Bulgarian Chemical Communications, Volume 46, Special issue B (pp. 7 –10) 2014

Effect of composition and microwave radiation on electrical impedance spectrum of cow milk

E.Vozáry*, N. Pálfy, L. Markó

Department of Physics and Control, Corvinus University of Budapest, Budapest, Hungary

Received September 25, 2014; revised December 10, 2015

Electrical impedance spectrum of cow milk with 1.5%, 2.8%, 3.5% and full fat content was determined in frequency range from 30 Hz up to 1 MHz. The impedance magnitude and the phase angle were measured before and after microwave irradiation – with power 900 W and with radiation time of 10, 20, 30, 40, 50 and 60 s. The temperature of milk samples after radiation was measured. The impedance spectrum of samples with various fat contents was determined after conventional heating process at temperature reached under microwave radiation. The microwave radiation decreased the impedance magnitude in the whole investigated frequency range when radiation time increased up to 30 s, but further increase of radiation time did not caused further decrease. The phase angle in low frequency range (30 Hz – 10 kHz) also decreased after radiation and this change raised as the radiation time became longer. The conventional heating at low temperature range – 20 °C – 40 °C – resulted in increasing of impedance magnitude but at higher temperatures the decrease of impedance magnitude was observed. The effect of conventional heating on the phase angle was similar to the effect of microwave radiation. Electrical impedance spectroscopy can be used to distinguish milk sample heated by microwave radiation from milk heated by conventional method.

Key words: milk, microwave radiation, heating, electrical impedance spectrum.

INTRODUCTION

The milk undergoes several - among others some heating - processes before consumption. The radiation of microwave oven used in millions household for reheating and processing foods can cause various physical and chemical changes in processed object. In scientific literature there are few articles in which the effect of microwave radiation on structure of milk is discussed [1-3]. Generally there is stated, that microwave heating is very effective for destruction of microorganisms and the structure changes caused by it is similar to the changes after conventional heating [1,3].

The microwave of 2.45 GHz frequency excites the dipole of water molecules and the high energy of dipoles can cause a local temperature increase. The temperature gradient results in a heat flow and so the temperature of whole food in oven increases. Microwave exposure of milk can decrease the averages of fat, protein, dry substance and lactose concentrations while the density averages can increase [3]. Some structure changes can be observed in casein stabilized by microwave energy on gold-nanoparticles, too [4].

The electrical impedance spectrum of biological material contains four bands characteristic for ion concentration, membrane state, macromolecular organization, bound and free water [5]. The electrical impedance spectrum of milk can be described with a model circuit consisting of a parallel connection of serial RC element with a capacitance [6]. The admittance values can be used for detection of added water to the full fat milk [7].

The aim of our work was to investigate, whether the electrical impedance spectroscopy is sensitive enough to detect the structural changes caused by microwave radiation in milk.

EXPERIMENTAL

Full fat cow milk was purchased from a local farm and milk of 3.5 %, 2.8 % and 1.5 % fat content were bought in a local shop. 80 ml of milk in glassware was put into the domestic microwave oven of a Whirlpool VIP 20, with double emission system, and was radiated 10, 20, 30, 40, 50 and 60 s with 900 W powers. The temperature of milk was measured after microwave radiation. For conventional heating the glassware with milk was in water bath and the water temperature was controlled with a Hake DC10 P5 thermostat. Temperature value was set for the same value reached after microwave radiation.

The magnitude, *Z*, and phase angle, *φ*, of electrical impedance were measured with a HP 4284A precision LCR meter in frequency range

* To whom all correspondence should be sent.
E-mail: eszter.vozary@uni-corvinus.hu

from 30 Hz up to 1 MHz. Two ECG Ag/AgCl electrodes (Fiab Spa) in 1 cm distances from each other were put into milk. The measuring voltage was 1 V, which is too low to cause changes in biological material. The measured spectra were open-short corrected to eliminate the stray capacitance and inductance. The real part, $R=Z\cos\varphi$, and imaginary part, $X=Z\sin\varphi$ were calculated and represented as a function of frequencies. The difference spectra ($R(t)$-$R(22\ °C)$) obtained by subtraction of real part spectrum determined at room temperature (22 °C) from real part spectrum determined after microwave radiation at higher temperature, (t), were calculated. The same difference spectra were evaluated for imaginary parts ($X(t)$-$X(22°C)$), too. These difference spectra were also determined for conventionally heated milk samples.

RESULTS AND DISCUSSION

The electrical impedance spectrum of milk depends on its composition. Decreasing fat content increased the magnitude of impedance (Figure 1A) in the whole investigated frequency range. The phase angle values (Figure 1B) at low frequencies also increased with decreasing fat content. The impedance magnitude of milk with 3.5 % fat content was slightly lower, than the impedance magnitude of sample with 2.8 % fat. Similar anomalous change was observed if 2 - 3 % water was added to full fat milk [7]. This can be explained by the hydrolysis of milk fat [7].

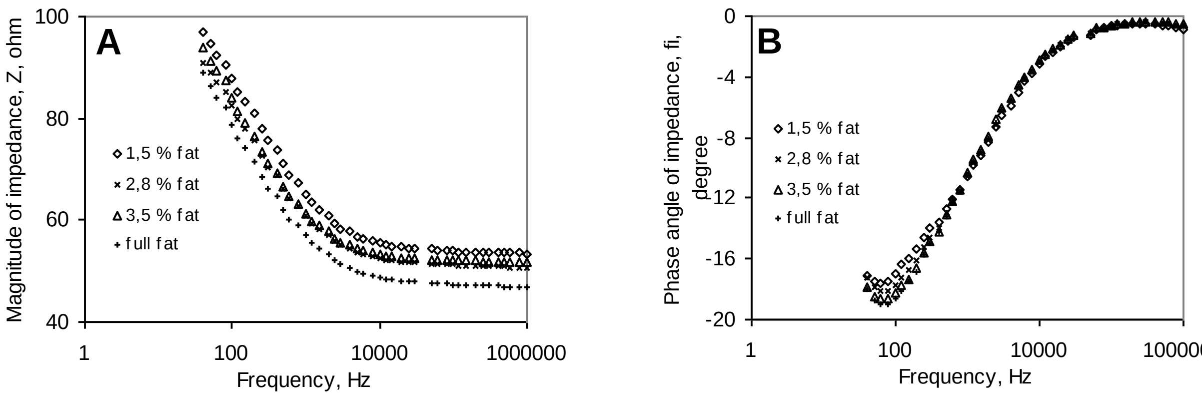

Fig. 1. Magnitude (A) and phase angle (B) of electrical impedance measured in milk with 1.5 %, 2.8%, 3.5% and full fat content at 22 °C temperature.

Microwave radiation (Figure 2A) of increasing time durations decreased the real part of impedance in full fat milk. 10 s and 20 s radiation caused only little decrease, but 30 s and longer radiation remarkably reduced the real part. The extent of real part decrease remained practically constant even the time of radiation was raised from 30 s up to 60 s. The imaginary part increased after microwave radiation and the measure of change was similar to the changes in real part. After 10 s, 20 s and 30 s microwave radiation the imaginary part became higher and higher and the increase was practically constants after 30 s and longer radiation. There was similar tendency in changes both in real and imaginary parts of milk samples with 3.5 %, 2.8 % and 1.5 % fat content (not shown).

After the conventional heating of full fat milk on water bath (Figure 2B) the real part of impedance increased and only at temperature higher than 43 °C decreased. The imaginary part of electrical impedance decreased as the temperature increased. There was similar tendency in changes both in real and imaginary parts of milk samples with 3.5 %, 2.8 % and 1.5 % fat content (not shown).

The difference spectra ($R(t)$-$R(22\ °C)$;$X(t)$-$X(22\ °C)$) of microwave radiated milk of 2.8 % fat content (Figure 3. A and B) are remarkably differ from difference spectra of no radiated, conventionally heated milk of 2.8 % fat content (Figure 4A and B). Differences increased while radiation time increased from 0 up to 30 s, and remained constant when the radiation time was further increased. It seems that during 30 s radiation the changes caused by microwave radiation were completed. Dumuta et al. [3] found that there is a critical radiation time about 30 s. The decrease of lipid, protein, lactose concentration and increase of density depended on radiation time from 0 s up to 30 s, but these changes not have further increased after 30 - 120 s radiation time [3]. The difference spectra of milk with 1.5 %, 3.5 % and full fat content were similar to difference spectra of 2.8 % fat containing milk (not shown).

Difference spectra for radiated milk samples can be explained by the several chemical processes observed after microwave radiation: auto oxidation milk lipid, induction of reactive oxygen species, resulting of free radicals, changes in whey protein structure, change in β-lactoglobulin folding process and changes in water structure [3].

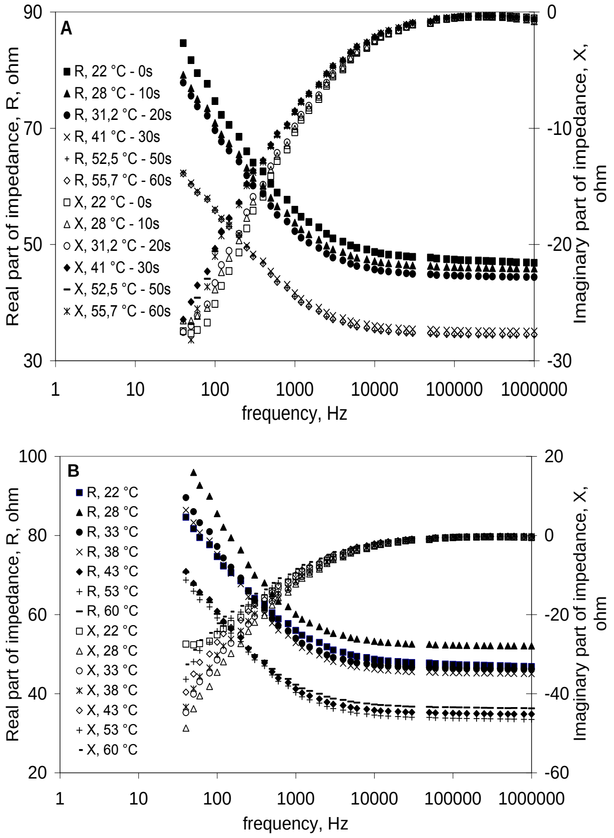

Fig. 2. Real part and imaginary part of electrical impedance of full fat milk after microwave radiation (A) and after conventional heating (B)

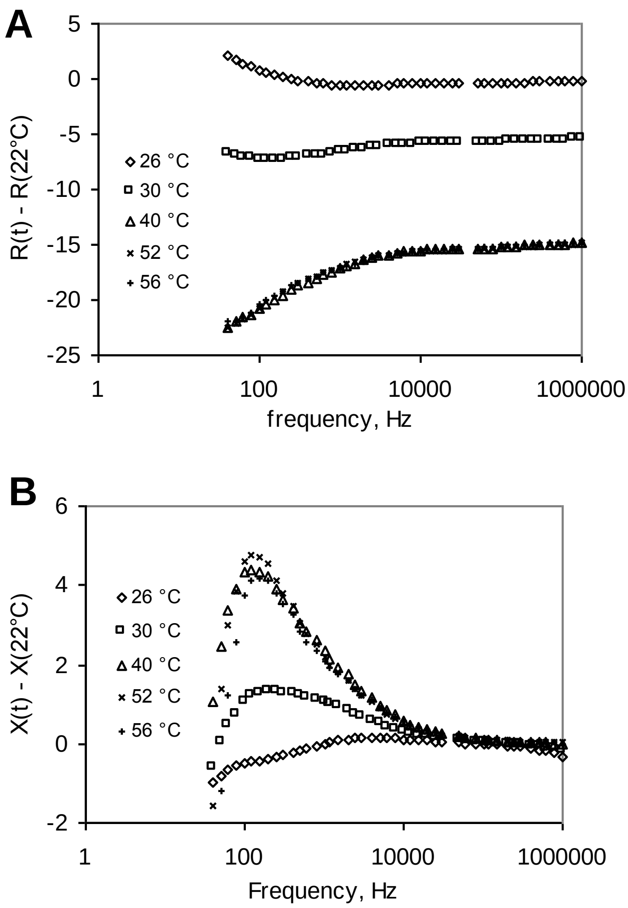

Fig. 3. Difference of real part (A) and imaginary part (B) of impedance spectrum of microwave radiated milk with 2.8 % fat at the reached average temperature according to the real and imaginary part of impedance spectrum of 2.8 % fat containing no radiated milk at 22 °C temperature

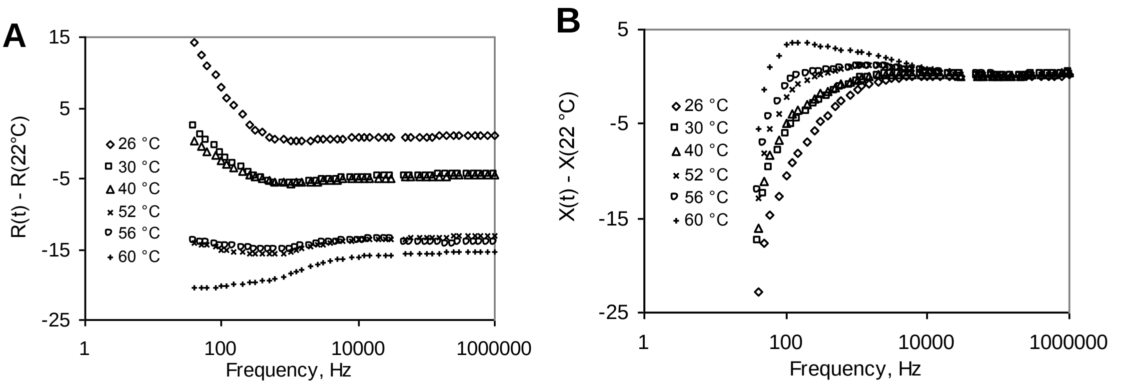

Fig. 4. Difference of real part (A) and imaginary part (B) of impedance spectrum of conventionally heated - up to temperature reached with microwave radiation - milk with 2.8 % fat according to the real and imaginary part of impedance spectrum of 2.8 % fat containing milk at 22 °C temperature.

CONCLUSION

The impedance magnitude and the real part of impedance of milk was decreased by microwave radiation when radiation time increased up to 30 s, but further increase of radiation time did not caused further decrease. The conventional heating at low temperature range resulted in increasing of impedance magnitude but at higher temperatures (> 40 °C) the decrease of impedance magnitude was observed. While the imaginary part of milk

impedance increased after microwave radiation the conventionally heating decreased the imaginary part of impedance. Electrical impedance spectroscopy is enough sensitive to show that the structure of microwave radiated milk differs from the structure of conventionally heated milk. This result can be used in the future in practice for detecting the microwave radiation of milk
.

REFERENCES

1. E. Valero, J. Sanz, I. Martinez-Castro, *Food Chem*., **66**, 333 (1999).
2. R. Sieber, P. Eberhard, P. U. Gallmann, *Int. Dairy J.*, **6**, 231 (1996).
3. A. Dumuta, L. Giurgiulescu, L. Mihaly-Cozmuta, Z. Vosgan, *Croat. Chem. Acta*, **84**, 429 (2011).
4. N. Molnár, K. Pribansky, E. Orosz, J. Mihály, Z. Keresztes, in: Book of abstracts (Proc. Regional Biophysics Conference, Smolenice Castle, Slovakia, 2014), T. Hianik (ed.), Comenius University in Bratislava and Slovak Academy of Sciences, Bratislava, 2014, p. 91.
5. S. Grimnes, O.G. Martinsen, in: Electrical properties of tissue. In: Bioimpedance and Bioelectricity Basics, S. Grimnes, O.G. Martinsen (Eds.), Academic Press, New York, USA, 2000, pp. 195-239.
6. M.F. Mabrook, M.C. Petty, *Sensors and Actuators B*, **84**, 136 (2002).
7. M.F. Mabrook, M.C. Petty, *Sensors and Actuators B*, **96**, 215 (2003).

ВЛИЯНИЕ НА СЪСТАВА И МИКРОВЪЛНОВОТО ОБЛЪЧВАНЕ ВЪРХУ ЕЛЕКТРИЧНИЯ ИМПЕДАНСЕН СПЕКТЪР НА КРАВЕ МЛЯКО

Е. Возари*, Н. Палфи, Л. Марко

Катедра Физика и контрол, Корвинус Университет на Будапеща, Будапеща, Унгария

Постъпила на 25 септември, 2014 г.; приета на 10 декември, 2014 г.

(Резюме)

В настоящата работа беше определен електричният импедансен спектър в диапазона от 30 Hz до 1 MHz на краве мляко с масленост 1.5%, 2.8%, 3.5%, пълномаслено. Големината на импеданса и фазовият ъгъл са измерени преди и след микровълново облъчване с мощност 900 W и продължителност 10, 20, 30, 40, 50 и 60 s. Измерена беше температурата на образците от мляко след облъчването. Импедансният спектър на образците с различно маслено съдържание беше определен след процес на конвенционално нагряване при температурата, която се достига при микровълновото облъчване. Микровълновото облъчване до 30 s доведе до намаляване големината на импеданса в целия изследван честотен диапазон, а по-нататъшното увеличаване на времето на облъчване не предизвика допълнително намаляване. Фазовият ъгъл, измерен в нискочестотния диапазон (30 Hz – 10 kHz), също показа намаление след облъчването, като тази промяна се увеличи при увеличаване времето на облъчването. Конвенционалното нагряване доведе до увеличаване големината на импеданса в нискотемпературния диапазон 20 °C – 40 °C и до намаляването му при по-високи температури. Ефектът на конвенционалното нагряване върху фазовия ъгъл беше подобен на ефекта от микровълновото облъчване. Електричната импедансна спектроскопия може да бъде използвана за различаване на образци от мляко, загрявани чрез микровълново облъчване, от образци, загрявани чрез конвенционален метод.