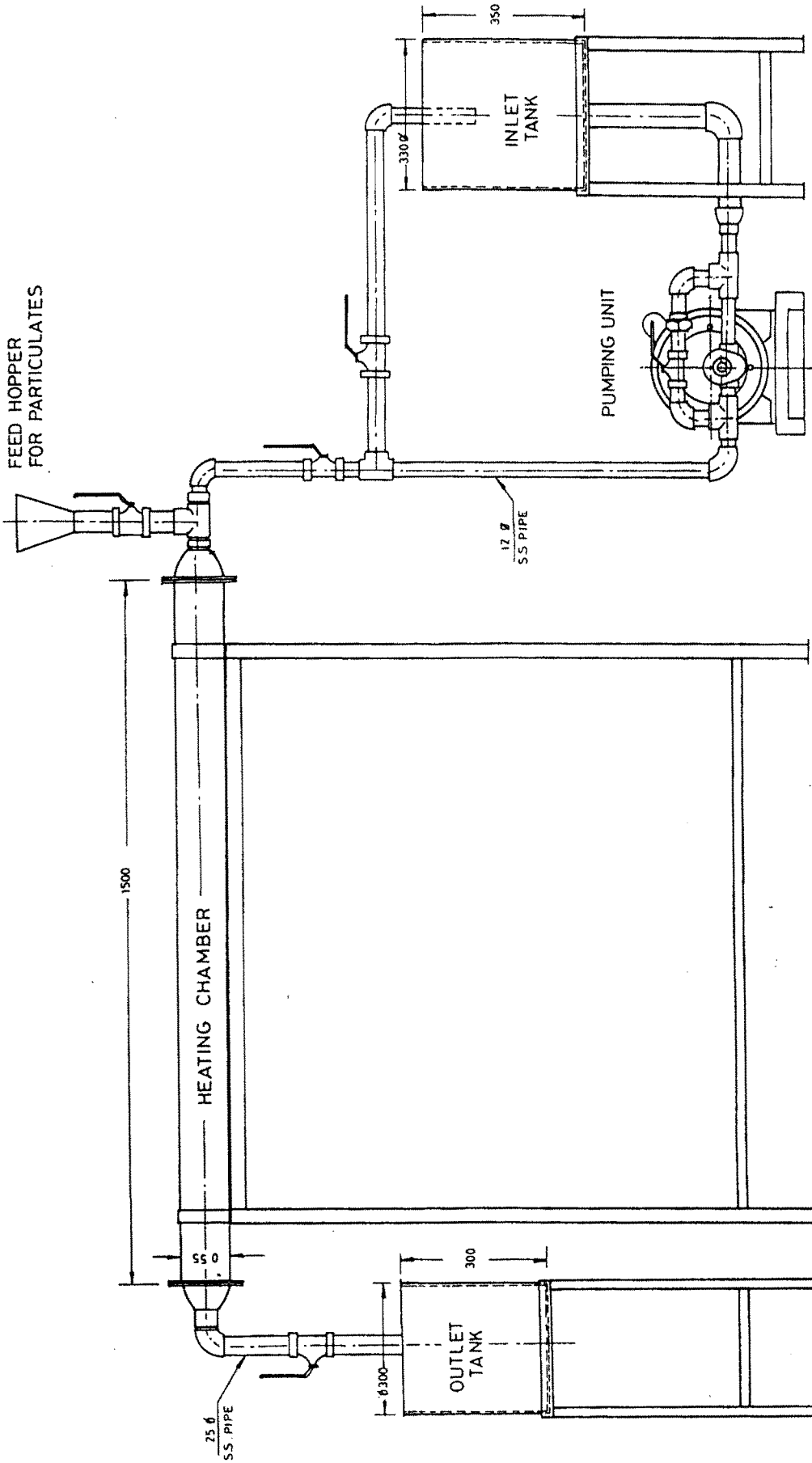
3.2.1. Preparation of raw materials

Peas (cv. Ooty-1), tomato (cv. CO-1) and mango (cv. Totapuri) were procured from the local market. Tomatoes were washed, sliced and then crushed in



1. SOURCE
2. AUTO TRANSFORMER
3. VAV METER
4. OHMIC HEATING CHAMBER
5. THERMOCOUPLES
6. DIGITAL PANEL WITH SELECTOR SWITCH

FIG. 3-2 OHMIC HEATING APPARATUS ALONG WITH MEASURING INSTRUMENTS



Dimensions in mm

FIG. 3.3 CONTINUOUS OHMIC HEATING SYSTEM



Plate 3.1 Continuous Ohmic heating System

1. Inlet tank
2. Pumping Unit
3. Feed hopper for particulates
4. Ohmic heating chamber
5. Outlet
6. Auto Transformer
7. Measuring Instruments

a mixer grinder. Mangoes were also washed peeled sliced and then crushed in mixer grinder. Crushed product was screened through a mesh of opening 3 mm (Lock Arthur, 1969). Filtrate was taken as pulp for experiment. Shelled green peas were taken for experiment. Brine (NaCl) solution prepared in three concentrations viz., 0.001 M, 0.01 M and 0.1 M (Appendix I) were used for study.

3.2.2. Open pan blanching

Tomato pulp, mango pulp and peas in brine solution were taken in a container for blanching. Thermocouple was placed inside to measure the temperature. The container was heated in direct flame heating using a gas burner, burned at a rate of 1554 k cal/h.

3.2.3. Cleaning of the apparatus

When the food processing is complete the power is turned off and apparatus is pre rinsed with water. This is followed by cleaning with a 2% (w/v) solution of caustic soda maintained at a temperature of 80°C. After the detergent wash, the apparatus is rinsed again with hot water. Finally the apparatus was sterilized with chlorine solution with the strength of 200 ppm.

3.3. Measurement of Engineering Properties

3.3.1. Firmness

Firmness is an important quality attribute for peas. A hardness tester was used for the measurement of firmness of raw peas, ohmically heated peas and conventionally blanched peas. The hardness tester used for the experiment is shown in Plate 3.2. The sample was placed on the loading platform of the hardness tester. The load was applied by means of turning the loading screw. The reading was shown in the dial gauge.

3.3.2. Colour

Colour of raw, ohmically heated and conventionally heated mango pulp, tomato pulp and peas were measured, using Munsell colour chart.

The seven charts displayed 196 different standard plates, systematically arranged according to munsell colour notation. The munsell colour notation comprises of three variables namely hue, value and chroma.

The hue notation of a colour indicates its relation to red, yellow, green, blue and purple. The value indicates its lightness and chroma notation indicates its strength (or departure from a neutral of same lightness).

The munsell notation for colour consists of separate notation for hue, value and chroma, which are combined in order to form the colour designation. The symbol for hue is a letter (abbreviation of colour). R stands for red, YR stands for yellow and red and Y for yellow. Each of these letter have a range of values from 0 to 10. Within each letter range, hue becomes more yellow and less red as the number increases the zero point of one range coincide with the 10 point of the previous one.

The notation of value consists of number from zero for absolute black to 10 for absolute white. The notation for chroma is number ranging from zero to a maximum value of 20. While writing munsell colour notation the order is hue, value and chroma with a space between hue and following value number and a virgule between value and chroma.

The colour of ohmically heated peas, mango pulp and tomato pulp were measured by taking a small sample each and comparing it with a standard munsell colour plate.

3.3.3. Bulk density

Change in the bulk density was noted for both ohmically heated and conventionally heated pulp. It was measured by pouring a known quantity of pulp in a vessel of uniform geometry (cylinder).

$$\rho = \frac{m}{v} \quad \dots\dots 3.1$$

Where,

ρ is the bulk density, g/cc

m is the weight, g

v is the volume, cc

3.3.4. Viscosity

Viscosity of fresh, ohmically heated and conventionally heated mango pulp and tomato pulp were measured using a rotational viscometer. The rotational viscometer used for the experiment is shown in Plate 3.3.

In this instrument, the viscous drag of a rotating body, immersed in a liquid is measured by a function of time (Mohsenin, 1970). In between the two concentric cylinder, liquid is poured and equal weights are put on the two pans. Thread is wound for two complete revolution around the bob. As soon as the

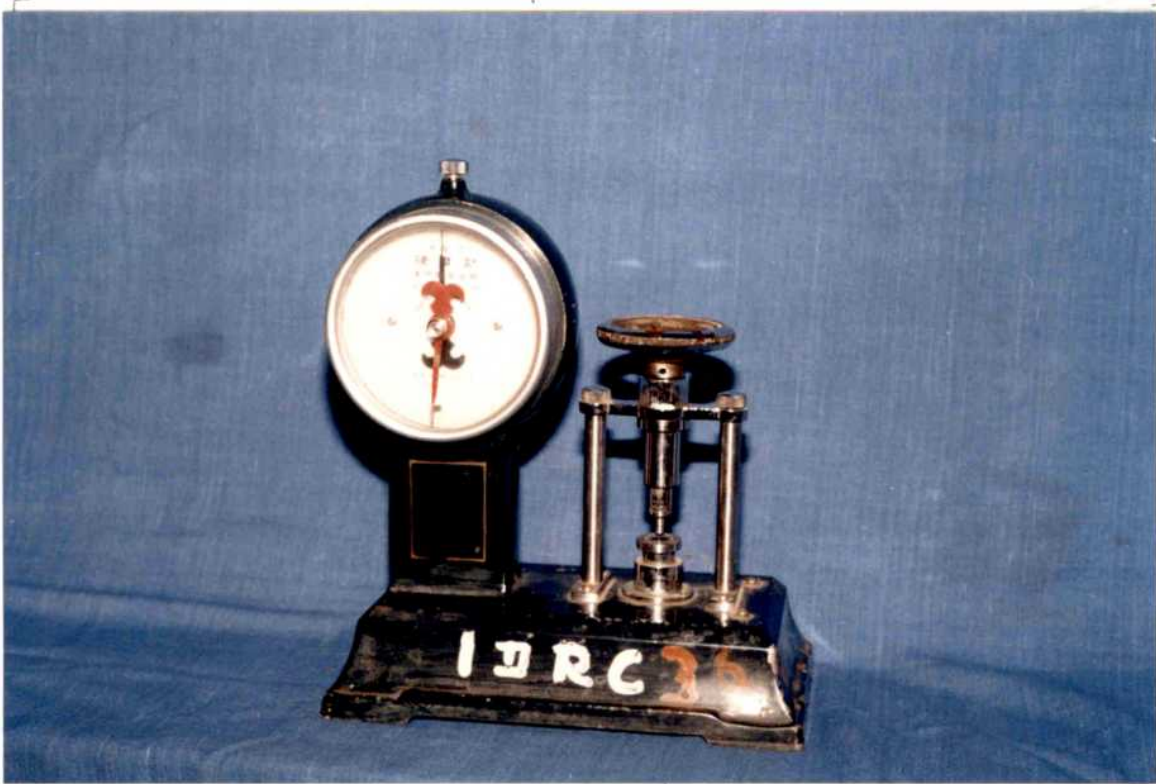


Plate 3.2 Hardness Tester

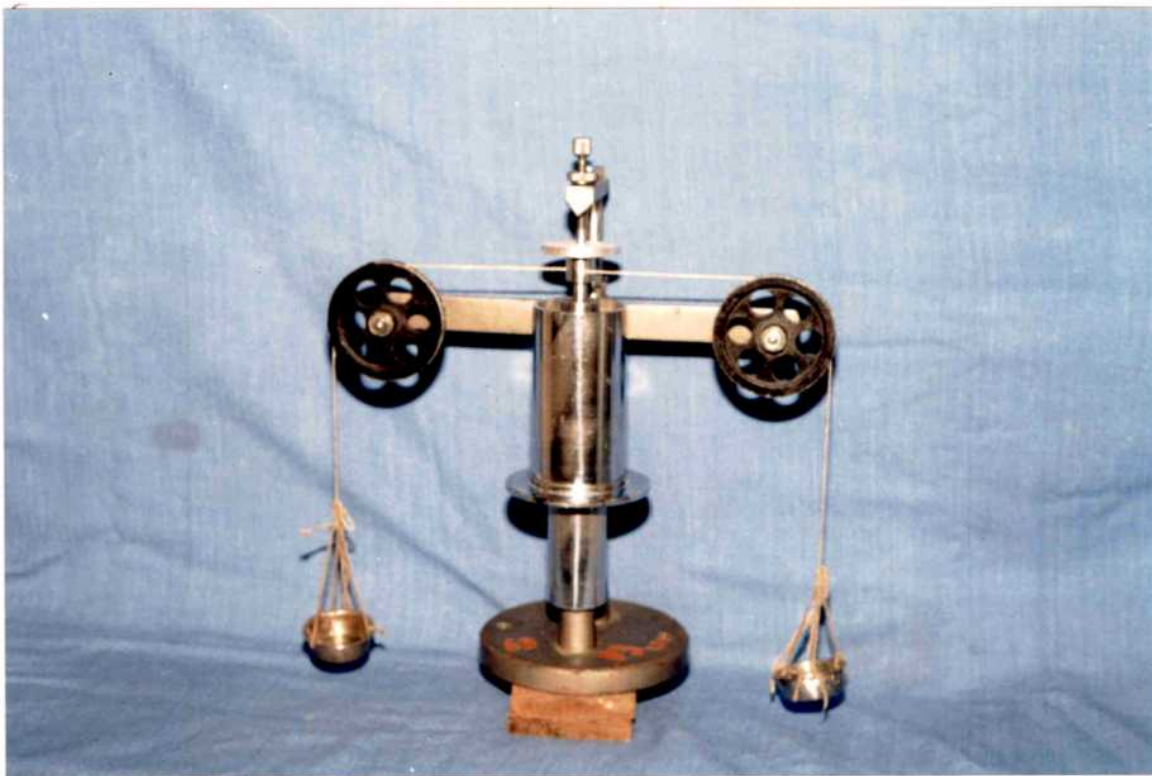


Plate 3.3 Rotational Viscometer

spindle on the disc is released, the time taken to unfold the two revolution of thread around the bob is noted. Viscosity is calculated using the formula,

$$\eta = \frac{M}{4 \pi h \Omega} \left\{ \frac{1}{R_b^2} - \frac{1}{R_c^2} \right\} \times 980.6 \quad \dots\dots 3.2$$

Where,

η is viscosity in poise

M is the applied torque, g-cm

h is height of the liquid in the cylinder, cm

Ω is angular velocity of inner cylinder, radians/s

R_b is radius of the inner cylinder, cm

R_c is the radius of outer cylinder, cm

3.4. Biochemical Studies

3.4.1. Estimation of polyphenol oxidase

The various reagents used for estimation fo polyphenol oxidase were:

- ◆ Catechol solution
- ◆ Sorbitol
- ◆ Sodium chloride
- ◆ Phosphate buffer
- ◆ Tris-HCl buffer
- ◆ Enzyme extract

3.4.1.1. Phosphate buffer

To prepare phosphate buffer of pH 6.5, 68.5 ml of 0.2 M monobasic sodium phosphate (27.8 g in 1000 ml) and 31.5 ml of 0.2 M disodium phosphate (53.65 g in 1000 ml) was dissolved in 200 ml distilled water.

3.4.1.2. Tris HCl buffer

50 ml of 0.2 M Tris (hydroxy methyl) amino methane (24.2 g in 1000 ml) and 44.2 ml of 0.2 N dilute HCl was diluted to 200 ml to prepare Tris HCl buffer of pH 7.2.

3.4.1.3. Enzyme extract

5 g of fruit or vegetable sample was ground with a mortar and pestle in 20 ml medium, containing 50 mM Tris HCl, 0.4 M sorbitol and 10 mM NaCl. The homogenate was used for assay.

3.4.1.4. Procedure

2.5 ml of 0.1 M phosphate buffer (pH 6.5), 0.3 ml of catechol solution (0.01 M) was poured into a cuvette and spectrophotometer was set at 495 nm. 0.2 ml of enzyme extract was added to it and the change at every 30 seconds was noted upto 5 minutes.

The rate of change of absorbance (ΔA) was determined

The enzyme units = $0.272 \times \Delta A$ 3.3

The procedure was repeated for determination of the enzyme activity in mango pulp, tomato pulp and peas for raw, ohmically heated and open pan blanched samples.

3.4.2. Ascorbic acid

Ascorbic acid content was determined by titrating sample solution against dye solution. Following reagents were used:

- ◆ 4% oxalic acid
- ◆ Dye solution
- ◆ Working standard
- ◆ Ascorbic acid content

3.4.2.1. Dye solution

42 mg solution bicarbonate and 52 mg 2,6 dichlorophenol indophenol was dissolved in 200 ml distilled water to prepare the dye solution.

3.4.2.2. Working standard solution

100 mg of ascorbic acid was dissolved in 100 ml of 4 per cent oxalic acid. 10 ml of this solution was pipetted out and was diluted to 100 ml using 4 per cent oxalic acid, to prepare working standard solution.

3.4.2.3. Ascorbic acid extract

Sample was ground with 4 per cent oxalic acid using mortar and pestle. The extract was made upto 100 ml.

3.4.2.4. Procedure

5 ml of working standard solution was pipetted out into a 100 ml conical flask. 10 ml of 4 per cent oxalic acid was added and titrated against the dye. The end point was appearance of pink colour. The volume of dye consumed (V_1) was equal to the amount of ascorbic acid. Then 5 ml of ascorbic acid was titrated against the dye (V_2).

Amount of ascorbic acid in mg present in 100 g sample

$$= \frac{0.5}{V_1} \times \frac{V_2}{5} \times \frac{100}{\text{Weight of sample}} \times 100 \quad \dots\dots 3.4$$

The above procedure was followed for raw, ohmically heated and conventionally heated peas, mango pulp and tomato pulp.

3.4.3. Estimation of betacarotene and lycopene

Lycopene is the red colouring pigment in tomato, whereas betacarotene is yellow in colour. The estimation procedure for both is same. Materials required were:

- ◆ Acetone AR
- ◆ Petroleum ether
- ◆ Anhydrous sodium sulphate AR
- ◆ Betacarotene / Lycopene extract

3.4.3.1. Betacarotene/Lycopene extract

5 g of sample was ground with a mortar and pestle, using acetone. It was extracted till the residue becomes colourless.

3.4.3.2. Procedure

Acetone extract was poured into a separating funnel containing 20 ml of petroleum ether. To it, 20 ml of 5 per cent sodium sulphate solution was added. The supernatant was collected and the lower aqueous phase was reextracted with 20 ml petroleum ether. The petroleum ether extracts were pooled together. 10 g of

anhydrous sodium sulphate was then added to it and kept aside for 10 minutes. Then it was made upto 10 ml using petroleum ether. Then the absorbance was measured using spectrophotometer at 435 nm for estimating betacarotene and at 503 nm for lycopene.

Lycopene present in mg per 100 g sample

$$= \frac{3.12}{1000} \times \frac{\text{Absorbance value at 503} \times 104 \times 100}{\text{Weight of sample}} \dots\dots 3.5$$

Betacarotene present in mg per 100 g of sample

$$= \frac{\text{Absorbance at 453 nm}}{0.2592} \times \frac{\text{Total volume} \times 100}{\text{Weight of sample}} \dots\dots 3.6$$

Above procedure was adopted for fresh, ohmically heated and open pan blanched samples.

3.5. Cost and Energy Analysis

Cost economics of the developed continuous ohmic heating system at 30 kg/h capacity was worked out. The procedure is given in Appendix III.

Energy efficiency of the developed apparatus was calculated by using the formula,

$$\eta = \frac{\text{Energy utilized}}{\text{Energy supplied}}$$

$$= \frac{m C_p \Delta T}{V I t 1000} \quad \dots\dots 3.7$$

Where,

- m is the mass of the product, kg
- C_p is the specific heat of the product, kJ / kg°C
- ΔT is the change in temperature, °C.
- V is the voltage applied, volts
- I is the current consumed, amperes
- t is time taken to heat upto 100°C, seconds

3.6. Modelling and Simulation

Modelling and simulation of batch type of ohmic heating apparatus developed by Anil (1998) was done for four food materials. Pieces of carrot at different particulate percentage (w/v) viz., 10, 20, 30 and 40 per cent in 0.001 M, 0.01 M and 0.1 M NaCl solution, pieces of papaya at 10, 20, 30 and 40 per cent particulate concentration in 0.001 M, 0.01 M and 0.1 M in sugar solution, peas at 20, 40 and 60 per cent in 0.001 M, 0.01 M and 0.1 M NaCl solution and tomato pulp were heated at different voltages upto 100°C. Empirical relationships were established between time taken to heat the product upto 100°C and applied voltage for a particular particulate and conducting solution concentration by using Excel-2000 package. A C language program was written to give the time taken to heat a given product at a given particulate percentage (w/v) in a given concentration of conducting solution at a given voltage (Appendix V). Flow chart for simulating ohmic heating process time is given in Fig. 3.4.

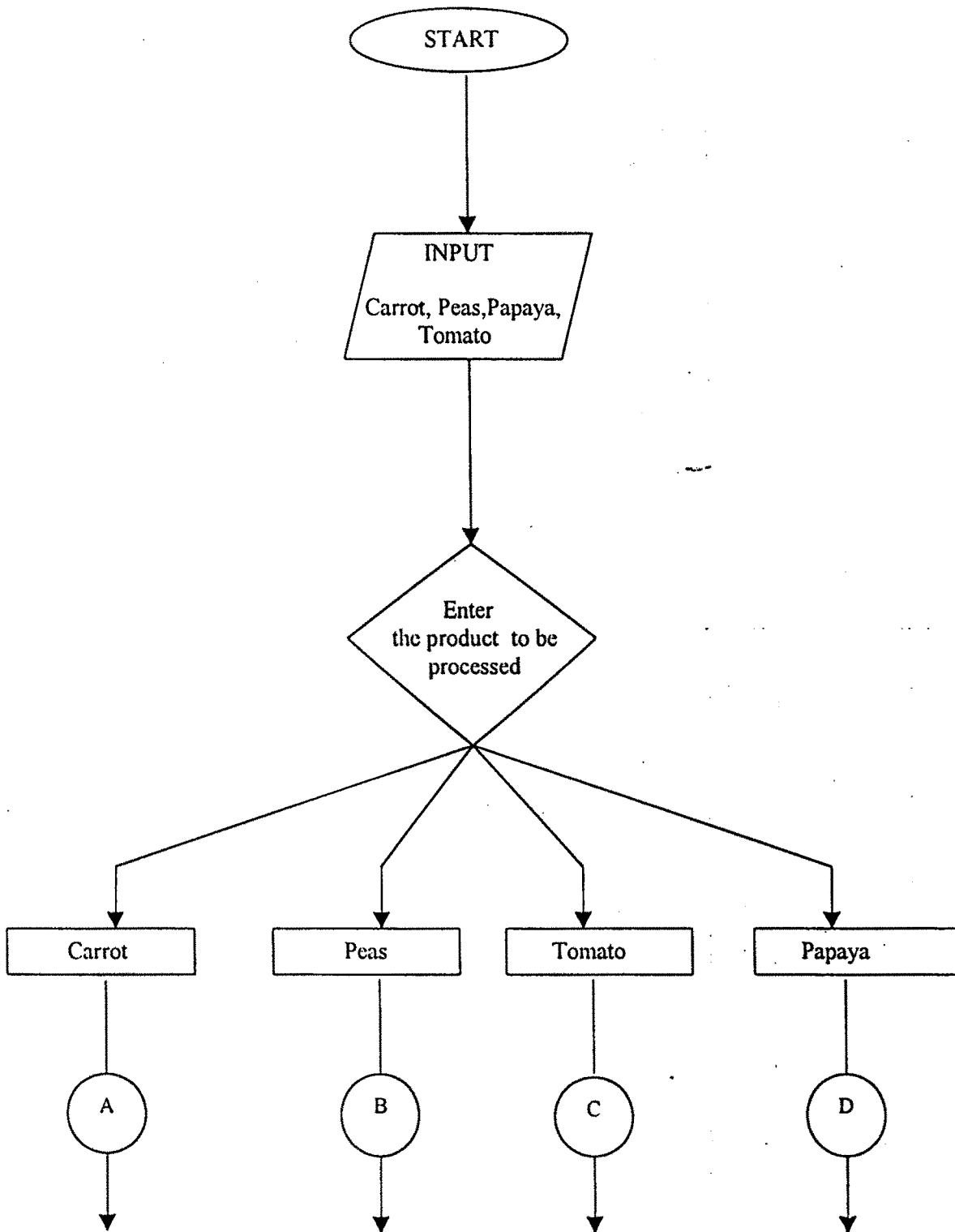
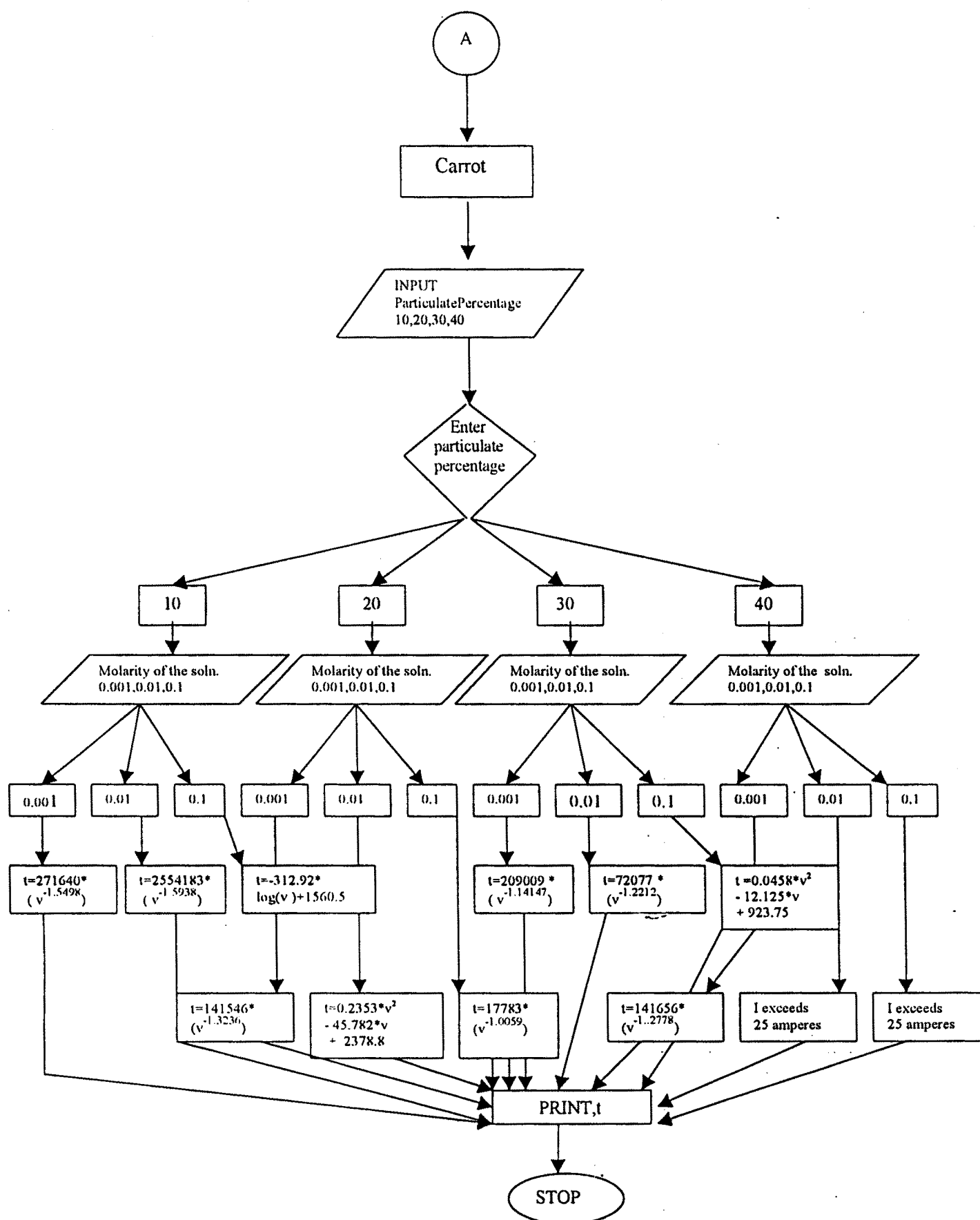
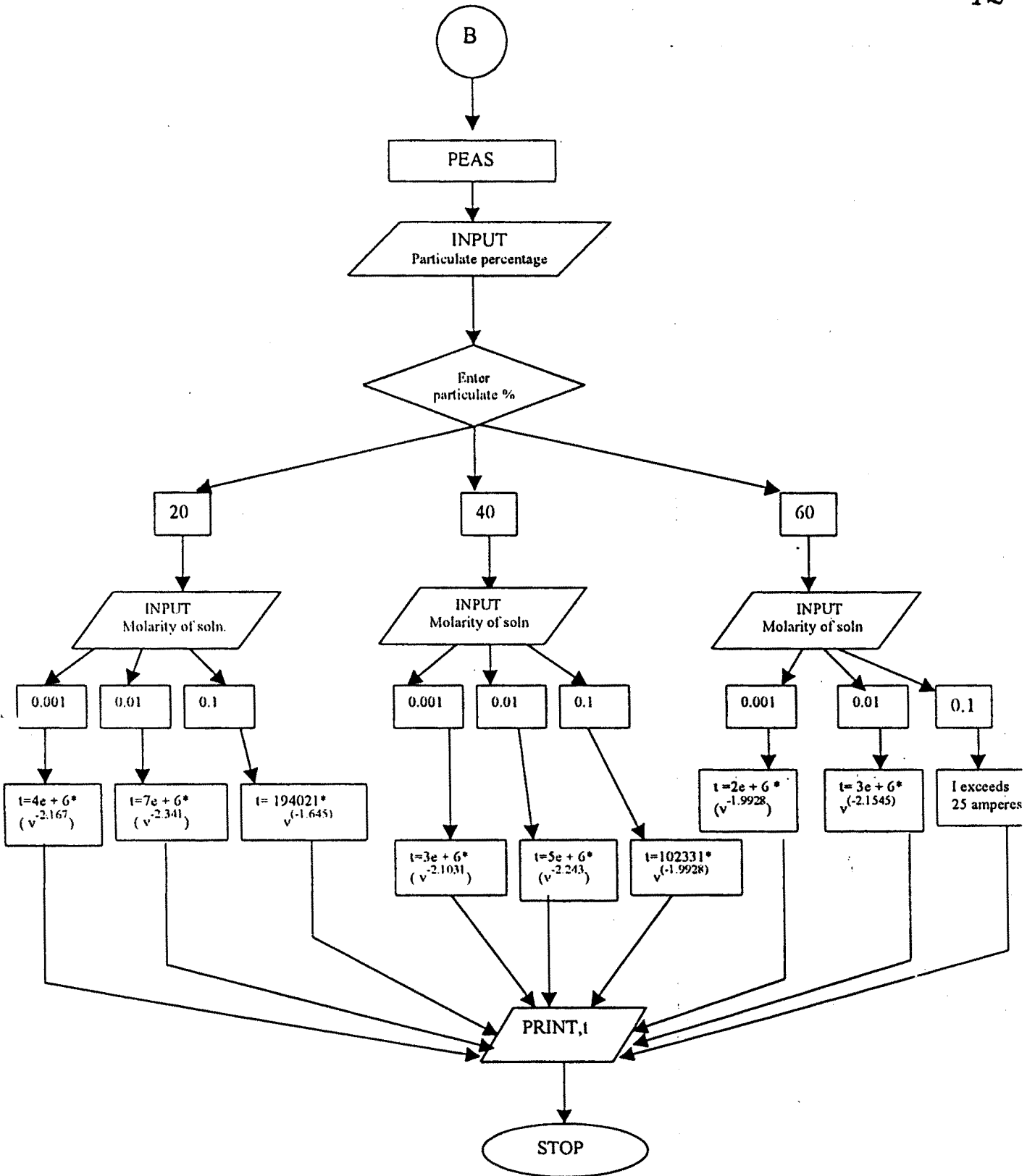
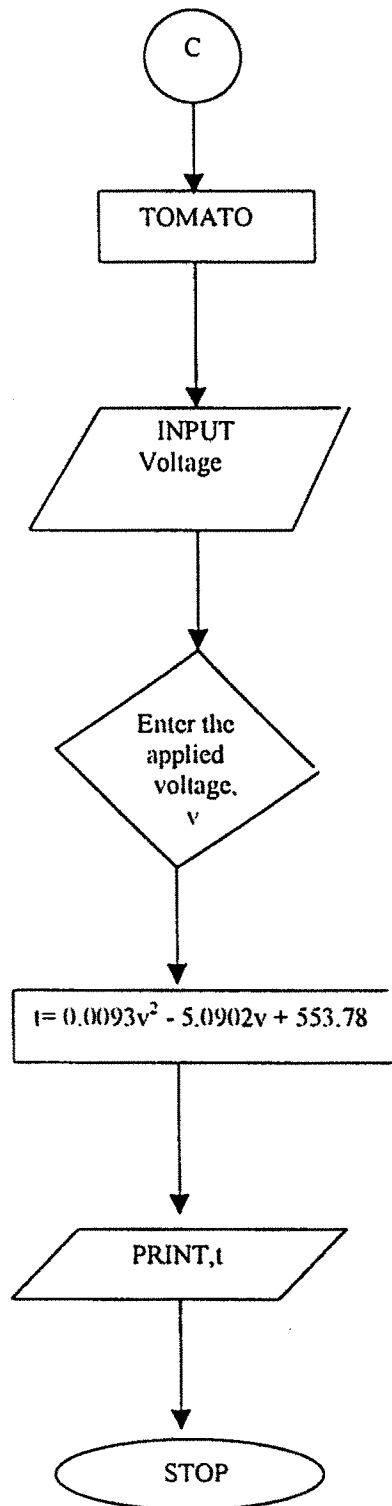


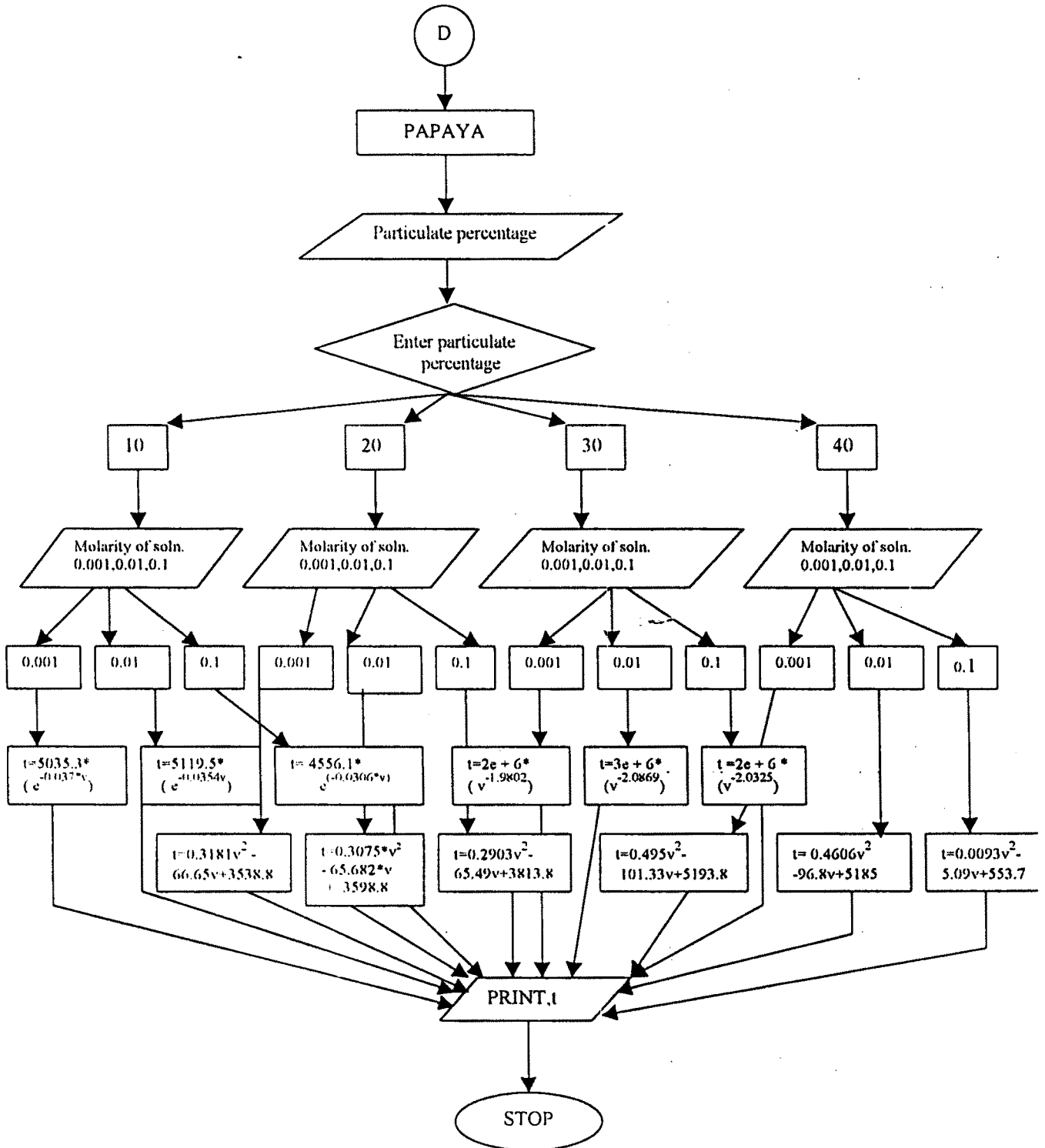
Fig. 3.4 Flow chart for simulating ohmic heating process time

Contd...









Results and Discussions

Chapter IV

RESULTS AND DISCUSSIONS

Ohmic heating is a novel technique employed in food processing applications. In this method, alternating current is passed through food materials to be heated and material will offer some resistance to the flow of current. This results in part of electric energy being converted to thermal energy, resulting in overall increase in temperature of the product. The ohmic heating process is rapid and highly efficient.

In this chapter the design specifications of the continuous ohmic heating system are furnished, and the results obtained in ohmic heating are presented under the following headings.

- ◆ Heating rate of tomato pulp, mango pulp and peas.
- ◆ Current and power consumption during ohmic heating.
- ◆ Engineering properties of the processed products.
- ◆ Biochemical studies of the processed product.
- ◆ Cost and energy analysis.
- ◆ Simulation and modelling of existing batch type ohmic heating apparatus.

4.1. Design Specifications of Ohmic Heating Apparatus

A continuous ohmic heating apparatus of 30 kg/h was designed and fabricated. The design specifications of ohmic heating system are furnished in Table 4.1.

Table 4.1. Specifications of the continuous ohmic heating apparatus

S. No.	Particulars	Material	Details
1.	Overall dimensions		
	(i) Length, mm		2860
	(ii) Width, mm		610
	(iii) Height, mm		1865
2.	Weight (Dead), kg		90
3.	Heating unit		
	(a) Heating chamber	Polypropylene pipe	
	(i) Length, mm		1500
	(ii) Diameter, mm		55
	(iii) Thickness, mm		4
	(b) Electrodes	Stainless steel	
	(i) Length, mm		1300
	(ii) Width, mm		50
	(iii) Thickness, mm		1.5
4.	Feeding system		
	(a) Inlet tank	Aluminium	
	(i) height, mm		350
	(ii) diameter, mm		330
	(b) Stand	Mild steel	
	(i) height, mm		500
	(ii) length, mm		340
	(iii) width, mm		340
	(c) Feed hopper (for particulates)		
	aluminium		
	(1) Funnel		
	(i) height, mm		127
	(ii) diameter, mm		127
	(d) Pumping unit		
	(i) Gear pump capacity	Stainless steel	20 l min ⁻¹
	(ii) Motor		0.5 hp
5.	Discharge unit		
	(a) outlet tank	Aluminium	
	(i) height, mm		300
	(ii) diameter, mm		300
	(b) stand	Mild steel	
	(i) height, mm		610
	(ii) length, mm		310
	(iii) width, mm		310

4.2. Effect of Voltage on Heating rate of Mango pulp, Tomato pulp and Peas

Ohmic heating of mango pulp, tomato pulp and peas were carried out in the continuous ohmic heating system at different voltages, viz., 30, 60, 90 and 110V. Effect of voltage on ohmic heating rate of mango pulp, tomato pulp and peas are shown in fig. 4.1, 4.2 and 4.3 respectively.

Time taken to attain a temperature of 100°C at a flow rate of 0.5 l min⁻¹ in mango pulp at 30, 60, 90 and 110 V were 26 minutes, 20 minutes, 14 minutes 30 seconds and 10 minutes respectively. In case of tomato pulp, at a flow rate of 0.5 l min⁻¹ time taken to attain a temperature of 100°C at 30, 60, 90 and 110 V were 8 minutes, 6 minutes, 5 minutes and 4 minutes respectively. Peas in brine solution of 0.1 M concentration at 30V, 60V, 90V and 110V took 12 minutes, 8 minutes, 6 minutes and 5 minutes respectively to attain a temperature of 100°C. It could be seen from the figures that, when the applied voltage increased in the continuous ohmic heating system the ohmic heating rate increased in the mango pulp, tomato pulp and peas in brine solution.

The sharp rise of temperature at higher voltages could be attributed to electrophoresis and increase in the electrical conductivity. Electrophoresis is the process by which cell wall rupture might occur at the instance, when higher voltages are applied (Halden *et al.*, 1990). Also due to electro osmotic effects, electrical conductivity increases with voltage gradient (Palaniappan and Sastry, 1991a).

4.3. Effect of Flow Rate on Heating Rate

It was also observed from the fig. 4.1 and fig. 4.2. that decrease in flow rate increased the heating rate in both the mango pulp and tomato pulp. At 110 volts,

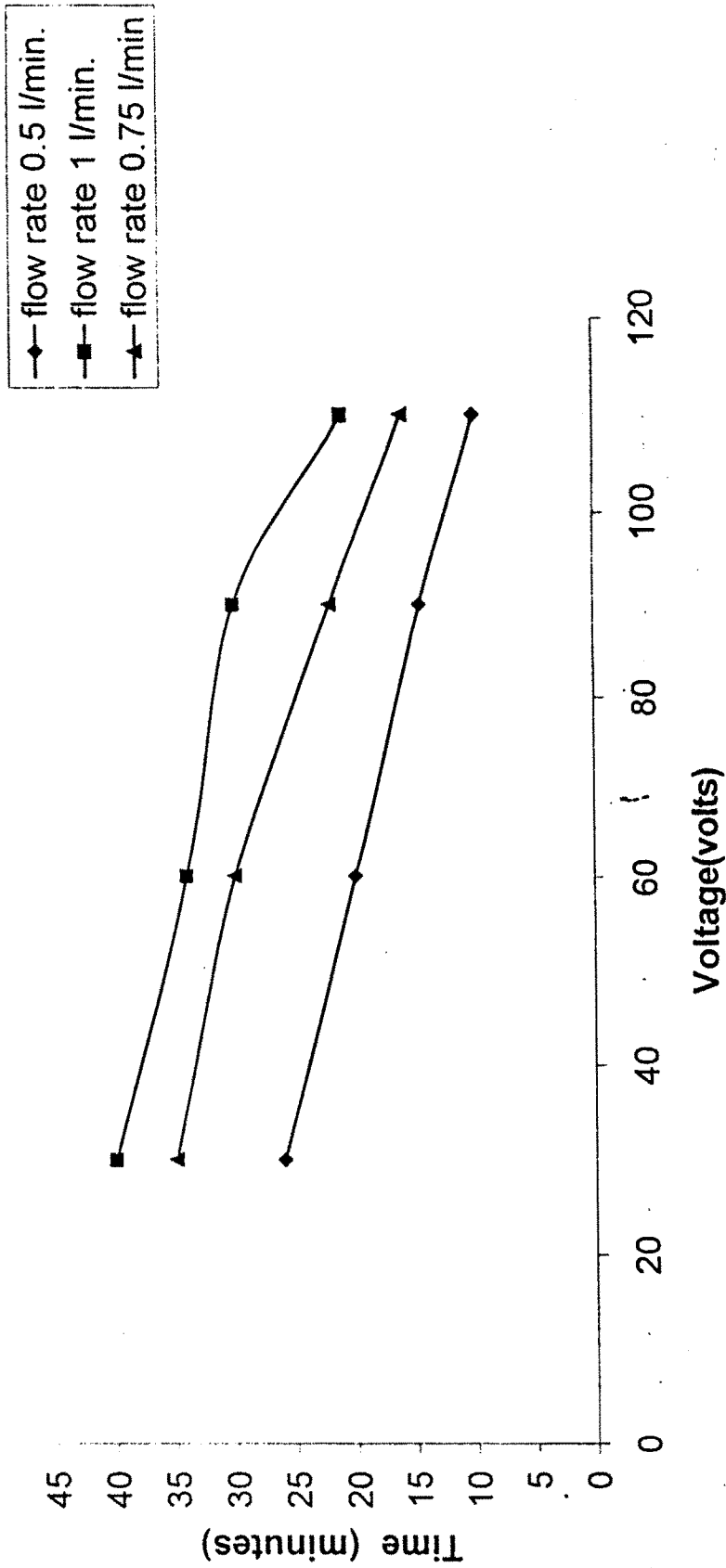


Fig.4.1.Effect of voltage on time taken to heat mango pulp to 100°C at different flow rates in the continuous ohmic heating system

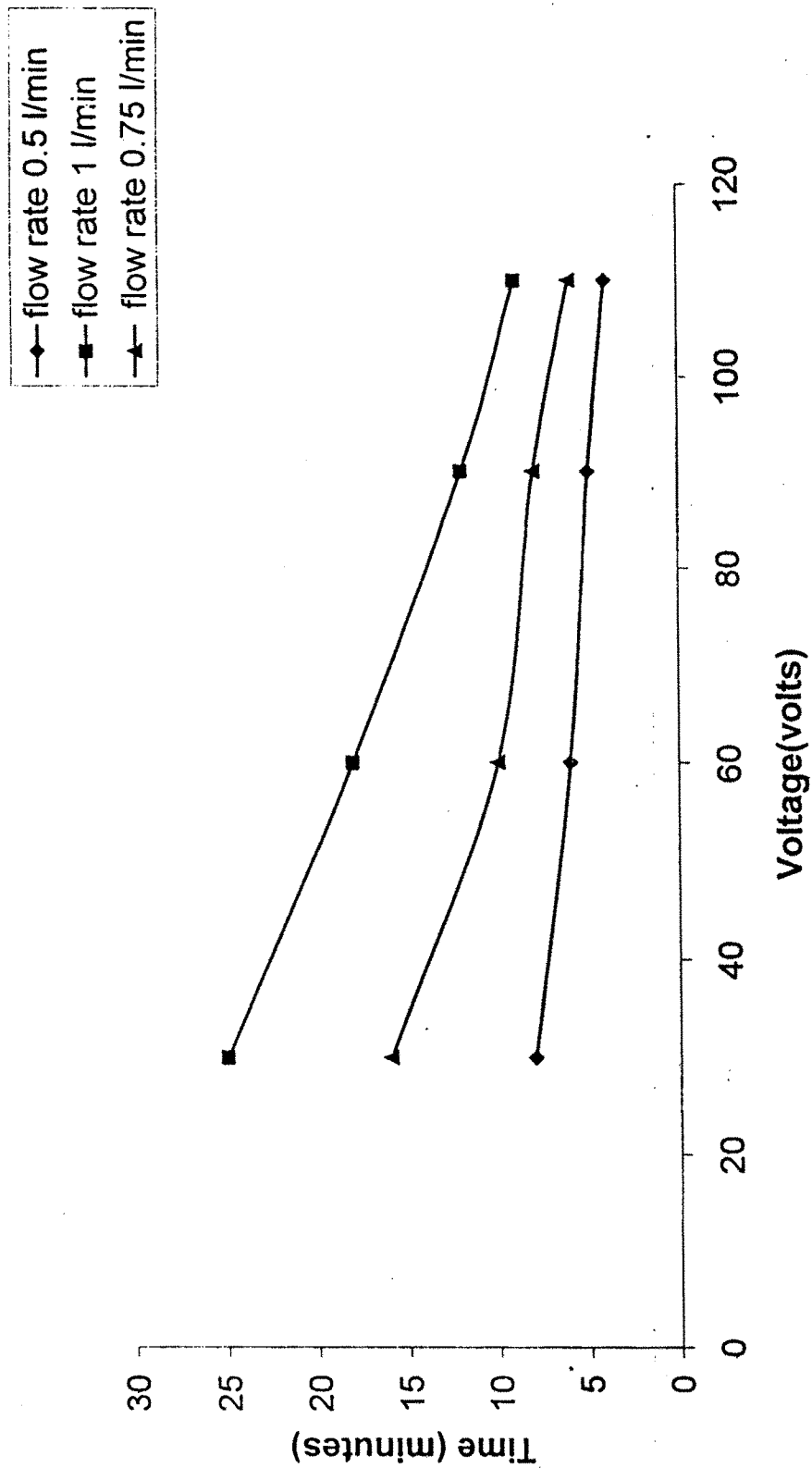


Fig. 4.2. Effect of voltage on time taken to heat tomato pulp to 100°C at different flow rates in the continuous ohmic heating system

time taken to reach 100°C for mango pulp at 0.5 l min⁻¹, 0.75 l min⁻¹ and 1 l min⁻¹ were 10 minutes, 16 minutes and 21 minutes respectively.

In case of tomato pulp, at 110 volts, time taken to reach 100°C at 0.5 l min⁻¹, 0.75 l min⁻¹ and 1 l min⁻¹ were 4 minutes, 6 minutes and 9 minutes respectively.

Reduction in the heating time, when flow rate is reduced indicated that a certain residential time was required for the fluid in the heating chamber for proper heating (Palaniappan and Sastry, 1991b).

4.4. Effect of Concentration of Conducting solutions on Heating rate of Liquid particulate mixture

Continuous ohmic heating of peas was carried out at three different concentrations of brine stock. Salt solution was added to peas to bring it to fluidized state and to ensure uniform passage of electric current. Fig. 4.3 shows effect of concentration of conducting solution on heating rate of peas. It was observed that, as the concentration of conducting solution increased, the heating rate of particulate mixture increased. At 110V, time taken to attain 100°C temperature at 0.1 M, 0.01 M and 0.001 M NaCl concentration was 5 minutes, 7 minutes and 10 minutes respectively.

Heating rate increased with the concentration of conducting solution. Actually, infusion of salt increased electrical conductivity which reduced products residence time during processing (Palaniappan and Sastry, 1991b).

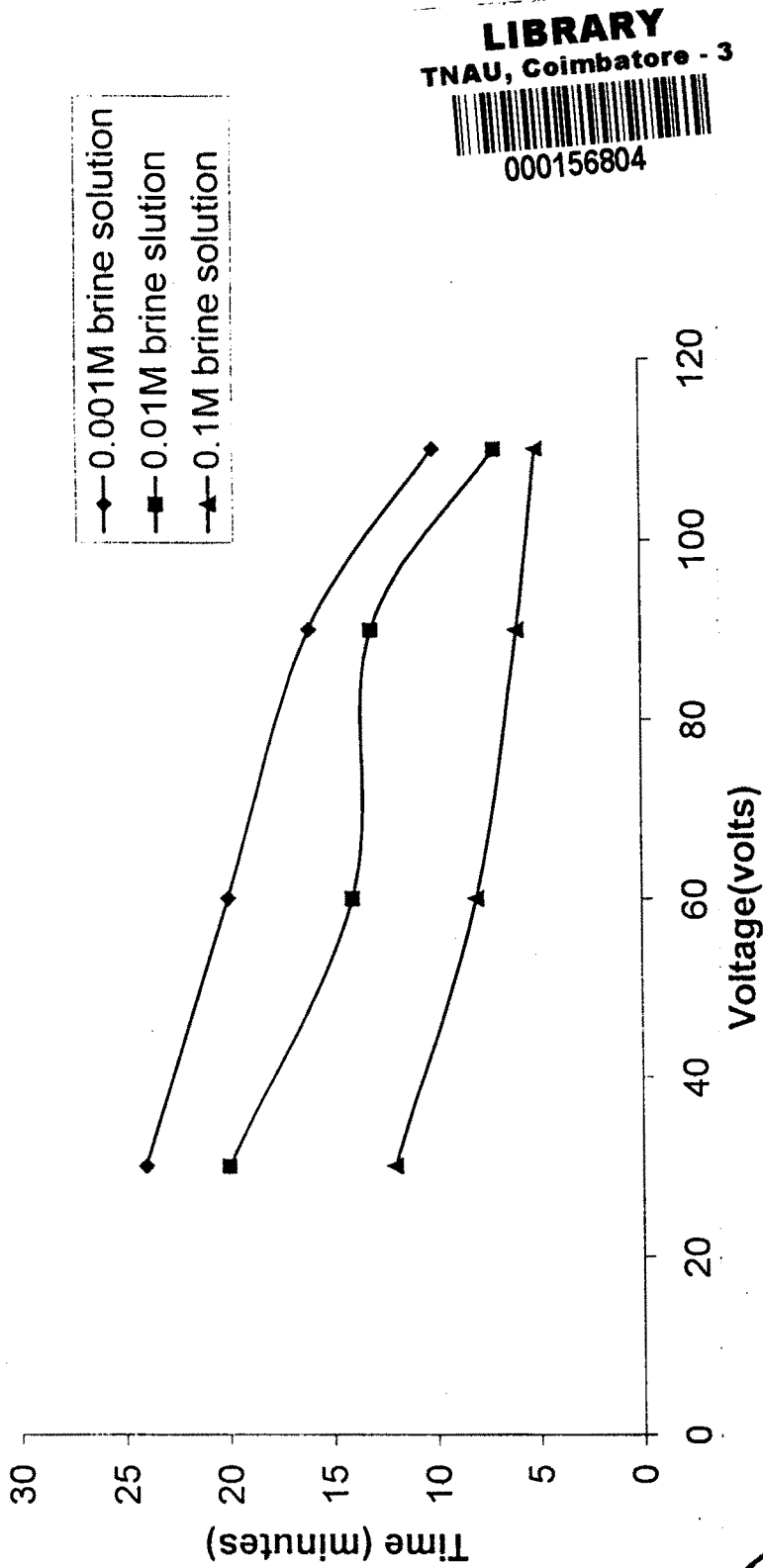


Fig.4.3. Effect of voltage on heating time of peas in different concentration of brine solution at 0.5 l/min. flow rate in the continuous ohmic heating system



4.5. Current and Power Consumption during Ohmic Heating

Current and power consumption during ohmic heating of mango pulp, tomato pulp and peas at different concentration of conducting solution were recorded at 30, 60, 90 and 110 V at a product temperature of 100°C. The recorded data is presented in Table 4.2. It is seen from the table that, the current and power consumption at the product temperature of 100°C increased with the applied voltage for all the three products viz., mango pulp, tomato pulp and peas. It is also evident from the table that the current and power consumption for the peas in brine solution increased with the increase in concentration of the brine solution. Maximum power consumption to heat tomato pulp, mango pulp and peas to a temperature of 100°C was found to be 2.25 kW, 1.325 kW and 2.64 kW respectively when heated at a voltage of 110V with current consumption of 20A, 12A and 24A respectively.

4.6. Effect of Ohmic Heating on Engineering Properties

Engineering properties measured were firmness and colour of peas, viscosity, colour and bulk density in case for both mango pulp and tomato pulp.

4.6.1. Effect of Ohmic Heating on Firmness of Peas

Firmness of raw peas was 0.182 kg/mm², Firmness of ohmically heated and open pan blanched peas was found to be 0.114 kg/mm² and 0.0814 kg/mm² respectively. Firmness decreased with thermal treatment. Ohmically heated peas retained more firmness than open pan blanched peas. This could be attributed to the fact that during ohmic heating, heat generation at core and the surface would be same (Anil, 1998), as heating takes place due to the resistance offered by the material, whereas, in case of conventional heating, heat penetrates from outside to inside leading to over processing of exterior portion than interior.

Table 4.2. Current and power consumption during ohmic heating at product temperature of 100°C

Voltage V	Mango pulp		Tomato pulp		Peas					
					0.001 M		0.01 M		0.1 M	
	Current A	Power W	Current A	Power W	Current A	Power W	Current A	Power W	Current A	Power W
30	6.0	195	6.15	184	5	152	8	240	16	485
60	12	730	9	540	7	425	10.5	635	18	1080
90	15	1370	10	940	8.5	810	12	1085	21	1900
110	20	2250	12	1325	10	1150	17	1900	24	2640

4.6.2. Effect of ohmic heating on bulk density and viscosity of tomato and mango pulp

Table 4.3 shows the effect of ohmic heating on viscosity, bulk density of tomato pulp and mango pulp and firmness of peas. Ohmic heating increased the viscosity and bulk density of tomato pulp from an initial value of 94.98 poise and 1.04 g/cc to 96 poise and 1.06 g/cc and that of mango pulp from 2136.4 poise and 1.16 g/cc to 2140 poise and 1.17 g/cc respectively. However, in case of open pan blanching the product gets concentrated while heating and this might be because of water loss in the form of vapour during open pan blanching. Thus, ohmically heated product could be observed to retain more fresh like characteristics.

4.6.3. Effect of ohmic heating on colour of mango pulp, tomato pulp and peas

Colour values of mango pulp, tomato pulp and peas are shown in Table 4.4. The fresh mango pulp, tomato pulp and peas had a hue of 7.5 YR, 7.5 R and 7 G and a value of 7, 8 and 7 and chroma of 8,8,8 respectively. These values changed after ohmic heating. This might be due to the inactivation of colouring pigment like β -carotene, lycopene and chlorophyll at higher temperatures. Raw, ohmically heated and open pan blanched mango pulp, tomato pulp and peas are shown in plates 4.1, 4.2 and 4.3 respectively.

4.7. Biochemical Studies

The various biochemical parameters studied are β -carotene content, lycopene content, ascorbic acid content and polyphenol oxidase activity.

Table 4.3. Effect of ohmic heating on viscosity and bulk density of tomato pulp and mango pulp and firmness of peas

Product	Tomato pulp		Mango pulp		Peas
	Viscosity (poise)	Bulk density (g/cc)	Viscosity (poise)	Bulk density (g/cc)	Firmness (kg/mm ²)
Raw pulp	94.98	1.04	2136.4	1.16	0.182
Ohmically heated pulp	96	1.06	2140	1.17	0.114
Open pan blanching	142	1.2	2612.16	1.4	0.0814

Table 4.4. Munsell colour values of ohmically heated mango pulp, tomato pulp and peas

Product	Mango pulp			Tomato pulp			Peas		
	Hue	Value	Chroma	Hue	Value	Chroma	Hue	Value	Chroma
Fresh	7.5 YR	7	8	7.5 R	8	8	7 G	7	8
Ohmically heated to 100°C	10 YR	8	8	7.5 R	5	6	7 G	7	6
Open pan blanched (80°C, 5 minutes)	10 YR	8	9	7.5 R	5	4	7 G	7	7

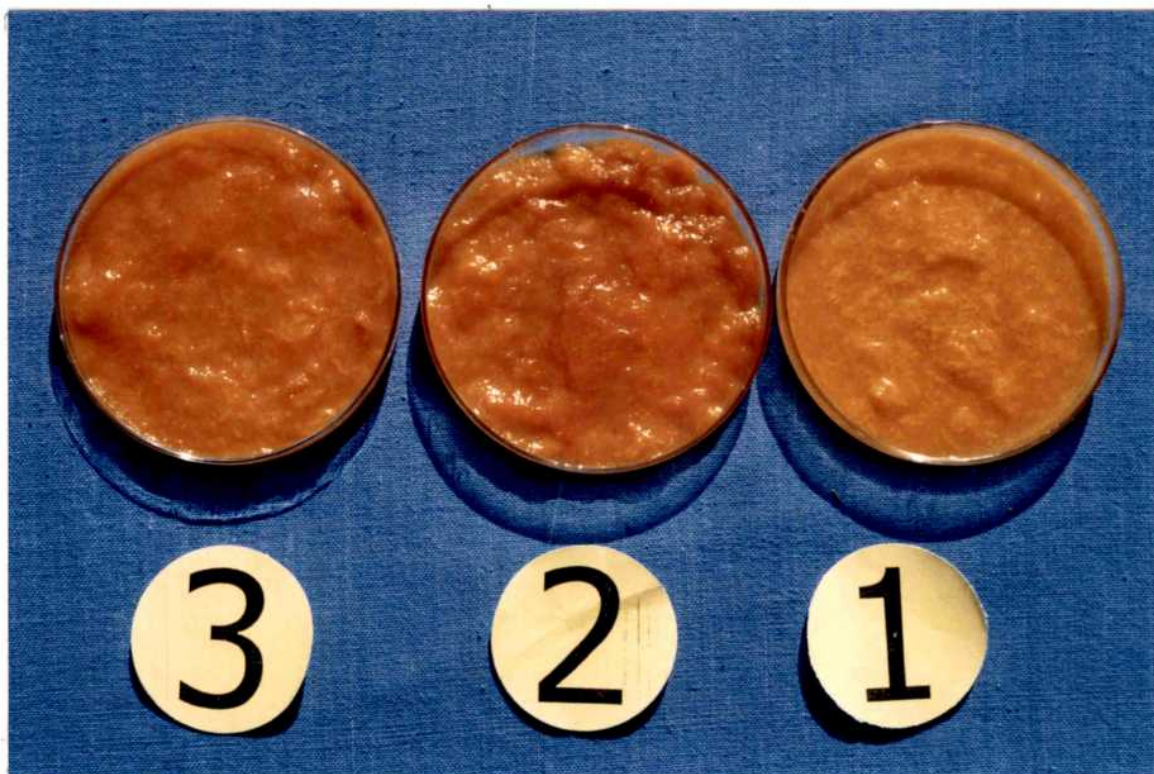


Plate 4.1 Raw, Open pan blanched and Ohmically heated
Mango Pulp

1. Raw mango pulp
2. Open pan blanched mango pulp
3. Ohmically heated mango pulp



Plate 4.2 Raw, Ohmically heated and open pan blanched
Tomato pulp.

1. Raw tomato pulp
2. Ohmically heated tomato pulp
3. Open pan blanched tomato pulp



Plate 4.3 Raw, Ohmically heated and open pan blanched Peas

1. Raw peas
2. Ohmically heated peas
3. Open pan blanched peas

4.7.1. Effect of ohmic heating on polyphenoloxidase activity of tomato pulp, mango pulp and peas

Table 4.5. shows the effect of ohmic heating and open pan blanching on polyphenol oxidase activity of tomato pulp, mango pulp and peas. The polyphenol oxidase activity after ohmic heating to a temperature of 100°C reduced to 376, 250 and 40 unit/mg from an initial value of 440, 300 and 45 unit/mg for tomato pulp, mango pulp and peas respectively. Thus polyphenol oxidase activity after ohmic heating to 100°C comes to a comparable level to open pan blanching at 80°C for 5 minutes. One unit of PPO activity represents the enzymes which transforms 1 μ mol of dihydric phenol to 1 μ mol of quinone per minute (Sadasivam and Manickam, 1992).

4.7.2. Effect of ohmic heating on ascorbic acid content of tomato pulp, mango pulp and peas

Table 4.6 shows the effect of ohmic heating and open pan blanching on ascorbic acid content of tomato pulp, mango pulp and peas. In case of tomato pulp, ascorbic acid content from an initial level of 30 mg/100 g reduced to 25 mg/100 g in ohmically heated sample and 18 mg/100 g in open pan blanched sample. This indicated a retention of 83.33 per cent ascorbic acid in case of ohmic heating and 60 per cent in case of open pan blanching. Thus ohmic heating retains 23.33 per cent ascorbic acid more than open pan blanching.

In case of mango pulp ohmically heated sample retains 30 mg/100 g showing a retention of 80 per cent whereas open pan blanched sample retains 25.5 mg/100g, which shows a retention of 68 per cent.

Table 4.5. Effect of ohmic heating on polyphenol oxidase activity of tomato pulp, mango pulp and peas

Sample	Polyphenol oxidase activity (unit/mg)		
	Tomato pulp	Mango pulp	Peas
Fresh	440	300	45
Ohmically heated to 100°C	376	250	40
Open pan blanched (80°C, 5 min)	370	246	35

Table 4.6. Effect of ohmic heating on ascorbic acid content of tomato pulp, mango pulp and peas

Sample	Ascorbic acid content (mg/100 g)		
	Tomato pulp	Mango pulp	Peas
Fresh	30	37.5	12
Ohmically heated to 100°C	25	30	10
Open pan blanched (80°C, 5 min)	18	25.5	8

In case of peas from an initial value of 12 mg/100 g after ohmic heating ascorbic acid content comes down to 10 mg/100 g indicating a loss of 16.6 per cent whereas open pan blanched sample shows a loss of 33.34 per cent.

4.7.3. Effect of ohmic heating on β -carotene content of mango pulp and lycopene content of tomato

β -carotene content of fresh mango pulp was found to be 3000 $\mu\text{g}/100\text{ g}$. After ohmically heating to 100°C it reduced to 2047 $\mu\text{g}/100\text{ g}$. In case of open pan blanching after heating at 80°C for 5 minutes beta carotene content was found to be 1950 $\mu\text{g}/100\text{ g}$ as shown in Table 4.7.

In case of tomato pulp initial lycopene content was found to be 670 $\mu\text{g}/100\text{g}$. After ohmically heating to 100°C lycopene content reduced to 200 $\mu\text{g}/100\text{ g}$ and in case of open pan blanching at 80°C for 5 minutes lycopene content reduced to 205 $\mu\text{g}/100\text{ g}$.

Ohmically heated mango pulp retains 5 per cent more beta-carotene than open pan blanched sample whereas lycopene content of ohmically heated tomato pulp, was 3 per cent less than open pan blanched sample. The results indicate that ohmic heating and open pan blanching are at par.

4.8. Cost and Energy Analysis

Cost of developed continuous ohmic heating system was found to be Rs.17,000 and cost of operation Rs.58.07/h (Appendix II). In the conventional open pan blanching the cost of operation was Rs.184.49/h (Appendix IV). Energy efficiency of the system was found to be 42.35 per cent for heating peas and 45.38 per cent for pulps (Appendix III). The energy efficiency of steam blancher as reported by Thomas *et al.* (1981) was 31 per cent.

Table 4.7. Effect of ohmic heating on beta-carotene content of mango pulp and lycopene content of tomato pulp

Product	β-carotene content of mango pulp ($\mu\text{g}/100\text{ g}$)	Lycopene content of tomato pulp ($\mu\text{g}/100\text{ g}$)
Fresh	3000	670
Ohmically heated to 100°C	2047	200
Open pan blanched (80°C, 5 min)	1950	205

4.9. Simulation and Modelling

Simulation and modelling of batch type ohmic heating apparatus of 1 litre capacity (Anil, 1998) was done to obtain information that will aid in the design of continuous ohmic heating system. Data pertaining to heating time of tomato pulp, peas and carrot at different particulate percentage in different concentration of NaCl solution, papaya at different particulate percentage and in different concentration of sugar solution, when heated at different voltages is presented in the form of Fig. 4.4 to 4.15. Computer program (Appendix V) solves the empirical relationship between applied voltage and time and gives the time taken to attain 100°C by the product, when product name, particulate percentage, concentration of conducting solution and voltage at which apparatus is operated is provided.

4.9.1. Effect of particulate percentage, concentration of conducting solution and voltage on heating rate of peas

Fig. 4.4 shows the variation of heating rate with respect voltage gradient at 20 per cent particulate percentage heated in different concentration of conducting solution. Empirical relationships between applied voltage and heating time at 20 per cent particulate concentration and 0.001 M, 0.01 M and 0.1 M concentration of conducting solution were also given.

From Fig. 4.4 it is evident that at higher voltages the concentration of conducting solution was immaterial, as the time taken to attain 100°C core temperature at 150 V was 58 seconds at 0.001 M brine concentration, 50 seconds at 0.01 M brine concentration and 49 seconds in 0.1 M brine concentration. The same trend could be noticed for 40 and 60 per cent particulate concentration from Fig. 4.5 and Fig. 4.6 respectively. Further, though the concentration of particulate

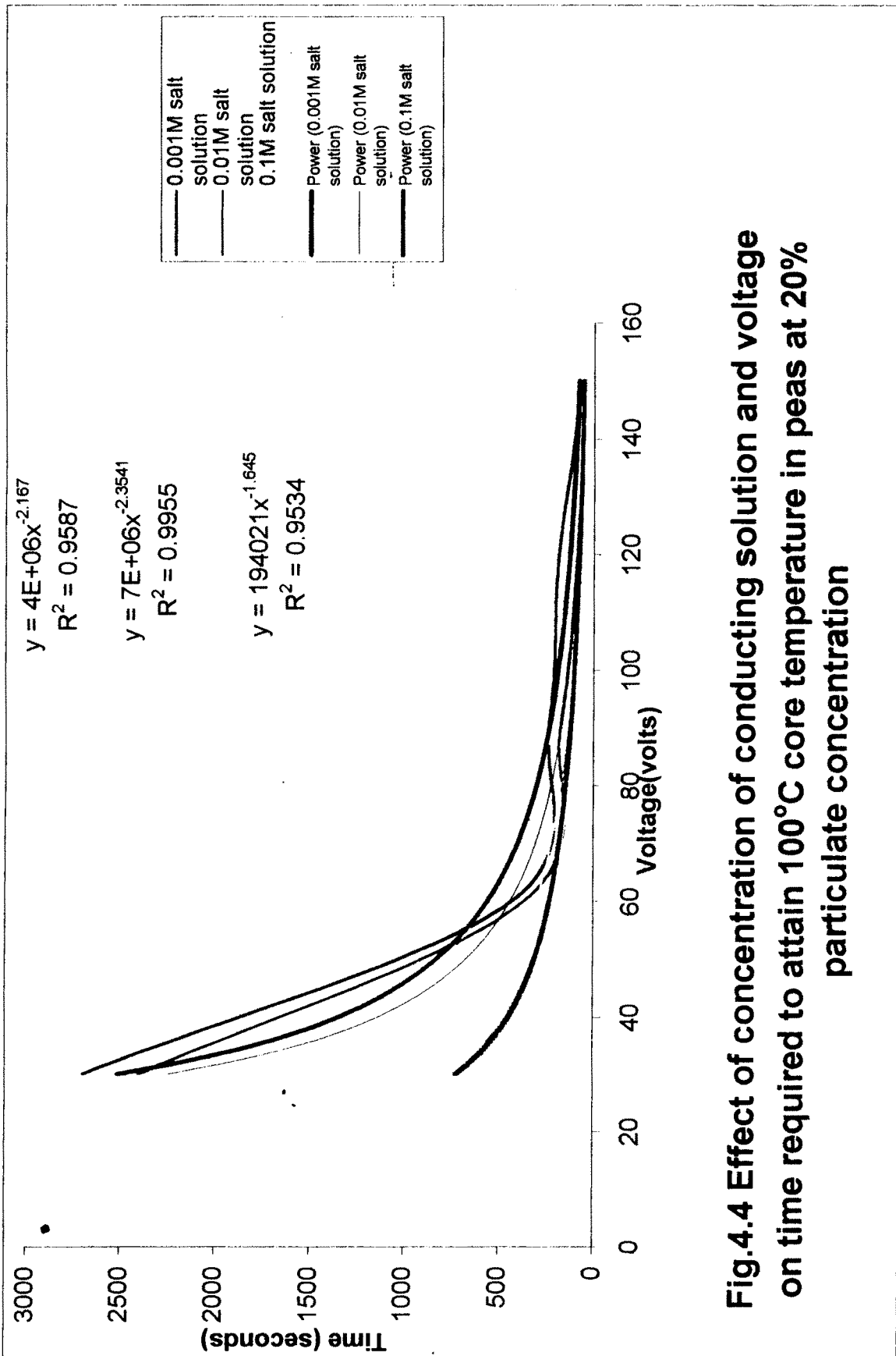


Fig.4.4 Effect of concentration of conducting solution and voltage on time required to attain 100°C core temperature in peas at 20% particulate concentration

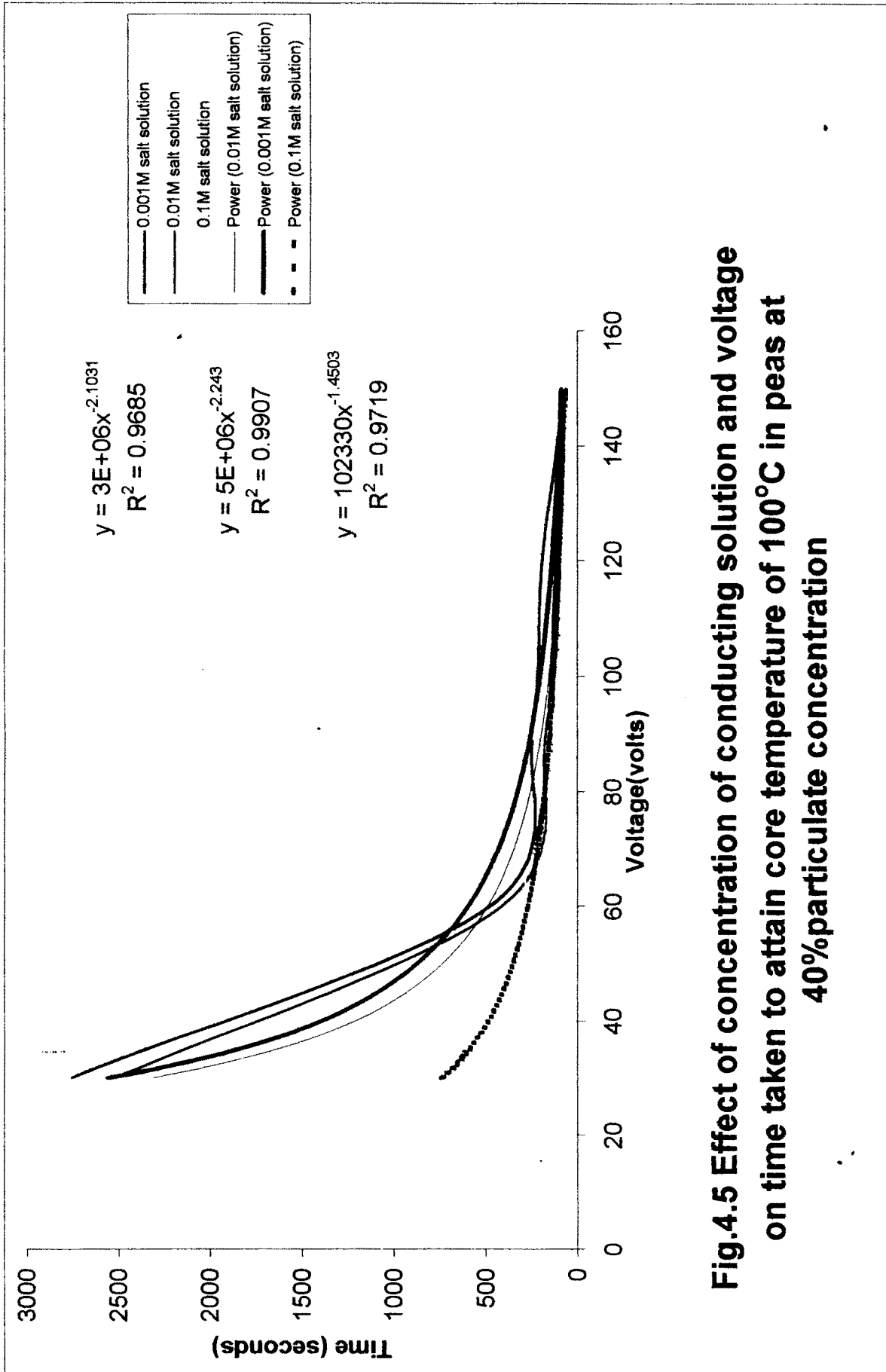


Fig.4.5 Effect of concentration of conducting solution and voltage on time taken to attain core temperature of 100°C in peas at 40% particulate concentration

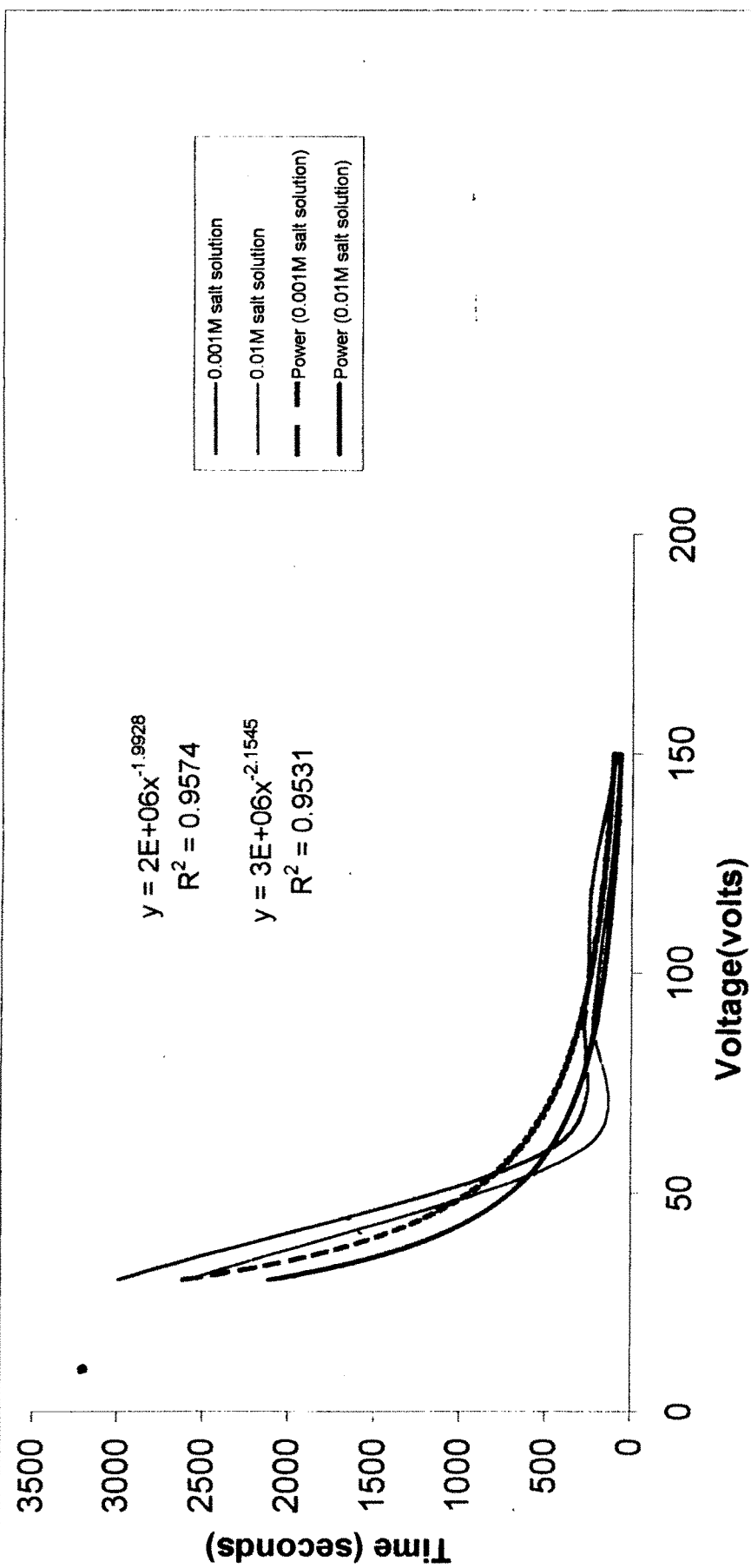


Fig.4.6 Effect of concentration of conducting solution and voltage on time required to attain a core temperature of 100°C in peas at 60% particulate concentration

differs as 20, 40 and 60 per cent (Fig. 4.4, 4.5 and 4.6) the maximum heating time was 1 minute 25 seconds in 60 per cent particulate concentration at 150 volts and 0.001 M brine solution. Thus, it could be concluded that ohmic heating apparatus is capable of processing products containing upto 60 per cent particulates (Alam and Naik, 2000).

4.9.2. Effect of particulate percentage, concentration of conducting solution and voltage on heating rate of papaya pieces

Fig. 4.7 depicts the variation of heating rate with respect to voltage gradient at 10 per cent particulate percentage at different concentration i.e, 0.001 M, 0.01 M, 0.1 M of conducting solution. Time taken to heat papaya pieces at 120 V at 0.001 M concentration of conducting solution was 1 minute, at 0.01 M concentration of conducting solution was 2 minutes. Thus a reverse trend of increase in the heating time with the increase in sugar concentration could be observed unlike NaCl as conducting solution, where heating time reduced with the increase in salt concentration. This might have occurred because NaCl had covalent bonds, thus ionic nature of NaCl helped it to become a good electrolyte. Similar trend could be seen in Fig. 4.8, 4.9 and 4.10.

4.9.3. Effect of applied voltage on the heating rate of tomato pulp

Fig. 4.11 shows the effect of voltage gradient on the time taken to attain 100°C for tomato pulp. Empirical relationship between time taken and applied voltage is also given in Fig. 4.11. It could be seen from the figure that as voltage gradient increased time taken to attain 100°C reduced. This might be attributed to electroosmotic effect at higher voltages (Palaniappan and Sastry, 1991a).

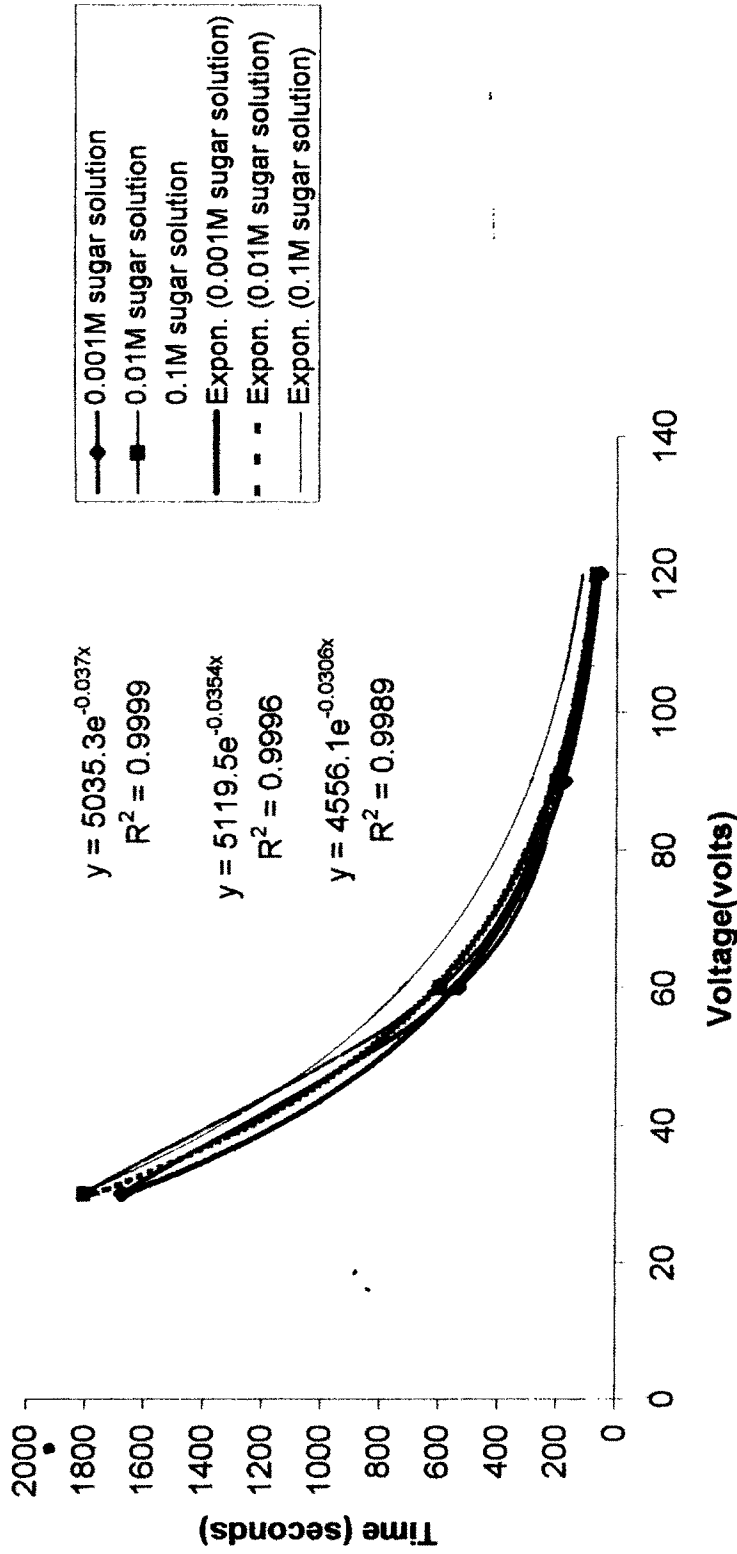


Fig.4.7 Effect of concentration of conducting solution and voltage on time required to attain 100°C core temperature in papaya at 10% particulate concentration

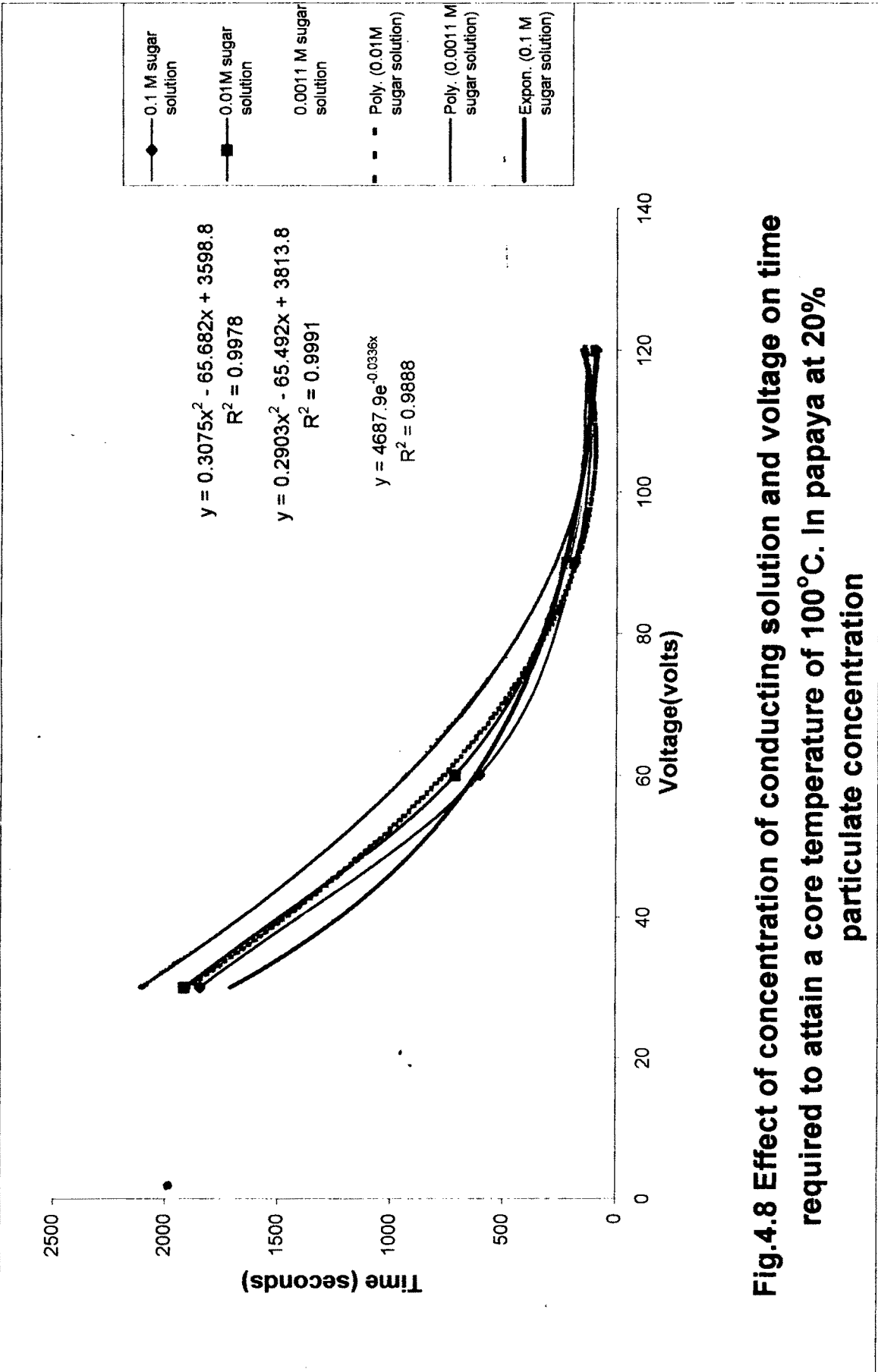


Fig.4.8 Effect of concentration of conducting solution and voltage on time required to attain a core temperature of 100°C. In papaya at 20% particulate concentration

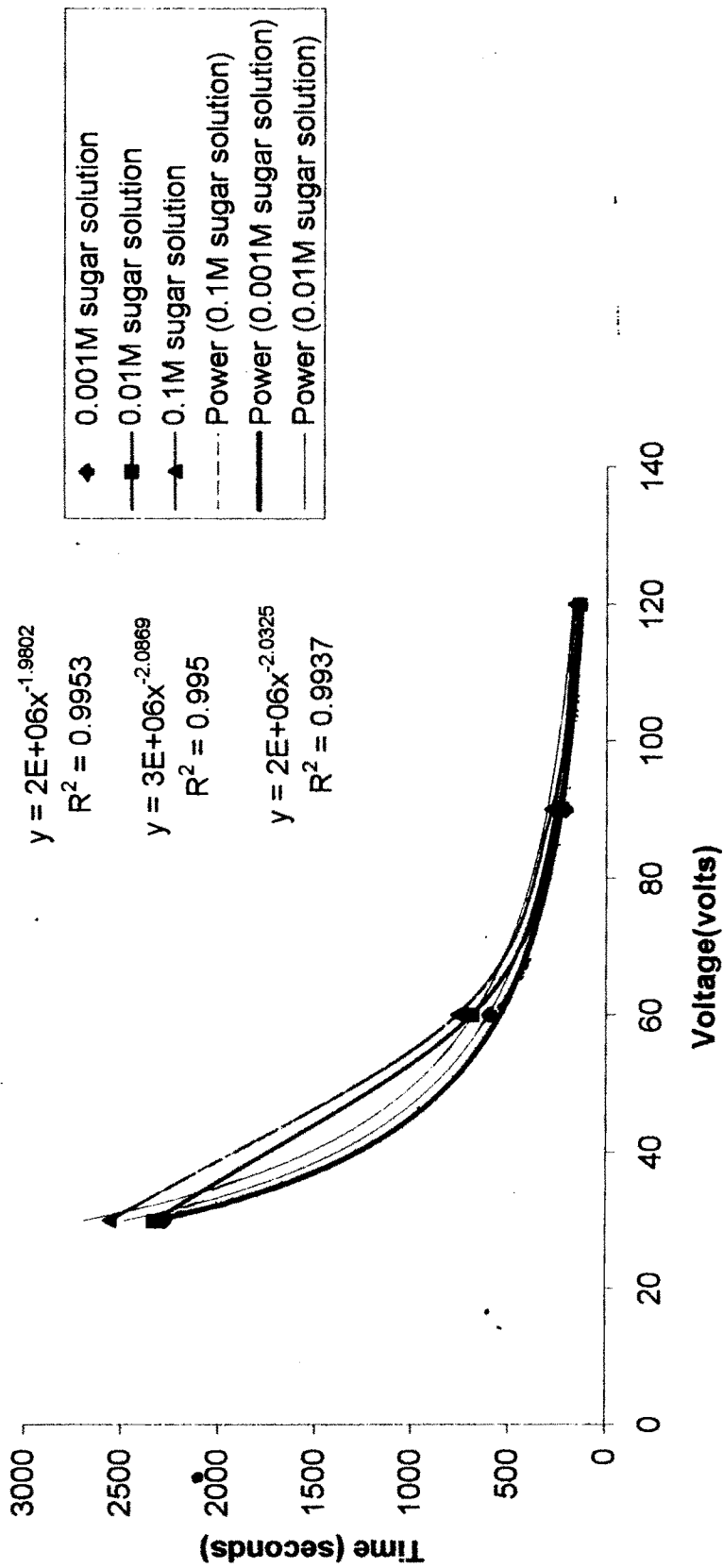


Fig.4.9 Effect of concentration of conducting solution and voltage on time required to attain 100°C core temperature of 100deg core temperature in papaya at 30% particulate concentration

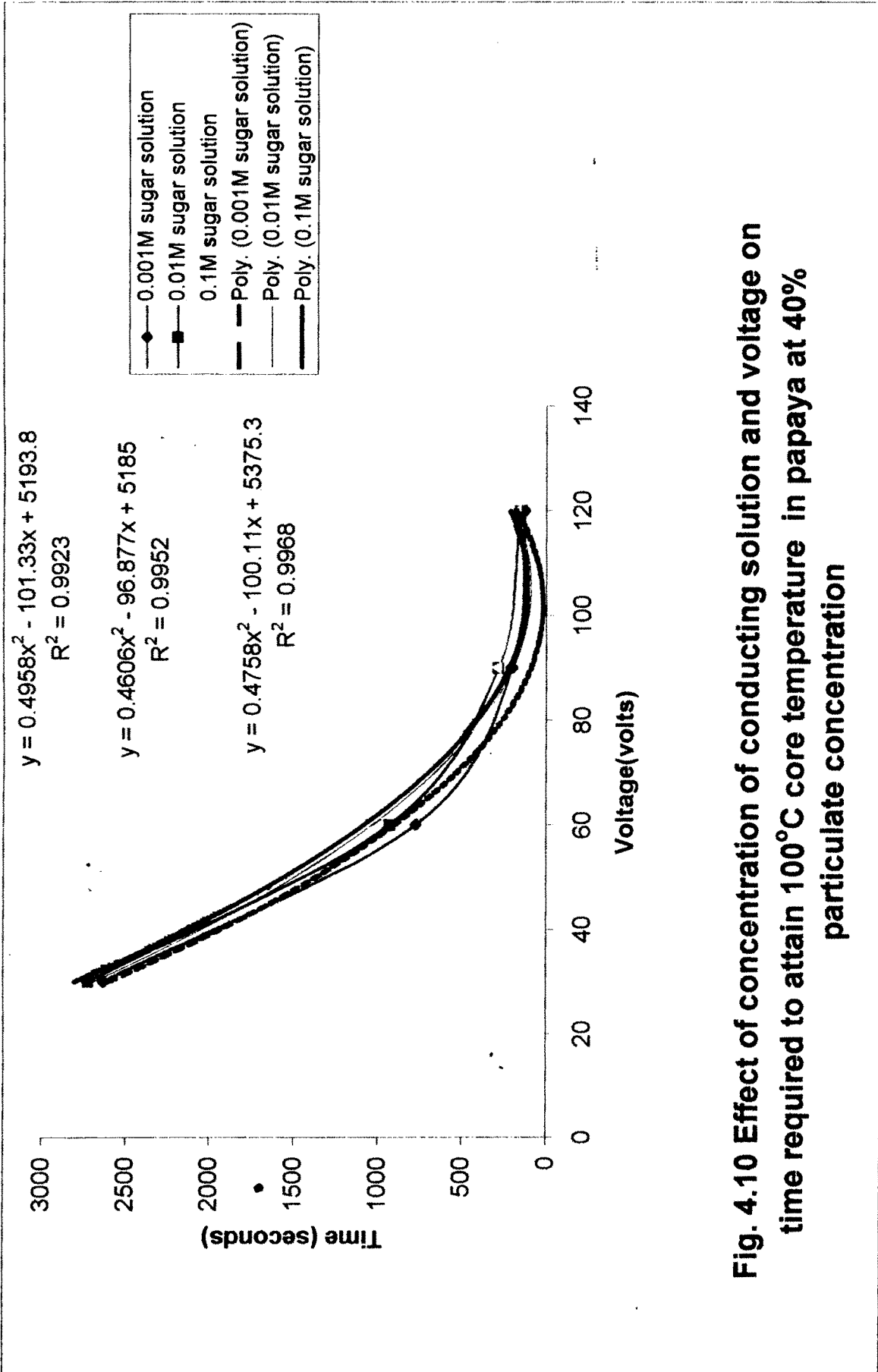


Fig. 4.10 Effect of concentration of conducting solution and voltage on time required to attain 100°C core temperature in papaya at 40% particulate concentration

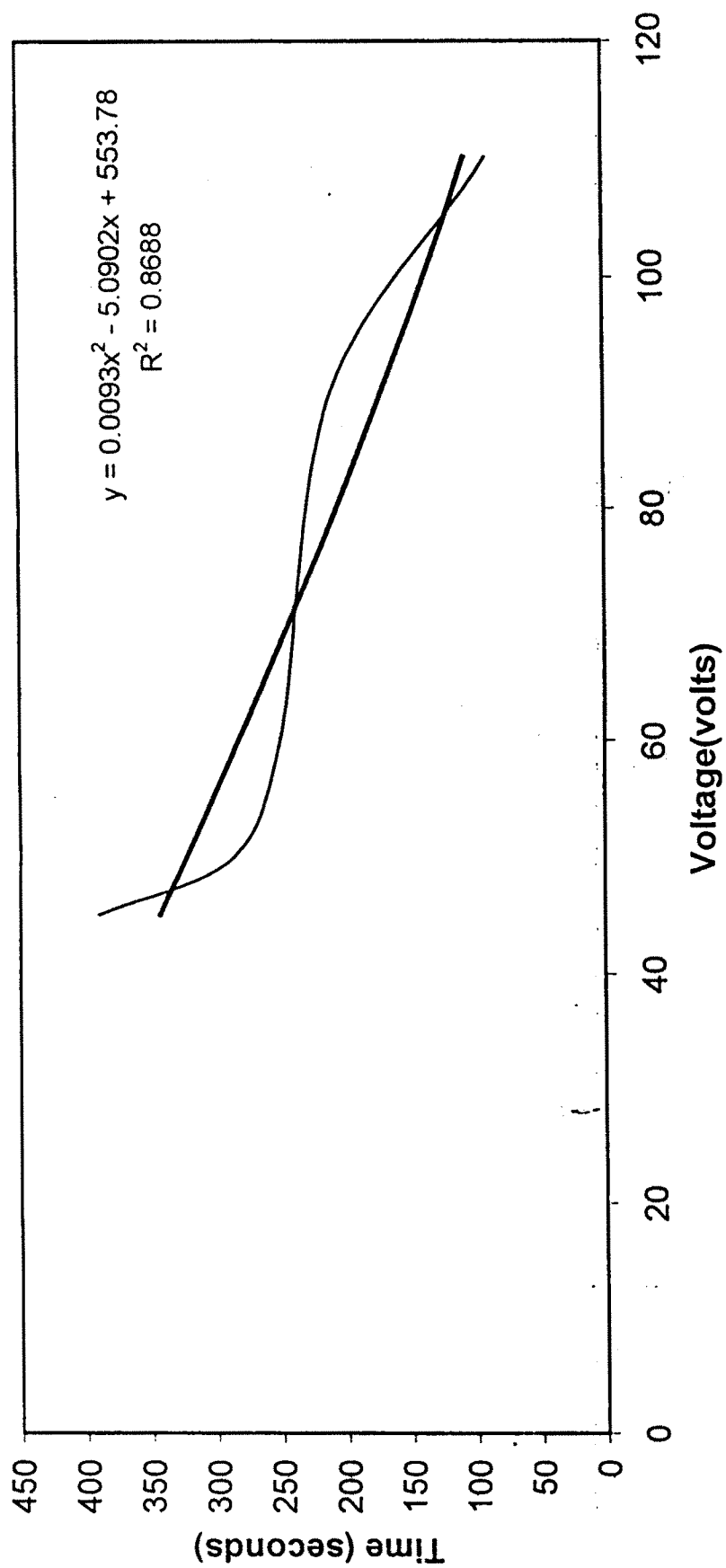


Fig.4.11 Effect of applied voltage on time taken to attain 100°C temperature by tomato pulp

4.9.4. Effect of particulate percentage, concentration of conducting solution and applied voltage on heating rate of carrot pieces

Fig. 4.12 shows the effect of applied voltage and concentration of conducting solution at 10 per cent concentration on heating rate. The empirical relationship between time taken to heat carrot pieces to 100°C and applied voltage is also given.

From the graph it is evident that as the concentration of NaCl in solution increased the heating rate also increased. This might be due to increased ionic availability.

Heat generation during ohmic heating was due to passage of electric current, so with the increased current conduction at higher concentration of NaCl, the heat generation was more. Fig. 4.13, 4.14 and 4.15 also show the same trend. Further, it could be observed that heating time of carrot was more, maximum being 4 minutes 30 seconds at 40 per cent particulate concentration and 0.001 M concentration at 120 volts applied voltage, which was higher than peas (1 minute 30 seconds) and papaya (2 minute 15 seconds). This could be attributed to the fact that carrot pieces were harder than peas and papaya (ripened), so, the salt infiltration was less which might result in increased heating time.

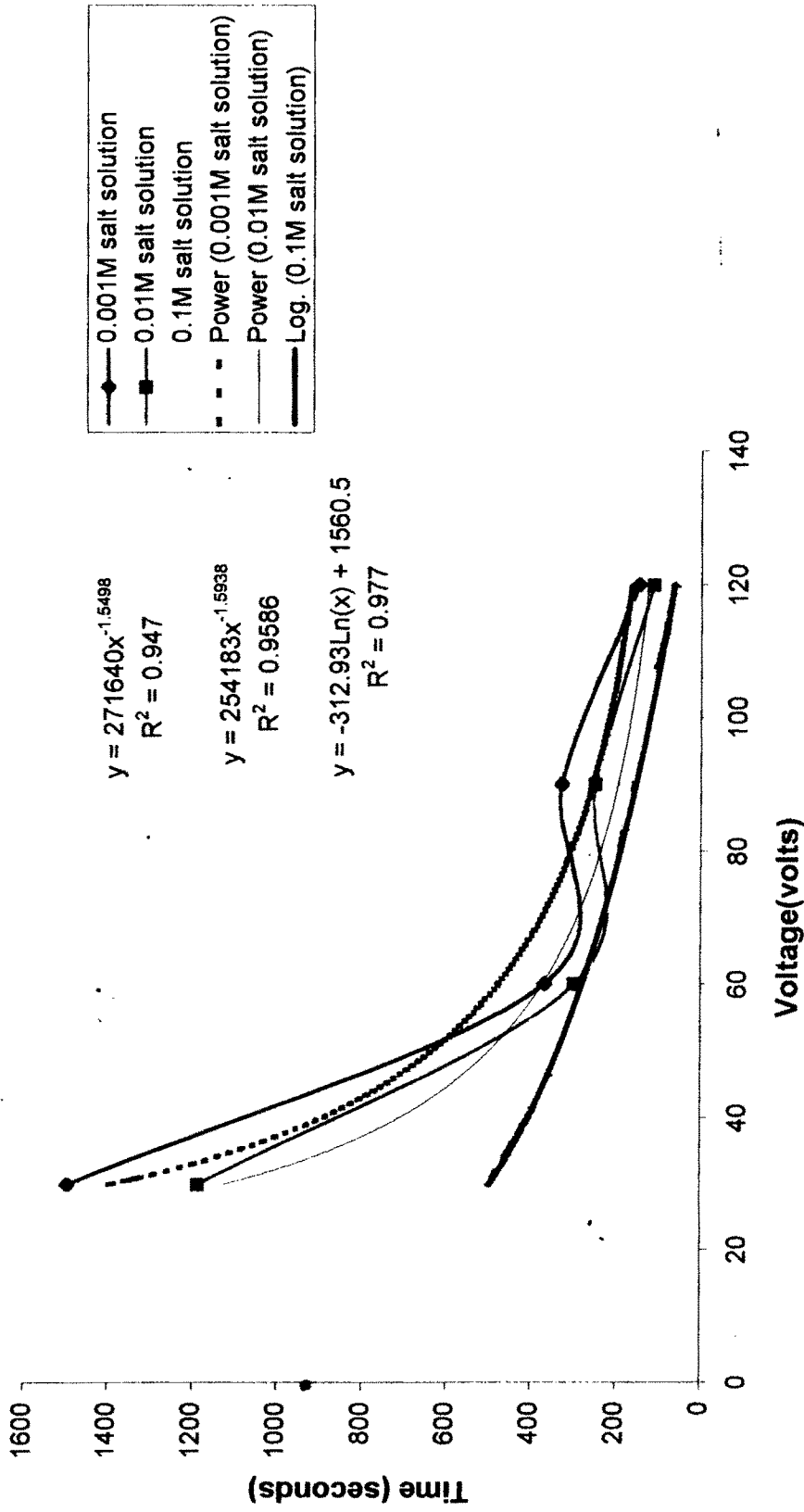


Fig.4.12 Effect of concentration of conducting solution and voltage on time required to attain a 100°C core temperature in carrots at 10% particulate concentration

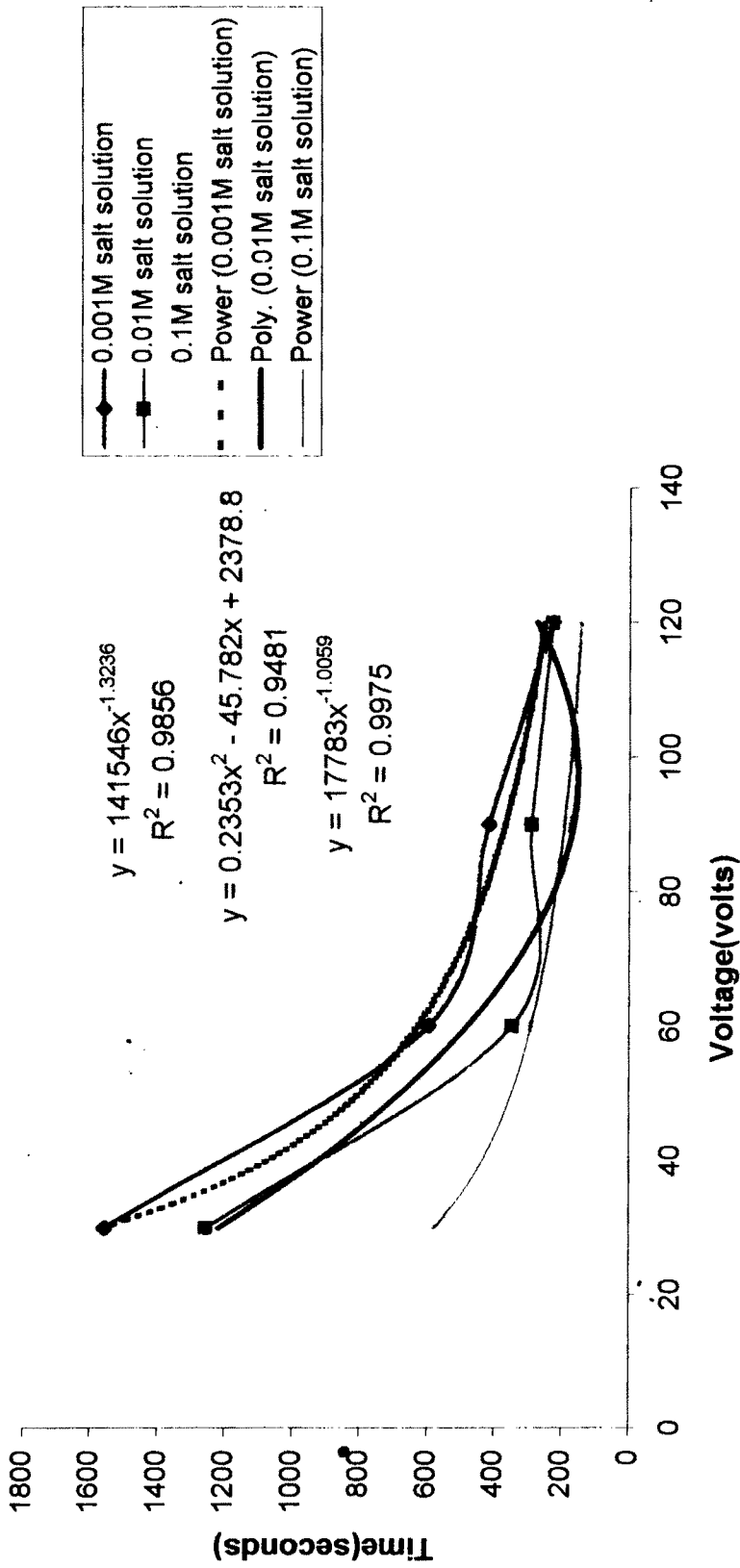


Fig.4.13 Effect of concentration of conducting solution and voltage on time required to attain 100°C core temperature in carrot at 20% particulate concentration

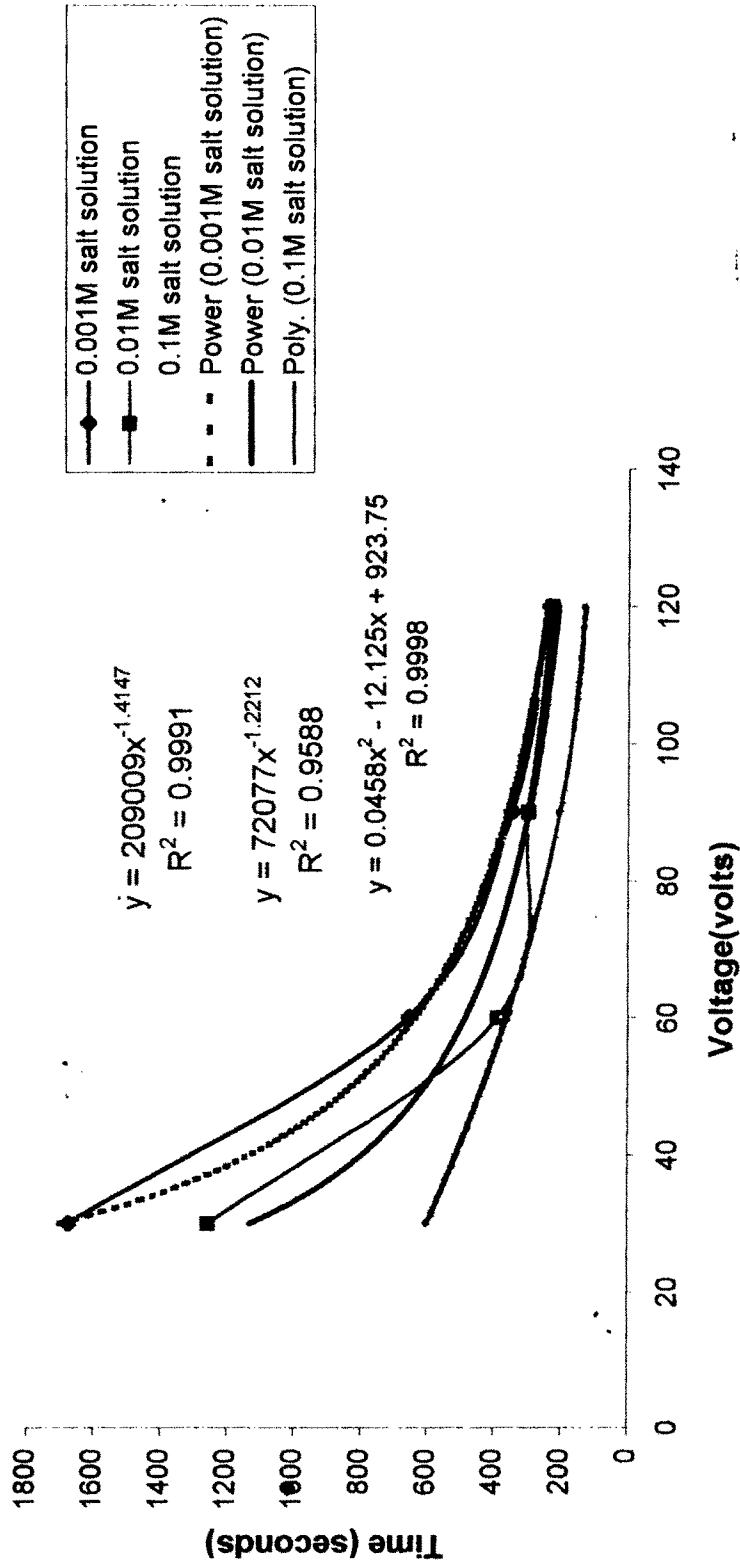


Fig.4.14 Effect of concentration of conducting solution and voltage on time required to attain 100°C core temperature in carrot at 30% particulate concentration

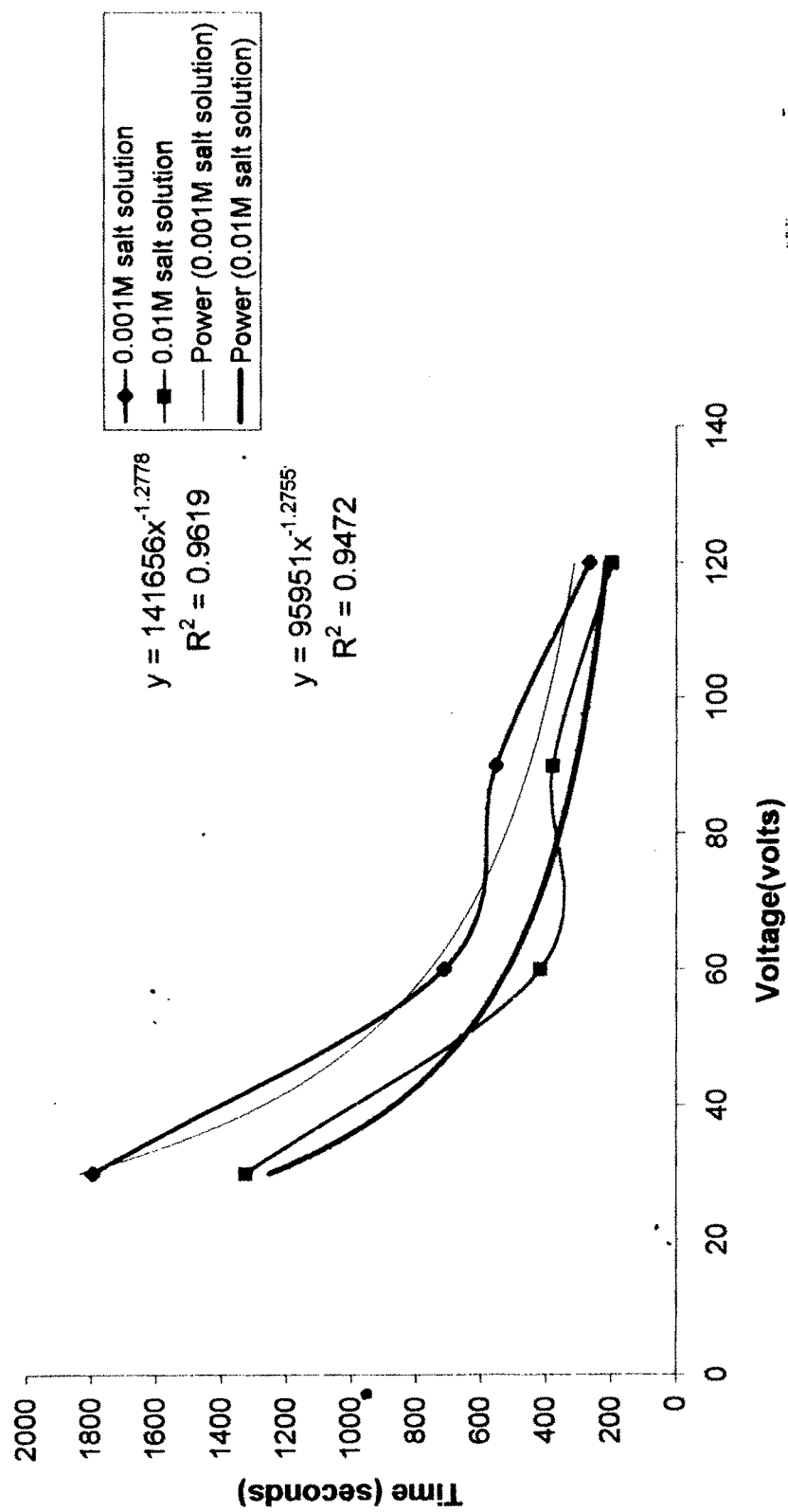


Fig.4.15 Effect of concentration of conducting solution and voltage on time required to attain 100°C core temperature in carrots at 40% particulate concentration

Summary and Conclusions

Chapter V

SUMMARY AND CONCLUSIONS

Annual post harvest losses of about 50 per cent occurs in fruits and vegetables due to poor infrastructural facilities in handling and processing. In order to increase the keeping quality of fruits, preservation techniques must be thought off. Thermal treatments can effectively hinder enzymatic and microbial spoilage. The thermal treatment carried out to inactivate enzymes ensures complete microbial death. Polyphenol oxidase is a heat stable enzyme which accelerates ageing in fruits and vegetables. For the inactivation of polyphenol oxidase, conventionally, blanching is opted. But in the process, in order to ensure a sterile central portion, exterior portion is overcooked and also during this process heat labile nutrients are lost.

Ohmic heating is an innovative technique capable of maintaining a balance between processability and organoleptic or nutritional considerations. In this process, food materials are heated by passing alternating current through them. Heat generated during ohmic heating is due to the resistance offered by the material to the flow of electric current. During ohmic heating of particulate foods, a solution is added to ensure uniform passage of electric current and to bring it to fluidised state incase of continuous system. Among the advantages claimed for this technology are uniformity of heating, product safety and improvements in quality with minimal structural, nutritional or organoleptic changes. The initial promise of this technology has resulted in its serious considerations for aseptic processing of liquid particle mixture.

The present study was aimed at finding the possibility of employing ohmic heating to some of the popular canned products like mango pulp, tomato pulp and peas in brine stock. A continuous ohmic heating system was designed and fabricated. Apart from ohmic heating system the experimental setup consisted of an auto transformer a V-A-W meter and thermocouples attached with digital panel and a selector switch.

Studies were carried out to find the effect of applied voltage and concentration of conducting solution on ohmic heating rates of peas, and effect of applied voltage and flow rate on ohmic heating rates of mango pulp and tomato pulp. Change in the engineering properties like viscosity, bulk density, colour and firmness were measured and compared with open pan blanched samples. Biochemical parameters studied were betacarotene and lycopene for mango pulp and tomato pulp respectively and vitamin C and PPO activity for mango pulp, tomato pulp and peas. Simulation and modelling of the existing one litre capacity batch type of ohmic heater was done and a computer programme in C language was also written to simulate the ohmic heating process time.

The following are the specific conclusions drawn from the study:

1. A continuous ohmic system of capacity 30 kg/h was designed and fabricated. It consisted of a heating unit, pumping unit, feed hopper for particulates, inlet and outlet tanks. Developed system could be used for ohmic heating of mango pulp, tomato pulp and peas in brine solution.
2. Heating rate of the food material was found to increase with the applied voltage. As the voltage was increased from 30 to 110 V, heating time

reduced from 26 minutes to 10 minutes in mango pulp, 12 minutes to 6 minutes and 9 seconds in case of tomato pulp and 12 minutes to 5 minute in case of peas in 0.1 M brine solution.

3. As the flow rate inside the heating chamber reduced heating time reduced. As the flow rate was reduced from 1 l min^{-1} to 0.5 l min^{-1} time taken to attain 100°C reduced from 9 minutes to 4 minutes in case of tomato pulp and 21 minutes to 10 minutes in case of mango pulp.
4. Heating rate increased with the increase in the concentration of conducting NaCl solution for the peas. Time required to heat peas to a temperature of 100°C was 10 minutes at 0.001 M concentration at 110 V which reduced to 5 minutes when concentration of NaCl solution was 0.1 M.
5. Current and power consumption increased with voltage. At a particular voltage, current consumption increased with time and when operated at 110 V maximum current consumption of 20 A for mango pulp, 12 A for tomato pulp and 24 A for peas in 0.1 M solution were recorded. Current and power consumption also increased with concentration of conducting solution.
6. Firmness of peas reduced from an initial value of 0.182 kg/mm^2 to 0.114 kg/mm^2 after ohmic heating. Density and viscosity of raw tomato pulp increased from 1.04 g/cc and 94.98 poise to 1.06 g/cc and 96 poise after ohmic heating. Similarly for mango pulp from an initial value of 1.16 g/cc and 2136.4 poise the density and viscosity increased to 1.4 g/cc and 2612.16 poise.
7. Colour of mango pulp, tomato pulp and peas changed after ohmic heating. The raw mango pulp had a hue, value and chroma of 7.5 YR, 7 and 8. These

values changed to 10 YR, 8 and 8 after ohmic heating. Raw tomato pulp had hue, value and chroma of 7.5 R, 8 and 8, after ohmic heating it attained a hue of 7.5 R, value of 5 and chroma of 6. In case of peas from an initial value of 7 G, 7 and 8, hue, value and chroma changed to 7 G, 7 and 6 respectively.

8. The polyphenol oxidase activity of fresh tomato pulp, mango pulp and peas reduced from 440 unit/mg, 300 unit/mg and 45 unit/mg to 376 unit/mg, 250 unit/mg and 40 unit/mg respectively after ohmic heating.
9. Ascorbic acid content of fresh tomato pulp, mango pulp and peas reduced from 30, 37.5 and 12 mg/100 g to 25, 30 and 10 mg/100 g respectively after ohmic heating.
10. Betacarotene content of mango pulp reduced to 2047 $\mu\text{g}/100\text{ g}$ from an initial value of 3000 $\mu\text{g}/100\text{ g}$ after ohmic heating, similarly lycopene content of tomato reduced to 200 $\mu\text{g}/100\text{ g}$ from 670 $\mu\text{g}/100\text{ g}$.
11. Cost of the developed continuous ohmic heating system was found to be Rs. 17,000. Cost of operation was found to be Rs. 58.07/h and efficiency of the system was found to be 45.38 per cent while heating pulps and 42.35 per cent while heating peas.
12. Simulation and modelling of existing batch type ohmic heating apparatus of 1 litre capacity was done. A C language program was written to simulate time taken to heat upto 100°C when the information pertaining to product, applied voltage and concentration of conducting solution were provided.

Suggestions for Future Work

1. Different thickness of SS sheets as electrode material can be tried to find out the effect of thickness of electrode on heating rate.
2. Cellular arrangement of electrodes inside the heating chamber can be tried to get rapid heating of the food material.
3. Positive displacement metering pump can be used to pump the liquid particulate mixture to the heating chamber.

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Appendices

APPENDIX - I

PREPARATION OF SODIUM CHLORIDE AND SUCROSE SOLUTIONS AT DIFFERENT CONCENTRATIONS

Concentration	Weight, g	Volume of water, ml
Sodium chloride		
0.001 M	0.05844	1000
0.01 M	0.5844	1000
0.1 M	5.844	1000
Sucrose		
0.001 M	0.3423	1000
0.01 M	3.423	1000
0.1 M	34.23	1000

$$1 \text{ M solution} = \frac{\text{Molecular weight, g}}{\text{1000 ml water}}$$

Molecular weight of sodium chloride = 58.44

Molecular weight of sucrose = 342.3

APPENDIX - II

COST OF OHMIC HEATING APPARATUS

Sl. No.	Component	Quantity	Amount
1.	Holding tank (Aluminium)	2 nos.	550.00
2.	Heating unit		
	PP pipe (5.5 cm ID)	1.5 m.	360.00
	SS strips (130 x 5 x 0.15 cm)	2 nos.	50.00
3.	Pumping unit		
	SS Gear pump (20 l min ⁻¹)	1 no.	2500.00
	Motor (0.5 hp)	1 no.	3500.00
	Pump motor link couples	1 no.	200.00
4.	SS pipes		
	12.7 mm ϕ	3 m.	1300.00
	25.4 mm ϕ	2 m	
5.	SS ball valves		
	12.7 mm	3 nos.	935.00
	25.4 mm	2 nos.	
6.	Pipe fitting		
	SS flange 152.4 x 6 mm	4	725.00
	SS flange 101.6 x 6 mm	1	
	Leather washer 101.6 x 3 mm	3	30.00
	Tee		
	12.7 mm	3	
	25.4 mm	1	280.00
	Couplings		
	12.7 mm	1	
	25.4 mm	1	140.00

Sl. No.	Component	Quantity	Amount
	Elbow		
	12.7 mm	5	
	25.4 mm	2	475.00
	Union 12.7 mm	1	60.00
	Nipple		
	12.7 mm	12	
	25.4 mm	2	1150.00
	Nut bolt washers		
	6.35 mm	1 packet	80.00
	4.76 mm	15 nos.	60.00
7.	Stands		
	L angle 19.05 x 3.17	15 m	360.00
	L angle 25.4 x 6.35	15 m	
8.	Consumables		
	Shellac	5 nos	35.00
	Teflon tape	3 nos	45.00
	Total material cost		12835.00

Fabrication changes (25% of material cost) = Rs. 3208.75

Wastage of materials (5% of material cost) = Rs. 641.75

Total cost of the unit = Rs. 16685.50

COST OF OPERATION

Assumptions

- (i) Cost of the apparatus = Rs. 17000.00
- (ii) Useful life = 1 year
- (iii) Annual usage of plant = 8000 hours
- (iv) Interest rate = 18 per cent
- (v) Cost of building = 100000.00
- (vi) Cost of power = 3 per unit

FIXED COST

(a) Depreciation $= \frac{17000 - 1700}{8000}$
 $= \text{Rs. } 1.91/\text{h}$

(b) Interest on capital $= \frac{17000 + 1700}{2} \times \frac{0.18}{8000}$
 $= \text{Re. } 0.21 / \text{h.}$

(c) Insurance and taxes
 (2 per cent of initial cost of unit) $= \frac{17000}{8000} \times 0.02$
 $= \text{Re. } 0.0425 / \text{h}$

(d) Housing $= \frac{10000}{8000}$
 $= \text{Rs. } 12.5 / \text{h}$

Total fixed cost $= a + b + c + d$
 $= 1.91 + 0.21 + 0.0425 + 12.5$
 $= \text{Rs. } 14.66/\text{h}$

VARIABLE COST

(a) Energy consumption

(i) One number 0.5 hp motor	=	0.5 x 0.746
	=	0.373 kW
(ii) Energy consumption of ohmic heating (75 per cent capacity of plant)	=	110 x 25
	=	2.75 kW
Total energy consumption per hour	=	2.75 + 0.373
	=	3.123 kW
Cost of energy consumption per hour	=	3.123 x 3
	=	Rs. 9.369/h

(b) Labour changes

Labour required for preparation of raw material	=	2 women labour
Labour requirement for plant operation	=	1 man labour
Wages of women labour	=	50 / 8 x 2
	=	Rs. 12.5/h
Wages of man labour	=	80 / 8 x 1
	=	Rs. 10/h
Total labour charges	=	10 + 12.5
	=	Rs. 22.5/h

(c) Repair and maintenance

Repair and maintenance charge (@ 30 per cent of initial cost)	=	17,000
		----- x 0.3
		8000
	=	Re. 0.637/h

(d) Cost of input

For particulate food sugar or salt solution is required. If 0.1 M of sodium chloride or 0.1 M of sucrose solution is used, which will form 50 per cent of total flow volume, then,

$$\begin{aligned}
 \text{(i) quantity of sodium chloride required} &= \frac{30 \times 0.6 \times 5.84 \times 10^{-3}}{1.04} \\
 &= 0.101 \text{ kg/h}
 \end{aligned}$$

$$\begin{aligned}
 \text{Cost of sodium chloride} &= 0.101 \times 6 \\
 &= \text{Re. } 0.606/\text{h}
 \end{aligned}$$

$$\begin{aligned}
 \text{(ii) quantity of sugar required} &= \frac{30 \times 0.6 \times 34.23 \times 10^{-3}}{1.016} \\
 &= 0.606 \text{ kg/h}
 \end{aligned}$$

$$\begin{aligned}
 \text{Cost of sugar} &= 0.606 \times 17 \\
 &= \text{Rs. } 10.302/\text{h}
 \end{aligned}$$

$$\begin{aligned}
 \text{Total input cost} &= 0.606 + 10.302 \\
 &= \text{Rs. } 10.908/\text{h}
 \end{aligned}$$

$$\begin{aligned}
 \text{Total variable cost} &= a + b + c + d \\
 &= 9.369 + 22.5 + 0.637 + 10.908 \\
 &= \text{Rs. } 43.414/\text{h}
 \end{aligned}$$

$$\begin{aligned}
 \text{Cost of operation per hour} &= \text{Total fixed cost} + \text{Total variable cost} \\
 &= 14.66 + 43.414 \\
 &= \text{Rs. } 58.074/\text{h}
 \end{aligned}$$

APPENDIX - III

Energy Efficiency

$$\text{Efficiency} = \frac{\text{Energy gained by food materials}}{\text{Energy supplied}}$$

(1) Peas in brine solution

$$\begin{aligned} \eta &= \frac{3.31 \times 12 \times 70 + 4.183 \times 18 \times 70}{110 \times 24 \times 2 \times 3.6} \\ &= 42.35\% \end{aligned}$$

(2) Tomato pulp

$$\begin{aligned} \eta &= \frac{(0.5 \times 1.04) \times 3.95 \times 70}{\left\{ \frac{110 \times 12}{1000} \right\} \times 4 \times 60} \times 100 \\ &= 45.38\% \end{aligned}$$

APPENDIX - IV

COST ANALYSIS OF OPEN PAN BLANCHING

Assumptions

Initial cost	=	Rs. 20,000.00
Useful life	=	5 years
Annual usage	=	8000 hours
Interest rate	=	18 per cent
Cost of building	=	Rs. 100,000.00

Fixed cost

a) Depreciation	=	$\frac{20,000 - 2000}{5 \times 8000}$	
	=	Re. 0.45/h	
b) Interest	=	$\frac{20,000 + 2000}{2} \times \frac{0.18}{8000}$	
	=	Re. 0.2475/h	
c) Insurance and taxes (2 % of initial cost)	=	$\frac{20,000}{8000} \times 0.02$	
	=	Re. 0.05/h	
d) Housing	=	$\frac{100,000}{8000}$	
	=	Rs. 12.5/h	
Total fixed cost	=	a + b + c + d	
	=	Rs. 13.24/h	

Variable cost

(a) Energy consumption of blancher = 1554 k cal/h

Cost of fuel = 1554
----- x 10
105

(b) Labour charges

Labour requirement for preparation of raw material = 2 women labour

Labour requirement for plant operation = 1 man labour

Wages of women labour = 50
---- x 2
8

= Rs. 12.5/h

Wages of man labour = 80
---- x 1
8

Total labour charges = Rs. 22.5/h

(c) Repair and maintenance cost = 20,000
----- x 0.3
8000

= Re. 0.75/h

Total variable cost = a + b + c

= Rs. 171.25/h

Cost of operation per hour = Total Fixed Cost + Total Variable Cost

= 13.24 + 171.25

= Rs. 184.49/h

APPENDIX - V

'C' LANGUAGE PROGRAMME TO SIMULATE OHMIC HEATING PROCESS TIME

```
#include<stdio.h>
#include<conio.h>
#include<string.h>
#include<math.h>
void main()
{
    char k,c,o,p,i;
    int a,v;
    float b,t;
    clrscr();
    printf("*****Enter the product name*****\n");
    printf("\n");
    printf("\n c stands for carrot\n");
    printf(" o stands for tomato\n");
    printf(" p stands for papaya\n");
    printf(" i stands for peas\n");
    scanf("%s",&k);
    switch(k)
    {
        case 'c':
            {
                printf("\nEnter the particulate percentage\n");
                printf("\n 10,20,30,or 40\n");
                scanf("%d",&a);
                printf("\nEnter the concentration of the salt solution in molarity\n");
                printf("\n 0.001,0.01,0.1\n");
                scanf("%f",&b);
                printf("Enter the voltage at which the apparatus is operated\n");
                scanf("%d",&v);
                if ((a==10)&&(b==0.001))
                {
                    t= 271640*pow(v,-1.5498);
                    printf("Time taken to attain a core temperature of 100 deg C is
                    :%f",t);
                }
                else if ((a==10)&&(b==0.01))
                {
                    t=254183*pow(v,-1.5938);
                    printf("Time required to attain a core temperature of 100deg. is:%f",t);
                }
                else if ((a==10)&&(b==0.1))
                {
                    t= (-312.92*log(v))+1560.5;
                    printf("Time taken to attain a core temperature of 100deg.C is:%f",t);
                }
            }
    }
}
```

```

else if ((a==20)&&(b==0.001))
{
t=141546*pow(v,-1.3236);
printf("Time taken to attain a core temperature of 100deg.C is:%f",t);
}
else if ((a==20)&&(b==0.01))
{
t=(0.2353*v*v)-(45.782*v) + 2378.8;
printf("Time taken to attain a core temperature of 100deg.C
is:%f",t);
}
else if ((a==20)&&(b==0.1))
{
t=17783*pow(v,-1.0059);
printf("Time taken to attain a core temperature of 100deg.C is:%f",t);
}
else if ((a==30)&&(b==0.001))
{
t=209009*pow(v,-1.4147);
printf("Time taken to attain a core temperature of 100deg.C is:%f",t);
}
else if ((a==30)&&(b==0.01))
{
t=72077*pow(v,-1.2212);
printf("Time taken to reach a core temperature of 100deg.C is:%f",t);
}
else if ((a==30)&&(b==0.1))
{
t=(0.0458*v*v)-(12.125*v)+923.75;
printf("Time taken to attain a core temperature of 100deg.C is:%f",t);
}
else if ((a==40)&&(b==0.001))
{
t=141656*pow(v,-1.2778);
printf("Time taken to attain a core temperature of 100deg.C is:%f",t);
}
else if((a==40)&&(b==0.01))
{
t=95951*pow(v,-1.2755);
printf("Time taken to attain a core temperature of 100deg. is:%f",t);
}
else
{
printf("current exceeds 25 amperes");
}
}
break;

```

```

case 'p':
{
printf("Enter the particulate percentage\n");
printf("10,20,30 or 40\n");
scanf("%d",&a);
printf("Enter the concentration of sugar solution in molarity\n");
printf("0.001,0.01,0.1\n");
scanf("%f",&b);
printf("Enter the voltage at which the apparatus is to be operated\n");
scanf("%d",&v);
if((a==10)&&(b==0.001))
{
t=5035.3*exp(-0.037*v);
printf("Time required to attain a core temperature of 100deg.C
is:%f",t);
}
else if ((a==10)&&(b==0.01))
{
t=5119.5*exp(-0.0354*v);
printf("Time required to attain a core temperature of 100deg.C is
:%f",t);
}
else if((a==10)&&(b==0.1))
{
t=4556.1*exp(-0.0306*v);
printf("Time required to attain a core temperature of 100deg.C is
:%f",t);
}
else if ((a==20)&&(b==0.001))
{
t=(0.3181*v*v)-(66.658*v)+3538.8;
printf("Time required to attain a core temperature of 100degC is
:%f",t);
}
else if((a==20)&&(b==0.01))
{
t=(0.3075*v*v)-(65.682*v)+3598.8;
printf("Time required to attain a core temperature of 100deg.C
is:%f",t);
}
else if((a==20)&&(b==0.1))
{
t=(0.2903*v*v)-(65.492*v)+3813.8;
printf("Time required to attain a core temperature of 100deg.C
is:%f",t);
}
else if ((a==30)&&(b==0.001))
{
t= 2*2.718+(6*pow(v,-1.9802));
printf("Time required to attain a core temperature of 100deg.C
is:%f",t);
}
else if ((a==30)&&(b==0.01))

```




```

printf("Time required to attain a core temperature of 100deg.C
is:%f",t);
}
if ((a==20) && (b==0.01))
{
t=7*2.718+6*pow(v,-2.3541);
printf("Time taken to attain a core temperature of 100deg.C
is:%f",t);
}
if ((a==20) && (b==0.1))
{
t=194021*pow(v,-1.645);
printf("Time taken to attain a core temperature of 100deg. C
is:%f",t);
}
if ((a==40)&&(b==0.001))
{
t=3*2.718+6*pow(v,-2.1031);
printf("Time taken to attain a core temperature of 100deg.C
is:%f",t);
}
if ((a==40)&&(b==0.01))
{
t=5*2.718+6*pow(v,-2.243);
printf("Time taken to attain a core temperature of 100deg.C is
:%f",t);
}
if ((a==40)&&(b==0.1))
{
t=102330*pow(v,-1.4503);
printf("Time taken to attain a core temperature of 100deg.C
is:%f",t);
}
if ((a==60)&&(b==0.001))
{
t=2*2.718+(6*pow(v,-1.9928));
printf("Time required to attain a core temperature of 100degC
is:%f",t);
}
if ((a==60)&&(b==0.01))
{
t=3*2.718+(6*pow(v,-2.1545));

```

```
is:%f",t);
    printf("Time required to attain a core temperature of 100 deg.C
    }
    if ((a==60)&&(b==0.1))
    {
        printf("current exceeds 25 amperes");
    }
    break;
default:
    {
        printf("Enter the product name,concentration of solution and particulate
percentage correctly");
    }
}

getch();
}
```