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An Experimental Study on the Heating Performance Evaluation of Bean Specimens

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Abstract
Radio Frequency (RF) heating is an emerging alternative way of heating, drying, sterilizing/pasteurizing processes. Rapid and relatively even heat transfer and high quality end products make RF heating preferable. A well-designed RF heating unit plays a major role on the efficiency of the process. Different parameters affect the heating performance of the system such as dielectric and geometrical properties of the material, electrode gap and so on. Designing the heating unit of the system for a specified material, one should measure the effectiveness of the proposed parameters. In this study, bean specimens were heated in a parallel plate 13.56 MHz frequency and 5 kW RF oven. 20 mm and 40 mm height of bulk bean specimens were exposed to RF process at three different electrode gaps (65, 75 and 85 mm). To determine the heating performance, heating performance index (HPI) was proposed. The thermal images were evaluated in the light of HPI and heating rate (HR) values. According to the results, electrode gap and material height (thickness) affects differently the HPI and HR. So both values should be considered while designing an effective RF oven.
Keywords: Radio Frequency Heating, Heating Performance Index, Heating Rate

1. Introduction

Radio frequency (RF) technology is an emerging technology that is used in various fields like heating, drying, sterilizing/pasteurizing [1-5]. Advantages like even and fast heating, smaller application field requirement, volumetric heating makes RF treatment being an alternative to the conventional methods. RF application is based on electromagnetic radiation. The process is based on two mechanisms; dipole rotation and ionic conduction [6]; this implies that the polarization of the polar molecules so that the friction is occurred. A common used RF process is exposure of a dielectric material between two electrodes. Upper electrode is called anode, bottom electrode is called cathode (Figure 1).

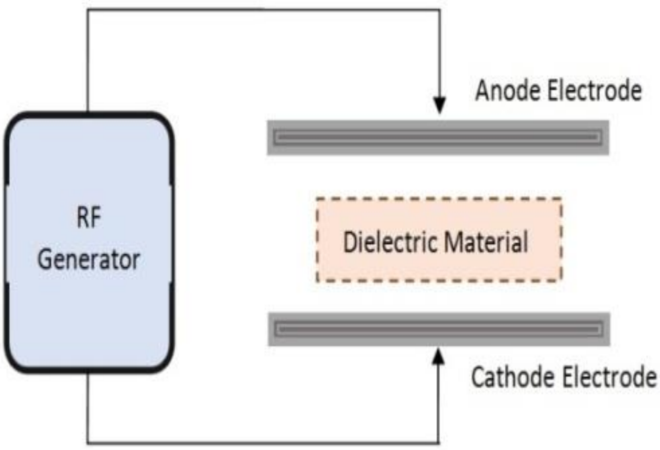

Figure 1.The schematic diagram of parallel plate RF heating system.

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The hot topic about the RF applications researches is providing homogenous temperature distribution over the material. In a thermally insulated material, a temperature gradient is occurred. Temperature increases from center to edges [7]. Various block-shaped foods [8] and load volumes were studied numerically for gaining a view about the role of the geometrical parameters on the heating efficiency of the RF drying system. In a study, researchers focused on the heating uniformity of RF heating and put PEI blocks on and bottom of a polypropylene container and conducted the experiments [9]. In another study, the same researchers cover the case with PEI sheet and reported that they enhanced the temperature uniformity in either method [10]. Arching is an important problem which should be considered for the specific application [11]. Water immersion of the material is studying for preventing the arching and obtaining a more uniform temperature distribution [12]. To predict the temperature uniformity some different indexes were proposed [13-14]. But these equations are generally convenient for computer simulations as they require elemental data or volume integration.

In this study, a set of experiments were conducted with beans to determine the temperature distribution at different electrode gaps. An approach called ‘Heating Performance Index (HPI)’ was proposed to able to draw a realistic evaluation to the heating performance of the oven.

2. Material and Method

2.1 Heating Performance Index (HPI)

Designing an efficient oven is very important to put forward the advantages of RF applications. A designer should be able to measure the heating performance of the existing oven so that the designer enhances the design. HPI is a tool which measures the heating performance of the oven by considering the average temperature after heating, temperature gradient, temperature difference of the average temperature before and after heating (Eq. 1). This index is claimed that it presents a true heating performance of the oven for related material. It should be noted that this index is valid only for the related material. If the oven will be used for different materials, experiments should be repeated for all materials to draw a comprehensive insight.

$$\left(\frac{T_{h,max}-T_{h,min}}{T_{h,ave}-T_{,ave}}\right)\left(T_{h,max}-T_{h,ave}\right) \text{ if } T_{h,ave} \geq \frac{T_{h,max}+T_{h,min}}{2}$$

(1)

$$\left(\frac{T_{h,max}-T_{h,min}}{T_{h,ave}-T_{c,ave}}\right)\left(T_{h,ave}-T_{h,min}\right) \text{ if } T_{h,ave} \leq \frac{T_{h,max}+T_{h,min}}{2}$$

Where $T_{h,max}$, $T_{h,min}$, $T_{h,ave}$, are maximum, minimum and average temperature of the heated top surface respectively and $T_{c,ave}$ is average temperature of the top surface before heating.

2.2 Heating Rate (HR)

Heating rate (HR) is a crucial parameter which should be considered while process design of a material. Because, different processes such as curing, disinfestations, pasteurization/sterilization etc., require various heating procedures. These procedures generally includes particular HRs. Equation 2 presents the calculation of HR

$$HR = \frac{T_{h,ave}-T_{c,ave}}{t} \tag{2}$$

where t represents time (min.).

2.3 Experimental Procedure

‘Bean’ was used as specimen. Experiments were held in a 13.56 MHz, 5kW laboratory scale RF applicator as seen in Fig. 2. Three different electrode gap (65, 75 and 85 mm) and two different heights (20 mm and 40 mm) were set to evaluate the effect of the electrode gap and the thickness on the heating performance index. A polypropylene container was used for housing the bean specimens. All experiments were conducted 600 s. After the experiments, specimens were immediately taken out from the oven and the thermal images of the upper surface of the material were taken. FLIR-E6 model thermal camera was used for taking thermal images of the heated specimens.

Polyprophylene container was filled with beans up to the desired height. First three experiments were conducted in 65, 75 and 85 mm electrode gaps with 20 mm height of beans while last three experiments were held with the same electrode gaps with 40 mm heigh.

Figure 2. RF generator and integrated oven.

3. Results and discussion

According to the experimental results, HPI values decreased with increasing electrode gap (Fig. 3).The lower the HPI values, the better the heating performance. The better heating performance implies the higher heating uniformity. HR values decreased with increasing electrode gap as expected. A sharp increase is seen in HPI from 65mm to 75 mm EG whereas a slight decrease is observed between 75 mm and 85 mm EG. This may be attributed to existence of an optimum electrode gap for the desired heating performance. These results were validated with both 20 mm and 40 mm height specimens .

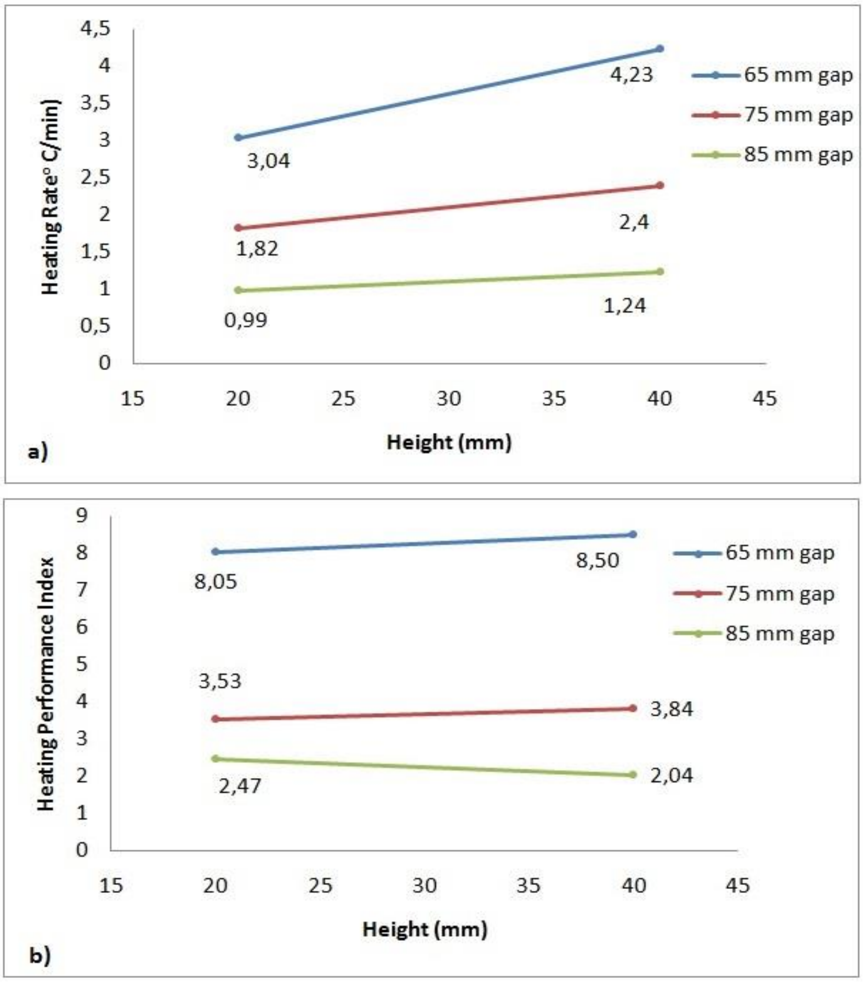


Figure 3. a) HPI and b) HR change depending on electrode gap.

HPI is more sensitive to EG change compared to specimen height change while HR is more sensitive to specimen height change compared to EG change (Fig. 4). A slight difference was observed for HPI values in both specimens with different heights. But HR values were increased up to 1.4 times for the 40 mm height bean specimens.

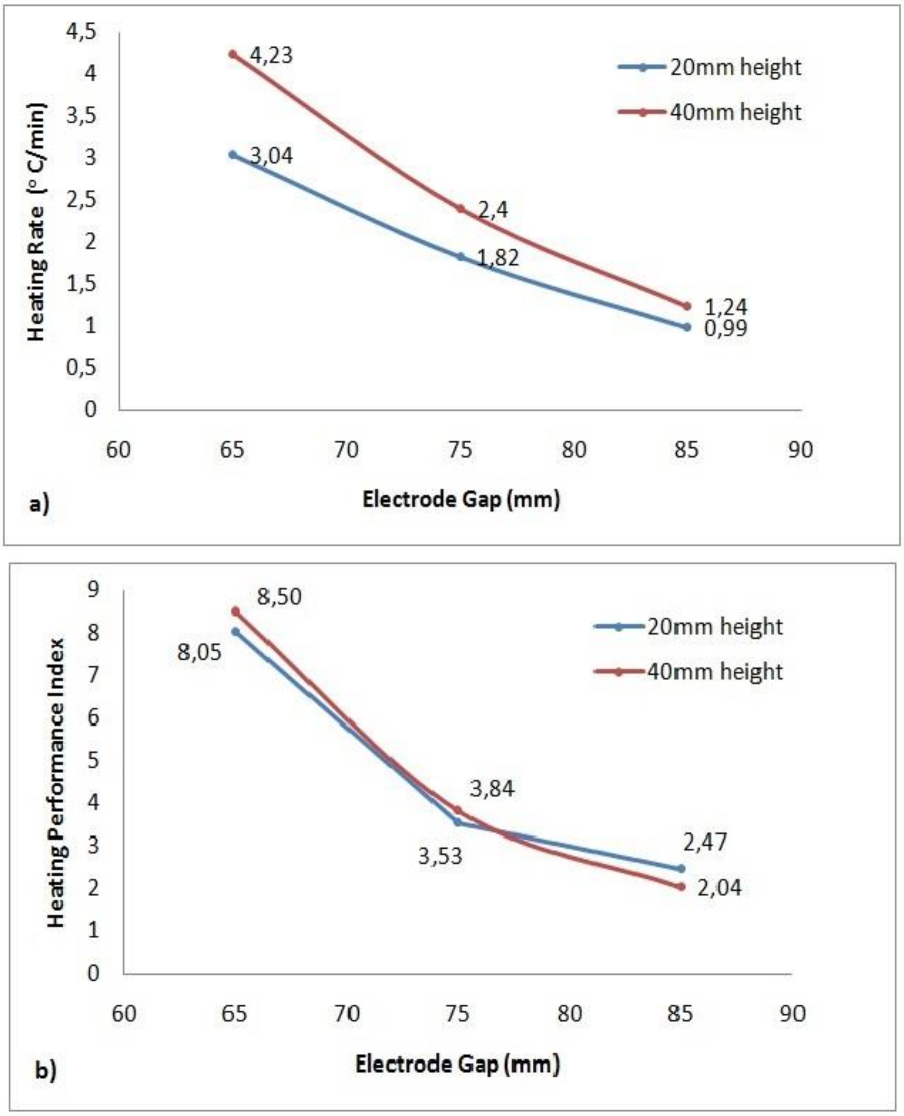
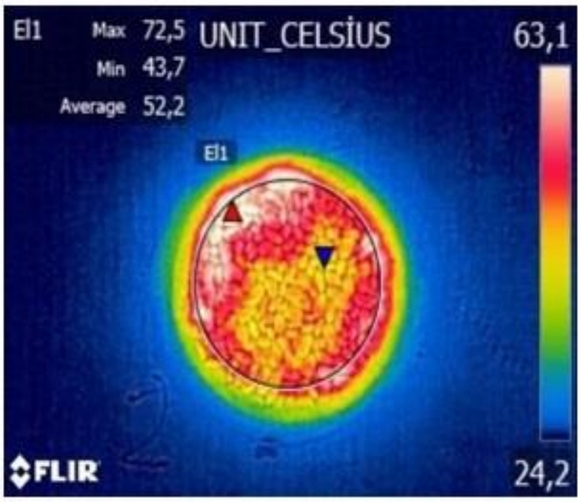
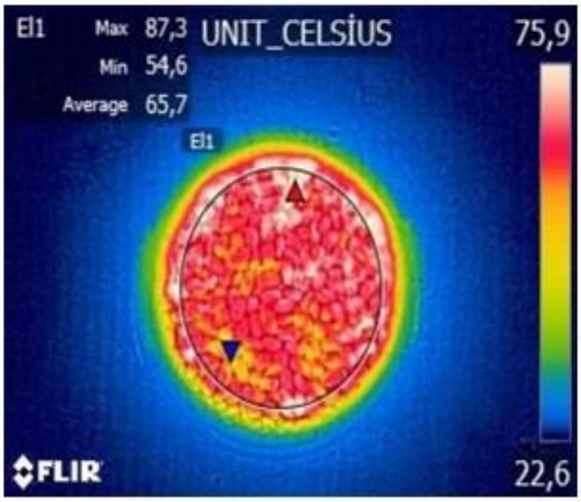


Figure 4. a) HPI and b) HR change depending on material height.

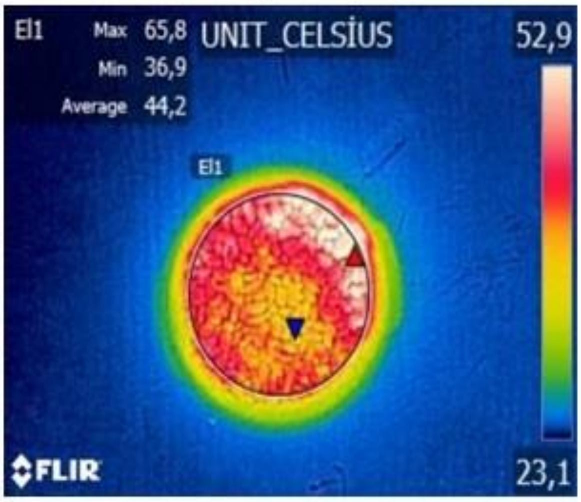
When compared the change of HR and HPI values, it is clearly seen that HPI values are more sensitive to electrode gap. This represents that heating performance of the system increases more severely than the decreasing of HR values. This result may be important for the processes which the HR has constraints. Fig. 5 shows the thermal images of the specimens. These thermal images include the maximum, minimum and average temperature values of the heated top surfaces of the specimens. According to these values, the temperature of the edges of the specimens is higher than the central areas of the specimens. This causes the deterioration of the heating uniformity, therefore, the efficiency of the oven.



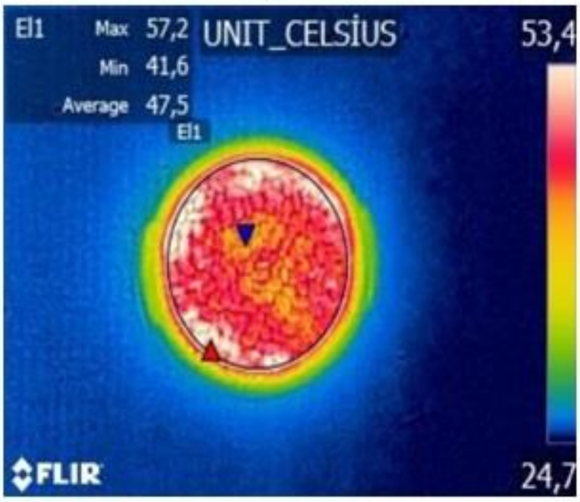
20mm height- 65mm EG



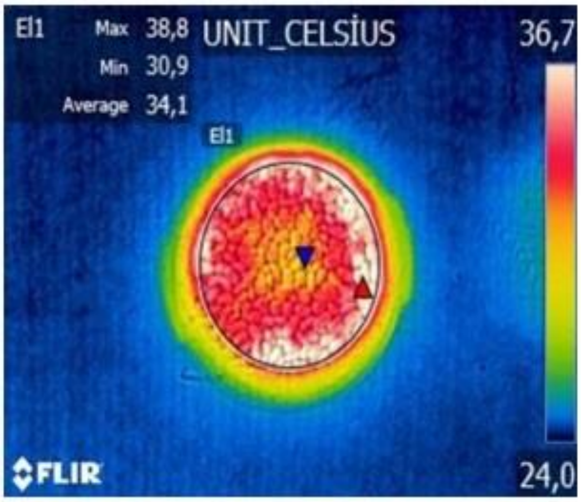
40mm height- 65mm EG



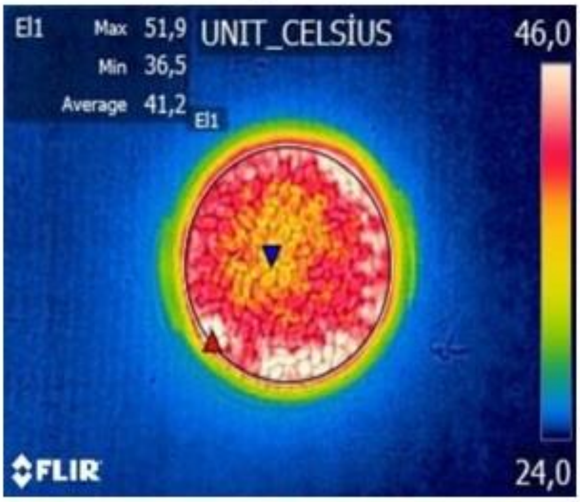
20mm height- 75mm EG



40mm height- 75mm EG



20mm height- 85mm EG



40mm height- 85mm EG

Figure 5. Thermal images of the specimens for three EG and two heights bean specimens.

4.Conclusions

Heating uniformity is an important parameter for evaluation of the heating performance of the RF heating system. An index called HPI has been proposed for determine the heating performance of the RF system. By using this index, the heating performance of the bean specimens were observed. According to results, the heating non-uniformities were detected and quantified. This non uniform heating is caused by overheating of the edges of the specimens. Further studies should be performed to improve the heating uniformity.

5.Acknowledgement

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