TEMPERATURE DEPENDENT ELECTRICAL CONDUCTIVITY OF SOYMILK DURING OHMIC HEATING

Thesis

Submitted to the Punjab Agricultural University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE
In
PHYSICS
(Minor Subject: Mathematics)

By

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LUDHIANA-141004

2016

CERTIFICATE I

This is to certify that the thesis entitled, **“Temperature Dependent Electrical Conductivity of Soymilk during Ohmic Heating”** submitted for the degree of **Master of Science,** in the subject of **Physics** (Minor subject: **Mathematics**) of the Punjab Agricultural University, Ludhiana, is a bonafide research work carried out by **Jasleen Kaur (L-2014-BS-316-M)** under my supervision and that no part of this thesis has been submitted for any other degree.

The assistance and help received during the course of investigation have been fully acknowledged.

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ACKNOWLEDGEMENT

First and foremost I would like to thank my loving creator, the almighty, for his showers of blessings throughout my research work to complete the research successfully. You have given me the power to believe in myself and pursue my dreams. I could never have done this without the faith I have in you, the almighty .Thank you so much God!!

*I warmly thank and appreciate my mother **Baljeet Kaur** and father **Jaswant Singh** for their material and spiritual support in all aspects of my life. I want to express my gratitude and deepest appreciation to my loving brother **Jashan**. I am eternally grateful to my beloved parents for their unconditional love, endurance and encouragement. They have been selfless in giving me the best of everything and I express my deep gratitude for their love without which this work would not have been completed. I take this moment to express my never ending love and respect towards them for their blessings. I would never ever forget the untold sacrifices that you quietly made for my better and brighter career. Words are not alone enough to thank them. Thank you my mommy and Daddy.*

*I want to express my deep thanks to my esteemed Major Advisor **Dr Paramjit Singh** for the insightful discussion, valuable advice, for his support during the whole period of the study, and especially for his patience and guidance during the writing process. His dynamism, vision, sincerity and motivation have deeply inspired me. He has taught me the methodology to carry out the research and to present the research works as clearly as possible. It was a great privilege and honor to work and study under his guidance. I would like to express the deepest appreciation to all the members of my advisory committee, viz **Dr M. Javed, Dr Rama Kumari, Dr Manpreet Kaur and Dr Rajeev Sharma** for conscientious guidance and encouragement to accomplish this work. I also want to express my special thanks to **Dr Kiran jeet and Dr Parveen Bala** for their constant appreciation, encouragement and support. It was a great pleasure to have the opportunity to discuss with them. A special thanks to Dr. Hosain Darvishi (University of Kurdistan, Iran) for his guidance during completion of this work.*

*I express my sincere thanks to Arvinder Kaur aunty, Amrik Singh uncle, Rajnish uncle, Surjit Singh uncle, Amarjit Singh uncle and Pawandeep Kaur aunty. Without their help, timely submission of my thesis would not have been possible. Special thanks to my best friend **Nupur** for taking my mind off on a long flight when needed and increasing my stress buster hormones so badly to the point of dying out of uncontrollable laughter and that was surely needed!! I would never forget the liveliness you brought in me during some of the toughest times. Thank you so much dear. Thanks to my seniors Sunpreet dee and Sheenam dee for their support, guidance and care. Thanks to my classmates Avneet, Avtar, Gunvir, Chetna, Harneet, Gurpreet, Sukhjit and Gurpreet for motivating me whenever needed. Special thanks to my friends Kritika, Divya, Aishwarya and Prabhjot for their love and support. Thank you my juniors Ramanjit, Mitika, Harpreet, Aman, Nisha, Anjali, Tavneet, Bindiya, Supreet, Manpreet and Kiran for those laughters that we shared together. There are so many others whom I may have inadvertently left and I sincerely thank all of them for their help.*

(Jasleen Kaur)

Title of the Thesis : Temperature Dependent Electrical Conductivity of Soymilk during Ohmic Heating

Name of The Student And Admission No. : Jasleen Kaur
L-2014-BS-316-M

Major Subject : Physics

Minor Subject : Mathematics

Name and designation of Major Advisor : Dr. Paramjit Singh
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Degree to be Awarded : Master of Science

Year of award of Degree : 2016

Total Pages in Thesis : 56+Vita

Name of University : Punjab Agricultural University
Ludhiana – 141004

ABSTRACT

Ohmic heating, also known as 'resistive heating' or 'Joule heating' is a process when electrical current is passed through a conducting substance and due to its internal resistance heat is generated within that conducting substance. The present study aimed to design, built ohmic heating system and ohmic heating behavior was studied in soymilk. Study was conducted on five different voltage gradients (14, 12, 10, 8 and 6V/cm) and concentrations (100, 90, 80, 70, 60%) in the temperature range 30 to 70˚C. Ohmic heating behavior of any sample is affected by different parameters like electrical conductivity, viscosity, pH, soluble solids etc. Results indicated that there was a significant effect of voltage gradients and concentrations on the heating rate and heating rate showed a linear behavior. Also, plots between temperature and electrical conductivity depicted a linear trend. Other parameters- viscosity, pH and total soluble solids (TSS) were measured before and after ohmic heating. Statistical analysis was done on all of these parameters and it was concluded that ohmic heating had no effect on viscosity and TSS of sample, but there was a significant effect of this treatment on pH at 14 and 6V/cm and non-significant effect on rest of the voltage gradients. System performance coefficient (SPC) was calculated for all voltage gradients and all concentrations. It was observed that SPC was higher for 14V/cm for all concentrations and its value decreased as we decrease the voltage gradient.

Keywords: Ohmic heating, Soymilk, Electrical conductivity, pH, TSS, Viscosity, SPC

Signature of Major Advisor

Signature of the Student

ਖੋਜ ਪ੍ਰਬੰਧ ਦਾ ਸਿਰਲੇਖ : ਓਮਿਕ ਹੀਟਿੰਗ ਦੌਰਾਨ ਸੋਇਆ ਮਿਲਕ ਦੀ ਬਿਜਲੀ ਚਾਲਕਤਾ ਤੇ ਤਾਪਮਾਨ ਦਾ ਪ੍ਰਭਾਵ
ਵਿਦਿਆਰਥੀ ਦਾ ਨਾਮ ਅਤੇ ਪ੍ਰਵੇਸ਼ ਨੰ. : ਜਸਲੀਨ ਕੌਰ (ਐਲ-2014-ਬੀ ਐਸ-316-ਐਮ)
ਮੁੱਖ ਵਿਸ਼ਾ : ਭੌਤਿਕ ਵਿਗਿਆਨ
ਨਿਮਨ ਵਿਸ਼ਾ : ਗਣਿਤ
ਮੁੱਖ ਸਲਾਹਕਾਰ ਦਾ ਨਾਮ ਅਤੇ ਅਹੁਦਾ : ਡਾ. ਪਰਮਜੀਤ ਸਿੰਘ
ਪ੍ਰੋਫੈਸਰ
ਡਿਗਰੀ : ਐਮ.ਐਸ.ਸੀ.
ਡਿਗਰੀ ਮਿਲਣ ਦਾ ਸਾਲ : 2016
ਖੋਜ ਪ੍ਰਬੰਧ ਦੇ ਕੁੱਲ ਪੰਨੇ : 56+ਵੀਟਾ
ਯੂਨੀਵਰਸਿਟੀ ਦਾ ਨਾਮ : ਪੰਜਾਬ ਖੇਤੀਬਾੜੀ ਯੂਨੀਵਰਸਿਟੀ, ਲੁਧਿਆਣਾ - 141004, ਪੰਜਾਬ, ਭਾਰਤ

ਸਾਰ-ਅੰਸ਼

ਓਮਿਕ ਹੀਟਿੰਗ ਨੂੰ ਰਜਿਸਟਿਵ ਹੀਟਿੰਗ ਅਤੇ ਜੂਲ ਹੀਟਿੰਗ ਦੇ ਨਾਮ ਨਾਲ ਵੀ ਜਾਣਿਆ ਜਾਂਦਾ ਹੈ ਅਤੇ ਇਹ ਇੱਕ ਅਜਿਹਾ ਕਾਰਜ ਹੈ ਜਦੋਂ ਬਿਜਲੀ ਕਿਸੇ ਸੁਚਾਲਕ ਪਾਦਰਥ ਵਿੱਚੋਂ ਲੰਘਦੀ ਹੈ ਤਾਂ ਉਸ ਦੀ ਅੰਦਰੂਨੀ ਰੁਕਾਵਟ ਉਸਦੇ ਅੰਦਰ ਗਰਮੀ ਪੈਦਾ ਕਰਦੀ ਹੈ। ਮੌਜੂਦਾ ਅਧਿਐਨ ਦਾ ਉਦੇਸ਼ ਓਮਿਕ ਹੀਟਿੰਗ ਸਿਸਟਮ ਨੂੰ ਬਣਾਉਣ ਅਤੇ ਓਮਿਕ ਹੀਟਿੰਗ ਦੇ ਵਿਵਹਾਰ ਨੂੰ ਸੋਇਆ ਮਿਲਕ ਤੇ ਵਿਚਾਰਨਾ ਹੈ। ਇਸ ਅਧਿਐਨ ਵਿੱਚ ਪੰਜ ਵੱਖ-ਵੱਖ ਵੋਲਟੇਜ਼ ਗਰੇਡੀਐਂਟਸ (14, 12, 10, 8, 6 ਵੋਲਟ ਪ੍ਰਤੀ ਸੈ.ਮੀ.) ਅਤੇ ਸੋਇਆ ਮਿਲਕ ਦੇ ਵੱਖ-ਵੱਖ ਗਾੜ੍ਹੇਪਣਾਂ (100, 90, 80, 70, 60%) ਦਾ ਅਧਿਐਨ 30-70 ਡਿਗਰੀ ਸੈਲਸੀਅਸ ਦੀ ਤਾਪਮਾਨ ਸਿਗਮਾ ਵਿੱਚ ਦਰਜ ਕੀਤਾ ਗਿਆ ਕਿਸੇ ਵੀ ਨਮੂਨੇ ਦੇ ਓਮਿਕ ਹੀਟਿੰਗ ਦੇ ਵਿਵਹਾਰ ਨੂੰ ਬਿਜਲੀ ਦੀ ਚਾਲਕਤਾ, ਗਾੜ੍ਹਾਪਣ, ਪੀ ਐਚ, ਪੂਰਨ ਘੁਲਣਸ਼ੀਲ ਠੋਸ ਅਤੇ ਵੋਲਟੇਜ਼ ਗਰੇਡੀਐਂਟਸ ਪ੍ਰਭਾਵਿਤ ਕਰਦੇ ਹਨ। ਨਤੀਜਿਆਂ ਅਨੁਸਾਰ ਵੱਖ-ਵੱਖ ਵੋਲਟੇਜ਼ ਗਰੇਡੀਏਂਟਸ ਅਤੇ ਨਮੂਨਿਆਂ ਦੇ ਗਾੜ੍ਹੇਪਣ ਦਾ ਓਮਿਕ ਹੀਟਿੰਗ ਰੇਟ ਉੱਤੇ ਬਹੁਤ ਪ੍ਰਭਾਵ ਸੀ ਅਤੇ ਇਸ ਨੇ ਲੀਨੀਅਰ ਸੰਬੰਧ ਸਥਾਪਿਤ ਕੀਤਾ। ਹੋਰ ਤੱਤ ਜਿਵੇਂ ਕਿ ਗਾੜ੍ਹਾਪਣ, ਪੀ ਐਚ ਅਤੇ ਪੂਰਨ ਘੁਲਣਸ਼ੀਲ ਠੋਸ ਓਮਿਕ ਹੀਟਿੰਗ ਤੋਂ ਪਹਿਲਾਂ ਅਤੇ ਬਾਅਦ ਵਿੱਚ ਮਾਪੇ ਗਏ। ਇਹਨਾਂ ਸਾਰੇ ਤੱਤਾਂ ਦਾ ਅੰਕੜਾ ਵਿਸ਼ਲੇਸ਼ਣ ਕੀਤਾ ਗਿਆ ਅਤੇ ਇਹ ਸਿੱਟਾ ਕੱਢਿਆ ਗਿਆ ਕਿ ਓਮਿਕ ਹੀਟਿੰਗ ਦਾ ਗਾੜੇਪਣ ਅਤੇ ਪੂਰਨ ਘੁਲਣਸ਼ੀਲ ਠੋਸ ਉੱਤੇ ਕੋਈ ਪ੍ਰਭਾਵ ਨਹੀਂ ਸੀ ਪਰ ਪੀ ਐਚ ਤੇ 14 ਅਤੇ 6 ਵੋਲਟੇਜ਼ ਗਰੇਡੀਐਂਟਸ ਤੇ ਇਸ ਦਾ ਮਹੱਤਵਪੂਰਨ ਪ੍ਰਭਾਵ ਪਾਇਆ ਗਿਆ ਅਤੇ ਬਾਕੀ ਦੇ ਵੋਲਟੇਜ਼ ਗਰੇਡੀਐਂਟਸ ਤੇ ਇਸ ਦਾ ਕੋਈ ਪ੍ਰਭਾਵ ਨਹੀਂ ਸੀ। ਸਿਸਟਮ ਦੀ ਕਾਰਗੁਜ਼ਾਰੀ ਸਾਰੀ ਵੋਲਟੇਜ਼ ਗਰੇਡੀਐਂਟਸ ਅਤੇ ਗਾੜ੍ਹੇਪਣ ਲਈ ਕੱਢੀ ਗਈ ਅਤੇ ਇਹ ਪਾਇਆ ਗਿਆ ਕਿ ਬਾਕੀ ਵੋਲਟੇਜ਼ ਗਰੇਡੀਐਂਟਸ ਦੇ ਮੁਕਾਬਲੇ 14 ਵੋਲਟੇਜ਼ ਗਰੇਡੀਐਂਟਸ ਲਈ ਇਸ ਦੀ ਮਾਤਰਾ ਸਭ ਤੋਂ ਜ਼ਿਆਦਾ ਸੀ।

ਮੁੱਖ ਸ਼ਬਦ: ਓਮਿਕ ਹੀਟਿੰਗ, ਸੋਇਆ ਮਿਲਕ, ਬਿਜਲੀ ਚਾਲਕਤਾ, ਪੀ ਐਚ, ਪੂਰਨ ਘੁਲਣਸ਼ੀਲ ਠੋਸ, ਗਾੜ੍ਹਾਪਣ, ਸਿਸਟਮ ਦੀ ਕਾਰਜਸ਼ੀਲਤਾ

ਮੁੱਖ ਸਲਾਹਕਾਰ ਦੇ ਹਸਤਾਖ਼ਰ

ਵਿਦਿਆਰਥੀ ਦੇ ਹਸਤਾਖ਼ਰ

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CHAPTER-I

INTRODUCTION

India is the world’s second largest producer of food next to China, and it has the potential of being the biggest with the food and agricultural sector. Though India’s agricultural base is quite strong but wastage is very high and processing of food products is very low. According to a report by Emerson Climate Technologies India, India is the world’s second largest producer of fruits, vegetables and grains but it is throwing away fresh produce worth Rs 44,000crore every year because of the country’s lack of adequate cold storage facilities and refrigerated transport. The country’s processing sector is small and processing of food to consumable standards in India has reached only 10% (approximately). India’s share in exports of processed food in World trade has remained at about 1.5 percent (Bhuyan, 2010). Therefore, the issue of food losses is of high importance in the efforts to combat hunger, raise income and improve food security in the world’s poorest countries.

Food has been processed and packaged since ancient times. In traditional food processing the main aim was to maintain a continuous supply for hungry periods. But with the changing times, in addition to maintain the supply for hunger periods, maintenance of nutritional value of food materials also became very important. Since, conventional processing leads to a destruction of nutrients and change of flavor. It therefore attracts the great interest of people for development of advanced technologies of food processing to produce the high quality food products (Harrish and Leosecke 1960). Food crops including cereals, fruits and vegetables, roots are processed into various products, namely fruit juices, fruit salads, wine etc (Singh 1998). This result into the development of two types of processing techniques: novel thermal and novel non thermal processing techniques.

Novel thermal processing technologies are those in which main processing factor is change in temperature, whereas in novel non thermal processing technologies temperature may also be changed but not mainly responsible for food processing. Novel thermal processing is usually preferred because it helps in preserving the color, flavor and texture of food.

Food processing engineering involves a combination of processes termed as unit operations. Heating is one of the unit operations, used for shelf life extension of foods. Heating is probably the oldest means of processing foods and has been used by mankind for millennia. There are many unit operations in the food industry where steady or unsteady state heat transfer is taking place e.g. sterilization, dehydration, freezing etc. There are two types of heating, direct and indirect. Direct heating means when heat is generated within the material (e.g. by microwave and in the case of dielectric materials or by induction or resistance heating in the case of electrically conducting materials) and indirect heating means heat is transferred by conduction convection or radiation i.e. heat is transferred by some medium. Many heating methods are there like infrared heating, dielectric heating (microwave (MW)) and ohmic heating. Dielectric and Ohmic heating are direct methods; heat is generated within product while Infrared heating is an indirect method of heating and it relies on heat generated externally which is applied to the surface of food mostly by radiation, convection and to a lesser extent by conduction.

In dielectric heating a high frequency electric field or radio wave or microwave electromagnetic radiation heats a dielectric material. Food materials contain moisture in it and since water molecules are polar in nature, when some alternating electric field is applied, the dipoles tend to align themselves in an electromagnetic field. If the field is oscillating then these molecules rotate continuously aligning with it. As the field alternates the molecules reverses their direction and during this push and pull they collide with other molecules resulting in distribution of energy to adjacent molecules and due to molecular friction this energy appears as heat.

In inductive heating, electric coils placed near the food product generate oscillating electromagnetic fields that send electric currents through the food to heat it. Inductive heating may be distinguished from microwave heating by the frequency and the nature of the source (the need for coils and magnets for generation of the field, in the case of inductive heating, and a magnetron for microwave heating).

Ohmic heating, also known as ‘resistive heating’ or ‘Joule heating’ or ‘electro heating’,(Sastry and Barach 2000) is a process when electrical current is passed through a conducting substance and due to its internal resistance (Icier and llicali 2005a, Srikalong *et al* 2011)heat is generated within that conducting substance. Ohmic heating is caused by interactions between the moving particles i.e. electrons and the atomic ions that are present in the conducting substance required to be heated. Charged particles in an electric circuit are accelerated by an electric field and have electrostatic potential energy. When the charged particles collide with ions in the conductor and energy is dissipated in the form of heat in the conducting substance. The heat produced is proportional to the square of current applied (Shirsat *et al* 2004).

Ohmic heating is efficient than other techniques due to certain reasons. First is uniformity of heating. Since ohmic heating depends on internal heat generation therefore solid pieces in solid-liquid mixture are heated at the same rate as the fluid gets heated up. This is a significant advantage because in conventional heating methods, heat is transferred from outside and fluid is heated before the solid pieces. Ohmic heating also has considerable advantages in heating uniformity over microwave heating, since this method involve the application of complex electric fields that are difficult to characterize locally within a multicomponent material. Thus, these methods result in heating patterns wherein cold spots change locations and are difficult to characterize. Since there are no methods involved through which heating is done by hot surfaces so there is no chance of burning or fouling of food substance. Another advantage is that during microwave and radio frequency heating we need to apply high frequency to the respective heaters but ohmic heaters are operated at low frequencies. A major advantage of ohmic heating is that its energy conversion efficiencies are very high i.e. all the energy delivered to the food product is used. Generally this process have 90% efficiencies and above. This is in contrast to microwave heating, which is typically only 50% efficient (~67% energy efficiency in the magnetron, and about 80% delivery efficiency through waveguides). In long time space missions anything that is placed in the spacecraft increases the total volume of the spacecraft and this results in increase of the mass and the cost is calculated per Kg of material placed in orbit, so reduction of system mass is critical. The commonly used approach at NASA is the reduction of all attributes of a device to a common unit of equivalent system mass (ESM). Further, any energy-using device results in the need to increase the size of the vehicle's power plant, thereby increasing mass. The end result of a variety of such considerations results in a mass penalty for any new device, thus all devices serving a given function may be compared based on their ESM values. Since ohmic heating systems are compact therefore there ESM values are usually lower than conventional heating systems. Ohmic heating is therefore a logical choice for thermal treatments on Mars missions not only for this reason, but also given that the most likely available energy source within a space vehicle is electrical. Further, technologies such as microwaves are not allowed within space applications due to interference with radio signals. Even if allowed within a space environment, microwaves would result in larger ESM values due to their relatively low-energy efficiency and need for bulky waveguides.

When ohmic heating was reintroduced in 1980's its cost was of great concern but the cost of Ohmic heaters has declined greatly over the past ten years. This is due in part to the advent of less expensive solid-state power supplies, and to the increasing number of manufacturers in the industry. To obtain a required temperature conventional heating takes about 18% more time than ohmic heating (Shivmurti *et al* 2014). For liquid food products containing particulates, it is impossible, to achieve higher temperature in particulates than liquid by conventional heating, but it can be achieved by ohmic heating (Lima 2007). Ohmic heating inactivates microorganisms in similar way like the conventional pasteurization process (Kausal, 2013) but flavor deterioration is found to be less. OH heating also effects the textural properties of fresh solid food that the knowledge of texture evolution during ohmic heating can drive the selection of process conditions in order to obtain a product with predefined textural characteristics.

Soybean (Glycine max) is an industrial crop extensively cultivated for its oil and protein content. The global demand for soybean has increased dramatically over the last few years because it is a significant and cheap source of protein. The consumption of soy foods has also been linked to the prevention and treatment of chronic diseases, potentially lowering cancer mortality rates, and reducing the risk of heart disease due to the cholesterol lowering effect of soy proteins. The main uses of soybeans can be categorized into three groups: industrial, human food and livestock feed. Soybeans for human consumption are processed in many forms. Currently the main types of soy products relatively high in soy protein and which utilize the majority of the bean are soymilk and tofu (Liu, 1997). Processing of soymilk during and after extraction is therefore necessary to achieve the highest possible quality of soymilk. Soymilk is essentially a water extract of soybeans, and contains all of the components of the bean, except for some insoluble fiber removed during processing (called okara). Soymilk composition varies depending on processing conditions and bean variety and in general contains about 8-10% total solids, 3.6% protein, 2.0% fat, 2.9% carbohydrates and 0.5% ash, and it depends on processing conditions and soybean variety used (Liu, 1997).There are two main types of proteins in soymilk which are 7S conglycinin and 11S glycinin (Wagner *et al*, 2010). To achieve high efficiency, good quality of soymilk ohmic heating (OH) is used to study its processing conditions.

In Ohmic heating, properties like electrical conductivity, viscosity, TSS (total soluble solids), pH and density of the foods play a major role. Foods, which contain water and ionic salts in abundance, are most suitable to use in applications of ohmic heating. Information on conductivity measurements therefore may prove effective in product formulation and process control.

In a conventional heating system, the thermal conductivity of a particle controls its heating rate whereas in an ohmic process, the electrical conductivity is the controlling factor. The electrical conductivity is a function of food components and a complex function of temperature and other physical properties, which is directly reflected in the ohmic heating rate.

The salt components, acids and moisture are highly effective in increasing electrical conductivity, while fats, lipids, and alcohols decrease it. Highly conductive materials (e.g., very concentrated salt solutions) that allow most of the current to pass through are also not suitable. Precise knowledge of electrical conductivity for a given food system is therefore a key parameter for the food processors to design a safe thermal process so that no overcooking or undercooking occurs. Electrical conductivity can be calculated from voltage and current data.

Physicochemical properties are an essential factor during processing and preservation of food. The retention and changes in physicochemical properties depends upon the processing technique. Therefore following parameters are important in the present study.

Viscosity is another important parameter of food products as it is temperature dependent. It is property of fluid which offers resistance to the movement of one layer of fluid over its adjacent layer. The viscometer properties are essential in estimating various parameters such as evaporating rates, pumping, mixing requirements, is useful for designing flow and handling systems quality control and sensory evaluation.

Total soluble solids content of a solution is determined by the index of refraction. This is measured using a refract meter, and is referred to as the degrees Brix. Dissolved solids affect both density and refractive index (RI) of a liquid. Thus when the concentration of sugar in water is increased, the density and RI increase. One degree of Brix is equal to one gram of sucrose which is considered to be a sugar in solution. This tests the solids concentration of a sucrose containing solution.

pH is a numeric scale used to specify the acidity or basicity of an aqueous solution. It is roughly the negative of the logarithm to base 10 of the concentration, measured in units of moles per liter, of hydrogen ions. More precisely it is the negative of the logarithm to base 10 of the activity of the hydrogen ion. Solutions with a pH less than 7 are acidic and solutions with a pH greater than 7 are basic.

System performance coefficient of an ohmic heater is the ratio of energy gained by the sample to the energy supplied to the sample, where energy gained by the sample = $mC_p(T_f - T_i)$ and energy supplied to the sample=$\sum VIt$. Here m is the mass of the sample, C_p= specific heat of soymilk, T_f = final temperature, T_i = initial temperature, V is the voltage applied, I is current and t is time. This parameter is calculated because it gives us an idea that on which particular voltage gradient our ohmic heater performs better.

Therefore the objectives of this study are mentioned below-

a) To study the effects of voltage gradient on heating rates of soymilk having different concentrations of soymilk.

b) To study the effect of ohmic heating on TSS, pH, refractive index and viscosity of soymilk.

c) To investigate electrical conductivities at different concentrations of soymilk and develop mathematical model for predicting it during ohmic heating.

CHAPTER-II

REVIEWOFLITERATURE

Ohmic heating was first studied by James Prescott Joule in 1841 and independently by Heinrich Lenz in 1842. Joule immersed a length of wire in a fixed mass of water and measured the temperature rise due to a known current flowing through the wire for 30 minutes. By varying the current and the length of the wire he deduced that the heat produced was proportional to the square of the current multiplied by the electrical resistance of the wire.

The “electric pasteurization” process (Prescott, 1927) was used for milk treatment in six states in the United States in the 1930s. Getchel in (1935) successfully applied Ohmic heating in food processing. In this ohmic heating was used to pasteurize the milk, but because of two difficulties i.e. short supply of inter materials needed for electrodes and due to high processing cost, the applications of ohmic heating in food processing were abandoned. Thereafter, the technology almost disappeared for a number of years, only seeing application for blanching (Mizrahi *et al*, 1975). In the 1980s, Ohmic heating was introduced by APV, who licensed the technology from the Electricity Council of Great Britain (Biss *et al*, 1987). Ohmic heating has always been seen to fit this niche; its capability of achieving rapid and relatively uniform heating rates has made it an attractive option in the processing of particulate foods. Ohmic heating is influenced by electric nature of materials, so the knowledge of electrical properties of the agricultural food products is required, such as electrical conductivity, viscosity, pH and total soluble solids (TSS) etc. In this chapter the review of literature about these properties is therefore presented.

Sarang *et al* (2008) studied electrical conductivity of fruits and meats during ohmic heating. They heated each sample to 140˚C using alternating current of 60 Hz and voltage between 15 and 20V. it was concluded that electrical conductivity of various fruits and meats were found to increase linearly with temperature during ohmic heating at constant voltage gradient. Highly porous materials like apples showed lower electrical conductivity. They also tried to see the relationship between the measured fat content of the lean muscle cuts and their electrical conductivity and it was concluded that there was no significant relationship between the two parameters.

Darvishi *et al* (2012) studied ohmic heating behavior and electrical conductivity of tomato paste. In this study, tomato juice was ohmically heated at different voltage gradients range in 6-14V/cm in the temperature range of (26-96°C). Results showed that electrical conductivity of juice was affected by the applied voltage, concentration of electrolytes, food particle size and temperature. The effect of voltage gradient was statistically significant on the heating time. The conversion of electrical conductivity into heat was larger at higher voltage gradient. At larger voltage gradient the heating rate was high. It was also observed with the increase in voltage gradient the pH value decreased. The observed range of pH varied from 4.20 to 4.51.

Icier and Ilicali (2005b) studied electrical conductivities of peach and apricot purees during ohmic heating. In addition to electrical conductivity parameters such as total solid content, total soluble solid content, pH and acidity values of fruit purees were noted. Voltage gradient was applied between 20 and 70V/cm. It was observed that the changes of electrical conductivity of the fruit purees during ohmic heating were obtained in a band shape. Conclusion was that electrical conductivity of fruit purees was strongly dependent on temperature and dependent on ionic concentration and pulp content. The electrical conductivity of the fruit purees increased with temperature rise, linearly. Bubbling was also observed above 60˚C especially at higher voltage gradients which was due to acidity of samples. They also concluded that system performance coefficients could be helpful in the design of ohmic heaters.

Kautkar *et al* (2015) studied temperature dependent behavior electrical conductivity of ginger paste during ohmic heating. The ginger paste was ohmically heated to 80˚C at voltage gradients of 5, 7, 9, 11 and 13V/cm. It was observed that electrical conductivity increases with increasing temperature and time of heating and bubbling was also observed above 70˚C at high voltage gradients.

Sevugan and Sastry (1999) determine the effect of solid content and temperature on the electrical conductivity of orange juice and tomato juice. Behavior of apple particulates in fluid during thermal processing was studied by Wang and Wu (1999).

Ruhlman *et al* (2001) investigate the physical properties like electrical conductivity, density and viscosity along with other physical properties of liquid foods. These properties of liquid products were measured in temperature ranging from 40°C to 60°C. Electrical conductivities were found to be increased with temperature for apple, grape, orange and tomato juices.

Sun *et al* (2007) studied effects of ohmic heating on microbial counts and denaturation of protein in milk. The main aim of this study was to compare the inactivation effects of ohmic heating and conventional heating on viable aerobes and streptococcus thermophilus 2646 in milk under identical temperature conditions. Raw milk was used for the experiment and it was incubated at 20˚C for 48 h in order to obtain samples having ca. 107microbial cells/mL of viable aerobes. Streptococcus thermophilus strain 2646 strain was chosen as a representative heat-resistant microorganism. Streptococcus thermophilus was cultivated in sterilized skim milk solution which was obtained from the skim milk powder taken in particular amount dissolved in particular amount of water and the culture was incubated at 37˚C for 24 h. Next, 25 g of the concentrated culture (yoghurt) was suspended in

225 g of commercial whole sterilized milk to acquire ca. 107 cells/mL. The suspended milk was used for the inactivation experiment. Raw milk was centrifuged (3000 rpm, 30 min, 1500 g of relative centrifugal force) at 4˚C to obtain low-fat milk. The low-fat milk was used for the protein denaturation experiment. The experimental vessel for ohmic heating or conventional heating was filled with 250 mL of milk sample. The initial temperature of the sample was kept at 20˚C. The sample was heated to a set temperature by ohmic heating and by conventional heating. Conventional heating was performed in a water bath. For all the experiments done the initial counts of aerobes and streptococcus thermophilus were same. When the temperature reached the required temperature the number of microbial counts were reduced but it was observed that during ohmic heating the reduction of microbial counts were more than conventional heating also the D value of S. thermophilus in ohmic heating at 75˚C was lower than that in conventional heating. These results clearly show that ohmic heating causes a higher microbial death rate than conventional heating does. However, there was no difference in protein denaturation during the two treatment i.e. conventional and ohmic heating treatments.

Mohsen *et al* (2013) studied ohmic heating on mango pulp. The main aim of this work was to compare the processing of mango pulp using ohmic heating treatment and conventional heating treatment. The results showed that processing of mango pulp by using either Ohmic heating or conventional method caused a decrease in the contents of TSS, total acidity, total Carbohydrates, total sugars (reducing & non-reducing sugar) and an increase in phenolic content, Ascorbic acid and Carotenoids. Mango pulp processed by Ohmic heating contained more Phenolic compounds, carbohydrates and Vitamin C and less HMF (5-hydroxymethyel furfural) compared to that produced by conventional one. Total pectin and its fractions had slightly reduced by Ohmic heating and such reduction was increased by conventional method. Results also showed that total plate count, mold and yeast were reduced by processing of mango pulp by using the two methods. However, Ohmic heated mango pulp showed a less total plate count and mold &yeast after processing and during storage compared to that in conventional method. Coliform and thermophilic bacteria were completely inhibited by using both methods after processing and during storage. Results showed a reduction in poly phenoloxidase (PPO) & Polyglacturonase (PG) enzymes activity in mango pulp processed by conventional method. However Ohmic heating completely inhibited PPO&PG activities due to the affective heating treatment. An improvement in the Organoliptic properties of mango pulp processed by Ohmic heating compared to conventional process was noticed.

Assiry *et al* (2010) studied electrical conductivity of sea water during ohmic heating. The main aim of this study was to use ohmic heating as a technique for desalination of sea water rather than conventional methods like steam boilers. Ohmic heating treatment was applied to saline water at voltage gradient 6.35-11.04 (V/cm) and at frequency 60Hz. Different concentrations of sample was made within range of (38.9-106.1) PPT. quality parameters like electrical conductivity, pH, color, apparent specific heat and density of sea water were measured before and after ohmic heating. It was observed that the range of conductivity during ohmic heating of sea water was in the range of 55-399.6(mS/cm) and also this electrical conductivity was strongly dependent on TDS (total dissolved salts) and temperature. Due to the passing electrical current through the sea water, a sensible heat was generated causing the temperature of the seawater to rise. The range of the heating rate was 0.69-6.22 (˚C/s) depending on the concentration of the TDS and the electrical field strength. Higher TDS concentration and electrical field strength conditions resulted in higher heating rate. Thus it was concluded that ohmic heating method in desalination process should consider the advantage of this process should consider the advantage of this high heating rate. Electrical conductivity of seawater during ohmic heating was plotted against the corresponding temperature and the curve obtained was linear at 11.04V/cm voltage gradient. The experiment was done for three concentrations of sea water of varying TDS that were (38.9, 67.5 and 106.1 PPT). Color of sea water was changed during ohmic heating and which might be due to electrochemical reactions between electrodes and seawater. The range of apparent specific heat was found to be 3.664 to 3.981 (KJ/Kg˚C) at high and low concentrations respectively. The range of density was from 1.03 to 1.14(gm/cm^3) at TDS 38.9 and 106.1 respectively.

Wongsa-Ngasri and Sastry (2015) studied ohmic heating of tomato peeling. In this experiment tomato was placed in the ohmic heating tube and NaCl solution was filled in the tube. The concentrations of NaCl used in the experiment were 0.01, 0.02 and 0.03g/100ml with field strengths 8060, 9680, 11, 300 and 129, 00 V/m (for 0.01g/100ml NaCl), 6450, 8060, 9680 and 11, 300V/m (for 0.02g/100ml NaCl), 4340, 6450, 8060 and 9680V/m (for 0.03g/100ml NaCl). All experiments were set at specific conditions and were started from room temperature and experiment was stopped when cracking of the tomato peel had occurred. It was observed that higher voltage and higher concentration of NaCl resulted in shorter peeling time but it was also necessary to consider product quality factors so after analysis it was concluded that the best conditions of ohmic peeling were at 0.01g/100ml NaCl with 8060 and 9680V/m and at 0.03g/100ml NaCl with 6450 and 8060 V/m. These conditions showed potential because they require a relatively short time. It was also concluded in the current paper that ohmic heating could reduce environmental problems associated with lye peeling because of not using any lye in the process, rather only a very low concentration of NaCl while yielding a comparable quality of peeled tomatoes.

Assawarachan (2010) made some equations for predicting the electrical conductivities of red grape juice at different concentrations and at different voltage gradients. Samples of red grape juice having concentrations of 10.5, 12.5 and 14.5˚Brix were ohmically heated by applying three different voltage gradients (10, 12 and 15V/cm) in the temperature range of 25-80˚C. The mathematical models which were developed using multiple linear regression analysis showed that electrical conductivity depended on temperature and concentration. The predictions of electrical conductivities using the mathematical models was found to be highly accurate with R^2 value of 0.9975 when compared with the experimental data of red grape juice with concentration of 11.5˚Brix. The reducing chi-square (χ 2) and the root mean square error (RMSE) from the mathematical models were calculated and compared with the experimental data. As the results, multiple linear regressions on the coefficients of the mathematical model of electrical conductivity prediction had given highest values of the R^2 and lowest χ^2 and RMSE so it was concluded that the established model was highly accurate when estimating electrical conductivities of red grape juice.

Srivastav and Roy (2014) studied changes in electrical conductivity of liquid foods during ohmic heating. This treatment was applied to tomato juice at three different voltage gradients i.e. 50, 60 and 70V/cm. From the current and temperature data, a graph was plotted between temperature and electrical conductivity and it was concluded from the graph that trend was linear between temperature and electrical conductivity. Also, with the increase in voltage gradient, value of electrical conductivity increased. Bubbling was observed as the temperature was increased, especially at high voltage gradients. It was observed that electrical conductivities sharply increased with temperature rise after bubbling started due to formation of electrolytic hydrogen bubble as fruit juices are acidic. System performance coefficient (SPC) was also calculated and it was observed that SPC depended strongly on the voltage gradient applied. For the tomato juice samples the SPC increased from 0.779 to 0.943 as the voltage gradient decreased. At the voltage gradient of 50V/cm, the SPC was 0.943, which indicated that 6% of the electrical energy given to the system was not used to heat up the test liquid.

Castro *et al* (2004) studied ohmic heating of strawberry products. A set of experiments was conducted to determine the effect field strength on the electrical conductivity changes during ohmic heating. The strawberry pulp samples were heated up to 100˚C using eight different field strengths (from 25 to 100 Vcm^{-1}) with a 2cm gap between electrodes. Also strawberry based products were tested with four different field strengths (from 32 to 80 Vcm^{-1}) and a 2cm gap between electrodes. Basically two types of pulps named P1 and P2 were used for the experiment, where pulp P1 had an initial pH value of 4.0, a Brix value of 14.5˚ and 2.5% of starch content while pulp P2 had an initial pH value of 4.0, a Brix value of

26.5˚ and no starch. In all cases of experiments electrical conductivity increases with temperature, presenting linear or second order relations, depending on the product. The effect of a conventional or ohmic pre-treatment is different for the two samples. In strawberry pulp P1 a conventional preheating process showed higher electrical conductivity values then an ohmic process, due to its starchy composition. Sample P2 (without texturizing agents) showed a higher electrical conductivity when an ohmic pre-treatment process is applied, as compared to the conventional pre-treatment. The ascorbic acid degradation kinetics in strawberry industrial pulps for the temperature range of 60 to 97 ˚C were unaffected by lower values of the electric field strength (<20 Vcm-^{1}). Ascorbic acid degradation followed first order kinetics for both conventional and ohmic heating treatments.

Lakrari *et al* (2013) studied electrical properties of vegetable oils for the purpose of an application in electrical engineering. Samples for the experiment were: Argan, Rapeseed, and Sunflower oil. Electrical resistivity was measured from the current data and its variation was studied with temperature. It was concluded that the electrical resistivity decreased with the increasing temperature. Dynamic viscosity was also studied during this experiment with the help of Ostwald’s viscometer and it was observed that viscosity of the oils decreased because of the dependence of viscosity on the temperature. As the temperature increased, the attraction between polar molecules decreased while their thermal energy increased and due to this reason it was concluded that viscosity decreased with the rise in temperature.

Bozkurt and Icier (2009a) studied the change of apparent viscosity of liquid whole egg during ohmic and conventional heating. The main aim of this research was to study the effects of conventional and electrical heating methods on the rheological behavior of liquid whole egg. The samples for the experiment were heated from 20˚C to 60˚C by applying voltage gradient of 20V/cm. The same thermal history was applied to conventional heating method (using circulating water bath) so as to determine possible electrical effects during ohmic heating rather than thermal effects. Rheological properties were measured using Brookfield viscometer. The samples were taken from heating unit at each prescribed temperature and then taken immediately to the rheological measurement unit. During rheological measurements the temperature of the samples was kept constant by using the circulating water bath. During rheological measurements shear stress, shear rate, apparent viscosity and % torque values were recorded for each rotational speed. pH and TSS measurements were also done during this experiment. It was concluded from the data that Non-Newtonian shear thinning behavior was obtained for the liquid whole egg at the temperature range of 4-60˚C. Although, the temperature dependency of liquid whole egg was similar for ohmic and conventional heating methods but the activation energies of temperature-dependent apparent viscosities for ohmic heating were lower than conventional heating.

Darvishi *et al* (2015) studied ohmic heating process on tomato paste. Six voltage gradients ranging from 6-16V/cm were applied during ohmic heating. Variations of moisture content as a function of drying time at voltage gradients of 6-16V/cm were studied and from that plot it was concluded that drying time of the sample was higher for low voltage gradient and it decreased as the voltage gradient went on increasing. So, it was noticed that voltage gradient affected the drying rates of samples. The total heating times to reach the final moisture content of the tomato samples were 25.42, 12.88, 8.37, 5.62, 4.65 and 3.55 minutes at 6,8,10,12,14 and 16V/cm respectively. Variation of energy efficiency as a function of heating time and moisture content for different voltage gradients were also studied and was concluded that the energy efficiency of ohmic system was higher at the initial stage of the heating process, but it decreased during the heating with moisture content, and then remained constant until the end of the heating process. The stable energy efficiency was greater for tomato samples heated at a higher voltage gradient due to a shorter period of process. The energy efficiency of ohmic system for different gradients of 6, 8, 10, 12, 14, 16V/cm were 55.53-99.30%, 65.07-99.91%, 72.24-99.74%, 77.68-99.62%, 80.61-100% and 81.14-100% respectively. Variation of electrical conductivity with temperature was also studied and it was observed that increasing the voltage gradient from 6 to 16 V/cm led to a decrease in the electrical conductivity and this was because of the increase in the vapor formation at higher voltage gradient. In concluding lines this paper dealt with the performance evaluation of ohmic heating process of liquid food by applying energy analysis and the results showed that the most energy losses took place for 6V/cm voltage gradients.

Chakraborty and Athmaselvi (2014) studied changes in physiochemical properties of Guava juice during ohmic heating. Fresh juice was prepared for the experiment and four different voltage gradients (13.33, 16.66, 20 and 23.33V/cm) were applied to the sample at 50Hz frequency, until the temperature rose up to 95˚C. The physicochemical properties like pH, TSS, Acidity (%), Vitamin C, Ascorbic acid and color were noted for ohmic heating and for conventionally heated sample. These physicochemical properties were analyzed at an interval of 3 days. Initially the pH of the fresh juice was 4.1, whereas after ohmic heating for 1 min, 3 mins and 5 mins the pH was observed to be 3.8, 3.75 and 3.7 respectively. It was observed that pH decreased with increase in voltage gradient. The initial TSS of the fresh juice was 7.2˚Brix, but after ohmic heating as the voltage gradient increased the TSS was observed to increase. The acidity % decreased with increase in voltage gradient and temperature. Vitamin C loss was mainly due to handling and continuous storing under refrigerated conditions, but it was observed that the vitamin C loss was higher at high voltage gradients and treatment time. Voltage gradient also showed a significant change in color and it was also because of storage conditions. In the concluding lines it was observed that physicochemical changes were there during ohmic heating but ohmic heated juice retains the physicochemical properties for a longer duration, as compared to conventionally heated juice.

Icier and Ilicali (2004) studied the effects of concentration on electrical conductivity of orange juice concentrates during ohmic heating. The samples for the experiment were taken to be pre-pasteurized. Different concentrations of soluble solids of the fruit juices were prepared (0.20, 0.30, 0.40, 0.50 and 0.60 mass fraction soluble solids). Five different voltage gradients (20, 30, 40, 50, 60 V/cm) were applied for each concentration of the orange juice. The sample was ohmically heated up to a temperature of 80˚C at 50 Hz frequency, using different voltages to obtain different voltage gradients. Voltage, current and temperature data were logged at 1 s time intervals during heating. It was observed that the relationships between temperature and the electrical conductivity for each concentration and voltage gradient applied were linear. For the same concentration, as the voltage gradient increased, the electrical conductivity values increased at a given temperature. Variation of electrical conductivity with temperature at different concentrations and at same voltage gradient was also studied and it was observed that electrical conductivity of the sample at low concentration and at a given temperature was higher in comparison to low concentrated sample. Heating rate curves also showed a linear trend and heating rate was higher for less concentrated sample. It can be concluded that the electrical conductivity of orange juices changes with temperature and concentration during ohmic heating.

Pham *et al* (2014) studied effect of indirect ohmic heating on quality of ready-to-eat pineapple packed in plastic pouch. The motive of this study was to examine the effect of indirect ohmic heating on pH, total soluble solids (TSS), polyphenol oxidase activity, color and texture of ready-to-eat pineapple packed in a polypropylene pouch with 1% calcium chloride and 0.3% ascorbic acid packing solution. By indirect heating means that ohmic heating was applied through this polypropylene pouch. The pre-packed sample in a pouch was placed in the ohmic heating jar filled with 0.5% sodium chloride ohmic heating solution which was then ohmically heated at different voltage gradients (20, 30, 40 V/cm), to different packing solution temperatures (60, 70, 80°C) for 60s. Samples were kept at 4°C for quality measurement. It was observed that browning index (which is changes in color parameter during indirect ohmic heating) of ready-to-eat pineapple treated with 20 V/cm at 80°C, 30 V/cm at 70°C and 80°C, 40 V/cm at 80°C did not change during 12 days cold storage. Polyphenol oxidase was inactivated when the temperature of the pineapple was 62°C or higher. After 10 days at 4°C, the pineapple heated with 30 V/cm at 70°C had much higher firmness than the un-heated sample kept at the same storage condition. Thus, it was concluded that indirect ohmic heating of pre-packed ready-to-eat pineapple in polypropylene pouch with 30 V/cm at 70°C packing solution temperature for 60s could be used as minimal heating methods to maintain the quality of ready-to-eat fruits in 12 days at 4°C.

Darvishi *et al* (2012) studied ohmic heating of pomegranate juice. Properties like electrical conductivity, pH and system performance coefficient were examined. Freshly prepared pomegranate juice was used for the experiment. Four different voltage gradients (30, 35, 45 and 55V/cm) were applied to the sample and sample was heated from 20 to 85˚C. Temperature, current and voltage applied were monitored after an interval of 1sec. From the time and temperature data heating rates were 4.171, 2.755, 1.688 and 1.392˚C/s at voltage gradients of 55, 45, 35 and 30V/cm respectively. Therefore, it was concluded that at higher voltage gradient the heating rate was higher because more current flows through the sample at higher voltage gradient. Variation of electrical conductivity with temperature revealed that voltage gradient had a significant effect on the electrical conductivity. Electrical conductivity increased with increase in temperature and value of electrical conductivity was higher for higher voltage gradient. The electrical energies given to the system and the heat taken by the pomegranate juice samples were calculated by using the experimental data. The results indicated that SPC depended strongly on the voltage gradient applied. For the pomegranate juice samples the SPCs increased from 0.764 to 0.939 as the voltage gradient decreased. Therefore, it was concluded that 6.1-23.6% of the electrical energy given to the sample was not used in heating up the test sample. Voltage gradient had also significant effect on pH of the sample. The maximum increase in the pH was 6.35% at 30V/cm. The change in the pH at voltage gradients of 30-45V/cm decreased and then as the voltage gradient increased the change increased.

Kong *et al* (2008) studied the ohmic heating behavior of four kind of liquid food materials (tap water, yogurt, 0.5% aqueous sodium chloride solution and fruit-vegetable juice). This study involves the ohmic heating of these materials in static ohmic heater at different voltage gradients (7.5, 11.25, 15, 18.75, 22.5 and 26.25V/cm). Results indicate that electrical conductivity changed significantly with temperature. Under the same voltage gradient, highly influenced the ohmic heating efficiency. These different effects of voltage gradients on different products show the importance of food to be processed by ohmic heating.

Darvishi *et al* (2011) studied ohmic heating of lemon juice. The ohmic heating cell was constructed from Pyrex. The distance between two electrodes was 0.05m and the diameter of the electrodes was 0.04m and total volume of the cell was of 53.8ml. Four voltage gradients 30, 35, 45 and 55V/cm at 60Hz were applied to the sample and the sample was heated from 20 to 74˚C.The results indicated that that voltage gradient and temperature significantly altered (increased) the electrical conductivity value of lemon juice. The highest electrical conductivity was observed on 55V/cm, followed by 45, 35 and 30 V/cm. At high voltage gradients, the current passing through the sample was higher and this increased the heat generation rate. As the voltage gradient increased the heating time of the lemon juice required to reach the prescribed temperature decreased. The time required to heat the lemon juice from 20 to 74ºC at 30 V/cm was 1.64, 2.18 and 4 times longer than at 35, 45 and 55 V/cm, respectively. The electrical energies given to the system, the heat taken by the fruit juice concentrates, performance coefficients (SPC) and heating times for mathematical model calculated for each voltage gradient experiments. For the 30 V/cm voltage gradient SPC was approximately 0.92, which indicated that 8% of the electrical energy given to the system was not used to heat up the test liquid. However, for higher voltage gradients, SPC values were lower. System performance coefficients were in the range of 0.54-0.92.

Olivera *et al* (2013) studied the effects of ohmic heating treatment on texture of fresh solid food. For the process of ohmic heating, samples of fresh potatoes, carrots and apples were cut into cylinders (d = 30 mm, h = 9.0 mm) and were heated for 60, 120, 180 and 240 seconds at constant electric field gradients of 1100V/cm, 2200V/cm and 3300V/cm. The results indicated that Stress–deformation behavior of food samples processed by OH differs appreciably from raw untreated samples for all cooking times. Firmness of solid samples decreased with OH time. This study confirmed that OH significantly affects texture of solid foods, producing structural damage, even though food has a low electrical conductivity. It was observed that potato, carrot and apple exhibited low electrical conductivity. Their treatment in OH cell needed electric field strength higher than 1100 V/cm. For all the considered food substrate, appreciable firmness disintegration appeared only for electric field strength of 2200 V/cm and higher, apple being the food substrate more sensible to the softening effects due to OH treatment. The knowledge of texture evolution during OH can drive the selection of process conditions in order to obtain a product with predefined textural characteristics.

Lien *et al* (2014) studied ohmic heating of soya milk for tofu making. Raw soya milk was chosen for the experiment which was freshly prepared. The soya milk so obtained was adjusted to concentration of 10˚Brix. The sample was heated to 90˚C by ohmic heating with different voltages and those were 140, 150 and 160V. Graph was plotted between time and temperature and it was concluded from the graph that a larger voltage gradient resulted in faster temperature rise. The temperature rising rate was observed to be 3.82˚C/min. Curve between time and current was plotted and it was concluded from the curve that current was large at the beginning as dominated by the first-order dynamics. From the curve between temperature and electrical conductivity at different voltage gradients it was concluded that when the temperature was in between 22 and 60˚C, the electrical conductivity of soya milk had a positive temperature effect but after this temperature this effect saturated.

CHAPTER-III

MATERIAL AND METHODS

SELECTION OF SAMPLE

Different samples of soymilk of same brand were purchased from the market from different locations. Different parameters like pH, viscosity and TSS were observed, it was concluded that the samples were not standardized. Therefore, in order to get standardized soymilk it was prepared from the soybeans of the same quality and from the same lot.

PREPARATION OF SAMPLE

300g of soybeans were taken, and they were soaked overnight for approximately 10hours in 500ml of RO (reverse osmosis) water. After this the soaked beans were boiled for 15 minutes and were washed with tap water. The washed beans were grinded for approximately 60 seconds, and 900ml of distilled water was added to the grinded mixture. The mixture so obtained was filtered and the extract we got was soymilk. The above mentioned parameters were again tested on different samples which were prepared on different days and it was observed that the parameters on different samples were approximately same. Therefore this procedure was adopted to get standardized milk.

The soymilk so prepared was assumed to be of 100% concentration. Different concentrations (100, 90, 80, 70, and 60%) of milk were prepared by dilution of with distilled water. The purpose of choosing different concentrations of milk was to study the effect of changes in concentrations of soymilk on different parameters such as density, conductivity, viscosity, pH and TSS with OH. The concentrations obtained were prepared by volume by volume mode. Five different voltage gradients (14, 12, 10, 8, 6) V/cm were applied on each concentration. Experiment was repeated three times for each voltage gradient and for each concentration.

DENSITY MEASUREMENT OF SAMPLES

Density of the sample is calculated by dividing mass of the sample to the volume of the sample used i.e.

Density = Mass of Solution (Kg)/ Volume of the solution (m^3)

$\rho(Kg/m^3) = M/V$

Density measurements were done because of their need in the viscosity measurements. The soymilk so prepared was assumed to be of 100% concentration. The density measurements were done by specific gravity bottles of capacity 25 ml. Soymilk sample was filled in specific gravity bottle and its weight was noted on the electronic balance. Weight of empty bottle was also noted and by subtracting this empty bottle's weight from the previous measured weight, weight of the soymilk was calculated and its density was measured by dividing it with volume used i.e. 25 ml. This was repeated three times to get a concordant reading. Similarly density measurements were done for rest four concentrations.

ρ = mass of sample (g)/volume of sample (ml) = M/V

$= (a/25)\ (g/ml)$

$= (a \times 10^{-3})/\ (25 \times 10^{6})\ (Kg/m^{3})$

$= (a/25) \times 10^{3}\ (Kg/m^{3})$

VISCOSITY MEASUREMENT

Viscosity measurements were done with the help of Ostwald viscometer which is explained as below -

DESCRIPTION OF OSTWALD VISCOMETER

Ostwald viscometers are named after the German chemist Wilhelm Ostwald (1853-1932). Also known as U-tube viscometer or capillary viscometer is a device used to measure the viscosity of the liquid with a known density. In one arm of the U is a vertical section of precise narrow bore (the capillary). Above there is a bulb, with it is another bulb lower down on the other arm. In use, liquid is drawn into the upper bulb by suction, and then allowed to flow down through the capillary into the lower bulb. Two marks (one above and one below the upper bulb) indicate a known volume. The time taken for the level of the liquid to pass between these marks is proportional to the kinematic viscosity.

The instrument must first be calibrated with materials of known viscosity such as pure (deionized) water. Knowing the value of viscosity of one liquid, one can calculate the viscosity of other liquid.

$\eta_1 = \eta_2\ (\rho_1 t_1/\rho_2 t_2)$

Where η_1 and η_2 are viscosity coefficients of the liquid and water, and ρ_1 and ρ_2 are the densities of liquid and water, respectively.

MEASUREMENT OF VISCOSITY

The Ostwald method is a variation of poiseuille method. The time for a fixed volume of liquid to fall through a capillary from A to B (as shown in above figure) into a reservoir under a variable pressure head is a function of density and dynamic viscosity of liquid. The Oswald viscometer measures the kinematic viscosity which can be defined as the ratio of dynamic viscosity and density of liquid. A prepared sample of soymilk with known concentration was introduced through the opening to large bulb and then it was sucked with the help of pipette pump until it occupied the space a little above the mark A. With the removal of the pipette pump, the pressure increased on the sample in tube which caused it to flow through the portion AB. The time of the sample from the mark A to the mark B was recorded with the help of stop watch. The viscosity is calculated using poiseuille's equation

$$\eta = \frac{\pi r^4 Pt}{8Vl}$$

Where, P represents the pressure difference across the capillary viscometer, r is the radius of the tube, L is the length of the capillary, V is the volume of liquid passed through the capillary, t is the time of flow of fluid from mark A to mark B in actual experiment, the viscosity of a liquid is generally determined relative to another liquid (distilled water) of a known viscosity. It is done by using the factors V, P, r and L are kept same for two liquids. If the t_1 and t_2 are time of flow for the same volume of distilled water and liquid respectively and also η_1 and η_2 are their respective coefficient of viscosity, then

$$\frac{\eta_1}{\eta_2} = \frac{\pi r^4 t_1 h \rho_1 g}{8Vl} \times \frac{8Vl}{\pi r^4 t_2 h \rho_2 g} \qquad \frac{\eta_1}{\eta_2} = \frac{\rho_1 t_1}{\rho_2 t_2}$$

Where ρ_1 and ρ_2 are their respective densities. Knowing the value of viscosity of one liquid, one can calculate the viscosity of other liquid. On the same basis, the experiment was repeated for all concentrations of soymilk which was treated ohmically. Effect of ohmic heating was noted by measuring the viscosity before and after heating the sample ohmically.

DESCRIPTION OF pH METER

For measurement of pH of the samples Hanna pH waterproof tester was used whose range was from -2.0 to 16.0. It has some important features like automatic one or two point calibration to known buffer, automatic temperature compensation, battery percent level indicator at start up, and a stability indicator to alert the user when a stable reading has been obtained. There is a large multi level LCD display that shows both pH and temperature simultaneously.

MEASUREMENT OF pH

Measurement of pH was done with the help of Hanna pH meter. Firstly calibration was done with the help of two buffers of pH 4 and 7. Then after calibration sample was taken in a 40 ml beaker and reading was recorded after it became stable. pH reading was taken for five different concentrations and five different voltage gradients. Each observation was recorded three times at particular voltage gradient and at particular concentration to get a concordant reading.

DESCRIPTION OF HAND REFRACTOMETER

When light passes from one medium to another, the speed at which the light travels will change depending on the parameters of the materials. The ratio or change in the speed of light is called refractive index and instruments that measure this parameter are called refractometers. The refractive index of a liquid is related to its concentration and so a refractometer can display the concentration in suitable units, such as °Brix (% sugar).

MEASUREMENT OF TSS (TOTAL SOLUBLE SOLIDS)

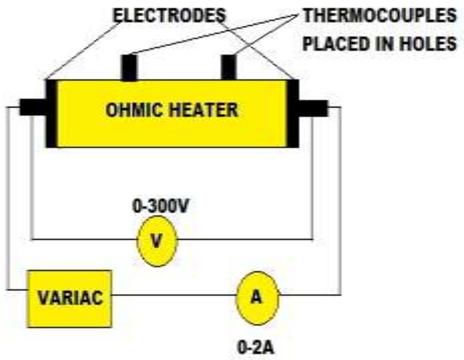
First of all calibration was done of refractometer with the help of distilled water, a drop of it was placed on the prism of refractometer and its reading was observed. Reading should be 0 for distilled water and after this a drop of soymilk was placed on the prism and reading was recorded. Data was recorded for five different concentrations and for five different voltage gradients before and after ohmic heating. Observations were repeated three times for particular concentration and voltage gradient to get a concordant reading.

DESCRIPTION OF OHMIC HEATER

The ohmic heating experiment was conducted at laboratory scale only and to study ohmic heating behavior of soymilk, ohmic heating system was designed and fabricated in PG Research Laboratory of Department of Mathematics, Statistics and Physics, Punjab Agricultural University, Ludhiana, Punjab. The design of ohmic heater consists of three major parts: Ohmic heating system, Electrodes and thermocouple, Power source which are described as follows.

OHMIC HEATING SYSTEM

The ohmic cell employed was constructed from PVC (Polyvinyl tetrachloride) cylinder having diameter 3.47cm and length of 10.5cm and two stainless steel electrodes with thickness of 0.2 cm were placed at the two corners of the tube. The distance between two electrodes was 10.5 cm resulting in a total sample volume of 125ml. Two holes with diameter 0.5cm each was created at a distance 2cm from each other to observe bubble formation, to insert the thermocouple and to exit of vapor in the cell. A voltmeter of range 0-300V was connected in parallel to the heating tube and an ammeter of the range 0-2A was connected in series between the power source that is variac and the heating tube.



MEASUREMENT OF ELECTRICAL CONDUCTIVITY

Measurement of electrical conductivity was done with the help of voltage and current data. Soymilk of known concentration was poured in the ohmic heating tube and the required connections were made as shown in above figure. A constant voltage was set with the help of variac whose value was noted from the voltmeter. With no loss of time stop watch was started and current and temperature readings were noted with the help of ammeter and thermocouples respectively at regular intervals of time. It was noted that as time passed the current values and temperature values were increasing. This experiment was allowed to continue until the temperature of the sample in the ohmic heating tube was 70˚C. From this recorded data the electrical conductivity values were calculated with the help of the equation which is mentioned below-

$$\sigma = IL/VA$$

where, I is current, V is voltage, L is length of ohmic heating tube and A is the area of cross section of the steel electrodes.

Experiment was performed for five different voltage gradients and for five different voltage concentrations. Each experiment was repeated for three times to get a mean reading.

SYSTEM PERFORMANCE COEFFICIENT

System performance coefficient of the ohmic heater can be calculated from the relation, SPC = Energy gained by the sample / Energy supplied to the sample

$$= mC_p(T_f - T_i) / \sum VIt \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where m is the mass of the soymilk in the ohmic heating tube, $C_p$is specific heat capacity, $T_f$is final temperature and T_i is initial temperature of soymilk before the treatment was applied, V is voltage applied, I is current and t is time required to heat the sample from initial temperature to final temperature.

Now, as we can see all the parameters used in the above equation are known except specific heat capacity of soymilk. Since not much literature was available for specific heat capacity of soymilk therefore it was decided to calculate it experimentally with the help of calorimeter and the procedure involved was based on the principle of Newton's law of cooling which states that loss of heat is proportional to difference in temperature between hot body and surroundings.

In this experiment 100 ml of water was taken and it was heated to some temperature which is approximately 40˚C higher than room temperature. The hot water as poured in the copper calorimeter and stop watch was started without any loss in time. Falling temperature was noted at regular intervals of time. When the temperature of water was some degrees higher than room temperature experiment was stopped. Also, mass of water was recorded with the help of electronic balance. After this soymilk of same volume was taken and it was heated to same temperature to which water was heated. Similarly data was recorded for it for falling temperatures. A graph was plotted between time and temperature and data for water and soymilk were plotted on the same graph. A range of temperature was selected on y-axis and two lines were drawn so that they intersect the two curves of water and soymilk. With the help of this, times for both water and soymilk were observed. After this specific heat was calculated from the following relation:

Specific heat of soymilk = $S_2 = (((WS + M_1S_1)\ t_2/t_1) - WS)/M_2$

Where, W is weight of calorimeter, S is specific heat of material used in calorimeter, M_1 is mass of water, S_1 is specific heat of water, t_2 and t_1 are times of water and soymilk respectively and M_2 is the weight of soymilk.

This procedure was repeated three times to get a mean concordant reading. To verify this method for calculation of soymilk, this method was applied on glycerin and mustard oil because their specific heat values were available in literature and it was observed that experimental values successfully matched the literature values. Therefore, this method was considered accurate to calculate specific heat capacity. Specific heat capacity was calculated for five different concentrations and each experiment was thrice to get a mean value.

In order to calculate SPC now we need to solve equation no.1, and for that a graph was plotted between time and current and by using equation of line obtained from the graph energy supplied to the sample was calculated. Dividing energy gained by the soymilk by the energy supplied to the sample SPC was calculated.

CHAPTER IV

RESULTS AND DISCUSSION

The experimental results of electrical conductivity, ohmic heating rate, viscosity, pH, TSS and SPC have been presented in this chapter. The experimental data was analyzed to obtain the knowledge of the dependence of these parameters on voltage gradient, concentration and temperature. Table 4.1 represents the physical parameters used for computation of results. Results obtained for each property and their relationship has been discussed.

Table 4.1 The parameters and properties used in the experiment.

Property or parameter	Value	Unit
Concentrations of Soymilk	60, 70, 80, 90, 100 %	% (v/v)
Voltage gradients applied	6, 8, 10, 12, 14	V/cm
Diameter of electrodes	0.0347	m
Distance between electrodes	0.105	m
Densities of Soymilk of 100% 90% 80% 70% 60%	 1680.12 1671.56 1663.20 1661.61 1660.96	Kg/ m^3

4.1 OHMIC HEATING RATE

The variation of temperature with time is known as heating rate. It is given by the total time required for the product to heat up to certain desired temperature. When heating rate is high, the product is exposed to high temperature for shorter time duration preserving the product quality. In this experiment, when voltage is applied across the two electrodes in an ohmic cell, current is passed through the sample and thereby heat is generated within the sample due to the resistance of the sample. Since heat is generated due to the passage of electric current through the sample therefore, heating rate in this process is known as ohmic heating rate. Ohmic heating rate can be affected by total solid content, viscosity, composition and acidity of liquid food. The observed values of temperature at different time intervals, voltage gradients and concentrations have been represented in the Tables 4.2 to 4.6. The data have only been given, when the samples attained temperature of 70˚C. The plots of temperature versus time for different concentrations and different voltage gradients are shown in the Figure 4.1 to 4.5.

It was observed that the variation of time and temperature followed a linear trend. The ohmic heating rate was 0.020, 0.044, 0.085, 0.149, 0.196˚C/sec at 6, 8, 10, 12, 14V/cm voltage gradients respectively for 100% concentration. Same trend was observed by Darvishi *et al* 2011, 2013, Icier and Ilicali 2005a, Assiry *et al* 2003, Lien *et al* 2014. Therefore, it can be said that the heating rates are voltage dependent. At high voltage gradients, the current passing through the sample was higher and this increased the heat generation rate. As the voltage gradient increased the heating time of the soymilk required to reach the prescribed temperature decreased (Darvishi *et al* 2011).

From the plots it was observed that the concentrations also affect the heating rates. Heating rate was higher for higher concentration. At some particular voltage gradient say at 14V/cm the heating rate observed was 0.095, 0.127, 0.149, 0.154, 0.196˚C/sec for 100, 90, 80, 70, 60% concentrations respectively. This high heating rate was because of greater amount of free ions or charge carriers in higher concentrations (Assiry *et al* 2010).

The application of ohmic heating at high voltage gradients and at higher solute concentrations could be advantageous to obtain faster heating at the industrial processing of these solutions. The precise measurement and the accurate control of the temperature during ohmic heating are crucial in the design procedures of ohmic heating systems.

Table 4.2 Change in temperature with time during ohmic heating of soymilk at 14V/cm.

Time (s)	**Temperature (°C)**					**Time (s)**	**Temperature (°C)**				
	100%	**90%**	**80%**	**70%**	**60%**		**100%**	**90%**	**80%**	**70%**	**60%**
0	32	32	31	31	31	110	52	51	46	46	40
10	34	35	33	33	32	120	55	53	48	47	41
20	36	37	34	34	33	130	57	54	50	48	42
30	37	39	35	36	34	140	59	55	51	49	43
40	39	40	36	37	35	150	60	57	53	50	43
50	40	42	38	38	35	160	63	58	54	52	44
60	42	44	39	39	36	170	65	60	55	53	45
70	44	45	41	41	37	180	67	62	57	55	46
80	46	46	42	42	38	190	69	63	59	56	47
90	48	48	44	43	39	200	70	65	60	57	48
100	50	50	45	45	40	-	-	-	-	-	-

Table 4.3 Change in temperature with time during ohmic heating of soymilk at 12V/cm.

Time (s)	Temperature (°C)					Time (s)	Temperature (°C)				
	100%	90%	80%	70%	60%		100%	90%	80%	70%	60%
0	32	32	31	31	31	140	52	48	44	42	38
10	34	34	32	31	31	150	54	49	45	42	39
20	35	35	33	32	32	160	55	50	45	43	39
30	36	36	34	33	32	170	57	52	46	44	40
40	38	37	35	34	33	180	58	53	47	45	41
50	39	38	36	35	33	190	60	54	48	46	42
60	41	39	36	35	34	200	61	55	49	47	42
70	42	41	37	36	34	210	63	57	50	48	43
80	43	42	38	37	35	220	65	58	50	48	44
90	45	43	39	37	35	230	66	59	51	49	44
100	46	44	40	38	36	240	68	61	52	50	45
110	48	45	41	39	37	250	70	62	53	51	46
120	49	46	42	40	37	260	71	63	54	52	46

Table 4.4 Change in temperature with time during ohmic heating of soymilk at 10V/cm.

Time (s)	Temperature (°C)					Time (s)	Temperature (°C)				
	100%	90%	80%	70%	60%		100%	90%	80%	70%	60%
0	32	31	30	30	30	90	40	39	37	34	34
10	33	33	31	31	31	100	41	39	38	35	34
20	34	33	32	31	31	110	42	40	38	35	34
30	35	34	33	32	31	120	42	41	39	36	35
40	36	35	33	32	32	130	43	41	40	37	35
50	37	36	34	33	32	140	44	42	40	37	35
60	38	37	35	33	32	150	45	43	41	37	36
70	39	37	36	33	32	160	45	44	41	38	36
80	40	38	37	34	33	170	46	44	42	38	36

Time (s)	Temperature (°C)					Time (s)	Temperature (°C)				
	100%	90%	80%	70%	60%		100%	90%	80%	70%	60%
180	46	45	42	39	37	330	61	57	52	47	43
190	48	46	43	39	37	340	62	58	53	47	44
200	49	46	44	40	38	350	63	58	53	48	44
210	50	47	45	40	38	360	64	59	54	48	44
220	51	48	45	40	38	370	64	60	54	49	44
230	52	49	46	41	39	380	65	61	55	50	45
240	53	49	46	42	39	390	66	62	55	50	45
250	54	50	47	42	39	400	67	63	56	51	46
260	55	51	47	43	39	410	68	63	57	52	46
270	55	52	48	43	40	420	68	64	58	52	47
280	56	53	49	44	40	430	69	65	58	53	47
290	57	53	50	44	41	440	70	66	59	54	47
300	58	54	50	45	41	450	70	67	59	54	48
310	59	55	51	46	42	460	71	68	60	55	48
320	60	56	51	46	43	470	71	68	60	56	48

Table 4.5 Change in temperature with time during ohmic heating of soymilk at 8V/cm.

Time (s)	Temperature (°C)					Time (s)	Temperature (°C)				
	100%	90%	80%	70%	60%		100%	90%	80%	70%	60%
0	33	32	30	30	30	110	38	38	35	33	32
10	34	33	31	31	30	120	38	39	35	34	32
20	35	33	31	31	30	130	38	39	35	34	32
30	35	34	32	31	30	140	39	39	36	34	32
40	35	35	32	32	30	150	39	40	36	35	33
50	36	35	33	32	30	160	40	40	37	35	33
60	36	36	33	32	31	170	40	41	37	35	33
70	36	36	33	32	31	180	40	41	38	35	34
80	37	37	34	32	31	190	41	42	38	36	34
90	37	37	34	33	32	200	41	42	39	36	34
100	38	38	34	33	32	210	42	42	39	37	34

Time (s)	**Temperature (°C)**					**Time (s)**	**Temperature (°C)**				
	100%	**90%**	**80%**	**70%**	**60%**		**100%**	**90%**	**80%**	**70%**	**60%**
220	42	43	39	37	34	490	54	54	47	45	40
230	42	43	40	37	34	500	54	54	47	45	40
240	43	44	40	38	35	510	55	55	47	45	41
250	43	44	40	38	35	520	56	55	48	46	41
260	44	45	40	38	35	530	56	56	48	46	41
270	44	45	40	39	35	540	56	56	49	46	41
280	44	46	40	39	35	550	57	57	49	47	41
290	45	46	41	39	35	560	57	57	49	47	41
300	45	46	41	39	36	570	58	58	49	47	42
310	46	47	41	40	36	580	58	58	49	47	42
320	47	47	41	40	36	590	59	59	50	48	42
330	47	47	41	40	36	600	59	59	50	48	43
340	47	48	42	40	36	610	60	59	50	48	43
350	48	48	42	41	36	620	60	60	50	49	43
360	48	49	42	41	37	630	60	60	51	49	44
370	49	49	43	42	37	640	61	61	51	49	44
380	49	50	43	42	37	650	62	61	52	50	44
390	50	50	44	42	38	660	62	61	52	50	44
400	50	51	45	42	38	670	63	62	52	50	44
410	50	51	45	43	38	680	63	62	52	50	44
420	51	51	45	43	39	690	63	63	52	51	45
430	51	52	45	43	39	700	64	63	53	51	45
440	52	52	46	43	39	710	64	64	53	51	45
450	52	52	46	44	40	720	65	64	53	52	45
460	53	53	46	44	40	730	65	65	54	52	45
470	53	53	46	44	40	740	66	65	55	52	45
480	54	54	47	45	40	750	66	65	55	52	46

Time (s)	Temperature (°C)					Time (s)	Temperature (°C)				
	100%	**90%**	**80%**	**70%**	**60%**		**100%**	**90%**	**80%**	**70%**	**60%**
760	66	66	56	53	46	800	68	68	57	54	47
770	67	66	56	53	46	810	69	68	57	55	47
780	67	67	56	54	47	820	69	68	58	55	47
790	68	67	57	54	47	830	70	69	58	55	47
840	70	69	58	56	48	-	-	-	-	-	-

Table 4.6 Change in temperature with time during ohmic heating of soymilk at 6V/cm.

Time (s)	Temperature (°C)					Time (s)	Temperature (°C)				
	100%	**90%**	**80%**	**70%**	**60%**		**100%**	**90%**	**80%**	**70%**	**60%**
0	31	31	31	30	30	180	36	36	34	32	32
10	31	31	31	30	30	190	36	36	34	32	32
20	31	31	31	30	30	200	36	36	34	32	32
30	32	32	32	30	30	210	36	36	35	33	32
40	32	32	32	30	30	220	36	36	35	33	32
50	32	32	32	30	30	230	36	36	35	33	32
60	32	33	32	30	30	240	37	37	35	33	32
70	32	33	32	30	30	250	37	37	35	33	32
80	32	33	32	30	30	260	37	37	35	33	32
90	33	33	33	31	30	270	38	38	36	34	32
100	33	33	33	31	30	280	38	38	36	34	32
110	33	33	33	31	30	290	38	38	36	34	32
120	34	34	33	31	31	300	38	38	36	34	33
130	34	34	33	31	31	310	38	38	36	34	33
140	34	34	33	31	31	320	38	38	36	34	33
150	35	35	34	32	31	330	39	39	37	35	33
160	35	35	34	32	31	340	39	39	37	35	33
170	35	35	34	32	31	350	39	39	37	35	33

Time (s)	**Temperature (°C)**					**Time (s)**	**Temperature (°C)**				
	100%	**90%**	**80%**	**70%**	**60%**		**100%**	**90%**	**80%**	**70%**	**60%**
360	40	40	37	35	34	630	45	45	41	40	36
370	40	40	37	35	34	640	45	45	41	40	36
380	40	40	37	35	34	650	45	45	41	40	36
390	40	40	38	36	34	660	46	46	42	40	37
400	40	40	38	36	34	670	46	46	42	40	37
410	40	40	38	36	34	680	46	46	42	40	37
420	41	41	38	37	34	690	47	46	42	41	37
430	41	41	38	37	34	700	47	46	42	41	37
440	41	41	38	37	34	710	47	46	42	41	37
450	42	41	39	37	34	720	47	47	43	41	37
460	42	41	39	37	34	730	47	47	43	41	37
470	42	41	39	37	34	740	47	47	43	41	37
480	42	42	39	38	35	750	48	48	44	42	37
490	42	42	39	38	35	760	48	48	44	42	37
500	42	42	39	38	35	770	48	48	44	42	37
510	43	43	40	38	35	780	49	48	44	42	38
520	43	43	40	38	35	790	49	48	44	42	38
530	43	43	40	38	35	800	49	48	44	42	38
540	44	43	40	39	36	810	49	49	44	43	38
550	44	43	40	39	36	820	49	49	44	43	38
560	44	43	40	39	36	830	49	49	44	43	38
570	44	44	41	39	36	840	50	49	45	43	38
580	44	44	41	39	36	850	50	49	45	43	38
590	44	44	41	39	36	860	50	49	45	43	38
600	45	45	41	39	36	870	50	50	46	44	38
610	45	45	41	39	36	880	50	50	46	44	38
620	45	45	41	39	36	890	50	50	46	44	38

Time (s)	**Temperature (°C)**					**Time (s)**	**Temperature (°C)**				
	100%	**90%**	**80%**	**70%**	**60%**		**100%**	**90%**	**80%**	**70%**	**60%**
900	51	50	46	44	39	1170	56	55	50	49	41
910	51	50	46	44	39	1180	56	55	50	49	41
920	51	50	46	44	39	1190	56	55	50	49	41
930	52	51	47	45	39	1200	57	56	51	49	41
940	52	51	47	45	39	1210	57	56	51	49	41
950	52	51	47	45	39	1220	57	56	51	49	41
960	52	51	47	45	39	1230	57	56	51	50	41
970	52	51	47	45	39	1240	57	56	51	50	41
980	52	51	47	45	39	1250	57	56	51	50	41
990	53	52	48	45	39	1260	58	57	52	50	42
1000	53	52	48	45	39	1270	58	57	52	50	42
1010	53	52	48	45	39	1280	58	57	52	50	42
1020	53	52	48	46	40	1290	59	57	52	51	42
1030	53	52	48	46	40	1300	59	57	52	51	42
1040	53	52	48	46	40	1310	59	57	52	51	42
1050	54	53	49	46	40	1320	59	58	53	51	42
1060	54	53	49	46	40	1330	59	58	53	51	42
1070	54	53	49	46	40	1340	59	58	53	51	42
1080	55	53	49	47	40	1350	59	58	53	52	42
1090	55	53	49	47	40	1360	59	58	53	52	42
1100	55	53	49	47	40	1370	59	58	53	52	42
1110	55	54	49	47	40	1380	60	59	54	52	43
1120	55	54	49	47	40	1390	60	59	54	52	43
1130	55	54	49	47	40	1400	60	59	54	52	43
1140	56	54	50	48	41	1410	61	59	54	53	43
1150	56	54	50	48	41	1420	61	59	54	53	43
1160	56	54	50	48	41	1430	61	59	54	53	43

Time (s)	**Temperature (°C)**					**Time (s)**	**Temperature (°C)**				
	100%	**90%**	**80%**	**70%**	**60%**		**100%**	**90%**	**80%**	**70%**	**60%**
1440	61	60	55	54	44	1680	66	64	59	56	46
1450	61	60	55	54	44	1690	66	64	59	56	46
1460	61	60	55	54	44	1700	66	64	59	56	46
1470	62	60	55	54	44	1710	66	64	59	56	46
1480	62	60	55	54	44	1720	66	64	59	56	46
1490	62	60	55	54	44	1730	66	64	59	56	46
1500	62	61	55	55	44	1740	67	65	60	57	46
1510	62	61	55	55	44	1750	67	65	60	57	46
1520	62	61	55	55	44	1760	67	65	60	57	46
1530	63	61	56	55	44	1770	67	65	61	57	46
1540	63	61	56	55	44	1780	67	65	61	57	46
1550	63	61	56	55	44	1790	67	65	61	57	46
1560	63	62	56	55	45	1800	68	66	61	58	46
1570	63	62	56	55	45	1810	68	66	61	58	46
1580	63	62	56	55	45	1820	68	66	61	58	46
1590	64	62	57	55	45	1830	68	66	62	58	46
1600	64	62	57	55	45	1840	68	66	62	58	46
1610	64	62	57	55	45	1850	68	66	62	58	46
1620	64	63	58	56	45	1860	69	67	62	59	47
1630	64	63	58	56	45	1870	69	67	62	59	47
1640	64	63	58	56	45	1880	69	67	62	59	47
1650	65	63	58	56	45	1890	70	67	63	59	47
1660	65	63	58	56	45	1900	70	67	63	59	47
1670	65	63	58	56	45	1910	70	67	63	59	47

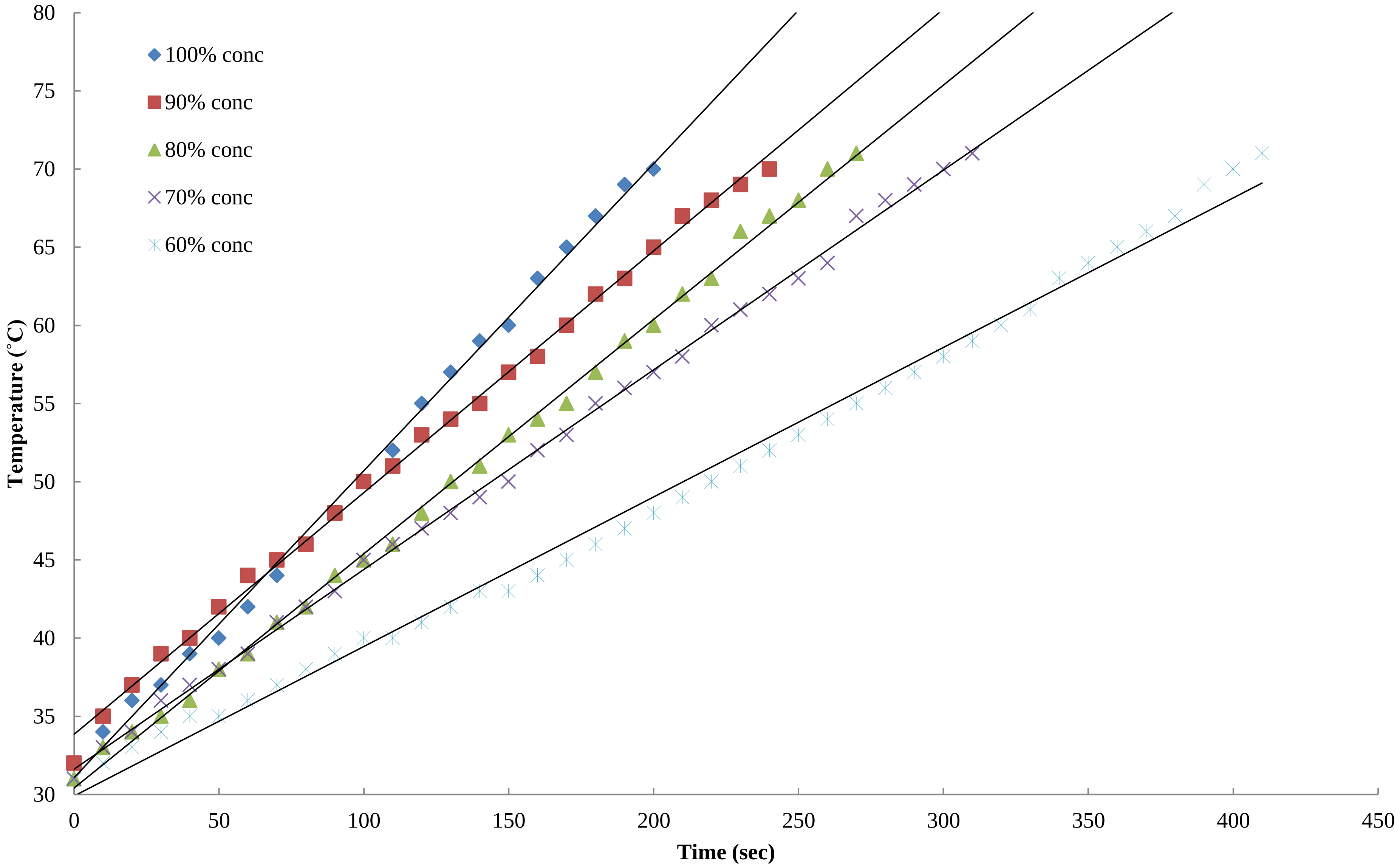


Figure 4.1 Variation of temperature with time during ohmic heating of soymilk at 14V/cm.

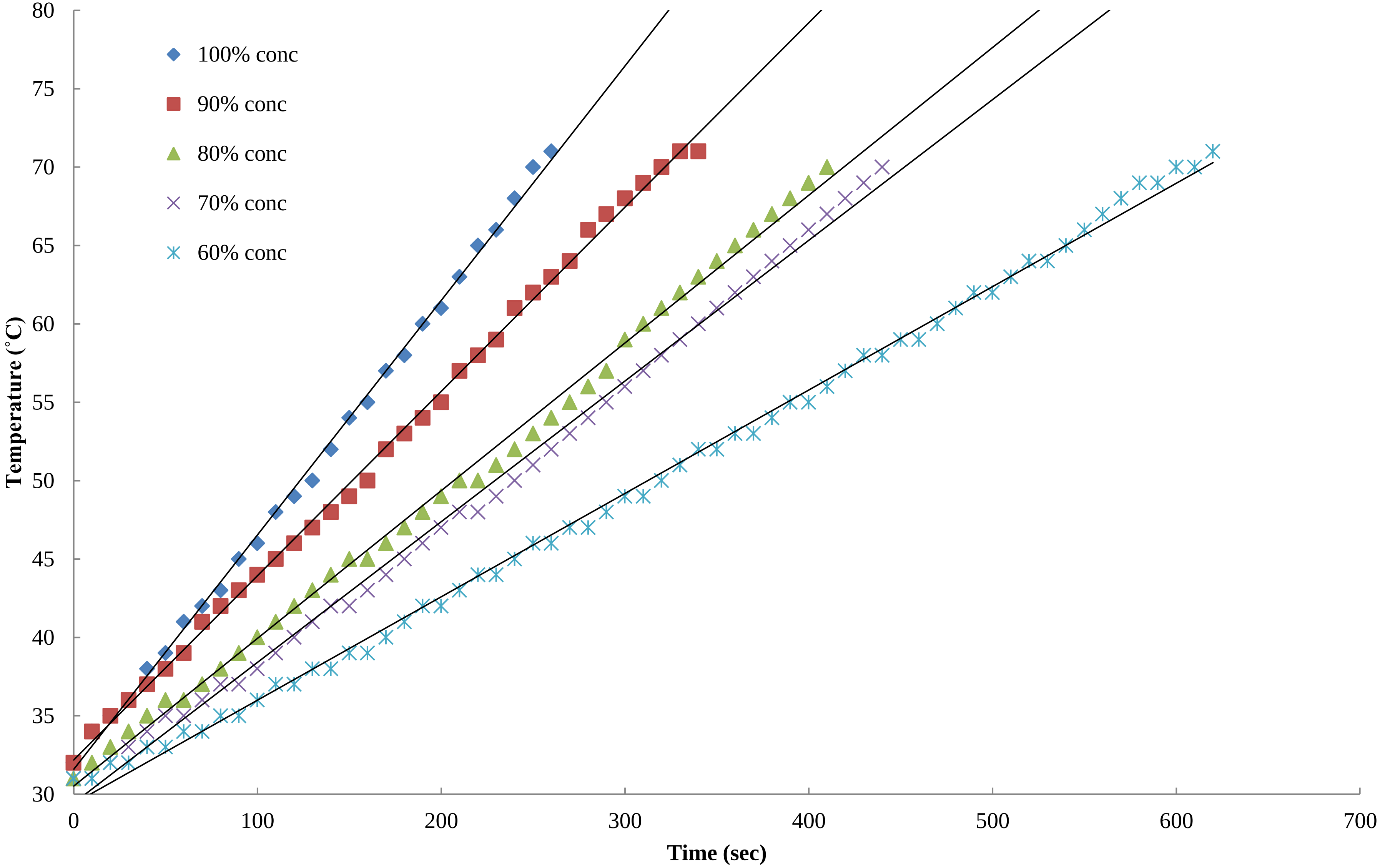


Figure 4.2 Variation of temperature with time during ohmic heating of soymilk at 12V/cm

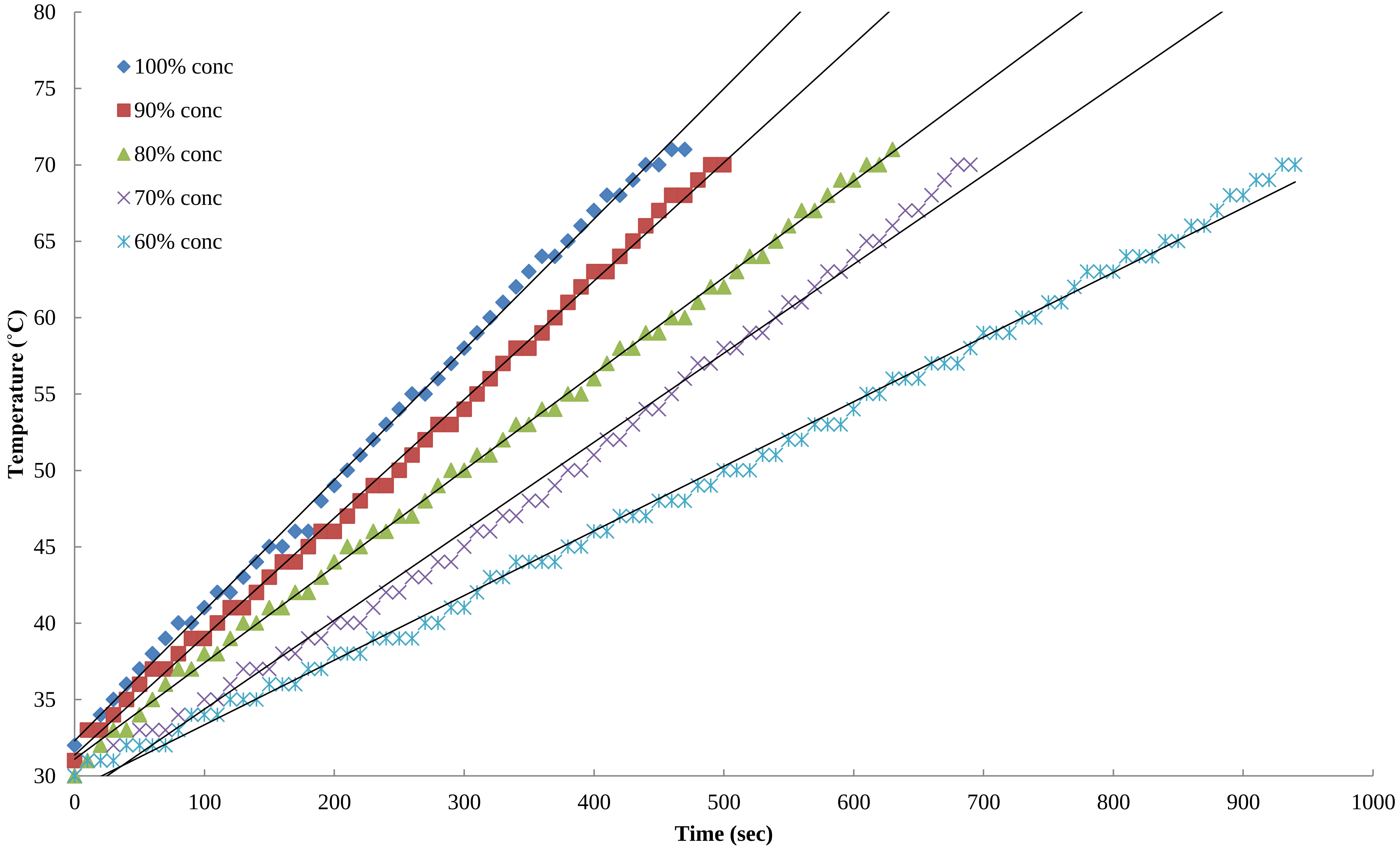


Figure 4.3 Variation of temperature with time during ohmic heating of soymilk at 10V/cm.

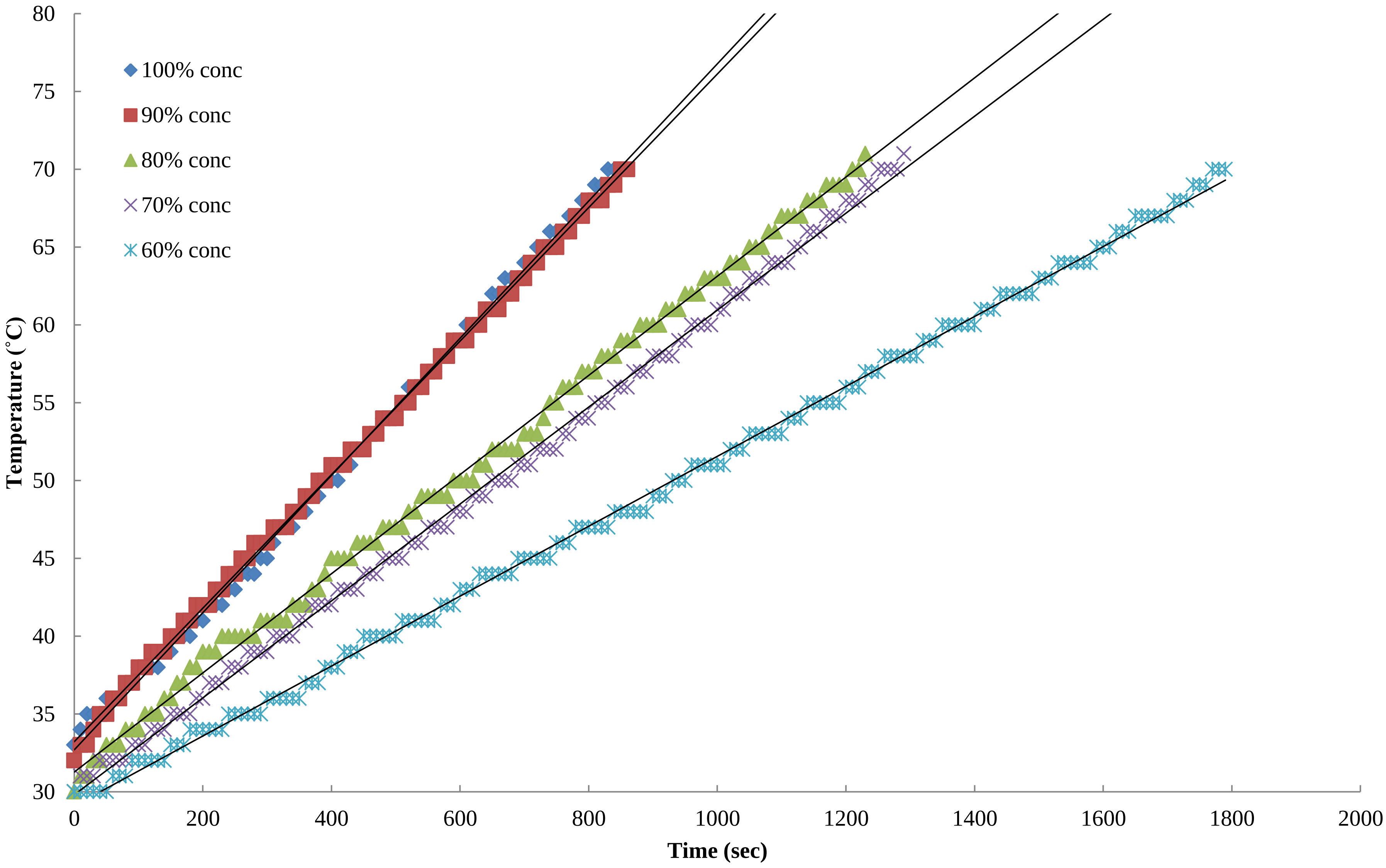


Figure 4.4 Variation of temperature with time during ohmic heating of soymilk at 8 V/cm.

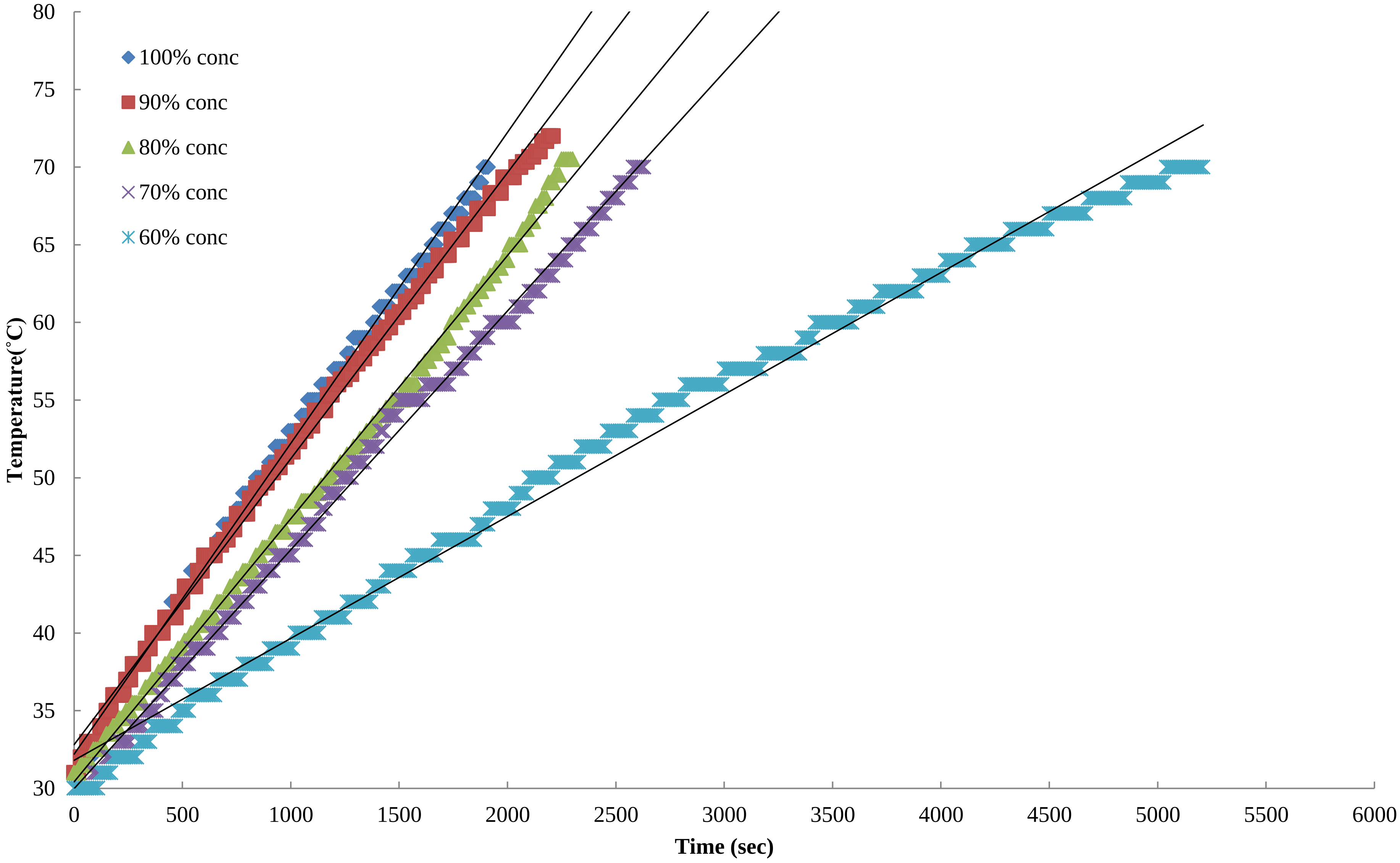


Figure 4.5 Variation of temperature with time during ohmic heating of soymilk at 6V/cm.

4.2 VARIATION OF ELECTRICAL CONDUCTIVITY

The experimentally observed values of electrical conductivity at different temperatures and voltage gradients have been presented in Tables 4.7 to 4.11 for all the five concentrations of soymilk. The curves depicting the variation of electrical conductivity with temperature are outlined in the Figures 4.6 to 4.10. It can be seen from the plots that the variation of electrical conductivity with temperature follows a linear trend. Basically the variation of electrical conductivity with temperature was noted at one voltage gradient and at five different concentrations. The electrical conductivity for 100% concentration sample at 14V/cm is higher than the electrical conductivity at 90% concentration which is further greater than conductivity at 80% concentration and so on i.e. the higher concentrated sample has higher electrical conductivity. This similar trend was observed by Assiry *et al* (2010). In his study the sample which was containing more TDS value i.e. which was more concentrated possessed more value of conductivity. Similar trend was also observed by Halden *et al* (1990), Palaniappan *et al* (1991) and Assawarachan (2010).

This is due to the fact that as concentration increases solid particles in sample also increases. The increased solid particles accelerate more electric current through the sample at high concentration than low concentrated sample. Thus the concentrations of soluble solid particles explain the change in electrical conductivity.

Also, voltage gradient has a significant effect on variation of electrical conductivity with temperature. Generally, at one particular voltage gradient and one concentration electrical conductivity of the sample increases linearly with temperature. This trend was shown by the experimental results obtained from soymilk in this study which are consistent with the results obtained by Kumar *et al* 2011, Icier *et al* 2008, Darvishi *et al* 2011, Kemp and Fryer 2007, Icier and Ilicali 2004, 2005a and Amiali *et al* 2006. Generally, as voltage gradient increases for one particular concentration electrical conductivity increases but in the present study it was observed that this particular trend was somewhat abrupt i.e. electrical conductivity of highest voltage gradient was not necessarily high although the heating rate was following the required trend i.e. at high voltage gradient heating rate was high. This was due to the fact that the voltage gradients chosen had small difference between them. Although the current values were increasing with the increase in voltage gradient but this increase was not so high to cause any significant increase in electrical conductivity with voltage gradient. Since the heating rate is proportional to the square of current therefore trend of heating rate was correct, but as electrical conductivity is proportional to single power of current and also we have voltage in the denominator which counter balances the increasing effect of current. Therefore the results obtained at one concentration for different voltage gradients were abrupt. These results were somewhat similar to the results obtained by Darvishi *et al* (2015).

Table 4.7 Variation of electrical conductivity of soymilk at 14V/cm during ohmic heating.

Sr. No.	**Temp.(°C)**	**Electrical conductivity (in S/m)**				
		100%	**90%**	**80%**	**70%**	**60%**
1	35	0.3687	0.2933	0.2857	0.2623	0.1967
2	40	0.3987	0.3183	0.3107	0.2873	0.2133
3	45	0.4287	0.3433	0.3357	0.3123	0.2300
4	50	0.4587	0.3683	0.3607	0.3373	0.2467
5	55	0.4887	0.3933	0.3857	0.3623	0.2633
6	60	0.5187	0.4183	0.4107	0.3873	0.2800
7	65	0.5487	0.4433	0.4357	0.4123	0.2967
8	70	0.5787	0.4683	0.4607	0.4373	0.3133

Table 4.8 Variation of electrical conductivity of soymilk at 12V/cm during ohmic heating.

Sr. No.	**Temp.(°C)**	**Electrical conductivity (in S/m)**				
		100%	**90%**	**80%**	**70%**	**60%**
1	35	0.4057	0.3263	0.2827	0.2473	0.1860
2	40	0.4407	0.3547	0.3077	0.2673	0.2010
3	45	0.4757	0.3830	0.3327	0.2873	0.2160
4	50	0.5107	0.4113	0.3577	0.3073	0.2310
5	55	0.5457	0.4397	0.3827	0.3273	0.2460
6	60	0.5807	0.4680	0.4077	0.3473	0.2610
7	65	0.6157	0.4963	0.4327	0.3673	0.2760
8	70	0.6507	0.5247	0.4577	0.3873	0.2910

Table 4.9 Variation of electrical conductivity of soymilk at 10V/cm during ohmic heating.

Sr. No.	Temp.(°C)	Electrical conductivity (in S/m)				
		100%	90%	80%	70%	60%
1	35	0.3040	0.2960	0.2770	0.2517	0.1830
2	40	0.3307	0.3210	0.3020	0.2733	0.1980
3	45	0.3573	0.3460	0.3270	0.2950	0.2130
4	50	0.3840	0.3710	0.3520	0.3167	0.2280
5	55	0.4107	0.3960	0.3770	0.3383	0.2430
6	60	0.4373	0.4210	0.4020	0.3600	0.2580
7	65	0.4640	0.4460	0.4270	0.3817	0.2730
8	70	0.4907	0.4710	0.4520	0.4033	0.2880

Table 4.10 Variation of electrical conductivity of soymilk at 8V/cm during ohmic heating.

Sr. No.	Temp.(°C)	Electrical conductivity (in S/m)				
		100%	90%	80%	70%	60%
1	35	0.3100	0.2725	0.2725	0.2303	0.1795
2	40	0.3400	0.3000	0.2975	0.2503	0.1945
3	45	0.3700	0.3275	0.3225	0.2703	0.2095
4	50	0.4000	0.3550	0.3475	0.2903	0.2245
5	55	0.4300	0.3825	0.3725	0.3103	0.2395
6	60	0.4600	0.4100	0.3975	0.3303	0.2545
7	65	0.4900	0.4375	0.4225	0.3503	0.2695
8	70	0.5200	0.4650	0.4475	0.3703	0.2845

Table 4.11 Variation of electrical conductivity of soymilk at 6V/cm during ohmic heating.

Sr. No.	Temp.(°C)	Electrical conductivity (in S/m)				
		100%	90%	80%	70%	60%
1	35	0.3450	0.2960	0.2640	0.2104	0.1750
2	40	0.3800	0.3210	0.2890	0.2306	0.1900
3	45	0.4150	0.3460	0.3140	0.2515	0.2050
4	50	0.4500	0.3710	0.3390	0.2792	0.2200
5	55	0.4850	0.3960	0.3640	0.2931	0.2350
6	60	0.5200	0.4210	0.3890	0.3155	0.2500
7	65	0.5550	0.4460	0.4140	0.3385	0.2650
8	70	0.5900	0.4710	0.4390	0.3590	0.2800

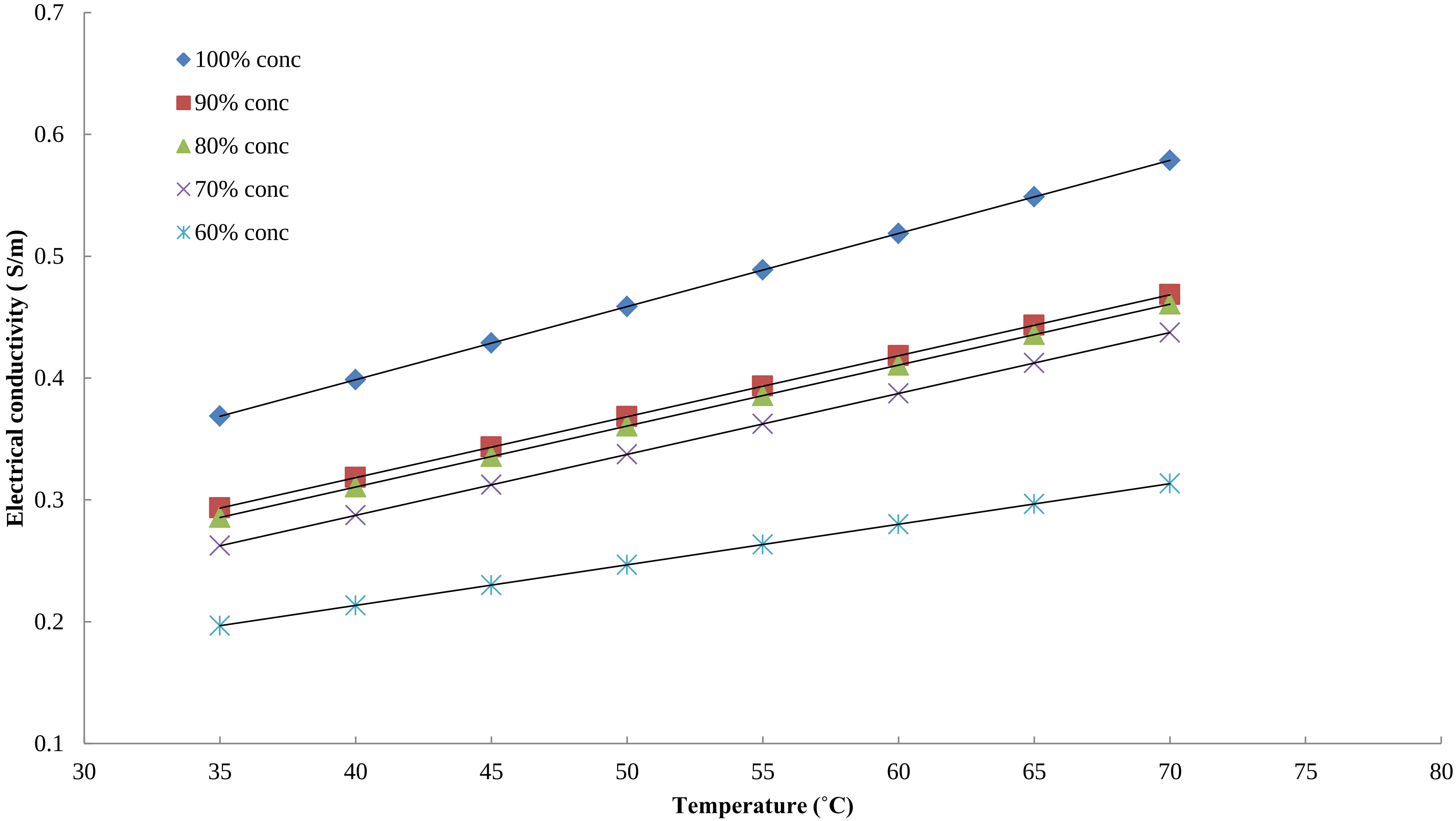


Figure 4.6 Change in electrical conductivity with temperature at five concentrations of soymilk for 14V/cm voltage gradient.

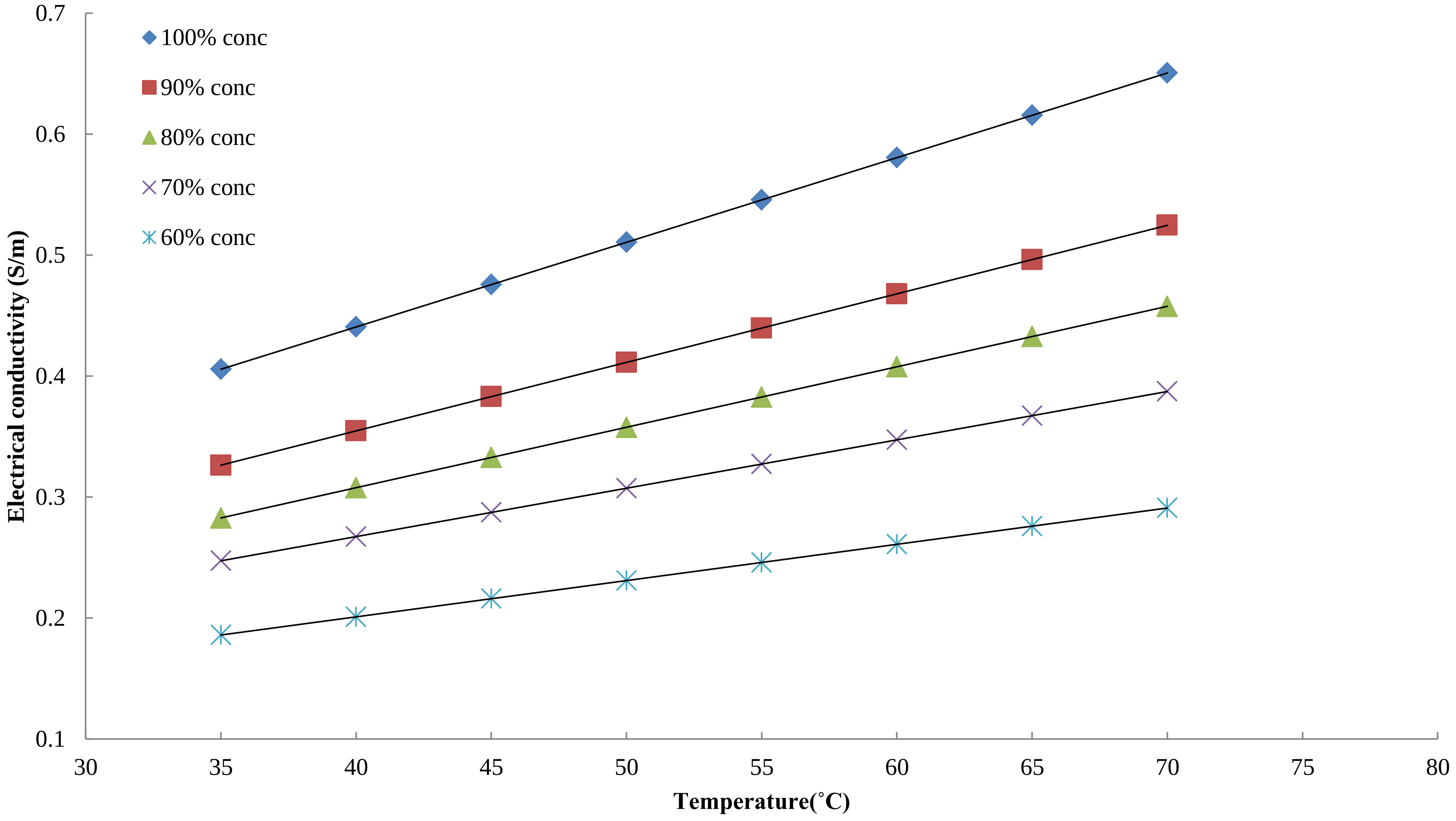


Figure 4.7 Change in electrical conductivity with temperature under five concentrations of soymilk for 12V/cm voltage gradient.

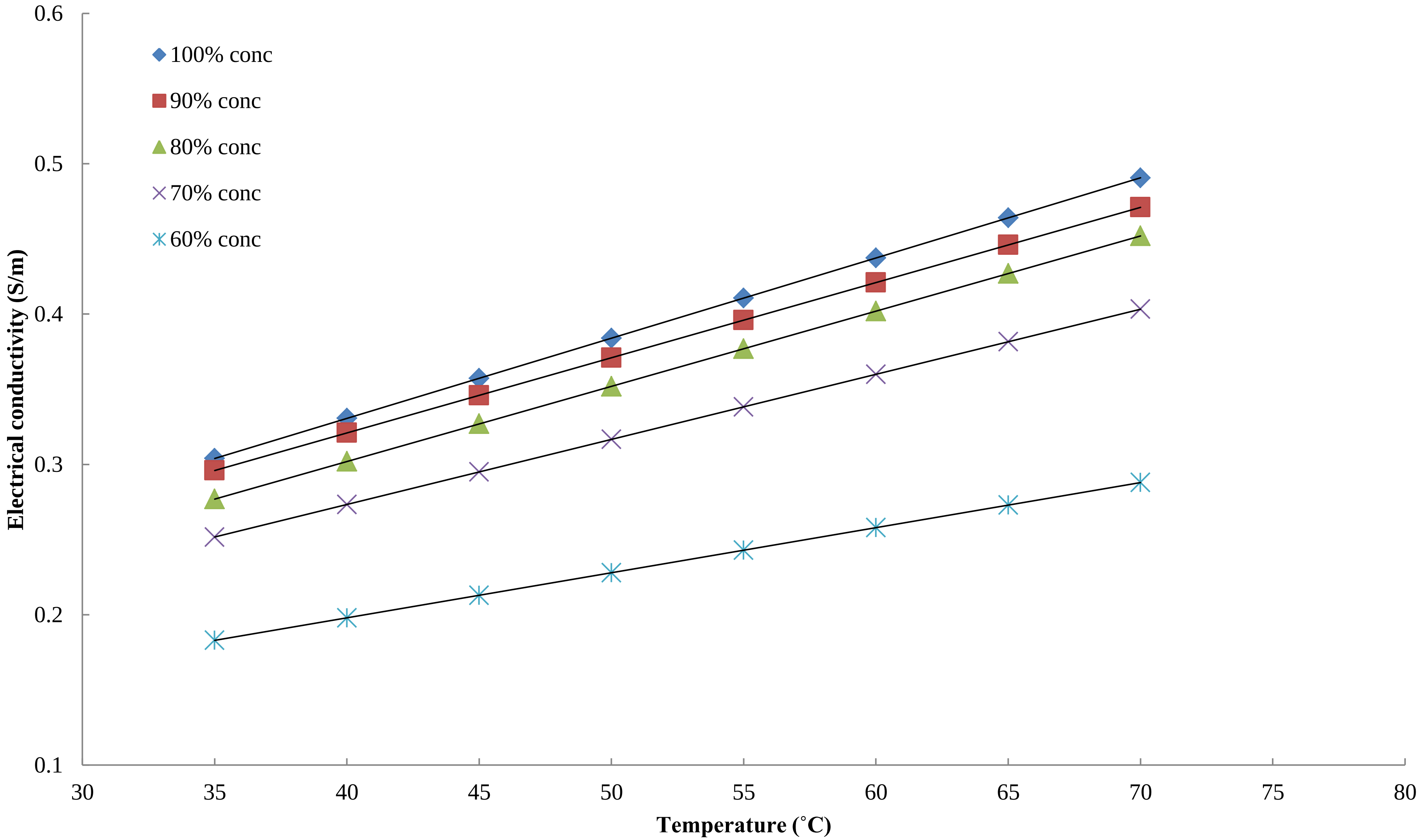


Figure 4.8 Change in electrical conductivity with temperature at five concentrations of soymilk for 10V/cm voltage gradient.

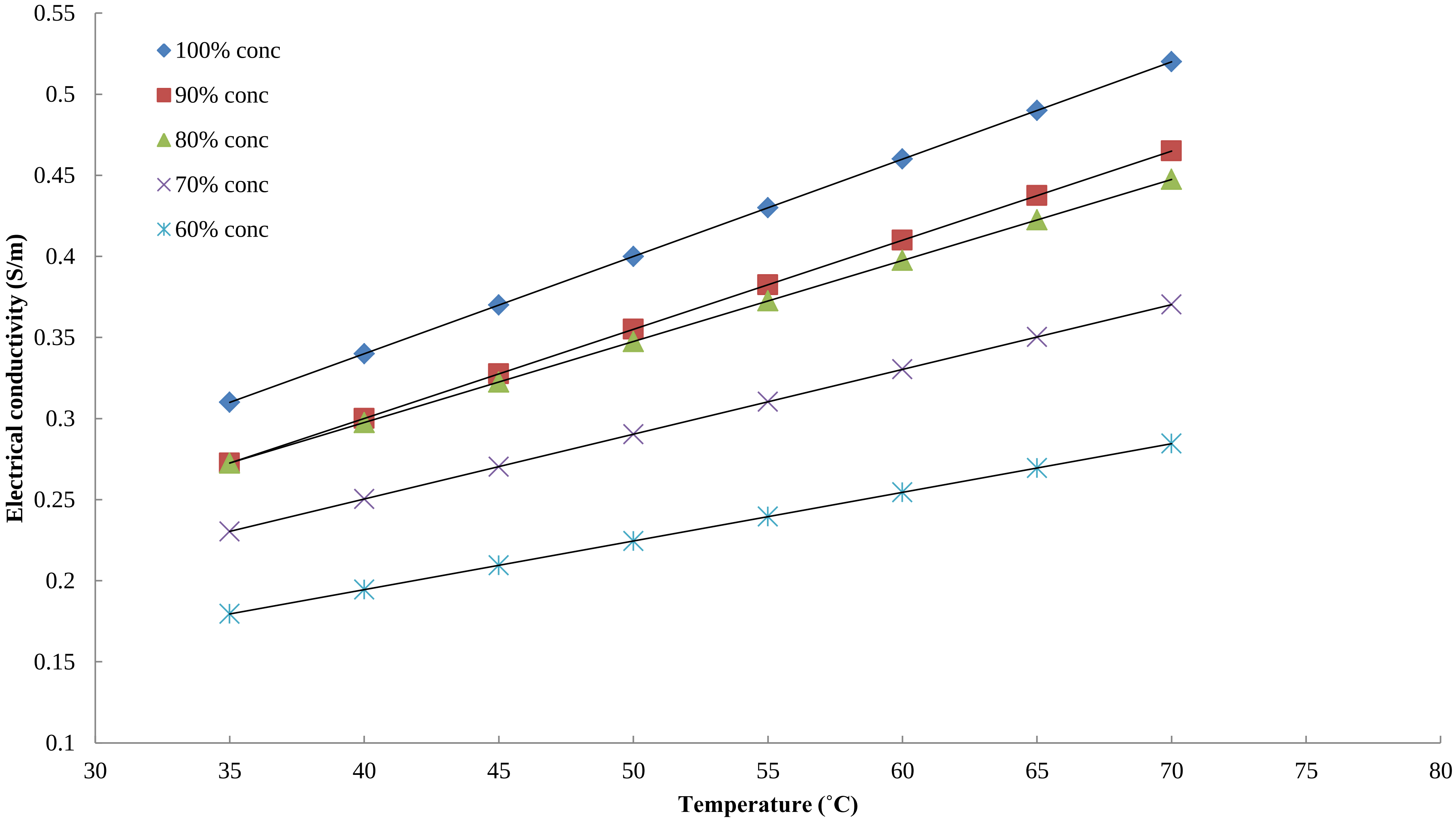


Figure 4.9 Change in electrical conductivity with temperature at five concentrations of soymilk for 8V/cm voltage gradient.

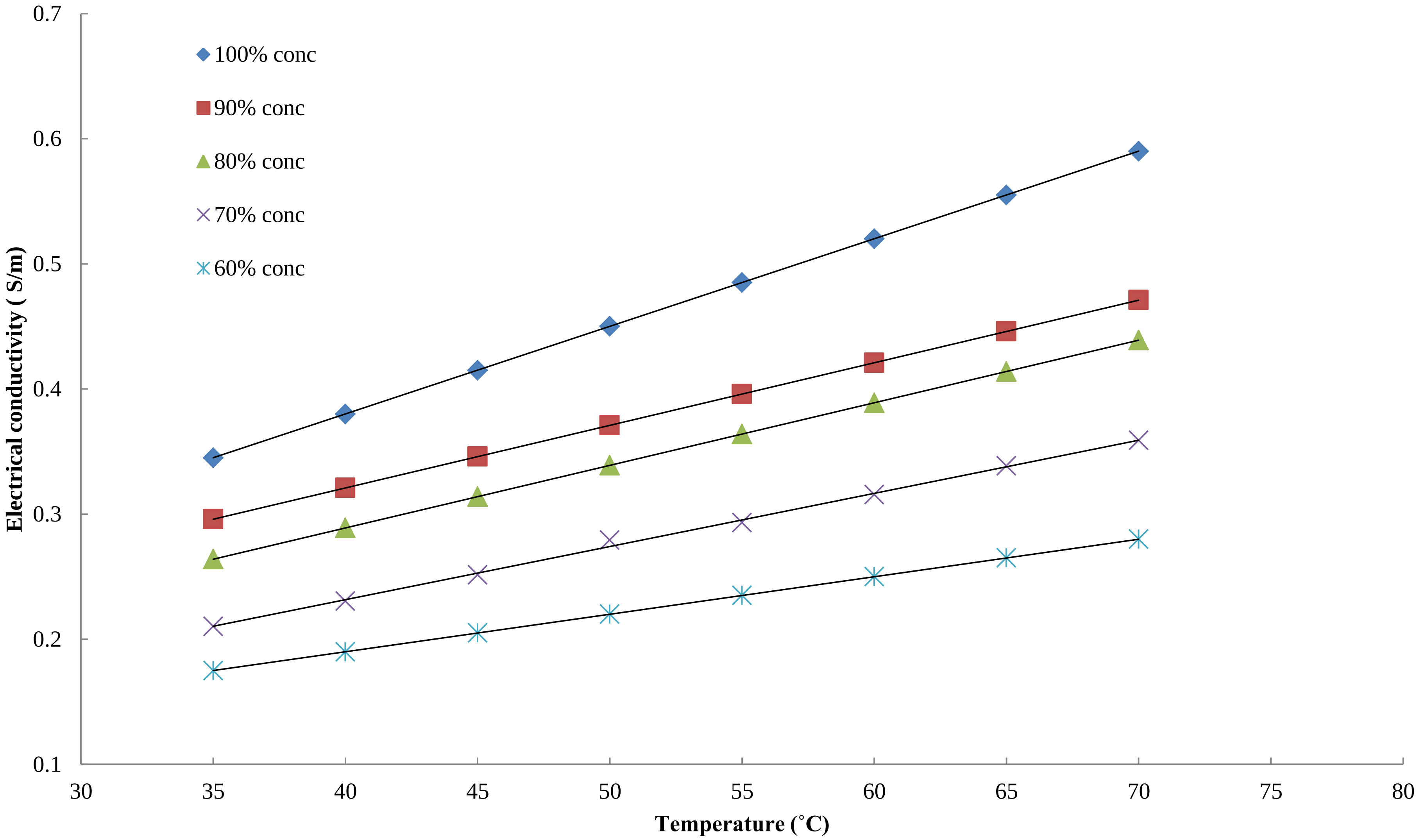


Figure 4.10 Change in electrical conductivity with temperature at five concentrations of soymilk for 6V/cm voltage gradient.

4.3 MODELING OF ELECTRICAL CONDUCTIVITY

In statistical modeling, regression analysis is a statistical process for estimating the relationships among variables. It includes many techniques for modeling and analyzing several variables, when the focus is on the relationship between a dependent variable and one or more independent variables. More specifically, regression analysis helps one understand how the typical value of the dependent variable changes when any one of the independent variables is varied, while the other independent variables are fixed. The coefficient of determination (R^2) is one of the primary criteria for selecting the best model to define the ohmic heating curves. In addition to R^2, reduced chi-square (χ^2) and root mean square error (RMSE) are used to determine the goodness of the fit. The higher values of the coefficient of determination (R^2) and lower values of the reduced chi square (χ^2) and the root mean square error (RMSE) were chosen as the criteria for goodness of fit (Icier and Bozkurt (2011) and Assawarachan (2010)).

Since the experimental electrical conductivity results for the soymilk samples were given in plots 4.6-4.10 showed a linear trend with increasing temperature, therefore linear model was used to fit the electrical conductivity data of soymilk.

$\sigma(V,C,T) = A\ (V,C)+B\ (V,C)T$

Where, $\sigma(V,C,T)$ represents the electrical conductivity of soymilk obtained at a specific concentration and voltage gradient. A(V,C) and B(V,C) are the regression constants which are the function of voltage gradient and concentration, T is the temperature. The regression constant A(V,C) and B(V,C) represents the slopes and the intercepts respectively for the curves shown in Figure 4.6 to 4.10. Physically, A(V,C) denotes the constant of electrical conductivity-temperature relationship whereas B(V,C) imparts the information about to what extent electrical conductivity values gets affected on raising the temperature.

The Table 4.12 shows the results of statistical analysis using the regression are simply the modeling of electrical conductivity of soymilk with temperature along with mathematically fitted equation, as obtained by regression analysis using the software SPSS version 20.0. Statistical results obtained from the model are shown in table, includes the various best fit relations of electrical conductivity with the temperature. The R^2 values for the soymilk samples with different concentrations being heated ohmically at different applied voltage gradients were in the neighborhood of mean value 1.00 for most of combinations of applied voltage gradient and the concentration of samples. Thus, linear model represent the electrical conductivity of soymilk during ohmic heating. The linear model has also been suggested by others to describe the ohmic heating of apricot and peach purees by Icier and Illicali (2005), meat by Zell *et al* (2010) and orange juice by Icier and Illicali (2005), seawater by Assiry *et al* (2010) and lemon by Darvishi *et al*(2011).

Table 4.12 The constants and coefficients of electrical conductivity-temperature relationship of soymilk heated ohmically at different concentrations.

Voltage gradient (V/cm)	Concentration (% by volume)	Electrical conductivity-Temperature model	Regression coefficient (R^2)
6	60	σ = 0.003T+0.070	1.000
	70	σ = 0.004T+0.061	0.998
	80	σ = 0.005T+0.089	1.000
	90	σ = 0.005T+0.121	1.000
	100	σ = 0.007T+0.100	1.000
8	60	σ = 0.003T+0.075	1.000
	70	σ = 0.004T+0.090	1.000
	80	σ = 0.005T+0.097	1.000
	90	σ =0.005T+0.080	1.000
	100	σ = 0.006T+0.100	1.000
10	60	σ = 0.003T+0.080	1.000
	70	σ = 0.004T+0.100	1.000
	80	σ = 0.005T+0.102	1.000
	90	σ = 0.005T+0.121	1.000
	100	σ = 0.005T+0.117	1.000
12	60	σ = 0.003T+0.080	1.000
	70	σ = 0.004T+0.107	1.000
	80	σ = 0.005T+0.107	1.000
	90	σ =0.005T+0.128	1.000
	100	σ = 0.007T+0.160	1.000
14	60	σ = 0.003T+0.080	1.000
	70	σ = 0.005T+0.087	1.000
	80	σ = 0.005T+0.111	1.000
	90	σ = 0.005T+0.118	1.000
	100	σ = 0.006T+0.159	1.000

4.4 EFFECT OF OHMIC HEATING ON VISCOSITY

Viscosity is an important parameter associated with the quality of food products. In the present study the viscosity values of different samples and at different voltage gradients were determined by using the prior information of density (Kg/m^3) and time of flows of soymilk. The experimentally observed values of coefficient of viscosity η before and after the ohmic heating for five different concentrations (100, 90, 80, 70, and 60%) at different voltage gradient have been represented in the Table 4.13. Singh *et al* (2008) and Icier and Ilicali (2005) stated that concentration of liquid foods will affect the electrical conductivity as well as the viscosity of liquid. The table revealed that the maximum and minimum viscosity before and after ohmic heating was 2.827, 1.689 and 2.550, 1.643 respectively. In both cases the maximum value is obtained for 100% and minimum value obtained for 60% concentration. This concludes that the viscosity of soymilk was increased with elevation in concentration.

Table 4.13 Viscosity values for different voltage gradients at five concentrations of soymilk.

Concentration of soymilk (v/v)	**Viscosity values of soymilk (h) (cP)**					
	Before ohmic heating	**After ohmic heating**				
		Voltage gradient (V/cm)				
		14	**12**	**10**	**8**	**6**
60%	1.762	1.653	1.702	1.674	1.681	1.927
70%	2.073	1.925	2.043	2.016	2.045	1.909
80%	1.982	1.808	1.821	1.768	1.858	2.324
90%	2.107	1.728	2.122	2.226	1.760	1.844
100%	2.389	2.551	2.617	2.191	2.230	2.015

T-test was carried out for Statistical analysis of coefficient of viscosity values before and after giving ohmic heating treatment to soymilk. The results obtained for analysis of coefficient of viscosity has been represented in the Table 4.14.

Table 4.14 t- values for coefficient of viscosity for applied voltage gradients to five different concentrations of soymilk.

Concentration (v/v)	**Voltage gradient (V/cm)**				
	14	**12**	**10**	**8**	**6**
60%	1.898^{NS}	6.282*	4.119^{NS}	2.318^{NS}	13.223**
70%	2.900^{NS}	1.286^{NS}	4.949*	4.334*	2.581^{NS}
80%	1.285^{NS}	.081^{NS}	4.001^{NS}	1.290^{NS}	19.393**
90%	1.170^{NS}	2.312^{NS}	3.347^{NS}	.148^{NS}	.573^{NS}
100%	2.275^{NS}	2.576^{NS}	4.365*	.186^{NS}	10.936**

*t-values were significant at 5% level of significance

**t-values were significant at 1% level of significance^{NS} t-value is non-significant

The change in the viscosities of soymilk before and after ohmic heating for various voltage gradients came out to be overall non-significant. Although it can be seen from the table 4.13 that there is somewhat decrease in viscosity at different voltage gradients. This is due to the fact that with the increase in temperature the cohesive force between the molecules decreases Singh *et al* (2008). Although, the decrease in viscosity is there after ohmic heating but this decrease is non - significant statistically. Therefore, it can be concluded that ohmic heating has a very little or no effect on viscosity of soymilk. Same results were reported by Fryer *et al* (1992).

4.5 EFFECT OF OHMIC HEATING ON pH

pH is a measure of acidity or basicity of some material. The observed values of pH for soymilk samples prepared with five different concentrations (60-100%), before as well as after ohmic heating process performed at different applied voltage gradients at room temperature are given in Table 4.15. The maximum and minimum value of pH before ohmic heating is 6.65, 6.48 and after ohmic heating 6.64, 6.28 respectively.

Table 4.15 pH values for different voltage gradients applied to different concentrations of soymilk.

Concentration of soymilk (v/v)	pH values of soymilk					
	Before ohmic heating	After ohmic heating				
		Voltage gradient (V/cm)				
		14	12	10	8	6
60%	6.65	6.45	6.54	6.30	6.35	6.42
70%	6.60	6.31	6.36	6.48	6.45	6.48
80%	6.56	6.28	6.37	6.28	6.44	6.39
90%	6.54	6.57	6.46	6.54	6.43	6.36
100%	6.48	6.64	6.43	6.39	6.42	6.62

Statistical analysis using t-test was carried out for the pH values before and after giving ohmic heating treatment to soymilk. The results obtained for analysis of pH has been represented in the Table 4.16. The change in the pH of soymilk before and after ohmic heating for various voltage gradients came out to be overall non-significant.

Table 4.16 t-values for pH for applied voltage gradients to five concentrations of soymilk.

Concentration (v/v)	Voltage gradient (V/cm)				
	14	12	10	8	6
60%	13.000**	3.051^{NS}	11.000**	3.556^{NS}	14.000**
70%	6.286*	7.723*	3.592^{NS}	4.274^{NS}	3.580^{NS}
80%	3.881^{NS}	10.000*	3.179^{NS}	4.190^{NS}	11.117**
90%	12.000**	3.883^{NS}	2.538^{NS}	1.525^{NS}	4.979*
100%	13.000**	3.051^{NS}	11.000**	3.556^{NS}	14.000**

*t-values were significant at 5% level of significance

**t-values were significant at 1% level of significance

^{NS} t-value is non-significant

It can be seen from the Table 4.16 that for voltage gradients 12, 8, 6V/cm the results are significant. These results are consistent with the results obtained by (Icier and Ilicali 2004, 2005a, Kulshetra and Sastry 2006, Icier *et al* 2008, Bozkurt and Icier 2009, Yildiz*et al* 2009, 2010, Darvishi*et al* 2012, Pham *et al* 2014). It is observed that there is significant effect of ohmic heating for voltage gradients 14 and 6V/cm. When the voltage gradient is 6V/cm, heating time is very high or heating rate is less, therefore pH change was maximum at this voltage gradient. This result is consistent with the results obtained by Darvishi*et al* (2012).

4.6 EFFECT OF OHMIC HEATING ON TSS

TSS (total soluble solids) gives us the information of sugars in the sample. The observed values of TSS for soymilk samples prepared with five different concentrations (60-100%), before as well as after ohmic heating process performed at different applied voltage gradients at room temperature are given in Table 4.17. The experimentally obtained maximum and minimum values of TSS were 2.9 and 1.8 for 100% and 60% concentrated soymilk samples respectively. This concludes that TSS increases with the increase in concentration of soymilk in both cases i.e. before and after ohmic heating. This is because, the TSS measures the number of solid particles in sample and as the concentration increases the number of solid particles increase thus the TSS increases.

Table 4.17 TSS values for different voltage gradients at five different concentrations of soymilk.

Concentration of soymilk (v/v)	TSS values of soymilk					
	Before ohmic heating	After ohmic heating				
		Voltage gradient (V/cm)				
		14	12	10	8	6
100%	2.9	2.8	3.0	3.0	2.9	3.0
90%	2.2	2.2	2.2	2.3	2.2	2.3
80%	2.0	2.0	2.0	2.0	2.0	2.0
70%	1.9	1.8	2.0	2.0	2.1	1.8
60%	1.8	1.6	1.9	1.8	1.8	1.9

Astatistical analysis of TSS was carried out using t-test for applied voltage gradient. The analysis results are listed in the table 4.18 corresponding to each concentration and voltage gradient. The tables reveal that there was no significant effect of the application of ohmic heating treatment to soymilk. Thus the effect of ohmic heating on the TSS was non-significant.

Table 4.18 t-values for TSS for applied voltage gradients to five concentrations ofsoymilk.

Concentration (v/v)	Voltage gradient (V/cm)				
	14	12	10	8	6
100%	NS	NS	NS	.500^{NS}	NS
90%	NS	NS	1.512^{NS}	NS	1.000^{NS}
80%	NS	NS	NS	NS	NS
70%	2.000^{NS}	2.000^{NS}	1.000^{NS}	1.732^{NS}	2.000^{NS}
60%	2.000^{NS}	2.000^{NS}	1.000^{NS}	NS	2.000^{NS}

^{NS} t-value is non-significant

-indicates that the t value cannot be computed because the standard error of the difference is 0.It can be seen from the Table 4.18 that the change in TSS with voltage gradient before and after ohmic heating is non-significant. This result is in accordance with the results obtained by Icier and Ilicali (2004, 2005), Icier *et al* (2008), Bozkurt and Icier (2009b).

4.7 SYSTEM PERFORMANCE COEFFICIENT (SPC)

The ohmic heating system performance coefficients (SPCs) were calculated by the use of energy given to the sample and the energy supplied to the ohmic heating system. For the simplifications of the calculations of SPC it was assumed that the specific heat capacity of soymilk was constant within a range of temperature considered.

SPC was calculated for all five concentrations and five voltage gradients. For 60% concentration it was observed that the SPC value for 14V/cm was approximately equal to 0.98 and for 6V/cm it was 0.54 i.e. SPC for higher voltage gradient was higher and it went on decreasing as the voltage gradient went on decreasing. The calculations for all the rest concentrations and voltage gradients are represented in the table 4.19 as shown below-

Table 4.19 SPC values for five voltage gradients and five voltage gradients of soymilk.

Concentration	Voltage gradient (V/cm)				
	14	**12**	**10**	**8**	**6**
60%	0.98	0.95	0.92	0.73	0.54
70%	0.94	0.92	0.89	0.75	0.65
80%	0.98	0.96	0.91	0.73	0.68
90%	0.98	0.96	0.90	0.87	0.71
100%	0.93	0.90	0.86	0.78	0.74

It can be seen from the table during 60% concentrations of sample heat loss for 14V/cm voltage gradient is 2% and for 12, 10, 8, 6V/cm heat loss is 5%, 8%, 27%, 46% respectively. Same trend was observed for all concentrations; however the heat loss was different in all cases. This trend can be attributed to the fact that at high voltage gradients heating rate was higher but at low voltage gradients heating rate was very less that's why it can be said that heat loss was higher at low voltage gradients because the heat gained by the sample was almost same for all voltage gradients but the factor which affects the SPC value was the heat supplied from outside and at low voltage gradient time required to heat the sample to the required temperature was very high which dominates the overall effect of energy supplied therefore performance coefficient of heater at low voltage gradient was less.

CHAPTER V

SUMMARY

In the first chapter the present scenario of food storage and wastage in India has been presented. Need and importance of food processing has been discussed. Some basic idea about various types of heating methods including direct and indirect heating methods has been discussed and direct heating has been greatly emphasized due to its certain advantages over indirect heating methods. Then introduction on ohmic heating and its advantages has been discussed. Also, various parameters of the food material which are supposed to be affected by ohmic heating have been presented and some description about them has been given. The objectives which are to be fulfilled during the study are presented at the end of the chapter.

Second chapter presents the brief summary of the studies which have already been done and published. A brief history has been given, from where this concept came into picture and then the studies has been given where this technique was used as an advantage for the processing of food materials. Some studies investigate the effects of ohmic heating on electrical conductivity, pH, viscosity, TSS of liquid or solid food products and some studies determine the applications of ohmic heating and a few deals with the comparison study of ohmic heating with other heating methods. The usual trend of all studies was that the heating rate and variation of electrical conductivity followed a linear trend and also a conclusion was made that ohmic heating was more beneficial than other heating methods.

In the third chapter procedure of sample preparation has been discussed. The voltage gradients and the concentrations which are to be used for the study have been presented. The parameters which are supposed to be measured to know the effect of ohmic heating on the sample has been given and description of the instruments and procedures used to carry out the experiment have been discussed.

In fourth chapter, the results have been presented and discussed using tables and graphs. Graphs plotted have been shown between time and temperature for all voltage gradients and concentrations, and it was observed that heating rate decreased as voltage gradient decreased. Also, graphs plotted between temperature and electrical conductivity for different concentrations at particular voltage gradient have been presented. The highly concentrated sample had higher electrical conductivity. Statistical analysis of experimental data using the softwareSPSS-20.0 shows that the interrelation between electrical conductivity and temperature could be represented by linear regression equation of type

$$\sigma (V,C,T) = A (V,C)+B(V,C)T$$

Where, σ (V,C,T) represents the electrical conductivity of soymilk data which is a function of temperature, concentration and voltage gradient. T is the temperature, A (V,C)and B(V,C) are regression constants. Statistical interpretations were made for the parameters like pH, Viscosity, TSS. Viscosity was calculated from the prior information of the density of the samples and statistical analysis was performed to study the effect of ohmic heating on the soymilk. Table showing t-values have been presented and it was observed that ohmic heating had no significant effect on viscosity of the sample. Similarly, statistical analysis was done on pH and TSS. Ohmic heating had no significant effect on TSS of the sample also but in case of pH the effect was there for two voltage gradients i.e. for 14V/cm and 6V/cm.

System performance coefficient was calculated for all voltage gradients at one particular concentration of the sample to know the heat loss during ohmic heating. A table has been presented for all values of SPC. A conclusion was made that the SPC value was almost higher for higher voltage gradient and its value had fallen as voltage gradient was decreased.

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OCPA : 8.08/10.00

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Publication in Journal

Kaur J and Tarsikka P S (2016) Effect of ohmic heating on electrical conductivity and other physiochemical parameters of soymilk. *Int J Agric Biol Eng* (Communicated).

Publication in Conferences

Kaur J and Tarsikka P S (2015) Effect of Ohmic heating on electrical conductivity of Soymilk. 3rd IAPT National Student Symposium on Physics held at Punjab University, Chandigarh from 17-19 September.

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