DESIGN UPSCALING OF OHMIC MILK HEATING SYSTEM

THESIS SUBMITTED TO THE

ICAR - NATIONAL DAIRY RESEARCH INSTITUTE

(DEEMED UNIVERSITY)

KARNAL (HARYANA)

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE AWARD OF THE DEGREE OF

MASTER OF TECHNOLOGY

IN

DAIRY ENGINEERING

BY

VISHAL THAKUR

B.Tech. (Dairy Technology)

DAIRY ENGINEERING DIVISION
ICAR - NATIONAL DAIRY RESEARCH INSTITUTE
KARNAL-132001 (HARYANA), INDIA

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Reg. No. 17-M-DE-07

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Approved by:

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This is to certify that the thesis entitled "**DESIGN UP-SCALING OF OHMIC MILK HEATING SYSTEM**" submitted by **VISHAL THAKUR** in partial fulfillment of the requirement for award of the degree of **MASTER OF TECHNOLOGY IN DAIRY ENGINEERING** of the ICAR - National Dairy Research Institute (Deemed University), Karnal (Haryana) is a bonafide research work carried out by her under my supervision and guidance and no part of the thesis has been submitted for any other degree or diploma.

Prashant S. Minz

Date: 10 July, 2019

(Mr. P. S. Minz)
MAJOR ADVISOR

Dedicate to........

"Lord Shiva,

My beloved Family & My idolized, Guide"

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Date: 10 July, 2019 *(VISHAL THAKUR)*

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Abstract

Ohmic heating is a process wherein an alternating current is passed through food material and heat is internally generated in the material due to electrical resistance when electric current is passed through it. Ohmic heating is known for its rapid and uniform heating. The present study was carried out in three phases. In the first phase, ohmic heating setup (5 kg) was modified and automatic temperature control system was integrated into the system. Paired plate type system was designed and developed with an objective to eliminate fouling and to minimize localized heating of plates. Control system consisted of voltage controller, contractors, current data logger and temperature data logger. Effect of ohmic heating was studied for pairing time of 0, 20, 30, 40 and 50s. In the second phase, paired plate type ohmic heating system was used for heating of buffalo milk and data of buffalo milk heating was compared with cow milk heating. In the third phase, up-scaled rotating field type ohmic milk heater (10 kg capacity) was designed, developed and assessed. Effect of ohmic heating was studied for pairing time of 0, 1, 2 and 3 min. The performance evaluation parameters for ohmic heating system were temperature profile, heating time, heating rate, average temperature gradient, electrical conductivity, power consumption and thermal efficiency. Time required for heating was minimum (23 min) for pairing time of 50s in paired plate configuration. The designed setup gave a heating rate of 3.3^{o}C/min. Uniformity in milk heating was evident by low temperature gradient (0.20-0.90^{o}C). The thermal efficiency of paired plate type ohmic heater was very high (>90%). Both paired plate and rotating field type ohmic heating system minimized localized heating of plates and almost no plate fouling was observed. Time required for heating was minimum (49 min) for pairing time of 3 min in rotating field ohmic heating setup. Heating rate was observed to be satisfactory with a rate of 1.53^{o}C/min. There was uniformity in milk heating with low temperature gradient (0.30-1.50^{o}C).

दूध को गर्म करने की ओमिक प्रणाली का उच्च स्तरीय डिजाइन

संक्षेप

ओमिक हीटिंग एक ऐसी प्रक्रिया है जिसमें एक प्रत्यावर्ती धारा को खाद्य सामग्री के माध्यम से पारित किया जाता है और विद्युत प्रतिरोध के कारण सामग्री में गर्मी आंतरिक रूप से उत्पन्न होती है जब विद्युत प्रवाह इसके माध्यम से पारित होता है। ओमिक हीटिंग अपने तीव्र और समान ताप के लिए जाना जाता है। वर्तमान अध्ययन तीन चरणों में किया गया । पहले चरण में ओमिक हीटिंग सेटअप (5 किलो) को संशोधित किया गया और स्वचालित तापमान नियंत्रण प्रणाली को सिस्टम में एकीकृत किया गया । युग्मित प्लेट प्रकार प्रणाली को फॉलिंग को खत्म करने और प्लेटों की स्थानीय हीटिंग को कम करने के उद्देश्य से डिजाइन और विकसित किया गया । नियंत्रण प्रणाली में वोल्टेज नियंत्रक, रिले, विद्युत डेटा रिकॉर्डर और तापमान डेटा रिकॉर्डर शामिल था। ओमिक हीटिंग के प्रभाव का अध्ययन 0, 20, 30, 40 और 50 सेकंड के समय के लिए किया गया । दूसरे चरण में भैंस के दूध को गर्म करने के लिए पेयर किए गए प्लेट प्रकार ओमिक हीटिंग सिस्टम का इस्तेमाल किया गया और भैंस के दूध के हीटिंग के आंकड़ों की तुलना गाय के गर्म दूध से की गई। तीसरे चरण में वर्धित घूर्णन क्षेत्र प्रकार का ओमिक दूध हीटर (10 किग्रा क्षमता) का डिजाइन, विकास और मूल्यांकन किया गया। ओमिक हीटिंग के प्रभाव का अध्ययन 0, 1, 2, और 3 मिनट के लिए किया गया । ओमिक हीटिंग सिस्टम का प्रदर्शन मूल्यांकन तापमान प्रोफ़ाइल, हीटिंग समय, हीटिंग दर, औसत तापमान प्रवणता, विद्युत चालकता, बिजली की खपत और थर्मल क्षमता के आधार पर किया गया । युग्मित प्लेट कॉन्फ़िगरेशन में 50 सेकंड के समय के लिए हीटिंग हेतु आवश्यक समय न्यूनतम (23 मिनट) था। डिज़ाइन किए गए सेटअप ने हीटिंग की दर 3.3ºC प्रति मिनट थी। कम ताप प्रवणता (0.20-0.90 ºC) द्वारा दूध के ताप में समानता स्पष्ट थी। युग्मित प्लेट प्रकार ओमिक हीटर की थर्मल क्षमता बहुत अधिक (> 90%) थी । दोनों युग्मित और घूर्णन क्षेत्र प्रकार ओमिक हीटिग सिस्टम ने प्लेटों के स्थानीय हीटिंग को कम से कम किया और लगभग कोई प्लेट फॉलिंग नहीं पाई गई। घूर्णन क्षेत्र के ओमिक हीटिंग सेटअप में 3 मिनट समय के लिए हीटिंग हेतु आवश्यक समय न्यूनतम (49 मिनट) था। ताप की दर 1.53 ºC प्रति मिनट की दर से संतोषजनक पाई गई। कम ताप प्रवणता (0.30-1.50ºC) के साथ दूध के ताप में समानता स्पष्ट थी।

INTRODUCTION

1. INTRODUCTION

Food is a basic part needed by all living beings for proper nutrition essential for their life and growth (Richa et al., 2017). Thus there is continually a requirement to process food to prevent, reduce and to eliminate toxins as well as microorganisms that ends up in causing numerous kind of food deterioration. Food production processes inactivate microorganisms and supply safe and high quality finished product (Akanbi et al., 2006). Principally conventional heating methods are used for processing of food products.

Conventional heating and cooking has several disadvantages such as low heat transfer rate that elongates cooking time such that outer layer of product absorbs more heat resulting in surface hardening and therefore deteriorate the quality of the product. High amount of heat losses also occurs throughout the three modes of heat-transfer that includes conduction, convection as well as radiation. Incidence of heterogonous heating due internal resistance leads to significant loss of product quality (Poojitha and Athmaselvi, 2018). Hence various technologies are introduced to overcome these disadvantages. Ohmic heating(OH) is such a substitute and speedy heating technique that has prospective demand in both dairy and food processing companies, in distillation processes, and also used for sludge processing (Sakr and Lui, 2014).

Ohmic heating is outlined as a heating methodology whereby alternating current is moved across the food sample with an aim to heat up the same by changing electrical energy into thermal energy, leading to quick and consistent temperature increase within the food (Cappato *et al.*, 2017). OH is an emerging technology that provides speedy and consonant heating and leading to less thermal harm to the food product. To carry out ohmic heating appropriately, an electrical conductivity of food component should be within the range of 0.01–10 S/m (Lyng et al., 2007).

Ohmic heating may be a new heating methodology employed within the food production processes to process vast varieties of food components (Cho *et al.*, 2016). It has large number of applications including thawing, cooking, sterilization and pasteurization, blanching, evaporation, distillation and in waste-water treatment. Ohmic heating is technically simple, has high efficiency (more than 90%) and has low investment costs (Kaur *et al.*, 2016). It is widely applied throughout meat, fruits and vegetables processing.

Its application continues to be restricted in milk and milk products processing because of problem of fouling and corrosion of plates. Localized heating of plates is another major drawback of an ohmic heating apparatus. Presence of fat globules in food is additionally problematic throughout ohmic heating. But OH also provides fast and uniform heating, whereas it also results in lesser thermal destruction as compared to traditional heating methods (Guo *et* al., 2017). The problem of localized heating of plates during heating can be minimized by changing to the rotating field within the ohmic reactor vessel. So development of rotating field type ohmic heater will be helpful for small and medium dairy processors. Thus, there is large scope to use ohmic heating for processing in food industries. Therefore present study was undertaken with following objectives:

1. To develop rotating field type ohmic heating system.
2. To upscale ohmic heating system suitable for small scale dairy.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Previous work on ohmic heating was reviewed from the literature study as follows:

2.1 Ohmic heating technology

Ohmic heating is outlined as a heating methodology whereby electrical current is allowed to flow through food components with an aim of generating heat by changing current into thermal energy, leading to quick and consistent temperature increase within the food (Cappato et al., 2017). The passage of an electrical current across the food materials throughout ohmic treatment generates heat internally because of an electrical resistance offered by constituents of the food materials on passage of an electrical current. A comparison between ohmic and other alternative heating techniques (microwave and inducting heating) can be made by placing or inserting heating plates within the reactor vessel that makes direct physical contact with the sample which is to be heated and frequencies or waveforms used.

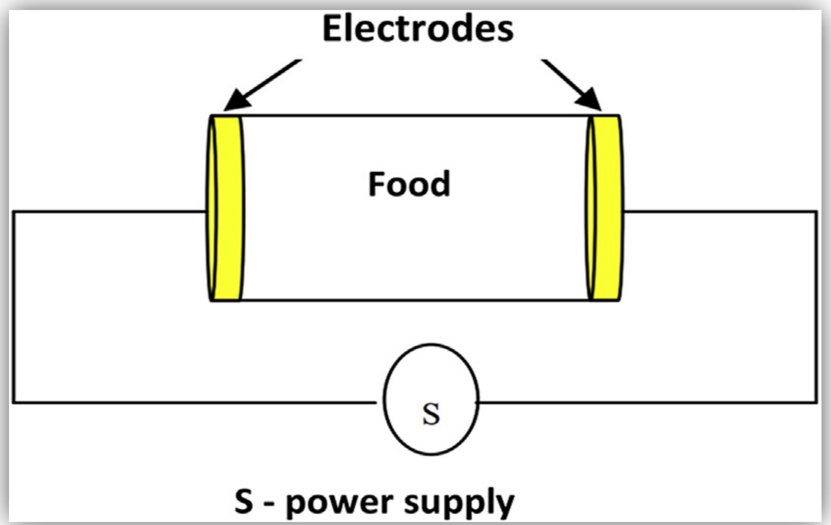

Fig 2.1: Schematic representation of ohmic heating system

OH is a unique approach that provides quick and consonant heating, imposes minor thermal casualty or injury to the product that is to be processed. Knirsch et al., (2010) reported that since all heating occurs as a result of heat which is generated internally on the application of an electrical current, so OH is additionally referred to as internal thermal energy generation methodology. OH leads to progressive heating and it is utilized within food processing industries to process huge varieties of products (Cho et al., 2016), especially those products that are originated from plant sources like fruits and vegetables processed foods. Higher thermal potency, lower installation costs and simplicity or ease in operation etc are some of the factors which increase interest towards application of ohmic heating (Kaur et al., 2016). OH also results in minimum changes in structural, dietary and sensory attributes of the food (Priyanka et al., 2018). Instant startup and close-down of ohmic heating apparatus make it easy to use. OH is one among the most effective applications of law of energy conservation in which electrical energy is converted into thermal energy (Joshi, 2018).

2.1.1 Advantages of ohmic heating (OH)

The ohmic heating system has number of benefits once utilized in the processing of food. Major advantages of OH are (Sakr and Lui, 2014):-

- Temperature needed for heating is attained with quickness.
- Higher heating rates.
- Surface fouling issues are less
- Homogenous treatment
- Compactness of ohmic installation
- Once the current is shut-off, no residual heat transfer would take place.
- No emission
- Ohmic heating results in volumetric heating of product with lower values of temperature gradient.
- High energy conversion efficiencies are possible. The ohmic heating system provided with agitator has an efficiency of more than 90%.
- The instant shutdown of the system is possible.

- The ohmic heating system lacks moving parts, hence have reduced maintenance costs.
- A quiet environmentally friendly system because it does not produce any noise and pollution.
- Retaining the original taste of processed sample.

2.1.2 Limitations of ohmic heating

Major limitations of the ohmic system include (Sakr and Lui, 2014):-

- It is difficult to heat fatty or oily products through ohmic heating because of low electrical conductivity of fat.
- Electricity cost:- Ohmic heating has high energy expenditure. Further electricity costs vary from region to region.
- Electrical conductivity is directly proportional to temperature, this increases the risk of ‘runaway’ heating (FDA-CFSAN,2000)
- Fouling on electrodes plate is still an issue
- Ohmic system has a scarcity of generalized information.
- High installation cost.
- Confined frequency range.
- Continuously controlling and monitoring of the system is difficult.
- Complex coupling between temperature and electric field distribution.
- The major parameter on which ohmic heating depends is electrical conductivity. Electrical conductivity is directly proportional to electrolytes concentration as well as temperature and inversely proportional to rise in particles size. The critical values of electrical conductivity to carry out ohmic heating should have scale of 0.01-10 S/m. Thus product whose EC value fallen in above mentioned range is most suitable for processing through ohmic heating whereas products outside above mentioned EC range are difficult to process by ohmic heating.

2.2 History of ohmic heating technology

Ohmic heating (OH) technology is not a new concept within food industries. Earlier around twentieth century, milk pasteurization as well as pasteurization of different products was carried out by means of electrical methods. One such electrical method is OH, in which product which is to be heated is placed between electrode plates having a potential difference among them (De Alwis et al., 1990).

In 1827, German physicist, Georg Ohm released his thesis: The Galvanic Circuit Investigated Mathematically where he described Ohm's law. The event in which electrical energy dissipates into thermal energy was 1st explained by "Prescott Joule". Hence on the name of "Prescott Joule" OH is also mentioned as a Joule heating. OH is also known as electro-heating, electro-conductive heating, electric resistance heating and internal thermal energy heating (Sastry, 2008).

Ohmic heating to carry out the sterilization of liquid food in 1897 and canned food in 1900 was patented in the 19th century. The aseptic packaging of product being pasteurized by using ohmic heating is not mandatory. The ohmic heating was also utilized for pasteurization of baby milk in 1914.

In the 1930s "electric pasteurization" method by ohmic heating was utilized for treatment of milk within the six states of USA. In 1938, McConnel and Olsson developed an ohmic heating system within which electrical current was passed through electrodes for preset time with a purpose of cooking sandwiches. Around 1980s, Ohmic heating was introduced by APV and "Electricity council of The Great Britain" gave license for the application of ohmic heating within food industries (Skudder, 1988).

In the meanwhile, technology has achieved some industrial applications that embrace pasteurization of liquid eggs and processing of fruit products. Ohmic heating is regarded as excellent technology and is utilized for processing of food. It has large number of applications including thawing, cooking, sterilization and pasteurization, blanching, evaporation, distillation and in waste-water treatment. In 1989, the first commercial ohmic heating plant of 75 kW capacity was installed within England. In 1991, ohmic heating technology was permitted for stabilization of low acid food. Later in 1993, the FDA also permitted the application of ohmic heating for processing of low acid food. After approval from FDA, the application of ohmic heating was utilized in America, Japan and in many countries of Europe. Still, a lot of research is needed to be conducted for boosting the quality of processed product with overall control in process.

2.3 Ohmic heating vs conventional heating

Conduction, convection as well as the radiation are comprised into three heat transfer mechanisms. All the heat transfer mechanisms are utilized for heating of food products during conventional heating. The time required for producing adequate amount heating within the interior of product and to succeed in securing a final temperature depends on the product geometry. This could result in over cooking, or undercooking of foodstuff and finally adversely affects its quality (Kumar et al., 2014).

In OH, heat is uniformly induced within the complete mass of the food (Cho et al., 2016). OH causes more and faster heating, is cleaner, more environmentally friendly and also results in maximum recovery of food nutritional content. OH is able to cause products heating swiftly and evenly without inflicting any thermal damage to products undergoing heat treatment (Darvishi et al., 2013).

By changing the thermal properties of foodstuff, OH is less influenced as compared to alternative heating techniques like induction and microwave heating. Ohmic heating gives higher values of thermal efficiencies during processing of juices. This is because of transformation of alternating current into thermal energy at higher rate. The homogenous temperature distribution will be simply obtained on the passage of current. Ohmic heating produces no waste after heating of material and additionally there is no requirement of steam as well as hot water for heating (Cokgezme et al., 2017).

OH has the number of advantages over CH, because it providing uniform heating with the low-temperature gradient. During OH, both phases such as solid as well as liquid within product are heated at a faster rate with homogenized heating. The surface fouling issues are less throughout ohmic heating due to absence of hot surfaces. It also decreases chances of thermal harm to the sample. Ohmic heating also produces high value finished products with minimum anatomical, dietary or sensory changes (Cho et al., 2016).

Following are the advantages of OH over conventional heating (Joshi, 2018):

1. Uniform heating: In ohmic heating both the phases of food (solid as well as liquid) are heated evenly, whereas it is not possible when conventional heating methods are used.
2. Ohmic heating is utilized for heating of solid, liquid as well as foods with high viscosity.
3. Easy to control the process of heating throughout ohmic heating because of instant on and off facility.
4. Higher Energy Efficiency: High energy conversion efficiencies are possible. The ohmic heating system provided with agitator has an efficiency of more than 90%. Higher is the conversion rate of electrical energy to thermal energy, higher will be the values of thermal efficiencies.
5. Fouling Reduction: Surface fouling issues are less as there is no hot surface available throughout ohmic heating. Therefore cost associated with cleaning is reduced with reduction in heating period.
6. Non-thermal effects or electroporation: A phenomenon of electroporation encourages cell destruction within microorganisms by decreasing the resistance shown by microbes to heat treatment. The resistance heating or ohmic heating utilized higher values of electrical field intensity (greater than 100 V/cm) and lower frequencies of alternating current (50-60 Hz) to carry out electroporation. Cho et al., (2016) reported that presence of porous cell wall enables membrane to develop charges and to create disruptive openings. The phenomenon of electroporation arises due to specific dielectric strength of cell membranes which will be further increased by increasing electrical field strength. Lee and yoon, (1999) also reported that when cells are excessively exposed to high electrical field strength, then cell destruction occurs because of loss intracellular constituents through the pore openings. Hence a high quantity of cell destruction occurs during electroporation phenomenon and ohmic heating will increase its fatal effects.

2.4 Principle of ohmic heating

In ohmic heating, power is directly converted into heat with no loss of heat. This principle is employed to generate internal energy in the material that further results in the heating of the material. The internal heat generation within the material has direct relationship with the product of square of current, resistance offered by material and time duration for which heating happens (Palaniappan and Sastry, 1991). The above statement is also referred as Joule's 1st law of heating. A mathematical expression for above law is given in eq=^{n} (5). The motion and collisions between ions within material is responsible for internal heat generation (Richa et al., 2017). This collision causes the transfer of momentum that will increase the kinetic energy thus generating heat in it. The transfer of momentum is the quantity of momentum that one particle transfers to another. Ohmic heating are often differentiated from remaining heating techniques (induction heating, microwave heating etc) because heating plates makes direct contact with the sample which is to be heated. Generally, 50-60 Hz alternating current is used for ohmic heating (Knirsch et al., 2010).

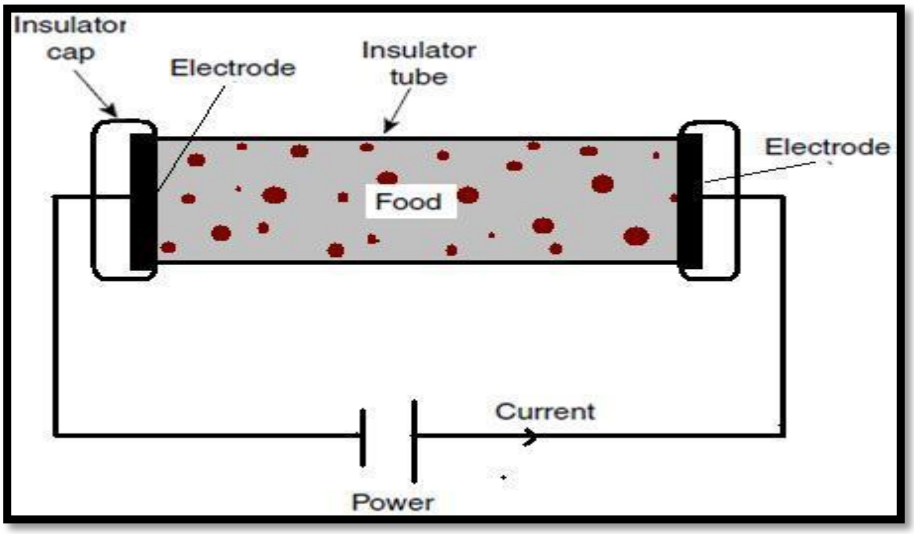

Fig 2.2: Working principle of ohmic heating system

Foods have conductive properties because of the presence of water and ionic salts however due to their resistive behavior, it generates heat on application of AC current. A food sample behaves same as that of resistor because it opposes movement of current and ions. The foremost crucial parameter in determining how rapidly food will heat is its electrical resistance. Therefore in product formulation, process control, and quality assurance, conductivity measurement is very important for all foods that are heated electrically (Richa et al., 2017).

Ohmic heating depends on the ohm's law. This law states voltage and current within the conductor are directly related to each other i.e. the rise in voltage also raises the current within the conductor. The mathematical expression for ohm's law is expressed in equation (1) as:

$$V=IR \quad (1)$$

The measured resistance is converted to conductivity using:

$$R=\rho L/A = L/\sigma A \quad (2)$$

So by putting R value in equation V= $I\ (1/\sigma)\ L/A$

$$\sigma=IL/VA \quad (3)$$

$$E=V/L \quad (4)$$

$$H=I^2Rt \quad (5)$$

Where,

ρ= Resistivity of product

σ= Product conductivity in (S/ m)

R= Resistance in ohms (Ω)

V = Voltage (volts)

L = Length of the cell in (m)

A = Cell area (m^2)

L/A =Cell constant

E =electric field strength

I = Current flowing through conductor

V/ L = Voltage gradient i.e. ratio of voltage applied to distance between two electrode

I/A = Current density

t= amount of time in seconds

H= amount of heat (kJ)

2.4.1 Heat power supplied to ohmic heater

Heat power supplied for the purpose of heating within ohmic heater is estimated by utilizing potential and alternating current throughout the time of heating (Icier & Ilicali., 2005).

Work done on resistor = Energy given to system

$$W = VI \triangle t$$

$$W/\triangle t = E = VI \quad (6)$$

$$W = E = VI \triangle t \quad (7)$$

Where,

W= Work done

E =Energy supplied to the ohmic heater

V= Applied potential

I= Current

2.4.2 Rate of heat generation

The application of electrical current produces heat and thus a sensible heat is generated that causes rise within the temperature of the sample from T_i to T_f. Energy needed to heat the product may be calculated from the subsequent equation (8).

$$Q = m\,Cp\,(T_f - T_i) \quad (8)$$

Electrical resistance of the food produces energy that causes a change in thermal energy of the product between influx and outflow (Ghnimi *et al*., 2008).

$$P = VI = m\,C_p\,(T_f - T_i) + m\,l + Q_{loss} \quad (9)$$

Heat dissipated through product = thermal heat generated in the product

Where,

m is the quantity of material used for heating (kg)

C_p is the sample specific heat (kJ/kg^{o}C)

T_i is the temperature of sample at starting point (^oC)

T_f is the temperature of sample at the end of heating (^oC)

2.6 Factors affecting ohmic heating

The number of factors affects processing of food through ohmic heating. Most crucial factor on which ohmic processing of food products depends is electrical conductivity (Joshi, 2018). Some other most important parameters affecting ohmic heating includes temperature, voltage gradient, frequency, moisture content, nature of food, particle size, flow properties etc (Joshi, 2018).

2.6.1 Electrical conductivity (EC)

The ability of a material that enables the current to pass through it when subjected to an electric field is known as electrical conductivity (EC) (Joshi, 2018). Electrical conductivity (EC) has a direct relationship with current and inversely proportional to applied voltage. Higher the electrical conductivity of sample, faster it will take to heat the sample. EC can be calculated from the given equation (Richa et al., 2017):

$$\sigma = (I/V)*(L/A)$$

$$V=IR$$

Where,

σ = Electrical conductivity (S/m)

L = Spacing between the electrodes (m)

A = Heating plates area (m^2)

R = Resistance (ohms)

V = Potential (Volts)

I = Current (A)

It is chiefly depends on food chemistry and structure and temperature. Food components include ionic components (salt), quantity of acid and type of electrolyte, pH, protein and moisture content will increase electrical conductivity while fat, lipids and alcohol have negative effect on it (Omodara and Olaniyan, 2012). Hence by changing all these factors, EC can be changed. The rise in values of electrical conductivity (EC) will result in temperature rise within liquid foods (Kumar et al., 2014). This is due to the fact of increased ionic mobility. In case of solids, at low values of potential gradient EC shows linear relationship with respect to the temperature. Thus high temperature can be produced by increasing either current or voltage and by using the larger distance between electrodes. A factor including changing the tissue structure like cell wall break down, softening and reducing the phase viscosity affects ionic mobility (Richa et al., 2017). Table 2.1 shows the electrical conductivity of different foods in relation to the ohmic heating.

Table 2.1: Electrical conductivity of different food products in relation to ohmic heating

Sr. no.	Electrical conductivity (σ)	Ohmic heating	Food products
1	σ >0.05 S/m	Good	Yoghurts, wine, eggs, milk desserts, stabilizers etc.
2	0.005< σ <0.05 S/m	Low	Marmalade, margarine etc.
3	σ <0.005 S/m	Poor	Fat, liquor, frozen foods, syrup etc.

(Source: Goullieux and Pain, 2014)

The critical values of electrical conductivity to carry out ohmic heating should have scale of 0.01-10 S/m. The high values of current and potentials are required for heat generation such that temperature rises considerably through joule heating. Milk is a good conductor of electricity because it contains fairly high amounts of salts that chiefly contribute towards the electrical conductivity. The electrical conductivity of milk is 0.52 S/m such that it can be heated rapidly within short time intervals.

2.6.2 Temperature

It is the main parameter that affects the electrical conductivity. Temperature, as several researchers found that increases with increase in EC (Darvishi et al., 2013). The rise in values of electrical conductivity (EC) will result in temperature rise within liquid foods (Kumar et al., 2014).

Palaniappan & Sastry, (1991) suggested an equation that shows how conductivity is related to the temperature for liquid foods. The resultant equation is:

$$\sigma = \boldsymbol{\sigma}_{25}\,(1 + a\,(T - 25))$$

in which, a = Proportionality constant ($^{o}C^{-1}$)

However, it is also observed that always electrical conductivity cannot rise with temperature rise. At higher temperatures, a slight decrease in EC values is also observed due to the formation of bubbles and foaming (Darvishi et al., 2012).

For temperature observation during ohmic heating, a new and more suitable thermocouple probe (Triple point thermocouple) was developed (Zell et al., 2009). Throughout ohmic heating, mathematical models are used to analyze and estimate heat transfer and temperature distributions (Sakr and Liu, 2014).

2.6.3 Voltage gradient

The voltage change w.r.t displacement is understood as voltage gradient. Electrical conductivity varies with voltage gradients together with the temperature (Kumar et al., 2014). Kaur et al., (2016) reported that within capillaries, rise in liquid motion was observed on increasing field intensity that further increases with increase in EC. The time needed for ohmic heating application is inversely related to the potential gradient which means increase in values of potential gradient significantly reduces heating time (Darvishi et al., 2012).

2.6.4 Frequency

Frequency also has a noticeable effect on ohmic heating. Many times, increase in heating rate will be observed due to rise in electrical conductivity with increasing frequency. However, at all times it is not possible. In most of the cases (e.g. turnip, Japanese white radish, etc.) it is found that there is an increase in temperature with a decrease in frequency. The lower the frequency, quickly the sample reaches higher temperatures (Kaur et al., 2016). On increasing the frequency of heating samples from 50 Hz to 1000Hz, the time needed is approximately 6 times for heating samples to reach 80^{o}C (Lima et al., 2004).

2.6.5 Electrolytic concentration

The electrical conductivity of food material varies linearly with the electrolytes present in it. The electrolytes are charged molecules or ions in the form of salts present within the foods. The electrical conductivity of foods is also increased or decreased by varying its ionic concentration (Kumar et al., 2014). Higher is the ionic concentration quicker is the heating rate and therefore higher will be the conductivity of the product (Kaur et al., 2016).

2.6.6 Moisture content

The amount of free water present in food is understood as moisture content. This free water within the food acts as an electrical conductor. Thus with increase in the moisture content, EC will also increased and vice versa. As the transformation of water to vapour occurs, then increase in temperature causes increase in ionic movement at approximately 50^{o}C (Kong et al., 2008). Higher moisture content cannot always leads to high EC values, but it can also decreases EC because increase in moisture content decreases ionic concentration. Ionic concentration is directly proportional to EC.

2.6.7 Nature of food

The two main factors in relation to the nature of food are the concentration of electrolytes and the amount of free water present in food. Generally, the EC of solid particles is lower as compared to liquids (Kaur et al., 2016). Intermolecular bonds also having little effect on EC.

2.6.8 Particle size

Particle size is directly proportional to ohmic heating time and inversely proportional to electrical conductivity. As the size of the sample rises, specifically higher time is required for attaining identical increase in temperature. Among the two-parts of food (liquid as well as solid), the condemnatory parameter to seek out the rate of heating is particle size and concentration. A similar study was conducted by Zareifard et al., (2010) in which food containing two parts (liquid part comprises starch and salt whereas solid part contains carrot solids) was processed through ohmic heating. They additionally reported inverse relationship in between electrical conductivity and particle size.

2.6.9 Flow properties

The ohmic heating rate depends on the thickness of sample, solid content within sample as well as on the sample acidity. The viscosity could be a temperature dependent parameter and also effects electrical conductivity. The juices electrical conductivity has strong impact on the viscosity (Icier et al., 2017). The ohmic heating performance for extremely viscous liquids has been evaluated by Ghnimi et al. (2008). They reported that, higher ohmic heating rates were ascertained for higher viscous fluids than for lower viscosity fluids. Different researchers reported vice-versa (Icier, 2012). This dispute could also be because of different reactions occurring within the reactor vessel during ohmic heating based on the composition of heating sample.

2.7 Classification of the ohmic heater

Ohmic heaters are classified into the following categories (Ramaswamy et al., 2014):

I. According to the mode of operation
  - Batch process
  - Continuous Process

II. According to the shape of the cell
  - Tubular
  - Jet
  - Plane

III. According to dimension and position

- Intrusive
- Affluent

IV. According to the alloy used for construction of electrode

- SS-304
- SS-316
- SS-316L
- Titanium
- Platinum
- Graphite

2.8 Design aspect of an ohmic heater

The ohmic heater comprises of various elements like electrodes, the power supply source, temperature measuring probes i.e. thermocouples, a heating cell, and a data logger. For ohmic heating apparatus, different possibilities concerning the construction and fabrication are available. The ohmic heating apparatus consists of following components:

i) **The power supply source:** It delivers alternating current to run the ohmic heating apparatus.

ii) **Reactor vessel:** Various metals and alloys like SS-304, SS-316 etc are utilized to construct ohmic reactor vessel (Zareifard et al., 2010). It consists of electrodes, a stirrer to prevent fouling problems on electrode plates. In order to prevent thermal loss and evaporation, the heating cell is supplied with correct insulation. Thus increases the efficiency of heating.

iii) **Electrodes:** The electrodes are placed in a heating cell, connected to the main electricity line and make direct contact with the food component which to be heated by passage of an electrical current through it. By inducing alterations in parameters such as system geometry, the dimensions of the system and distance between electrodes, the electrical field intensity [Volt/cm], also fluctuates. The materials with high conductivity like alloys of stainless steel (SS-

304, SS-316, SS-316L), titanium, graphite and aluminum etc are used for the development of electrodes. The material for construction of electrodes is selected on the basis of cost (cheaper), availability, corrosion resistance and strength. Low-cost carbon electrodes are utilized in waste treatment as product quality is not essential during this method. The alloys of SS and titanium are considered as most well-liked for construction of heating plates. The heating efficiency of electrodes is influenced by the material used for the development of electrodes and also the thickness of the electrodes. To prevent contamination of product, an alternating current of higher frequency (around 10 kHz) can be utilized. The product contamination occurred due to electrochemical reactions at the surface of plates throughout heating. The plate corrosion can be prevented by using higher AC frequency in comparison of choosing suitable metals for construction of (Samaranayake et al., 2005). Some studies state that no apparent metal dissolution happens once the frequency is increased above 100 kHz. Samaranayake et al., (2005) also reported platinized titanium is the foremost appropriate material for construction of electrodes because of toughness, ability to provide higher heating rates and shows resistance against electrolysis phenomenon.

iv) **Temperature probe:** For monitoring the temperature, pt-100 temperature probes are often placed at numerous positions within the ohmic reactor vessel.

v) **Temperature and current data logger:** To note down the temperature values throughout ohmic heating, temperature data logger is utilized. Signals from thermocouples are fed to data logger and values are recorded. For recording current values throughout ohmic heating, a current data logger is used.

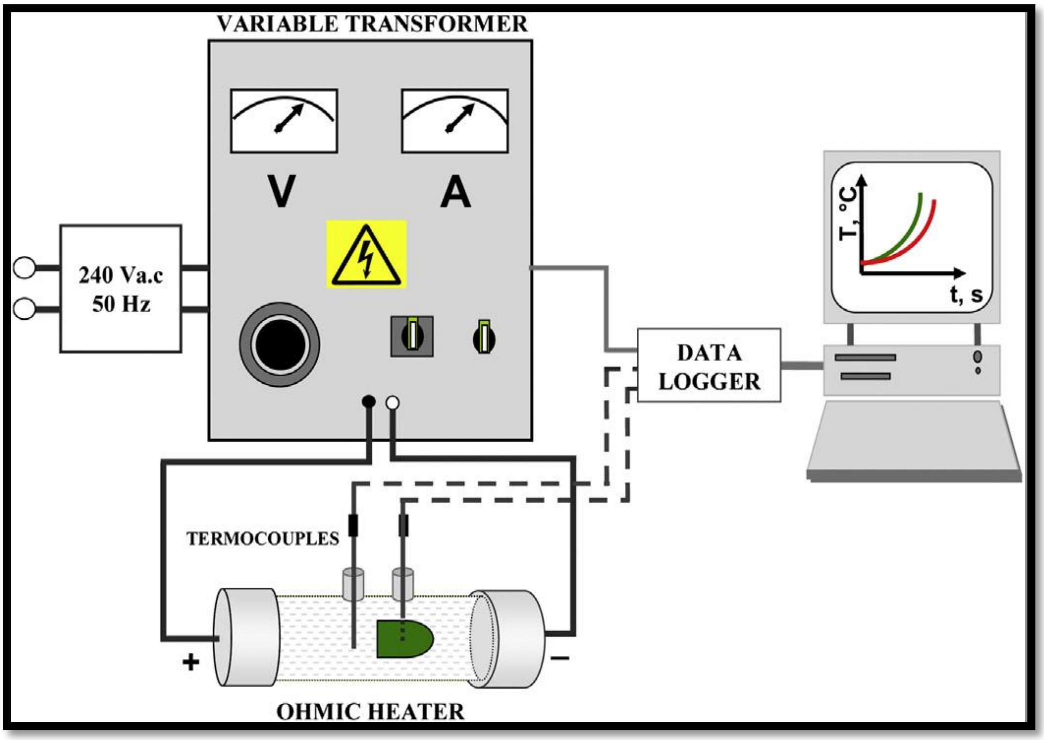

Fig 2.3: Experimental setup of ohmic heating system

2.9 Configurations of ohmic heating system

There are primarily three generic configurations of electrodes within the ohmic heating system (Goullieux and Pain, 2014).

I. In the batch configuration, heating plates are homocentric (the one which has cylindrical geometry). There is no flow of product in a batch configuration. It is also referred to as discontinuous configuration.

II. In the transverse configuration, sample which is to be heated moves lengthwise along the heating plates and this movement is perpendicular w.r.t constant electrical field.

III. Within collinear configuration, the movement of sample which is to be heated is from one heating plate to another. The product moves along the electrical field produced within the heating plates. This configuration typically has constant current density and electrodes are generally widely spaced.

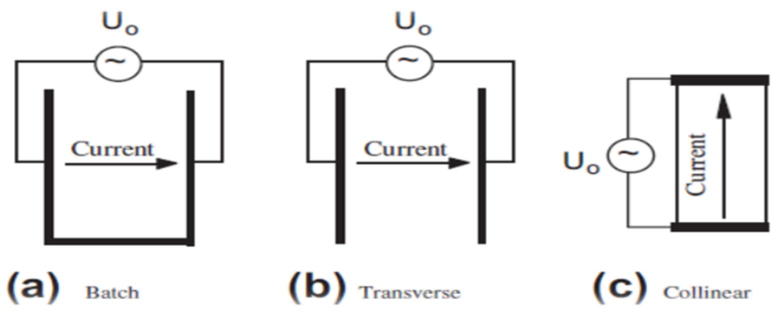

Fig 2.4: Generic configuration of the ohmic heating system

a) Batch configuration

In batch or discontinuous configuration, a medium that is to be heated is placed between electrodes and there is no flow of product within electrodes. It is insulated from outside to extend the efficiency of heating. Mostly the discontinuous configuration type ohmic heating system is utilized (1) for observing and validating model regarding behavior of components (solid, liquids as well as complex mixtures) throughout ohmic heating (2) for formulating adjustments regarding various electric factors (3) also utilized for high temperature short time processes (Goullieux and Pain, 2014).

Fundamental parameters like electrical conductivity (EC) of sample, time taken for heating, heating pattern, temperature distribution, product composition and quality of finish product are determined by using the batch heater. With apparatus efficiency, it is possible to evaluate perfect conditions to carry out ohmic heating continuously for controlling 3 steps throughout ohmic treatment viz heating, holding as well as cooling (Goullieux and Pain, 2014). The major advantages of batch or discontinuous heater include handing of smaller amount of product, it is easy to use, and also makes assessment of electrical conductivities values possible. Naveh et al., (1983) reported that discontinuous operations are restricted to industrial applications and used only for meat as well as fish thawing.

b) Continuous configuration

Nowadays ohmic heaters are specifically built for continuous operations (Varghese et al., 2014). Different configuration for continuous operations includes:-

Transverse configuration: In this configuration, sample to be heated moves along the heating plates and is perpendicular w.r.t electrical field. Heating plates typically have cylindrical geometry. This configuration additionally offers easy design and fabrication facility.

This type of configuration possesses two major electrical issues (1) the space between live electrode and inlet as well as outlet of reactor vessel is very less, such that huge amount of electrical current is leaked from a sample throughout heating. (2) The current density in direction of sample movement varies from phase line to neutral line at the edges of heating plates (Varghese et al., 2014). Other limiting factors include localized overheating, boiling and electrode erosion.

Collinear configuration: A sample movement is along electrical field and additionally from one electrode to the other one. The spacer tube and housing for heating plates are two basic units of the collinear configuration type ohmic heater. In this type of configuration, operational voltages between heating plates will reach 3V-3KV. Thus, from view point of safety, all the internal surfaces which makes physical contact with food are required to be made up of insulating materials for safe, reliable and long service.

A moving system, like conveyor or tube, is often categorized depending upon the location of heating plates (electrodes) along with relevant sample flow path into 2 systems. One is in-line field system and other one is cross field system (Varghese et al., 2014).

In-line field system: In this system, different locations are utilized within heating cell to place heating plates (electrodes) such that electrodes are parallel to the sample flow path. Once sample moves in upstream, it senses greater electrical field as compared to sample movement in downstream because of voltage decrease within this arrangement (Varghese et al., 2014).

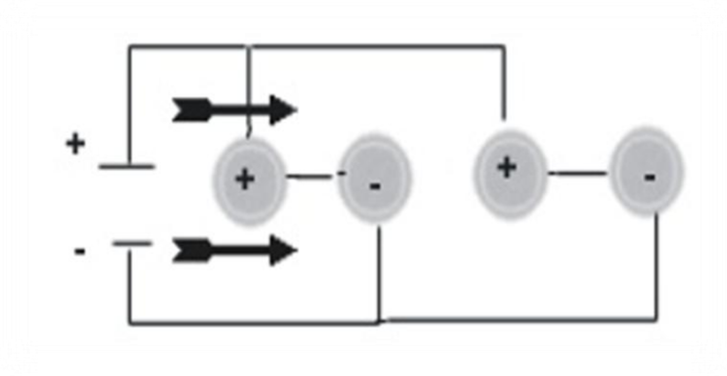

Fig 2.5: Inline field system

Cross-field system: Here the flow path of sample is perpendicular to the heating plates whereas electrical field is constant throughout heating.

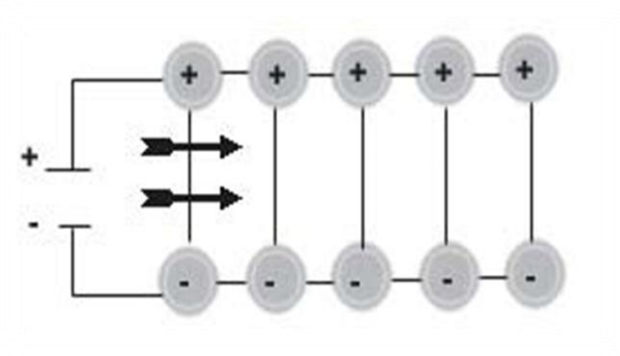

Fig 2.6: Crossfield system

2.10 Physicochemical changes in food takes place during ohmic heating

Ohmic heating is employed for processing of wide range of fruits and vegetables. During processing of fruits and vegetables, the consequences of ohmic heating on nutritional properties of the same were reviewed (Kaur et al., 2016). The ohmic heating causes numerous number of quality and nutritionary changes. It includes degradation of heat sensitive compounds, destruction as well as inactivation of microbes, inactivates various undesirable enzymes, and additionally causes alterations in pH and colour value etc. It has been observed that the rate of deactivation of enzymes and micro-organisms will be increased on application of electric field during ohmic heating. The deterioration of heat delicate components which includes colour pigment anthocyanins, vitamin C etc. rises with rise in voltage and solid contents throughout ohmic heating (Joshi, 2018).

Ohmic heating for processing of dairy products was assessed by Cappato et al., (2017). They reported that in goat milk processing through ohmic heating, there was no modification in FFA content as compared to the traditional method. This showed that ohmic treatment does not affect product quality. An experiment was conducted to process papaya pulp through ohmic heating such that rheology of pulp, electrical conductivity as well as biological properties were studied (Gomanthy et al., 2015). They reported overall decrease within the lycopene, carotenoids as well as ascorbic acid content in 100g fresh papaya pulp when the pulp was subjected to ohmic heating. This decrease throughout ohmic heating was because of lycopene and beta-carotene isomerisation that causes alterations within trans to sis-isomer therefore reduces overall nutritionary content (Joshi, 2018).

Ohmic heating is an alternative preservation technique (Shivmurti et al., 2014). Shivmurti et al., (2014) ascertained that the results of chemical analysis interpret that ohmic heating and conventional heating technology provides products with similar chemical properties. They also tested alternative parameters of milk and found that at 40°C electrical conductivity increases with increase in temperature whereas viscosity shows inverse relationship with temperature. Milk density was also inversely proportional to milk temperature.

2.10.1 Effect on enzymes

Castro et al., (2004) conducted an experiment to study the consequences of electrical field applied during ohmic heating on enzymes. Enzymes have numerous applications in food processing which includes flavor as well as texture improvement within finished product, byproducts recovery and to get high extraction of components. Enzymes additionally undergone numerous deteriorative reactions like off- flavor and off- color developments within fruits and vegetables processing. Enzymes in addition have an effect on texture parameters of food components. Therefore, it is necessary to inhibit undesirable activity of enzymes in many operations. A very less information is available that concerns with the physicochemical changes that takes place in activity of enzymes during ohmic heating. The studied enzymes include lipoxygenase, pectinase, polyphenol oxidase, pectin methyl esterase, and peroxidase (Joshi, 2018).

1) Polyphenol oxidase (PPO)

Enzyme PPO is responsible for browning reactions that happen in fruits and vegetables. Browning principally occurs on destruction of tissues such that components inside tissues made direct contact with air. The electrical field also has an auxiliary effect on the inactivation of PPO. It has been determined that once food is subjected to the ohmic heating, there is a significant reduction in the inactivation time (Joshi, 2018).

Saxena et al, (2016) conducted an experiment for optimization of electrical field and time combination for inactivation of PPO in sugarcane juice throughout ohmic heating. The inactivation of polyphenol oxidase activity through ohmic heating was measured under completely different potential gradients (0.24, 0.32, and 0.48V/m) and different times of holding (15, 30, 45, 60, and 75s) at temperature 80 ± 2^{o}C and optimized by conventional thermal treatment. They found process condition of 0.32V/m and holding time of 60s was optimum. They concluded that PPO activity was inhibited in shorter times during ohmic heating compared to conventional/traditional thermal treatment.

2) Pectin methyl esterase (PME)

PME is chiefly present within every plant structure, microorganisms as well as within many fungus. The galactosyluronate methyl group esters within pectin undergo deesterification reaction that is catalyzed by pectin methyl esterase (Jakob et al., 2010). A study was conducted to process orange juice through ohmic heating (kaur et al., 2016). They reported that there is 98% reduction in pectin methyl esterase activity upon ohmic heating (kaur et al., 2016).

3) Peroxidase

The most heat stable enzyme present in fruits and vegetables is peroxidase. Inactivation of peroxidase enzyme indicates the adequacy of blanching. Icier et al, (2006) conducted an experiment on blanching of puree manufactured from peas at four completely distinct potential gradients (0.20-0.50 V/m) through ohmic heating. Icier et al, (2006) reports less time needed for inactivation of peroxidase enzyme once blanching is carried through ohmic heating as compared to conventional blanching at/or higher than 0.30V/m. In ohmic blanching, with increase in voltage gradient the critical inactivation time decreases.

4) Lipoxygenase (LOX)

Enzyme lipoxygenase is widely present in vegetables. Among most of the vegetables, enzyme lipoxygenase is responsible for evolution of various off-flavour defects as well as damaging the colour value. LOX additionally utilized in bakery industry because interaction of enzyme lipoxygenase with gluten increases hydrophobicity of gluten. The higher will be the hydrophobicity, higher will be the toughness of gluten and hence higher will be the gas retention ability. The electrical field also has an auxiliary impact on the inactivation of LOX. It has been observed that when food is subjected to the ohmic heating, there is a significant reduction within the inactivation time (Joshi, 2018).

5) Pectinase (PEC)

Enzyme pectinase has numerous applications within food process industries. It is utilized in beverage industries for clarification of most of the fruit juices and wines. It also hydrolyses pectin and therefore reduces viscosity. Joshi, (2018) reported that the inactivation of enzyme pectinase was not influenced by electrical field applied during ohmic heating.

2.10.2 Effect on color

Boldaji et al., (2015) studied mechanism of manufacturing paste from tomatoes through ohmic heating methodology. They reported that in ohmic cooking, the colour parameters of tomato samples vary considerably with a voltage gradient.

The brightness of the samples was also improved and heating method also protects or intensifies the slightly green color of tomato samples. They additionally found a decrease in pH on increasing voltage gradient. The peak rise in pH was 8.89% at 6V/cm.

Kaur et al., (2016) reviewed the implications of ohmic heating on nutritional value during processing of the fruits and vegetables. Acerola contains color pigments (anthocyannins and beta-carotene) in high quantity (Joshi, 2018). The continual deterioration of pigments throughout heating of acerola causes loss of colour within the finished produce. Due to the prevalence of electrochemical reactions, higher color changes take place at low electric field frequency (10Hz). Icier et al., (2006) conducted an experiment for peroxidase inactivation and to measure color alterations that takes place in blanching of puree (pea puree) through ohmic heating. They reported that amendment in color follows 1^{st} order reaction throughout ohmic heating. Gomes et al., (2018) conducted an experiment to carry out blanching of pumpkin through ohmic heating. Gomes et al., (2018) additionally investigated the consequences of ohmic heating on inactivation of peroxidase activity as well as alterations within colour values. They reported that ohmic heating was economical in retaining colour and inactivates peroxidase enzyme efficiently.

2.10.3 Effect on pH

The chemical composition and also the pH of pasteurized milk were not influenced in electric field. Boldaji et al., (2015) studied mechanism of manufacturing paste (tomatoes) through ohmic heating methodology. They found a decrease in pH on increasing voltage gradient. The peak rise in pH was 8.89% at 6V/cm.

An experiment to review the behavior of ohmic heating during processing of tomato paste was conducted by Darvishi et al., (2012). They also investigated the alterations that take place in values of electrical conductivity as well as pH throughout ohmic heating. Based upon the application of potential gradient throughout ohmic heating, they reported slight amendment in pH (hydrogen ion concentration) values of paste. The pH and potential gradient are inversely proportional to each other (Darvishi et al., 2012). Once the processing of tomato paste was done, the final pH found to be vary in range of 4.20-4.51.

2.10.4 Effect on heat-sensitive compounds

1) Anthocyanin degradation

The anthocyanin degradation of various fruits was studied by Kaur et al., (2016). An experiment was conducted to study deterioration of anthocyanin during pulp (blueberry) treatment through both ohmic as well as traditional heating (Sarkis et al., 2013). They reported that anthocyanin degradation is directly proportional to electrical potential and solid content. The proportion of degradation was lower when lower voltage/potential was used throughout ohmic heating as compared to traditional heating.

2) Degradation of ascorbic acid (AA) and vitamin-C

The AA and vitamin C degradation was reviewed by Kaur et al., (2016). It has been found that application of higher voltages throughout ohmic heating increases rate of deterioration of vitamic C than that of traditional heating (Assiry et al., 2003). A comparative study was conducted by using both ohmic as well as traditional heating. The study gave same result for both vitamin C and AA degradation once the ohmic heating was conducted at low voltage gradient. As voltage gradient will increase, AA degradation will be increased (Joshi, 2018). It is due to the electrochemical reactions.

Vikram et al., (2005) utilizes ohmic heating for processing of orange juice and also studied the deterioration mechanism of ascorbic acid. They reported that when applied electric field strength was 42V/cm, the degradation of ascorbic acid was around 35% after 3 min of heating at 90^{o}C.

2.10.5 Effect on rheological characteristics

Bozkurt and Icier, (2009) utilized ohmic heating to studied the rheology of quince nectar. During their study ohmic heating at completely different voltage gradients (10-40V/cm at 50 Hz) was applied to quince nectar. Different mathematical models were utilized to check the rheological behavior of quince nectar. They reported that for all temperatures, the foremost effective model fitted to experimental data was Herschel-Bulkley model. The Non-Newtonian shear thinning behavior at temperature-time combination of 65-70°C/0-30 min was obtained for quince nectar. They reported that rheological properties of quince nectar remain same after ohmic and conventional heating. A similar study was performed by Krokida, Maroulis, and Saravacos (2001). The literature data available on rheological properties of different fruit pulps were studied by Krokida, Maroulis, and Saravacos (2001). They reported pseudoplastic behavior was followed by fruit pulps.

2.10.6 Effect on texture

The necessary quality trait which influences the sensual opinion and provides peace of mind to customer is food texture. A study was conducted in which cauliflower was processed through ohmic heating and feasibility of the experiment was evaluated (Eliot-Godéreaux et al. 2001). They reported that textural properties of final products were enhanced because heating takes place homogenously and at a quicker rate throughout ohmic heating. The final product with acceptable firmness was obtained from ohmic sterilization process.

Farahnaky et al., (2012) utilized ohmic heating for processing of many root vegetables and its consequences on the texture of vegetables were measured. They investigated texture of root vegetables in Texture profile analyzer (TPA). The data obtained from Texture profile analyzer (TPA) shows that ohmic heating accelerates the softening rates. They further reported softening rate is directly proportional to applied electrical potential that means with increase in value of applied potential, the softening rate will also increases and vice-versa.

Chui, (2002) conducted an experiment for cooking of ham emulsion through ohmic heating and the textural properties of the ham emulsion was studied. They found that softer and chewier texture was obtained in ohmically cooked ham as compared to the conventionally cooked sample.

2.11 Applications of ohmic heating

Ohmic heating has number of applications such that some of the applications are commercial and a few applications have to be commercialized. Ohmic heating has wide range of applications which comprises ohmic pasteurization/Sterilization; ohmic blanching, ohmic thawing, bread proofing, starch gelatinization, microbal inactivation, and sludge treatment etc. (Sastry, 2008).

2.11.1 Pasteurization and sterilization

Industries accepted ohmic heating for process liquids and solid-liquid mixtures. Recently ohmic heating was employed for the sterilization of guava juice. Ohmic pasteurization/sterilization preserves the standard quality of food products. Meanwhile in the initials of twentieth century, the pasteurization of milk was carried out using ohmic heating methodology. UHT processing of food that primarily consists of sizable fragments (around 2.5 cm) will be carried out by ohmic heating (Joshi, 2018).

The ohmic heating was utilized for pasteurization of paste prepared from fermented red pepper (Cho et al., 2016). A greater pasteurization impact was produced by ohmic heating because of homogenous internal heat generation as compared to that of traditional/conventional heating when the frequency of alternating current was low. The vegetative cells of strains of Bacillus are effectively reduced (99.7%) and inactivated by ohmic heating whereas traditional heating carried out at temperature-time combination of 100 °C and 8 min, generating 81.9% diminution of Bacillus strains. The finished product quality produced by ohmic heating was superior as compared to the fresh samples as well as from the traditional heating methods (Cho et al., 2016).

2.11.2 Blanching

Blanching may be a pretreatment applied to fruits and vegetables for the inactivation of enzymes liable for undesirable browning. Enzymes that are inactivated include polyphenol oxidase, catalase, peroxidase. Blanching is carried out in a hot water bath around 85^{o}C for 10-15 minutes.

Ohmic blanching inactivates enzyme activity at a lesser time than that of traditional water blanching with higher retention of color quality (Joshi, 2018). Thus, ohmic heating is applied for blanching. Ohmic heating accelerates the enzymatic inactivation method such that ohmic blanching took 2 min for reduction of higher than 90% peroxidase initial activity, whereas time duration for the blanching carried out by conventional methods was 4 min to obtain identical inactivation rate (Gomes et al., 2018). An experiment was conducted for blanching of puree ready from peas at four completely contrasting potential gradients (0.2-0.5 V/m) by ohmic heating (Icier et al., 2006). Icier et al., (2006) concluded time needed for the inactivation of peroxidase enzyme was less in blanching carried out by ohmic heating as compared to hot water blanching when the values of voltage gradient was more than or equal to 0.30 V/m. In ohmic blanching, higher the value of voltage gradient lesser will be the time needed for the inactivation.

2.11.3 Cooking

Ohmic heating results in accelerated cooking due to its ability to generate fast heat within the food material. Kanjanapongkul, (2017) suggested ohmic heating as a substituted technique for preparation (cooking) of rice. They reported that quicker expansion was observed within the rice grains once the cooking was carried out temperature greater than 80^{o}C. Kanjanapongkul (2017) states that within the rice grains, water diffused at a quicker rate when temperature was kept above 80^{o}C and even more rapidly when boiling water was utilized for steeping. There is an immediate relationship between electric field strength and diffusion rate. Ohmic cooking consumes less energy that is around 25% of overall energy expenditure of electrical cooker with reduction in heating time (18 and 17 min). The firmness of samples cooked through ohmic heating was more as compared to that of samples processed through conventional heating. However, there is no modification in yield and fat retention. Ohmic heating results in lesser volume reduction i.e. from 5.36% to 6.97% as compared to conventional cooking wherever the reduction in volume throughout cooking was around 26.01% to 31.59%. The ohmic heating was utilized in combination of plate heating, such that secured products within shorter cooking times was produced (Ozkan et al., 2004).

2.11.4 Thawing

The thawing of frozen food is additionally an application of ohmic heating. The frozen food components are inserted in space between two heating plates followed by passage of an electrical current to those plates. The thawing carried out by ohmic heating is homogenous/consistent due to the fact of volumetric heating. Other advantage includes its ease of control. No water and wastewater are generated during ohmic thawing.

Duygu and Umit, (2015) utilized ohmic heating for thawing of meat and study the consequences of ohmic heating on overall quality of meat. Duygu and umit, (2015) observed that the weight loss within frozen meat throughout the ohmic heating was less and additionally thawing was carried out in shorter duration.

An experiment was conducted for thawing of beef cuts through ohmic heating and there histology as well as textural properties was studied (Icier et al., 2010). Three totally different potential gradients viz. 0.10, 0.20, and 0.30 V/m respectively were utilized to carry out ohmic thawing of beef cuts, however thawing by conventional methods was carried out in incubator (at 25°C, 95% RH). They reported that ohmic thawing of the frozen beef provides good results at three completely different potential gradients viz. 0.10, 0.20, and 0.30 V/m as compared to that of conventional thawing. The thawing time decreased with a rise in voltage gradients, whereas the thawing loss remained unchanged (Richa et al., 2017).

2.11.5 Evaporation

Evaporation is a vital operation carried out in the food industry with the aim of product concentration. Sabanci and Icier, (2017) conducted study on concentration of bitter cherry juice by ohmic heating (from 19.2% TSS to 65% TSS). They found that at three completely different values of voltage gradient 0.14 V/m, 0.12 V/m, and 0.10 V/m and for conventional vacuum evaporation, the time required for ohmic heating were 0.67, 0.92, 1.25, and 1.42 hr respectively

(Sabanci and Icier, 2017). They reported that heating times for concentration of fruit juices will be lowered when processed through ohmic heating.

When ohmic heating was utilized for vacuum evaporation, then moisture evaporates at higher rate through a food sample than that of traditional methods of vacuum evaporation for same duration of time and finished product was brighter and kept more aromas (Wang and Chu, 2003).

2.11.6 Starch gelatinization

The foremost vital factor throughout the starch gelatinization is “Gelatinization temperature”. The ohmic heating was utilized to seek out the temperature required for gelatinization of starch. For determination of starch gelatinization, the ohmic heating was evaluated as adequate methodology compared to alternative methods (Kumar et al., 2014). Electrical conductivity increases with a rise in temperature whereas slight decrease in electrical conductivity was observed with gelatinization degree due to anatomical changes and a rise in water content that is bound to the components (Wang and Sastry, 1997).

2.11.7 Wastewater treatment

Biological Oxygen Demand (BOD) value of wastewater is high. BOD of wastewater having high protein concentration is reduced by either protein coagulation by heating or by subsequent separation. Ohmic heating is an economical technique that heats the fluid in an exceedingly shorter time. Therefore in most of the surimi production processes, ohmic heating may be utilized as a substituted method for wastewater treatment (Kumar et al., 2014). The ohmic heating was also applied to wash water generated during surimi production processes, where heating results in protein coagulation thus improved the quality of water (Huang et al., 1997).

2.11.8 Distillation

Distillation is extremely vital unit operation carried out in industries. It is the foremost time as well as energy absorbing operation for manufacturing bio-ethanol (Gavahian et al., 2016). Ohmic assisted hydro-distillation (OAHD) is a fresh technique that essentially utilizes the ohmic heating advantages as well as makes separation of essential/volatile oil possible (Gavahian et al., 2016). The distillation of ethanol was carried out in OAHD device within which heating plates are made up of titanium (Gavahian et al., 2016). They found that only one third of the total energy was needed for ethanol separation within ohmic assisted hydro-distillation device as compared to energy needed in hydro-distillation. This study introduces that ohmic assisted hydro-distillation is a cost effective and pollution free technique to carry out distillation of ethanol (Gavahian et al., 2016).

The extraction of important essential oils can be carried out by ohmic heating. An experiment was conducted for extracting oil from lavender using ohmic accelerated steam distillation (OASD) and results were compared with conventional steam distillation (SD) (Gavahian and Chu, 2018). They reported that the yield of proposed technique was same as that of steam distillation. They concluded that OASD is time and energy saving technique and alternative to SD for industrial units. OASD consumed less energy (0. 4kWh vs. 0.9kWh for 1mL essential oil) and time needed for extraction (0.838 ± 0.035 hr vs. 1.878 ± 0.098 hr) was additionally less as compared to SD.

2.11.9 Bread Proofing

Bread dough proofing was studied at a target temperature of 35°C under ohmic heating (Gally et al., 2017). The findings of the study showed that considerably quicker proofing can be obtained by using ohmic heating. They concluded that heating time required to get expansion ratio around three was shorter when higher ohmic heating rates were used. When heating rates varies from 1 to 10°C/min, to attain same expansion ratio ohmic heating took 1.08-1.17 hr whereas proofing carried out by conventional methods took 2.03 hr. Ohmic heating times for proofing of bread dough were 1.44, 1.37, and 1.35 at applied voltages of 50, 100, and 150V respectively. OH-assisted proofing consumes less energy to achieve the optimum temperature of fermentation quickly, offers flexibility and stimulates the souring mechanism stimulates the fermentation process with high potency (Gally et al., 2017).

2.11.10 Microbial Inactivation

Microbiological safety of food products treated by ohmic heating is not affected however might even be improved. Microbial inactivation is based on thermal inactivation. The thermic impact is the principle behind destruction of microorganism through ohmic heating. Somavat et al., (2012) utilized ohmic heating for inactivation of spores (*Geobacillus stearothermophilus*). They reported that ohmic heating accelerates inactivation at 60Hz and 10KHz. Once the electrical field at high-temperature conditions was applied, then it results in accelerated inactivation due to vibration of polar dipicolinic acid molecules and spore proteins (Somavat et al. 2012). A similar study was conducted by Cho et al., (1999) to inactivates *Bacillus subtilis* spores through ohmic heating. They also investigated ohmic heating consequences on bacillus spores and compared the results with traditional heating. They conclude that there is a significant reduction within the D-value of spores under ohmic treatment heated at 97.2^{o}C.

Listeria monocytogenes inactivation through ohmic heating at 75^{o}C for 30s and 2 min, respectively was studied by Inmanee et al., (2019) and results were compared with traditional heating at same process conditions. They found that ohmic heating took lesser period and produces greater than or equal to 5- log reductions, such that 3-log reductions and 4-log reductions were achieved throughout traditional heating at 30s and 2 min, respectively.

2.11.11 Extraction

Ohmic heating will be applied together with traditional extraction processes. Researchers found that there is rise in the extraction efficiency of sucrose from sugar beets. Asl et al., (2018) conducted an experiment for oil extraction from species herbs through ohmic heating. The results of hydrodistillation carried through ohmic heating were correlated with the hydrodistillation through traditional methods. They reported that ohmic heating lead to roughly 30% greater extraction of essential oil within approximately one forth of a time used by the traditional hydrodistillation.

Aamir & Jittanit, (2017) additionally utilized ohmic heating for extraction for oil gac fruit. They also studied the consequences of ohmic heating on physical characteristics, extraction potency and on biologically active components of oil extracted from Gac fruit. They reported that ohmic heating improves the pigments content (lycopene and carotenoid), extraction potency as well as colour properties of extracted oil. The extraction efficiency of 81.40% was obtained with ohmic heating. A similar study for extraction of inulin from tuber through ohmic heating was conducted by Termrittikula et al., (2018). A higher yield of inulin was obtained by ohmic extraction.

2.11.12 Dairy and food industry

The ohmic heating is utilized in food and dairy industries for processing of wide variety of products. Its consequences on food and dairy products were studied by several researchers. Some of them were discussed below (Meena et al., 2016):-

Ohmic heater was utilized for buffalo milk heating and later paneer was manufactured from that milk (Kumar et al., 2014). The buffalo milk was heated ohmically as well as conventionally from 20^{o}C to 72^{o}C. Paneer manufactured from both conventional and ohmic treated milk was evaluated sensorially and microbiologically. The sensory attribute of paneer manufactured by ohmic treated milk was considerably higher however lower hardness value was observed than that of paneer prepared by conventionally treated milk. The microbial quality of ohmic treated milk was also higher than that of raw and conventionally treated milk.

The suitability of ohmic heating to heat soyabean milk (10^{o}Brix) up to 90^{o}C for tofu manufacture was investigated by Kaur, (2016). They determined that with an increase in voltage, the temperature was enhanced from 1.46-3.82^{o}C/min. They concluded that ohmic heating was an economical and applicable technique for tofu manufacturing.

The ohmic heating was utilized for sweet whey processing (Costa et al., 2018). Samples of whey were subjected to each ohmic heating as well as traditional heating. The consequences of heating at completely different voltage gradients (2, 4, 5, 7 and 9V/cm at 60Hz, up to 72–75°C/15s) within ohmic heating and conventional heating (72–75°C/15s) were investigated. For the processing of sweet whey, electric field intensity is very important parameter for ohmic heating. At low electrical fields, higher values of saturation, color value, and luminosity were observed. The sensory profile of sweet whey processed by ohmic heating at voltage gradient of 4 and 5V/cm offers same results as we get from traditional heating. Costa et al, (2018) evaluated ohmic heating as a convenient alternative for whey processing.

MATERIALS & METHODS

3. MATERIALS AND METHODS

Ohmic heating (OH) is a novel heating method wherein alternating current is passed through food materials with an aim of heating by converting electrical energy into thermal energy, that results in rapid and uniform heating with less thermal damage to the food product. Ohmic heating is based on principle of Joule effect. The rate of heat generation is directly proportional to square of electric field strength and electrical conductivity of material.

This chapter details the experimental techniques employed to fulfill the various objectives envisaged for this study. In preliminary phase, conventional ohmic heating setup was modified and automatic temperature control system was integrated into the system. A paired plate type ohmic heating setup was designed, fabricated and its performance was evaluated for both cow and buffalo milk. In the later phase, up-scaled rotating field type ohmic milk heater (10 kg capacity) was designed, developed and assessed. The performance evaluation parameters for ohmic heating system were temperature profile, heating time, heating rate, average temperature gradient, electrical conductivity, power consumption and thermal efficiency.

The experimentation procedures for the present study have been discussed under the following sub-headings:

3.1 Experimental setup

The conceptual diagram for conventional ohmic heating system is shown in Fig. 3.1. The conventional ohmic heating system of 5 liters capacity was fabricated. The experimental setup consists of ohmic reactor vessel, electrodes, outlet valve, insulation chamber, thermocouples, agitator and data logging system (Fig. 3.3). Two heating plates (electrodes) were parallel to each other and placed within the ohmic reactor vessel, connected to power supply and are in physical contact with the milk, in order to pass electric current through it. In ohmic heating, electrical energy is directly converted into thermal energy without loss of any heat. This principle is used to generate an internal energy in material which causes heating of material. By changing the geometry of system, size of system and distance between electrodes, the electric field strength also varies. Static ohmic heating system comprised of following components:

3.1.1 Ohmic reactor vessel

Different materials can be used for construction of ohmic reactor vessel. Mainly alloys of stainless steel are used for construction for ohmic reactor vessel due to its high strength and corrosion resistance properties. It consists of heating plates (electrodes) and stirrer to prevent fouling on electrode plates. Reactor vessel is provided with proper insulation to prevent thermal losses and increases heating efficiency. Reactor vessel was also provided with rounded corners for quick draining of the product. Round corners also improve cleaning efficiency. The capacity of reactor vessel is of 20 kg. The dimensions of vessel were: internal diameter 35 cm, edge to edge diameter 42 cm and height 24 cm from base of the vessel.

3.1.2 Outlet valve

A two way valve (SS-304) was connected at the base of ohmic reactor vessel. These valves are specially designed to shut the flow or to regulate varying amounts of flow. Such valves have been called by various names such as regulating, throttling, metering, or needle valves. It is a manual valve that uses a tapered plug to permit or prevent straight through flow through the body. The plug has a straight through opening. This opening is of same area as the area of the inlet and outlet ports of the valve. Both the end connections of valve were threaded. One end was connected to the vessel with the help of bend. The purpose of valve at the base of the vessel was to collect the sample after processing without any need of removing all the connections and without dismantling the whole setup.

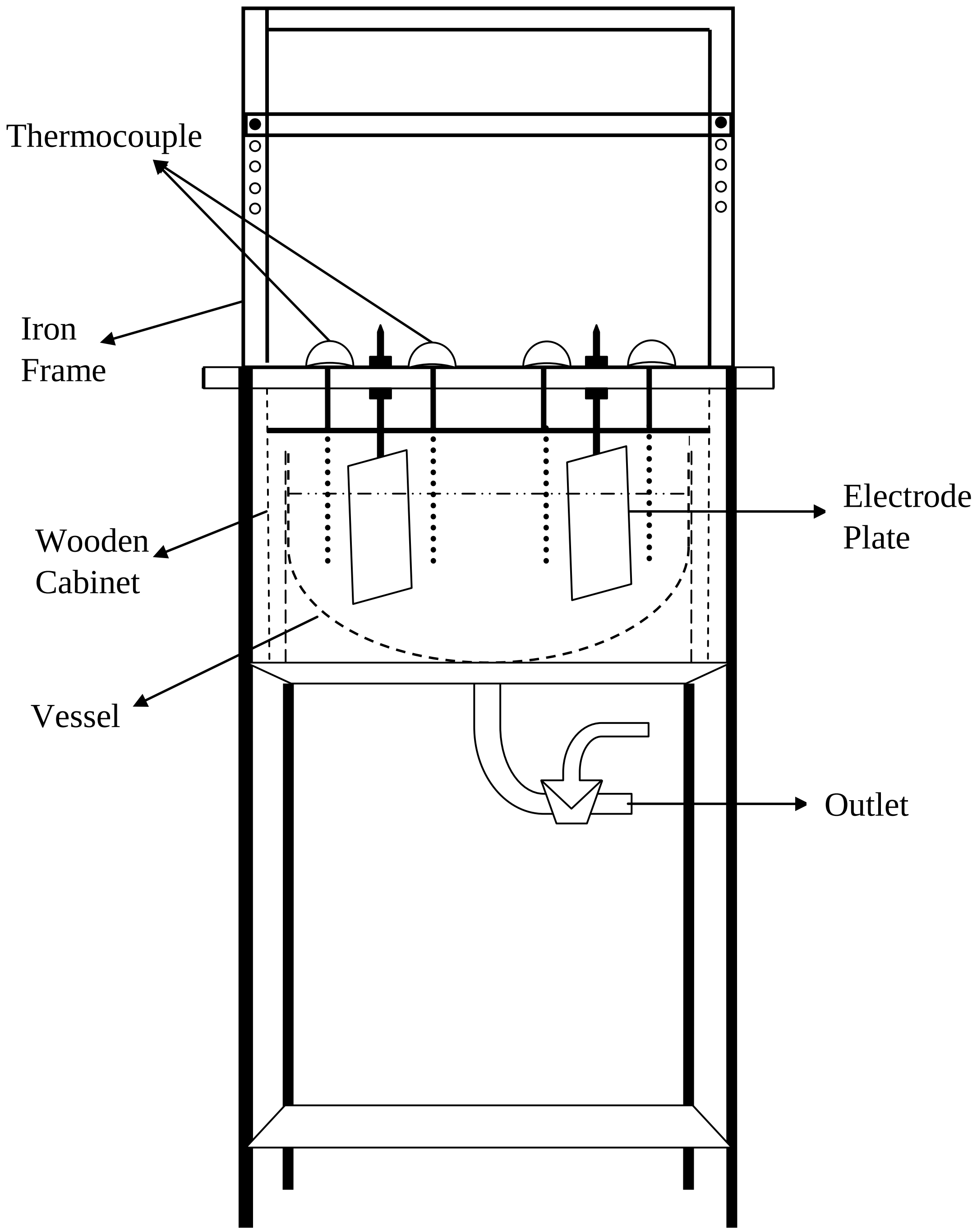

Fig. 3.1: Conceptual diagram of ohmic heating system

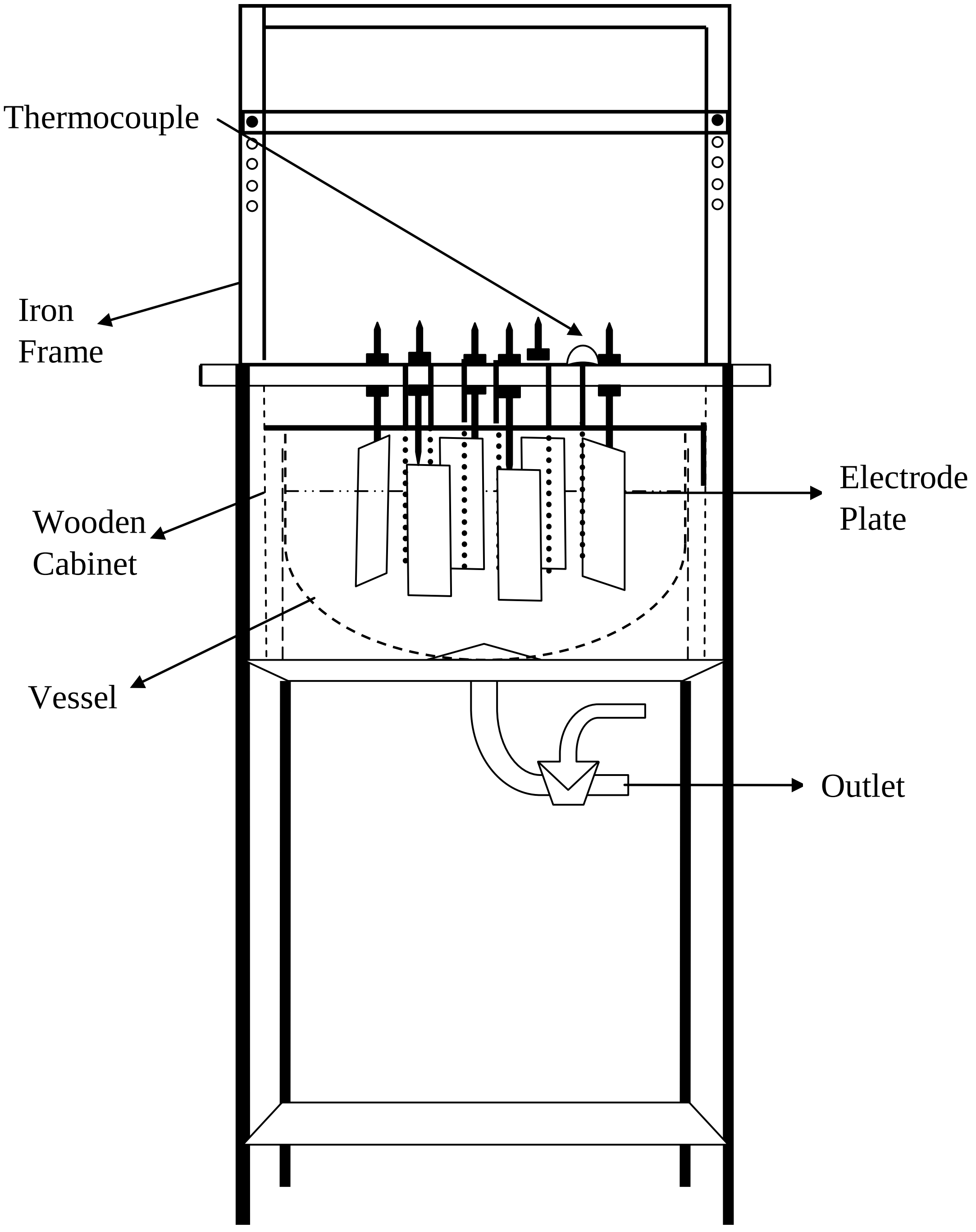

Fig. 3.2: Conceptual diagram of upscaled rotating field type ohmic heating system

Fig. 3.3: Upscaled rotating field type ohmic heating system

Fig. 3.4: Control system of upscaled ohmic heating setup

3.1.3 Insulation chamber

Ohmic reactor vessel was surrounded by insulation chamber to prevent thermal losses and increases heating efficiency. Inverse of thermal conductivity (k) is a measure of insulating capability of a material that means high value thermal conductivity is equivalent to low insulating capability (Resistance value). In thermal engineering, other important properties of insulating materials are product density (ρ) and specific heat capacity (cp). Wooden cabinet of suitable dimension (47 cm x 47 cm x 27.5 cm) is used as an insulation chamber. High current flows through milk vessel which is in contact with the heating plates. Wooden cabinet was used to insulate the vessel to ensure safety of the user as the vessel is conductive to current. To avoid heat loss glass wool insulation was provided in space between the wooden cabinet and reactor vessel. Glass wool is an excellent insulating material made from glass fibers which are arranged by using a binder into a texture similar to wool. The process traps many small pockets of air between the glass, and these small air pockets result in high thermal insulation properties. The principle being that the gases have poor thermal conduction properties compared to liquids and solids, and thus glass wool exhibits good insulation properties.

3.1.4 Heating plates

Electrodes are placed in reactor vessel and connected with power supply. These plates make direct physical contact with the sample to be heated, to pass an electric current through it. Different conductive materials like stainless steel, titanium, platinized titanium; aluminum and graphite etc are used for construction of electrodes. These are usually selected based on price, resistance to corrosion and the desired application. Mostly stainless steel is considered as a most suitable alloy for construction of heating plates. SS plates are widely used in food, dairy, chemical, paper, and textile industry due to its good mechanical properties. In case of milk heating, SS plates causes slight fouling but its properties, cost availability and cleaning efficiency of stainless steel makes it the suitable material to be used as electrodes during ohmic heating. In the literature, it was found that plate gap has a significant effect on the ohmic heating. The plate gap was fixed according to formula proposed by Lanjewar and Minz (2015) for 1 kg ohmic heating system.

2W = $\sqrt{d^2 - L^2}$

Where,

W = Plate width,

d = Diameter of reactor vessel,

L = Plate gap

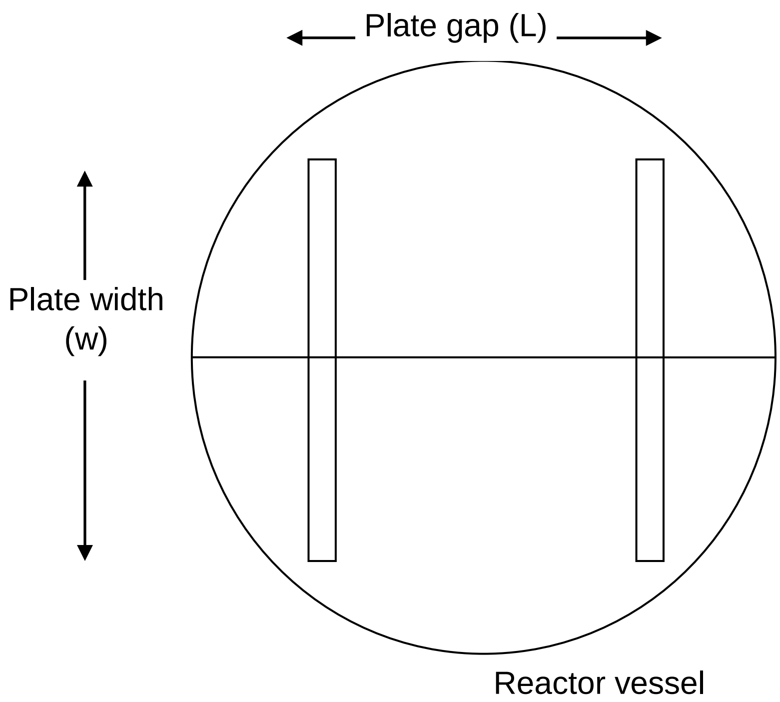

Fig. 3.5: Geometric arrangement of plates

3.1.5 Control unit

Control unit was used for centralized power supply to all the electrical components of the ohmic reactor viz Variable transformer, current, and temperature data logger. One Miniature Circuit Breaker (32 Amp) is also provided in the control unit for safety reasons so that whenever current drawn is large or in case of short circuit it will cut the supply of current

3.1.6 Voltage regulator

A voltage regulator is a device developed for automatically maintaining a constant voltage level. Its design includes a simple feed-forward design or may include negative feedback. It works on the principle of an electromechanical mechanism. It may be used to regulate one or more AC or DC voltages on the basis of its design. It consisted of on/off switch and a variable transformer. Voltage is one of the main factors affecting ohmic heating. Variable voltage transformer (Rating 32 A) was used to vary voltage for ohmic heating. When the current reached 22 A, variac was used to reduce in steps (10 V). It was done to protect the variac from damage. But for high trial manual voltage regulation was required. A clamp-meter and current data logger was used to measure current in the circuit during ohmic heating.

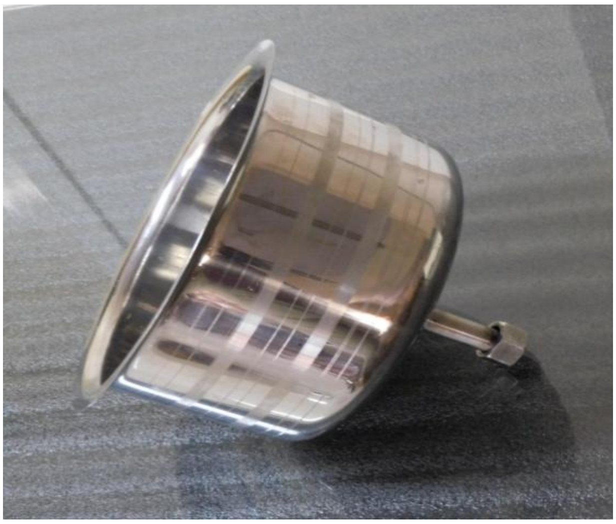

Fig. 3.6: Stainless steel ohmic reactor vessel

Fig. 3.7: Stainless steel valve

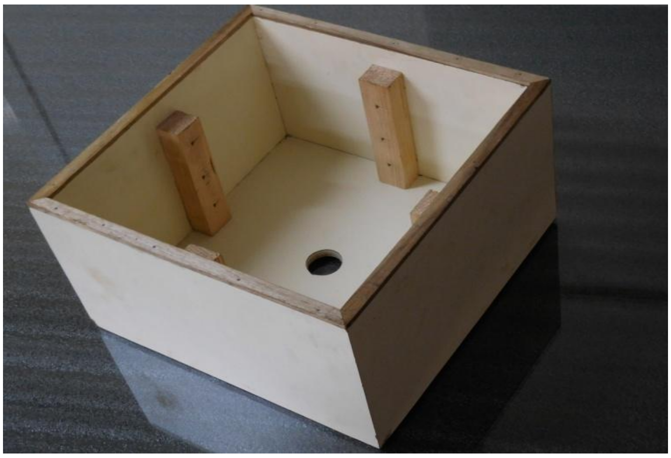

Fig. 3.8: Cabinet for electrical insulation of reactor vessel

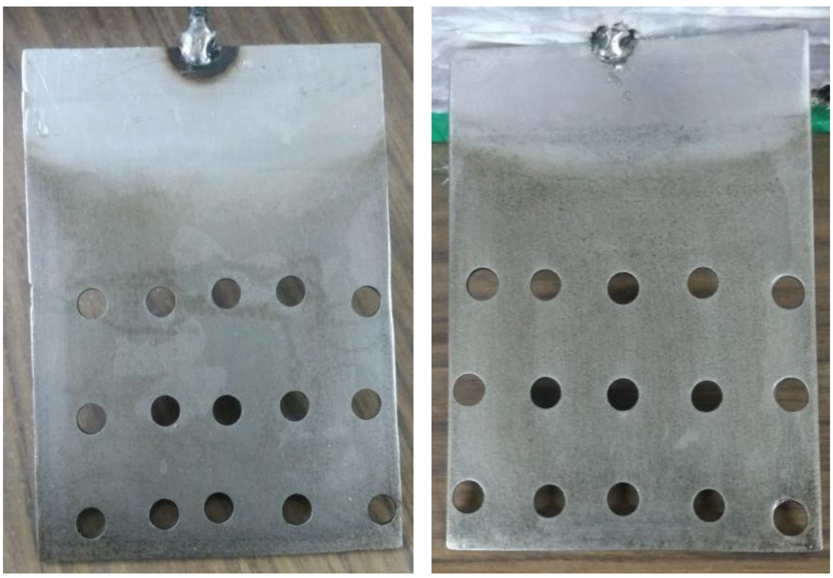

Fig. 3.9: Heating plates

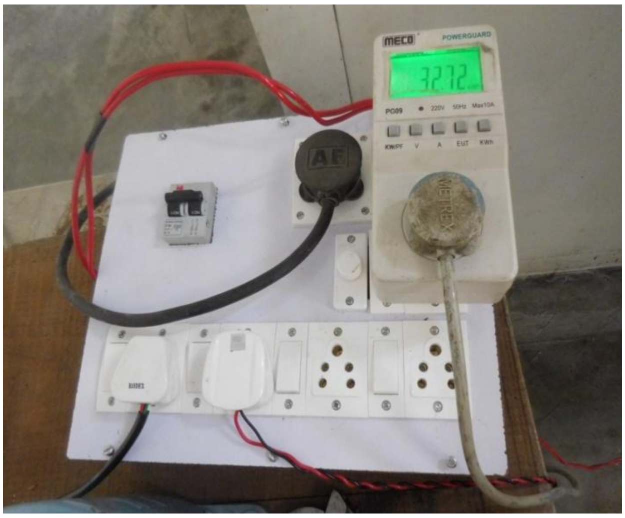

Fig. 3.10: Control unit

Fig. 3.11: Variac (Voltage regulator)

3.1.7 Temperature Data logger

A temperature data logger is used for monitoring of temperature. It is a portable measurement instrument having capability of continuously recording temperature over a defined period of time. The digital data can be retrieved, viewed and evaluated after it has been recorded. Study of heating pattern during ohmic treatment is very important. Real time temperature was measured using temperature probes (pt 100) connected to data logger. Temperature gradient was determined to ensure uniform heating of milk. To determine temperatures of milk at different points in ohmic reactor, a eight channel data logger was used. Temperature data is saved directly in USB pen drive as a MS Excel compatible file. Microprocessor based data logger is linearised for J/K/R thermocouples and pt-100 sensors. It has in built auto cold junction compensation for thermocouples as well as for 3 wire pt-100 sensors. In this number of usable channels are selectable (max. 8) and having Auto/Manual mode of scanning can be selected. The rate of logging is settable by user in Mins: Secs. The digital offset user settable for individual channels and internal real time clock with battery backup for saving values along with Date and Time. The data is saved on pen drive in a file named as “TempLog.csv”.

Table 3.1: Specifications of Temperature Data Logger

Display	4+4 digit 0.56” 7 segment Red LED
Sensor	J,K,R & 3 wire PT100
Range	J T/C : 0 to 750˚C K T/C : 0 to 1250˚C R T/C : 0 to 1700˚C PT100: -100.0 to +600.0˚C
Accuracy	±0.1% of Full Scale ± 1 digit
Relay Logic	Programmable as Heater/Cooler logic On/Off or time proportional with 15 sec cycle time for heater logic On/Off for cooler logic 5 Amps/220V AC Relay Contact outputs
Proportional Band	-7.0˚C to +3.0˚C around set point with 10% per degree cut
Hysteresis Band	Settable from 0˚C to 20.0˚C
Percentage Power	User programmable from 0% to 100% to avoid overshoots and save power
Offset Band	Settable from -20.0˚C to +20.0˚C
Memory	Non-volatile EEPROM to save settings
Configuration Lock	Open terminals 4&5 to lock the Sensor type, Relay logic and Set Limits
Supply	220V AC ± 15% @ 50/60Hz
Dimensions	96mm x 96mm x 135mm. Cut Out : 91mm x 91mm
Weight	800 grams

3.1.8 Current data logger

To record the current drawn by the reactor, current data logger was used. Data is recorded directly on USB Pen Drive in an MS Excel compatible file. The data logger has separate display for current and time. Logging rate can be set by the user in minutes or seconds. The current threshold beyond which logging is enabled is also user settable. Internal real time clock with battery backup enables saving values along with date and time. Thus saving data on pen drive allows a very large amount of storage space at very low cost. Specifications of the current data logger are shown in table below:

Table 3.2: Specifications of current data logger

Display	0.56”Red LED display for current 0.56” Red LED display for clock
Display Range	0-30.0 Amps AC for input 0-1 Amp AC (CT Ratio- 30:1)
Resolution	0.1 Amp
Logging rate	1 second to 99 mins 59 seconds
Logging Threshold	Logging is enabled when current exceeds the current “Set” Limit
Data logging	Directly create a .csv file on the pen drive (compatible with Excel) giving a tabular format values of Date, Time and AC current
Sensor	Current Transformer with conversion ratio 30:1
Real Time Clock	Adjustable Calendar (Month/Date) and Time (Hrs:Mins)
Accuracy	±1% ±1 Least Significant Digit for Current
Power Supply	230 AC ± 15% at 50/60Hz
Mounting type	Panel/bottom surface
Front Facia	96mm x 96mm

Fig. 3.12: Temperature data logger with pt 100 sensors

Fig. 3.13: Current data logger

3.1.9 Sequential Timer (PT380)

It is a 4 digit multifunction LED digital sequential and multi-time range digital timer with push buttons for controlling operation of equipment, machinery, systems or processes in a wide range of industrial applications. Within time range from 0.01 to 999hr, four timing functions can be selected together and these functions operate on different modes like Multifunction: On delay, Interval, Cyclic ON first, Cyclic OFF first to operate 8 channels with timer capability of 10 years memory retention. The output contacts can be configured as timed outputs or instantaneous output. Timer panel is housed in compact enclosure and is powered from 85 to 270Vac/dc.

Table 3.3: Specifications of Sequential timer (PT380)

Display Type	LED
Display Configuration	2 + 4 Digits
Relay Contact	8 Channels
Feature	Memory Retention
Range	99.99, 999.9sec, 99:59min:sec, 99.59hr:min, 999.9 hr
Operating Modes	ON Delay / Interval OFF / Cyclic ON First / Cyclic OFF First
Counting Direction	Down
Supply Voltage	85 to 270V AC / DC
Size	96 x 96mm
Mounting Type	Panel Mount

3.1.10 Current Transformer

A current transformer (CT) is used to measure alternating current. It produces a current in its secondary coil which is proportional to the current in its primary coil. A current transformer has a primary winding, a core and a secondary winding, although some transformers use an air core. In principle, the only difference between a current transformer and a voltage transformer is that the former is fed with a constant current while the latter is fed with a constant voltage.

Table 3.4: Specifications of current transformer

1.	Class of Accuracy	1.0
2.	Rated Burden	5.00 VA
3.	Power Frequency Withstand Voltage	3KV
4.	Ratio	100/5 A
5.	Frequency	50 Hz
6.	Supply System	3 Ph. Solidly grounded Neutral System

3.1.11 Proportional integral derivative (PID) controller

A proportional–integral–derivative controller (PID controller or three-term controller) is a control loop feedback mechanism widely used in industrial control systems and a variety of other applications requiring continuously modulated control. Selec PID500 is used in up-scaled rotating field type ohmic heating system for automatic shut-off of the power from mains to electrode plates. The PID500 controller accepts signals from a variety of temperature sensors (thermocouple or RTD elements) and 4 to 20 mA or 0 to 10 VDC signals. It precisely displays the process temperature, and provides the appropriate output control signal to maintain the process accurately at the desired temperature. The controller operates in the PID control mode for both heating and cooling, with on-demand auto-tune, which will establish the tuning constants. The PID tuning constants may be fine-tuned by the operator at any time and then locked from further modification. The controller employs a unique overshoot suppression feature, which allows the quickest response without excessive overshoot. The controller may also be programmed to operate in the ON/OFF control mode with adjustable hysteresis.

Table 3.5: Specifications of PID Controller (Selec PID500)

Display Type	7 Segment LED Dual Display
Display Configuration	4+4 digits
Type of Inputs	Thermocouple: J, K, T, R, S, C,E, B, N, L, U, W, Platinel II. RTD: PT100, Signal Inputs: (DC) -5 to 56mV, 0 to 10V, 0 to 20mA (Selectable)
Control Output	Relay or SSR or Current : 4 to 20mA DC (max load 500E) or Voltage :0 to 10V DC(min load 10K)
Auxiliary Output	Relay
Feature	Extra alarm output, Retransmission output
Communication	RS485 MODBUS communication (optional)
Supply Voltage	85 to 270V AC / DC
Size	48 x 48mm
Mounting Type	Panel Mount
Certification	CE, UL

Fig. 3.14: Sequential timer

Fig. 3.15: Current transformer

Fig. 3.16: PID controller

3.2 Design and fabrication of paired plate type ohmic heating system

The major drawback of ohmic heating is fouling on the surface of electrodes, which mainly occurs in high mineral content foods, such as milk products (Stancl and Zitny, 2010). Fouling causes many issues in dairy processing plants, which includes hindering the cleaning process, loss of quality and reduction of heat transfer rates, thus compromising the microbiological stability of a product. A layer can be formed on the surface of the electrodes due to the denaturation of proteins. This layer offers more electric resistance and hence more electric energy is dissipated into heat that results in localized heating of plates, thus fouling.

The main limitations of conventional ohmic heating setup include high current requirements during heating and excessive fouling of electrodes due to localized heating of plates. To reduce the fouling problems and higher current requirement within the ohmic heating setup, paired plate type ohmic heating setup was designed and fabricated. A paired plate type ohmic heating setup provides better temperature distribution, higher heating rate, high thermal efficiency, and reduces fouling. The overall current requirement for paired plate type setup is also less as compared to conventional ohmic heating setup.

The study of the heating pattern during ohmic treatment is very important. The real-time temperature was measured using temperature probes (pt 100) placed at four corners of a reactor vessel (figure 3.19) and connected to the data logger. The temperature gradient was determined to ensure uniform heating of milk within the heating cell. A paired plate type ohmic heating system consists of two sets of heating plates placed within the reactor vessel as shown in figure 3.19. Each set of heating plates was connected to the contractor and these contractors were programmed through a sequential timer. The time duration for which current should be given to plates was set manually in sequential timer. Initially current was given to one set of plates for fixed time interval. Once the duration was completed, sequential timer deenergizes the contractor and the contractor cuts the power supply. In the meantime, sequential timer energizes other set of plates and cuts the supply after set time duration. This rotation of field minimizes localized heating of plates and thus a reduction in fouling was observed. Furthermore, the decrease in overall current requirement was also observed.

The three speed agitator motor was also incorporated in the reactor vessel. A single phase AC motor was mounted on the angle iron stand with a provision to remove it whenever required. Solid state speed controller was used in the control panel to regulate the speed of agitator. Provision was made in the iron stand at various positions to adjust the vertical position of agitator in the reactor vessel. The position of agitator was such that it was exactly at the centre between the plates *i.e.* at a distance of 13 cm from edge of the vessel. Height of agitator was also such that the rotating blades are exactly at height equal to the midpoint of the plate height. Agitator rpm was checked with digital tachometer and after preliminary trials at various rpm, optimum rpm for proper mixing was found in the range of 350-400. The agitator shaft is connected to the motor by a teflon rod to prevent current leakage of current in frame of setup. For automatic temperature control within the system, PID controller (Selec PID500) was also incorporated in the heating setup.

The plate gap is one of the important parameter in design of ohmic heater. The top cover of ohmic reactor was designed with provision to vary distance between the plates. The plate gap and width for the 5 kg system was determined based on the data optimized by Lanjewar and Minz (2015):

$$2W = \sqrt{d^2 - L^2}$$

Where,

W = Plate width

d = Diameter of reactor vessel

L = Plate gap

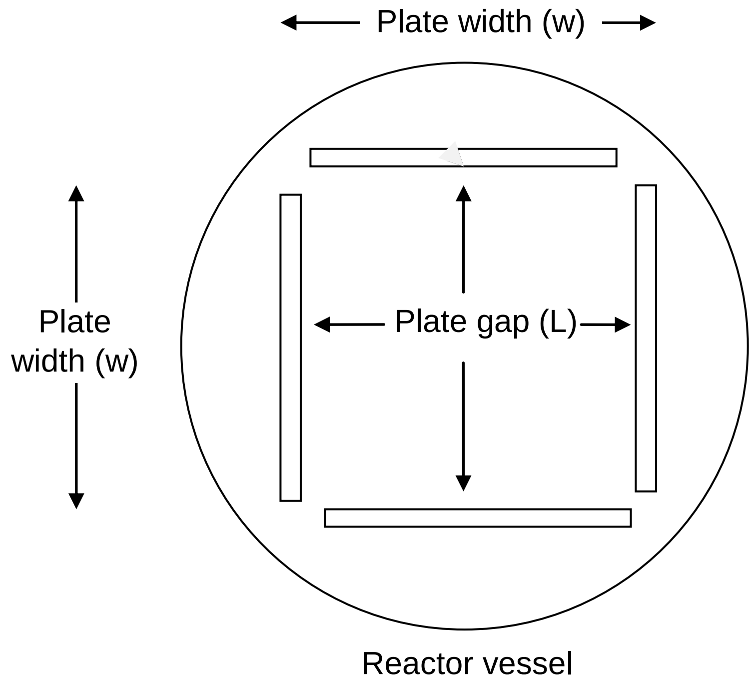

Fig. 3.17: Geometric arrangement of plates

The calculations for electrodes for 5 kg system

2W = $\sqrt{d^2 - L^2}$

Where,

W = width of the electrodes at different position in the beaker

d = Diameter of ohmic reactor vessel = 25 cm

L = Plate gap = 13.5cm

2W = $\sqrt{25^2 - 13.5^2}$ = 21

W = 10.5cm

Table 3.6: Plate width and effective area for 5 litre ohmic heating system

Voltage (V)	Plate gap (cm)	Plate width (cm)	Actual Plate height (cm)	Effective Plate height (cm)	Plate area(cm^2)	Area of drilled holes (cm^2)	Effective plate area (cm^2)
100	13.5	10.5	14.5	11.8	123.93	12.72	111.21

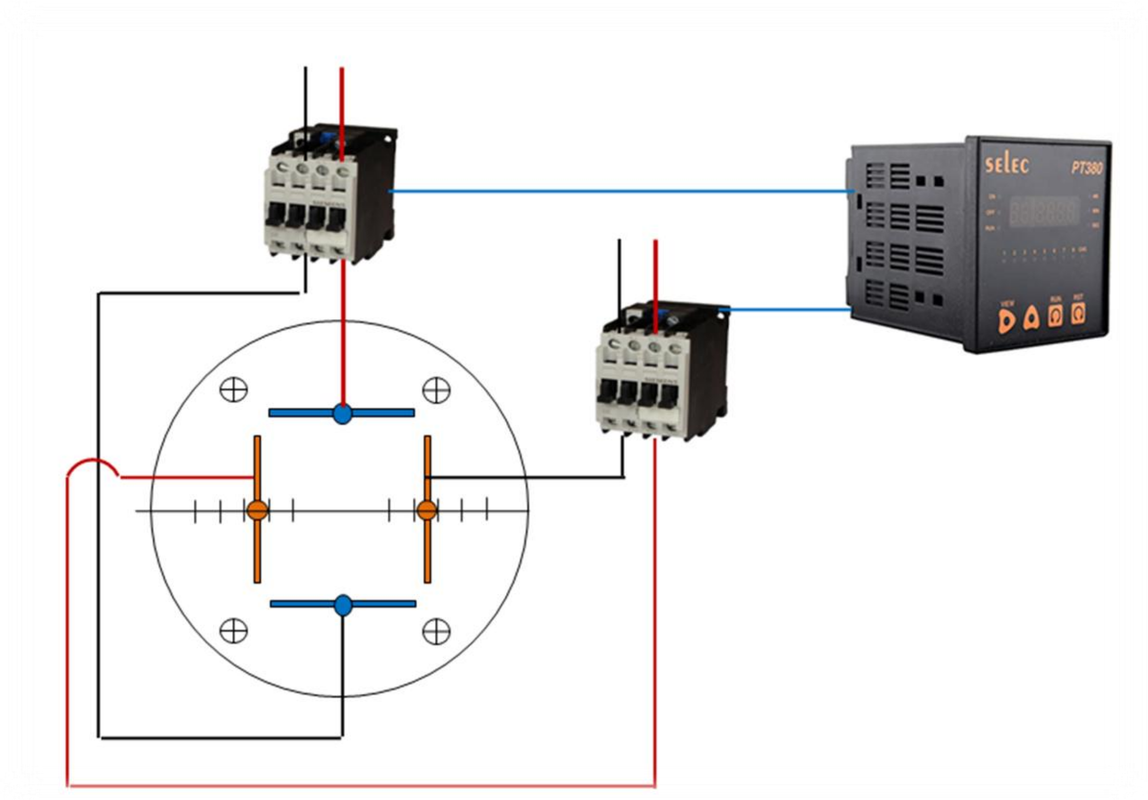

Fig. 3.18: Operating principle of paired plate type ohmic heating system

Figure 3.18 shows the operating principle of paired plate type ohmic heating system. In paired plate type setup, two set of plates (one set having orange color and another set having blue color) were placed within the reactor vessel. Each set of plates was connected to the contractor and the contractor was further programmed through sequential timer (Selec PT380). A current was passed to one set of plates for a given time duration. Once the time duration was over, the sequential timer sends an electrical signal to the contractor. Thus contractor cuts off the power supply and switches the power supply to another set of plates and vice-versa. Two air break contractors of 22A were used in the ohmic heating setup. During trials current was maintained below 20A for safe working of contractors.

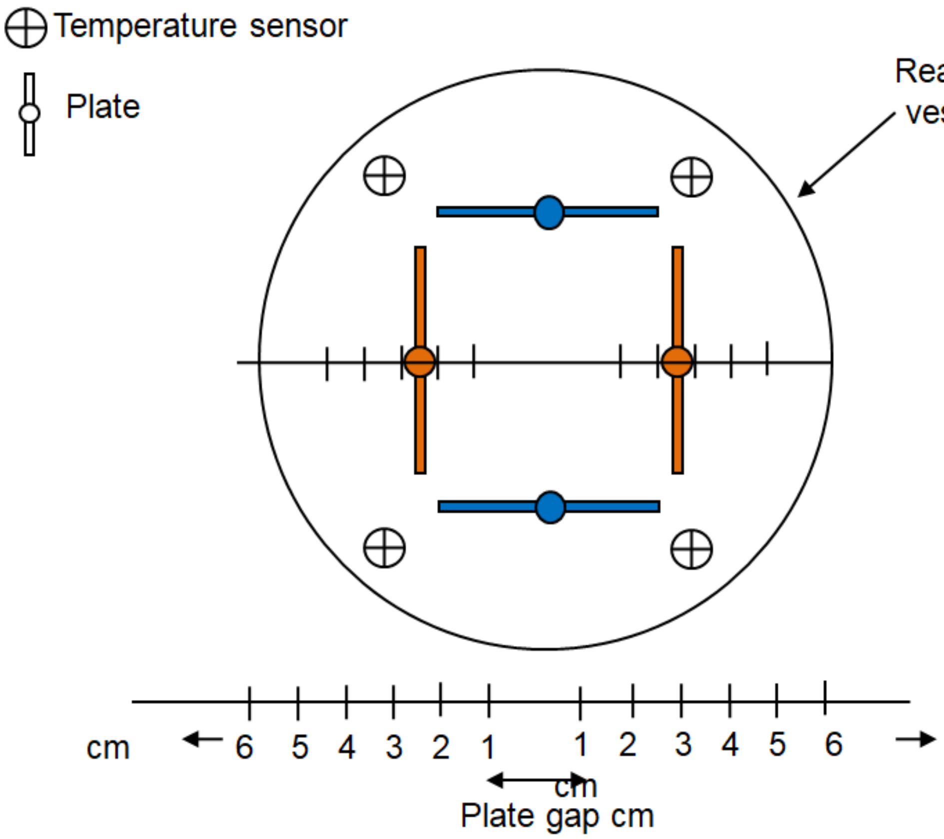

Fig. 3.19: Geometric arrangement of plates and temperature probes

3.3 Performance evaluation of paired plate type ohmic heating system (for cow milk)

The experiments were planned to evaluate the performance of paired plate type ohmic heating system (Table 3. 7). Two sets of plates were placed within the reactor vessel. Each set was connected to the contractor and further these contractors were programmed through the sequential timer. A current was passed to plates for different pairing time of 0, 20, 30, 40 and 50s respectively. Trials were conducted in three replications. The processing parameters for studying an experimental design consist of variable, fixed and thermal performance parameters. The performance evaluation parameters for ohmic heating system were temperature profile, heating time, heating rate, average temperature gradient, electrical conductivity, power consumption and thermal efficiency. The applied voltage was regulated manually to keep current below 22A.

Table 3.7: Experimental design for studying the effect of different pairing times on ohmic heating

Process parameters		Time (seconds)
Variable parameters	Pairing Time	0
		20
		30
		40
		50
Fixed parameters	Raw milk Temperature	20°C
	Final Milk Temperature	90°C
	Plate width	10.5 cm
	Agitator speed	300-400 rpm
	Milk type	cow milk
	Fat	4.2 %
	SNF	7.5 %

Thermal performance parameters
(Responses)
• Heating time • Heating rate • Average temperature gradient • Power consumption • Thermal efficiency • Temperature profile • Electrical Conductivity

3.4 Performance evaluation of paired plate type ohmic heating system (for buffalo milk)

Experiments were planned to evaluate the performance of paired plate type ohmic heating system for buffalo milk (Table 3. 8). The effect of ohmic heating was studied for pairing time of 0, 10, 20, 30, 40, and 50s respectively. Trials were conducted in three replications. The performance evaluation parameters for ohmic heating system were temperature profile, heating time, heating rate, average temperature gradient, electrical conductivity, power consumption and thermal efficiency. On the basis of above performance parameters, the effect of ohmic heating on cow and buffalo milk was compared. The applied voltage was regulated manually to keep current below 22A.

Table 3.8: Experimental design for studying the effect of different pairing time on ohmic heating

Process parameters		Time (seconds)
Variable parameters	Pairing Time	0
		20
		30
		40
		50
Fixed parameters	Raw milk Temperature	20°C
	Final Milk Temperature	90°C
	Plate width	10.5 cm
	Agitator speed	300-400 rpm
	Milk type	Buffalo milk
	Fat	6.2 %
	SNF	9.1 %

Thermal performance parameters
(Responses)
• Heating time • Heating rate • Average temperature gradient • Power consumption • Thermal efficiency • Temperature profile • Electrical Conductivity

3.5 Design and fabrication of upscaled rotating field type ohmic heating system

The conventional ohmic heating setup was upscaled according to the need of small dairy processing plants. The upscaled ohmic heating system was designed for 10 kg capacity. Firstly, rotating field type core was designed and developed with an objective to eliminate fouling and to minimize localized heating of plates. The rotating field type core consists of 3 sets of electrode plate (each set has 2 plates) arranged in hexagon shape within the ohmic reactor vessel. Fig. 3.23 shows the arrangement of plates in rotating field type core. Further each set of plates were connected to the contractors and programmed through sequential timer. Control system consisted of voltage controller, contractors, clamp meter, PID controller, sequential timer, current data logger and temperature data logger. During the trials voltage was regulated manually to keep current below 22A.

For automatic temperature control within the system, the PID controller (Selec PID500) was also incorporated in the heating setup. One air break contractor was incorporated in the main power supply line which was programmed through the PID controller. The setpoint value of the PID controller was kept at 90°C. Once the temperature reached 90°C, the PID controller sends a signal to the contractor and the contractor cuts the main power supply. The PID controller was incorporated for the safe working of the ohmic heating setup. The temperature sensors (pt 100) were also used to determine the average temperature gradient within the heating cell. Six temperature probes were placed within the reactor vessel to ensure uniformity of milk heating.

The agitator was also incorporated in the reactor vessel. A single phase AC motor was mounted on the angle iron stand with a provision to remove it whenever required. Solid state speed controller was used in the control panel to regulate the speed of agitator. Figure 3.21 shows the complete setup diagram with agitator. Provision was made in the iron stand at various positions to adjust the vertical position of agitator in the reactor vessel. The position of agitator was such that it was exactly at the centre between the plates *i.e.* at a distance of 21 cm from edge of the vessel. Height of agitator was also such that the rotating blades are exactly at height equal to the midpoint of the plate height. Agitator rpm was checked with digital tachometer and after preliminary trials at various rpm, optimum rpm for proper mixing was found in the range of 200-300. The agitator shaft is connected to the motor by a teflon rod to prevent current leakage of current in frame of setup.

The plate gap is one of the important parameter in design of ohmic heater. The top cover of ohmic reactor was designed with provision to vary distance between the plates. The plate gap and width for the 10 kg system was determined based on the data optimized by Lanjewar and Minz (2015).

$2W = \sqrt{d^2 - L^2}$

Where,

W = Plate width

d = Diameter of reactor vessel

L = Plate gap

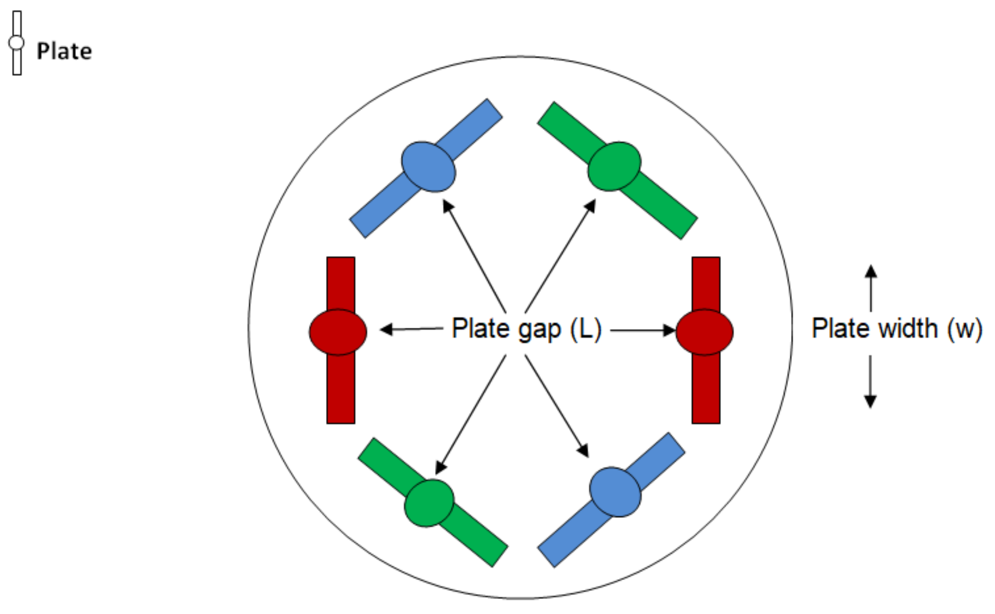

Fig. 3.20: Geometric arrangement of plates in rotating field type core

The calculations for electrodes for 10 kg system

$2W = \sqrt{d^2 - L^2}$

Where,

W = width of the electrodes at different position in the beaker

d = Diameter of ohmic reactor vessel = 35 cm

L = Plate gap = 28 cm

$2W = \sqrt{35^2 - 28^2} = 21$

W = 10.5cm

Table 3.9: Plate width and effective area for 10 litre ohmic heating system

Voltage (V)	100
Plate gap (cm)	28
Plate width (cm)	10.5
Actual plate height (cm)	14.5
Effective plate height (cm)	8.3
Plate area without drilled holes (cm^2)	87.15
No. of drilled holes in effective plate height	15
Area of one drilled hole (cm^2)	0.636
Effective plate area (cm^2)	77.61

Table 3.10: Specifications of reactor vessel

Capacity (kg)	20
Internal diameter (cm)	35
Edge to edge diameter (cm)	42
Height from base of vessel (cm)	24
Material of construction	SS-316L

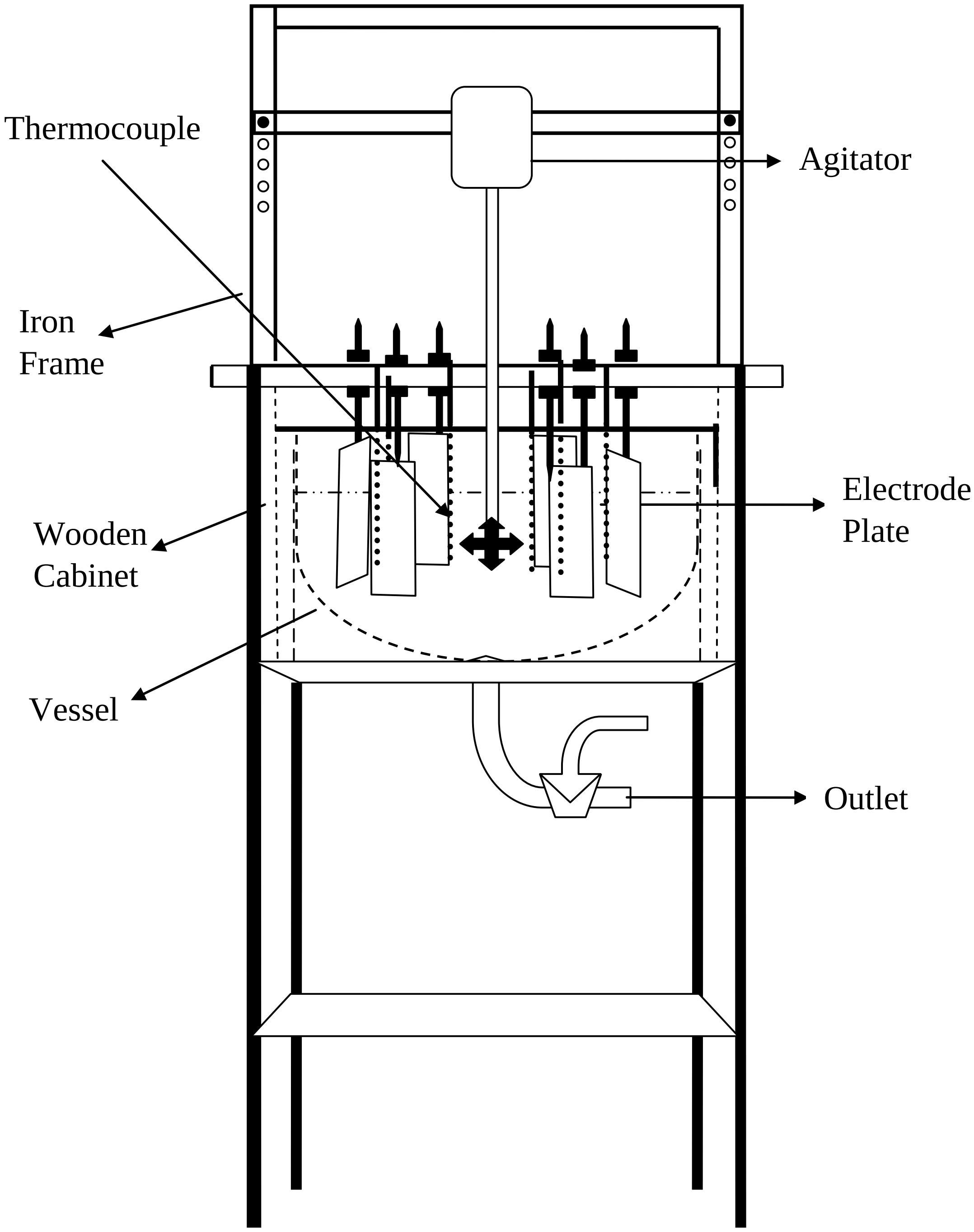

Fig. 3.21: Conceptual diagram of upscaled ohmic heating system

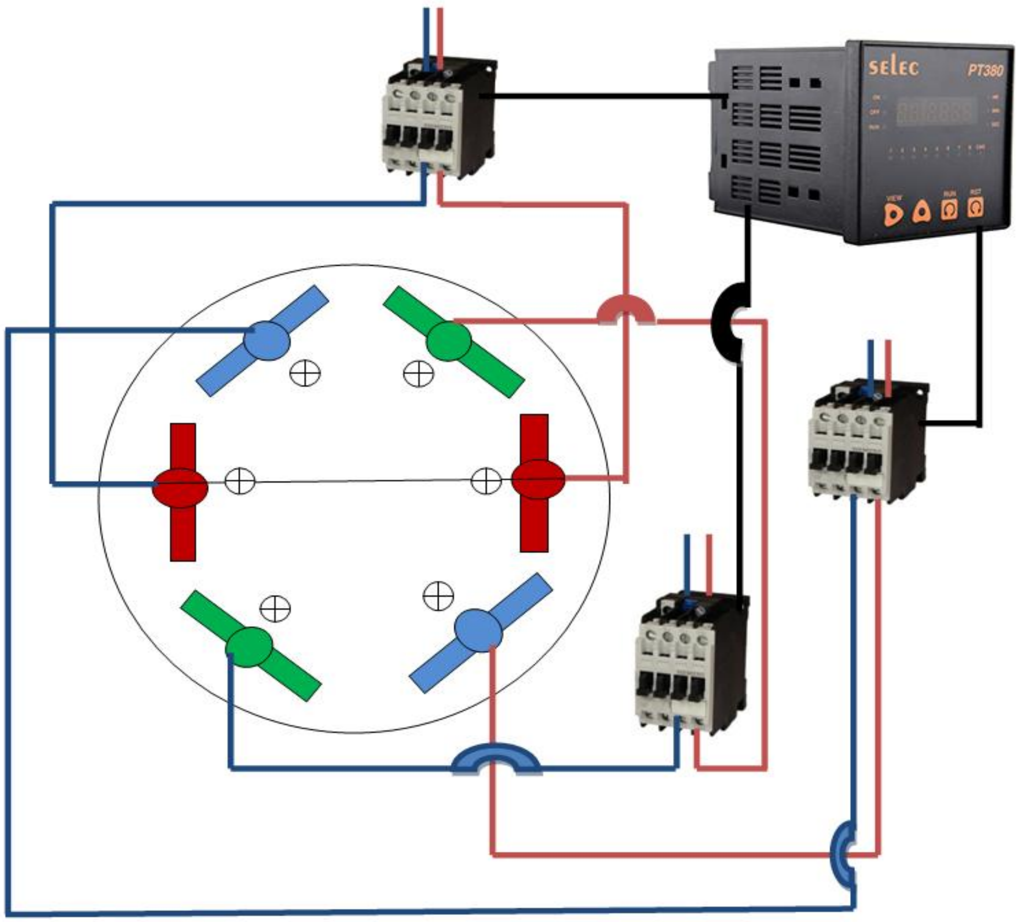

Fig. 3.22: Operating principle of rotating field type ohmic heating system

Figure 3.22 shows the operating principle of the rotating field type ohmic heating system. In rotating field type setup, heating plates were arranged in hexagon shape within the ohmic reactor vessel. Three sets of plates (one red, one blue and one red respectively) are shown in figure 3.23. Each set of plates was connected to the contractor and further these contractors were programmed through a sequential timer (Selec PT380). The sequential timer was provided with a digital display. A current was passed to the first set of plates for a fixed interval of time such that no current was passed through a second and third set of plates. Once the set time interval was completed, a sequential timer sends an electrical signal to the contractor and the contractor cuts off the power supply. Similarly, the current was passed to the second set of plates such that no current will flows through the first and third set. On completion of time duration, a sequential timer de-energizes the contractor and the contractor cuts the power supply. After that current was passed to the third set of plates while no current was flowing through the first and second set of plates. The same cycle was repeated until the milk temperature reached up to 90°C. Once the temperature reached 90°C, the PID controller automatically cuts down the main power supply. Three air break contractors of 22A were used in rotating field type ohmic heating setup.

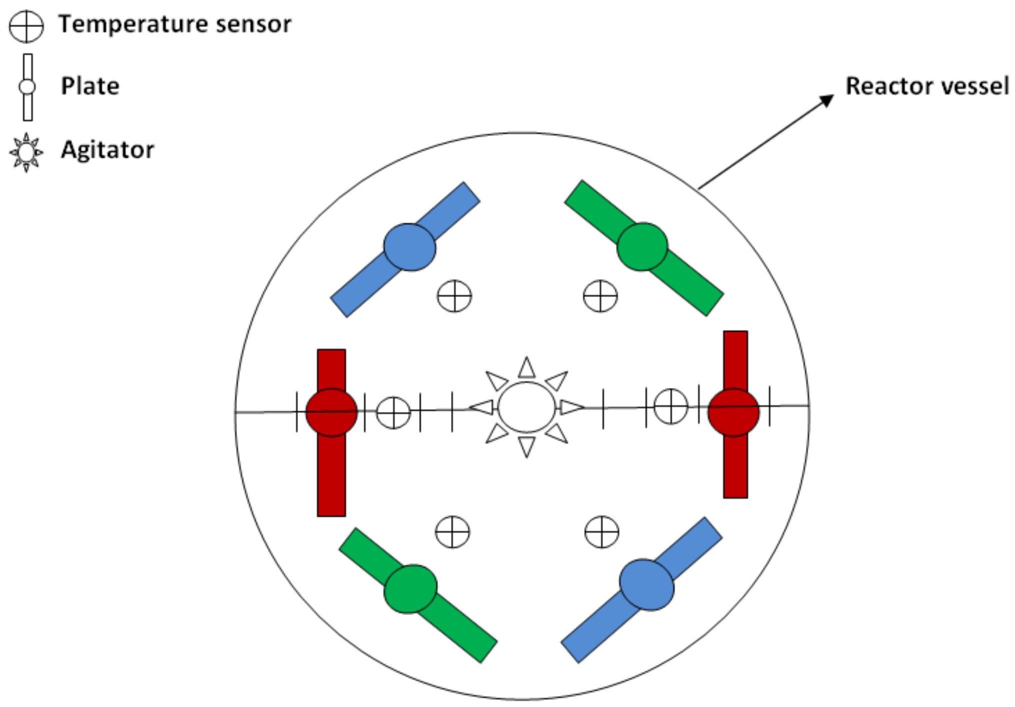

Fig. 3.23: Geometric arrangement of plates within reactor vessel

3.6 Performance Evaluation of up-scaled ohmic milk heating system

The experiments were planned to evaluate the performance of up-scaled rotating field type ohmic heating system (Table 3. 11). Three sets of plates were arranged in a hexagon shape within the ohmic reactor vessel. Each set was connected to the contractor and further these contractors were programmed through the sequential timer. A current was passed to each set of plates for different pairing times of 0, 1, 2 and 3 min respectively. Trials were conducted in three replications. The applied voltage was regulated manually to keep current below 22A.

Table 3.11: Experimental design for studying the effect of different pairing times on up-scaled ohmic heating system

Process parameters		Time (mins)
Variable parameters	Pairing Time	0
		1
		2
		3
Fixed parameters	Raw milk Temperature	20°C
	Final Milk Temperature	90°C
	Plate width	10.5 cm
	Agitator speed	200-300 rpm
	Milk type	cow milk
	Fat	4.2 %
	SNF	7.5 %

Thermal performance parameters
(Responses)
• Heating time • Heating rate • Average temperature gradient • Power consumption • Thermal efficiency • Temperature profile • Electrical Conductivity

3.7 Performance evaluation parameters

Temperature profile: Temperature profile indicates the pattern of temperature rise in milk during ohmic heating. Average temperature was plotted against time.

Heating time: Ohmic heating took less time as compared to other conventional heating systems like induction and electrical heating for the same quantity of milk. There is a decrease in heating time at high voltage gradients due to a higher energy generation rate (Bozkurt and Icier, 2010).

The total time required to increase temperature from 12^{o}C to 90^{o}C was calculated as total heating time.

Heating rate: The heating rate examines the extent of rapid heating. The heating rate was calculated as the rise in temperature per minute. The ohmic heating rates depend on electrical conductivities of the product, electrical field strength applied and the geometric configuration of the system (i.e. ratio between the surface of electrodes and the length separating the electrodes) (Marcotte et al., 1998). The ohmic heating rates increases with increase in voltage gradient. When material is heated at higher voltage gradients, the higher input energy increases the activity of water molecules resulting in higher heating rates.
Average heating rate was calculated as:-

$$\textbf{Heating rate} = \Delta T/t$$

Where,

ΔT= temperature difference (90-12^{o}C)

t=time

Average temperature gradient: Uniform heating of milk is very important. To study of uniformity of ohmic heating of milk, the average temperature gradient was calculated. The value of higher heating rates induces non-uniform heating that result in higher values of a temperature gradient within the ohmic reactor vessel. So for uniform heating, the value of the temperature gradient should be low. Four temperature sensors were used to determine the average temperature gradient. A temperature of pt-100 sensors was recorded as T1, T2, T3, and T4 respectively.

Average temperature gradient = $(|T_1 - T_3| + |T_2 - T_4|) /2$

Electrical conductivity: Electrical conductivity is the ability of a material that allows the current to pass through it when subjected to an electric field. It is the ratio of the current density to the electric field strength. Higher is the value of electrical conductivity, shorter will be the ohmic heating times. According to the literature data, EC is directly proportional to temperature i.e higher is the temperature, higher will be the value of EC due to increase in ionic mobility. The direct relationship between EC and temperature is related to the reduced drag of ions (Darvishi et al., 2015; Icier & Ilicali, 2005). At temperature above $70^{o}C$, a non-linear relationship between electrical conductivity and temperature is observed. This is due to bubble formation as bubbles do not conduct electric current.

Electrical conductivity (σ) was determined from the resistance of the sample and the geometry of the cell using the following equation:

$$\sigma = LI/AV$$

Where,

σ is the electrical conductivity (S/m)

L= is the gap between two electrodes (m)

A= is the cross-section area of the sample in the heating cell (m^2)

I= is the current (A)

V= is the voltage (V)

L/A= is known as the cell constant (k) of the ohmic heating unit

Power requirement: Power is directly proportional to current. As ohmic heating begins, the power requirement of heating setup is also increases. Power can be calculated by using formula given below:

$$P=VI$$

Where,

P= Power (kW)

V=Voltage (V)

I=Current (A)

Energy consumption: The most important factor that attracts research towards ohmic heating technology is energy consumption. The energy consumption of ohmic heating system is less as compared to other conventional heating methods. The reason for this is that ohmic heating is the direct heat generation technique that reduces heating times. In ohmic heating, energy consumption mainly depends upon the voltage gradient (Darvishi et al., 2014; Icier and Illicali 2005). Higher the value of current and voltage, the higher will be the energy consumption. Energy consumption also increases due to the longer heating times. Plate fouling is also a source of higher energy consumption because deposits on plate surface offers resistance to flow of current. The higher efficiency of ohmic heating was one of the major factors which attracted towards its study.

The energy consumption calculated with the equation:-

$$E=VIt$$

Where,

E= energy consumption (Wh)

V= voltage (V)

I= current (A)

t= time (hr)

System performance coefficient: is defined by the ratio of energy required for heating to the energy given to the sample. In other words, it is the ratio of energy output to energy input.

$$\mathbf{SPC = E_{taken}/E_{given} = Q/P}$$

$$\mathbf{= m\, c_p\, (T_f - T_i)/\sum VIt}$$

Where,

P=is the energy given to the system (J)

Q= heat required to heat the sample (J)

M=mass of the sample (kg)

Cp= is the specific heat capacity (3.93 KJ/Kg.K)

T= heating time (s)

V=voltage given to the system (V)

I= current (A)

RESULTS & DISCUSSION

4. RESULTS AND DISCUSSION

The present study was carried out in three phases. In the first phase, the ohmic heating setup (5 Kg capacity) was modified and an automatic temperature control system was integrated into the system. The paired plate type system was designed and developed with an objective to eliminate fouling and to minimize localized heating of plates. The control system consisted of a voltage controller, contractors, current data logger, and temperature data logger. Effect of ohmic heating was studied for pairing time of 0, 20, 30, 40 and 50s. In the second phase, paired plate type ohmic heating system was used for heating of buffalo milk and data of buffalo milk heating was compared with cow milk heating. In the third phase, up-scaled rotating field type ohmic milk heater (10 kg capacity) was designed, developed and assessed.

4.1 Design and fabrication of paired plate type ohmic heating system and its performance evaluation

The paired plate type system was designed and developed with an objective to eliminate fouling and to minimize localized heating of plates. The control system consisted of a voltage controller, contractors, current data logger, and temperature data logger. After completion of design and fabrication, preliminary trials were conducted to estimate the performance of the developed setup. The performance evaluation parameters for the ohmic heating system were temperature profile, heating time, heating rate, average temperature gradient, electrical conductivity, power consumption, and thermal efficiency. Effect of ohmic heating was studied for pairing time of 0, 20, 30, 40 and 50s.

4.1.1 Temperature profile

Temperature profile indicates the pattern of temperature rise in milk during ohmic heating. Average temperature was plotted against time. Fig 4.1 represents the average temperature profile of milk at different pairing time of

0, 20, 30, 40 and 50s. The temperature profile was almost linear for different pairing times.A similar result was reported by Liu et al. (2016) throughout their experiment on thawing of frozen tuna at high frequency by ohmic heating. They outlined linear relationship between temperature and heating time throughout ohmic thawing (Liu et al., 2016).There was a rapid increase in temperature for pairing time of 0, 30, 40 and 50s. Initially, the temperature rise was linear with time but in a later part of trials it becomes parabolic. During ohmic heating, when temperature increases, current in the circuit also increases and thus voltage needs to be reduced to kept current within the set limits. Reduction in voltage reduces heat generation and therefore sudden temperature drop was observed. The average initial temperature of milk for all the treatments was around 12^{o}C. Milk was heated from 12^{o}C to 90^{o}C. The time duration to reach final temperature of 90^{o}C was least incase of control (20 min) and highest for R20 (36 min). The ohmic heating time for remaining treatments (R30, R40, and R50) was almost around 23 min.There is a large gap between the curve of R20 and other remaining curves. This is due to the fact that in R20 field is rotated for the 20s and hence no effective heating of plates takes place. Hence it leads to localized heating of plates which causes a higher amount of fouling and thus increases ohmic heating times.Liu et al. (2017) conducted an experiment on thawing of frozen at high frequency by ohmic heating. They outlined linear relationship between temperature and heating time throughoutohmic thawing (Liu et al., 2017).

4.1.2 Current profile

Fig 4.2 represents the current profile of paired plate type ohmic heating system for pairing time of 0, 20, 30, 40 and 50s. According to Ohm's law voltage is directly proportional to the current i.e current in the system is increased with an increase in voltage and had a direct relationship with pairing time. Peak current requirement was in the increasing order from R20 to R50. The peak value of current for R20, R30, R40, and R50 were 16.3, 16.5, 17 and 19A respectively. There were small fluctuations in the value of current which was accurately recorded by the current data logger. The reason for

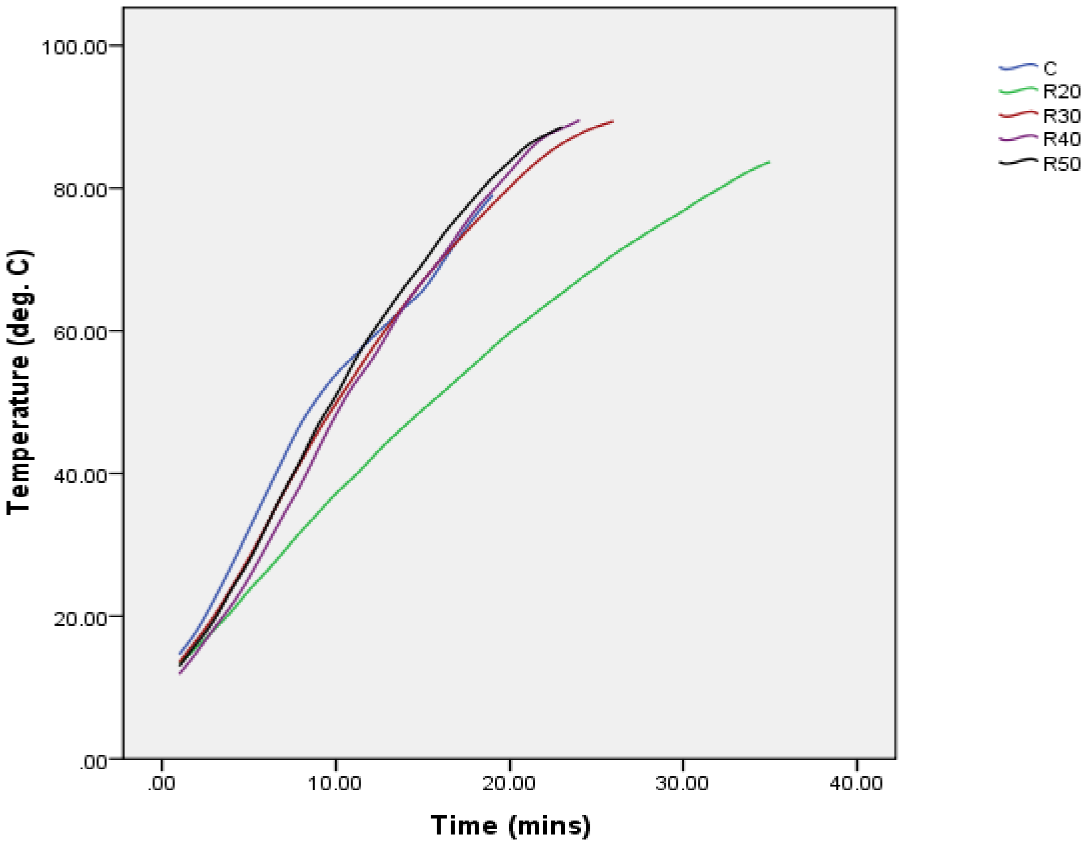

Fig. 4.1: Temperature profile during ohmic heating

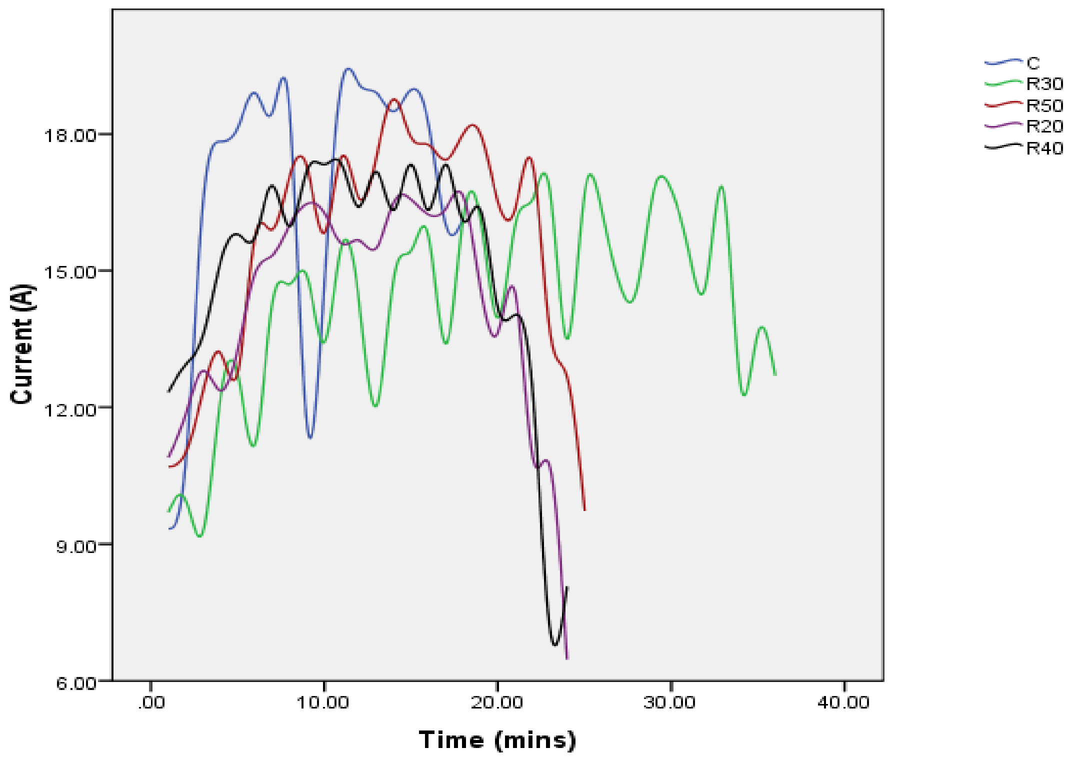

Fig. 4.2: Current profile during ohmic heating

fluctuations includes manual reduction of voltage when current reaches maximum allowable current value (22A). For rotating current within the plates, microseconds switch was on and off in paired plate type setup that also results in fluctuations.The trend of current was almost the same for all trials except for control (C) where fluctuations were large because the current is directly applied to plates without changing the field that causes localized heating of plates with excessive fouling and hence leads to the higher current requirement. During trials current was maintained below 20-21 A. Therefore, applied voltage had to be reduced whenever the current exceeds 21 A.

4.1.3 Temperature gradient

Fig 4.3 represents the temperature gradient within the reactor vessel during ohmic heating. Uniform heating of milk is very important. For uniform heating, the value of the temperature gradient should be low. For temperature monitoring, four probes were placed in the reactor vessel to ensure uniform heating. Uniformity in milk heating was observed with a low-temperature gradient (0.2-0.9^{o}C). Lowest value of temperature gradient was observed in R20 (0.50^{o}C) followed R30 (0.55^{o}C), R40 (0.80^{o}C) and R50 (0.90^{o}C) respectively. The higher heating rate induced uneven heating resulted in higher temperature gradient values in the ohmic reactor vessel (Fryer et al., 1993). A similar result was reported by Sarkis et al. (2013) for agitated and stable conditions. They concluded that for analysis of solids content, lower field intensity provides lower values of temperature gradient (Sarkis et al., 2013). In our trial voltage cannot be increased above 100 volts because of limitation of maximum current.

The fluctuation in values of temperature gradient was also noticed. The main reasons behind these fluctuations were agitation of milk at high speed and reading interval of temperature data logger was small i.e. 5s.

4.1.4 Electrical conductivity (EC)

EC of normal milk is between 0.40-0.50 S/m at 25^{o}C (Nielen et al., 1992). Electrical conductivity (EC) has a direct relationship with current and inversely proportional to applied voltage. As shown in fig 4.4, electrical conductivity

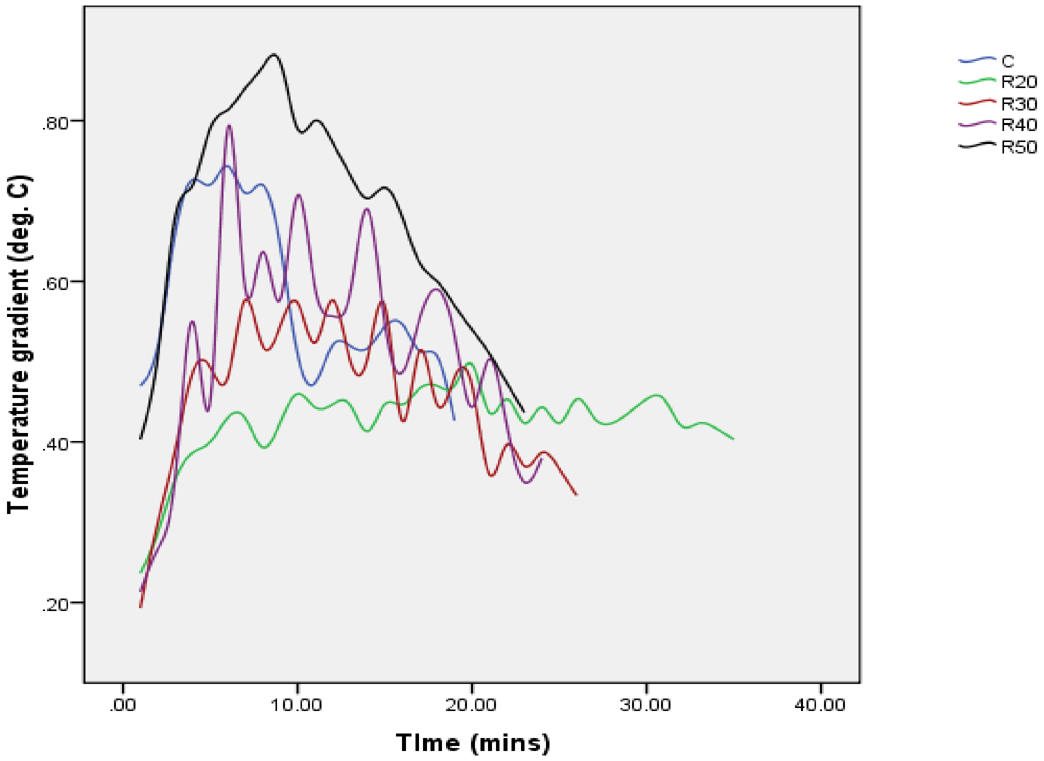

Fig. 4.3: Paired plate configuration effect on temperature gradient

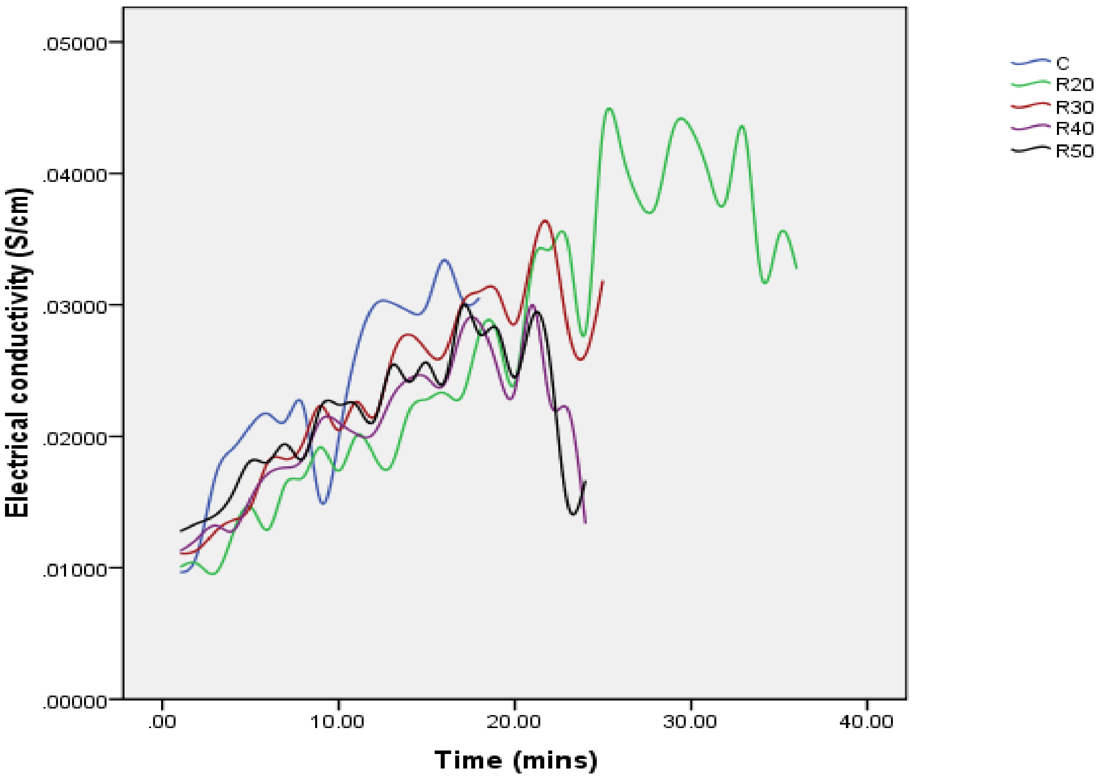

Fig 4.4: Effect of paired plate configuration on electrical conductivity

shows an increasing trend with time and in later stages, a slight decreased was observed. This may be due to fluctuations in the value of current; hence the values of EC are also fluctuating. There may be a sudden increase in the value of EC (fig 4.4) due to a sudden decrease in voltage to maintain current within the set limits. In case of control (0s), the EC value at the beginning of the process was 0.01 S/cm then increases to 0.033 S/cm at about 80^{o}Cand then once again decreases to 0.027 S/cm on completion of heating. The same values for treatment R50 were 0.013, 0.027 and 0.015 S/cm respectively. The higher electrical conductivity values are the results of higher voltage (Fadavi et al., 2018). At higher temperatures (>80^{o}C), a slight decrease in EC values is also observed due to the formation of bubbles and foaming. According to the literature data, EC is directly proportional to temperature. The rise ofelectrical conductivity with temperature rise is in relation with the reduced drag of ions (Fadavi et al., 2018).

4.1.5 Heating time

Ohmic heating causes quick and consonant heating. The time duration to carry out ohmic heating is as compared to other conventional heating systems like induction and electrical heating for the same quantity of milk. Because of higher rate of energy generation there is decrease in ohmic heating times at higher values of voltage (Bozkurt and Icier, 2010). Fig 4.5, shows the ohmic heating times for field rotation of 0(control), 20, 30, 40 and 50s respectively. It is evident from figure 4.5 that ohmic heating time for control is less as compared to field rotation of 20, 30, 40 and 50s respectively because the current was directly applied to electrode plates whereas, in treatments (R20, R30, R40, and R50), the field was changed after set time. Ohmic heating time for control is 22 min but heavy fouling of electrode plates was observed. Ohmic heating time for R50 (23 min) is less followed by R40 (25 min), R30 (28 min) and R20 (40 min) with no fouling of electrode plates. So it can be concluded that field rotation of the 50s took the least time in heating of milk to the required temperature with elimination in fouling. Pairing time has remarkable consequences on heating time at 5% level of significance. With the increase in pairing time, ohmic heating times are significantly reduced.

Higher applied voltage lowers the ohmic heating time. Therefore higher voltages should be used for the rapid heating of milk in the ohmic heater. A similar experiment was conducted by Darvishi et al. (2015) for studying the analysis of exergy and energythroughout tomato production byohmic heating.To reach upto the finished moisture content within tomato samples, they calculated ohmic heating times at completely different voltage gradient. They found that at completely different voltages0.06, 0.08, 0.10, 0.12, 0.14, and 0.16 V/m, the ohmic heating times were 0.424, 0.215, 0.139, 0.094, 0.078 and 0.06hr respectively. They concluded that rise in voltage gradient from 0.06 to 0.16 V/m reduces the overall time required for ohmic heating by 90% (Darvishi et al., 2015).

4.1.6 Heating rate

The heating rate examines the extent of rapid heating. The heating rate was calculated as the rising in temperature per minute. The product electrical conductivity, voltage gradient and also the structural arrangement of the systemare the vital parameters on which rate of ohmic heating depends (Marcotte et al., 1998).

Figure 4.6 shows the comparison of heating rates for field rotation at 0, 20, 30, 40 and 50s respectively. It is evident from the figure that the heating rate was higher in case of control (3.5^{o}C/min) as compared to the pairing time of 20, 30, 40 and 50s respectively. This is because the current is continuously applied to electrode plates in case of control without any change in rotation field that results in higher heating rates. Among pairing time of 20, 30, 40 and 50s, the maximum heating rate was observed in field rotation of 50s i.e R50 (3.3^{o}C/min) followed by R40 (3.2^{o}C/min), R30 (2.9^{o}C/min) and R20 (1.9^{o}C/min) respectively. Paired plate type ohmic heating system minimizes localized heating of plates, hence fouling of plates. Thus heating takes place at lower values of current as compared to that of control. So the effect of current was outstanding during heating and reduction in current results in lower heating rates in case of field rotation of 20, 30, 40 and 50s respectively. Pairing time significantly increased the heating rate ($p<0.05$) due to increase in voltage gradient. The lower ohmic heating rates were observed at low values of electrical field intensity (Salengke and Sastry, 2007). A similar result was reported Darvishi et al., (2019) during preservation of orange concentrate through ohmic heating. They reported that increase in value of voltage gradient increases the ohmic heating rate throughout heating. Icier &Ilicali, (2005) also reported same result that at higher voltage gradient, the energy input to the sample is also higher that increases the water molecules activity within the sample and further leads to higher ohmic heating rates.

4.1.7 Energy consumption

The most important factor that attracts research towards ohmic heating technology is energy consumption. The energy efficiency of ohmic heating was high (around 82-97%)with reduction in ohmic heating times (around 90-95%) in contrast with traditional heating techniques (De Halleux et al., 2005).Figure 4.7 shows the power requirement of paired plate type ohmic heating system for pairing time of 0, 20, 30, 40 and 50s respectively. Initially power increases as heating of milk begins. As heating continues, decrease in power was observed in all the treatments. The values of power are fluctuating due to fluctuations in value of current as power is directly proportional to current.

Fig 4.8 shows energy consumption of paired plate ohmic heating setup at differentpairing time of 0, 20, 30, 40 and 50s respectively.The main reason behind higher energy consumption was prolonged heating time, plate fouling and the system had to be operated for a longer duration. Average energy consumption for heating of 5kg milk was maximum in the case of treatment R20(0.524 kWh). This isbecause of heating takes place for longer duration of period with excessive fouling of electrodes plates. Energy consumption decreases with an increase in pairing time. The values of energy consumption for pairing time of 0, 20, 30, 40, and 50s were 0.443, 0.524, 0.472, 0.429, 0.383 kWh respectively. Within pairing time (20, 30, 40, and 50s), decreasing trend in energy consumption was obtained due to decrease in heating time because of increase in heating rate. A similar result were outlined by Darvishi et al. (2015) that prolonged heating times at lower electrical field intensity results in higher energy consumption.

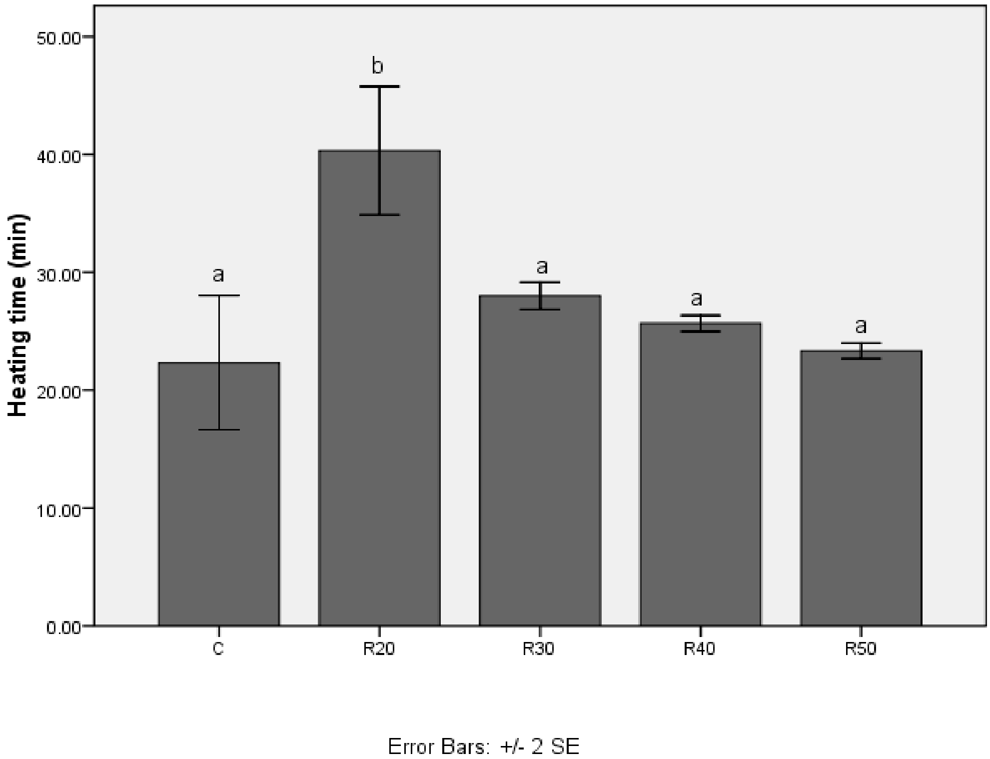

Fig 4.5: Effect of paired plate configuration on heating time

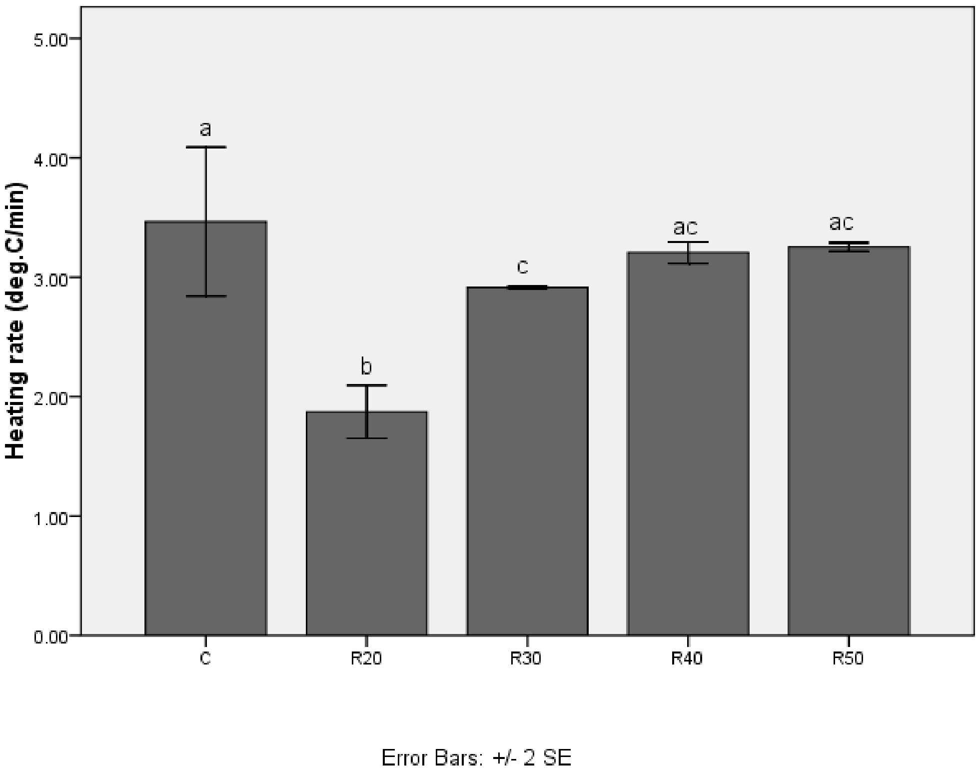

Fig 4.6: Paired plate configuration effect on heating rate

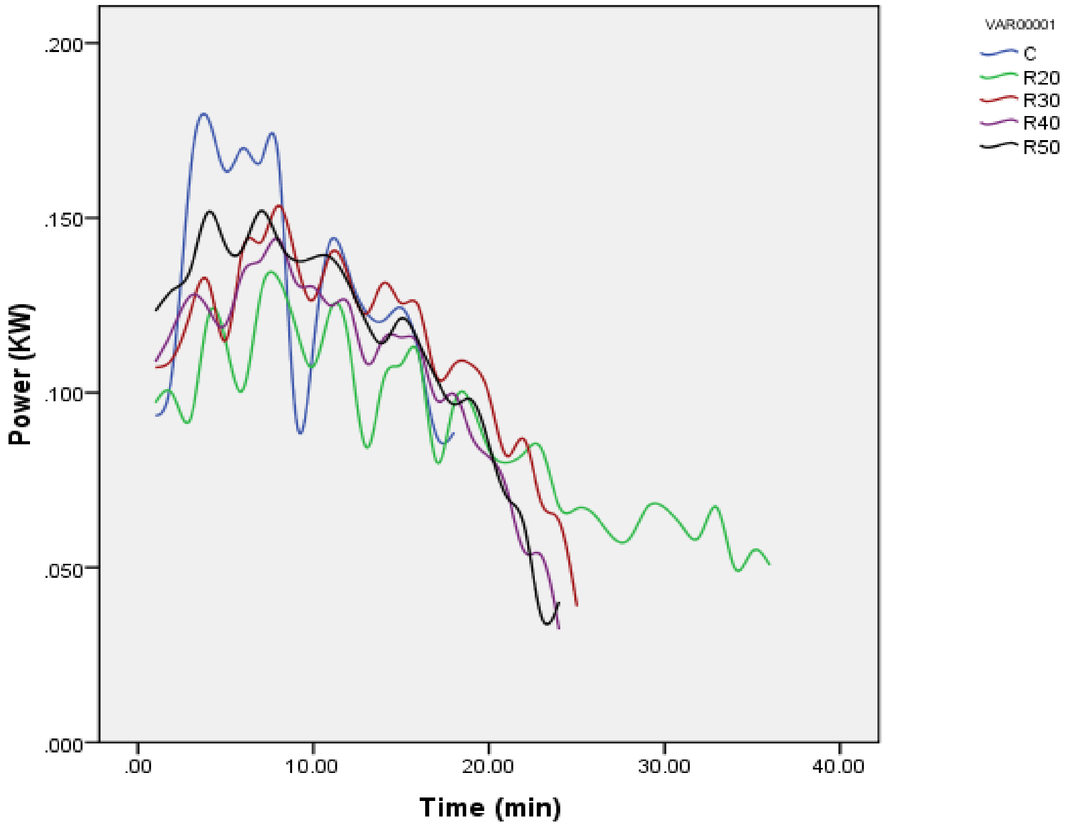

Fig 4.7: Paired plate configuration effect on power requirement

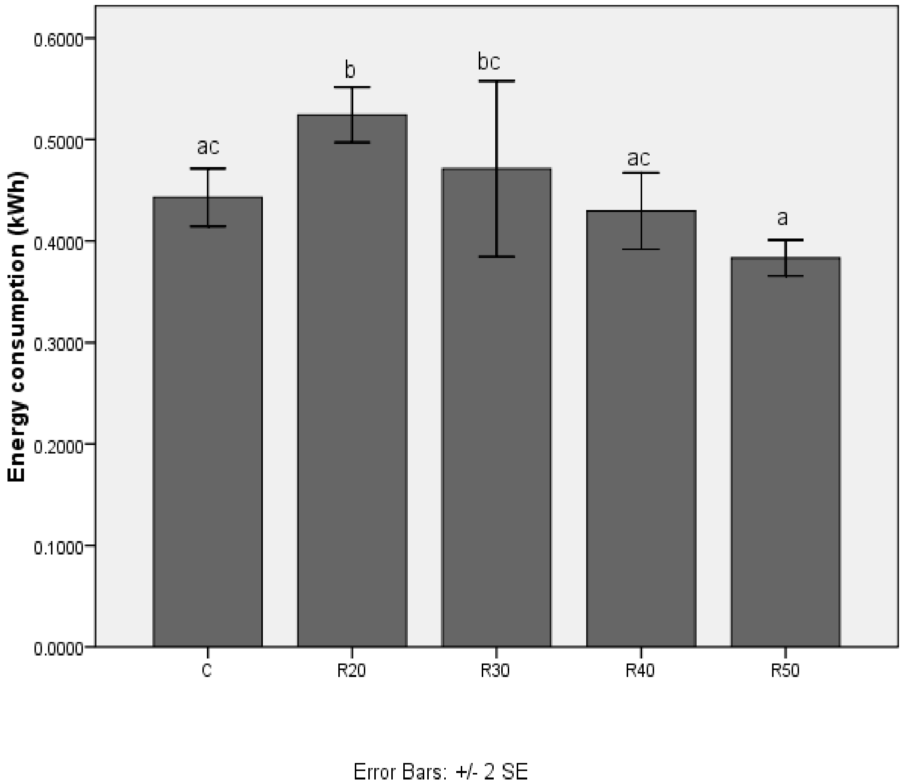

Fig 4.8: Paired plate configuration effect on energy consumption

4.2 Performance evaluation of paired plate type ohmic heating system for buffalo milk heating

A paired plate type ohmic heating system was used for buffalo milk heating and its performance was evaluated. The performance evaluation parameters for the ohmic heating system were temperature profile, heating time, heating rate, average temperature gradient, electrical conductivity, power consumption, and thermal efficiency. Effect of ohmic heating was studied for pairing time of 0, 20, 30, 40 and 50s. Results of paired plate type ohmic heating system for cow milk and buffalo milk heating were also compared.

4.2.1 Temperature profile

Ohmic heating follows a sigmoid trend. Fig 4.9 represents the average temperature profile of milk at different pairing time of 0, 20, 30, 40 and 50s. The trend for temperature profile was similar in all the trials. The temperature profile was almost linear for different pairing times. There was a rapid increase in temperature for pairing time of 0, 20, 30, 40 and 50s respectively. Initially, temperature rises linearly with time but in later stages of trials, it becomes parabolic. As temperature increases, the current requirement also increases and thus applied voltage needs to be reduced. This reduction in voltage decreases heat generation and hence temperature drop was observed which makes curve parabolic in later stages of trials. A similar result was reported during ohmic heating of mango puree (Makroo et al., 2019). They reported that there is direct relationship between temperature and time duration for which electrical field was applied (Makroo et al., 2019).

4.2.2 Current profile

The current profile was not linear. There were small fluctuations in the value of current which was accurately recorded by the current data logger. The trend of current was almost same for all trials. These fluctuations may be due to manual reduction of voltage to keep current below maximum allowable limit (22A) and rotating current within the plates by on an off of microsecond switch. Fig 4.10 represents the current profile of paired plate type ohmic heating system for pairing time of 0, 20, 30, 40 and 50s. The initial current drawn by the ohmic heating systemwas 7.5 A which further increases as

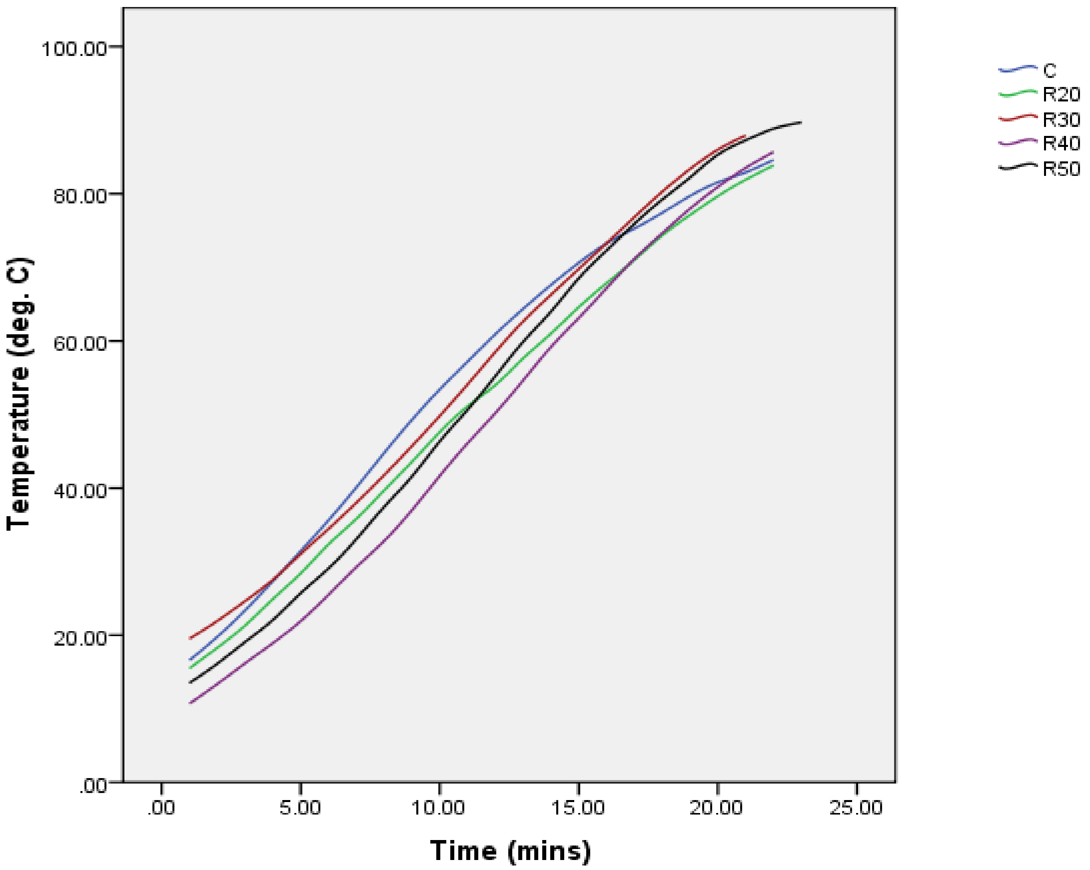

Fig. 4.9: Temperature profile during ohmic heating of buffalo milk

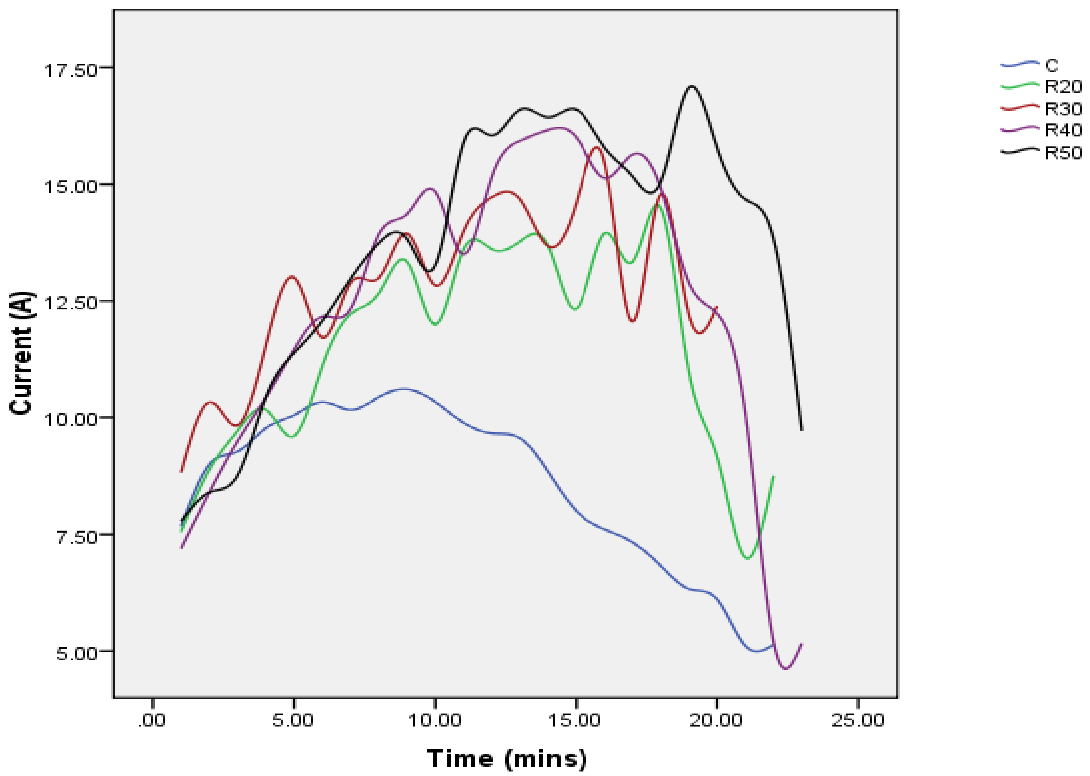

Fig. 4.10: Current profile during ohmic heating of buffalo milk

In buffalo milk heating, a direct relationship between current and pairing time heating proceeds.was observed. The current requirement was minimum for control and maximum for treatment R50. Peak current requirement for pairing time of 0s (10.5 A), 20s (14 A), 30s(15.5 A), 40s(16 A) and50s(17 A) respectively. Mean values of the current show an increasing trend from control to the rotation field of the 50s. Mean values of current for control (8.54 A), R20(11.33 A), R30(12.83 A), R40(12.29 A) and R50(13.54 A) respectively. Pairing time significantly increases the current requirement ($p<0.05$). During trials current was maintained below 20-21 A. Therefore, applied voltage had to be reduced whenever the current exceeds 21 A.

4.2.3 Temperature gradient

The uniform heating of milk is very important. For uniform heating of milk, value of temperature gradient should be low. Figure 4.11 represents the temperature gradient within the reactor vessel during heating. No regular trend was observed among treatments. Uniformity in milk heating was observed with a low-temperature gradient (0.20-0.70^{o}C). Among control (0s) and treatments (R20 and R50), significant difference was observed at a 5% level of significance. No significant difference was observed in control and treatments (R30 and R40) at the same level of significance (5% level of significance). This may be due to improper mixing of reactor vessel contents by the agitator. Mean values of temperature gradient observed for control (0.50^{o}C), R20(0.344^{o}C), R30(0.518^{o}C), R40(0.522^{o}C) and R50(0.364^{o}C) respectively.

The fluctuations in values of temperature gradient were observed. These fluctuations may be due to mixing within the reactor vessel at high rpm and scanning rate of temperature data logger was 5s i.e. in every 5s reading was recorded by data logger.

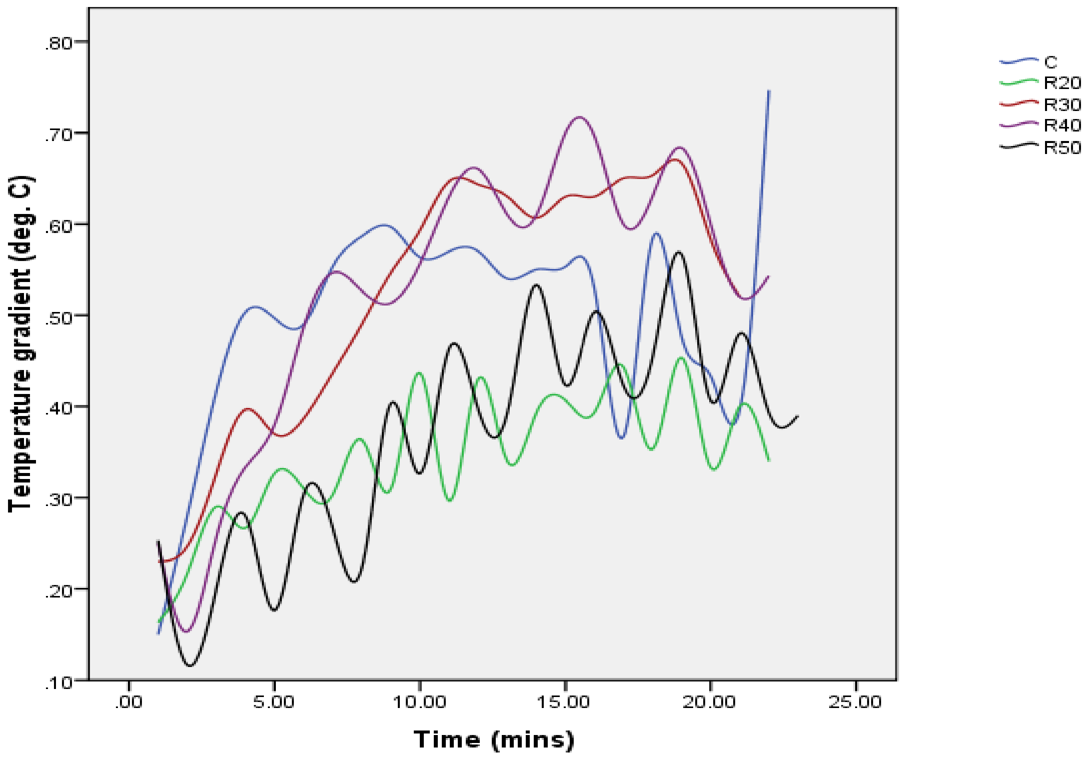

Fig 4.11: Paired plate configuration effect on temperature gradient

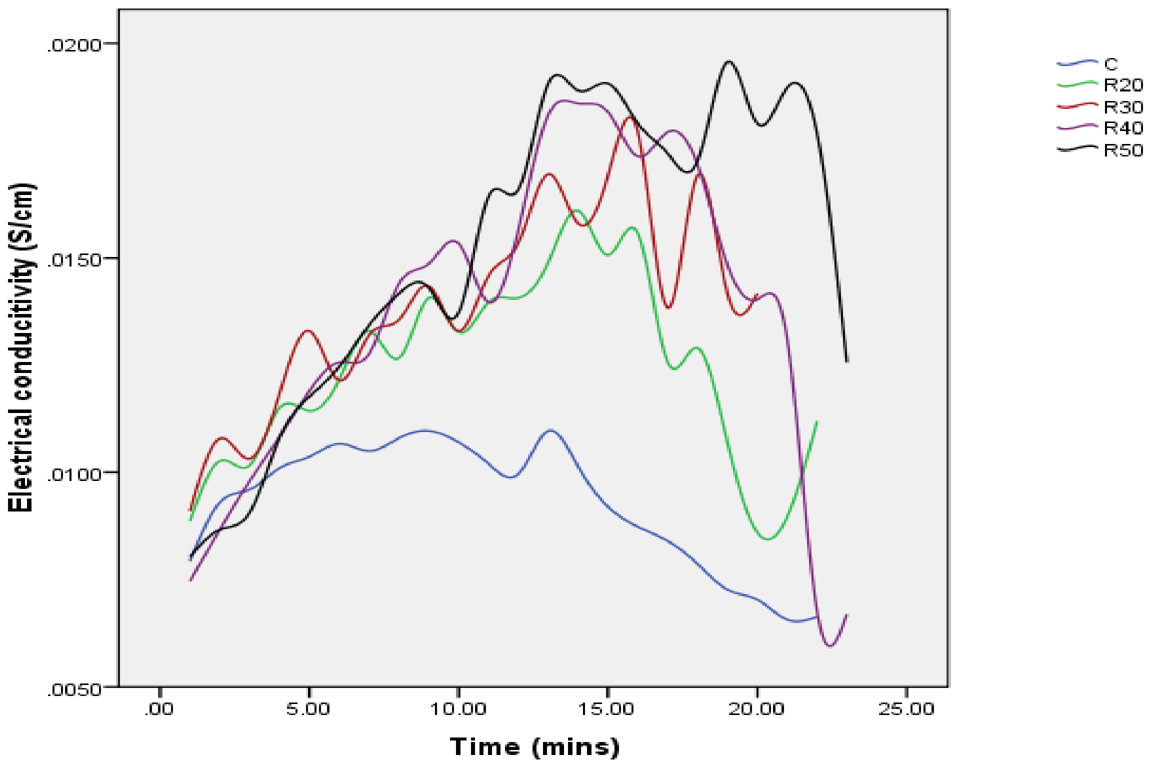

Fig 4.12: Paired plate configuration effect on electrical conductivity

4.2.4 Electrical conductivity (EC)

From figure 4.12, it is evident that the trend of electrical conductivity was almost the same in all the trials. Initially, EC has shown an increasing trend with time and in later stages, a slight decrease in the value of electrical conductivity was observed.This is due to foaming and bubble formation at a higher temperature (>80°C). According to literature data, electrical conductivity is directly proportional to temperature;at a higher temperature a slight decrease was observed. This may be due to fluctuations in values of current, as EC is directly proportional to current. Mean values of EC at different pairing times (0, 20, 30, 40 and 50) were 0.009, 0.0124, 0.0139, 0.0135 and 0.015 S/cm respectively. Electrical conductivity has a significant effect for different pairing times (0, 20, 30, 40 and 50) at a 5% level of significance ($p<0.05$). EC increases with an increase in pairing time and temperature. Similar results were reported by Sabanci and Icier (2017) when lemon juice was ohmically heated. They reported that values of electrical conductivity rises from 54 S/cm (at 20°C) to 92 S/cm (at 75°C) throughout the ohmic heating (Sabanci and Icier, 2017).

Values of EC are fluctuating with time due to the manual controlling of voltage to keep current below the maximum allowable limit and rotating current in paired plate type setup by on and off of microsecond switch of sequential timer.

4.2.5 Heating time

Ohmic heating time for control (0s) is less as compared treatments (R20, R30, and R40) because of higher heating rate (3.48°C/min). From figure 4.13, it is evident that the decreasing trend in heating time was observed among treatments with a decreasing level of fouling. The average values of heating time for different pairing times (0, 20, 30, 40 and 50s) were 23 min, 25.33 min, 24.33 min, 23.33 min, and 22.33 min respectively. So, treatment R50 gives a lower value of heating time (22.33 min) with the elimination of fouling at electrode plates. Higher the voltage gradient, shorter will be the ohmic heating times due to higher heating rates. A similar trend was reported by Sabanci and Icier, (2017) when sour cherry juice was concentrated by ohmic heating (from 19.2% TSS to 65% TSS). They found that at three completely different values of voltage gradient 0.14 V/m, 0.12 V/m, and 0.10 V/m and for conventional vacuum evaporation, the time required for ohmic heating were 0.67, 0.92, 1.25, and 1.42 hr respectively (Sabanci and Icier, 2017). Gally et al. (2017) also reported similar results whenohmic heating was utilized for bread dough proofing.They concluded that heating time required to get expansion ratio around three was shorter when higher ohmic heating rates were used. When heating rates varies from 1 to 10°C/min, to attain same expansion ratio ohmic heating took 1.08-1.17 hr whereas proofing carried out by conventional methods took 2.03 hr.Ohmic heating times for proofing of bread dough were 1.44, 1.37, and 1.35 at applied voltages of 50, 100, and 150V respectively.

Treatment R50 also gives the best result in the case of cow milk heating. Heating time for cow milk and buffalo milk was 23.67 and 22.33 min respectively. Heating time for buffalo milk is less as compared to cow milk due to higher electrolytic concentration in buffalo milk.

4.2.6 Heating rate

The heating rate was used to measure the extent of heating. Figure 4.14 shows the heating rate during buffalo milk heating for pairing time of 0, 20, 30, 40 and 50s respectively. The maximum heating rate was observed in the case of control (3.48°C/min) because the current was continuously applied which results in higher heating rates with fouling of plates. Among treatments, the increasing trend of heating rate was observed from R20 to R50. Mean values of heating rate for different pairing times (0, 20, 30, 40 and 50s) were 3.48, 2.99, 3.10, 3.28 and 3.36°C/min respectively. Heating rate can be increased by increasing applied voltage but that additionally result in non-uniform heating. The activity of molecules of water present within the samples can be enhanced at higher values of voltage gradient, so leads to higher ohmic heating rates (Darvishi et al., 2019).

Treatment R50 gives the best results in both cow and buffalo milk. Compared to cow milk (3.25^{o}C/min), higher heating rates were observed in buffalo milk (3.36^{o}C/min) due to higher ionic concentration.

4.2.7 Energy consumption

In ohmic heating, energy consumption mainly depends upon the voltage gradient (Darvishi et al., 2015; Icier and Illicali 2005). Higher the value of current and voltage, the higher will be the energy consumption. Fig 4.15 shows the relationship between power and time duration throughout heating. It is evident from fig. 4.15 that as heating begins; the power requirement of system also increases. Once the power reaches the peak values after that overall decrease in power was observed throughout heating. This is due to the fact that at higher temperature, heating takes place at lower values of current due to increase in conductivity of milk. The fluctuations in value of power are due to fluctuations in value of current throughout heating. The power requirement increases with increase in pairing time.

Energy consumption also increases due to the longer heating times. Figure 4.16 shows energy consumption at different pairing times of 0, 20, 30, 40 and 50s respectively. Energy consumption decreases with increase in pairing time. Average energy consumption for different pairing times (0, 20, 30, 40 and 50s) was 0.373, 0.512, 0.484, 0.446 and 0.393 kWh respectively. This decrease in energy consumption may be due to decrease in ohmic heating times because heating occurs rapidly with higher values of heating rate. The decrease in energy consumption may be due to decrease in plate fouling with increase in pairing time. Energy consumption was less for control due to shorter heating times. Gally et al. (2017) reported dissimilar results whenohmic heating was utilized for proofing of bread dough. They reported that the energy expenditure increases with increase in heating rate still the time duration to hold out heating was smaller. Energy consumption at different applied voltages of 50, 100 and 150V were 88.3, 98.2 and 98.7 KJ respectively.

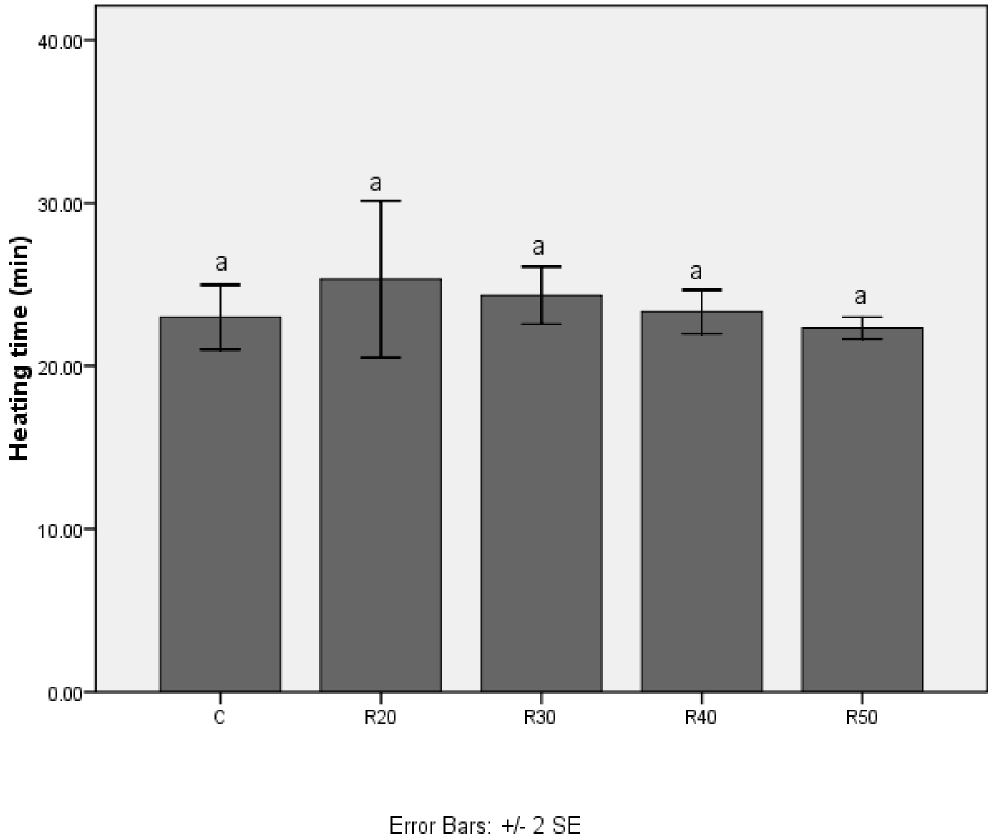

Fig. 4.13: Effect of paired plate configuration on heating time

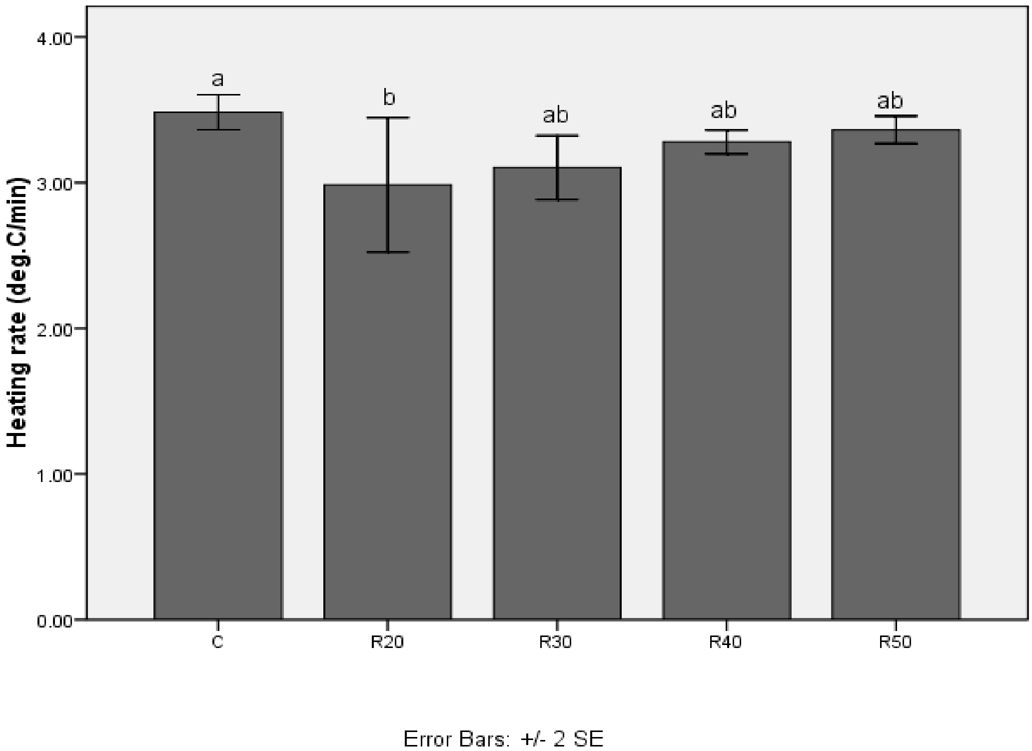

Fig. 4.14: Effect of paired plate configuration on heating rate

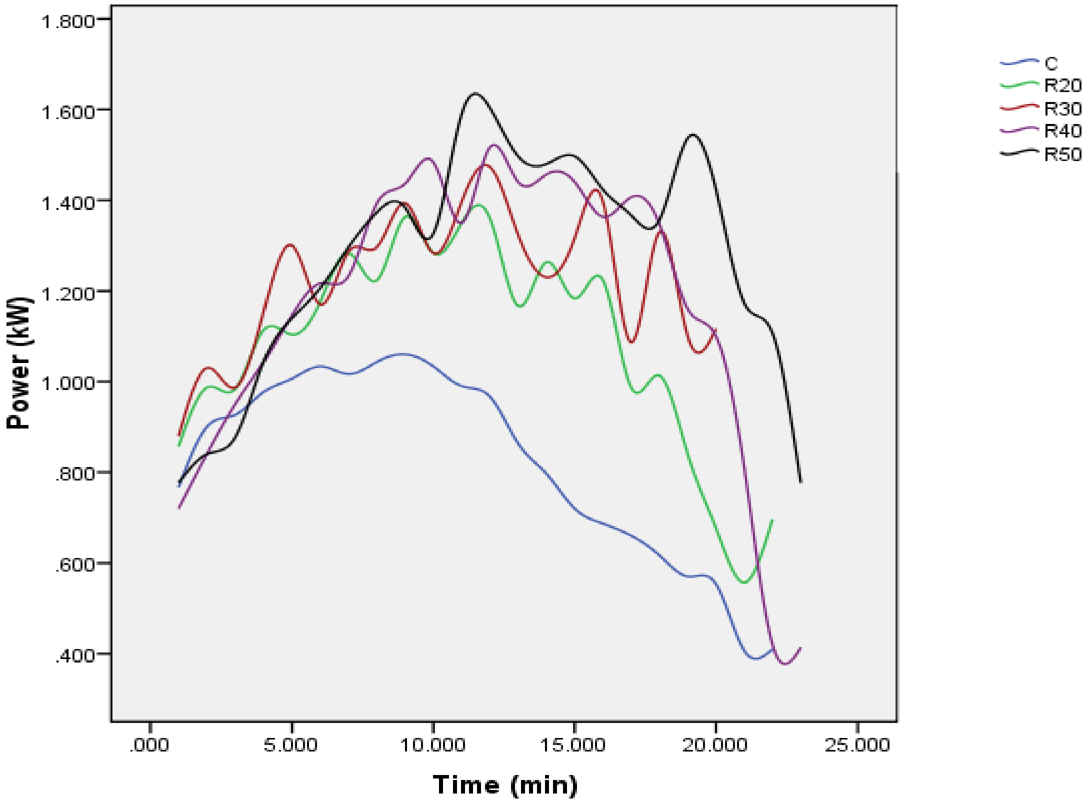

Fig. 4.15: Effect of paired plate configuration on power

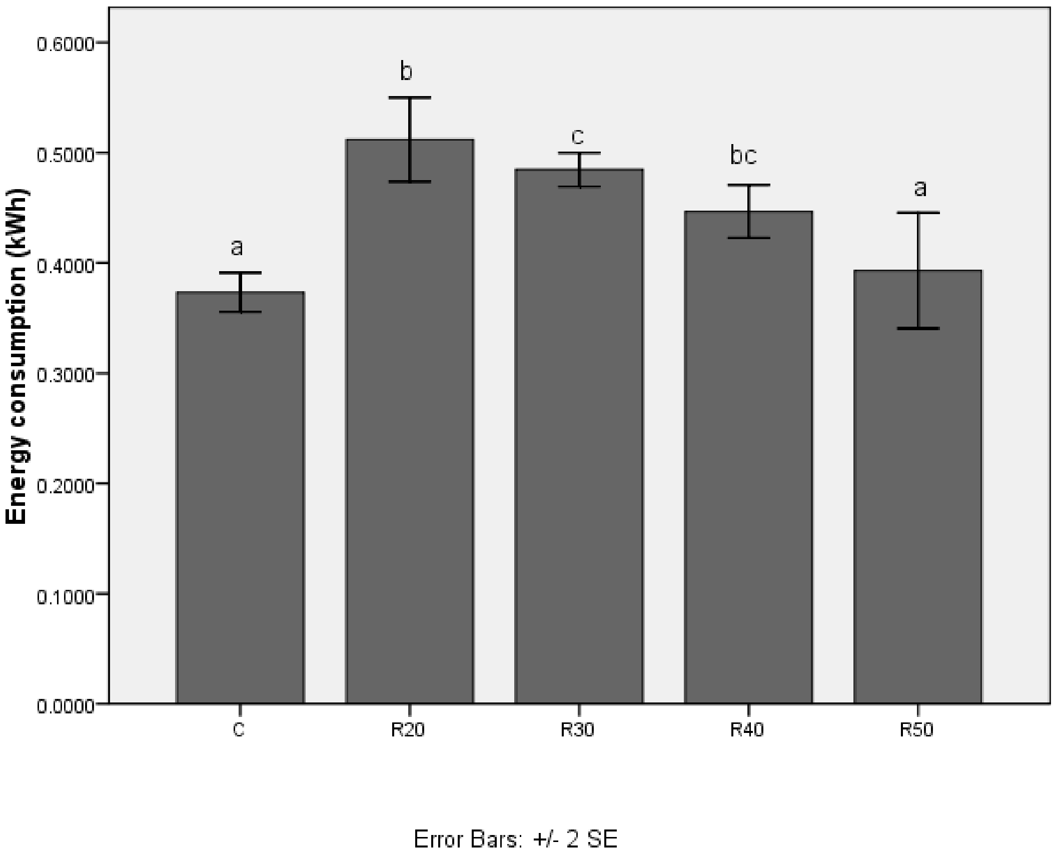

Fig. 4.16: Effect of paired plate configuration on energy consumption

4.3 Performance evaluation of upscaled rotating field type ohmic heating system

In this phase, the up-scaled rotating field type ohmic milk heater (10 kg capacity) was designed and developed. The effect of heating for pairing times of 0, 1, 2 and 3min were assessed. The performance evaluation parameters for the ohmic heating system were temperature profile, heating time, heating rate, average temperature gradient, electrical conductivity, power consumption, and thermal efficiency. Rotating field type core of ohmic heating system consists of 6 electrode plates (3 sets) which were arranged in hexagon shape within the reactor vessel. To overcome the problem of fouling, the agitator was integrated within the reactor vessel.

4.3.1 Temperature profile

The temperature profile has shown an increasing trend with time (fig. 4.17). The temperature profile was linear initially but became parabolic towards the later part of trials. The average initial temperature of milk was kept below 20^{o}C in all the trials. The final temperature up to which milk heated was 90^{o}C. The temperature profile of treatment R2 and R3 were almost close to each other. As shown in figure 4.15, the temperature in case of control cannot reach 90^{o}C because of the excessive fouling of plates that leads to the higher current requirement and also leads to higher ohmic heating times. Figure 4.18 shows the problem of extreme fouling in case of control. The temperature curve of treatment R1 was flatter towards horizontal due to lower heating rates that increase ohmic heating times. Among control (0s) and treatments (R1, R2, and R3), significant difference was observed at a 5% level of significance.

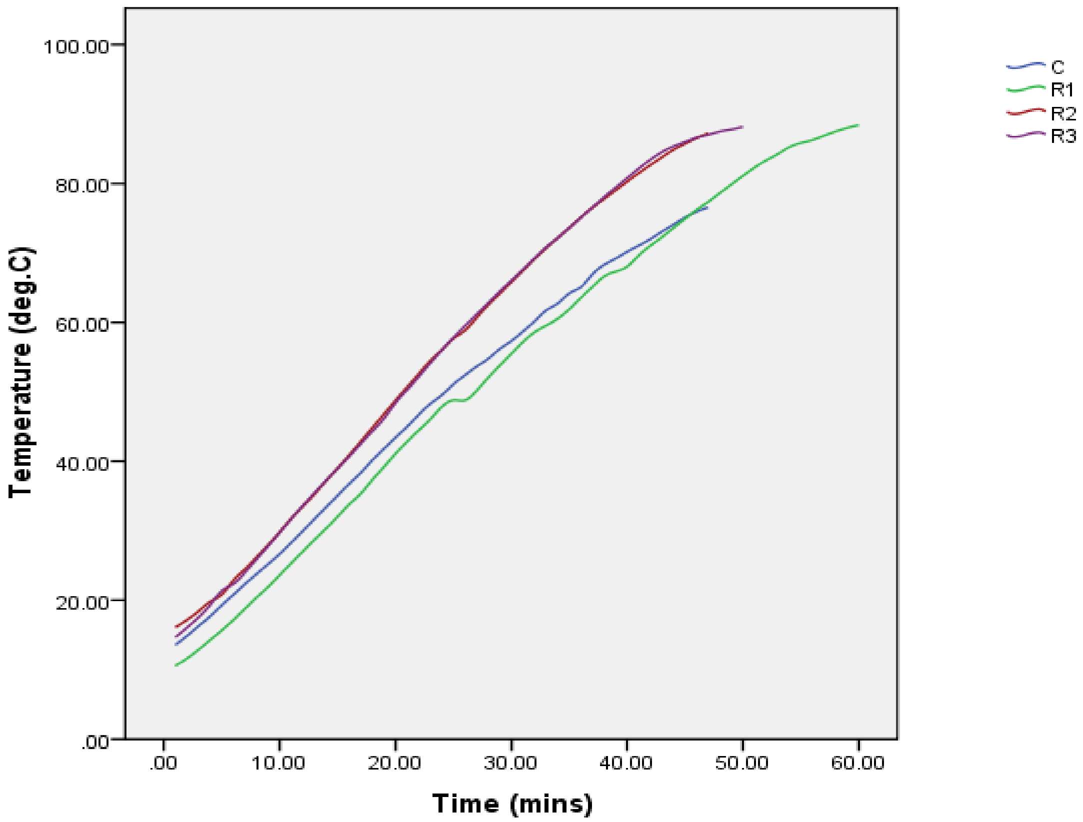

Fig. 4.17: Temperature profile for up-scaled rotating field type ohmic milk heating system

Fig. 4.18: Problem of extreme fouling in case of control in up-scaled rotating field type ohmic heating system

4.3.2 Current profile

Figure 4.19 shows the current profile during heating for pairing times of 0, 1, 2 and 3 min respectively. The increase in current was not linear. The current was fluctuating throughout the trials.These fluctuations may be due to manual reduction of voltage to keep current below maximum allowable limit (22A) and rotating current within the plates by continuous on an off of microsecond switch. The trend of current was almost the same in all the trials. The current requirement has an inverse relationship with the pairing time. Mean values of current for pairing time of 0, 1, 2 and 3 min were 6.12A, 5.36A, 4.89A, and 4.76A respectively. The current requirement of treatments (R1, R2, and R3) was less as compared to control because the current was passed to plates for a fixed interval of time and the current was switched off to another set of plates, whereas in control current was directly applied to plates without changing its rotation field. This leads to the extreme fouling of plates. Among control (0s) and treatments (R1, R2, and R3), significant difference was observed at a 5% level of significance.

4.3.3 Temperature gradient

The uniformity of milk heating is very important. As shown in figure 4.20, the temperature gradient was lower for control (0.2-1.30ºC) as compared to treatment R3 (0.3-1.50ºC). In the up-scaled ohmic heating system, heating of milk takes place at higher voltage gradient values because the quantity of milk to be heated also increases. Higher values of voltage gradient result in higher heating rates. Mean values of the temperature gradient for pairing time of 0, 1, 2 and 3 min were 0.985, 1.080, 1.120 and 1.273ºC respectively. Among control (0s) and treatments (R1, R2, and R3), significant difference was observed at a 5% level of significance.

Qihua et al. (1993) assessed the temperature at 5 completely different locationswithin the two reactor vesselsthroughoutprocessing of orange juice by ohmic heating. The lower temperature gradient values (1-2°C) were determined within the smaller ohmic reactor vessel (0.048 m length) whereas the values of temperature gradient at three completely different voltage

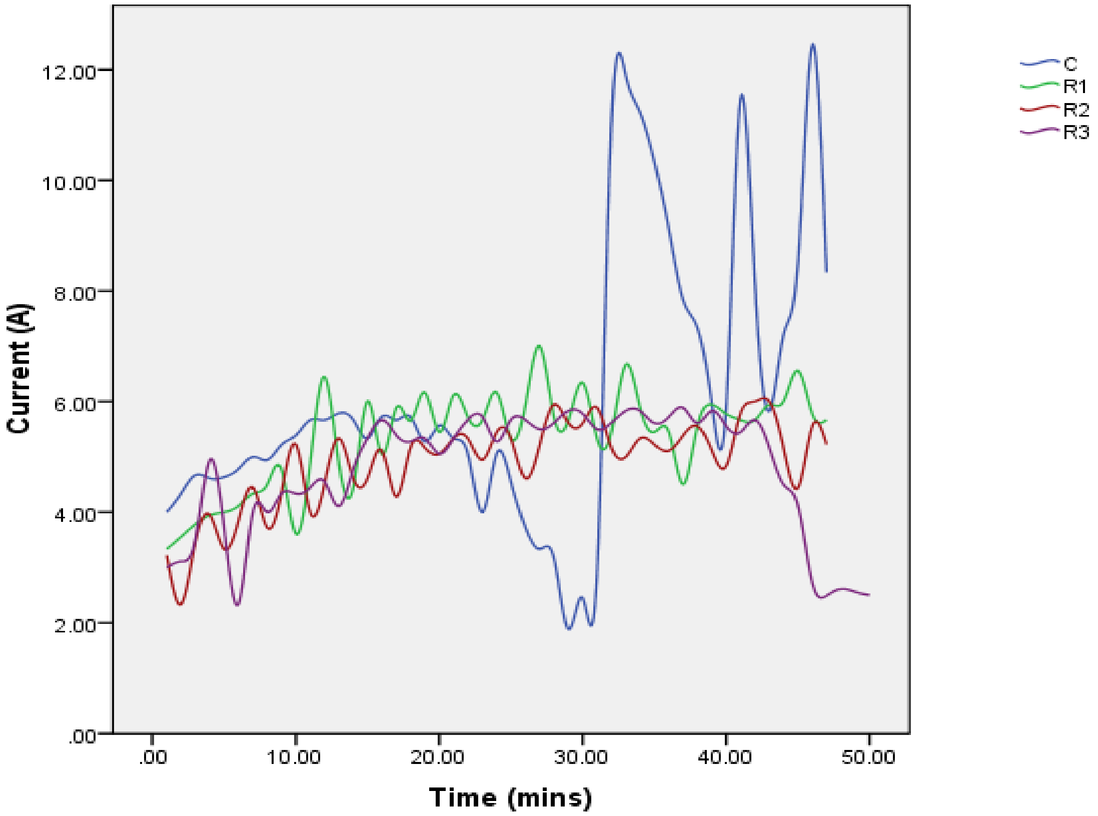

Fig. 4.19: Current profile for up-scaled rotating field type ohmic milk heating system

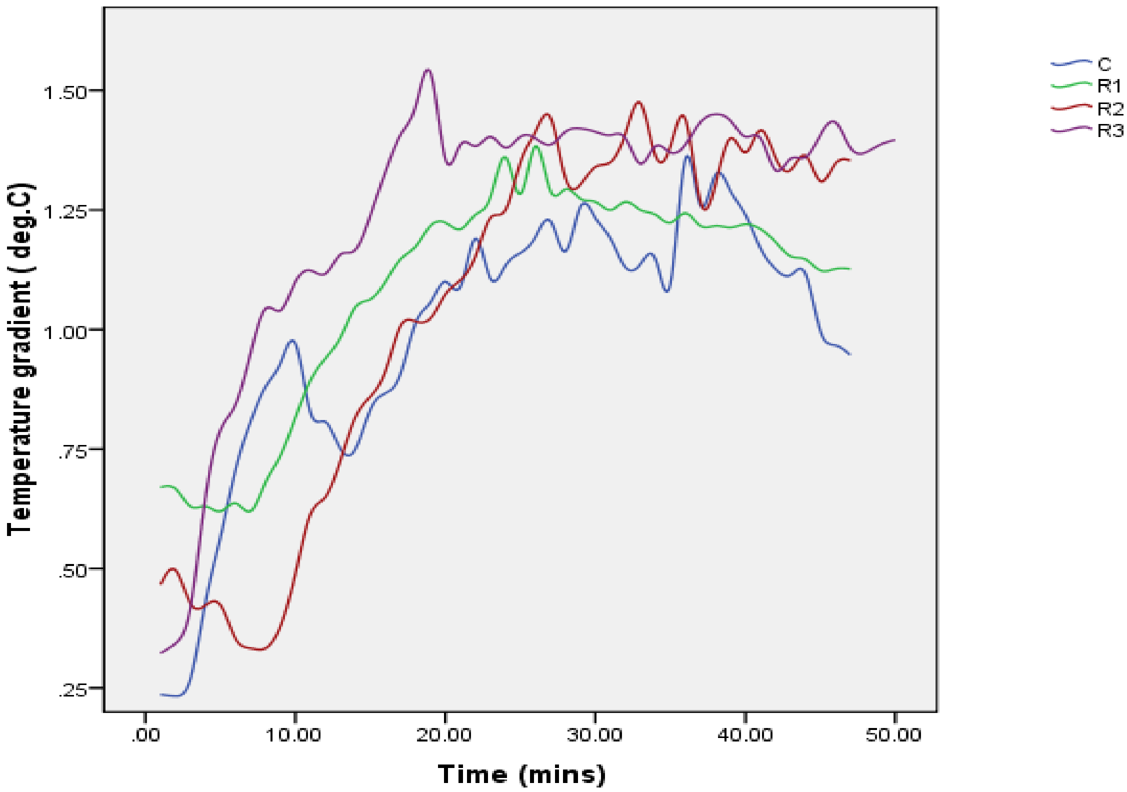

Fig. 4.20: Temperature gradient for milk heated in up-scaled ohmic heating system

around2.6, 3.0 and 5.8 °C, respectively. This specifies that the reduction in dimensions of the reactor vessel offers additionalhomogenous and consistent heating (Sarkis et al., 2013). So, in up-scaled (10 kg capacity) ohmic heating system higher values of temperature gradient were observed as compared to 5 kg capacity ohmic heating system.

The fluctuations in values of temperature gradient were observed. These fluctuations may be due to mixing within the reactor vessel at high rpm and scanning rate of temperature data logger was 5s i.e. in every 5s reading was recorded by data logger.

4.3.4 Electrical conductivity (EC)

Electrical conductivity has a direct relationship with current and inversely proportional to applied voltage. Electrical conductivity has shown an increasing trend with time (fig. 4.21). The trend of electrical conductivity was almost the same as that of the current profile. Peak values of electrical conductivity were obtained in case of control (0 min) due to large current requirements during trials. The values of electrical conductivity also show an increasing trend with temperature but in later stages, the slight decrease may be noticed due to bubbling. These fluctuations in values of EC may be due to fluctuations in the value of current due to manual reduction in voltage to keep maximum allowable current below 22A and current is rotated within the heating plates by on and off of microsecond switch. Mean values of EC for pairing time of 0, 1, 2 and 3 min were 0.0072, 0.0057, 0.0059 and 0.0065 S/cm respectively. EC value in case of control was higher due to a continuous supply of current without changing field rotation whereasin R1, R2 and R3 field is rotated after 1, 2 and 3 min respectively.

4.3.5 Heating time

Ohmic heating results in rapid and uniform heating. The time required for heating in the ohmic heater is less as compared to other heating methods for the same quantity of milk. From figure 4.22, it is evident that the time required for heating was less in treatments (R1, R2, and R3) as compared to control (0 min). The last time was taken in treatment R3 followed by R2 and R1 respectively. Heating time is longer in case of control because the current is applied directly to plates that results in localized heating of plates thus extreme fouling. Fouling takes place to such an extent that the temperature of milk cannot rise above 75°C. Average heating time for different pairing times (0, 1, 2 and 3 min) was 64.33, 56, 51.66 and 49 min respectively. Increasing the pairing time significantly ($p<0.05$) reduces the heating times.Higher values of voltage gradient give higher heating rates and thus reduce ohmic heating times. The rise in voltage gradient significantly reduces the cooking time (Bozkurt and Icier, 2010).

4.3.6 Heating rate

Figure 4.23 shows the heating rate within the reactor vessel for the pairing time of 0, 1, 2 and 3 min respectively. It is evident from the figure that heating rate increases with an increase in pairing time. The heating rate for control, R1, R2, and R3 are 1.357, 1.36, 1.436 and 1.53°C/min. The heating rate was least in case of control due to excessive fouling of plates. Heating rate increases with an increase in plate area (Lanjewar, 2015). The heating rate was also less due to the increase in the quantity of milk for heating without increasing the plate area. Heating rate can be increased by increasing applied voltage but that result in non-uniform heating.

4.3.7 Energy consumption

Energy consumed during ohmic heating mainly depends upon the voltage gradient. Higher the values of the voltage gradient, the higher will be the energy consumption. Longer heating times at low voltage gradient also results in higher energy consumption. From figure 4.25, it is evident that energy consumption decreases with an increase in pairing time. Increasing pairing time significantly ($p<0.05$) reduces energy consumption. The energy consumption was higher for control (0.40 kWh) and least for treatment R3 (0.33 kWh).

Fig. 4.24 shows the variation of power throughout ohmic heating. As heating begins, power starts increasing with time, then achieve maximum values and then decreases throughout heating. Within pairing time of 1, 2 and 3 min, increasing trend of power was observed. The fluctuations in value of power are due to current fluctuations throughout milk heating.

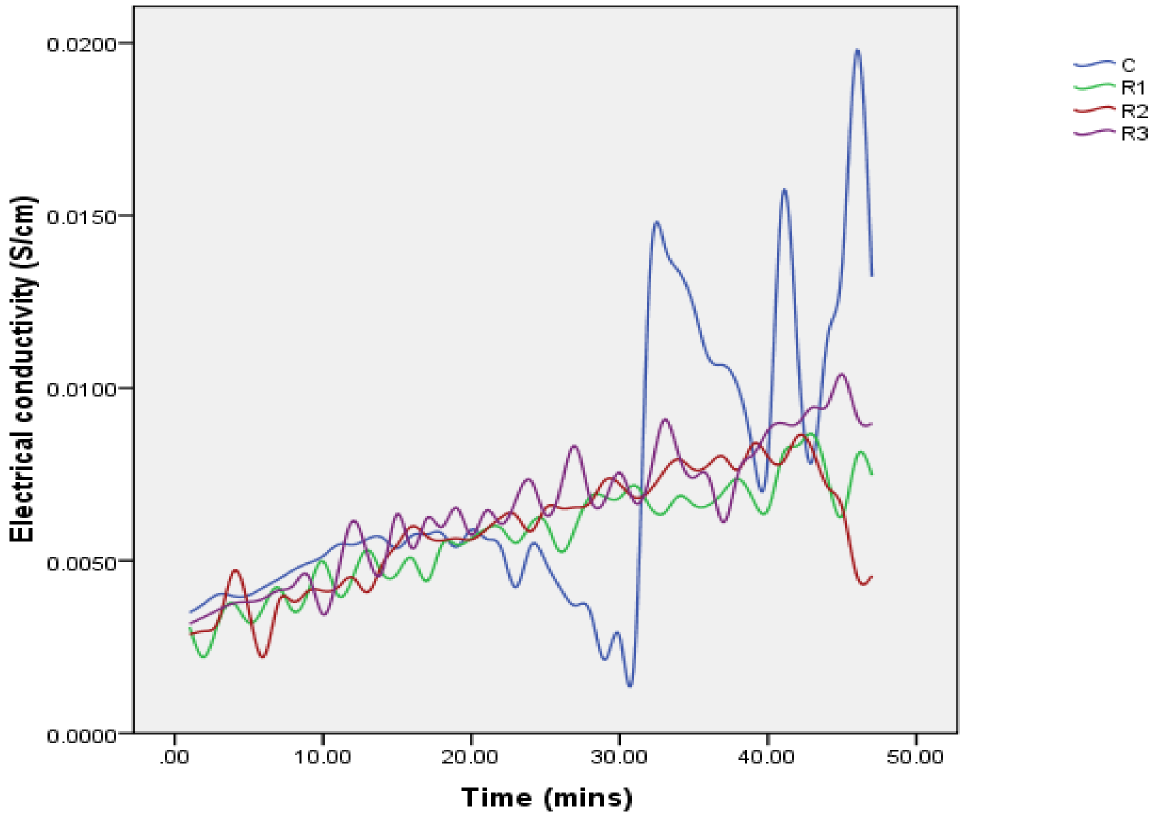

Fig. 4.21: Effect of up-scaling on electrical conductivitywith time

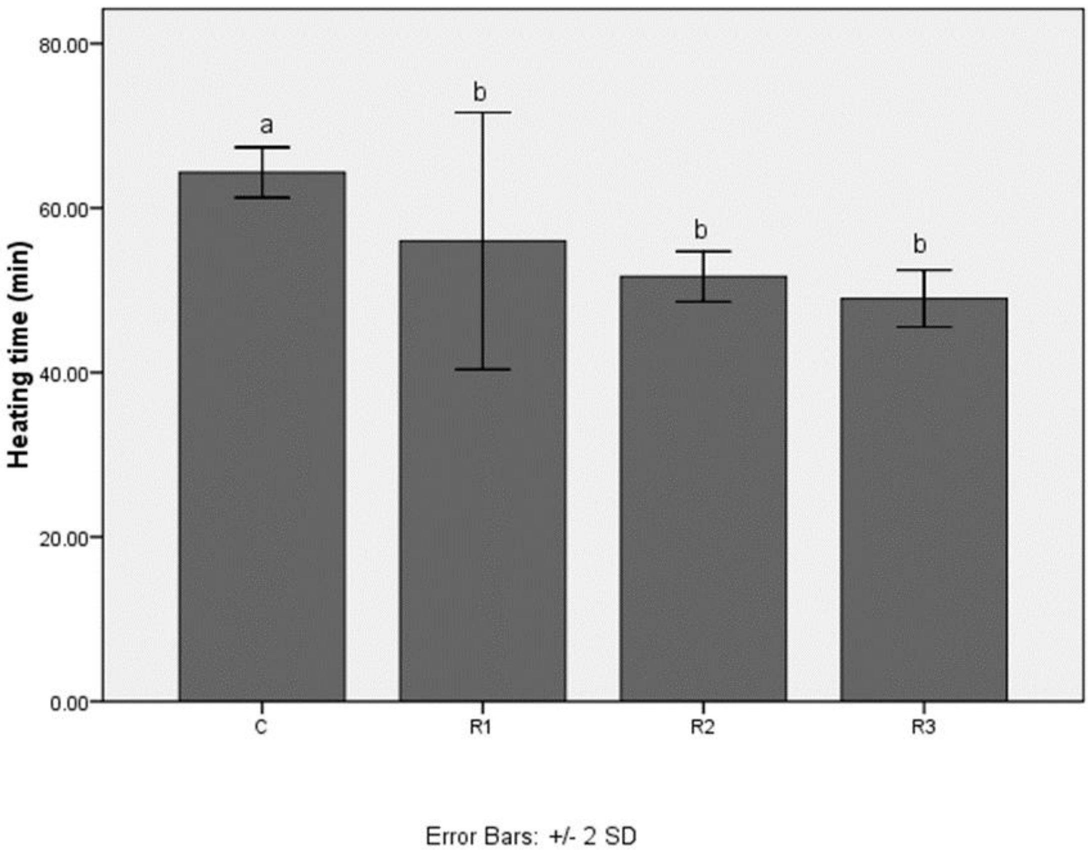

Fig. 4.22: Effect of up-scaling on heating time

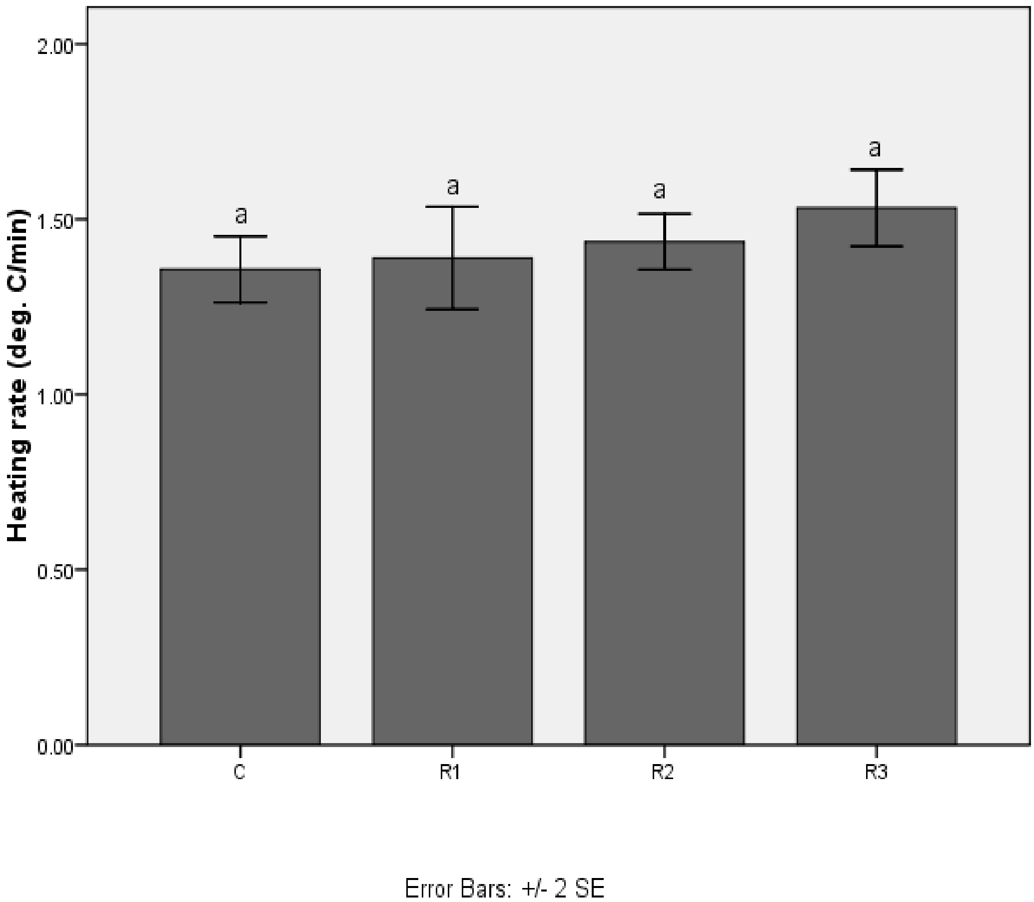

Fig. 4.23: Effect of up-scaling on heating rate

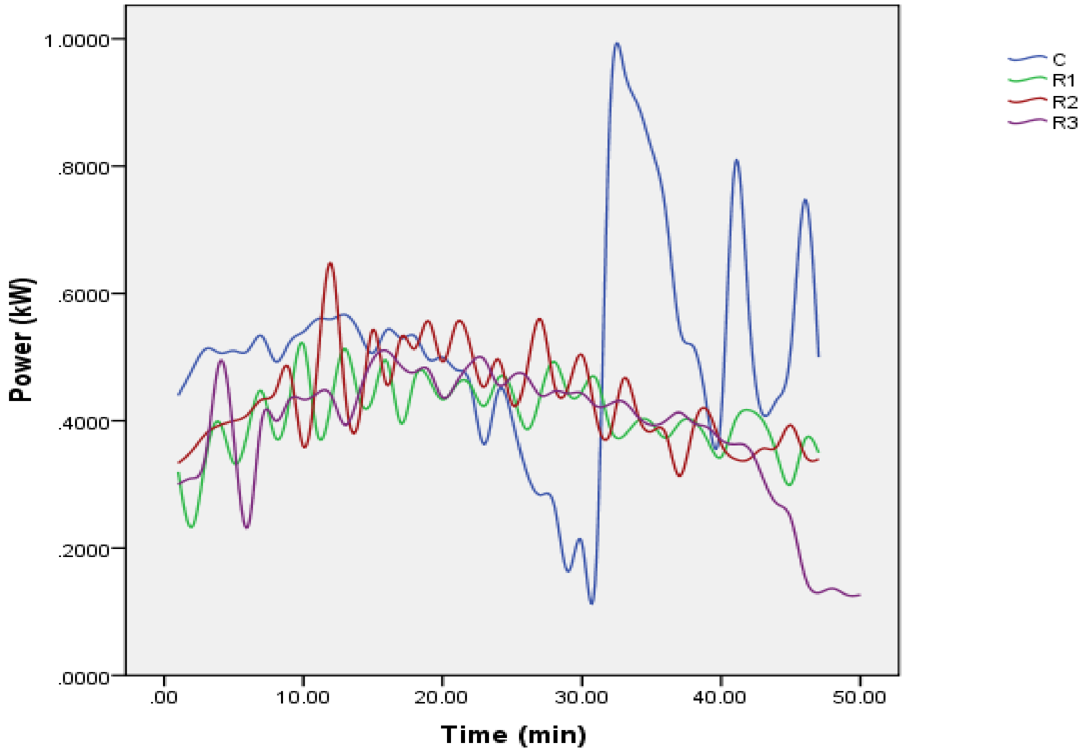

Fig. 4.24: Effect of up-scaling on power requirement

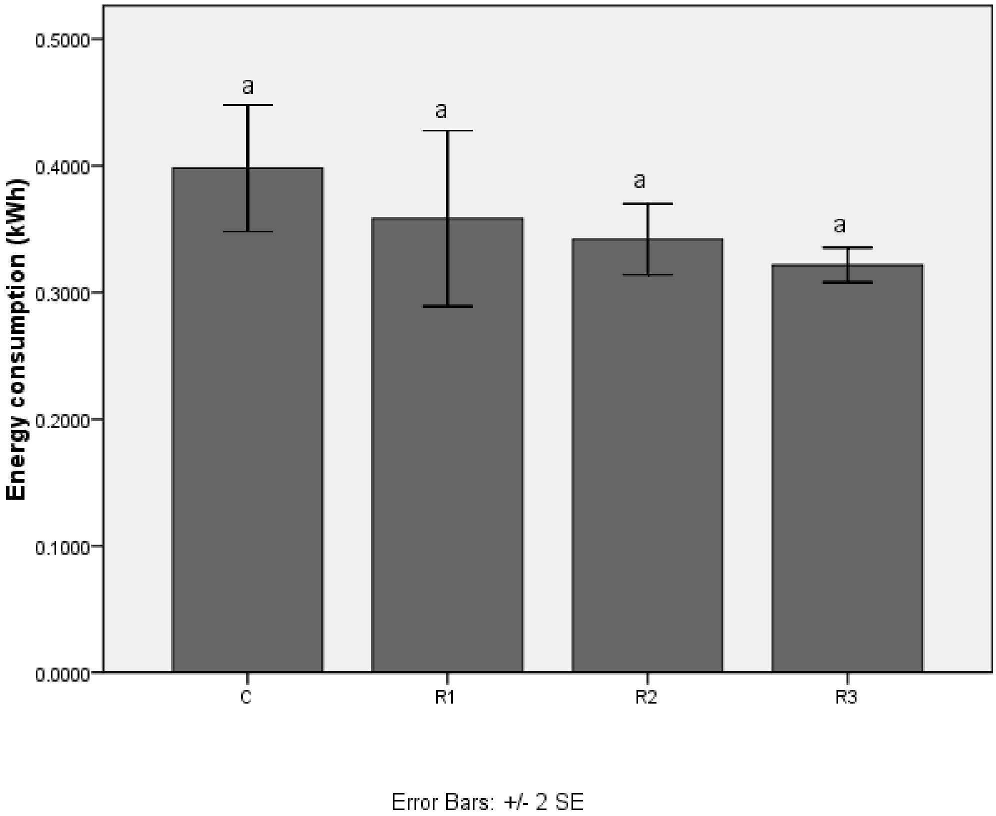

Fig. 4.25: Effect of up-scaling on energy consumption

SUMMARY & CONCLUSION

5. SUMMARY AND CONCLUSIONS

5.1 Design and fabrication of thepaired plate type ohmic heating system (5 kg)

- Paired plate type ohmic reactor core was designed and fabricated. The ohmic heating setup was modified and automatic temperature control system was integrated into the system. Finally, the preliminary trials were conducted to check the feasibility of the setup. The performance evaluation of paired plate type ohmic heating setup was studied for pairing time of 0, 20, 30, 40 and 50s.
- Results of the preliminary trials confirmed the feasibility of the five kg paired plate type ohmic heating system. Paired plate type ohmic heating system minimized localized heating of plates and almost no plate fouling was observed.
- Uniformity in milk heating was evident by low temperature gradient (0.2-0.9^oC).
- Heating rate was observed to be satisfactory with a rate of 3.3^oC /min for treatment R50. Pairing time significantly increased the heating rate ($p<0.05$).
- The heating time was least in case of treatment R50 (23 min). With the increase in pairing time, ohmic heating times are significantly reduced. Further heating time in case of control (0s) was 22 min but heavy fouling of electrode plates was observed.
- The heating setup was insulated by placing reactor vessel within the wooden cabinet and space between vessel and cabinet was filled with glass wool. Such that thermal efficiency of paired plate type ohmic heating system was more than 90%. The maximum thermal efficiency was observed in case of treatment R50 (92.2%).
- The temperature profile was almost linear for different pairing times. Initially average temperature varies linearly with time but in later stages it becomes parabolic.

- The trend of current was almost similar for all the treatments except for control (0s) because of large fluctuations. Pairing time significantly increased the current requirement. . The peak value of current for treatment R20, R30, R40, and R50 were 16.3, 16.5, 17 and 19A respectively.
- The energy consumption of paired plate type ohmic heating setup for heating of 5 kg milk from 20 to 90^{o}C was in range of 0.40-0.47 kWh.

5.2 Performance evaluation of paired plate type ohmic heating setup for buffalo milk heating

- A paired plate type ohmic heating system was used for buffalo milk heating and its performance was evaluated. Effect of ohmic heating was studied for pairing time of 0, 20, 30, 40 and 50s.
- Heating takes place rapidly because of higher ionic content within buffalo milk.
- There was no tinge of fouling on electrode plates.
- Uniformity in milk heating was evident by low temperature gradient (0.20-0.70^{o}C).
- Heating rate was observed to be maximum for treatment R50 (3.36^{o}C/min). Pairing time significantly increased the heating rate ($p<0.05$).
- The average value of heating time was least for treatment R50 (22.33 min). Higher heating rate reduces ohmic heating times.
- Thermal efficiency of heating setup for buffalo milk heating was more than 90%.
- The temperature profile was almost linear for different pairing times. Initially average temperature varies linearly with time but in later stages it becomes parabolic.
- The current profile is not linear. The fluctuations in value of current were observed during heating among all treatments. The peak current requirement was maximum for pairing time 50s (17A). Pairing time significantly increased the current requirement ($p<0.05$). The peak current

requirement was less in buffalo milk (17A)as compared to cow milk (19A) for treatment R50.

- The trend of energy consumption was similar for all treatments. Energy consumption was maximum for treatment R50 (0.43-0.47 kWh).

5.3 Performance evaluation of upscaled rotating field type ohmic heating setup (10 kg)

- Rotating field type core was designed, fabricated and upscaled to 10 kg capacity. The automatic temperature control system was integrated into the system. Finally, the preliminary trials were conducted to check the feasibility of the setup. The effect of heating for pairing times of 0, 1, 2 and 3min were assessed.
- Rotating field type ohmic heating system minimized localized heating of plates and almost no plate fouling was observed. This was due to rotation of current within 3 sets of heating plates after fixed time duration.
- Uniformity in milk heating was observed because of low temperature gradient (0.30-1.50^{o}C).
- Heating rate was higher for treatment R3 (1.53^{o}C/min). Pairing time significantly increased the heating rate ($p<0.05$). Heating rate was less as compared to paired plate type ohmic heating setup because of increase in quantity of milk for heating without increasing plate area.
- Heating time was least in case of treatment R3 (49 min). Heating time is longer in case of control (64 min) because the current is applied directly to plates that results in localized heating of plates thus extreme fouling. Fouling takes place to such an extent that the temperature of milk cannot rise above 75^{o}C.
- The temperature profile was linear initially but became parabolic towards the later part of trials.
- The current profile is not linear. The fluctuations in value of current were observed during heating among all treatments. The trend of current was almost the same in all the trials. The current requirement has an inverse relationship with the pairing time.

- The energy consumption was higher for control (0.45-0.50 kWh) and least for treatment R3 (0.31-0.33 kWh).Increasing pairing time significantly ($p<0.05$) reduces energy consumption.

From this study, it is concluded that both paired plate and rotating field type ohmic heating setup were confirmed feasible for milk heating in terms of performance evaluation parameters. Both configurations minimize localized heating of plates and almost no plate fouling was observed.

Future study

This system can be improved by using automatic current control system and can be up-scaled to a 40 litre system. For higher capacity system, variac of higher capacity is required. The cost of electrical energy is more, so there is need to run ohmic heating system through solar energy.

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APPENDIX

APPENDIX-1

1) Effect of paired plate configuration on heating time

Univariate Analysis of Variance

Between-Subjects Factors

		N
Treatment	C	3
	R20	3
	R30	3
	R40	3
	R50	3

Descriptive Statistics

Dependent Variable: Heating time

Treatment	Mean	Std. Deviation	N
C	22.3333	4.93288	3
R20	40.3333	4.72582	3
R30	26.0000	.00000	3
R40	24.3333	.57735	3
R50	23.6667	.57735	3
Total	27.3333	7.31600	15

Tests of Between-Subjects Effects

Dependent Variable: Heating time

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	654.667[a]	4	163.667	17.289	.000
Intercept	11206.667	1	11206.667	1.184E3	.000
Treatment	654.667	4	163.667	17.289	.000
Error	94.667	10	9.467		
Total	11956.000	15			
Corrected Total	749.333	14			

a. R Squared = .874 (Adjusted R Squared = .823)

Post hoc

Multiple Comparisons

Heating time
LSD

(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
C	R20	-18.0000*	2.51219	.000	-23.5975	-12.4025
	R30	-3.6667	2.51219	.175	-9.2642	1.9308
	R40	-2.0000	2.51219	.444	-7.5975	3.5975
	R50	-1.3333	2.51219	.607	-6.9308	4.2642
R20	C	18.0000*	2.51219	.000	12.4025	23.5975
	R30	14.3333*	2.51219	.000	8.7358	19.9308
	R40	16.0000*	2.51219	.000	10.4025	21.5975
	R50	16.6667*	2.51219	.000	11.0692	22.2642

Based on observed means.
The error term is Mean Square (Error) = 9.467.

*. The mean difference is significant at the .05 level.

Heating time

Duncan

Treatment	N	Subset	
		1	2
C	3	22.3333	
R50	3	23.6667	
R40	3	24.3333	
R30	3	26.0000	
R20	3		40.3333
Sig.		.203	1.000

2) Effect of paired plate configuration on heating rate

Univariate Analysis of Variance

Between-Subjects Factors

		N
Treatment	C	3
	R20	3
	R30	3
	R40	3
	R50	3

Descriptive Statistics

Dependent Variable: Heating rate

Treatment	Mean	Std. Deviation	N
C	3.4649	.53880	3
R20	1.8720	.19167	3
R30	2.9145	.00645	3
R40	3.2054	.07744	3
R50	3.2522	.03043	3
Total	2.9418	.62234	15

Tests of Between-Subjects Effects

Dependent Variable:
Heating rate

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	4.754[a]	4	1.189	17.792	.000
Intercept	129.812	1	129.812	1.943E3	.000
Treatment	4.754	4	1.189	17.792	.000
Error	.668	10	.067		
Total	135.234	15			
Corrected Total	5.422	14			

a. R Squared = .877 (Adjusted R Squared = .828)

Post Hoc

Heating rate

Duncan

Treatment	N	Subset		
		1	2	3
R20	3	1.8720		
R30	3		2.9145	
R40	3		3.2054	3.2054
R50	3		3.2522	3.2522
C	3			3.4649
Sig.		1.000	.157	.268

Means for groups in homogeneous subsets are displayed.
Based on observed means.
The error term is Mean Square (Error) = .067.

3) Effect of paired plate configuration on energy consumption

Univariate Analysis of Variance

Between-Subjects Factors

		N
Treatment	C	3
	R20	3
	R30	3
	R40	3
	R50	3

Descriptive Statistics

Dependent Variable:
Energy consumption

Treatment	Mean	Std. Deviation	N
C	.443000	.0246374	3
R20	.524333	.0235867	3
R30	.471167	.0750705	3
R40	.429667	.0325935	3
R50	.383333	.0152753	3
Total	.450300	.0590574	15

Energy consumption

	Treatment	N	Subset 1	Subset 2	Subset 3
Duncan[a]	R50	3	.383333		
	R40	3	.429667	.429667	
	C	3	.443000	.443000	
	R30	3		.471167	.471167
	R20	3			.524333
	Sig.		.113	.256	.137

Means for groups in homogeneous subsets are displayed.
Based on observed means.
The error term is Mean Square (Error) = .002.

4) Effect of paired plate configuration on temperature gradient (buffalo milk)

Univariate Analysis of Variance

Between-Subjects Factors

		N
Treatment	C	66
	R20	66
	R30	63
	R40	66
	R50	69

Descriptive Statistics

Dependent Variable: Temperature gradient

Treatment	Mean	Std. Deviation	N
C	.4979	.14923	66
R20	.3441	.10667	66
R30	.5183	.15397	63
R40	.5221	.19466	66
R50	.3642	.16449	69
Total	.4479	.17430	330

Tests of Between-Subjects Effects

Dependent Variable:
Temperature gradient

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2.035[a]	4	.509	20.770	.000
Intercept	66.565	1	66.565	2.718E3	.000
Treatment	2.035	4	.509	20.770	.000
Error	7.960	325	.024		
Total	76.200	330			
Corrected Total	9.995	329			

a. R Squared = .204 (Adjusted R Squared = .194)

Post Hoc

Multiple Comparisons

Temperature
gradient
LSD

(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
C	R20	.1538*	.02724	.000	.1002	.2074
	R30	-.0204	.02757	.460	-.0746	.0339
	R40	-.0242	.02724	.374	-.0778	.0294
	R50	.1337*	.02695	.000	.0807	.1867

Based on observed means.
The error term is Mean Square (Error) = .024.
*. The mean difference is significant at the .05 level.

5) Effect of paired plate configuration on electrical conductivity (buffalo milk)

Univariate Analysis of Variance

Between-Subjects Factors

		N
Treatment	C	66
	R20	66
	R30	60
	R40	69
	R50	69

Descriptive Statistics

Dependent Variable:
Electrical conductivity

Treatment	Mean	Std. Deviation	N
C	.009268	.0019023	66
R20	.012377	.0035754	66
R30	.013926	.0028217	60
R40	.013542	.0039168	69
R50	.015064	.0042505	69
Total	.012842	.0039410	330

Tests of Between-Subjects Effects

Dependent Variable:
Electrical conductivity

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.001[a]	4	.000	27.786	.000
Intercept	.054	1	.054	4.628E3	.000
Treatment	.001	4	.000	27.786	.000
Error	.004	325	1.172E-5		
Total	.060	330			
Corrected Total	.005	329			

a. R Squared = .255 (Adjusted R Squared = .246)

Post Hoc

Multiple Comparisons

Electrical conductivity
LSD

(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
C	R20	-.003109*	.0005958	.000x	-.004281	-.001936
	R30	-.004658*	.0006106	.000	-.005859	-.003457
	R40	-.004274*	.0005893	.000	-.005433	-.003114
	R50	-.005796*	.0005893	.000	-.006955	-.004636
R20	C	.003109*	.0005958	.000	.001936	.004281
	R30	-.001549*	.0006106	.012	-.002750	-.000348
	R40	-.001165*	.0005893	.049	-.002325	-.000006
	R50	-.002687*	.0005893	.000	-.003846	-.001528
R30	C	.004658*	.0006106	.000	.003457	.005859
	R20	.001549*	.0006106	.012	.000348	.002750
	R40	.000384	.0006042	.526	-.000805	.001573
	R50	-.001138	.0006042	.061	-.002326	.000051
R40	C	.004274*	.0005893	.000	.003114	.005433
	R20	.001165*	.0005893	.049	.000006	.002325
	R30	-.000384	.0006042	.526	-.001573	.000805
	R50	-.001522*	.0005827	.009	-.002668	-.000375
R50	C	.005796*	.0005893	.000	.004636	.006955
	R20	.002687*	.0005893	.000	.001528	.003846
	R30	.001138	.0006042	.061	-.000051	.002326
	R40	.001522*	.0005827	.009	.000375	.002668

Based on observed means.
The error term is Mean Square (Error) = 1.17E-005.

*. The mean difference is significant at the .05 level.

6) Effect of paired plate configuration on energy consumption (Buffalo milk)

Univariate Analysis of Variance

Between-Subjects Factors

		N
Treatment	C	3
	R20	3
	R30	3
	R40	3
	R50	3

Descriptive Statistics

Dependent Variable:
Energy consumption

Treatment	Mean	Std. Deviation	N
C	.373333	.0152753	3
R20	.512000	.0330454	3
R30	.484667	.0133167	3
R40	.446667	.0208167	3
R50	.393000	.0455741	3
Total	.441933	.0595225	15

Energy consumption

	Treatment	N	Subset 1	Subset 2	Subset 3
Duncan[a]	C	3	.373333		
	R50	3	.393000		
	R40	3		.446667	
	R30	3		.484667	.484667
	R20	3			.512000
	Sig.		.415	.131	.265

Means for groups in homogeneous subsets are displayed.
Based on observed means.
The error term is Mean Square (Error) = .001.

7) Effect of paired plate configuration on heating time (buffalo milk)

Univariate Analysis of Variance

Between-Subjects Factors

		N
Treatment	C	3
	R20	3
	R30	3
	R40	3
	R50	3

Descriptive Statistics

Dependent Variable: Heating time

Treatment	Mean	Std. Deviation	N
C	23.0000	1.73205	3
R20	25.3333	4.16333	3
R30	24.3333	1.52753	3
R40	23.3333	1.15470	3
R50	22.3333	.57735	3
Total	23.6667	2.16025	15

Tests of Between-Subjects Effects

Dependent Variable:
Heating time

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	16.667[a]	4	4.167	.856	.522
Intercept	8401.667	1	8401.667	1.726E3	.000
Treatment	16.667	4	4.167	.856	.522
Error	48.667	10	4.867		
Total	8467.000	15			
Corrected Total	65.333	14			

a. R Squared = .255 (Adjusted R Squared = -.043)

Post Hoc

Heating time

Duncan

Treatment	N	Subset 1
R50	3	22.3333
C	3	23.0000
R40	3	23.3333
R30	3	24.3333
R20	3	25.3333
Sig.		.156

Means for groups in homogeneous subsets are displayed.
Based on observed means.
The error term is Mean Square (Error) = 4.867

8) Effect of paired plate configuration on heating rate (buffalo milk)

Univariate Analysis of Variance

Between-Subjects Factors

		N
Treatment	C	3
	R20	3
	R30	3
	R40	3
	R50	3

Descriptive Statistics

Dependent Variable:
Heating rate

Treatment	Mean	Std. Deviation	N
C	3.4833	.10408	3
R20	2.9864	.39994	3
R30	3.1041	.18999	3
R40	3.2796	.07092	3
R50	3.3630	.08214	3
Total	3.2433	.25541	15

Tests of Between-Subjects Effects

Dependent Variable:
Heating rate

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.476[a]	4	.119	2.721	.091
Intercept	157.782	1	157.782	3.608E3	.000
Treatment	.476	4	.119	2.721	.091
Error	.437	10	.044		
Total	158.695	15			
Corrected Total	.913	14			

a. R Squared = .521 (Adjusted R Squared = .330)

Post Hoc

Heating rate

Duncan

Treatment	N	Subset	
		1	2
R20	3	2.9864	
R30	3	3.1041	3.1041
R40	3	3.2796	3.2796
R50	3	3.3630	3.3630
C	3		3.4833
Sig.		.067	.065

Means for groups in homogeneous subsets are displayed.
Based on observed means.
The error term is Mean Square (Error) = .044.

9) Effect of up-scaling on temperature profile

Univariate Analysis of Variance

Between-Subjects Factors

		N
Treatment	C	141
	R1	180
	R2	140
	R3	151

Descriptive Statistics

Dependent Variable:
Average temperature

Treatment	Mean	Std. Deviation	N
C	47.6504	19.46235	141
R1	53.8148	24.33516	180
R2	54.3344	22.57221	140
R3	55.8582	23.71046	151
Total	53.0176	22.87874	612

Tests of Between-Subjects Effects

Dependent Variable:
Average temperature

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	5637.433[a]	3	1879.144	3.636	.013
Intercept	1696089.786	1	1696089.786	3.282E3	.000
Treatment	5637.433	3	1879.144	3.636	.013
Error	314182.518	608	516.748		
Total	2040070.821	612			
Corrected Total	319819.951	611			

a. R Squared = .018 (Adjusted R Squared = .013)

Post Hoc

Multiple Comparisons

Average temperature
LSD

(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
C	R1	-6.1645*	2.55650	.016	-11.1851	-1.1438
	R2	-6.6841*	2.71218	.014	-12.0105	-1.3577
	R3	-8.2079*	2.66215	.002	-13.4360	-2.9797
R1	C	6.1645*	2.55650	.016	1.1438	11.1851
	R2	-.5196	2.56162	.839	-5.5503	4.5111
	R3	-2.0434	2.50858	.416	-6.9699	2.8832
R2	C	6.6841*	2.71218	.014	1.3577	12.0105
	R1	.5196	2.56162	.839	-4.5111	5.5503
	R3	-1.5238	2.66706	.568	-6.7616	3.7140
R3	C	8.2079*	2.66215	.002	2.9797	13.4360
	R1	2.0434	2.50858	.416	-2.8832	6.9699
	R2	1.5238	2.66706	.568	-3.7140	6.7616

Based on observed means.
The error term is Mean Square (Error) = 516.748.

*.The mean difference is significant at the .05 level.

10)Effect of up-scaling on current profile

Univariate Analysis of Variance

Between-Subjects Factors

		N
Treatment	C	141
	R1	141
	R2	141
	R3	150

Descriptive Statistics

Dependent Variable: Current

Treatment	Mean	Std. Deviation	N
C	6.0991	3.17130	141
R1	4.8899	1.53273	141
R2	5.3567	.98059	141
R3	4.7608	1.30245	150
Total	5.2685	1.99716	573

Tests of Between-Subjects Effects

Dependent Variable: Current

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	157.238[a]	3	52.413	14.039	.000
Intercept	15942.420	1	15942.420	4.270E3	.000
Treatment	157.238	3	52.413	14.039	.000
Error	2124.275	569	3.733		
Total	18186.427	573			
Corrected Total	2281.513	572			

a. R Squared = .069 (Adjusted R Squared = .064)

Post Hoc

Multiple Comparisons

Current
LSD

(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
C	R1	1.2091*	.23012	.000	.7572	1.6611
	R2	.7424*	.23012	.001	.2904	1.1944
	R3	1.3383*	.22664	.000	.8931	1.7834
R1	C	-1.2091*	.23012	.000	-1.6611	-.7572
	R2	-.4667*	.23012	.043	-.9187	-.0147
	R3	.1291	.22664	.569	-.3160	.5743
R2	C	-.7424*	.23012	.001	-1.1944	-.2904
	R1	.4667*	.23012	.043	.0147	.9187
	R3	.5959*	.22664	.009	.1507	1.0410
R3	C	-1.3383*	.22664	.000	-1.7834	-.8931
	R1	-.1291	.22664	.569	-.5743	.3160
	R2	-.5959*	.22664	.009	-1.0410	-.1507

Based on observed means.
The error term is Mean Square (Error) = 3.733.

*. The mean difference is significant at the .05 level.

11) Effect of up-scaling on temperature gradient

Univariate Analysis of Variance

Between-Subjects Factors

		N
Treatment	C	141
	R1	141
	R2	141
	R3	150

Descriptive Statistics

Dependent Variable: Temperature gradient

Treatment	Mean	Std. Deviation	N
C	.9851	.31983	141
R1	1.0804	.36008	141
R2	1.1205	.49505	141
R3	1.2727	.39027	150
Total	1.1172	.40916	573

Tests of Between-Subjects Effects

Dependent Variable: Temperature gradient

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	6.281[a]	3	2.094	13.314	.000
Intercept	711.462	1	711.462	4.524E3	.000
Treatment	6.281	3	2.094	13.314	.000
Error	89.477	569	.157		
Total	810.905	573			
Corrected Total	95.758	572			

a. R Squared = .066 (Adjusted R Squared = .061)

Post Hoc

Multiple Comparisons

Temperature gradient
LSD

(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
C	R1	-.0953*	.04723	.044	-.1881	-.0026
	R2	-.1354*	.04723	.004	-.2282	-.0426
	R3	-.2876*	.04651	.000	-.3790	-.1963
R1	C	.0953*	.04723	.044	.0026	.1881
	R2	-.0401	.04723	.397	-.1328	.0527
	R3	-.1923*	.04651	.000	-.2837	-.1009
R2	C	.1354*	.04723	.004	.0426	.2282
	R1	.0401	.04723	.397	-.0527	.1328
	R3	-.1522*	.04651	.001	-.2436	-.0609
R3	C	.2876*	.04651	.000	.1963	.3790
	R1	.1923*	.04651	.000	.1009	.2837
	R2	.1522*	.04651	.001	.0609	.2436

Based on observed means.
The error term is Mean Square (Error) = .157.

*.The mean difference is significant at the .05 level.

12) Effect of up-scaling on heating time

Univariate Analysis of Variance

Between-Subjects Factors

		N
Treatment	C	3
	R1	3
	R2	3
	R3	3

Descriptive Statistics

Dependent Variable:
Heating time

Treatment	Mean	Std. Deviation	N
C	64.3333	1.52753	3
R1	56.0000	7.81025	3
R2	51.6667	1.52753	3
R3	49.0000	1.73205	3
Total	55.2500	7.02107	12

Tests of Between-Subjects Effects

Dependent Variable:
Heating time

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	404.917[a]	3	134.972	7.862	.009
Intercept	36630.750	1	36630.750	2.134E3	.000
Treatment	404.917	3	134.972	7.862	.009
Error	137.333	8	17.167		
Total	37173.000	12			
Corrected Total	542.250	11			

a. R Squared = .747 (Adjusted R Squared = .652)

Post Hoc

Multiple Comparisons

Heating Time
LSD

(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
C	R1	8.3333*	3.38296	.039	.5322	16.1345
	R2	12.6667*	3.38296	.006	4.8655	20.4678
	R3	15.3333*	3.38296	.002	7.5322	23.1345
R1	C	-8.3333*	3.38296	.039	-16.1345	-.5322
	R2	4.3333	3.38296	.236	-3.4678	12.1345
	R3	7.0000	3.38296	.072	-.8011	14.8011
R2	C	-12.6667*	3.38296	.006	-20.4678	-4.8655
	R1	-4.3333	3.38296	.236	-12.1345	3.4678
	R3	2.6667	3.38296	.453	-5.1345	10.4678
R3	C	-15.3333*	3.38296	.002	-23.1345	-7.5322
	R1	-7.0000	3.38296	.072	-14.8011	.8011
	R2	-2.6667	3.38296	.453	-10.4678	5.1345

Based on observed means.
The error term is Mean Square (Error) = 17.167.
*. The mean difference is significant at the .05 level.

13) Effect of up-scaling on heating rate

Univariate Analysis of Variance

Between-Subjects Factors

		N
Treatment	C	3
	R1	3
	R2	3
	R3	3

Descriptive Statistics

Dependent Variable:
Heating rate

Treatment	Mean	Std. Deviation	N
C	1.3571	.08174	3
R1	1.3894	.12701	3
R2	1.4358	.06872	3
R3	1.5327	.09469	3
Total	1.4288	.10687	12

Tests of Between-Subjects Effects

Dependent Variable:
Heating rate

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.053[a]	3	.018	1.922	.205
Intercept	24.496	1	24.496	2.684E3	.000
Treatment	.053	3	.018	1.922	.205
Error	.073	8	.009		
Total	24.622	12			
Corrected Total	.126	11			

a. R Squared = .419 (Adjusted R Squared = .201)

Post Hoc

Multiple Comparisons

Heating rate
LSD

(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
C	R1	-.0322	.07800	.690	-.2121	.1476
	R2	-.0787	.07800	.342	-.2586	.1011
	R3	-.1756	.07800	.054	-.3555	.0043
R1	C	.0322	.07800	.690	-.1476	.2121
	R2	-.0465	.07800	.568	-.2263	.1334
	R3	-.1434	.07800	.103	-.3232	.0365
R2	C	.0787	.07800	.342	-.1011	.2586
	R1	.0465	.07800	.568	-.1334	.2263
	R3	-.0969	.07800	.249	-.2767	.0830
R3	C	.1756	.07800	.054	-.0043	.3555
	R1	.1434	.07800	.103	-.0365	.3232
	R2	.0969	.07800	.249	-.0830	.2767

Based on observed means.
The error term is Mean Square (Error) = .009.

14) Effect of upscaling on energy consumption

Univariate Analysis of Variance

Between-Subjects Factors

		N
Treatment	C	141
	R1	141
	R2	141
	R3	150

Descriptive Statistics

Dependent Variable:
Energy consumption

Treatment	Mean	Std. Deviation	N
C	.008533	.0037121	141
R1	.006674	.0016757	141
R2	.006795	.0019979	141
R3	.006907	.0017885	150
Total	.007222	.0025375	573

Tests of Between-Subjects Effects

Dependent Variable:
Energy consumption

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.000[a]	3	.000	18.370	.000
Intercept	.030	1	.030	5.068E3	.000
Treatment	.000	3	.000	18.370	.000
Error	.003	569	5.901E-6		
Total	.034	573			
Corrected Total	.004	572			

a. R Squared = .088 (Adjusted R Squared = .083)

Post Hoc

Multiple Comparisons

Dependent Variable: Energy consumption

	(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
LSD	C	R1	.001859*	.0002893	.000	.001291	.002427
		R2	.001738*	.0002893	.000	.001169	.002306
		R3	.001626*	.0002849	.000	.001066	.002185

Based on observed means.
The error term is Mean Square (Error) = 5.90E-006.

*. The mean difference is significant at the .05 level.

Energy consumption

	Treatment	N	Subset	
			1	2
Duncan[a]	R1	141	.006674	
	R2	141	.006795	
	R3	150	.006907	
	C	141		.008533
	Sig.		.449	1.000

Means for groups in homogeneous subsets are displayed.
Based on observed means.
The error term is Mean Square (Error) = 5.90E-006.

a. Uses Harmonic Mean Sample Size = 143.147.

VISHAL THAKUR

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ACADEMIC QUALIFICATIONS

STANDARD	YEAR	SCHOOL/ COLLEGE	BOARD/ UNIVERSITY	MARKS/ CGPA
M.Tech. (Dairy Engineering)	2017-2019	ICAR-National Dairy Research Institute	ICAR-National Dairy Research Institute, Karnal	8.59/10
B.Tech. (Dairy Technology)	2013-2017	College of Dairy Science and Technology	Guru Angad Dev Veterinary and Animal Sciences University, Ludhiana, Punjab	8.59/10
12th	2012	Jawahar Navodaya Vidyalaya, Hamirpur, Himachal Pradesh	CBSE	86.60%
10th	2010	Jawahar Navodaya Vidyalaya, Hamirpur, Himachal Pradesh	CBSE	89.30%

M.TECH THESIS TITLE: "Design upscaling of ohmic milk heating system"

INDUSTRIAL EXPOSURE

✓ One year In-plant training at MILKFED Punjab (each of 6 months).

1. **Verka milk plant, Mohali (Punjab)**
    - Milk handling capacity- 6 lacs lts/day
    - Undergoes training in different sections of plant viz. production, quality testing, marketing, procurement, engineering and administration.
    - Learn about dairy products manufacturing such as market milk processing, paneer, curd, kheer, buttermilk, ghee, butter etc.
    - Quality testing of dairy products
    - Procurement of milk at village level
    - Marketing of dairy products and resolving the problems of wholesalers, retailers and consumers
    - Got knowledge about hygiene practices and their implementation in plant
    - **Qualitative analysis** of dairy products

2. **Verka milk plant, Ludhiana (Punjab)**
    - Milk handling capacity:- 6 lacs lts/day
    - Undergoes training in different sections of plant viz. production, quality testing, marketing, procurement and engineering.
    - Product manufactured in plant includes market milk, lassi, curd, milk cake, ghee, butter, powder (whole milk powder and skim milk powder).
    - Learn about the quality testing of milk
    - Checking efficiency of **pouch filling machine**

- Regeneration efficiency of **pasteurizer**
- Skimming efficiency of **cream separator**
- **Qualitative analysis** of dairy products
- Actively worked on **Kaizen projects**
- Specialization in **powder manufacturing**

LANGUAGES KNOWN

- English, Hindi and Punjabi

COMPUTER PROFICIENCY: Profound knowledge of MS office, Auto-CAD and internet navigation

EXTRA-CURRICULAR ACTIVITIES & ACHIEVEMENT

- **Dean's Merit certificate** winner for excellence in academics at NDRI Karnal during 2017-18
- Achieved **AIR-11** in **ICAR-AIEEA 2017**
- **ICAR-JRF scholarship** holder throughout my masters degree program
- **ICAR-NTS scholarship** holder throughout my B-Tech
- Got **2nd prize** in oral presentation on the topic "**Design upscaling of ohmic milk heating system**" in **IDEA** conference held in Indore
- Got **3rd prize** in poster presentation in IDEA seminar 2018 held in Indore on the topic "**Applications of biosensors in food and dairy industry**"
- Served as a class representative for consecutive 3 years during my B-tech program
- **"A" certificate** holder in **NCC**
- **Interuniversity volleyball winners** in 2017-18 held at NDRI, Karnal
- **Active participation** in **youth festivals** held at GADVASU Ludhiana
- **Active participation** in **NSS** for 4 semesters during B-Tech

MEMBERSHIP OF PROFESSIONAL SOCIETIES:

- Student member of IDA (Indian Dairy Association)
- Lifetime membership of IDEA (Indian Dairy Engineers Association)

PUBLICATIONS:

1. **Thakur V**., Minz P. S. and Patel D. H**.** Rangi P., Lanjewar P. and Nayak S. Design upscaling of ohmic heating system. National seminar on Dairy Process Engineering from 'farm to Table'. Pp: 80-84.

2.**Thakur V**., Minz P. S. Vairat A. D., Kumari K. and Patel D. H. Biosensors and their application in food and dairy industry. National seminar on Dairy Process Engineering from 'farm to Table'. Pp: 123.

3.Patel D. H**.**, Minz P. S. and **Thakur V.** Evaluation of various sensor for monitoring of quality changes in frying oil. National seminar on Dairy Process Engineering from 'farm to Table'. Pp: 85-90.

4. Patel D. H**.**, Minz P. S. and **Thakur V.** Role of robotics in dairy and food industry. National seminar on Dairy Process Engineering from 'farm to Table'. Pp: 123.

HOBBIES & PERSONAL ATTRIBUTES

- Singing , Reading , Playing Cricket , Travelling
- Leadership, Discipline, Decision making, Planning