# THE INFLUENCE OF FIELD STRENGTH, SUGAR AND SOLID CONTENT ON ELECTRICAL CONDUCTIVITY OF STRAWBERRY PRODUCTS

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## ABSTRACT

*The effects of field strength, soluble solids (from 14 to 59.5 °Brix) and particle size (using two size distributions) on electrical conductivity were investigated. Electrical conductivity increased with temperature for all the products and conditions tested following linear or quadratic relations. Electrical conductivity was found to vary greatly between strawberry-based products. An increase of electrical conductivity with field strength was obvious for fresh strawberries and strawberry jelly but not for strawberry pulp, probably due to the presence of texturizing agents. This parameter decreases with the increase of solids and sugar content. For some of the formulations tested (solid content over 20% w/w and over 40 °Brix) a different design of ohmic heater may be necessary because of the low values of electrical conductivity.*

## INTRODUCTION

Ohmic heating is defined as a process where electric currents are passed through foods with the main purpose of heating them by internal energy generation (de Alwis and Fryer 1990; Fryer and Li 1993). Its ability to heat

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materials rapidly and uniformly is its principal advantage. It 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 (Palaniappan and Sastry 1992), and pasteurization.

The most critical property affecting ohmic heating rate is food electrical conductivity ($\sigma$). Food electrical conductivity is affected by a large number of parameters such as temperature, ionic strength, free water (Lima and Sastry 1999) material microstructure and solids content (Sastry and Palaniappan 1992; Sastry 1992). Solids content, in particular, is known to have a significant influence on the electrical properties of the slurry and may have a decisive effect on the performance of the heat treatment process (Sastry 1992; Zhang and Fryer 1993; Sastry and Li 1996; Sastry and Salengke 1998). Likewise, for a given solids content, it is expected that solid particles' size and shape will induce significant changes in the electrical conductivity of the mixture.

Studies on electrical conductivity changes of fruits during growth and ripening have been done (Bean *et al.* 1960; Sasson and Monselise 1977). Changes occurring in cell walls, membranes and compositions of cell contents were found to be factors influencing changes in electrical conductivity. As vegetable tissue is heated, structural changes like cell wall breakdown, tissue damage and softening occur, affecting $\sigma$. Heating causes more mobile moisture, which increases ionic strength that in turn increases $\sigma$.

Sastry and Palaniappan (1991) reported that electrical conductivities of tomato and orange juices increase with temperature and decrease with solids content; reducing the particle size of juice solids increases the effective conductivity of the juice.

In order to evaluate the potential use of this technology for industrial strawberry pulp processing it is important to study the dependence of electrical conductivity on various parameters such as total solids, moisture, sugar and fat contents, pH, and viscosity (Zoltai and Swearingen 1996)

In this work, the values of electrical conductivity for strawberries and several commercial strawberry based products were determined for different electrical field strengths, Brix values, solids content (0-20% w/w) and particle size.

## MATERIALS AND METHODS

Experiments were conducted using a static ohmic heater handmade at the laboratory (Fig. 1). Samples were heated using an alternating current source, of 50 Hz frequency, with different voltages. Temperatures were monitored using type-K thermocouples, set at the geometrical center of the chamber.

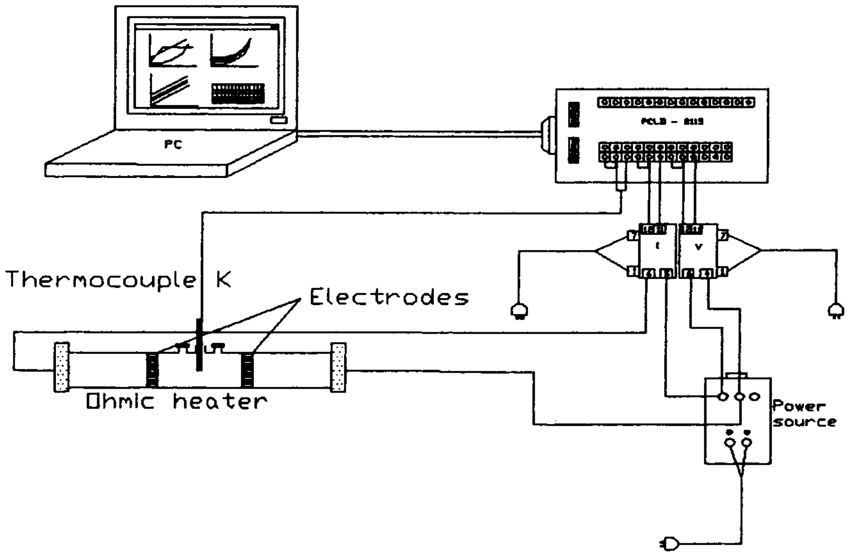

FIG. 1. EXPERIMENTAL SET-UP TO MEASURE ELECTRICAL CONDUCTIVITY

A data acquisition system (software - Labview 6.0 Professional, National Instruments, USA; hardware - PCL-880 HG, Labtech, USA) was employed to record continuously and simultaneously current intensity, voltage and temperature. In order to measure voltage across and current through the samples voltage and current transducers (Fema Electrónica S.A., Portugal; model CCT-04 and CCT-08) were used. Electrical conductivity was determined by the following equation (see nomenclature for explanation of the symbols).

$$\sigma = \frac{L}{AR} \qquad (1)$$

$A$ - Inner cross sectional area of ohmic heater ($m^2$)
$L$ - Interval between electrodes (m)
$R$ - Resistance ($\Omega$)
$\sigma$ - Electrical conductivity (S/m)

Three replications were made for each of the experiments described below. The presented values are the averaged results. In all cases the variation coefficient between the replicates is lower than 5%.

## Heater Description

The heater used is represented in Fig. 1 and consisted of a cylindrical glass tube of 30 cm total length and 2.3 cm inside diameter. Three thermocouple openings were provided; two at an equal distance of the center of the tube and one at the center, where the thermocouple was placed. Two Titanium electrodes with Teflon pressure caps were placed at each top of the tube.

## Strawberry Products

Frulact S.A., a Portuguese company producing fruit jams, provided strawberry fruits and pulps.

At the company, strawberries were kept frozen and cut into cubic pieces, as supplied by the producers. Pulps (strawberry puree, water and additives) were collected immediately before industrial pasteurization and were transported under refrigerated conditions to University of Minho. Experiments were conducted promptly in order to avoid microbiological deterioration, which might affect the results mainly due to the generation of carbon dioxide originating from the product's fermentation. Two pulps were used (ahead designated as P1 and P2) with different formulations. Initial pH values were 4.0 and 3.2 and Brix values were 14.5° and 26.5°, respectively.

Strawberry jelly was acquired at a local supermarket (The Kroger Co., Cincinnati, Ohio).

## Field Strength Experiments

A set of experiments was conducted to determine the effect of input voltage on the electrical conductivity changes during ohmic heating. The strawberry pulp (P1) samples were heated up to 100C using eight different power supply voltages (32 V/cm to 100 V/cm) with a 2 cm gap between electrodes.

Fresh whole strawberries and strawberry jelly were also tested with four different power supply voltages and a 2 cm gap between electrodes. The electric field was initially adjusted to the predictable electrical conductivity of the product in test.

## Brix Gradient Experiments

Studies were made using two different industrial strawberry pulps (P1 and P2) in which Brix was adjusted to six different concentrations (from 14.5° to 41.0° and from 26.5° to 59.5°), respectively, by adding sucrose. Brix was measured with a thermostated refractometer (Abbe Schmidt Haench - Elaptron, Germany) at 20C.

Samples were heated using a 60 V/cm and 80 V/cm voltage input for P1 and P2, respectively.

### Solid Content Experiments

Strawberry cubic pieces were added to several samples of strawberry pulp P1 in order to achieve a solid content ranging from 0 to 20% (w/w). This solid content range is the one used industrially for this type of pulp. Frozen strawberries were cut into two different sizes: S1 (average size 6.40 mm) and S2 (average size 7.90 mm). Due to the irregularities of the fruit it is not possible to obtain a unique size, so size distributions were determined in a series of sieves by shaking (Retsch VE 1000, 50 Hz, Germany) a 100 g sample for 5 min. Results are reported in Fig. 2.

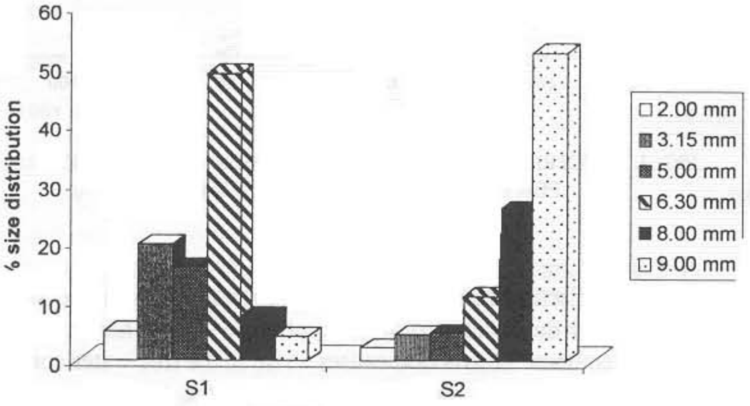

FIG. 2. SIZE DISTRIBUTION OF STRAWBERRY PIECES

## RESULTS AND DISCUSSION

### Field Strength

Figure 3 shows data on electrical conductivity *versus* temperature for fresh strawberries, obtained using different field strengths. Electrical conductivity seems to increase linearly with increasing field strength. One of the curves (field strength 40 V/cm), however, curves downwards, suggesting that the samples used in these experiments were slightly different from the others, namely in terms of their maturation degree. In fact, nonuniform tissues presenting not fully ripe (which have higher cell wall resistance to destruction during heat thus showing a lower electrical conductivity) parts lead to the obtained differences in the conductivity dependence on temperature (Sasson and Monselise 1977).

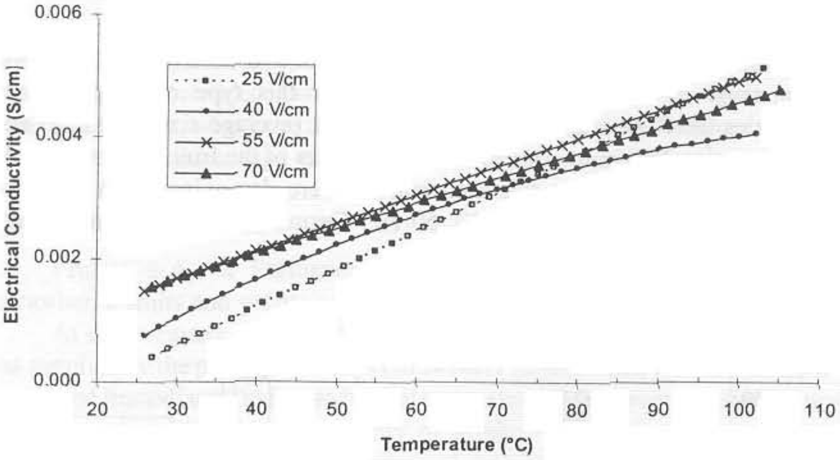

FIG. 3. ELECTRICAL CONDUCTIVITY OF FRESH STRAWBERRY, FOR DIFFERENT FIELD STRENGTHS

Halden (1990) discussed in detail this increase with voltage and suggested that it was principally due to electro-osmotic effects. During heating structural changes occur. Membrane destruction causes a rise in the free water content and voltage application results in fluid motion through the capillaries, which is directly proportional to electrical conductivity.

A linear relation between electrical conductivity and temperature is evident for the strawberry pulp (Fig. 4) but this aspect changes for the strawberry jelly that presents a quadratic relation (Fig. 5).

On the other hand, data presented in Fig. 4 show that, although in strawberry pulp electrical conductivity increases with temperature, the effect of field strength is not as evident as in the fresh strawberries or strawberry jelly. This behavior may be due to the presence of texturizing agents that act with the rise of temperature and increase the drag forces of the medium, reducing the mobility of the fluid and of the ionic components present. In fact, the increase of viscosity was evident at the end of the heating phase, for strawberry pulp. This was not observed for fresh strawberries or strawberry jelly.

Heating curves presented in Fig. 6 clearly demonstrate the significant differences of electrical conductivity between the three products tested. Strawberry jelly has considerably lower electrical conductivity (5% of the electrical conductivity of fresh strawberry and 4% of the strawberry pulp) and a consequently lower heating rate (0.25C/s comparing to 2.85C/s for the fresh strawberry and 6.22C/s for the pulp) that would necessitate use of a different ohmic heater design for this product. This shows the importance of evaluating the electrical properties of a food intended to be processed by ohmic heating.

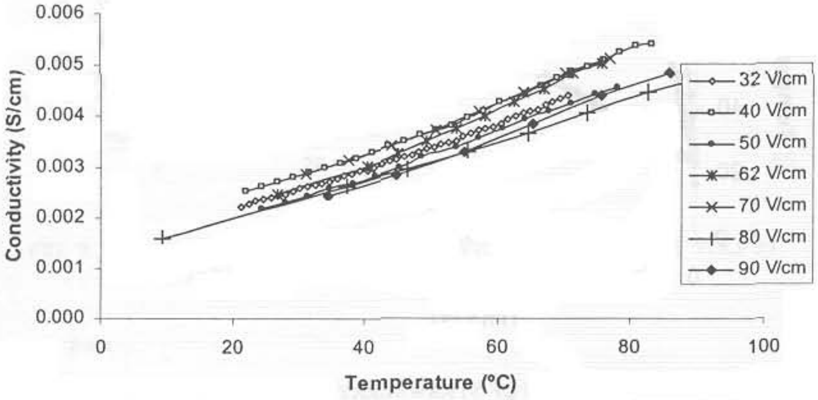

FIG. 4. ELECTRICAL CONDUCTIVITY OF STRAWBERRY PULP P1, FOR DIFFERENT FIELD STRENGTHS

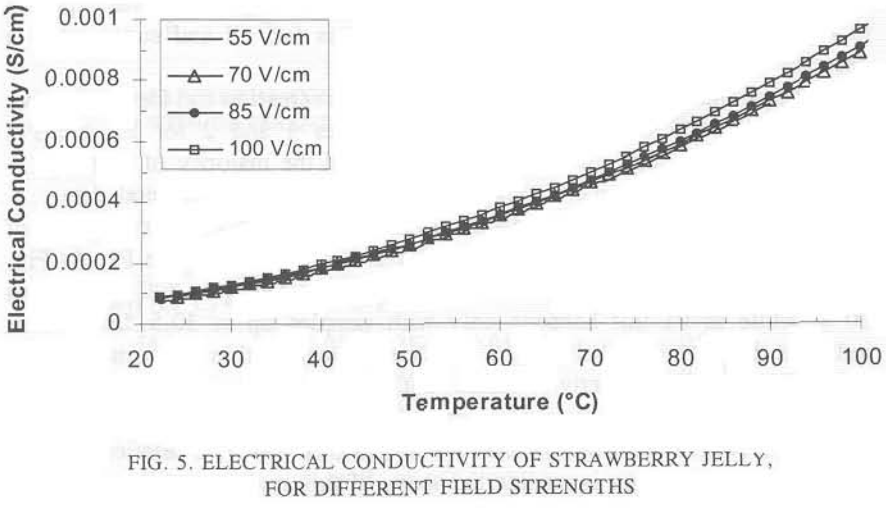

FIG. 5. ELECTRICAL CONDUCTIVITY OF STRAWBERRY JELLY, FOR DIFFERENT FIELD STRENGTHS

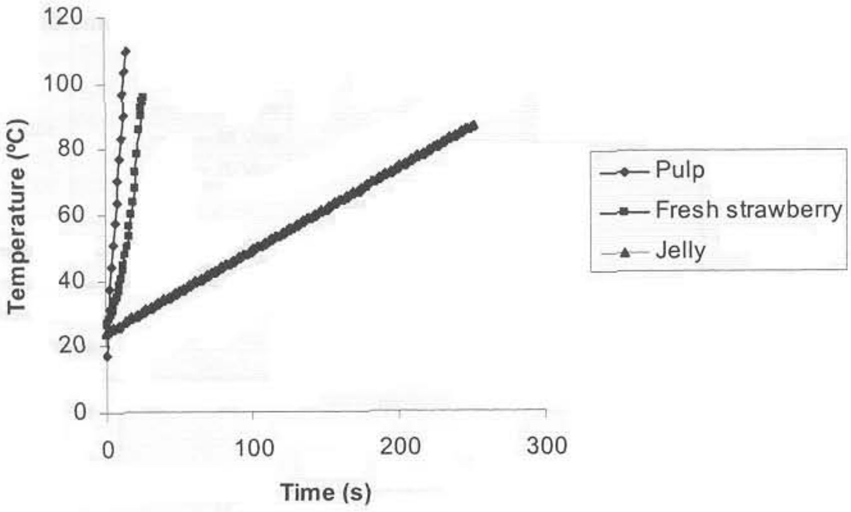

FIG. 6. HEATING CURVES OF STRAWBERRY AND STRAWBERRY PRODUCTS, DURING OHMIC HEATING, WITH FIELD STRENGTH OF 70 V/cm

### Brix Gradient

The results in Fig. 7 and 8 indicate that the conductivity of strawberry pulp is suppressed (up to 60% decrease) by the presence of sugar. This was expected to happen because nonionic constituents such as fat, oil and sugar cause a decrease in electrical conductivity (Sastry 1992).

The parameters of $\sigma$-T models determined by regression and their respective correlation coefficients ($r^2$) are listed in Tables 1 and 2 for P1 and P2, respectively. Although linear models showed, in the majority of cases, $r^2 > 0.97$, quadratic models were considered to best fit the experimental data.

P2 has significantly lower electrical conductivity than P1, but the effect of sugar content on the electrical conductivity is less evident than in P1. As Fig. 9 and 10 show, P2 samples up to 45 °Brix can be heated up to 80C in less than 30 s, while in P1 this happens only with samples up to 30.5 °Brix. This indicates that P1 has probably more ionic constituents within its formulation, as shown by the high conductivity values, but the ionic movement is more rapidly affected by interactions between sugars and P1 constituents (texturizing agents) than in P2 (where texturizing agents are absent). However, a detailed analysis of products formulation is outside the scope of this study.

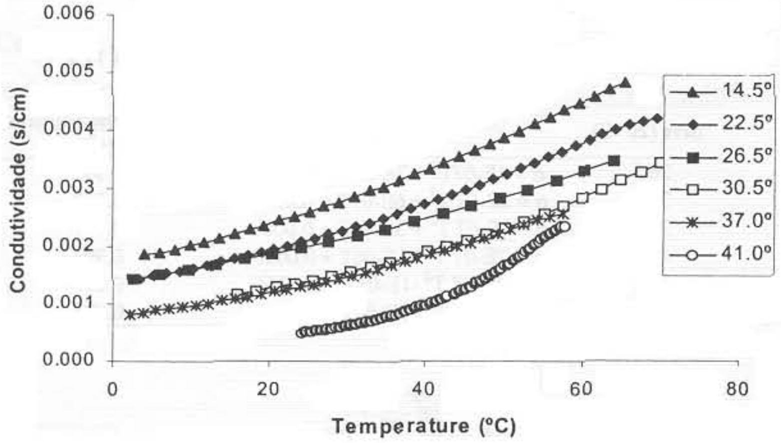

FIG. 7. ELECTRICAL CONDUCTIVITY CURVES OF STRAWBERRY PULP P1, WITH DIFFERENT BRIX, DURING OHMIC HEATING

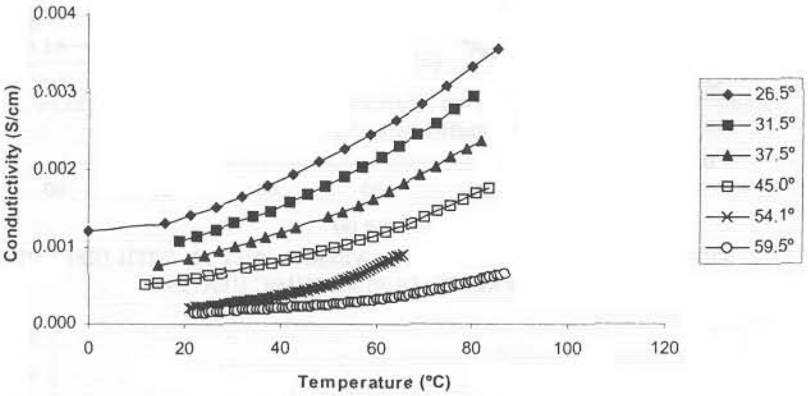

FIG. 8. ELECTRICAL CONDUCTIVITY CURVES OF STRAWBERRY PULP P2, WITH DIFFERENT BRIX VALUES, DURING OHMIC HEATING

TABLE 1.
ELECTRICAL CONDUCTIVITY-TEMPERATURE MODELS FOR P1, WITH VARIOUS BRIX VALUES

| °Brix (20 C) | σ-T model | Correlation coefficient ($r^2$) |
|---|---|---|
| 14.5 | $\sigma = 3E\text{-}07\ T^2 + 3E\text{-}05T + 0.0017$ | 0.999 |
| 22.5 | $\sigma = 3E\text{-}07\ T^2 + 2E\text{-}05T + 0.0013$ | 0.999 |
| 26.5 | $\sigma = 2E\text{-}07\ T^2 + 2E\text{-}05T + 0.0014$ | 1.000 |
| 30.5 | $\sigma = 4E\text{-}07\ T^2 + 7E\text{-}06T + 0.001$ | 0.999 |
| 37.0 | $\sigma = 3E\text{-}07\ T^2 + 1E\text{-}05T + 0.0008$ | 0.999 |
| 41.0 | $\sigma = 2E\text{-}06\ T^2 - 8E\text{-}05T + 0.0016$ | 0.988 |

TABLE 2.
ELECTRICAL CONDUCTIVITY-TEMPERATURE MODELS FOR P2 WITH VARIOUS BRIX VALUES

| °Brix (20 C) | σ-T model | Correlation coefficient ($r^2$) |
|---|---|---|
| 26.5 | $\sigma = 3E\text{-}07T^2 + 7E\text{-}05T + 0.0012$ | 0.999 |
| 31.5 | $\sigma = 2E\text{-}07\ T^2 + 6E\text{-}06T + 0.0009$ | 0.999 |
| 37.5 | $\sigma = 2E\text{-}07\ T^2 + 3E\text{-}06T + 0.0007$ | 0.999 |
| 45.5 | $\sigma = 2E\text{-}07\ T^2 - 1E\text{-}06T + 0.0006$ | 0.994 |
| 54.1 | $\sigma = 3E\text{-}07\ T^2 -1E\text{-}05T + 0.0004$ | 0.997 |
| 59.5 | $\sigma = 1E\text{-}07\ T^2 - 5E\text{-}06T + 0.0002$ | 0.997 |

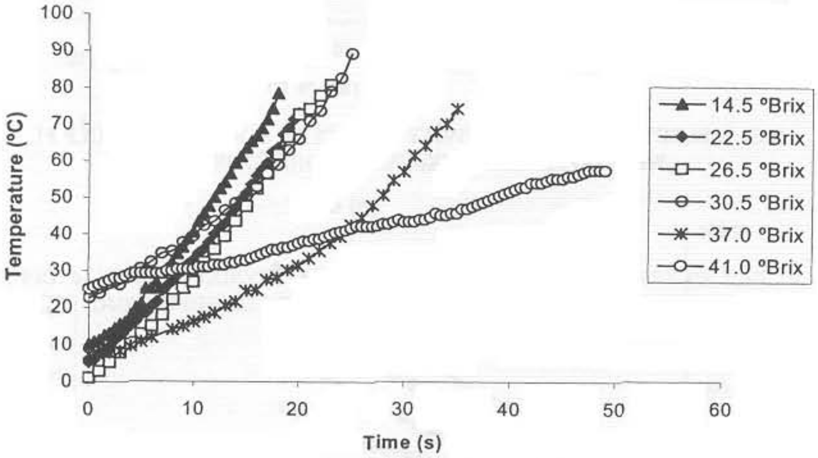

FIG. 9. HEATING CURVES OF STRAWBERRY PULP P1, WITH DIFFERENT BRIX VALUES, DURING OHMIC HEATING

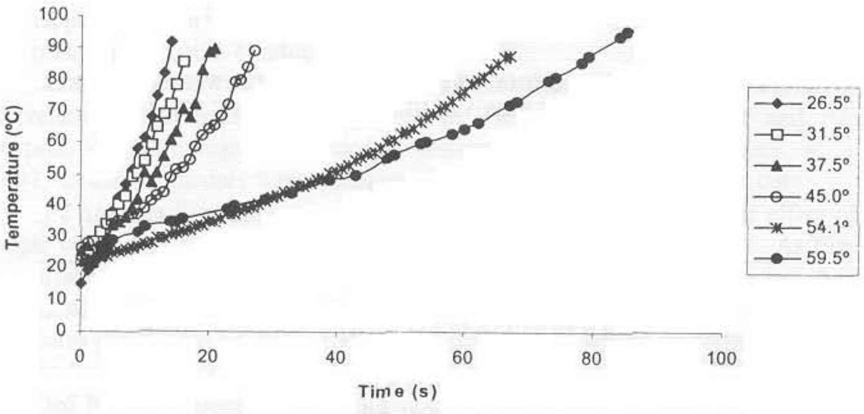

FIG. 10. HEATING CURVES OF STRAWBERRY PULP P2, WITH DIFFERENT BRIX VALUES, DURING OHMIC HEATING

### Solid Content

Electrical conductivities of P1 for different solid contents and two different size distributions of solids are shown in Fig. 11 and 12.

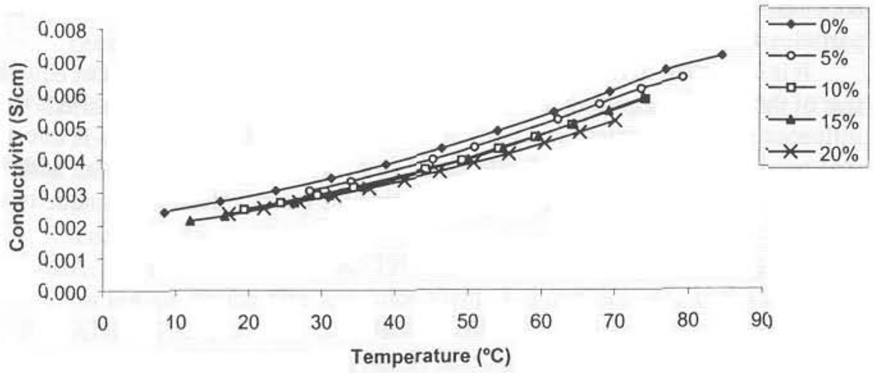

FIG. 11. ELECTRICAL CONDUCTIVITY CURVES OF S1 (6.4 mm), WITH DIFFERENT SOLIDS CONTENT, DURING OHMIC HEATING

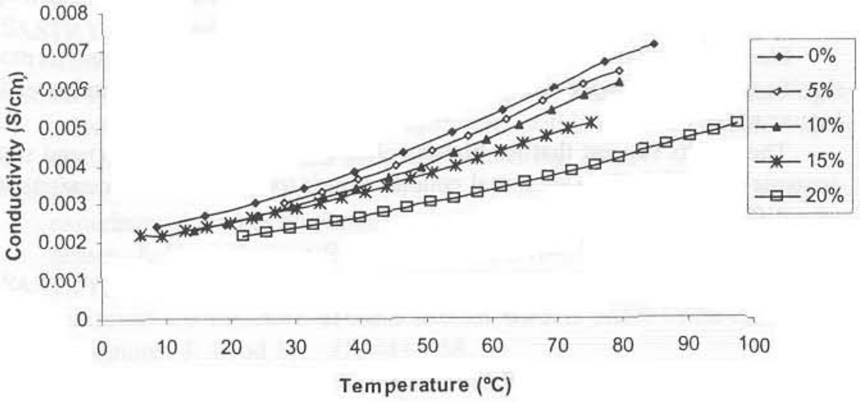

FIG. 12. ELECTRICAL CONDUCTIVITY CURVES OF S2 (7.9 mm), WITH DIFFERENT SOLIDS CONTENT, DURING OHMIC HEATING

Anon (1982) explained the increase of electrical conductivity with temperature by the reduction of drag for the movement of ionic components, much in the same way that, later on, Halden *et al.* (1990) did when explaining the increase of electrical conductivity with field strengths. The decrease in electrical conductivity for both size distributions with the increase of solids content may be explained by the increase of the resistance for ionic movement. For the same solids content, a maximum of 30% decrease in electrical conductivity with increasing particle sizes can be observed meaning that smaller particles may reduce the resistance for ionic movement.

It is important to note that electrical conductivity of the solids almost equals that of the liquid suggesting that, as Palaniappan and Sastry (1991) reported, the influence of solids content and particle size on electrical conductivity is due to structural rather than chemical effects. In fact, the solid pieces cause an added resistance to the current passage, thus lowering the overall electrical conductivity.

## CONCLUSION

Electrical conductivity is a very useful parameter to determine the applicability of ohmic heating technology for specific products. There are cases in which the differences in $\sigma$ may go up to 70% increase (depending on the temperature) with a field strength twice as large. However, for most of the products tested it was found that the field strength does not greatly affect electrical conductivity, which is in turn significantly different from product to product.

Electrical conductivity increases with temperature, in every case, although it may not be a linear relation.

Electrical conductivity decreases with solid content but the decrease is more significant for the bigger size particles tested. The value of $\sigma$ is also lower for higher sugar contents.

The results suggest that for higher solids content (> 20% w/w) and sugar contents over 40.0 °Brix electrical conductivity is low enough to necessitate use of a different ohmic heater design.

## ACKNOWLEDGMENTS

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