Evaluating the Effectiveness of Ohmic Heating in Fruit Juice and Tomato Puree Processing

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Abstract

This research work evaluated the effectiveness of Ohmic heating in fruit juice and tomato puree processing. The effect of added salt was investigated from 0 to 1.4 grams of salt to 100 grams of tomato puree, while the effect of added sugar on thermal and electrical conductivities of fruit juice was investigated from 0 to 25 grams of sugar to 100 grams of juice. The samples for Ohmic heating were similar with respect to salt and sugar content. Findings reveal that electrical conductivity increases with added salt but decreases with added sugar. No significant changes in thermal conductivity were observed for the range investigated for both added sugar and salt. Significant changes in heating rates, processing times and dehydration rates were observed as added salt and sugar increases during Ohmic heating processing. While added salt promotes the heating rate of food, added sugar slows down the heating rate. This implies that more time and energy will be required to process foods with reduced salt content using Ohmic heating approach and vice versa. For foods with reduced sugar, less time and energy will be required to reach the target temperature and vice versa.

1 Introduction

The importance of developing new food products with reduced salt and sugar is growing due to the associated potential health benefits. There have been several calls for food reformulation towards reducing their salt and sugar contents (Reeve and Magnusson, 2015; Heredia-Blonval et al., 2014). Salt and sugar intakes have significant impacts on human health. Excessive salt intake has been proven to relate to high blood pressure, stroke and coronary heart disease; while excessive dietary sugar intake causes dental caries, overweight, heart disease and type-2 diabetes (NHS Choices, 2015). The £10 million Innovate UK call from October 2015 to March 2016 titled optimising food composition was specifically for scope on reducing levels of salt, sugar, saturated fat and/or total fat, and increasing levels of dietary fibre. This indeed confirms the pressure and calls for food reformulation with respect to salt and sugar content.

While attempts are being made to reduce salt and sugar content in food, the effect of this reduction on food thermal and electrical properties should also be investigated. This is because the operations of many processing equipment are based on the thermo-physical and electrical properties of the foods being processed. It is important to note that these properties of food are not only crucial in the accurate design of food processing equipment but also in the accurate prediction of temperature change during the heat treatment operation.

Ohmic heating is an emerging and advanced thermal processing technology that can be used in food processing applications. Ohmic heaters use two or more electrodes to transfer heat energy directly into the entire mass of food materials rather than via a heat transfer medium. Direct transfer of heat to processed foods eliminates problems associated with product fouling on the food contact surfaces of traditional heat exchangers. This consequently reduces the amount of water required in food processing as frequent cleaning associated with product fouling is eliminated. Applying Ohmic heating technology in food processing offers reduction in energy requirements. This is because the products are heated directly rather than via a heating exchanger system. Absence of a heating exchange system other than the foods being processed in Ohmic Heating System (OHS) implies that the thermo-physical and electrical properties of the foods will greatly influence the performance of an OHS. Findings from the literature show that effectiveness of

OHS depends on the electrical conductivity of the foods being processed (Darvishi et al. 2012). It is therefore important to investigate how changes in added salt and sugar in foods affect their thermo-physical and electrical properties and consequently their time-temperature processing requirements using OHS. Also the current pressure on the food processors on the need to reduce the salt and sugar levels in processed foods prompts the need to investigate the effectiveness of Ohmic heating at different salt and sugar levels.

2 Materials and Methods

2.1 Samples Preparation

Orange and pineapple juice and fresh tomato samples were obtained from local supermarket in Holbeach. The tomato samples were blended and thoroughly mixed to obtain fresh tomato puree. Puree consistency at 17^{o}C was measured to be 3.5 Bostwick scale (trough running for 20 seconds) on a 24cm Bostwick Consistometer (Camlab, UK) and puree density was determined to be 660 kg/m^3.

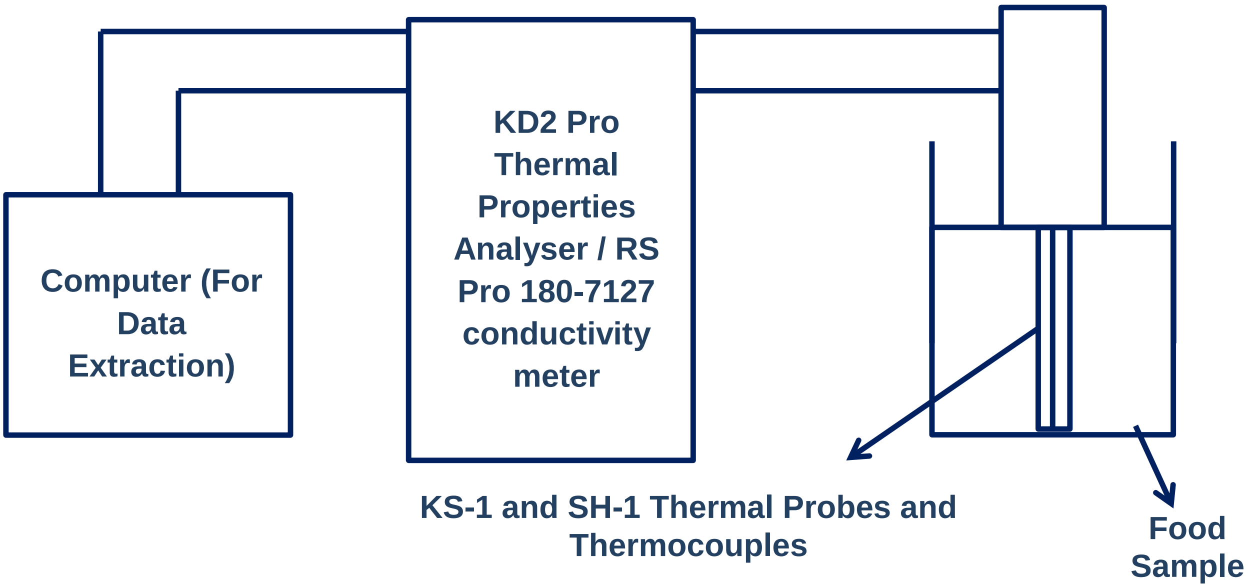
2.2 Methods-Thermal and Electrical Conductivities

As recommended by the UK NHS Choice (2015), a low amount of salt per 100g of food is 0.3g while a high amount of salt is 1.5g per 100g of food; and for sugar, a low amount per 100 g is 5g while a high amount is 22.5g of total sugar per 100g of food. Using these guidelines, the effect of added salt on thermal and electrical conductivities of tomato pulp was investigated from 0 to 1.4 grams of salt to 100 grams of tomato pulp, while the effect of added sugar on thermal and electrical conductivities of fruit juice was investigated from 0 to 25 grams of sugar to 100 grams of juice.

2.3 Equipment and procedure- Thermal and Electrical Conductivities

The electrical conductivities were measured by RS Pro 180-7127 conductivity meter. The thermal properties of the food samples were analysed and measured by KD2 Pro Thermal Properties Analyzer (Decagon Devices, USA) using the experimental set-up shown in Figure 1. The measurement method for the thermal properties was based on the ASTM and IEEE thermal conductivity measurement standards (IEEE442 and ASTM 5334).

Figure 1: Experimental Procedures (Thermal and Electrical Properties)



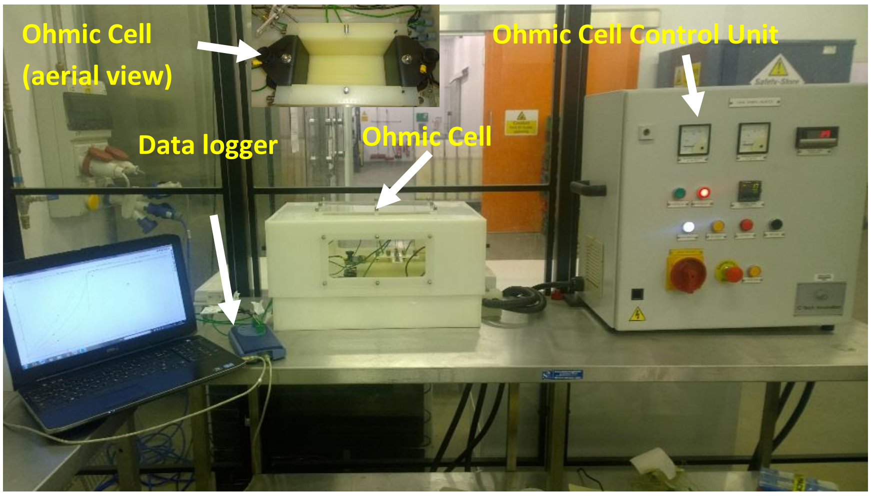
2.4 Methods - Ohmic Heating Processing

The Ohmic heating cell of dimension 30.0 x 9.0 x 9.6 cm was used for tomato puree processing and 18.0 x 9.0 x 9.6 cm cell was used for juice processing. The cells were filled with the samples (Tomato puree of mass 0.66kg and density of 660kg/m^3, and orange juice of mass 0.50kg and density of 1035 kg/m^3); fresh sample for each experimental run.

Commercially processed orange juice was subjected to pasteurisation process using the Ohmic Heating System at 75ºC while fresh tomato puree made from Cherry Tomatoes was subjected to dehydration, heated from room temperature to 100ºC for 900 seconds.

A 10kW Ohmic Heater (C-Tech Innovation, Chester, UK) was used for both heat treatments. Pasteurisation heat treatment was carried out using auto power setting while dehydration heat treatment was used using manual power setting at 50%. The effect of added sugar on the effectiveness of pasteurisation treatment by the Ohmic heater for the juice was investigated from 0 to 125 grams of sugar to 500 grams of juice and this takes into consideration recommendations for low to high sugar content in food by the UK NHS Choice (2015). The effect of added salt on the effectiveness of dehydration treatment by Ohmic heating for the fresh tomato puree was investigated from 0 to 15 grams of added salt to 660 grams of fresh tomato puree and this also takes into consideration recommendations for low to high salt content in food by the UK NHS Choice (2015). Sample temperatures were recorded at four different positions in the Ohmic cell during the thermal treatments using PICO TC-08 data logger (PICO Technology, Eaton Socon, St Neots, UK). Figure 2 shows the set-up for the Ohmic heating system.

Figure 2: Ohmic Heating Experimental Set-up



3 Results and Discussion

3.1 Thermal and Electrical Conductivities

3.1.1 *Effect of Salt on Thermal and Electrical Conductivities of Tomato Puree*

Over the range of added salt investigated, the change in thermal conductivity of the fresh tomato puree did not change significantly as the amount of added salt increased or decreased. As shown in Figure 3a and Figure 3b, the measure of goodness-of-fit of linear regression is 0.2299 and this implies only 22.99% of the variability in thermal conductivity can be explained by the variability in added salt to 100 grams of tomato puree. Also, the slope of the trend line tends to zero and this implies that no significant relationship exists between the thermal conductivity and the amount of added salt to tomato puree over the range investigated.

On the other hand, electrical conductivity of the puree increased as the amount of added salt increased, as shown in Figure 4a. Figure 4b shows further that the measure of goodness-of-fit of linear regression is 0.9931 and this implies 99.31% of the variability in electrical conductivity can be explained by the variability in added salt to 100 grams of tomato puree. Also, the slope of the trend line is 1.871; this implies that positive relationship exists between the electrical conductivity and the amount of added salt to tomato puree over the range investigated. Figure 4b also confirms that electrical conductivity increases as the amount of added salt increases.

3.1.2 Effect of Sugar on Thermal and Electrical Conductivities of Fruit Juice

As shown in Figure 5, thermal conductivity of the juice slightly decreases from 0.55 to 0.48 W/ (m.K) as the amount of added sugar increases from 0 to 12.5 grams. This property remains constant at 0.48 W/ (m.K) as added sugar increases from 12.5 to 25 grams. The negative slope (-0.0074) of the trend line confirms a decrease in thermal conductivity as the amount of added sugar increases. However, the value of the slope which tends to zero implies that thermal conductivity of the juice is not significantly affected by the amount of added sugar over the range investigated.

Figure 6 summarises the effect of added sugar on electrical conductivity of fruit juice. As shown in Figure 6a, electrical conductivity of the sample decreases as the amount of added sugar increases. Figure 6b further shows that the measure of goodness-of-fit of linear regression is 0.9909 and this implies 99.09% of the variability in electrical conductivity can be explained by the variability in added sugar to 100 grams of fruit juice. Also, the slope of the trend line is -0.1835. This implies that negative relationship exists between the electrical conductivity and the amount of added sugar to fruit juice over the range investigated; hence electrical conductivity decreases as the amount of added sugar increases.

Figure 3: Effect of Salt on Thermal Conductivity of Tomato Puree

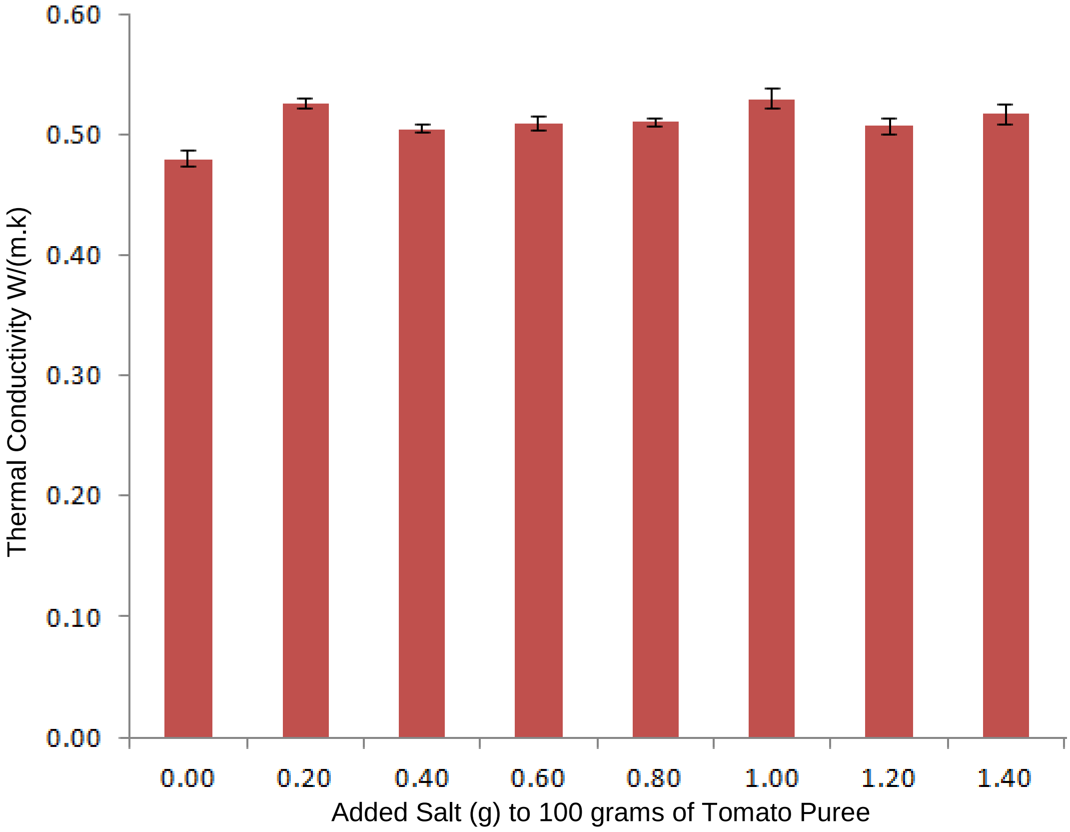


Figure 3a: Salt Effect on Thermal Conductivity of Tomato Puree

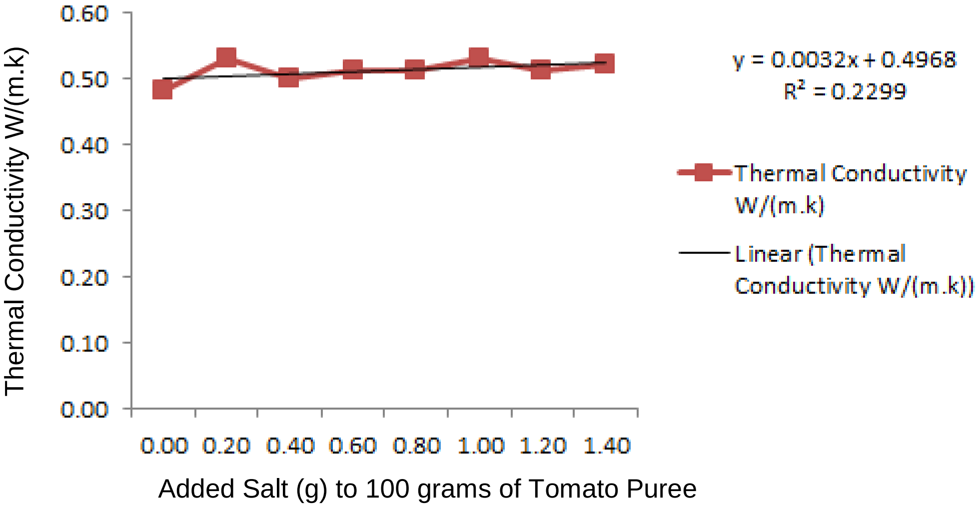


Figure 3b: Salt Effect on Thermal Conductivity of Tomato Puree (Trendline and R^2)

Figure 4: Effect of Salt on Electrical Conductivity of Tomato Puree

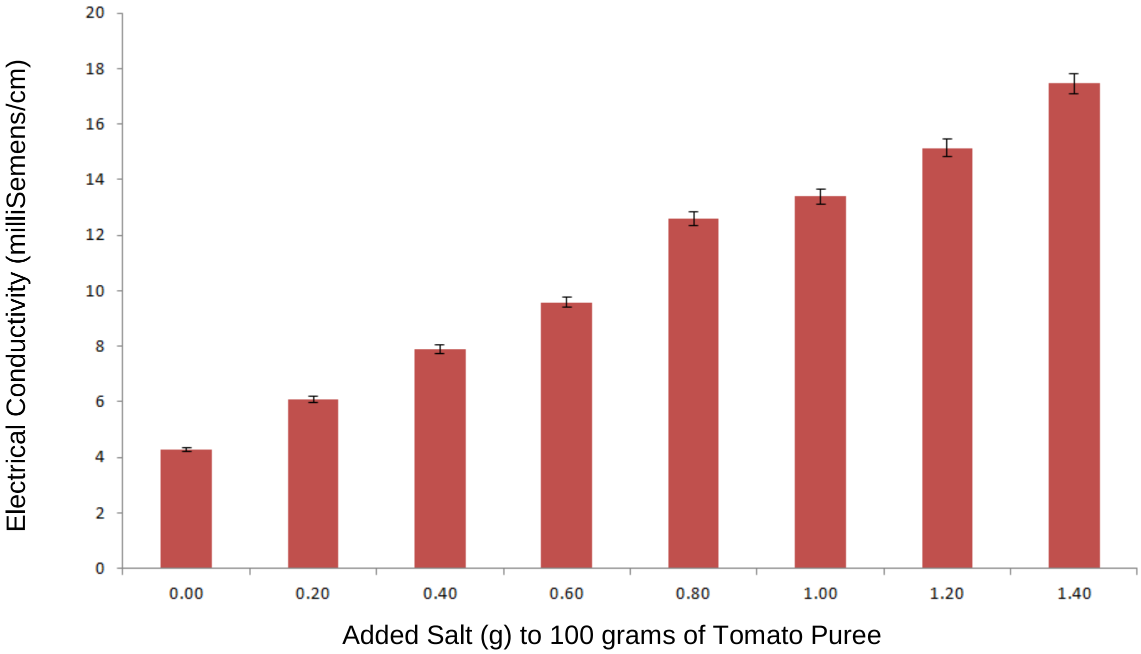


Figure 4a: Salt Effect on Electrical Conductivity of Tomato Puree

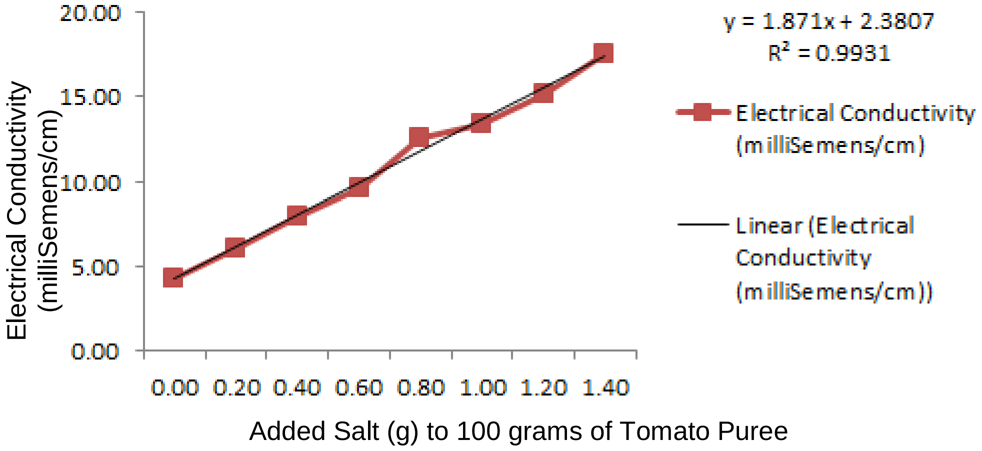


Figure 4b: Salt Effect on Electrical Conductivity of Tomato Puree (Trendline and R^2)

Figure 5: Effect of Sugar on Thermal Conductivity of Fruit Juice

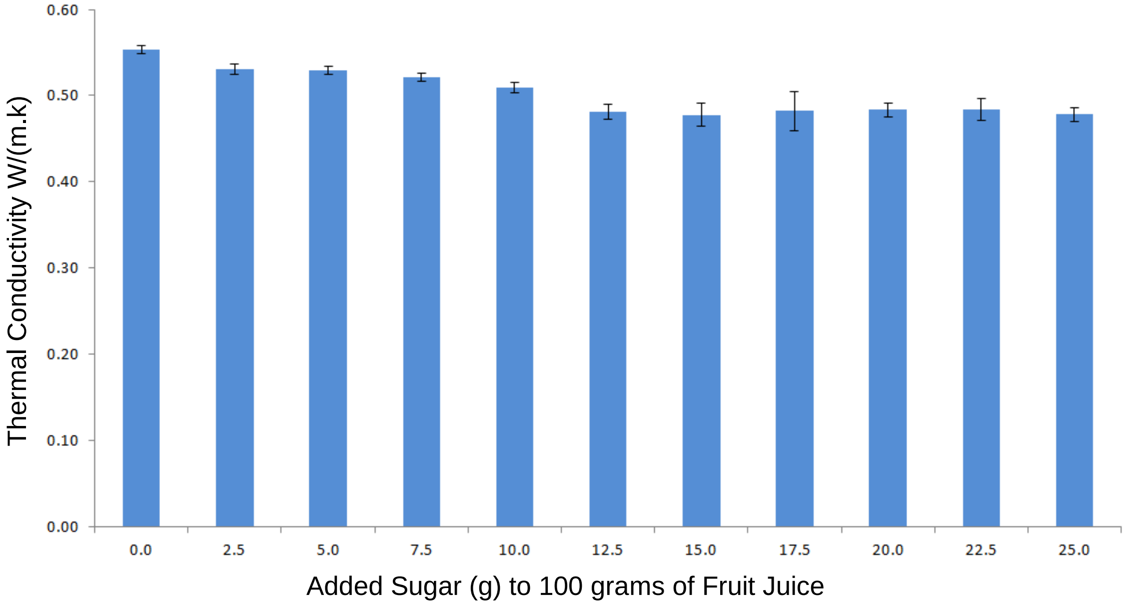


Figure 5a: Sugar Effect on Thermal Conductivity of Fresh Juice

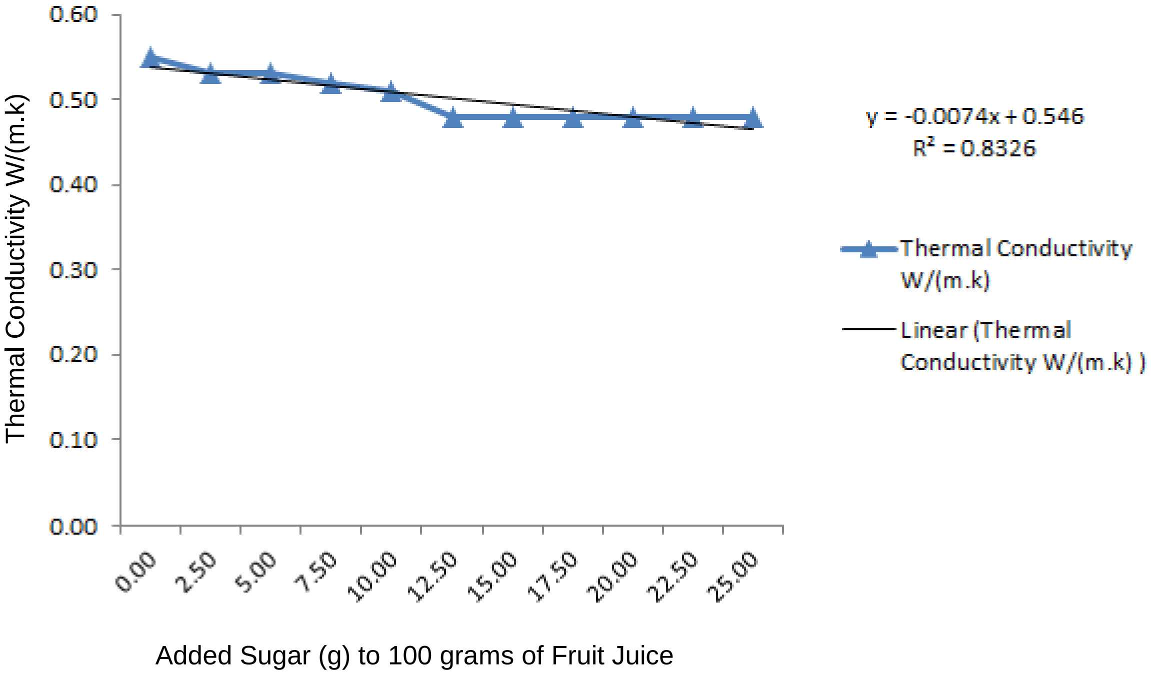


Figure 5b: Sugar Effect on Thermal Conductivity of Fresh Juice (Trendline and R^2)

Figure 6: Effect of Sugar on Electrical Conductivity of Fruit Juice

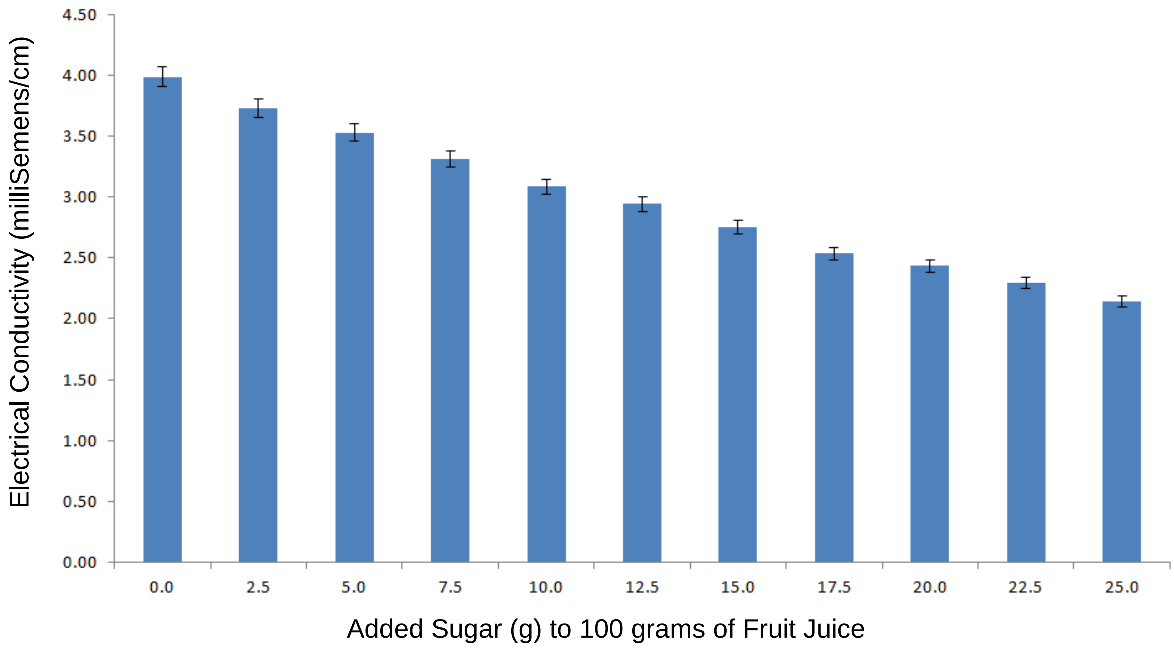


Figure 6a: Sugar Effect on Electrical Conductivity of Fruit Juice

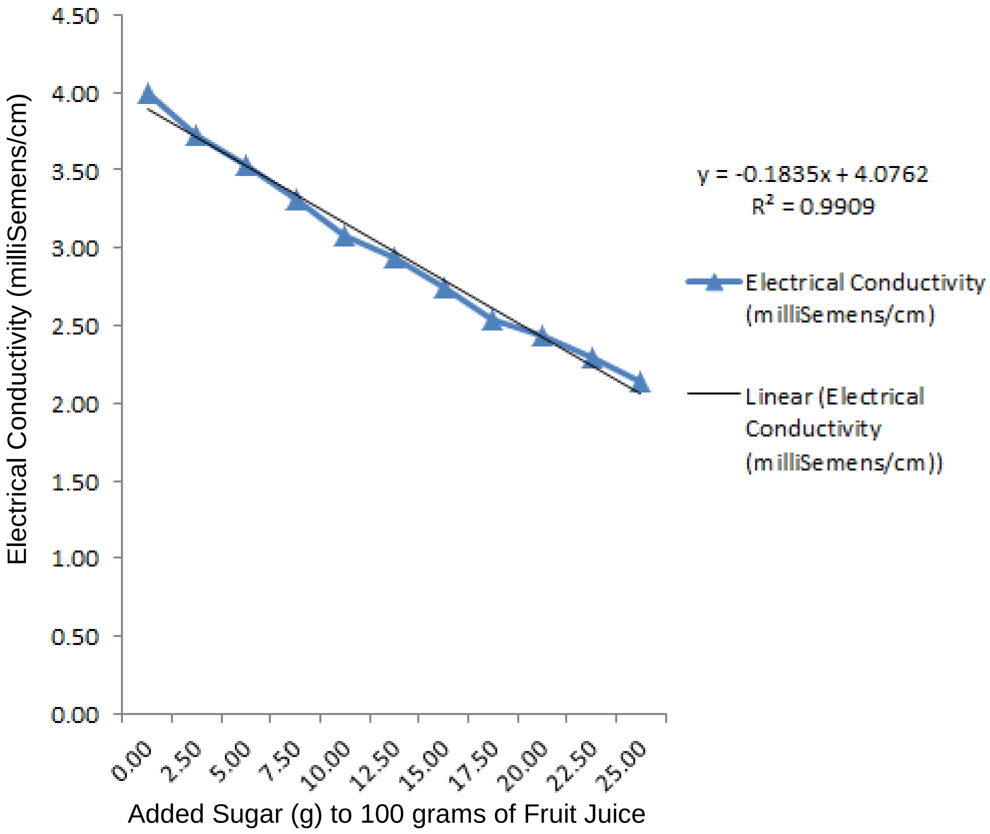


Figure 6b: Sugar Effect on Electrical Conductivity of Fruit Juice (Trendline and R^2)

3.2 Ohmic Heating Processing

3.2.1 Tomato Puree Dehydration

Findings reveal that the amount of water removed and the heating rate of tomato puree depends on the amount of added salt. As shown in Figure 7, while it took 300 seconds for 660g puree with 15g of added salt to reach 100^{o}C, the same amount of puree with 2.5g of added salt required 810 seconds to reach the target temperature of 100^{o}C. This implies that as the amount of added salt increases, heating time required to reach 100^{o}C decreases, as shown in Figure 8. Also the amount of water removed during 900s the Ohmic heating processing varies with the amount of added salt. Figure 9 shows that as the amount of added salt increases, the amount of water removed from the puree increases.

3.2.2 Fruit Juice Pasteurisation

Findings also show pasteurisation time varies with the amount of sugar added to the fruit juice. When compared with the effect of added salt, it is interesting to note that the amount of added sugar has opposite effect on the heating rate. Less added sugar will accelerate the heating process. As shown in Figure 10, juice with no added sugar reached the pasteurisation temperature of 75^{o}C in 285 seconds while at the other extreme, juice with 125g of added sugar required 510 seconds to reach the same temperature. This implies that Ohmic heating technology supports the call for sugar reduction in food as the heating is quicker in juice with less sugar. As shown in Figure 11, the time required to reach the target temperature of 75^{o}C increases steadily as the amount of added sugar increases. Linear equations approximating the temperature-time curves in Figure 10 have been placed in Table 1. As shown in Table 1 and Figure 12, temperature change rate decreases as the amount sugar increases.

These findings agreed with the initial findings on the effect of salt and sugar on the electrical conductivity. The findings show the significance of electrical conductivity of foods in Ohmic heating processing. The processing time decreases as electrical conductivity of foods to be processed using Ohmic heating increases.

Figure 7: Combined Temperature-Heating Time Curves for 660g Tomato Puree Dehydrated at Different Salt Levels using 10kW Ohmic Heater at 50% Power

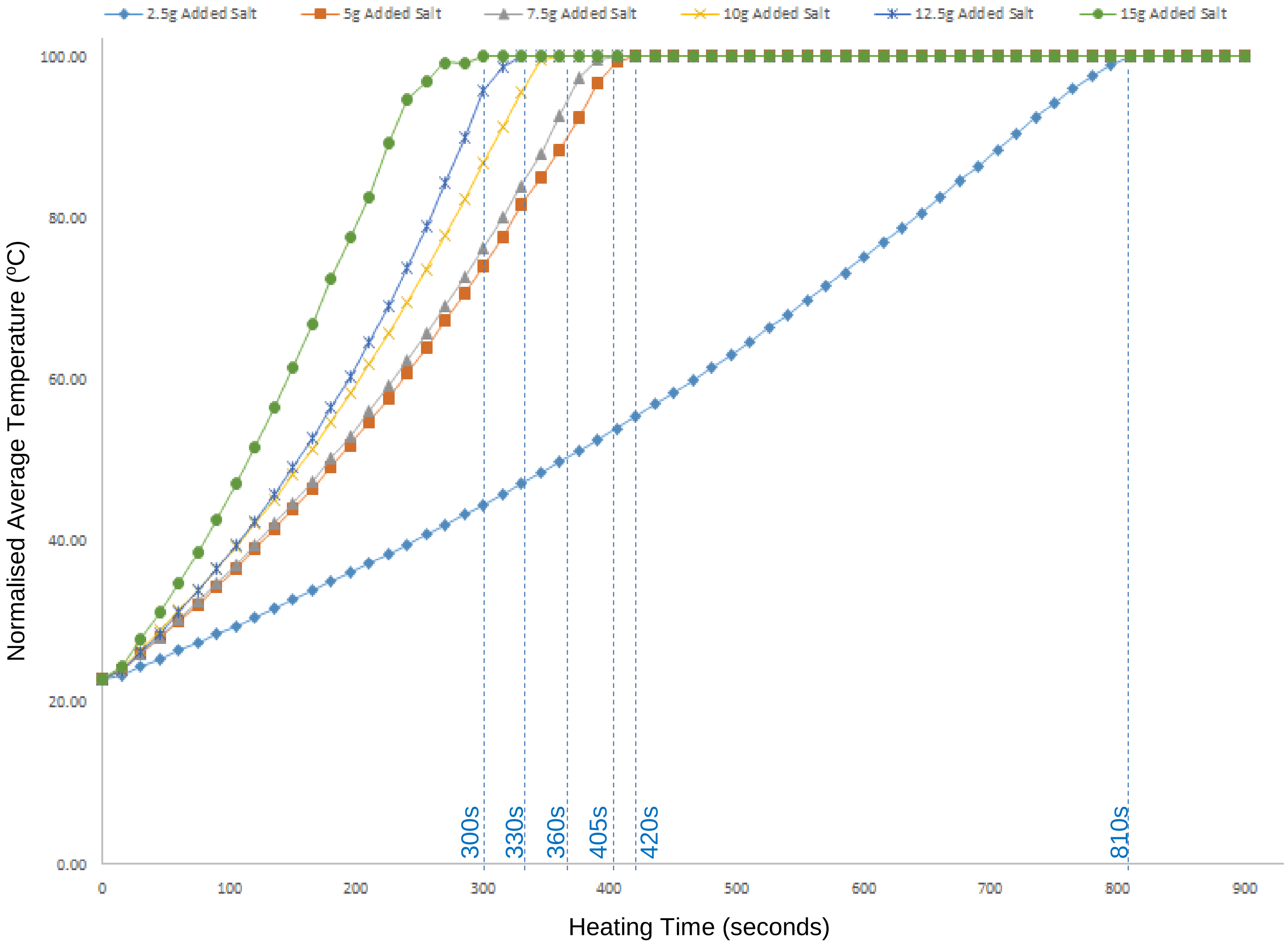


Figure 8: Time to reach 100ºC during Dehydration of 660g Tomato Puree at different Salt Levels using 10kW Ohmic Heater at 50% Power

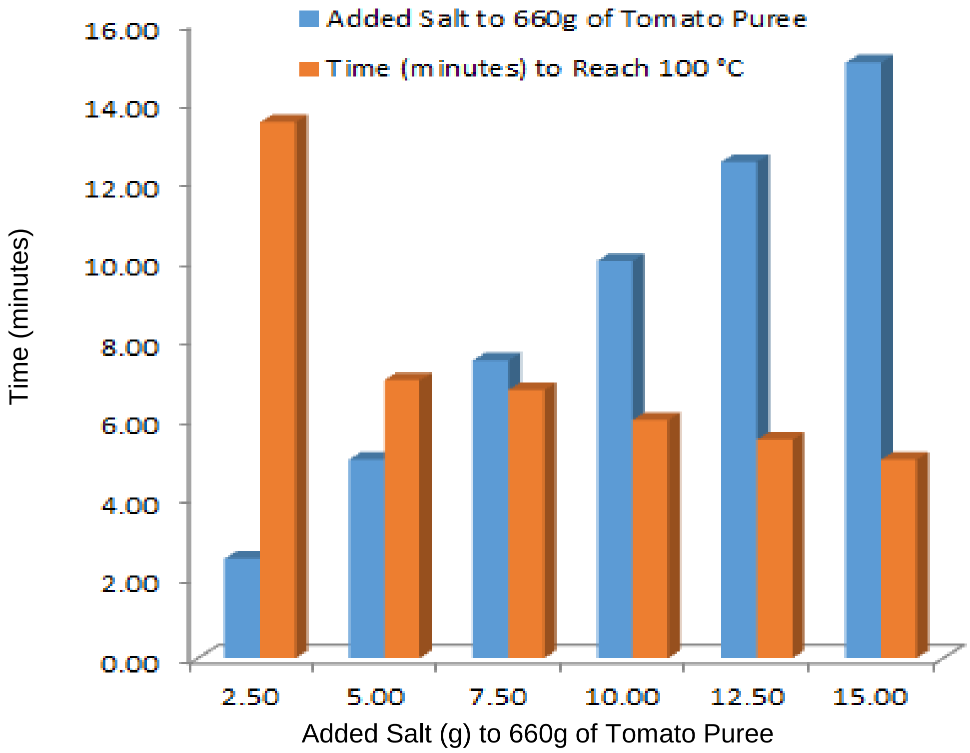


Figure 9: Dehydrated Water (g) during processing of 660g Tomato Puree at different Salt Levels using 10kW Ohmic Heater at 50% Power

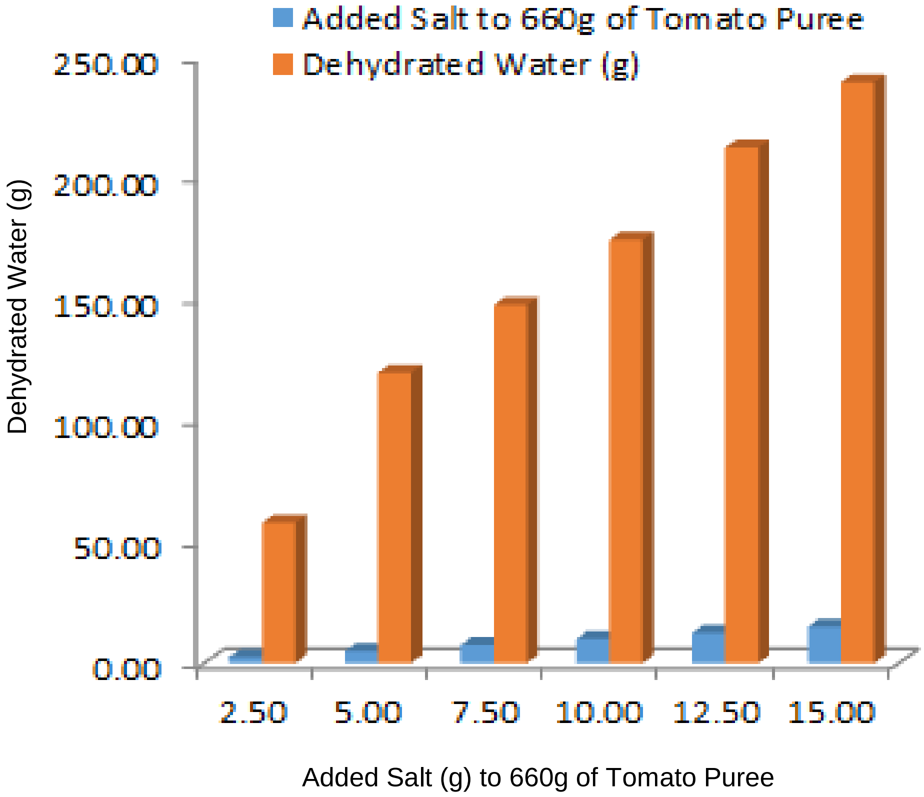


Figure 10: Combined Temperature-Heating Time Curves for 500g Juice Pasteurisation at Different Sugar Levels using 10kW Ohmic Heater

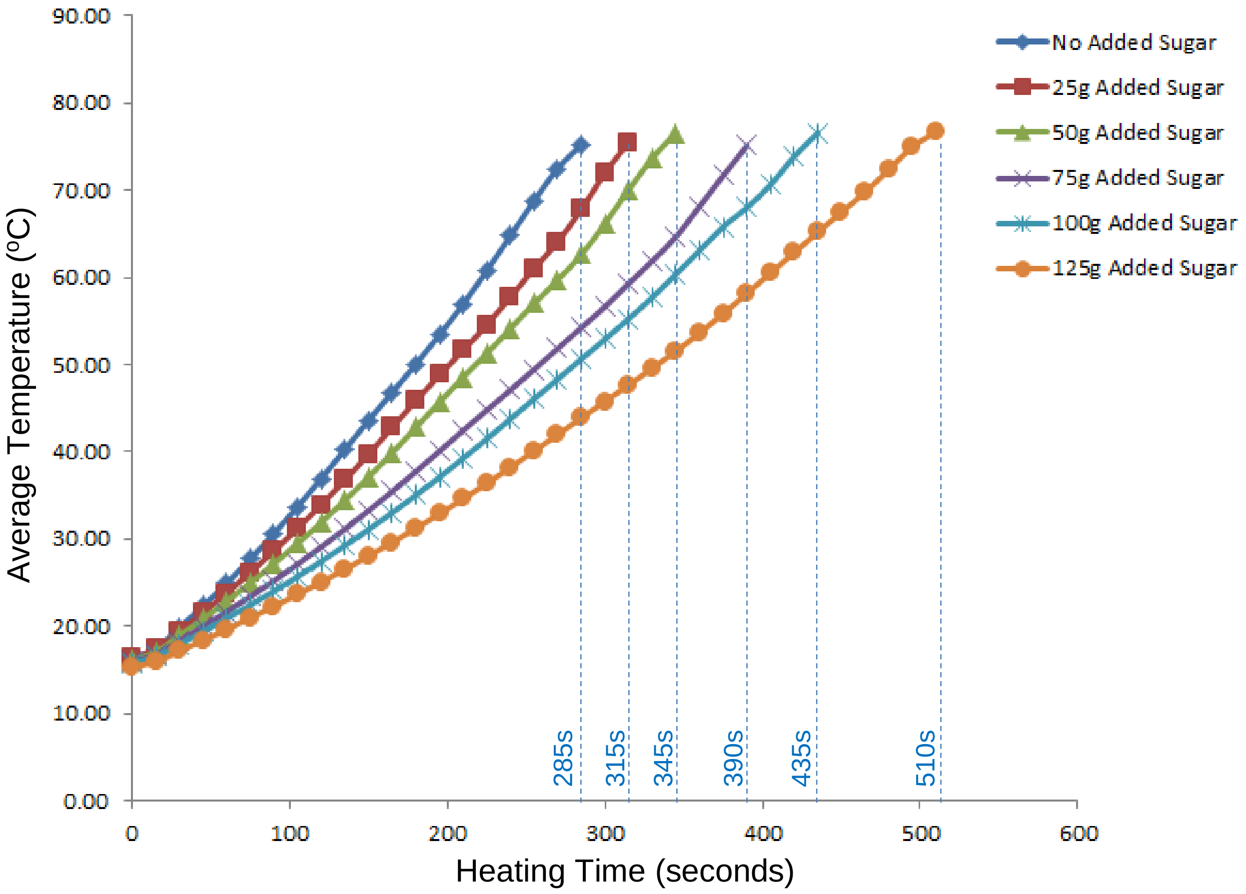


Figure 11: Ohmic Heater Pasteurisation Time with corresponding Added Sugar Level

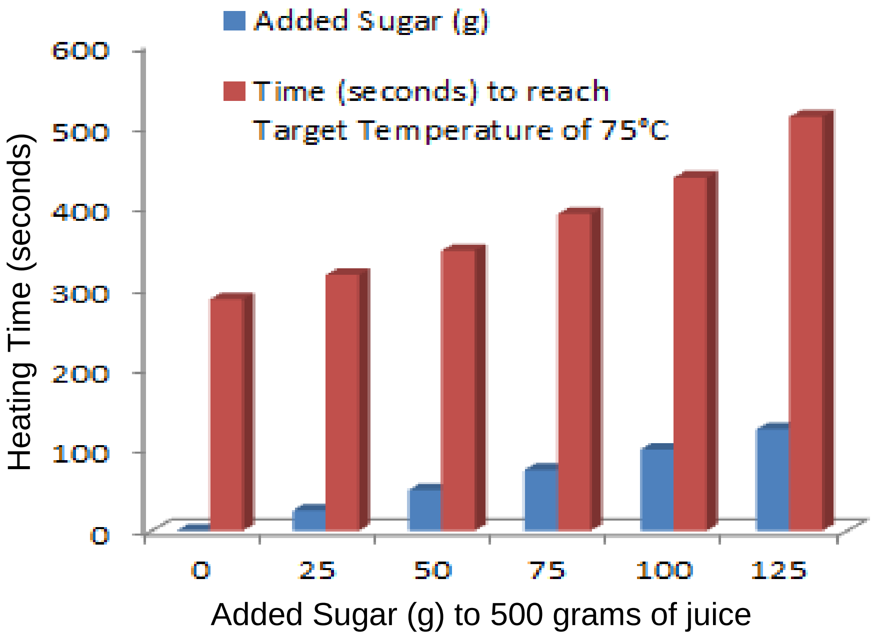
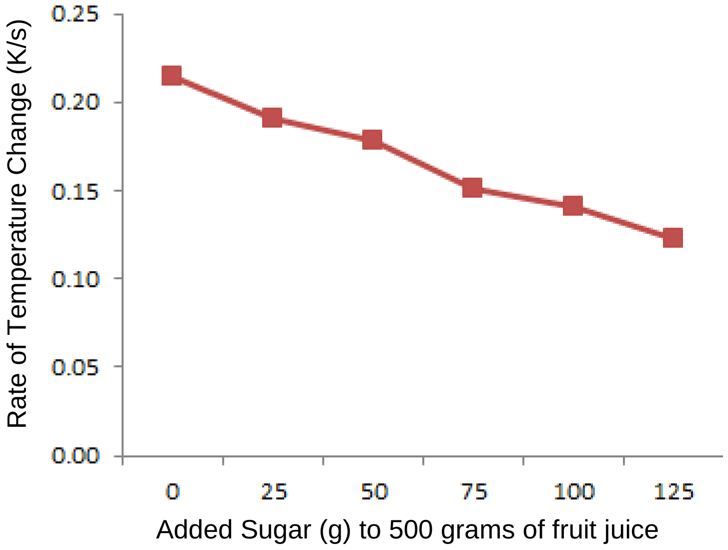


Table 1: Linear Trend Lines for Juice Pasteurisation Curves

Samples	Linear Function	R^2	Slope (Temperature Change Rate)
No Added Sugar	y = 0.2141x + 12.641	0.9942	0.2141
25g Added Sugar	y = 0.1902x + 12.637	0.9932	0.1902
50g Added Sugar	y = 0.1783x + 12.125	0.9922	0.1783
75g Added Sugar	y = 0.1508x + 12.175	0.9910	0.1508
100g Added Sugar	y = 0.1415x + 11.545	0.9904	0.1415
125g Added Sugar	y = 0.1223x + 10.935	0.9892	0.1223

Figure 12: Rate of Temperature Change with corresponding Added Sugar Level to 500g of fruit Juice



4 Conclusions

Ohmic heating has not been used extensively in food processing at an industrial scale. The system uses two or more electrodes to directly transfer heat energy through electrical energy into the entire mass of food materials rather than via a heat transfer medium. Findings from this research show that the effectiveness of Ohmic heating in food processing depends extensively on the electrical properties of foods rather than the thermal properties. This supports findings from Darvishi et al. (2012). Small decrease in the thermal conductivity of fruit juice was observed with increase in added sugar. Sugar and Salt have opposite effect on the electrical conductivity. While the electrical conductivity increases with added salt, it decreases with added sugar. Small changes were observed for the range investigated for both added sugar and salt for the thermal conductivity.

Thermal destruction of microorganisms depends on both the temperature of exposure and the holding time required at this temperature. This implies that changes in food sample temperature with time during Ohmic heating processing can be used to assess the microbiological characteristics of the food sample. Findings from this study show that the rate of heating by Ohmic heater; the dehydration rate; and the time to reach the target temperature, are all affected by the amount of added salt and sugar in the investigated samples. As the amount of added salt in food sample increases, heating rate increases, and consequently, the time required to reach the target temperature decreases. This implies that energy required for heat treating foods and its associated costs decrease as their salt content increases.

On the other hand, as the amount of added sugar in food sample increases, heating rate decreases, and consequently, the time required to reach the target temperature increases. This implies that energy required for heat treating foods and its associated costs will increase as their sugar content increases. Hence, the efficiency of Ohmic heater increases as sugar content in food decreases.

5 References

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