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ELECTRICAL CHARACTERISTICS INVESTIGATION OF OHMIC HEATING ON PARTICULATE FOOD STERILIZATION

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Abstract: *Ohmic heating is a method where alternating current is passed through a particulate food medium acting as a resistance between a pair of positive and negative electrodes which in turn volumetrically heats up the entire mass of the food systems. In order to effectively control ohmic heating for particular foods sterilization, the full understanding of electrical characteristics of ohmic heating needs to be investigated and determined using samples of popular food in Sarawak. Thus a joint study between electrical and food technology teams was formed at the Electrical Engineering Laboratory in UCTS to design the electrical circuit model and verify the main electrical characteristics of an ohmic heating process on particulate foods. The ohmic heating electrical system model was first set-up to prove that the model is working. The model is a simple electrical system that needs only a variable transformer to supply alternating current to the electrode of the ohmic cell and the particulate food sample. Electrical tests and measurements on two local popular fruits known as Sarawak pineapple and Dabai were conducted. The experiments have observed that the current and temperature rise significantly with time for different concentrations of the food postulate. These experiments also verified that ohmic heating process produces a uniform heat distribution within the food medium and the associated electrical characteristics like electrical conductivity (σ) were determined. The heating process is observed to be more efficient compared to other known heating process methods. The Food Technology department then have designed and fabricated Ohmic Heating (OH) test equipment prototype with the purpose of rapid repetition of the experimental procedure and exploring ohmic heating for other industrial applications.*

Keywords: *Ohmic Heating, Particulate Foods, Prototype, Heating Temperature.*

Introduction

Ohmic heating is a thermal processing method where alternating current went through a particulate food acting as a resistance between positive and negetive electrode. This heating process volumetrically heat the whole mass of the food sample.

The theory of ohmic heating start with the two-electrode conductivity measurement, the motion of positive and negative ions in the electric field carries current through the solution. Coupling of the ionic and electronic current occurs at the interface between the metal electrode and the solution. The interface can be thought of as a capacitor with the metal electrode being one plate and the adjacent electrolyte being the other. The alternating voltage causes the capacitor to charge and discharge, allowing the current to cross the interface. This Ohmic heating principle is illustrated in **Figure 1**.

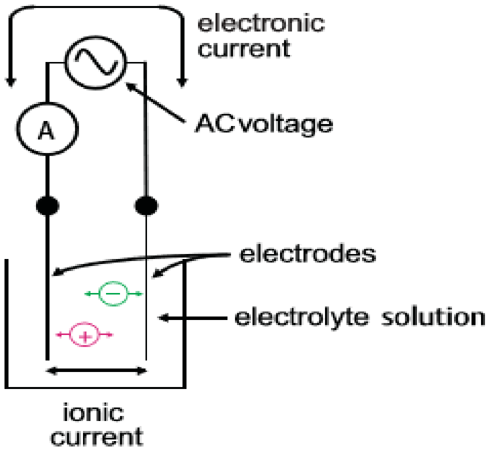

Figure 1: Ohmic Heating Principle (Emerson Process Management, 2010).

The ohmic heating principle in **Figure 1** is converted into electrical circuit diagram representing Ohmic heating system as shown in **Figure 2**.

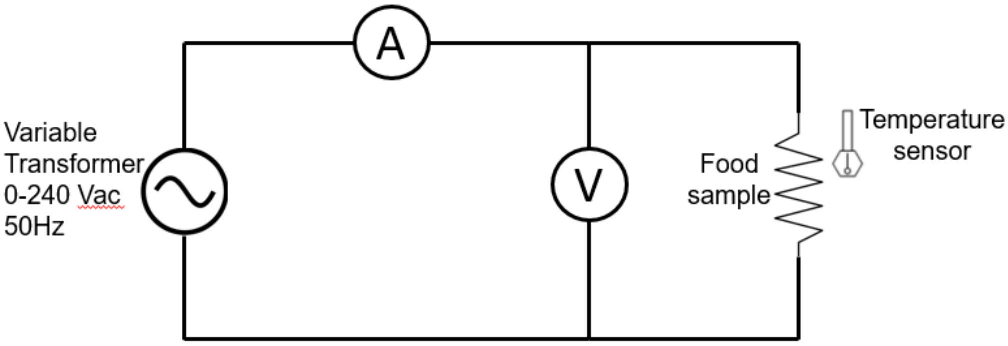

Figure 2: Electrical Circuit Diagram of OH Apparatus

The electrical conductivity of foods become a critical parameters for Ohmic heating process. Electrical conductivity can be derived as the reciprocal of resistance through a unit cross-sectional area A over a unit distance L, or the reciprocal of resistivity. The formula for elctrical conductivity of food is:

$$\sigma = L / (AR)$$ (**Equation 1**) (Zhang, 2009)

OR

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

where, A is the area of cross section of the sample (m^2), I is the current through the sample (A), L is the electrode gap or length of sample (m), R is the resistance of the sample (Ω), V is the voltage across the sample (V), and σ is the specific electrical conductivity (S/m).

The **Equation 1** can be used to design experiments for measuring the electrical conductivity of foods. **Table 1** show examples of the electrical conductivity of foods as reference for the research. The electrical conductivity of Fruit Juice and Vegetable Juice are found to increase with temperature (Zhang, 2009).

Table 1: The Electrical Conductivity (S/M) of Liquid Products Measured at Increasing Temperatures (Zhang, 2009)

Temperature	4°C	22°C	30°C	40°C	50°C	60°C
Fruit Juices						
Apple Juice	0.196	0.239	0.279	0.333	0.383	0.439
Orange Juice	0.314	0.360	0.429	0.500	0.600	0.690
Vegetable Juices						
Carrot Juice	0.788	1.147	1.282	1.484	1.741	1.980
Tomato Juice	1.190	1.697	1.974	2.371	2.754	3.140

The following are the relevant results by researcher for referencing in the ohmic heating research.

Author	Summary
(IMAI, 2007)	Lower frequency around 50Hz is the most effective for quick heating using ohmic heating.
(ICIER & ILICALI, 2007)	The higher the voltage gradient the shorter the heating times as a result from higher heating rates. The electrical conductivity of fruit juice will be the highest at the concentration around 40%.
(PERASIRIYAN, 2016)	The pH changes in fruit juice had significant change by using stainless steel electrode than titanium electrode.
(ITO, 2013)	The temperature increase was the slowest in the upper part of the cell near the electrode. The sterilization test of ohmic heating sample was almost the same as the retort-heated sample. The heating time was faster using ohmic heater.
(TOUDESHKI, 2008)	The using of capacitor can eliminate the voltage ripple in order to supply a continuous current to load during ohmic heating process.
(DUYGU & UMIT, 2015)	Using ohmic heating method to thaw the food required the shortest time and the least weight loss.

It is proposed in the research activities to conduct experimentation that will answer some or all of the following area of interest: -

i. Heating rate
ii. Liquid food conductivity
iii. Conductivity of multi-component food matrix

The main research objective is to explore ohmic heating as an alternative and fast heating method for potential application in particulate food sterilization. Sterilization is a process that eliminates, removes, kills, or deactivates all forms of life. Sterilization can be achieved through various means particularly through control heating.

Thus in order to effectively apply ohmic heating for processing particulate foods, the full understanding of electrical characteriscs of ohmic heating for any food sample need to be investigated and found. The main electrical characteristics investigated so far are electrical conductivity, heating rate and System Performance Coefficients (SPC) (Darvishi, Adel, Farzad 2012). As the electrical characteristics impact on food particulate determined it will enable an easily controlled process found for food sterilization purpose.

Methodology, Results and Discussion

The research focuses on the Ohmic behaviour of particulate foods of two popular fruits that can be found in Sarawak, Malaysia through the local markets namely "***Sarawak's pineapple***" and "***Dabai***" (*Canarium odontophyllum*) based on its uniform heating characteristic. The Ohmic heating electrical experiment set-up is shown in **Figure 3**. The schematic diagram of the experimental Ohmic heating system is shown in **Figure 4**.

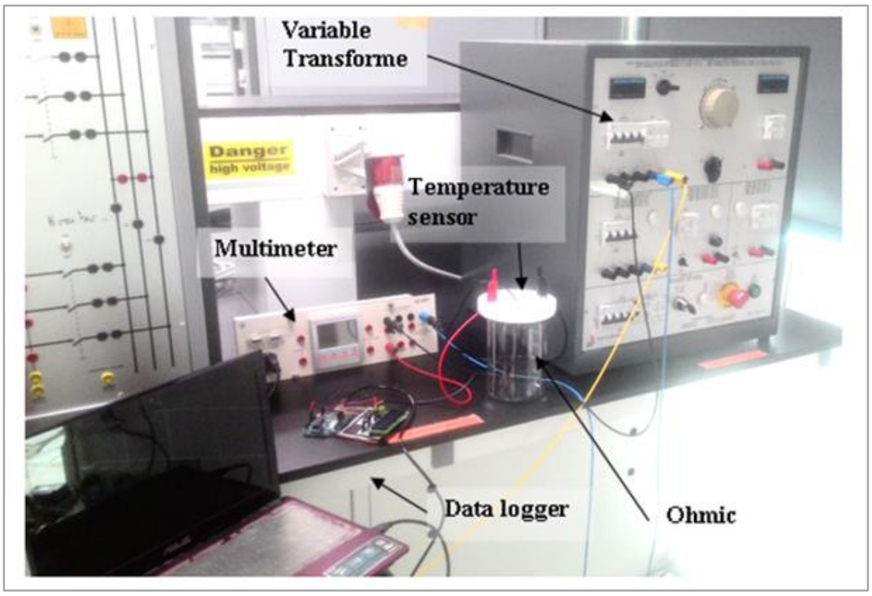

Figure 3: Ohmic Heating (OH) Electrical Set-Up Experiment

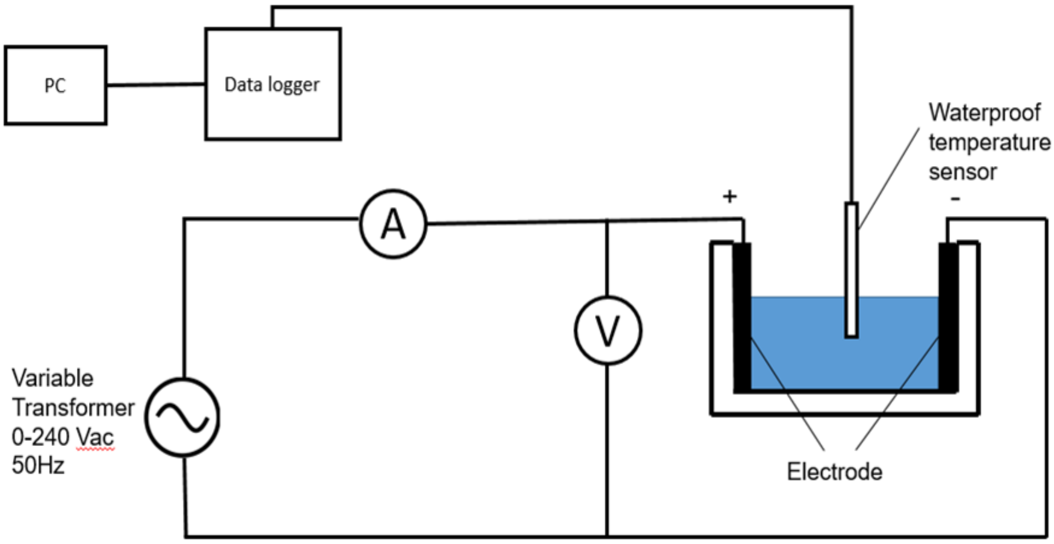

Figure 4: Schematic Diagram of The Experimental OH System

The constant variables in this experiment are the surface area of the electrode (A), the gap between the two electrodes (L), voltage supply and volume of the sample. The gap between the two electrodes L is 9.1 cm, surface area of the electrode can be calculate using the following equation:

$$A = 2\pi rh$$

which is,

$$A = 2 * \pi * 0.29 * 9.1$$
$$A = 6.327\ cm^2$$

The surface area of the electrode is 6.327 cm^2, the volumes of all food samples are fix at 300 ml and the voltage supply will be 240 V_{AC} but the voltage supply for soy ketchup will be 20 V_{AC} due to high current being generated. For the voltage supply, it was tuned to a fix voltage of 240 V_{AC} for pineapple juice food sample and 20 V_{AC} for soy ketchup food sample. The measurements of current and temperature of the food samples are taken after the voltage supply is tuned to the setting value.

Ohmic Heating Behaviour of Particulate Foods

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 the electrical conductivity of foods increases linearly with temperature (Palaniappan & Sastry, 1991) (Wang & Sastry, 1997).

Sarawak Pineapple and Dabai Results – Electro-Conductivity Study

In the research conducted, the heated materials are Pineapple juice and Dabai fruits in liquid soy (Ming, 2017). The electrical characteristics of Sarawak's pineapple juice are plotted in **Figure 5** for changes in temperature against heating time, **Figure 6** for changes in current against heating time and **Figure 7** as changes in electrical conductivity of different concentration of pineapple juice with temperature during Ohmic heating at 240 V_{AC}. It is observed that increasing the concentration of pineapple juice significantly increase the electro-conductivity of the Ohmic Heating process. Pineapple juice is an acidic material, which contains more charged ions and molecules that facilitate electrical conduction during the heating process. Rapid heating time is observed with the pineapple juice samples.

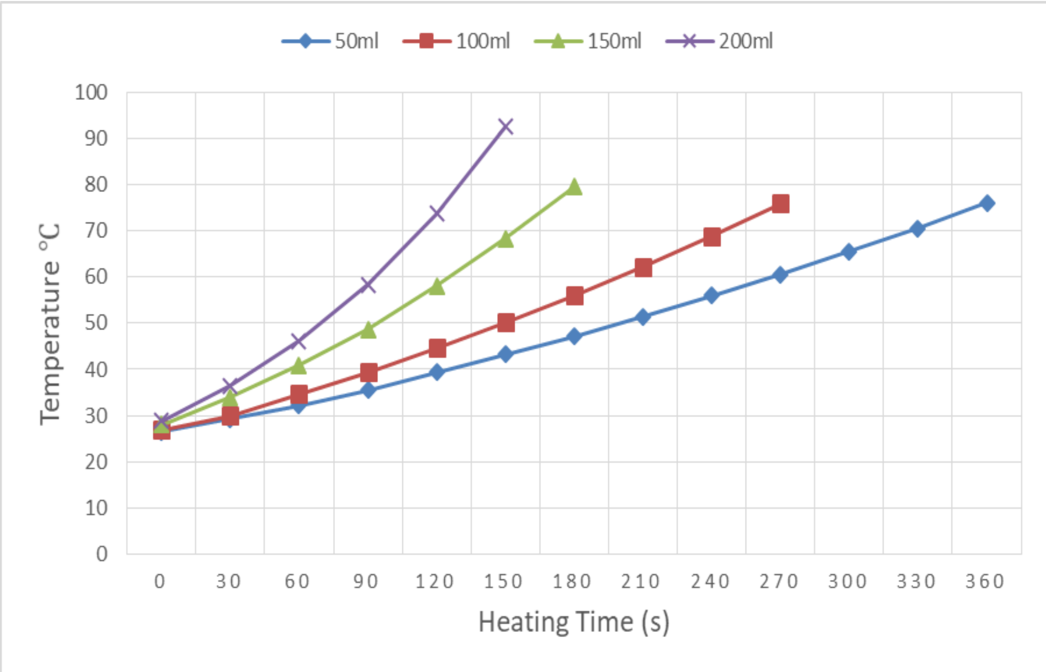

Figure 5: The Changes in Temperature of Different Concentration of Sarawak's Pineapple Juice with Heating Time

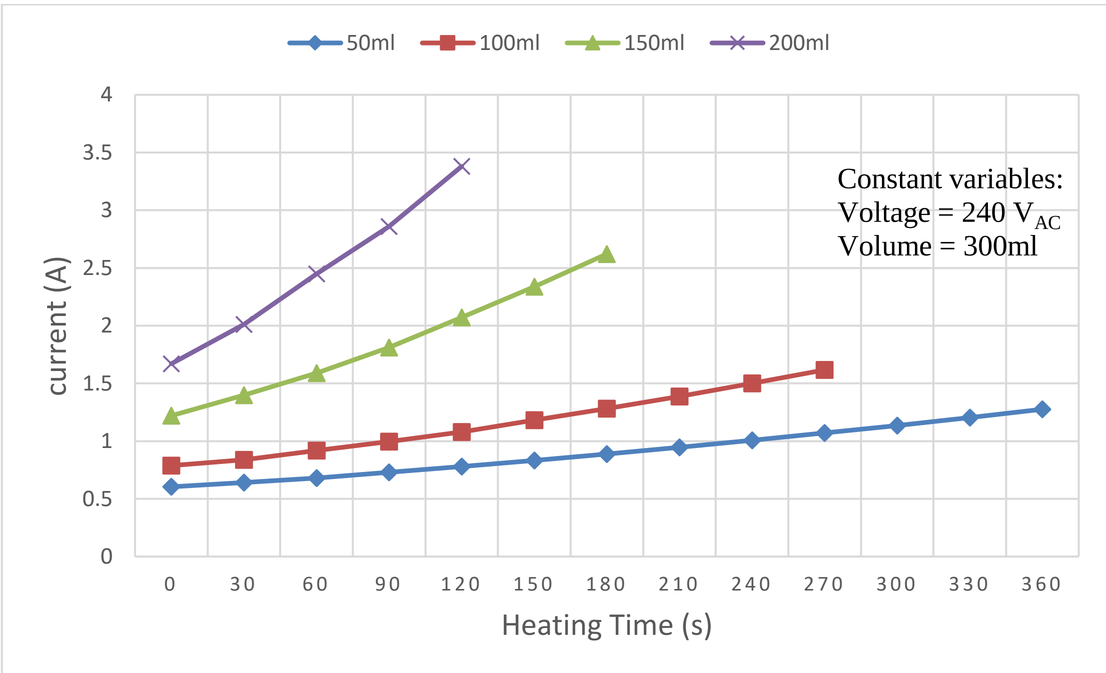

Figure 6: The Changes in Current of Different Concentration of Pineapple Juice with Time During Ohmic Heating at 240 V_{AC}.

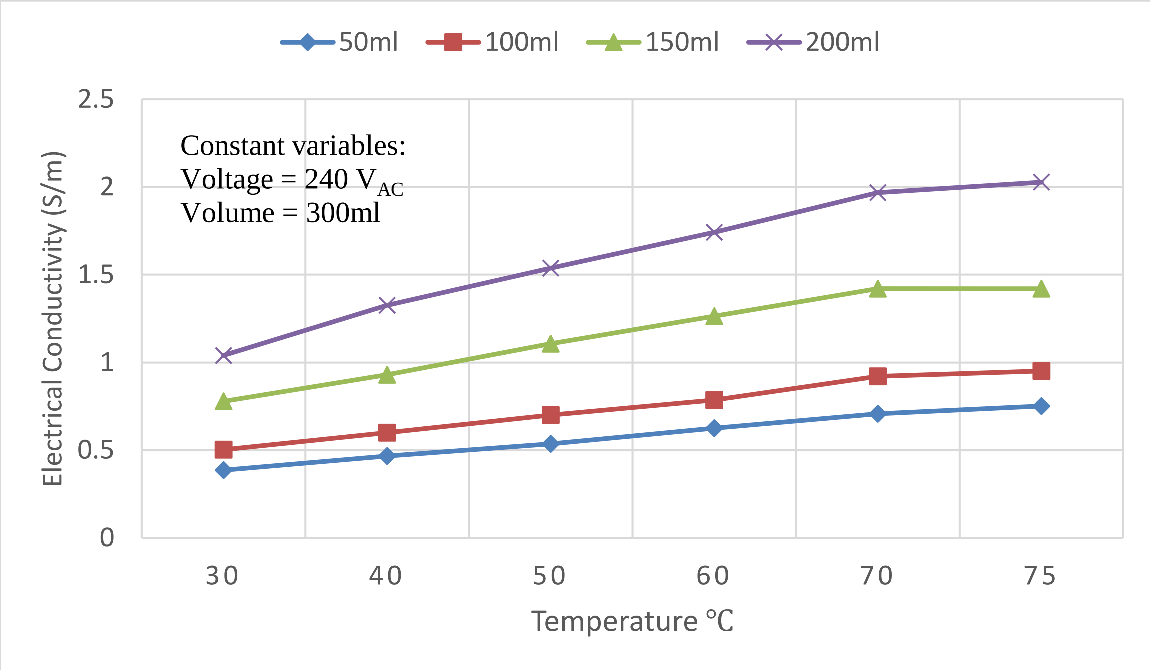

Figure 7: The Changes in Electrical Conductivity of Different Concentration of Pineapple Juice with Temperature During Ohmic Heating At 240 V_{AC}.

The same results are obtained for the changes in temperature of shredded Dabai suspended in liquid soy ketchup with heating time. The electrical conductivity of Sarawak pineapple juice and Dabai paste are 0.4 - 2.0 S/m for voltage range of 0 - 240 V_{AC} at 25°C and 0.19 S/m (extrapolated) for voltage range of 0 - 240 V_{AC} at 25°C.

The electrical conductivity results obtained in the experiment is compared with other standard value by known electrical researcher as shown in **Table 2**.

Table 2: Electrical Conductivity Analysis Values. (Ramaswamy, Marcotte, Sastry, & Abdelrahim, 2014)

	Food particulate	σ_T at 25°C	Standard by known electrical researcher
1.	Tap water	0.01962	0.058 S/m from Kong et al. (2008)
2.	Pineapple	0.3591	0.037 S/m from Sarang et al. (2008)
3.	Soy sauce	8.49	Not Available (NA)
4.	Soy sauce mixed with dabai	8.68	Not Available (NA)
5.	Dabai **	0.19	Not Available (NA)

** Extrapolated

Table 3 displays the rate of heating and the rate of current changing for the food sample in the experiments conducted using the OH setup.

Table 3: Heating Rate and Current Analysis. (Ming, 2017)

	Food particulate	Rate of heating (°C/min)	Rate of current changing (A/min)
1.	Tap water	0.224	18 mA
2.	Pineapple	8.27	134.4 mA
3.	Soy sauce	0.755	15.17 mA
4.	Soy sauce mixed with dabai	0.858	19.5 mA
5.	Dabai **	0.103**	4.33 mA**

Table 3 shows that the rate of heating and the rate of current changing for the food sample in this experiment. From the result shows that the rate of heating and rate of current changing is the largest for pineapple and lowest heating rate for tap water and lower current changing rate for soy sauce. For the heating rate and current changing rate for Dabai still need to be further experiment for more accurate result.

In summary the basic research performed at UCTS have confirmed that the electrical conductivity (ϭ S/m) of the heating sample (food particulate) depends on the temperature (°C), concentration of electrolytes (ml) and applied voltage gradient (V/cm). Further works are ongoing to applied statistical analysis to these results.

Energy Efficiency for Future Study

The energy efficiency needs to be calculated in order to evaluate the performance of the ohmic heating process method. The energy efficiency is defined in **Equation 2** (Sakr & Liu, 2014). The system performance coefficient (SPC) were defined to quantify the conversion of electrical energy into heat. The relationship between SPCs and voltage gradient can be represented by **Equation 3** (Darvishi, Hosainpour, & Nargesi, 2012). The next ohmic heating experimental study will explore the effectiveness of using this SPC when comparing with other alternative or traditional heating method.

$$\text{Energy efficiency} = \frac{\text{energy utilized to heat the sample}}{\text{Total input energy}} = \frac{mCp(T_f - T_i)}{\sum (VIt)} \qquad \textbf{(Equation 2)}$$

$$SPCs = 0.024\, \nabla V + 1.044 \quad R^S = 0.984 \qquad \textbf{(Equation 3)}$$

Design Considerations of Ohmic Heating and Prototype

The knowledge and experimental results on ohmic heating have been used to develop a prototype product called **Ohmic Heating (OH) Test Tool.**

Ohmic Heating (OH) Test Tool

The prototype of Ohmic heating test tool set-up is shown **Figure 8**. The technical specifications of the ohmic heating chamber is in **Table 4**. The prototype is designed to have the following functions: -

i. Variable transformer – voltage, or the power input to the Ohmic heaters, can be controlled by using a variable transformer
ii. Voltage/current transducer box
iii. Heater Cell
iv. Thermocouple signal conditioner – used to measure temperature

The Ohmic heating is currently being set-up to re-run the previous Ohmic heating experiments for particulate food and applying details statistical analysis.

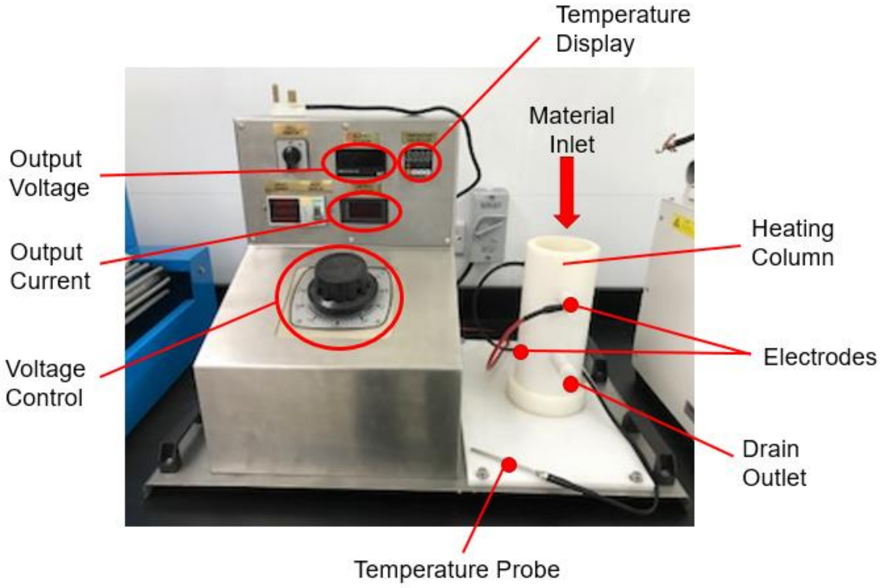

Figure 8: Ohmic Heating Test Tool

Table 4: Ohmic Heater Specifications. (A. Razak, Abidin, & Yaacob, 2017)

Heating vessel	Capacity: 1 litre Material: teflon
Electrodes	Material: S. Steel
AC Voltage regulator	Single phase (24V/50Hz)
Distance between electrodes (cm)	7.6
Area of single electrode surfaces (m^2)	4.04×10^{-3}

Ohmic Heating Public Feedback

The Ohmic Heating Test product was introduced to the public at Sarawak Innovation & Technology Exibition 2018 (SAINTEX18) on the 9-11 August 2018. Customer and industry examiner feedback gathered have given the following suggestion for fututre work study in ohmic heating in UCTS.

i. Decomposition process of Empty Fruit Bunches (**EFB**) of palm oil waste product. A faster evenly optimal temperature for the organism activity will be area of interest.
ii. Transfer offshore crude oil to the shore by pipeline problem namely to have proper heat treatment that can improve the ***fluidity of crude oils***.
iii. Durian paste warm up to eliminate bacteria and reduce water content before transported for long distance.

On studying the three industry applications recommended by customers, UCTS could conduct serious research works on EFB and fluidity of crude oil through the application of Ohmic heating.

Recommendations and Conclusion

A study was conducted at Electrical Laboratory UCTS with main objective to verify the main electrical characteristics of ohmic heating process. The main limitations are the thermal over processing problem that will damage the food particulates and rendered results invalid. A careful steps taken so that this limit is not reached.

The study proved the existance of static Ohmic heating modelling conducted on pineapple and Dabai fruits.

The results obtained have motivated the design and fabrication of one product called "***Ohmic Heating (OH) Test Tool"***. The Ohmic Heating Tool prototype was fabricated.

The test tool has been shown to the public and the responses have given ideas to look further than just research for food sterilization and extraction only. The electrical engineering and food technology research team at UCTS is proposing to elevate immediately to conduct research for (i***) empty fruit bunches (EFB)*** of palm oil waste product and (ii) ***fluidity of crude oils***.

References

A. Razak, A., Abidin, M., & Yaacob, A. (2017). Static Ohmic Heating Vessel Design Concept: A Review. *Modern Agricultural Science and Technology*, 33-37.

Darvishi, H., Hosainpour, A., & Nargesi, F. (2012). Ohmic Heating Behaviour and Electrical Conductivity of Tomato Paste. *Journal of Nutrition & Food Sciences*, 1 - 5.

Duygu, B., & Umit, G. (2015). Application of Ohmic Heating System in Meat Thawing. *Procedia - Social and Behavioral Science*, 2822-2828.

Emerson Process Management. (2010, January 1). *Rosemount Analytical*. Retrieved from Theory and Application of Conductivity: https://www.emerson.com/documents/automation/application-data-theory-application-of-conductivity-en-68442.pdf

Icier, F., & Ilicali, C. (2007). ELECTRICAL CONDUCTIVITY of APPLE and SOURCHERRY JUICE CONCENTRATES DURING OHMIC HEATING. *Food Process Engineering*, 159-180.

IMAI, T., Uemura, K., ISHIDA, N., YOSHIZAKI, S., & Noguchi, A. (2007). Ohmic heating of Japanese White Radish Raphanus sativus L. *International Journal of Food Science & Technology*, 461 - 472.

Ito, R., Fukuoka, M., & Hamada-Sato, N. (2013). Innovative Food Processing Technology Using Ohmic Heating and Aseptic Packaging for Meat. *Meat Science*, 675-681.

Kong, Y.-q., Li, D., Wang, L.-j., Bhandari, B., Chen, X., & Mao, Z.-h. (2008). Ohmic Heating Behavior of Certain Selected Liquid Food Materials. *International Journal of Food Engineering*, 1-14.

Ming, C. S. (2017). *The Modelling and Design of Ohmic Heating (OH) System for Application in Food Sterilization.* Sibu.

Palaniappan, S., & Sastry, S. K. (1991). Electrical Conductivities of Selected Solid Foods During Ohmic Heating. *Journal of Food Process Engineering*, 221-236.

Perasiriyan, V., Priya, S., Mangala Gowri, A., Ramasamy, D., & Sivakumar, T. (2016). Design and Evaluation of Electrical Resistance Unit(Ohmic Heating) for Food Processing. *International Research Journal of Engineering and Technology*, 1357-1361.

Ramaswamy, H. S., Marcotte, M., Sastry, S., & Abdelrahim, K. (2014). *Ohmic Heating in Food Processing.* Florida: CRC Press.

Sakr, M., & Liu, S. (2014). A Comprehensive Review on Applications of Ohmic Heating (OH). *Renewable and Sustainable Energy Reviews*, 263 - 267.

Sarang, S., Sastry, S. K., & Knipe, L. (2008). Electrical Conductivity of Fruits and Meats During Ohmic Heating. *Journal of Food Engineering*, 351-356.

Toudeshki, A., Mariun, N., Hizam, H. &., & Jamaludin, H. (2008). Variable High Frequency Voltage Source for an Ohmic Heating Process. *2nd International Power and Energy Conference* (pp. 594 - 598). Johor Bahru: IEEE Malaysia.

Wang, W.-C., & Sastry, S. K. (1997). Changes in Electrical Conductivity of Selected Vegetables During Multiple Thermal Treatments. *Journal of Food Process Engineering*, 499-516.

Zhang, H. (2009). Electrical Properties of Foods. In G. V. Barbosa-Canovas, *Food Engineering - Volume I* (pp. 110 - 119). Wyndmoor: EOLSS Publications. Retrieved from Food Engineering.