Performance Comparison Between Batch and Continuous Thawing of Food Products Assisted by Radio Frequency Heating

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Radio frequency (RF) assisted heating of foods is an established technique used in food processing such as postharvest treatment of in-shell fruits, drying of food materials and products. More recently, it has been proposed as industrial solution for continuous tempering of frozen meat blocks. In the last years, scientific literature has shown interest on using RF heating to enhance food thawing prior to further processing or consumption, due to the possibility to reduce processing time, raise the power efficiency of the thawing process, and eventually provide better quality and safety of the thawed product.

The purpose of this study was to evaluate the performance between batch and continuous thawing of food products assisted by RF heating. A pilot scale RF system with 27.12 MHz and 6 kW used to thaw 1.2 kg block of minced lean beef meat and to evaluate the performance under different conditions. The results showed that continuous RF thawing slightly improved the heating uniformity and relatively uniform heating rate compared to batch system under the same process conditions. End point temperatures of -0.2°C ± 1.5 and -0.4°C ± 0.7 were achieved at the center of the sample in 17 min thawing time using batch and continuous conditions, respectively. These comparison results may provide detailed performance information to optimize and design processing parameters and, to promote further practical applications of RF heating in food processing industry.

1. Introduction

Freezing operation is one of the most widely used methods to preserve food products for extended shelf life. It can also be used in preservation of raw materials during transportation and storage. Before consumption or further processing activities, frozen products, such as meat, poultry and seafood, need to undergo tempering (-5ºC to -2ºC) or thawing procedures (-2ºC to +5ºC) using safe and fast methods. Thawing should be performed in a way that maintains the characteristic properties of the food product. The US Food and Drug Administration (FDA) recommends thawing methods in refrigerated environment (at temperature of 5ºC or less), or completely submerging the frozen food to be thaw under running water at temperature of 21ºC or below (FDA Food Code, 2013). FDA Food Code (2013) explicitly mention the possibility to use microwave (MW) assisted thawing as a part of cooking process, with no references to any other process assisted by electromagnetic fields at high frequencies, as radio frequency (RF) processing at 27.12 MHz is. However, recommended conventional thawing methods need long processing time and, in case of thawing under running water, a considerable amount of water resource wasted. Thawing by itself is a slow process due to its constituent of various dissolved components, and takes place gradually over a range of temperature (Chamchong and Datta, 1999). The demand for fast and safe thawing methods increased with need for high quality food products and strong need for shelf-stable ready to eat foods. RF assisted tempering and thawing of those frozen products have great potential to reduce the quality loss encountered in slow conventional processing methods (Farag et al., 2011). RF treatment is a fast and volumetric heating, due to a direct interaction of electromagnetic field within food materials. The RF generator creates an alternating electric field between two electrodes; and when the food material placed between them, the free ions and dipoles present

in the food sample are displaced and attempt to follow charges (Marra et al., 2009). Thanks to its rapid and volumetric heating behaviour, it is also possible to achieve thawing in minutes rather than hours or days with minimized risk of product degradation (Farag et al., 2011; Uyar et al., 2015). It has been reported that RF thawing was able to reduce thawing time in 3-folds with respect to natural convective thawing (Uyar et al., 2015). Furthermore, RF thawing can be performed in both batch and continuous modes and it can also be carried out inside the packaging materials, such as carton boxes and polyethylene bags. In batch mode, food product is placed at the center of bottom electrode while in the case of continuous mode, the food product is placed on belt conveyor and transferred through the tunnel from right to left side passing through two electrodes. Continuous processes in food industries generally improve the economy of mass production and the quality level of the final products can be maintained within a relatively small range. In meat processing, emulsion type of sausages for manufacturing of heated meat products use continuous processing. Houben et al. (1991) reported that sausage products heated in continuous RF system had a good appearance, smooth surface and did not show moisture or fat release.

Recently, significant experimental and numerical studies have been reported on the application of RF thawing to frozen products (Bedane et al., 2017; Farag et al., 2011; Llave et al., 2016). It is one of the most rapid thawing methods in food industries with reasonable processing time and its ability to heat large sized food products. However, the performance of this method depends on various factors, such as shape, size, composition and physical configurations of RF equipment. Furthermore, the mode of operation, either in batch or continuous, also affects the temperature distribution and heating rate in the food sample. Moving the food product under the top electrode where electric field intensity distribution was not uniform, resulted in varied power absorption within the food product (Chen et al., 2015). Bedane et al. (2017) reported in their recent work that thawing of meat blocks on moving conveyor belt slightly improved heating uniformity. RF disinfestations of agricultural products, such as rice (Zhou and Wang, 2016), legumes (Wang et al., 2010) and wheat (Chen et al., 2015) on conveyor belt have also been reported. During thawing, it is necessary to understand the different phenomena that occur inside the RF cavity and the product by itself. It is also important to consider the balance between thawing time, safety of the food and the energy usage in order to select proper processing system. The objectives of this study were therefore to compare temperature-time histories, heating rate and heating uniformity during batch and continuous RF thawing of lean beef.

2. Materials and methods

2.1 Sample preparation

The lean beef meat block used in this study was prepared in a rectangular plastic container having internal dimensions 19 x 12.5 x 5.5 cm^3 (Figure 1) and weight of 1.2 kg. The meat was sorted manually before it was minced and filled in a plastic container using stage by stage tamping to avoid entrapped air. Then, the meat blocks were frozen in refrigerator (-20 ºC) for 24 h prior to thawing experiments. Detail sample preparation can be found in Bedane et al. (2017).

2.2 RF equipment and thawing procedure

A 6 kW, 27.12 MHz parallel electrode, free running oscillator RF equipment (COMBI 6-S, Strayfield International Limited, Wokingham, UK), available at College of Mechanical and Electronic Engineering, Northwest A&F University in Yangling (China), was used to thaw the frozen lean beef meat blocks. The RF equipment consists of an adjustable top electrode (9 cm to 19 cm), conveyor belt working at speed between 1 m/h to 60 m/h with a hot-air heating system (Figure 2). The hot-air heating system was not implemented in this experiment. Thawing of frozen lean beef blocks were performed in two ways; stationary (sample placed between two electrodes at the center of the bottom electrode) and moving condition (the sample placed on belt conveyor and transferred through the tunnel from right to left side passing through two electrodes). During batch thawing, the heat generated inside the food product depends on the gap between electrodes and heating time. For the case of continuous thawing, speed of conveyor belt and time were the main factors in addition to the gaps between electrodes. The effect of electrode gap on heating uniformity was assessed in preliminary experiments in order to select an optimum gap. Electrode gap of 10 cm was chosen and speed of belt conveyor was calculated by dividing length of top electrode (0.83 m) by time achieved during batch thawing of lean beef blocks. Three different speeds of conveyor belt (2.5 m h^{-1}, 3.0 m h^{-1} and 3.5 m h^{-1}) were tested and the effect of speed on heating uniformity was investigated.
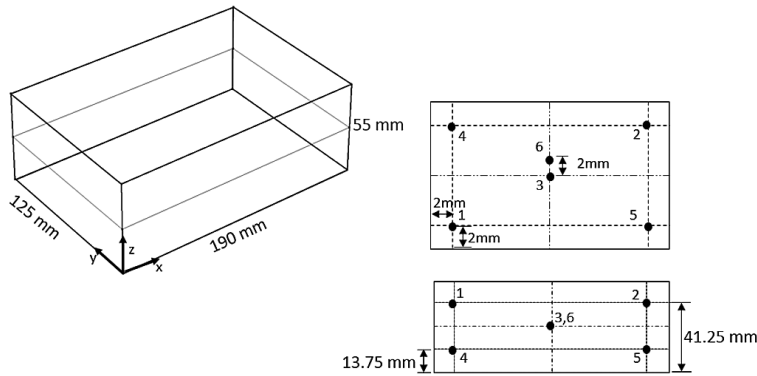
Figure 1: Dimensions of lean beef meat block and positions of temperature measurement
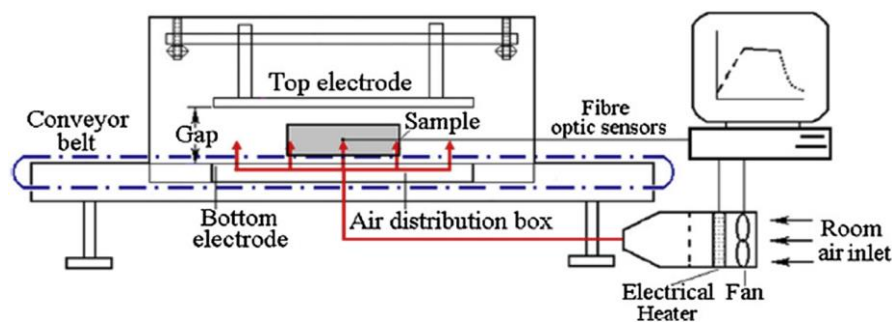

Figure 2: Schematic view of RF equipment with conveyor belt and electrodes (adapted from: Zhou et al., 2015)

2.3 Temperature measurement and analysis

The surface temperature distribution and the temperature evolution at selected points were recorded using IR camera (DM63-S, DaLi Science and Technology Co., LTD, Zhejiang, China) and a six-channel fiber-optic temperature sensor system (HQ-FTS-D120, HeQi Technologies Inc, Xi'an, China) respectively. The surface temperatures were collected and analysed using image analysis system (V1.0, DaLi Science and Technology Co., LTD, Zhejiang, China) while temperature-time histories were recorded using data logger (FTS-P104, Xi'an HeQi Opo-Electronic Technology Co., LTD, Shaanxi, China). Average temperature-time histories and standard deviations on top, middle and bottom were calculated and used to compare temperature distribution and heating uniformity.

2.4 Performance comparison of RF thawing methods

The performance of the RF thawing methods can be evaluated using uniformity of temperature distribution, the difference between hot and cold spots, heating rate and heating uniformity index. Uniformity index can be calculated as:

$$\lambda = \frac{\Delta \sigma}{\Delta T_m} \tag{1}$$

where $\Delta \sigma$ is rise in standard deviation (°C) and rise in average temperature, ΔT_m (°C). Uniformity index was calculated at the top, middle and bottom parts of the food product thawed by both batch and continuous thawing modes for different electrode gap and speed of conveyor belt. The smaller the value of uniformity index, the better the heating uniformity. This method has been successfully used to evaluate heating uniformity in RF treated agricultural products (Zhou et al., 2015; Zhou and Wang, 2016).

3. Results and discussions

3.1 Temperature-time histories

The comparison between average temperature-time histories at top, center and bottom portions of lean beef block thawed using batch and continuous RF thawing modes is shown in Figure 3. The temperature rise at the beginning of the process can be observed in both thawing modes. However, slow rise in temperature can be observed in continuous thawing with respect to batch one. The phase change occurs faster at top and bottom portions than at the center of the food product. The temperatures at the top and bottom were higher while remained lower at center even after complete thawing. Approximately 3 min and 2 min heating time were required to achieve complete thawing on the top and bottom sections of lean beef block thawed by batch and continuous modes, respectively. This could be due to the fast melting of ice crystals covered the surface of the meat blocks. On the other hand, the slower rise of temperature in continuous thawing with respect to batch one could be due to the fact that the food product enters to the area of high electric field gradually.
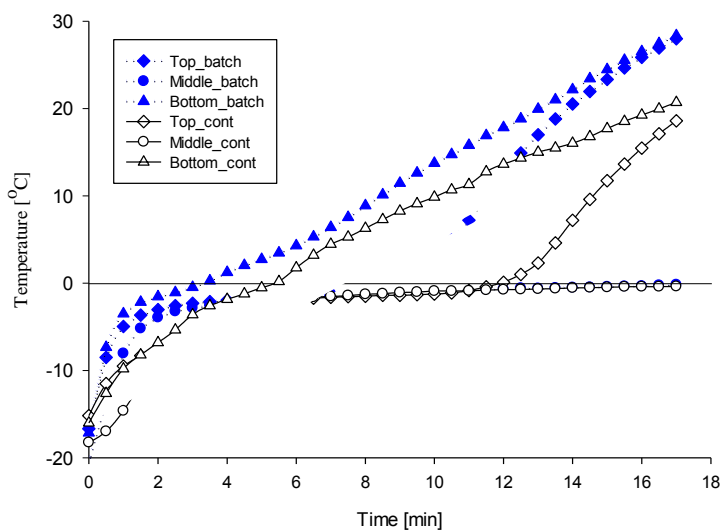

Figure 3: Temperature-time histories during lean beef meat thawing using batch and continuous RF thawing (10 cm electrode gap, 27.12 MHz, 6kW)
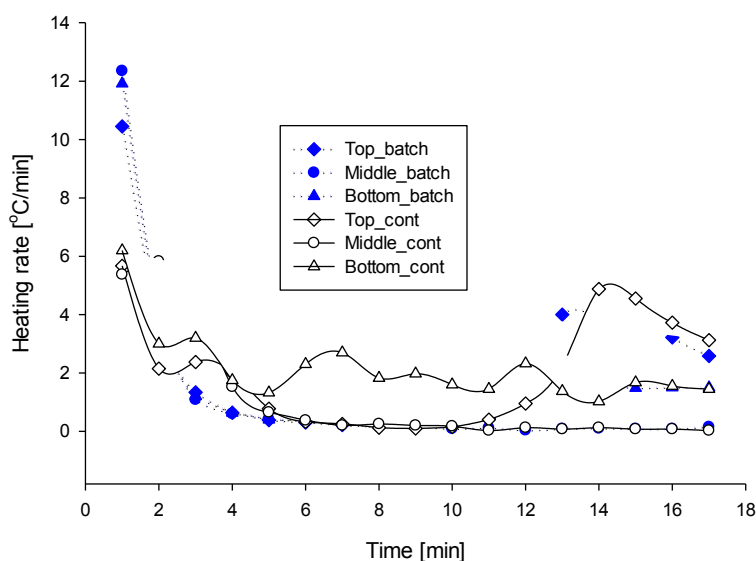

Figure 4: Average heating rate [ºC/min] at different sections of lean beef meat block during batch and continuous RF thawing at 27.12 MHz.

As shown in Figure 4, the average heating rates were higher at the beginning and tended to decrease as thawing process progressed. During thawing, the properties of food product (thermo-physical and dielectric properties) change dramatically with temperature. This phenomena cause differences in electric field distribution and power absorption during the process (Llave et al., 2015). Higher average heating rates of 10.5, 12.4 and 11.9 ºC/min for the batch thawing and 5.7, 5.4 and 6.2 ºC/min for continuous thawing were observed during the first minute heating on the top, middle and bottom sections of the sample, respectively.

Table 1: Maximum, minimum and average temperatures (ºC) with standard deviations (ºC) of the lean beef sample thawed in batch and continuous mode using 10 cm electrode gap

	Batch		2.5 mh^{-1}		3.0 mh^{-1}		3.5 mh^{-1}	
	Max/min	$T_m \pm$ SD	Max/min	$T_m \pm$ SD	Max/min	$T_m \pm$ SD	Max/min	$T_m \pm$ SD
Top	35.6/21.7	28±5.5	37.9/20.1	28.2±7.9	22.6/13.6	18.6±3.9	22.5/2.0	12.8±7.5
Middle	2.8/-1.1	-0.2±1.4	1.9/-0.9	0.7±1.1	0.8/-0.9	-0.4±2.0	-0.9/-1.3	-1±0.2
Bottom	39/17.8	28.4±8.4	38.8/12.2	24.8±12.6	37.9/6.3	20.7±12.1	30.5/6.7	13.1±0.1

Table 1. provides the comparison between maximum, minimum and mean temperatures with standard deviations after 17 min during batch and continuous RF thawing of lean beef block. The maximum temperatures, which were pronounced on the top and bottom sections of the sample, tended to decrease in continuous thawing with the increase of conveyor belt speed. However, the increase in temperature at the middle section of the product was not changed significantly. Therefore, allowing the food product to move on conveyor belt along the electric field area could improve the heating uniformity.
From the continuous experiments, it can be observed that increasing the speed conveyor belt improved the heating uniformity across the food product. Average temperatures of 12.8±7.5 ºC, -1±0.1 ºC and13.1±0.1ºC were achieved at top, middle and bottom sections, respectively, after heating time of 17 min for continuous RF thawing. This indicates that thawing can be achieved with improved temperature uniformity, since the final temperature at the geometric center of the food product is in the thawing temperature range (-2ºC to +5ºC).

3.2 Comparison of heating uniformity

Table 2 shows uniformity index (λ) calculated on top, middle and bottom sections of lean beef subjected to RF thawing batch/stationary at different electrode gaps and continuous thawing at different speed of conveyor belt. Heating uniformity allows to quantitatively compare the quality of thawing using different conditions. The results confirmed that overheating on the surfaces of the sample reduced as the gap between electrodes increased during batch thawing of lean beef meat block. The smaller the distance between top electrode and food product, the faster the heating and the higher the risk of over-heating (Uyar et al., 2014). Electrode gap of 10 cm showed better uniformity among all gaps used in the experiment. Results from continuous thawing indicated that heating uniformity significantly improved on top and middle sections while slight change observed at the bottom. Similar strategy has been used to improve heating uniformity during RF heating of agricultural products (Zhou et al., 2015; Zhou and Wang, (2016).
The effectiveness of improving heating uniformity using thawing food products on moving conveyor belt could be further improved by combining previously proposed strategies. Placing the food product in container made up of materials such as polyurethane foams (Wang et al., 2014), polyetherimide (PEI) (Jiao et al., 2015) and polystyrene (Huang et al., 2016) have been tested to improve heating uniformity during RF treatment of low moisture agricultural products. Those techniques could be combined with the hot air assisted heating associated with RF systems in order to mitigate the problems of overheating on the corners and surfaces of the food product.

Table 2: Comparison of heat uniformity index (λ) during batch (at different electrode gap) and continuous (at different speed of conveyor belt) RF thawing of lean beef meat block

Electrode gap (cm)	Top	Middle	Bottom	Speed (m/h)	Top	Middl3	Bottom
9	0.52	0.09	0.62	2.5	0.18	0.01	0.30
10	0.12	0.03	0.18	3.0	0.11	0.02	0.33
11	0.21	0.01	0.34	3.5	0.25	0.01	0.33

4. Conclusions

This study compares the performance of batch and continuous RF thawing of lean beef meat block based on temperature-time histories and heating uniformity. The results demonstrated that effects of electrode gap on heating uniformity were significant, indicating that small electrode gap resulted in non-uniform thawing. RF thawing on moving conveyor belt slightly improved heating uniformity with minimized difference between hot and cold spots with respect to batch. The comparison results my provide insights on performance information of the two RF thawing modes and help to choose desired operation mode in food processing industry.

Acknowledgments

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