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# Heating Performance Assessment of Domestic Microwave Ovens

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# HEATING PERFORMANCE ASSESSMENT OF DOMESTIC MICROWAVE OVENS

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## ABSTRACT

Due to inherent nature of standing wave patterns of microwaves inside a cavity and dielectric properties of different components in a food, microwave heating leaves non-uniform distribution of energy inside the food volumetrically. Achieving heating uniformity plays critical role in improving the safety of microwave heated products. In this paper, we present a method for assessing heating uniformity within domestic microwave ovens. A custom designed container was used to assess heating uniformity of a range of microwave ovens using IR camera. The study suggested that the best place to place food in a microwave oven is not at center but near the edge of turntable.

**Keywords:** Non-uniform heating, Food safety, Image processing, Temperature variation

## INTRODUCTION

Microwave (MW) heating is rapid but non-uniform. The issue of non-uniform heating is exasperated in frozen foods due to dramatic differences in dielectric properties of ice and liquid water. Many frozen food products are not-ready-to-eat, meaning that they may contain pathogens. Expectation is that the final cooking/heating step in the microwave oven assures food safety. Due to non-uniform heating, part of the frozen foods may not be heated adequately (165°F to kill *Salmonella*) in microwave ovens. The foodborne pathogens, if present in the cold spots, would survive and cause foodborne illnesses. Improvement in microwave heating uniformity has been a real challenge to both microwave cavity designers and food product development scientist. Vadivambal et al (2010) reviewed various studies on microwave heating and suggested a research need to improve heating uniformity. Improving heating uniformity of a microwave food product can be achieved by modifying food composition and geometry (Ryynänen et al. 1996). In past two decades, many serious efforts have been made by researchers to understand the phenomenon and come with solution to overcome non-uniform heating (Geedipalli et al. 2007; Rakesh et al. 2009; Bradshaw et al. 1997). Many studies have been conducted to understand and improve non-uniform heating experimentally and through computer simulation (Wäppling-Raaholt et al. 2006; Knoerzer et al. 2007). The efforts vary from pure empirical methods to complicated computer modeling software. These approaches need to be validated using experiments.

Historically wet thermal fax paper has been used in demonstrating MW heating non-uniformity in domestic oven (Bradshaw et al. 1997). The problem with this approach is that one has to use it in an empty cavity. Presence of food product will alter the electromagnetic field and therefore the severity of heating non-uniformity. Moreover, it does not provide quantitative assessment of heating uniformity. Commercially, there are microwave active compositions (Atlanta Chemical Engineering, Atlanta, GA) available that changes color depending upon temperature. Depending on the type of colorant used in the composition, it loses or gains color at certain spots under microwave irradiation. Response time of the colorant to change in temperature is short and the spots are well-outlined. The major limitation of this approach is that it is not quantitative.

Recently, chemical marker technique has been used in locating hot and cold spots and assessing MW heating uniformity in sterilization process validation (Pandit et al .2008). To quantify the color change, the authors developed a computer vision system to measure the temperature inside a model food product.

James et al. (2002) developed a methodology for assessing the heating performance of domestic microwave ovens using a set of quick response thermocouples. Swain (2008) developed a test procedure to characterize the performance of domestic microwave ovens for heating of chilled ready meal. They used a model food made of TX151 powder (Weatherford, Aberdeen, Scotland), a hydrophilic polymer and an array of 39 quick response thermocouples to study the heating performance of domestic microwave ovens.

For measuring performance of domestic oven, IEC 60705 standard suggests to use square container (228mm×228×30 mm) made of material transparent to microwaves (IEC, 2006). Wang et al. (2008) designed a test rig consists of an array of 24 plexiglass cups filled with water and array of 24 thermocouples to asses heating uniformity in a radio frequency heating system. They also used a foam sheet to evaluate heating uniformity of the radio frequency system using an infrared camera. Thermal imaging is an industry standard tool for assessing heating uniformity of product at the end of the heating process.

Our long-term goal is to develop a comprehensive risk assessment model to assess the food safety risk of consuming microwaveable foods. The risk assessment model takes into account of the variation in microwave parameters (power, location of food inside the oven), food composition, layout and its properties, microbial parameters (death kinetics parameters), and consumer behavior (cooking time, standing time, dose-response curve). This study is conducted to assess the variability of microwaves distribution within a cavity and how placement (location) of a food in the turntable affects the heating rate and uniformity. Therefore, the objective of this study is to assess the variation of microwave distribution within a cavity in a range of domestic microwave ovens. Specific objectives of this study are to:

1. Assess the microwave energy distribution within the cavity along the radial direction.
2. Assess the overall heating uniformity within the cavity for ovens of various power wattage.

As turntable is used to rotate the food in most of the domestic microwave ovens, there should be a minimal variation along the various sectors within the cavity and therefore is not assessed.

## MATERIALS AND METHODS

### *Experimental procedure*

As the objective is to study the variation of microwave distribution within a cavity, we used water as a sample food whose dielectric properties are well known. To get spatial distribution of microwave energy absorption by water, a round container (300 mm × 100 mm) made of polypropylene was designed with 36 equal volume compartments. The compartment was made with 2 mm thick a polypropylene strips, which absorb negligible amount of microwave energy compared to water. This plastic also acts as an insulator and minimizes heat transfer between the compartments (Figure 1). The design of the compartment ensured that the surface area of the compartments were same. By measuring the temperature of water in each compartment after microwave heating, we can estimate the microwave energy distribution within that location of the cavity. The top edge of the partition walls was painted with black paint to provide contrast between the compartments in a thermal image.

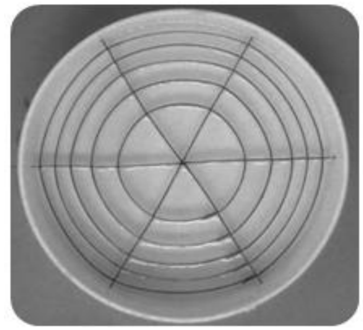

Fig. 1.Container for heating uniformity assessment

The designed container was used to assess heating uniformity in 16 microwave ovens. Microwave ovens were selected with the power output ranges from 700 W to 1300 W. One liter of water was weighed and poured into the container. There are small gaps at the bottom of the plastic strips that separated compartments, which allowed for water to distribute evenly to all compartments. This ensures that each compartment has the same volume of water. Initial temperature of the water was recorded using infrared (IR) imaging camera (FLIR thermal camera Systems, Inc. Boston, MA), which has a resolution of 480 x 640 pixels. The water filled container was placed at the center of turntable and subjected to heating for 2 min. Immediately after heating, the container was removed and a thermal image was acquired using the IR camera to record the final temperature of water in the container. All the steps followed for collecting IR images are shown in shown in Fig 2.

### *Image processing*

To determine the mean and standard deviation of temperature within each of 36 compartments in the container, image processing routines were developed in Matlab (Mathworks Corp, Natick, MA) software. Simple thresholding was not able to correctly separate all 36 compartments. Then, Hough transform algorithm, a special function in image processing toolbox for detecting lines and circles in an image, was used to segment the compartments. In the Hough transformed image, the coordinates of lines, centroid of the image, and radius of the circles were extracted. Using the extracted information, a binary image

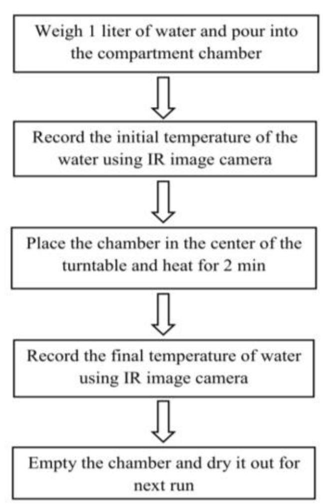


Fig.2. Experimental procedure

was created in which lines and circles were drawn with a value of zero, while the inside of the compartments has gray-level of 1 and the background with 0. The IR image was then multiplied pointwise (pixel-by-pixel) with the binary image.

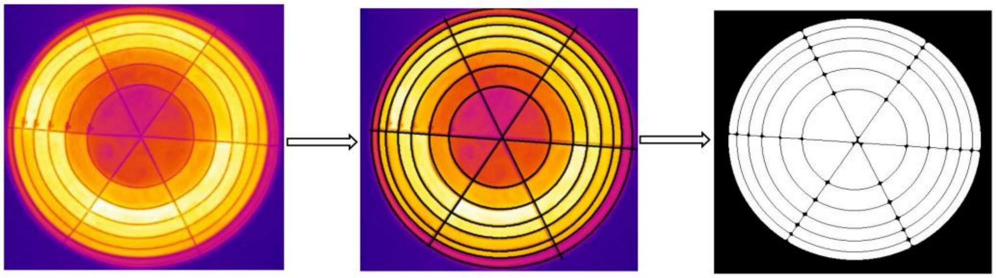


Fig. 3. Process of converting original IR image into binary image

A morphological blob analysis operation (Gonzales and Woods, 2008) was conducted on the resultant image to identify all the compartments. Then, mean and standard deviation of the temperatures in each compartment were calculated and saved in a text file for further analysis.

### *Measure of heating uniformity*

Coefficient of variation (COV) is used as a measure of the non-uniform heating in a normalized scale (equation 1). The dimensionless number, COV, describes variation (standard deviation) in a data set in the context of the mean of the data.

$$C_v = \frac{\sigma_t}{\mu_t} \quad \text{Eq. } (1)$$

$C_v -$ Coefficeint of variation

$\sigma_t -$ standard deviation of temperature variation in an individual compartment

$\mu_t -$ mean temperature in an individual compartment

## RESULTS

A total of sixteen microwave ovens are grouped into three categories based on their rated power level as shown in Table 1.

Table 1 Classification of microwave ovens based on rated power

| Low power | Medium power | High power |
|---|---|---|
| 700-1000 W | 1050-1100 W | 1200 -1300 W |
| 7 | 4 | 5 |

### *Effect of radial distance on average temperature rise and COV*

We studied the effect of radial distance on temperature variation within a cavity for all the three categories of the microwave ovens. The temperature was averaged over the entire individual ring to study the effect of radial distance on temperature rise. Fig. 4 shows a general trend in all three categories of the ovens tested in this study. The average temperature of water in central ring rose in range of 10-15°C whereas in outmost ring temperature reached in range of 20-30°C. It clearly explains that when the food item placed on the edge of the turntable, it will heat faster than when it is placed on the center of the turntable.

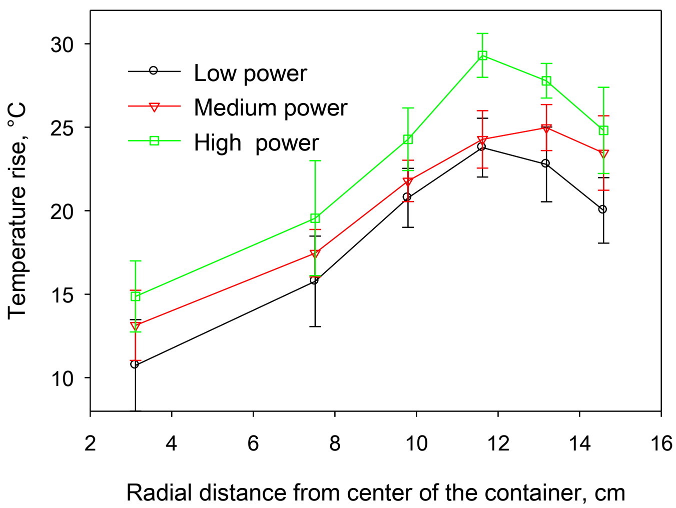


Fig. 4. Effect of radial distance on average temperature rise in low, medium and high power microwave ovens

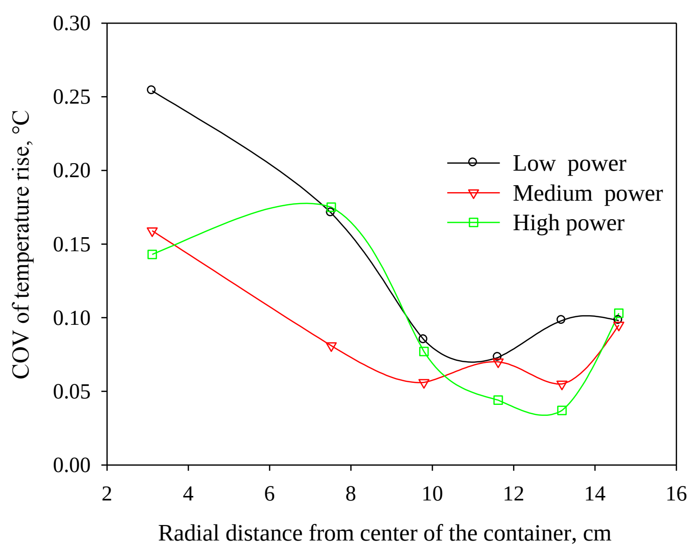


Fig. 5. Effect of radial distance on coefficient of variation of temperature rise in low, medium and high power microwave ovens

It is interesting to note a trend in Fig. 5 that coefficient of variation decreases as the radial distance increases. This indicates that, the variation in tempartures within the load when placed at the center is higher than the variation in temperature of the load when placed on the edges. Thus, it is extremely beneficial to place the load the edge of the turntable, because it not only receives more electromagnetic energy and heats faster, but also the heating uniformity is better.

## DISCUSSION

A quick and reliable heating uniformity assessment method was developed. For two minutes of heating 1-liter of water load in microwave oven, the temperature rise ranged from 10 ºC at the center of the cavity to 28 ºC at the edge of the turntable. Just for 2 minutes of heating, the temperature difference can be as high as 18 ºC. It was found that water will get more uniform heating in edge of the turntable rather than center of the turntable while allowed to rotate the compartment container. Thus, it is better to place the food at the edge of the turntable rather than at the center of the turntable for rapid and uniform heating. The developed test method can be used for performance testing of range of microwave ovens.

This study was conducted with the water load that covered most of the turntable surface and came up with the recommendation to place the food at the edge of the turntable. However, when the food (load) is placed on a small location within a cavity, the distribution of electromagnetic field changes. Therefore, further studies must be conducted with small water load placed at various radial distance and asses the heating rate and heating uniformity.

## ACKNOWLEDGEMENTS

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## REFERENCES

Bhuwan Pandit R., Tang J., Liu F., & Mikhaylenko G. (2007). A computer vision method to locate cold spots in foods in microwave sterilization processes. *Pattern Recognition*, 40(12), 3667-3676.

Bradshaw S., Delport S., & Van Wyk.E. (1997). Qualitative measurement of heating uniformity in a multimode microwave cavity. *Journal of Microwave Power and Electromagnetic Energy*, 32(2), 87-95.

Geedipalli S., Rakesh V., & Datta A. (2007). Modeling the heating uniformity contributed by a rotating turntable in microwave ovens. *Journal of Food Engineering*, 82(3), 359-368.

James C., Swain M.V., James S.J., & Swain M.J. (2002). Development of methodology for assessing the heating performance of domestic microwave ovens. *International Journal of Food Science & Technology*, 37(8), 879-892.

Knoerzer K., Regierb M., & Schubertb H. (2007). A computational model for calculating temperature distributions in microwave food applications. *Innovative Food Science & Emerging Technologies*, 9(3), 374-384.

Rakesh V., Datta A.K., Amin M.H.G., & Hall L.D. (2009). Heating uniformity and rates in a domestic microwave oven. *Journal of Food Process Engineering*, 32(3), 398-427.

Ryynänen S., Ohlsson T. (1996). Microwave heating uniformity of ready meals as affected by placement, composition, and geometry. *Journal of Food Science*, 61(3), 620-624.

Ryynanen S., Risman P.O., & Ohlsson T. (2006). Hamburger Composition and Microwave Heating Uniformity. *Journal of Food Science*, 69(7), 187-196.

Swain M.J., Spinassou A., & Swain M.V.L. (2008). A test procedure to characterize the heating performance of domestic microwave ovens. *International Journal of Food Science & Technology*, 43(1), 15-23.

Vadivambal R., Jayas D.S. (2010). Non-uniform temperature distribution during microwave heating of food materials-A review. *Food and Bioprocess Technology*, 3(2), 161-171.

Wang S., Luechapattanaporn K., & Tang J. (2008). Experimental methods for evaluating heating uniformity in radio frequency systems. *Biosystems engineering*, 100(1), 58-65.

Wäppling-Raaholt B., Risman P.O., & Ohlsson T. (2006). Microwave heating of ready meals – FDTD simulation tools for improving the heating uniformity. In : M.Willert-Poprada (Ed), *Advances in microwave and radio frequency processing.* pp. 243-255. Springer Berlin Heidelberg.

Rafeal C Gonzalez.,Richard Eugene Woods.(2008). Digital image processing. Pearson education, INC