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Static Ohmic Heating Vessel Design Concept: A Review

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Abstract: Ohmic heating is associated with its capability of achieving rapid and relatively uniform heating rates that is suitable in the processing of particulate food. Many food products exist in particulate form ranging from powders to emulsion, suspension and pellets. The size distribution of the particulate foods can affect its taste, appearance, stability, process suitability and function ability of the final products. In contrast to the conventional heating methods, it is often difficult to achieve the necessary high rates of heat transfer into the material in order to heat sufficiently without causing product degradation. The research conducted on this alternative heating approach in the aspects of energy efficiency and high quality method for a batch quantity of wet or moist materials. A prototype of Ohmic Heating equipment is being designed at laboratory scale and the main aim of the study is to prove that it is possible to design a heater that would successfully heat the food ohmically. For a given heater design and operational variables, it is possible to modify a product to enable the heating process to occur. The operational prototype will be tested on two selected particulate foods and a comprehensive reports published for commercial reference.

Key words: ohmic heating, static process, particulate foods, thermal heating process

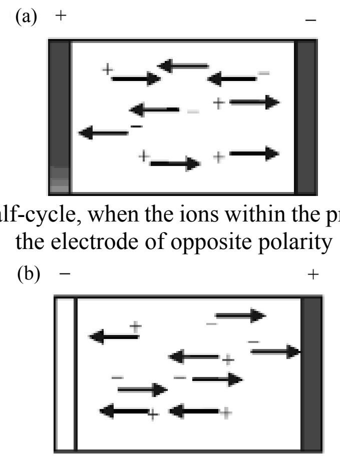
1. Introduction

In principle, Ohmic heating occur when electrical current is allowed to flow through food materials. The motion of charges within the material results in agitation of molecules or atoms which results in the increased of the particles' kinetic energy and therefore its temperature. In metallic conductors, the moving charges are electrons, however within food materials, the charges are usually ions or other charged molecules such as proteins, which migrate to the electrode of opposite polarity [1]. A schematic diagram of this mechanism is illustrated in Fig. 1. The diagram illustrate the movement of ionic during the Ohmic heating of an aqueous-based materials.

The rate of heat generation (U'') within the material may be characterized by the Eq. (1). The equation provides the basis for design of devices and formulation of products for Ohmic heating. The electric field strength ($E \approx V/l$) may be varied by the designer by changing either the applied voltage (V), or the electrode gap(l). The effective electrical conductivity (σ) is a function of temperature, frequency and product compositions.

$$U'' = E^2\sigma \quad [1] \qquad (1)$$

The justification for Ohmic heating being used instead of the conventional heating are explain in Table 1.



During one half-cycle, when the ions within the product move to the electrode of opposite polarity

Movement when electrode polarities are reversed

Fig. 1 Ohmic heating principle [1].

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Table 1 Advantages of Ohmic heating and priority in this research.

	Advantages	Priority in this study
1	Uniformity of heating	Priority 2
2	No theoretical upper temperature limit	
3	Controllable heating rate	
4	Cost	
5	Energy efficiency	Priority 1
6	In-situ process monitoring and feel-forward control	

Uniform heating in Ohmic Heating is a significant advantage over conventional heating due to heat being transferred from external medium through heat exchange walls and a carrier fluid before reaching the solid phase of the particulate foods [2, 3]. On the other hand, energy efficiency is also a major advantage for Ohmic Heating where all the energy delivered during the heating process is used internally which indirectly contribute to cost saving aspect [4]. Thus ohmic heating technology is an attractive option for use in the industrial environment.

2. Literature Review

The research will focus on the Ohmic behaviour of foods with its energy efficiency process, proving static Ohmic heating modelling as a basis and the prototype tested on two popular foods in the local market namely "*Fermented dabai fruit*" and "*Sarawak's pineapple*".

2.1 Ohmic Heating Behaviour of Foods

2.1.1 Uniformity of Heating

In an Ohmic process, the heating rate of a material depends directly on the conductivity of the element that act as resistance. The element can be liquid or solid and most experiments done have shown that the electrical conductivity of foods increases linearly with temperature [5, 6]. However this research paper will be dealing with a sample that consist of more than one phase known as a mixed system. An example of a mixed systems are a liquid mixture with solid or particles of solid food. The electrical conductivity of all phases must be considered when studying mixed systems because this property determines the system's temperature behaviour, particle geometry, size and concentrations of solid. It is considered as a rule of thumb for electrical property that current flows through the section with higher electrical conductivity [1]. These results are then taken as the temperature variations within the sample and are considered to be directly proportional to its current density.

2.1.2 Energy Efficiency

Ohmic heating is defined as direct-resistance heating in which as opposed to heating by conventional means through a hot surface exchanger. The non-existence of a hot wall should constitute a major advantage for food applications associated to high heating kinetics and homogeneity of treatment (in particular to the interest of solid-liquid suspension), thereby avoiding the degradation of thermosensitive compounds through overheating (change in taste, undesirable reactions, burning, etc.) and reducing the fouling or materials deposition onto the electrode (for constant thermal performances) [1]. However, the contribution of relative orientation of electric (E) and velocity field (V) (perpendicular/parallel orientation) or treatment in a laminar jet (no wall) constitute technical criteria that requires specific analysis. Furthermore, in food applications there is a need to scrutinize the interactions between food and the process itself. Thus thermal, electrical and hydrodynamics performances constitute fundamental criteria to control the process. Table 2 indicates the technical parameters, constraints to consider into Direct Joule heater and the priority in the research.

This research will focus on solid-liquid suspension treatments with direct Joule effect technology mentioned under energetic criteria (energetic efficiency, heating kinetics and temperature homogeneity). Issues of interest will be on the encountered difficulties and beneficial aspects (volume heating, fouling mechanisms, heterogeneous suspension treatment).

Table 2 Technical parameters, constraints and research priority.

Parameters	Constraints	Priority
1. Ohmic Technology	Batch or Continuous process Tabular, plane or jet Electrode dimension and position (intrusive, afferent) Electrode material (stainless steel, DSA)	*Batch* - - -
2. Electric supply	Electric Field: up to several 100 V/cm Frequency: 50 Hz to 30 KHz Current density: up to 5000 A/m^2 Max power: up to 480 kW	- - -
3. Product	Homogenous liquid/solid-liquid suspension Fouling propensity	*solid-liquid suspension*

2.2 Design Considerations of Ohmic Heating

2.2.1 Ohmic Heating Laboratory Units

There are a many variety of Ohmic heaters currently available in the market and it is up to the designer creativity to build a prototype that suit one specification meeting the aim of the research [3]. An example of a schematic of a laboratory scale Ohmic heating set-up is shown in Fig. 2. The main components and its function is as follows:

(1) Variable transformer — voltage, or the power input to the Ohmic heaters, can be controlled by using a variable transformer

(2) Isolation transformer — reduce potential shock hazards for the operator

(3) Voltage/current transducer box

(4) Heater Cell

Thermocouple signal conditioner — used to measure temperature.

2.2.2 Modelling of Ohmic heating

The mathematical modelling research in the context of Ohmic heating can be found as follows:

(1) The modelling of electrical conductivity in the context of ohmic heating.

(2) Modelling Basics as Applied to Ohmic Heating of Liquid and wall Cooling

(3) Modelling : Static vs. Continuous Systems

The modelling for static Ohmic heating is the subjects that is briefed in this paper. The mathematical formulation involves interdependent electrical and thermal problems. The electrical problem involves the determination of the voltage gradient (electrical field strength) and the thermal problems involves determination of liquids and particles temperature fields. The research team is planning to implement this static Ohmic heating model for the prototype and the selected food particulate to be tested.

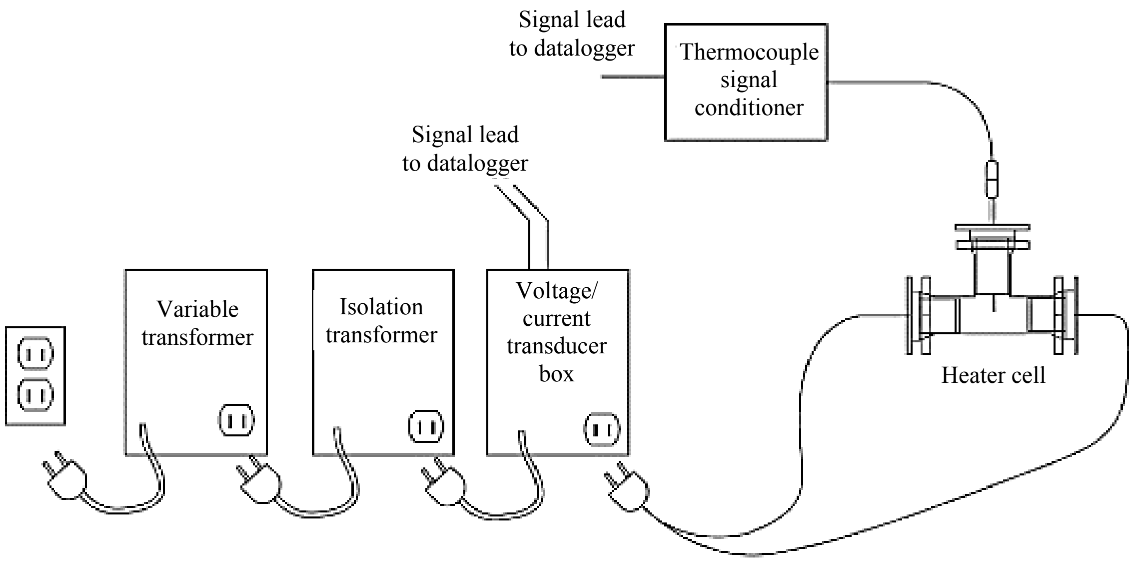

Fig. 2 Basic components making up an Ohmic heating set-up.

2.3 Ohmic Heating As Applied to Specific Foods

The commercial food products are usually solid-liquid mixtures. The traditional technique used by the food industry to sterilize these products is canning [7]. However, continuous processing of heterogeneous liquid-particle food products with alternative technologies (i.e., Ohmic heating) is being increasingly suggested as a substitute for batch sterilization [1]. The transformation from batch to a continuous processing in order to achieve high-temperature short-time (HTST) treatment of solid-liquid mixture is an empirical challenge [3]. It is recommended that the batch processing approach is to be conducted first before embarking on continuous processing.

The static Ohmic heating is applied to the following two specifics food which is very popular to the state of Sarawak in Malaysia.

(1) Fermented dabai fruit (*Canarium odontophyllum*) in soya sauce. Dabai fruit is a delicacy enjoyed locally in sarawak and abundantly available in Sarawak. It contain high lipid composition (give good sensory taste when consumed), but making it a poor electro-conductive material [8]. Hence, using soya sauce as the electrolyte medium for Ohmic Heating. It's "flavour" can be extracted (in liquid/powder form) as flavouring ingredient in other food products.

(2) Sarawak's pineapple juice with pulp are also considered to be abundantly available in Sarawak. It is considered to be an acidic material, therefore contains free ions that can act as electrolyte to accommodate electrical conductivity (Ohmic Heating) rather easily [9].

3. Ohmic Heating Prototype Design

After taking into account the requirements of (i) Ohmic heating behaviour of foods, (ii) mathematical modelling of Ohmic heating and (iii) application of specifics foods, the research team is proposing a "Single Phase Bench-top Batch Ohmic Heating" with design specifications as shown in Fig. 3.

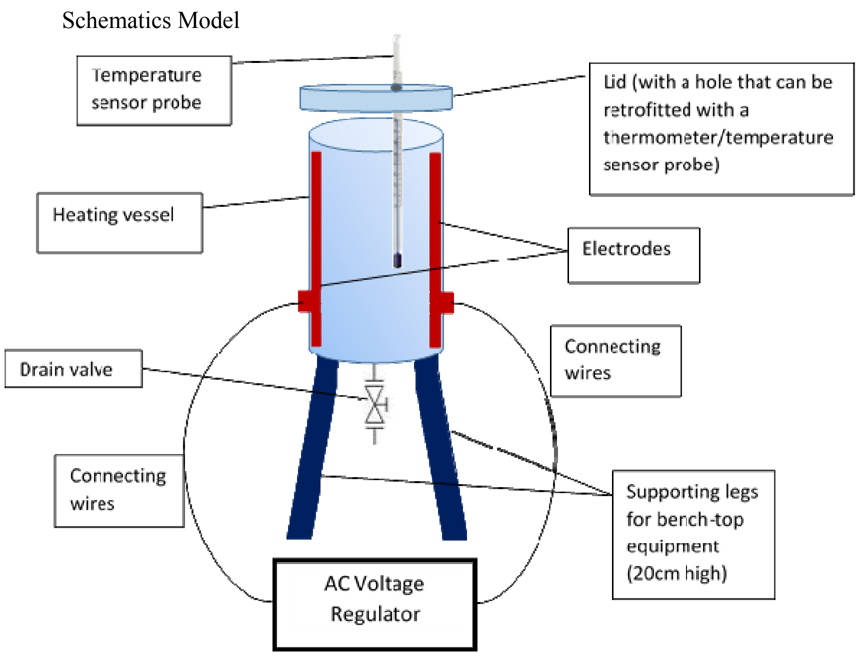

Fig. 3 Single phase bench-top batch Ohmic heating' design specifications.

Specification

Heating vessel	Electrodes	AC Voltage egulator
Capacity: 2 liter Material: teflon	Material: S. steel/aluminium/copper	50-60 Hz Single phase

4. Discussion and Recommendation

The feasibility in utilizing the high performance and efficiency of Ohmic heating in food processing has been described. The results obtained from the research could potentially be used to compare the three heating methods (classical heating, microwave radiation and Ohmic heating), in which the following research statement can be justified: “Ohmic heating can be used for food sterilization and extraction in aqueous media”.

The main advantages are (i) simplicity of design, (ii) low capital of the heater, (iii) ease of maintenance and handling, (iv) low heat capacity and (v) low thermal inertia of the Ohmic heating process. Ohmic heating has the possibility of fast and uniform heating, as well as the possibility of visual monitoring and addition of other reagents during the process, by which most microwave in closed cavities cannot achieve. We can make use of this feature as a highly advantageous and versatile option for organic sterilization and extraction in liquid medium.

Moreover, in an Ohmic heating process, the energy transfer depends on the electrical impedance of the medium and the applied voltage. The Ohmic heating process has huge potential in increasing the reactivity efficiency, has clear economic advantages and is environmentally sustainable. To better illustrate the scopes of this heating method, other examples of organic reactions are being studied and will be reported in the near future, as well as the probability of scaling up of the heater for future applications.

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