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ORIGINAL ARTICLE

Microwave chemistry: Effect of ions on dielectric heating in microwave ovens

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Abstract To understand the interactions of microwaves with dielectric materials and their conversion to thermal energy in aqueous systems, the effect of ionic concentration has been studied. Aqueous solutions of inorganic ions were exposed to microwaves (2.45 GHz) in a modified oven under identical conditions. Difference in solution temperatures with reference to pure (deionized) water was monitored in each case. A significant decrease in the temperature was observed with an increase in the quantity of ions. Experiments were repeated with several inorganic ions varying in size and charge. The information can be helpful in understanding the role of ions during dielectric heating.

1. Introduction

In the electromagnetic spectrum, microwaves having a frequency in the range of 0.3–300 GHz lay between infrared and radio waves (Menéndez et al., 2009; Meredith, 1998; Zlotorzynski, 1995). Microwaves are widely used in communication, remote sensing, navigation, food processing, and electron paramagnetic resonance spectroscopy, but in everyday life, their well-established use is for commercial and domestic heating. Besides, in the last couple of decades, conventional laboratory heating is being gradually replaced by microwave heating. The advantages that attracted the attention of chemists to microwave heating are; higher heating rates in less times, no direct contact between the reactants and energy source, and clean, selective and remote heating of the reactants in the desired atmosphere. In addition, non-thermal applications of microwaves include measuring the dielectric properties of a large variety of substances such as rubber, wood, paper, glass,

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synthetic polymers, and agricultural materials (Menéndez et al., 2009). Fundamental theories, database of dielectric properties of the substances and applications of microwaves have been adequately summarized in several books (Adam, 1969; Baden, 1990; Reich, 1953) and reviews (Caddick and Fitzmaurice, 2009; Horikoshi and Serpone, 2009; MacKenzie et al., 2009). Widespread use of microwaves gave birth to the continuing public and scientific discussions about the possible health hazards because of the interaction of electromagnetic radiations and tissues, which have also appeared in the literature in the near past (Jauchem, 2008).

Microwave energy can be transformed into heat when a dielectric substance, having permanent or induced dipoles, is exposed to microwave radiation of a certain band of frequency. The literature reveals that microwave heating occurs by two mechanisms, which are dipolar polarization, and ionic conduction whereas another called interfacial polarization is a combination of the two (Kingston and Jassie, 1998; Mingos and Baghurst, 1991; Taylor et al., 2005). Dipolar polarization is by which heat is produced in polar molecules like water. Dipoles align themselves by rotating with the electric field associated with waves. To achieve the thermal effect the frequency of microwave is so adjusted that in an alternating electric field, the phase difference between rotating the dipoles and orienting the field causes molecular friction and collisions that give rise to dielectric heating (Gabriel et al., 1998; Kappe, 2005). In conduction, dissolved charged particles (ions) in a sample oscillate back and forth under the influencing electric force of microwaves creating an electric current. This current faces internal resistance because of collisions of charged species with neighboring molecules or atoms, which cause materials to heat up (Metaxas, 1996; Ponne, 1996). The conduction principal has much stronger effect in comparison to dipolar polarization for heat producing capacity (Keiko, 2003). The interfacial polarization is a combination of conduction and dipolar polarization. It is important for such a heating system that includes a conducting material scattered in a non-conducting medium like dispersion of metal particles in sulfur.

Most of the general literature indicates that water containing ions is more efficiently heated by microwaves in comparison to pure (deionized) water (Gabriel et al., 1998) but one report (Metaxas, 1996) points out that microwaves of different frequency regions are needed to create oscillation in ions and rotation in polar molecules. Thus, microwaves of certain frequency band cannot produce heat simultaneously by both mechanisms. There are some reports that indicate less heating in the case of the presence of ions in water. Ponne (1996) developed microwave penetration profiles, calculated by Quasi-optical method, in pure water and 4% NaCl solution and found that microwave penetration depth significantly decreased in NaCl solution. Keiko (2003) studied the effect of concentration of sodium chloride on the heating efficiency of microwave and found that the solution was not efficiently heated in the microwave oven. Hasted (1973) found that at higher salt concentrations, the ions orient the water molecules around them, which lessen the ability of water molecules to adjust in the applied electric field, reducing the dielectric constant and thus, less heat is produced.

The present work has been carried out for in-depth study of the role of ions in dielectric heating. Aqueous solutions with ions having different charge, size, and nature were heated in a modified oven producing microwaves of 2.45 GHz at 900 W. For comparison, urea and sugar solutions were also subjected to investigation under similar conditions. The results can be helpful in better understanding the role of ions and their concentrations in microwave heating in domestic ovens.

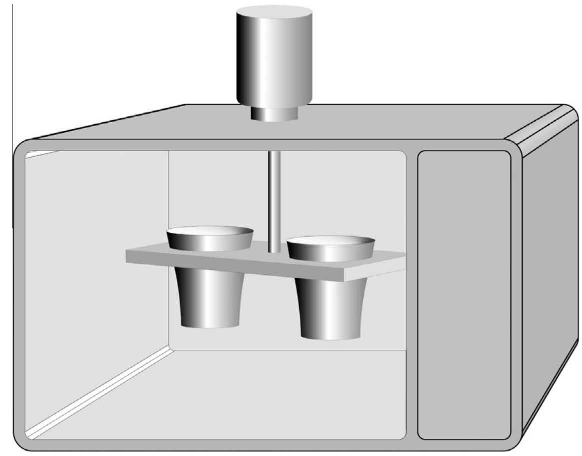

Figure 1 Personalized domestic microwave oven having rotating turntable with two identical arms to contain polystyrene cups; frequency 2.45 GHz; power full; time of exposure 40 s; volume of each solution 100 ml.

2. Materials and methods

2.1. Standard solutions

All the chemicals (anhydrous chlorides of lithium, sodium, potassium, cesium, magnesium, calcium, strontium, barium, nickel, copper and cobalt, urea, and sugar) were of AnalaR grade purity and were used without further purification. Deionized water was used throughout the work, while well washed Pyrex glassware was used for preparation of the solutions. Solutions having concentrations 0.01, 0.025, 0.05, 0.1, 0.25, 0.5, 1 mol/dm^3 of all the aforementioned compounds were prepared and stoppered.

2.2. Procedure

In order to overcome problems like zone heating and hot spots, the oven was fitted with a rotating turntable having two arms fitted with identical sample container holders, rotating at much higher speed (than the original turntable) to create a pseudo uniform exposure environment for both containers (Fig. 1). Rotation of 60 rpm also introduces turbulence in the sample containers thus stirring their contents evenly to rule out the formation of hot pockets. Reference container provides the facility to nullify the effect of magnetron power fluctuation.

One hundred millilitres of the sample solution taken in a polystyrene (PS) cup was placed in one arm of the turntable whereas 100 ml of deionized water in PS cup was placed on the opposing arm of the turntable. After the slow start of the turntable, the magnetron was turned on for full power for 40 s. After the aforementioned duration, both the cups were taken out and their temperatures were simultaneously measured with two separate identical digital thermometers. In each case, three solutions of the same concentration were exposed to