Design and development of continuous Ohmic Heater for Milk

ABSTRACT:

Present study aimed for design and development of a continuous ohmic heating system was developed for heating of milk. The holding capacity of designed heater was 8.24 litre and had a ‘tube in tube’ type arrangement. The heat transfer area of the ohmic heater was increased by employing two stages, consist of SS-316 pipes. Process was control by using an electrical panel equipped with all the required electrical components. The designed ohmic heater for milk was optimized for heating of milk temperature up to 73°C. Efficient heating of milk was heated at optimized conditions of 137.7 V (stage-1) and 72.2V(stage-2) with 1.5 l/min flowrate. The average heating rate for milk 4.6˚C/min. At optimized conditions, system performance co-efficient was found to be 86.95. The milk heated using ohmic heater showed no significant difference in the composition and sensory attributes, when compared to conventional heating method. Moreover, the alkaline phosphatase test was also negative for ohmic heated milk samples and milk was highly acceptable by the sensory panel.

INTRODUCTION:

The food industry has been experiencing a continuous evolution driven by novel technologies that enhance production processes, improve food safety, and create innovative products. Heating is a customary and extensively used application for the processing and preservation of various food products. In modern era, energy efficient as well as cost effective heating methods are in high demand considering the safety and quality of products. Ohmic heating is one of such treatment where electrical energy is converted to heat energy which can be further used for various food processing. In the era of technological advancement and consumer awareness towards effect of food processing, minimally processed and fresh like foods are the need of consumer (Bolhuis et al., 2022). Conventional methods of heating have number of disadvantages such as fouling, low overall heat transfer co-efficient, inefficient use of heating media and reportable loss of product quality so novel technologies like pulsed electric field, high pressure processing, irradiation, Ohmic heating are need to be introduce in food processing (Leong and Oey, 2022). Ohmic heating, also known as the electro-conductive heating, electro-heating, electrical resistance heating or direct electrical resistance heating is a novel technique of food processing where minimum deterioration takes place with respect to food quality (Kaur and Singh. 2016).

Currently, ohmic heating has gained significant attention in the food processing industry due to its ability to provide fast and uniform heating of food products. This method improves the quality of food products by preserving nutrients and flavours while reducing processing time and energy consumption. Its applications include processing of juices, soups, sauces and also dairy products. One major advantage of Ohmic heating is that large heating tubes with lower shear rates can be used because heat generation in ohmic heating is a direct function of geometry. Moreover, the electrical conductivity of a given product and voltage is influenced by the ion concentration in solution which also allows the heating of fragile food particles (Goullieux *et al*., 2014)

The future of ohmic heating technology looks promising, and it is expected to find significant use in the food industries. Ohmic heating is likely to become more popular with the rising demand for processed foods and the need for more efficient and sustainable processing methods, it has the potential to reduce energy consumption and processing time, and improve the quality of food products. It could also lead to the development of new and innovative products that were previously impossible to make. Hence, attempt has been made for design and development and optimize the parameter for heating of milk without affecting the sensorial and microbial quality of milk.

2.MATERIAL AND METHODS:

2.1 Working principle of ohmic heater:

Ohm’s law states that the current (I) through a conductor between two points is directly proportional to the potential difference (V) across the two points According to Ohm's law, the current flowing through a conductor between two places is directly proportional to the potential difference across the two sites when the temperature is constant. One arrives at the standard mathematical equation that represents this relationship by including the resistance as the constant of proportionality.

$I=V/R$

Commented [AD1]: Equation should be written using equation option in word file with number. That equation number must be cited in the content

Where,

I is the electric current through the conductor, Ampere

V is the potential difference measured across the conductor, Volt

R is the electric resistance of the conductor, Ohms.

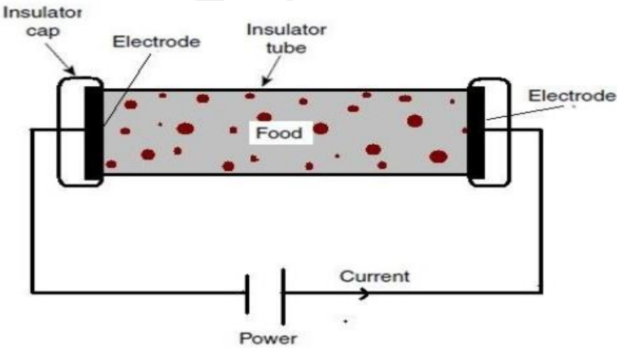

Fig 1: Principle of ohmic heating

Ohmic heating is a heating method that can be used to heat various food products. In ohmic heating of food, an electric current is passed through the food material, which acts as a resistor, causing it to generate heat. Energy generation (Q) is proportional to the square of the local electric field strength (I) and the electrical conductivity of the product.

$$Q=I^2Rt$$

Commented [AD2]: Equation 2 derivation and reference of this equation is missing. Author need to write the source and law. As this is joule’s first law

The food material is placed between the two electrodes that are connected to a power source. The electric current flows through the food material, causing the molecules to vibrate and generate heat through the resistance of the material. The heat generated is distributed uniformly throughout the material, leading to rapid and even heating. Since electrical conductivity is influenced by ionic content, it is possible to adjust the electrical conductivity of the product (both phases) with ion (e.g. salts) levels to achieve effective Ohmic heating. The non-polar materials (do not conduct electricity) cannot be heated by ohmic heating method (Kumar *et al*., 2018)

2.2 Design consideration:

In conductors, the amount of heat generated by current flow is measured in Joules. The following is a description of how Joule's law is represented mathematically.

i) When the electrical resistance of the wire and the period of current flow are constant, the amount of heat created in current conducting wire is exactly proportional to the square of the amount of current flowing through the circuit:

$H \propto I^2$ (When R and t are constant)

ii) When the circuit current and the duration of the current flow are constant, the amount of heat generated is exactly proportional to the electrical resistance of the wire.

$H \propto R$ (when I and t are constant)

iii) Heat generated due to the flow of current is proportional to the time of current flow, when the resistance and amount of current flow is constant.

$H \propto t$ (when I and R are constant)

When these three conditions are merged, the resulting formula is

$H= I^2Rt$

$H= (V^2 t)/R$

Joule's law $(V^2t)/R$ = work done (in joules) electrically when V volt electric potential is maintained through a resistor of R ohms for t second (Bru et al., 2015).

2.2 Electrical Conductivity

The electrical conductivity (σ) is the measure of how well a material puts up the movement of an electric charge. It is the ratio of the current density to the electric field strength. Its derived SI unit is the Siemens per meter (S/m). For any material, the electric conductivity can be obtained from the following equation

$\sigma = LI/AV$

Where:

σis the electrical conductivity (S/m)

I is the current in the circuit(amp)

L is the length of the piece of material measured in meters

V is the voltage, volt

A is the cross-sectional area in square meters

The specific heat of liquid foods lies between 3.85 to 4.2 kJ/kg K (milk is 3.85 kJ/kg°C) while the electrical conductivity values of liquid food ranges between 0.601 to 1.075 S/m (for milk is 0.601 S/m) (Fox *et al*.,2015).

2.3 Continuous Ohmic heating Unit design:

Ohmic heating unit was design in such a way that it can achieve optimum temperature with continuous flow of milk. The developed unit has two stage of heating cell to control the heating rate with more effective heat transfer area. As the area of heat transfer increase, U (overall heat transfer coefficient) value also increases (Sparrow *et al*., 2013). Two stage heating unit also had the advantage of processing heat sensitive products like milk which is prone to fouling because of its protein, fat and ash content. Stainless steel (AISI 316) material used for development of ohmic heating cell because stainless steel is a food grade material, have higher electrical conductivity and good mechanical strength. It can be used to create a hygienic design and is easy to assemble and disassemble. The ohmic heating cell has 'tube in tube' arrangement, where a gap was formed between two pipes, where the milk can pass through it. 'Tube in tube' type arrangement increases the effective heat transfer surface area that increases the overall heat transfer co-efficient value.

Minimum recommended pipe diameters (Phirke, 2014):

$$d = \frac{1.03\sqrt{Q}/S_g}{\rho^{0.33}}$$

Where,

d= pipe inner diameter, (inch)

Q=flow rate, gal/min(g/m) (1 gal.= 3785 cc)

Sg = fluid specific gravity, dimensionless.

ρ = Fluid density, lb/ft^3

Volumetric flow rate Recommended maximum fluid velocities (Phirke, 2014):

$$v = 0.47/\rho^{0.33}$$

Where

V= velocity, ft/s

Fluid density, lb/ ft^3

For milk density 1030 kg/m^3 (64.3 lb/ft^3)found maximum velocity 0.15 ft/s.

Two concentric stainless steel (AISI 316) pipes of length 112 mm were used. The outer pipe with inner diameter (do) of 72.04 mm and inner pipe with outer diameter (di) of 25.04 mm was used to create gap hmicof 23.32 mm between the two pipes.

The cell constant conductivity (K) is defined as the ratio of distance between two electrodes (l) to available cross section area (A).

$$\mathrm{K} = \frac{\mathrm{l}}{\mathrm{A}}$$

Cell constant conductivity (K) = $\frac{224}{16402.4}$ = 0.0136 mm^{-1}

So, the cell constant conductivity was calculated as 0.0136 mm^{-1}

Cell constant conductivity is a multiplier constant. The above equation shows that if the solution has lower conductivity, the electrodes should be placed together or larger electrodes should be used so that the cell constant remains less than one.

Holding volume for one ohmic heating cell (V):

$V = \pi \frac{do^2}{4} l - \pi \frac{di^2}{4} l$

$$V = \pi \frac{72.04^2}{4} 1120 - \pi \frac{25.4^2}{4} 1120$$

$$= 3995610\ mm^3$$

2.3.1 Ohmic Heater Pipe Design

The design of ohmic heater pipe plays a key role in the heating of milk. Two ohmic heating cells was design to increase the capacity and control the temperature of milk. One unit of ohmic heating cell consists of two stainless steel pipes. The outer pipe had the inner diameter of 72.04 mm, whereas the inner pipe with an outer diameter of 25.4 mm was used. The length and thickness used for both the outer pipes was 1.12 m and 3 mm, respectively. The length and thickness used for both the inner pipes was 1.37 m and 3 mm, respectively. Both the pipes were electro polished from inner and outer side. One heating stage consists of two pipes with ‘tube in tube’ type arrangement.

The ends of both pipes with same length were locked with teflon plates having silicon gasket. It is prime requirement to separate the anode and cathode supply of the pipes to prevent leakage of current so ends were secured with stainless steel washer and teflon plates. If the pipes were electrically connected, there were chances of short circuit, so food grade teflon material uses to electrically separate the two pipes.

Both the ohmic unit cell was insulated with ceramic braided rope. Ceramic is poor conductor of heat so it is widely used as an insulating material (Gençoğlu 2007). Ceramic braided rope type insulation can be easily done on pipe because it gains turn in any shape and size according to requirement. The rope was braided on the outer side of the both set of pipes to prevent the heat loss to the environment. In addition, an adjustable flow control valve was used to connect the two different stages of the heating cell.

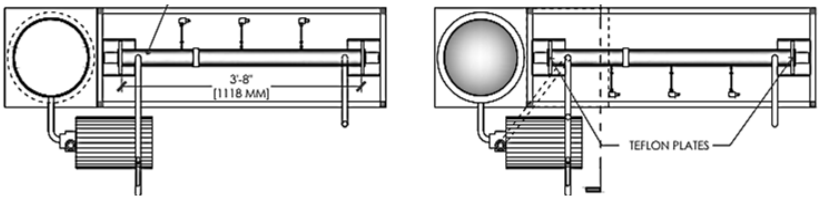

Fig 2: Pipe design of continuous ohmic heating unit

2.3.2 Electrode

The stainless-steel pipe was used in the development of ohmic heating cell. The pipe itself worked as an electrode. Stainless steel materials (AISI-SS316), when used as electrode, provides number of benefits such as more heat transfer surface area, higher electrical conductivity, less prone to fouling, cost effective, easy handling, food grade material, etc.

Type and size of electrode and its contact area plays important role in heating rate and therefore, SS 316 pipe with a length of 1.12 m was used, both the electrodes were separated using a food grade Teflon material.

Commented [AD3]: Abbreviation's full form is not given

In outer and inner pipe, electrical connection was provided by a copper plate as it is a good conductor for electrical conductivity and that can pass the high current passage without significant heat loss. The copper plate with a length of 150 mm, width of 25 cm and thickness of 3 mm was used. The plate was connected with 10 sq mm wire with lug for providing electric current supply.

Commented [AD4]: Representation of unit should be uniform. Square should be in superscript

2.3.3 Distance Between Electrodes

The diameter of outer pipe was 72.04 mm and inner pipe diameter was 25.4 mm so the distance between two pipes was 23.32 mm. Distance between two pipes should be as less as possible. When distance between the electrodes decreases, the resistance is increased and hence, there is increase in output temperature. Shorter distance between the electrodes will result in a more intense electric field and a higher rate of heating. However, a shorter distance can also increase the risk of arcing and other electrical issues so it is important to have optimum distance between two electrodes. The thickness of anode and cathode plates should be around 2 mm (Icier *et al*, 2008) and the electrode gap should be greater or equal to 1.0 cm for liquid food in order to avoid fouling (Jakób *et al.*, 2010).

Commented [AD5]: Check the english

2.3.4 Storage Tank

Two balance tanks, each with a capacity of 60 litres was installed on the unit. One tank was used for collecting the heated milk and the other was used to maintain the liquid level in another tank.

Calculation:

$$Volume = \frac{\pi}{4} d^2 l$$

Where,

V= volume of storage tank (m^3)

D= diameter of balance tank (m)

L= length of balance tank(m)

So,

$$V = \frac{\pi}{4}(0.355)^2(0.610)$$

= 0.06028 m^3

So, design balance tank has capacity of 62.09 kg milk

2.3.5 Liquid Level Controller

Automatic liquid level controller uses to maintain milk level in the balance tank. Level controller attached with contactor for ON and OFF the pump at low level and high level of milk respectively.

2.4 Electric Panel Design

Electric panel consists of all the required electrical components in ohmic heating cell. Panel is connected with miniature circuit breaker (MCB) for smooth running and safety of all components in panel. Voltmeter, ammeter, variac, kilowatt-hour meter, transformer, MCB and energy meter were the main components of electric panel.

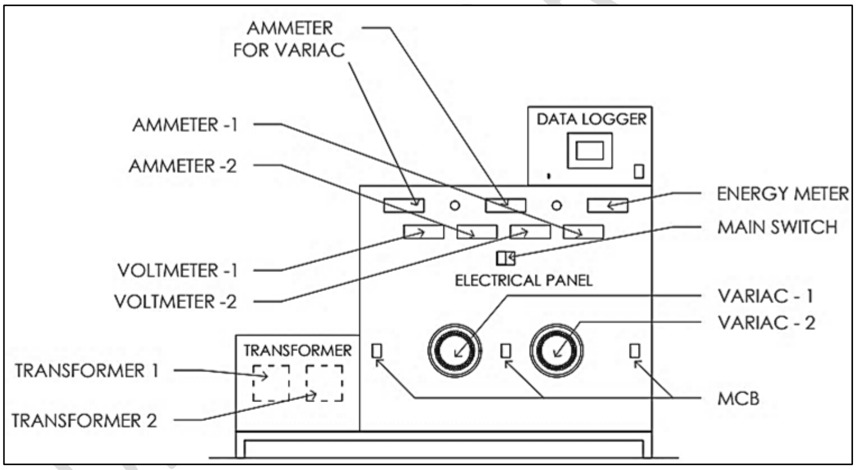

Fig 3: Diagram of Electrical panel for continuous ohmic heating unit

2.4.1 Voltmeter and Ammeter:

A voltmeter with measuring capacity of 0-500 V AC was used in the electrical panel. Digital MV15 type voltmeter with 240 V AC±20% was used for the measurement of applied voltage. Both the ohmic heating unit stages had separate voltmeter. The measuring range of ammeter used in the present study was 0-100 ampere AC. Digital MA12 with input supply 240 V AC±20% was used in the electric panel. A separate ammeter was used for both the stages of ohmic heater.

2.4.2 Variac

Variac, also known as auto transformer, is a device used to control the amount of electricity supply. Auto transformer is easy to handle, cheaper and lighter in weight compare to dual winding transformer. Two separate variac, each having 20 amp rated capacity was used in the panel for the two stages of ohmic heating unit.

Commented [AD6]: Unit of current is represented by A

2.4.3 Transformer

Step down transformer was installed for increasing the current supply in the unit. Current transformer set a ratio (250/5) VA-5, HSVIL-0.66/3-4 kV having maximum capacity of 660 V, CL-1.0 with 50 Hz frequency was used. Each of the two stages of ohmic heating unit consisted of separate 4 kVA transformer connected to individual variac.

2.4.4 Power Analyzer

A single-phase power analyser was used to measure the power consumption (kW) utilized by ohmic heating cell. Power analyser also provided readings for kVA and power factor.

2.4.5 Megger

A megger was used to confirm that there was no any electrical contact between two electrodes before starting of control panel.

Commented [AD7]: Check the sentence language and rewrite to make the sentence more meaningful. Megger meter is a device used to test insulation.

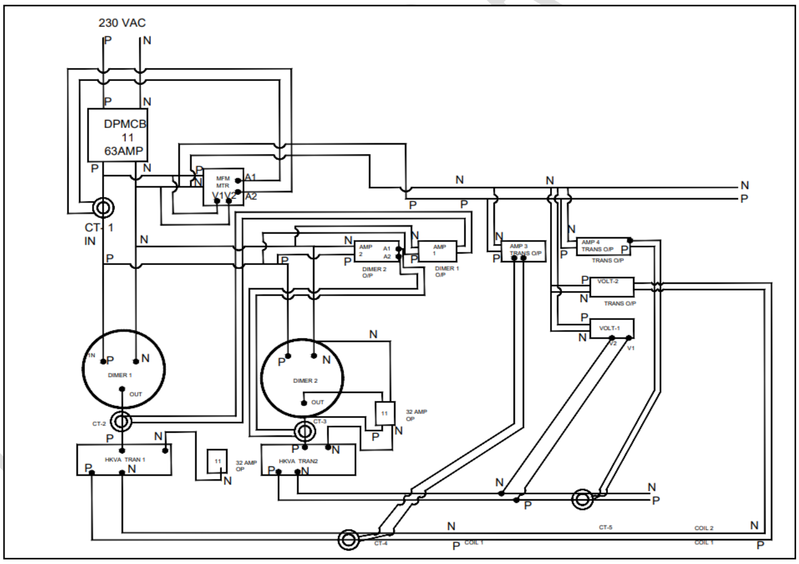

Fig 4: Technical drawing of control panel

Fig 5: Control panel for continuous ohmic heater

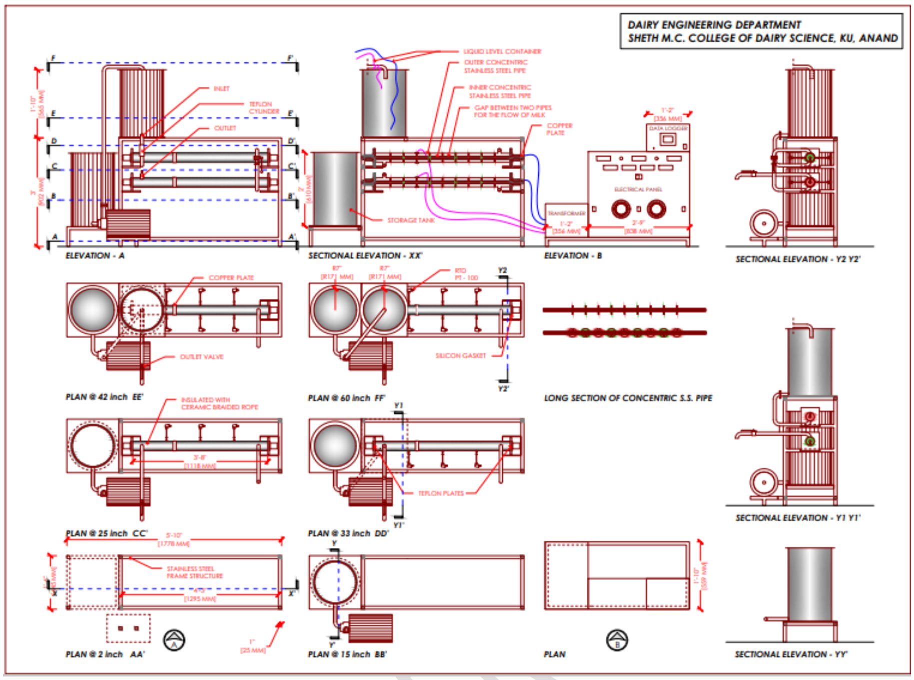

Fig 6: Auto CAD drawing for developed continuous ohmic heater

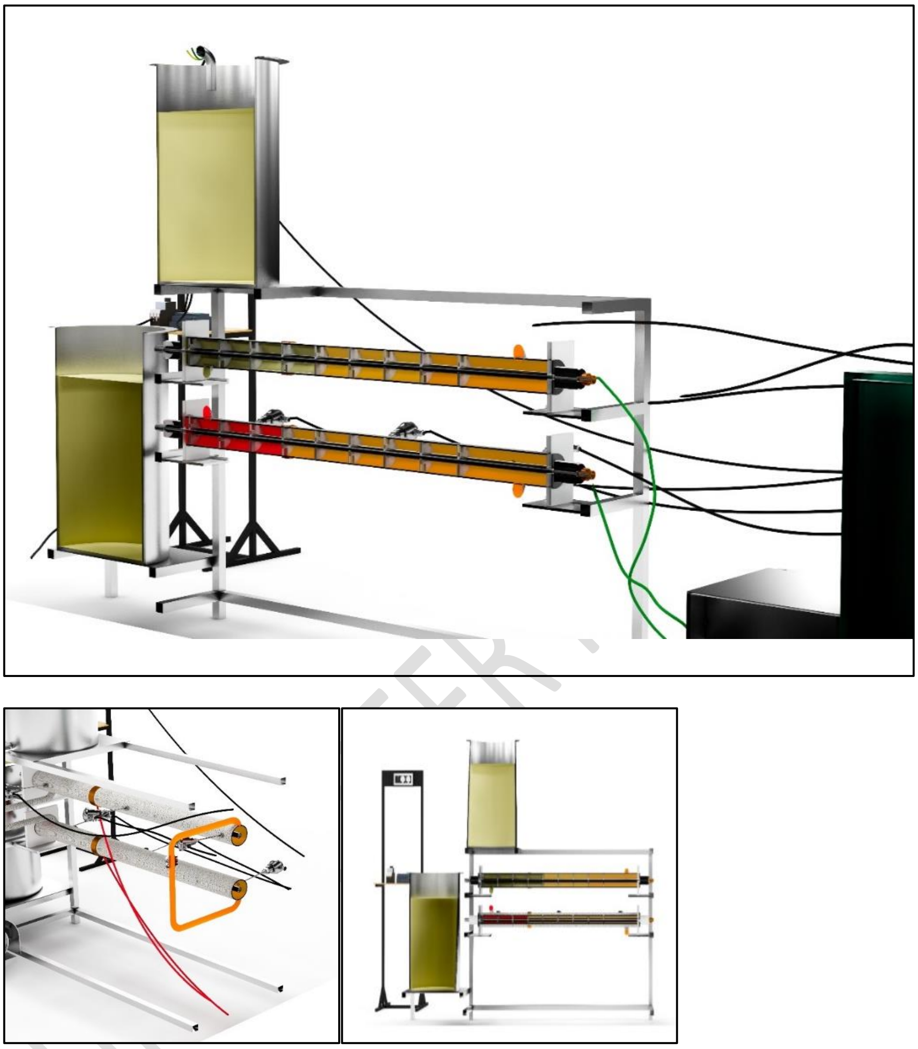

Fig 7: Sectional parts for designed ohmic heater (Auto CAD drawings)

3. RESULTS AND DISCUSSION:

3.1 Deisgn of developed Continous ohmic heater for milk:

The design included the calculations for the capacity of variac (auto transformer), energy meter, temperature sensor, step up transformer, voltmeter and ammeter for measuring the current and voltage supplied. Technical drawing of electric panel is as shown in Figure 4.2. In ohmic heater design there are many important criteria to be considered, as heat is generated within the product. Therefore, product composition and thermal and electrical properties of product affects the design of ohmic heater. The

Commented [AD8]: The mentioned Figure4.2 is not in the figure list. Enlisted figure numbering is different

Commented [AD9]: Comma should be used material of electrode and pipes are made up of food grade material (AISI-SS316). The ends of heater pipe are also in contact with milk and hence, food grade Teflon material and silicon gasket were used to prevent the leakage of product as well as current. The distance between the two electrodes (pipes) was maintained by using two concentric pipes separated by using grooved Teflon ends. Milk can thus flow in the gap created between the two pipes.

Electricity was supplied to the electrode using a copper plate which can be connected to the control panel. Each heating cell unit of ohmic heater had different electrical connection on the control panel, and hence, different voltage can be supplied to the both the stages of ohmic heating unit. Two balance tanks having the capacity of 60 kg milk was installed to maintain the level in the milk supply tank. Automatic liquid level controller was used for maintaining the level of milk in supply tank by using 'ON and OFF' system in the centrifugal pump when low and high level are reached, respectively. In the designed two stage continuous ohmic heater, six RTD (PT-100) are equipped to check the temperature of milk at inlet, outlet and at various location on the pipe.

Commented [AD10]: Which can be ?

Heating of milk upto 73 ±2°C and evaluate the thermal performance of designed ohmic heater, also investigated the effects of ohmic hating on the microbiological and compositional analysis of milk, as opposed to conventional heating.

3.2 Temperature profile:

The main factor to be controlled during the ohmic heating is the temperature-time profile, which is also important in the conventional heating treatment. Heating rate was measured using 6 different temperature sensors (PT-100) mounted on the equipment. The results found in the present study with regards to increase in heating rate with increasing the voltage were similar to the study conducted by Sastry and Palaniappan (1992) where the rate of heating is directly proportional to the electrical conductivity and the square of the electric field strength. Moreover, above 50°C, milk fat remains in liquid state and as a result, the heating rate of milk decrease beyond such temperature range. As voltage is worked as driving force, increase in driving force increase in ions mobility and hence there is an increase in ampere passing from product, ultimately increasing the heating rate.

Commented [AD11]: Author should mention the 6 different temperature. As there are numbers of temperature like thermistors, thermocouples, infrared, thermostat etc

Commented [AD12]: Rewrite this sentence to make it more meaningful

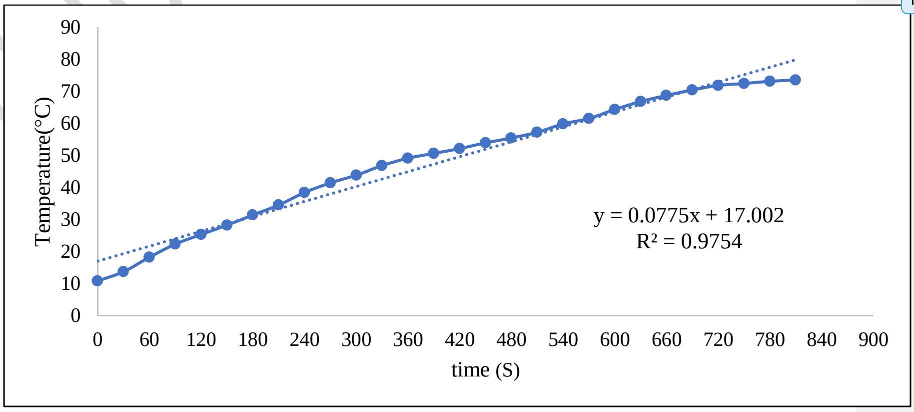

Fig 8: Temperature profile during ohmic heating for standardized milk

3.3 Current profile:

An Ampere vs. time graph represents the behaviour of electric current flowing through a milk over a period of time. Current flowing from the product depends on number of factors, where, the major factors are temperature of the product and voltage applied (Jha *et al*., 2011).

The current profile for ohmic heating of milk (Fig. 8) shows that, with increase in temperature, there is increase in current passing through the product. There was a linearly increase in current passing through product until the temperature reached up to 55°C, these implies that current passed through the product and temperature were affected to each other. From figure 4.53, 4.54 and 4.55 it can be observed that there is an increase in voltage when ampere is increase, besides that, at constant voltage, there is an increase in temperature of product with increase in ampere passing through milk. It may be attributed that because of increase in temperature of the product there is increase in the conductivity and decrease in resistance which allows higher ampere to pass from the product. Our results are in accordance with the results reported by Ghinea *et al*. (2022) where, the components of salt, acids and moisture were shown to be very effective in increasing the conductivity of electricity, while total solids content, sugar, fats, lipids and alcohols decreased the conductivity.

Commented [AD13]: The mentioned figure numbering is not the pattern mention in the manuscript. However, there figure4.53, 4.54 and 4.55 do not exist in the manuscript

Commented [AD14]: Correct word is current , not ampere

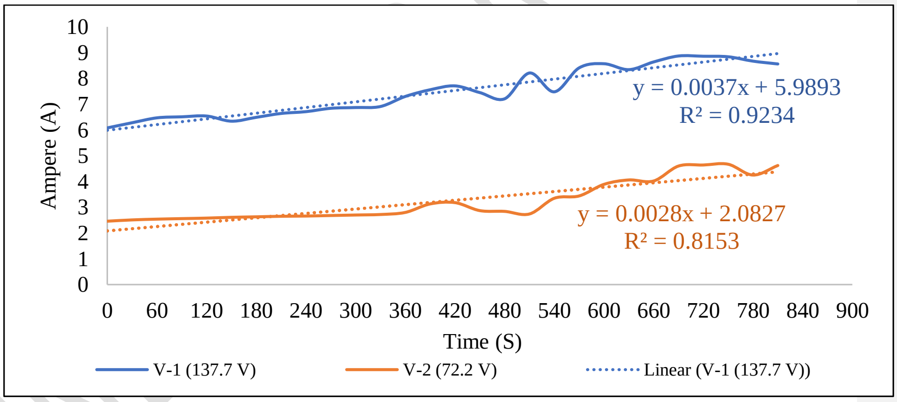

Fig 9: Current profile during ohmic heating for standardized milk

3.4 Heating Rate:

For standardize milk 137.7 V and 72.2 V to the first and second ohmic heater cell respectively, gave heating rate of 4.6°C per minute. From the present study it was found that increase in voltage supplied to ohmic heater that proportionally increased the heating rate. Cappato *et al*. (2017) found there was increase in electrical conductivity values (S/m) with increase in temperature from 4 to 60°C. The values of conductivity increased for skim milk and whole milk, leading to faster heating rates when the temperature was increased. Stirling (1987) showed that, Dairy products, custards, desserts and fruits in syrup have lower conductivity (0.1 - 0.5 Sm^{-1}), this group shows the potential of rapid heating 8-40°C/S.

Commented [AD15]: When the data is cited in the text, there was no need to give the figure. However, there is no citation of figure 10 in the content

Commented [AD16R15]: There is no reason and references quoted given for this standardized or optimized condition used for ohmic heating of milk.

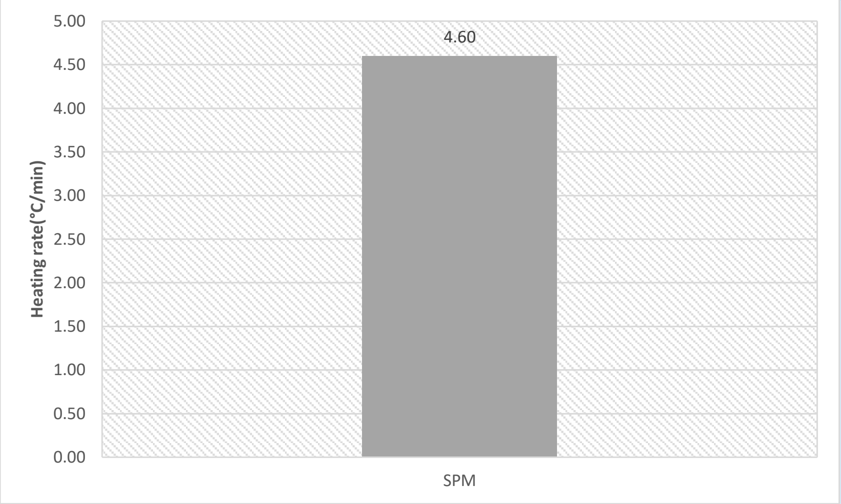

Fig 10: Heating rate during ohmic heating for standardized milk

Commented [AD17]: SPM full form is missing

3.5 System Performance Co-efficient

The specific performance coefficient of an ohmic heater refers to the ratio of the amount of heat generated by the heater to the electrical power consumed by it. It is a measure of the efficiency of the ohmic heater in converting electrical energy into heat energy.

The specific performance coefficient of an ohmic heater depends on various factors, including the design of the heater, the material used for the heating element, and the operating conditions such as the voltage and current applied to the heater. system performance coefficient of, standardize milk at optimized conditions was 86.95. These values indicate that increase in voltage usage increases the electrical consumption which ultimately decreases the system performance. Darvishi (2013), studied the effect of ohmic heating rate, electrical conductivity and pH of pomegranate juice at different voltage gradient used (30–55 V/cm) and found that as the voltage gradient increased, time, system performance and pH decreased. For the pomegranate juice samples the SPCs increased from 0.764 to 0.939 as the voltage gradient decreased, which indicated that 6.1– 23.6 per cent of the electrical energy of the system was not used in heating up the test sample. Ghnimi *et al*. (2007) studied the energy efficiency of an ohmic heating technology by fluid jet in food industrial process and found that energy efficiency of the ohmic heating process varied from 65 to 90 per cent, depending on the thermal balance of the system, The energy efficiency of the power supply was up to 90 per cent and was independent of pulse parameters, flowrate or fluid level inside the receptacle.

Commented [AD18]: Full form is missing

3.6 Power Consumption: The power consumption of an ohmic heater depends on several factors, including the product being heated, the applied voltage, and the current flowing through the heater. system performance coefficient of, standardize milk at optimized conditions found an average value of 1.47 kWh. Sofi'i *et al*. (2022) determined the energy requirements for patchouli using ohmic heating and the experimental results show that the energy consumption during the extraction process starting from the lowest was 3488.96 kJ (voltage 100 V), 4386.69 kJ (voltage 220 V) which resembles to present study where the energy requirements at 5148 kJ (V1=121 V and V2= 68 V). Ohmic heating requires less energy than conventional heating, implying a significant environmental advantage of this technology (Makroo *et al*., 2020).

3.7 Fabrication cost of developed equipment:

In fabrication of equipment consist of mainly two component, ohmic heater equipment and control panel. Control panel consist of mainly two variac, two transformer, digital volts meters, digital ammeters, energy meter, MCBs, RTD and high level and low-level controller with some micellous components have an average cost of 55000 ₹. Ohmic heater shall consist of mainly AISI (SS-316) stainless steel pipe for ohmic heater shall design, AISI (SS-314) stainless steel pipe for stand, gasket, teflon material, balance tank, pump etc have an average cost of 60000 ₹.

Table 1: Fabrication cost of developed equipment

1	**Construction materials**			**Unit**	**Qty**	**Rate (`)**	**Cost (`)**
	1.1	Electrode material (Pipe)	AISI (SS-316)	Kg	16.28	415	6756.2
	1.2	Ohmic heater stand material (Box Pipe)	AISI (SS-304)	Kg	15.5	385	5967.5
	1.3	Electrode connection (Fitting clamps)	Copper (width of 25 cm and thickness of 3 mm)	Nos.	4	300	1200
	1.4	Teflon material (PTFE)	Poly Tetra Fluoro Ethylene	Nos.	5	100	500
	1.5	Gasket Material	Silicon gasket	Nos.	8	15	120
	1.6	Insulation	Ceramic braided rope.	Kg	1	600	600
	1.7	Pump	0.5 HP Stainless steel	No.	1	10500	10500
	1.8	Balance tank	60 lit capacity (AISI-SS 304-3 mm sheet)	Kg	12	400	4800
	1.9	Other misc.		Set	1	1500	1500
2	**Electrical Panel Material**						
	2.1	Panel Box	130*30*65	cm	1	3500	3500
	2.2	Variac	20 A Rated Capacity	Nos.	2	7200	14400
	2.3	Digital Energy Meter	kW, kVA, Voltage, Frequency, Power factor	No.	1	1890	1890
	2.4	Transformer	4 kVA single phase	Nos.	2	11000	22000
	2.5	Digital Volt and Ammeter	MA12, MV15	Nos.	6	350	2100
	2.6	Temperature measurement	PT-100 (RTD)	Nos.	6	800	4800
	2.7	Miniature circuit breaker (MCB)	16-amp (main plug), 63-amp (transformers) 32- amp (separate MCB for both variac)	Nos.	4	1000	4000
	2.8	Connection from control panel to electrode	Single phase connection with 10sq mm wire	m	7	115	805
	2.9	High and low level	Automatic liquid level controller	Nos.	1	2500	2500
		Total (1+2)					87939
		Fabrication cost (₹)					21985
		Total Equipment cost (₹)					**109923**

3.8 Analysis of Milk

A comparison of the different chemical properties of samples subjected to conventionally and ohmically heated are shown in table 2.

Table 2: Compositional Analysis and AP Test of Milk

Type of Milk	Mode of Heating	Parameters (%)					
		Fat	SNF	Lactose	Protein	Ash	AP test
Standardized milk	Conventional	4.57±0.01b	8.65±0.03a	4.68±0.03a	3.21±0.02a	0.76±0.01a	-ve
	Ohmic	4.55±0.02b	8.64±0.02a	4.67±0.03a	3.20±0.01a	0.76±0.01a	-ve
*Mean±SD, values are means of three observations AP: Alkaline Phosphatase							

The statistical analysis of the data shows that there was no significant difference ($p > 0.05$) in all the compositional parameters of the ohmic heated milk compared to the samples which were heated conventionally. Hence, it can be concluded that, ohmic heating of milk does not affect the composition of milk and hence it can be used for processing of milk having different composition.

In addition, alkaline phosphatase (AP) test, which is a preliminary requirement for milk pasteurization, was also conducted for the processed milk samples. The negative alkaline phosphatase test indicates the absence of an enzyme, alkaline phosphatase in milk, which is efficiently pasteurized. All results in the present study showed that all the samples with varying compositions showed negative alkaline phosphatase test, independent of the type of heat treatment and hence, it can be concluded that ohmic heating can be used for efficiently pasteurizing the milk. Rocha *et al*. (2022) studied the effect of ohmic and conventional pasteurization on composition of high protein flavoured milk. Suebsiri *et al*. (2019) processed the milk using conventional and ohmic heating and estimated the protein content as well as examined the pasteurization efficiency using AP test. Pereira *et al.* (2008) compared various physico-chemical properties of ohmically and conventionally heated goat milk. The total solids and ash content were determined in the heated samples and their values suggested that ohmic heating did not have any influence on the analysed compositional characters. Moreover, the data obtained for conventional heating was statistically similar to those obtained for ohmic heating.

Table 3: Sensory Evaluation of Milk

Type of Milk	Mode of Heating	Sensory Attributes			
		Flavour	Colour and Appearance	Body and Texture	Overall Acceptance
Standardized milk	Conventional	8.93±0.21ab	8.99±0.22a	9.00±0.16a	8.95±0.16a
	Ohmic	8.88±0.15a	8.97±0.17a	8.98±0.17a	8.91±0.20a
* Mean±SD, Values are means of three observations					

Sensory evaluation of any food and dairy product is an importance measure for assuring its consumer acceptability and hence the prepared milk samples were studied for its sensory evaluation. Milk samples treated with conventional and ohmic method were heated and cooled were evaluated for sensory attributes including flavour, colour, body and texture as well as overall acceptability by trained panellist and the results are presented in Table 3. It can be observed that all the milk samples were highly acceptable by all the panellist. The flavour score for whole milk treated with conventional as well as ohmic treatment had slightly higher values, which may be attributed to the sample's high solid content, resulting to more acceptable mouth feel. However, there was no significant differences ($p>0.05$) in the flavour score of all the samples examined in the present study. Moreover, the colour of milk ohmic heated milk samples were also significantly at par with those heated using conventional heating. Parmar *et al.* (2018) and Balthazar *et al*. (2022) shows that the results suggests that milk samples heated with ohmic heating were having significantly similar flavour scores compared to that of the samples prepared using conventional heating.

4. CONCLUSION:

This study demonstrated that design and development of continuous ohmic heater was a suitable and promising technology for heating of milk. It showed the need to implement a heating profile with variable voltage supply in different heating steps in order to achieve an optimized sensory quality. Results shows that the heating rate and power consumption and system performance co-efficient of the ohmic unit was inversely proportional to voltage suppled and flow rate, whereas, the sensory scores were directly proportional to the voltage and flow rates. In present study, comparison with conventional heating, ohmic heating has shown many advantages in terms of sensory quality and cost reduction. Furthermore, found negative alkaline phosphatase test provide feasibility for pasteurization of milk by using ohmic heating technology. Overall, this process is still in need of optimization of the process variables and further fundamental research should be carried out for industrial application.

REFERENCES:

Balthazar, C. F., Cabral, L., Guimarães, J. T., Noronha, M. F., Cappato, L. P., Cruz, A. G., & Sant'Ana, A. S. (2022). Conventional and ohmic heating pasteurization of fresh and thawed sheep milk: Energy consumption and assessment of bacterial microbiota during refrigerated storage. *Innovative Food Science & Emerging Technologies*, 76, 102947.

Bolhuis, D., Mosca, A. C., & Pellegrini, N. (2022). Consumer awareness of the degree of Industrial Food Processing and the Association with Healthiness—A Pilot Study. *Nutrients,* 14(20), 4438.

Cappato, L. P., Ferreira, M. V., Guimaraes, J. T., Portela, J. B., Costa, A. L., Freitas, M. Q., & Cruz, A. G. (2017). Ohmic heating in dairy processing: Relevant aspects for safety and quality. *Trends in Food Science & Technology,* 62, 104-112.

Darvishi, H., Khostaghaza, M. H., & Najafi, G. (2013). Ohmic heating of pomegranate juice: Electrical conductivity and pH change. *Journal of the Saudi Society of Agricultural Sciences*, *12*(2), 101-108.

Fox, P. F., Uniacke-Lowe, T., McSweeney, P. L. H., O'Mahony, J. A., Fox, P. F., Uniacke-Lowe, T., & O'Mahony, J. A. (2015). Physical properties of milk. *Dairy chemistry and biochemistry*, 321-343.

Gençoğlu, M. T. (2007). The comparison of ceramic and non-ceramic insulators. Engineering Sciences, 2(4), 274-294.

Ghinea, C., Prisacaru, A. E., & Leahu, A. (2022). Physico-chemical and sensory quality of oven-dried and dehydrator-dried apples of the Starkrimson, Golden Delicious and Florina cultivars. *Applied Sciences*, 12(5), 2350.

Ghnimi, S., Dresch, M., Maingonnat, J., & Flach-Malaspina, N. (2007). Energy efficiency of an Ohmic heating technology by fluid jet in food industrial process. *ECEE Conference" Saving energy: Just do it* , 1527-1532.

Goullieux, A., & Pain, J. P. (2014). Ohmic heating. In Emerging technologies for food processing. Academic Press, 399-426.

Jakób, A., Bryjak, J., Wójtowicz, H., Illeová, V., Annus, J., & Polakovič, M. (2010). Inactivation kinetics of food enzymes during ohmic heating. *Food chemistry,* 123(2), 369-376.

Jha, S. N., Narsaiah, K., Basediya, A. L., Sharma, R., Jaiswal, P., Kumar, R., & Bhardwaj, R. (2011). Measurement techniques and application of electrical properties for nondestructive quality evaluation of foods: *A review. Journal of food science and technology*, 48, 387-411.

Kaur, N., & Singh, A. K. (2016). Ohmic heating: concept and applications—a review. *Critical reviews in food science and nutrition*, *56*(14), 2338-2351.

Kumar, T., Smith, D. D., Kumar, S., & Vimla, B. (2018). Effect of voltage gradient and temperature on electrical conductivity of grape (Vitis vinifera L.) juice during ohmic heating. International Journal of Current Microbiology and Applied Sciences, 7(05), 1914-1921.

Leong, S. Y., & Oey, I. (2022). Application of novel thermal technology in foods processing. *Foods*, 11(1), 125.

Makroo, H. A., Rastogi, N. K., & Srivastava, B. (2020). Ohmic heating assisted inactivation of enzymes and microorganisms in foods: A review. *Trends in Food Science & Technology*, 97, 451-465.

Parmar, P., Singh, A. K., Meena, G. S., Borad, S., & Raju, P. N. (2018). Application of ohmic heating for concentration of milk. *Journal of food science and technology*, 55, 4956-4963.

Pereira, R. N., Martins, R. C., & Vicente, A. A. (2008). Goat milk free fatty acid characterization during conventional and ohmic heating pasteurization. *Journal of Dairy Science*, 91(8), 2925-2937.

Phirke, P. S. (2014). Processing equipment and design. *Jain Brothers*, New Delhi.

Rocha, R. S., Silva, R., Ramos, G. L., Cabral, L. A., Pimentel, T. C., Campelo, P. H., & Cruz, A. G. (2022). Ohmic heating treatment in high-protein vanilla flavored milk: Quality, processing factors, and biological activity. *Food Research International*, 161, 111827.

Sastry, S. K., & Palaniappan, S. (1992). Mathematical modeling and experimental studies on ohmic heating of liquid-particle mixtures in a static heater 1. *Journal of Food Process Engineering*, 15(4), 241-261.

Sofi'i, I., & Arifin, Z. (2022, April). Energy consumption for patchouli oil extraction using ohmic heating. In IOP Conference Series: Earth and Environmental Science, 1012, 012062.

Sparrow, E., Gorman, J., & Abraham, J. (2013). Quantitative assessment of the overall heat transfer coefficient U. Journal of heat transfer, 135(6), 061102.

Stirling, R. (1987). Ohmic heating-a new process for the food industry. *Power Engineering Journal*, 1(6), 365-371.

Suebsiri, N., Kokilakanistha, P., Laojaruwat, T., Tumpanuvatr, T., & Jittanit, W. (2019). The application of ohmic heating in lactose-free milk pasteurization in comparison with conventional heating, the metal contamination and the ice cream products. *Journal of Food Engineering*, 262, 39-48.