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Design and development of continuous type ohmic heating unit

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Abstract
Researches on application of ohmic heating for processing of liquid food have been limited to batch type operations. This limits its applicability for various foods with reduced processing capacity. Ohmic heating can have wider application in food processing when used in continuous mode. A continuous type ohmic heating unit was designed for volumetric/processing capacity of 10 litres/hour and which can be able to elevate the temperature up to 20 ± 2.5 ^{0}C. Concentric tubes (2 Nos) with inner tube diameter 5 cm; outer pipe 7.5 cm and length 1.25 m was selected based on preliminary trials (Joule's law and Ohms law) for considering various piping combinations get the desired capacity and elevated temperature. The selected pipe sizing provided a 1.25 cm gap between the pipes for the liquid flow. The designed and fabricated ohmic heating section was tested for its performance at continuous mode at potential difference 60 V. As the solute content was increased, higher temperature elevation was observed in the liquid food.

Keywords: ohm law, joule's heat, stress, design, fabrication

Introduction
Ohmic heating is a thermal process in which heat is internally generated by the passage of alternating electrical current (AC) through a body such as a food system that serves as an electrical resistance (Castro *et al*. 2003). During OH treatment electric currents are passed through foods, which behave as a resistor in an electrical circuit, and heat is internally dissipated according to Joule's law (De Alwis and Fryer, 1989). The major benefits claimed for ohmic heating technology are the continuous processing without heat transfer surfaces, uniform heating of liquids and, under certain circumstances, heating of solids and carrier fluids at very comparable rates, thus making it possible to use High Temperature Short Time (HTST) technique (Kulshrestha and Sastry, 2003).

The concept of ohmic heating is quite simple. The passage of electric current through an electrically conductive food material obeys Ohm's law ($V = IR$); and heat is generated due to the electrical resistance of the food on basis of joule's law ($H= I^2RT$). Ohmic heating is a thermal process in which heat is internally generated by the passage of alternating electrical current (AC) through a body such as a food system that serves as an electrical resistance. During OH treatment electric currents are passed through foods, which behave as a resistor in an electrical circuit, and heat is internally dissipated according to Joule's law.

Ohmic heating (OH) is now receiving increasing attention from the food industry, once it is considered to be an alternative for the indirect heating methods of food processing. The major benefits claimed for ohmic heating technology are the continuous processing without heat transfer surfaces, uniform heating of liquids and, under certain circumstances, heating of solids and carrier fluids at very comparable rates, thus making it possible to use High Temperature Short Time (HTST) technique. For all these reasons, OH seems to allow obtaining value added products of a superior quality without compromising food safety. Because the energy is almost entirely dissipated within the heated material, there is no need to heat intervening heat exchange walls – thus the process has close to 100% energy transfer efficiency. Ohmic heating can be considered a high temperature short time (HTST) aseptic process. The potential applications of this technique in food industry are very wide and include, e.g. blanching, evaporation, dehydration, fermentation and pasteurization.

Application of ohmic heating to liquid material foods has proven a greater challenge, and the concept has not yet led to commercial applications in the processing sector. Researches on application of ohmic heating for processing of liquid food have been limited to batch type operations. This limits its applicability for various foods with reduced processing capacity. Ohmic heating can have wider application in food processing when used in continuous mode.

The continuous type system will not only increase the processing capacity but also increase its applicability. Hence, the present study is proposed to be undertaken to design, and evaluate a continuous type ohmic heating unit for liquid foods.

Materials and Methods

Theoretical considerations

Ohm's law

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. Introducing the constant of proportionality, the resistance (R), describes the relationship

$$I = \frac{V}{R} \qquad \ldots (1)$$

Joule’s law

According to Joule’s law, the amount of heat produced in a conductor is expressed as

$$H = I^2RT \qquad \ldots (2)$$

Also

The amount of heat required for changing a material's temperature (ΔT) is expressed as

$$H_1 = mC_p.\Delta T, \qquad \ldots (3)$$

Where,

H_1 = heat capacity, Joule

M = mass, kg

C_p = specific heat capacity, J $^oC^{-1}$ kg^{-1}

ΔT = Temperature changes, ^oC

Design of Ohmic heating unit

The ohmic heating unit comprised of three sections- storage tank, ohmic heating section and support frame. Each section were designed separately considering the various laws and then the three sections were assembled to form a single unit i.e. ohmic heating unit.

Design of storage tank

Design considerations

1. The storage tank should have enough capacity to operate the system for at least 2-3 hours.
2. Head space volume should be allowed for possible future needs, process events such as thermal expansion or foaming and also filling control, particularly when high speed pumping will be used.
3. Discharge mechanism with complete discharge should be adopted. This is done to ensure proper cleaning of the tank against the stored materials after use.

Stainless sheet (SS 304) was used as fabrication material of storage tank for maintaining hygiene and to resist corrosion as in the case of liquid food processing. While designing the tank outlet for the liquid discharge, funnel flow was adopted due to its simplicity and complete discharge. The funnel slope can be taken between 5- 10^0 for liquid having specific density between 1.0- 1.25 (Leizerson *et al.* (2005) [9]. Once the required volume was set, the shape of the tank was taken as Cylindrical with aspect ratio of 2:1 was taken for attaaining maximum capacity with least surface area. Different combination of height and diameter of the storage tank was tried and it was seen that for accommodating 25 l of liquid food, diameter of 25 cm and height 50 cm is the best combination for cylindrical tank. This combination will be the most cost efficient in terms of fabricating material requirement for 25 l capacity.

The maximum hydrostatic pressure is exerted at bottom and minimum at the top of the tank. It is constructed by welding plates of appropriate thickness depending on magnitude of hydrostatic pressure exerted. Hydrostatic pressure is calculated by following expression-:

$$p = \text{þ}(H - h) \qquad \ldots (6)$$

The minimum wall thickness (t_s) required to resist the exerted hydrostatic pressure (Phirke, 2009) can be determined by:

$$t_s = \frac{pD_i}{(2fJ)} \qquad \ldots (7)$$

Where,

H=height from bottom of the course under consideration.

þ=density of liquid food.

h = height of funnel = Radius of storage tank (cm) X Tan 5^o = 1.09 cm

J=joint efficiency usually taken 0.85.

f = Allowable tensile strength for steel grade of Fe 360 the tensile strength is 550 Kg/cm^2

It was seen that thickness of stainless steel sheet of 1.365 mm was required against the pressure exerted by stored liquid food. Hence, the thickness of the stainless steel sheet taken for the fabrication is taken as 1.3 mm which is readily available in commercial market as 18 gauge stainless steel sheet.

Design of Ohmic heating section

The design of ohmic heaters is governed by the electrical conductivity of the food. The most typical configuration for the batch type ohmic heater is that of a horizontal cylinder with one electrode placed in each extremity. It can range from a simple tube with pairs of opposing electrodes mounted on the tube walls opposite to each other, to coaxial tubes acting as electrodes with the food flowing between, or a vertical tube with the electrodes embodied at regular intervals. The choice of the best configuration will obviously depend on the food being processed and the objectives of the process (*e.g.* cooking, pasteurization, sterilization.

The proposed continuous type ohmic system should process certain volume of liquid food in a unit time. For this, two concentric pipe with one pipe connected to cathode and one attached to the anode side with liquid food in between the two pipes was used. The electric circuit will be completed using this arrangement and the electric resistance imposed by liquid food against the electric current flow heats the material between the two pipes. Inlets and outlets for the liquid food were provided at the diagonally opposite side of the outer pipe. The volumetric flow rate within the concentric pipe will depend upon the difference diameter of the two pipes and the residence time of the liquid food in the concentric tube. The residence time will further depend on the temperature elevation desired from the ohmic heating unit.

Design considerations

The capacity of the ohmic is around 10 litres per hour and hence appropriate concentric pipe dimension should be selected. However, arrangements should be made to control and vary its capacity (10 ± 2.5 litres per hour).

a) The feed to ohmic heating unit should be at controlled rate and continuous so that it reaches the outlet at desired increased temperature.
b) The thickness of anode and cathode plates should be around 2 mm (Icier *et al*, 2008) [6].
c) The electrode gap should be greater or equal to 1.25 cm for liquid food in order to avoid fouling (Jakób *et al*., 2010) [7]. Lower the thickness of moving strata of liquid, more will be increase in temperature of output. Hence, the two concentric pipes are selected considering the lowest possible thickness between them.
d) The heat transfer for moving liquid is generated by the resistive heat of the liquid in the ohmic unit.
e) The residence time liquid of should be sufficient to attain the desired temperature elevation.
f) The voltage should be adjusted to minimize fouling without sacrificing the efficiency of the system.

The ohmic heating unit considered for design in the project is of 10 litres/hour and which can be able to elevate the temperature up to 20 ^{0}C. Various combinations of dimensions of the two pipes were tried to get the desired capacity and elevated temperature. The minimum outer diameter of inner pipe was taken as 5 cm due to fabrication constraints while inner diameter of the outer pipe was taken as 7.5 cm so as provide a 1.25 cm gap between the pipes for the liquid flow.

The volumetric flow rate in the concentric pipe can be calculated using the formula

$$Q = \pi(r_i^2 - r_o^2)l \; X \; 3.6X10^6/t \qquad \ldots (7)$$

Where,
Q = volumetric flow rate or capacity, l/h
r_i= Inner diameter of concentric pipe, m
r_0=outer diameter of concentric pipe, m
l=length of pipe, m
t = time, h

The heat energy (H_1) generated due resistance posed by liquid food in the concentric pipe when electric current was passed was calculated using equation (2).

Also, heat capacity (H_2) of a liquid food within the concentric pipe for change in temperature (ΔT) was calculated using equation (3).

Considering no heat loss, $H_1 = H_2$,

The time required to obtain the elevation in temperature due to heat generated by Joule's law is given by

$$t = m.Cp.\Delta T/I^2 R \qquad \ldots (8)$$

The electric resistance(R) imposed by liquid food can be calculated using

$$R=\rho.l/A \qquad \ldots (9)$$

Where,
A= surface area from where liquid food will passes, m^2
l=length of concentric pipe, m
ρ=resistivity of milk (1/conductivity), Ohm - m

The time required for ohmic heating of milk for change in temperature of 10, 15, 20^{o}C at 110, 120 and 130 V were calculated using equation and it was seen that the concentric pipe with diameter 50 mm and 75 mm gave the closest combination for achieving volumetric capacity 10 ± 2.5 l/h.

Thus, the proposed ohmic heating section consisted of two concentric hollow pipes of inner diameter and outer diameter of 50 mm and 75 mm respectively. The thickness of the two pipe was around 2.25 mm. The two ends of the concentric pipe were closed using a 100 X 100X 15 mm Bakelite plate, which is a bad conductor of electric current. The closing arrangement is done using plate and frame method and the plate and the pipe frame is fastened using two pairs of bolts at each ends. Two holes were made at outer pipe at the diagonally opposite ends and control valves were attached to the holes using welded joints. This was done to regulate the processing capacity of the unit.

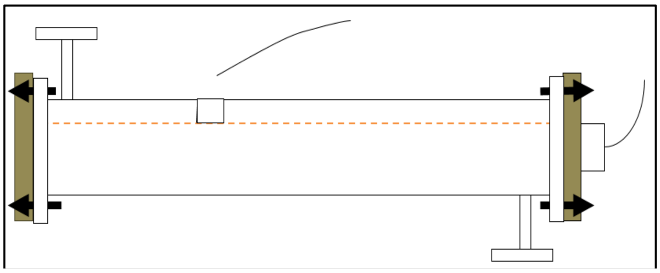


Fig 1: Schematic diagram of main section

Design of support frame

The whole frame is constructed of pieces of iron, cut to length and connected with bolts in order to make it portable. A portal frame consists of vertical member called columns and top member which may be horizontal. The vertical and top members built monolithically are considered as rigidly connected. The base of portal frame may be hinged. The portal frames are spaced at suitable distance and it supports the slab above the top members. Analysis of frames is done by Moment distribution method.

The frame and legs are made of 35 x 35 x 2.5 mm mild steel angle iron. Four lengths each 1500 mm and eight lengths each 1000 mm were cut and set at right angle to each other. The lengths were connected to each other and welded at the joints.

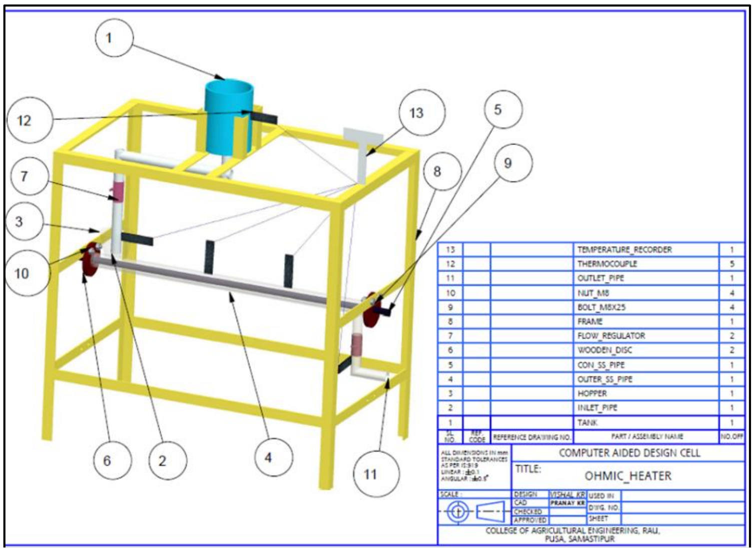
Results and Discussion

Ohmic heating experimental set up

The experimental set up (Fig. 2) consist of a continuous ohmic heating chamber, a power supply, a temperature recorder, thermocouples, digital thermometers, a variac and a storage tank. The continuous ohmic heating chamber, a concentric plugged with a Bakelite plate which was made leak proof. The electrode gap i.e distance between the two cylinders 1.25 cm, and the cross-sectional area was curved surface area of the cylinder. The product flows along the axis between the electrodes.

For the performance evaluation of ohmic heating unit,, 25 litre of test liquid was placed in the storage tank. The feed was conveyed to ohmic heating chamber by a gravity flow. The power was supplied in the chamber at 60 Hz, voltage controlled by a variac at 50 Volts and the liquid flow rate of 10 l pH. was maintained using control valves at the inlet and outlet of the ohmic heating unit (Kulshrestha and Sastry, 2006; Shirsat *et al*., 2004) [2, 8]. Samples temperature at the outlet of the unit was recorded at an interval of 5 minutes and average temperature of the liquid collected for this duration was recorded for the liquid. This sampling procedure was done for 30 minutes.

The liquid considered for the test was sugar water and the temperature change with respect to time was recorded with the help of digital laser thermometer. The experiments were done in triplicate.



SL NO.	REF. CODE	REFERENCE DRAWING NO.	PART / ASSEMBLY NAME	NO.OFF
13			TEMPERATURE_RECORDER	1
12			THERMOCOUPLE	5
11			OUTLET_PIPE	1
10			NUT_M8	4
9			BOLT_M8X25	4
8			FRAME	1
7			FLOW_REGULATOR	2
6			WOODEN_DISC	2
5			CON_SS_PIPE	1
4			OUTER_SS_PIPE	1
3			HOPPER	1
2			INLET_PIPE	1
1			TANK	1

Fig 2: A continuous type ohmic heating unit set up

Table 1: Observation recorded on developed ohmic heating unit on water at continuous mode (sugar, 2.5% w/w)

Applied voltage, V	Temperature of water at time interval, ^{0}C						
	0	**5**	**10**	**15**	**20**	**25**	**30**
60	14.6	50.8	51.5	52.9	53.0	53.1	53.2
60	14.6	50.9	52.2	52.9	53.7	53.0	53.6
60	14.6	50.6	52.6	53.5	53.7	53.7	53.8
Average	14.60	50.77	52.10	53.10	53.47	53.27	53.53

Table 2: Observation recorded on developed ohmic heating unit on water at continuous mode (sugar, 2.5% w/w)

Applied voltage, V	Temperature of water at time interval, ^{0}C						
	0	**5**	**10**	**15**	**20**	**25**	**30**
60	14.2	52.2	53.1	53.6	54.4	54.6	54.9
60	14.2	52.5	53.3	53.9	54.3	54.5	54.9
60	14.2	52.2	53.0	53.7	54.2	54.7	55.1
Average	14.2	52.30	53.13	53.73	54.30	54.60	54.97

It was observed from table 1 and 2 that the ohmic heating unit worked well in continuous mode with temperature elevation seen with treatment time. Also, increasing the solid content of liquid increased the resistance offered to electric flow thus, increasing the temperature increment. Temperature elevation of 40-45 ^{0}C was observed when operated at 60 V and 60 Hertz frequency for the developed Ohmic heating unit of capacity 10l/h.

Conclusions

Ohmic heating can have wider application in food processing when used in continuous mode. The continuous type system will not only increase the processing capacity but also increase its applicability. With suitable treatment combination of voltage and time, it can be successfully used for liquid pasteurization and other thermal processing of liquid foods.

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