HUNGARIAN AGRICULTURAL ENGINEERING
N° 34/2018 62-65
Published online: http://hae-journals.org/
HU ISSN 0864-7410 (Print) / HU ISSN 2415-9751(Online)
DOI: 10.17676/HAE.2018.34.62
Research Letter
Received: 2017.10.17.; Accepted: 2018.12.09.

PERIODICAL OF THE COMITTEE OF AGRICULTURAL AND BIOSYSTEM ENGINEERING OF
THE HUNGARIAN ACADEMY OF SCIENCES
and
SZENT ISTVÁN UNIVERSITY
Faculty of Mechanical Engineering

EVALUATION OF OHMIC HEATING DESIGN USING THERMOVISION

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Abstract

Ohmic heating is a promising technology for economic cooking. Electrical energy is directly affecting foodstuff and treatment starts inside. Viennese type smoked pork sausages were used in the experiment. Sausages were treated with and without immersion into NaCl solution. Two sausages were treated parallel at the same time in 3 replicates. Three levels of voltage were applied (50 V, 125 V and 200 V). Thermovision data was confirmed using infrared thermometer and compared to finite element simulation results. Both equipments had ±2% accuracy. Middle level of 125 V was found to be optimal for cooking. Highest surface temperature reached expected 75 °C rapidly.

Keywords

electrical engineering, Joule heating, cooking, Viennese sausage, thermal imaging

1. Introduction

Heat treatments are always in focus of attention, like pasteurization and sterilization. Ohmic heating, also called as Joule heating, is popular since it is fast and economic method without transfer medium. Jaeger et al. [1] investigated the literature and found that products of 0.1 – 10 S/m electrical conductivity can always be treated successfully with this technique. Mainly alternate current is used in order to prevent electrochemical and electrolytic effects. The field strength is typically in the range of 3.5 – 40 V/cm for meats. Highest values were observed for beef [2]. It was found that ground beef was cooked faster, final product was firmer, color was more homogeneous and volume reduction decreased compared to conventional technology. Ohmic cooking was successfully used to prepare meat balls [3]. The total mesophilic aerobic bacteria number decreased significantly, yeast and mould fall to undetectable levels using 15.46 V/cm voltage gradient. Since ohmic heating did not eliminate Listeria monocytogenes from meat ball samples, authors suggest application of this technology in combination with other methods. Engchuan et al. [4] cooked meat balls of ∅2.8 cm with immersion into NaCl solution, where salt content was adjusted to 1.5% of pork weight. The heating was designed to reach 80 °C temperature. According to the results, Sukprasert's semi-empirical temperature prediction model was improved. Scanning electron microscopy of the products revealed that significant difference is visible between conventional and ohmic heated meat ball texture. Ohmic cooking made more homogeneous microstructure with small pores. Raw beef muscle treated with additional 3% salt was cooked with 100 V voltage up to 72 °C and 95 °C target temperature by Zell et al. [5]. This treatment was found to be at least 7 fold faster than conventional heating, but its major advantage was the reduced cooking loss. All other quality parameters, such as sensory attributes, textural properties and color, were comparable to that of the traditional method. Zell et al. [6] also cooked turkey meat with this technology. The meat was injected with 3% salt solution up to 130% of initial weight. Voltage was adjusted to 100 V and treatment took 8 min. Significant difference was observed between cooking loss of traditional, ohmic slow and rapid cooking. It was concluded that products treated with ohmic heating were preferred over conventional, but kinetics must be optimized for best sensory values. According to the literature, raw meat samples were always treated with salt solution of different concentration before ohmic cooking. Ready to eat food products are unlikely to require pretreatment with salt solution due to higher salt content and prevention of change of sensory attributes. The objective of the presented work was to investigate different setups of ohmic heating by means of non contact temperature monitoring. Effects of electrical parameters, electrode configuration and immersion into NaCl solution were evaluated.

2. Materials And Methods

Materials

Viennese type smoked pork sausages were acquired in retail store. The packages of 160 g contained 6 pieces with the geometry of ∅2.8 cm and 17 cm length. Measurements were performed with two pieces in parallel and three replicates. According to the assumed salt content of sausages, three simulations were performed. Average salt content of the product was 2.5%, but changes can occur due to treatment and immersion into NaCl solution. Properties were adjusted in simulation according to Choi et al. [7] (Table 1).

Methods

Adjustable power supply (model TD 1001, TRAKIS) of 230/0-240 V and 1000 VA was applied to provide required electricity.

Multimeters measured voltage (VC2020, Voltcraft, Germany) and current (MY-64, Mastech, China). Electric circuit is introduced in the following figure (Figure 1). Three voltage levels were adjusted as 50, 125 and 200 V resulting in 3.33, 8.33 and 13.33 V/cm gradient.

Table 1. Electrical properties of sausages used in simulation

Property	Low	Medium	High
Salt content	1.25%	2.5%	5%
Thermal conductivity, W/mK	0.999	0.999	0.999
Electric conductivity, S/m	1.50	2.79	5.11
Density, kg/m^3	1023	1031.34	1048
Specific heat, J/kgK	3279.08	3239.42	3160.10

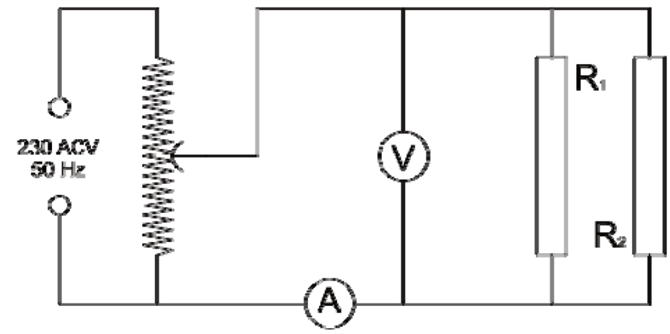

Figure 1. Electric circuit of the measurement

The vision system consisted of a thermal imaging instrument (MobIR®M4, Wuhan Guide Infrared Technology Co., China) operating in the spectral range of 8-14 µm with ±2% accuracy. Captured data were evaluated using bundled IR Analyzer software (Wuhan Guide Infrared Technology Co., China).

Besides still image acquisition, USB video grabber (MT4169, Media-Tech) was used to capture video of the treatment and read temperature values more frequently.

COMSOL® Multiphysics simulation software (5.3, COMSOL Inc., USA) was used to perform finite element modeling. Parameter values, such as density and specific heat of ingredients, were estimated according to Choi et al. [7]. Models calculated electromagnetic field and temperature data in sausage samples. Theoretical values were compared to experimental readings.

Experimental data was collected, preprocessed and evaluated in Excel® (Microsoft Inc., USA) and R (R Foundation for Statistical Computing, Austria) software.

3. Results and Discussion

Geometry model of sausages was made of a cylinder and two closing semi-spheres. Electrodes of cone shape were inserted at the top of the spherical ends (Figure 2). Simulations were performed on a workstation of Intel I7-3820 @ 3600 GHz CPU and 64 GB RAM in the laboratory of University of Salerno, Italy.

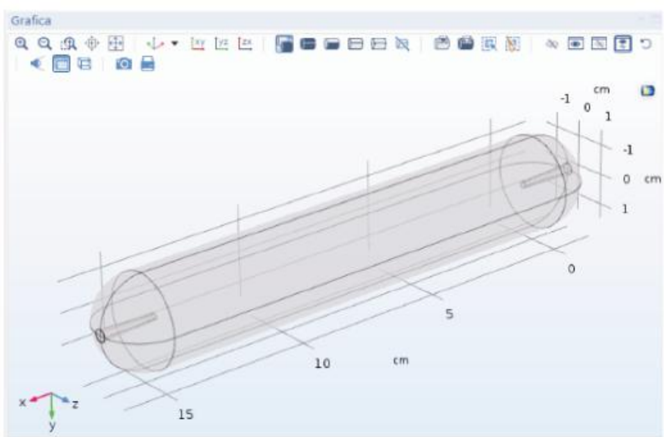

Figure 2. Shape model of sausages in COMSOL 5.3

Simulation results were in agreement with observed temperature distribution. The middle axis between the two electrodes was heated first and temperature increased in the cylindrical part (Figure 3). Simulation results shown that increasing salt content accelerate ohmic cooking. Immersion half way into 10% NaCl solution helped only to heat up transfer medium faster. In that case, sausages were found to have the same surface temperature as surrounding medium. Thermovision was unable to look inside salt solution, therefore manual IR temperature readings were collected on sausage surface above liquid level in that experiment. The primary factor affecting ohmic cooking was the applied voltage. It was observed that temperature and current increased parallel at the beginning and current reached the maximum when meat burnt around electrodes. Surface temperature increased for a while with decreasing current after maximum. Burnt meat is likely to isolate electrode and prevent current flow. The temperature increased with 60.5, 87.6 and 101.5 °C for 50, 125 and 200 V, respectively.

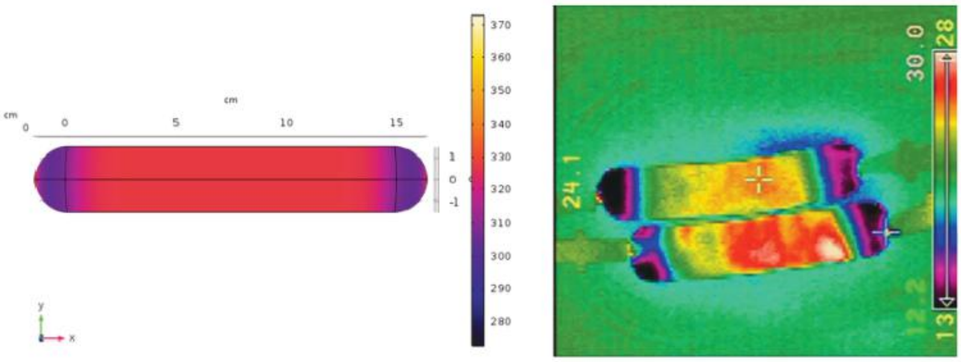

Figure 3. Heat distribution on surface by simulation (left) and thermovision (right)

Temperature and current data for 125 V are presented in Figure 4. The maximum current was reached at 22 s followed by the maximum temperature at 28 s. The observed shift between curves and their shape indicate that both electromagnetic field and internal heat transfer cooked sausages.

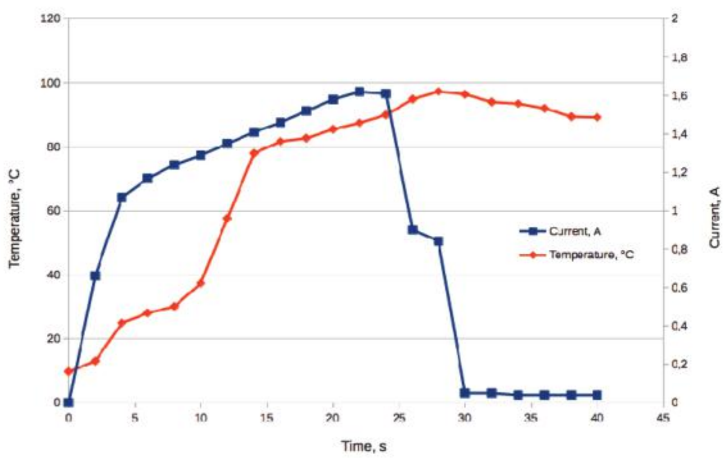

Figure 4. Temperature and current readings for treatment with 125 V

Surface temperature simulation shown a cold ring on the semi-spheres near the end of sausages and it was also observed on thermal images (Figure 3). The simulation of electromagnetic field confirmed that it has the minimum strength at that locations (Figure 5). The electromagnetic field was found to be homogeneous between electrodes and decrease rapidly at tip cap.

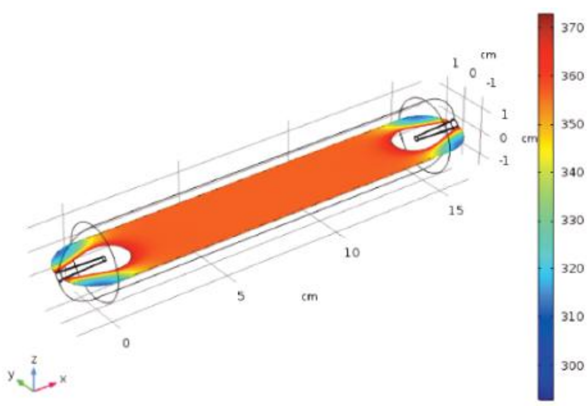

Figure 5. Simulation result of the electromagnetic field

According to the simulation result and observed surface temperature distribution, the cold point of the product is on the surface and close to electrodes far from the opposite one. Ohmic heating treatment time shall include the time required for heat transfer to cook coldest regions as well.

4. Conclusions

Pilot plant was assembled in order to investigate ohmic heating of Viennese type pork sausages. Compared to literature, ready to eat food product does not seem to require additional treatment to increase salt content or immersion into salt solution. The source electricity of 125 V was able to cook sausages rapidly and surface temperature increased with 87.6 °C during experiment. Lower level of 50 V was found to be slower and less practical. On the other hand, high level of 200 V was too rapid and burnt meat around electrodes quickly without useful cooking. Theoretical finite element simulation was in agreement with observed experimental readings. Temperature was observed to increase primarily in the cylindrical part between electrodes and the cold point was found on the surface of semi-spheres at the ends. Ohmic heating is a promising technology to cook homogeneous sausages rapidly and more economically. The treatment requires optimization in order to cook cold regions taking care of microbial safety and control source voltage to keep joule heating without burning the product.

Acknowledgements

The Project is supported by the European Union and co-financed by the European Social Fund (grant agreement No. EFOP-3.6.3-VEKOP-16-2017-00005).

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