**PS4.03 Electro-processing of meat and meat products: ohmic and radiofrequency applications** 264.00

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***Abstract*—Radiofrequency (RF) and ohmic heating (OH) are technologies with the potential to accelerate heat processing of meats to the extent that continuous pasteurisation of large diameter products becomes a reality. This paper will introduce RF and OH and will provide an overview of the issues we encountered in optimising their application to the cooking of meats. Overall, when the quality of RF/OH cooked meats was compared to conventionally heated, in many products, quality differences were not detected. Where differences were noted they were generally subtle with no definite trends and it is most likely that these were due to discrepancies in the extent of heating rather than the heating mechanisms per se. Results suggest that both technologies are certainly capable of producing meat products that are of comparable quality to conventionally cooked samples while non-comminuted meat products are likely to have a higher yield compared to conventionally cooked samples.**

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***Index Terms*— cooking, ohmic, quality, radio frequency.**

## I. INTRODUCTION

ELECTRO-HEATING encompasses heat processing operations in which electrical energy is either directly or indirectly converted to heat within a product. In terms of meat and meat products, the main research focus has been on technologies which either use electrical energy directly (e.g. OH where electrical current is passed directly through a product) or indirectly (e.g. microwave or RF heating in which electromagnetic radiation interacts with a product leading to heat generation). Large diameter products (e.g. ham) account for the greatest share of the cooked meats market. Pasteurisation of such meats by conventional means is slow as heat transfer within the product is conduction based. It is necessary to leave the product in the heating media for a relatively long time for the interior to reach an appropriate temperature. Meanwhile, the outer surface of the product will be at this high temperature for a relatively long period of time which can lead to overheating in this region. The aforementioned forms of electro-processing can be used for rapidly heating such products, though OH and RF have an advantage over microwaves which can have poor penetration in thicker products. Successful commercial applications for RF include thawing of products such as meat and post bake drying of biscuits while OH has been used for pasteurisation or sterilisation of pumpable liquids with suspended solids. A number of research groups have evaluated the potential for OH and RF in meat pasteurisation. Our group at UCD has made a significant contribution to this research and the objective of this paper is to give an overview of our findings in this regard.

## II. MEAT PASTEURISATION

By cooking meat we inactivate microorganisms and induce certain chemical reactions in the product which change its flavour, colour and texture. Appropriate combinations of time and temperature are required to optimise microbial kill and promote chemical reactions which result in the most desirable sensory properties. It is possible to estimate the extent of chemical and microbial changes in a product from time temperature profiles using cook values (Cs) (chemical) and pasteurisation units (PU) (microbiological). However, the Irish meat industry tends to follow guidelines issued by the Food Safety Authority of Ireland specifying that the “cold spot” of a product should be heated to a temperature of ≥70°C for 2 min or equivalent.

### *A. RF pasteurisation of meat*

With RF cooking heat is generated internally within the product predominantly by ionic depolarisation. Meat products have a certain amount of ionic compounds present naturally while others are added during manufacture. These ions are dispersed through the product relatively uniformly. When the latter is placed between (but not touching) a pair of parallel electrodes in an RF oven an electrical field is produced. The net effect is that positive ions in the product move towards negative region of the field and vice-versa. Because this field is not static with polarity continually changing at relatively high frequencies (e.g. 27.12 MHz), heat is generated internally (thereby avoiding the thereby avoiding the centre vs. surface temperature lag) and linear time temperature profiles are the norm.

Bengtsson and Green [1] described a continuous pasteurisation method for cured hams whereby packaged hams, surrounded by water in sealed moulds, were passed on a conveyor belt through an RF heater.

This procedure shortened cooking times by 1/3, reduced juice losses and improved ham quality. Other research [2,3,4] described a continuous RF pasteurisation system for sausage emulsions pumped through a tube surrounded by demineralised water. These workers found heating rates of up to 40°C $min^{-1}$ (vs. 1°C $min^{-1}$ for conventional). Microbial analysis suggested that the RF treatment was at least comparable to conventional while the product had a good appearance and taste. Orsat et al. [5] RF cooked hams for 10 min at 75 or 85°C following which they were packaged. They reported that the RF treatments reduced bacterial load and improved shelf-life. Laycock et al. [6] pasteurized ground, comminuted and whole muscle meat products in an applicator cylinder constructed of PTFE. They found the highest power efficiency and shortest cooking times for ground beef. RF cooked samples had lower juice losses and also acceptable colour and water holding capacity but the texture of ground beef was chewy and elastic and the whole beef colour was considered inferior. The authors suggested that well mixed comminuted and ground meat products appeared to be the most promising for RF cooking. In a separate paper [7] these workers evaluated the effectiveness of RF cooking in the reduction of *Escherichia coli* in ground beef and showed that RF cooking had significant effects on reducing *E. coli* while also giving more uniform heating.

*B. Ohmic pasteurisation of meat*

Lyng and McKenna [8] have reviewed OH of meats. OH occurs when electrically conducting products such as meat are placed in contact with two or more electrodes and an AC current is applied. Generally low frequency (50 or 60 Hz) AC is used although recent work has also shown positive benefits in changing to higher frequency (4 or 10 kHz) bipolar pulses. While both OH and RF heat primarily through friction generated by moving ions, relative to RF heating, electrically induced changes in ion direction under OH are at least $10^3$ (vs. 10 kHz AC) and more commonly $10^6$ (vs. 50 Hz AC) times slower than RF (e.g. 27.12 MHz). This large time differential between the two techniques means ions generate heat while travelling further distances between polarity changes within an OH vs. an RF product.

## III. OH vs. RF: Application differences (meat)

*Electrode contact:*

Commercial cooked meat production generally involves packaging products in sealed casings or vacuum package bags prior to cooking which has the advantage of preventing post process contamination following cooking. RF waves can pass through such packaging, though the use of traditional metal clip seals should be avoided. In contrast, OH requires either direct contact between the meat and the electrodes (with sealing following cooking) or packaging the product in a specially designed package/container with conductive regions to allow current to flow through the product. An example of such packaging was described by Jun and Sastry [9].

*Penetration depth:* In OH, provided a product has sufficient conductivity to allow a current to flow, localized variations in temperature increase will not be caused by changes in the electrical field strength but will most likely be attributable to either localized composition differences (e.g. fat marbling) within the product or localized heat loss (e.g. from product surfaces), both of these factors having an impact on electrical conductivity. In contrast, RF heating like microwave heating requires the propagation of electromagnetic waves through a product. As these waves pass through foods they are absorbed and as a result their energy is reduced. A term known as the penetration depth (dp) is used to describe this phenomenon.

OH and RF could be applied to meats being pumped continuously through a tube. Our approach has always been to package the product in casings prior to cooking. With RF our initial aim was to RF cook encased products in air but an unanticipated problem that emerged was arcing/burning of casings. Subsequent investigations revealed that immersing encased products in circulating water (80°C) in polyethylene cells during RF heating prevented arcing while also allowing post RF cooking holding times. During OH the encased product was left open at the ends (to allow electrode contact). However, heat loss via cell walls and electrodes led to localised under-heating. A range of strategies was investigated and the best option for minimising temperature differential within the product was a combined OH/convection heating system. Uniform distribution of ionic ingredients during curing was also critical.

## IV. OH and RF: Microbial inactivation

Microbial inactivation occurs primarily via thermal methods. “Cold pasteurisation” via mechanisms such as selective heating of microorganisms, electroporation, mechanical cell membrane rupture and magnetic field coupling has also been claimed though mixed views of these theories can be found in the literature. Relative to OH, RF heating causes more rapid changes in polarity and it is believed that this does not allow the building of sufficient charges at the cell walls to induce electroporation [10]. Throughout our research only thermal inactivation was assumed and suitable steps were always taken to ensure commercial pasteurisation, verified on occasion by performing microbial challenge studies.

## V. OH AND RF: PRODUCT YIELD AND COMPOSITION

Product yield is a key commercial consideration. Figure 1 summarises a comparison of yield between RF and conventionally cooked samples from our results. In comminuted products no differences (P≥0.05) were noted between the RF and conventionally cooked samples. However, for the non-comminuted products RF cooking consistently gave higher yields than steam cooking. As products cook, proteins such as myosin and collagen denature and lose water. The observed result may be indicative of less heat induced protein denaturation (and associated water loss) in the more rapidly heated RF cooked products which manifests in higher yield. Figure 2 shows the average composition (RF vs. Steam) from the SH, LH, B-, and B+ meats. The trend is for RF cooked meat to have higher moisture content and lower protein and fat contents suggestive of a dilution effect. This appears to be consistent with yield results and the theory outlined above.

Much of the published work to date on OH has been on highly comminuted meats (e.g. emulsions) where yield differences are less likely. However, our recent work suggests that ohmically heated non-comminuted meats (cooked to comparable endpoint temperatures) follow similar trends to those for RF heated meats.

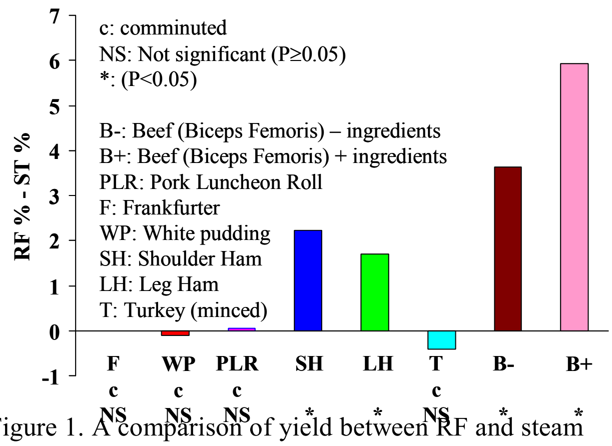


Figure 1. A comparison of yield between RF and steam (ST) cooked comminuted and non comminuted meats

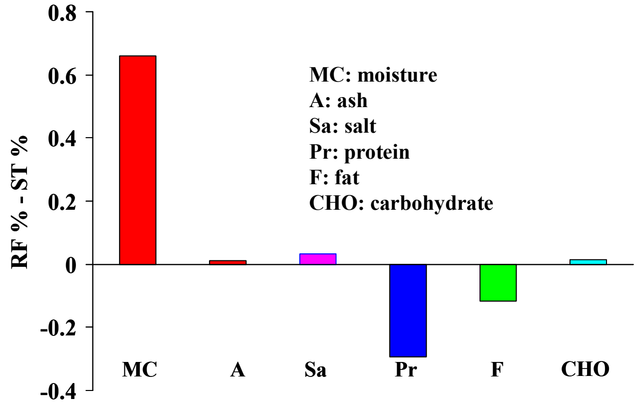


Figure 2. A comparison of proximate composition between RF and steam (ST) cooked non comminuted meats

## VI. OH AND RF: PRODUCT QUALITY

This section overviews UCD Dublin's findings on OH and RF cooked meat quality. It is important to emphasise that results presented are a summary of a large number of experiments.

*Texture:*

A range of instrumental texture measurement techniques have been used but only a small selection of results from texture profile analysis (TPA) will be presented. Figure 3 shows TPA hardness for RF cooked meats with each product denoted at the circumference (as in Figure 1). When the effect of cooking method is compared no definite trend emerges. RF and steam cooked F, WP, SH, T samples were not significantly different from each other (P≥0.05), in PLR and LH the RF cooked samples were harder (P<0.05) than steam cooked while for B the opposite was the case (i.e. steam cooked were harder than RF cooked (P<0.05)). Summarising the remaining TPA attributes (not presented), for cohesiveness, steam and RF cooked WP, PLR, SH, LH and T were not significantly different from each other (P≥0.05), in F and B-, RF cooked were higher than steam while for B+ the RF cooked was lower than steam. Similarly for springiness, no significant difference (P≥0.05) was observed between RF and steam cooked products except B+ where RF was slightly higher than steam cooked. For gumminess, no significant difference was obtained between RF and steam cooked F, WP, SH, LH and T, though in PLR RF had higher (P<0.05) gumminess than ST while for B+/- the RF cooked had lower gumminess than conventionally cooked. Finally for chewiness, significant differences were noted in

PLR (with RF being higher (P<0.05) than conventionally cooked) while for B+/- the RF was lower (P<0.05) than conventionally cooked. Overall, a number of points are evident from the texture of RF cooked meats including a lack of definite trends, few significant differences and where they do occur the magnitude is generally not large.

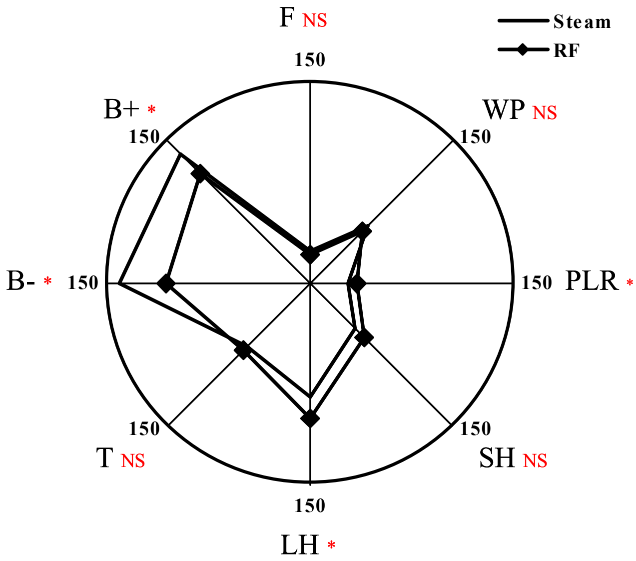


Figure 3. A comparison of texture profile analysis Hardness 1 results for steam and RF cooked meats

In terms of OH, a smaller range of products have been examined to date. Figure 4 shows the TPA attributes for a meat emulsion product cooked by steam or ohmically at 3 voltage densities (3, 5 and 7 V $cm^{-1}$). Overall the texture studies have revealed little evidence of significant differences between OH and conventional cooking.

*Colour:* The development of a cooked appearance is a key outcome of any heat processing operation for meat products. In meat it is largely the response of hemoproteins (particularly myoglobin) that determines cooked colour with the different forms of myoglobin differing in their sensitivity to heat [11]. It is believed that general protein precipitation is largely responsible for the lightening of meat on heating while the hue and chroma in cooked meats are primarily due to the nature of the haemoproteins present prior to cooking [12]. The lightness of meat increases during cooking up to temperatures of 80 to 85°C which is consistent with the myoglobin denaturation. A comparison of the L values of RF/OH vs. steam cooked meats across a wide range of experiments in the author's laboratories has shown the L values in RF/OH cooked to be virtually identical to steam cooked. One exception was a darker surface colour in steam cooked beef which is most likely due to chemical reactions in the outer regions of the product associated with longer exposure times to higher temperatures. In terms of hue angle and saturation/chroma and other colour

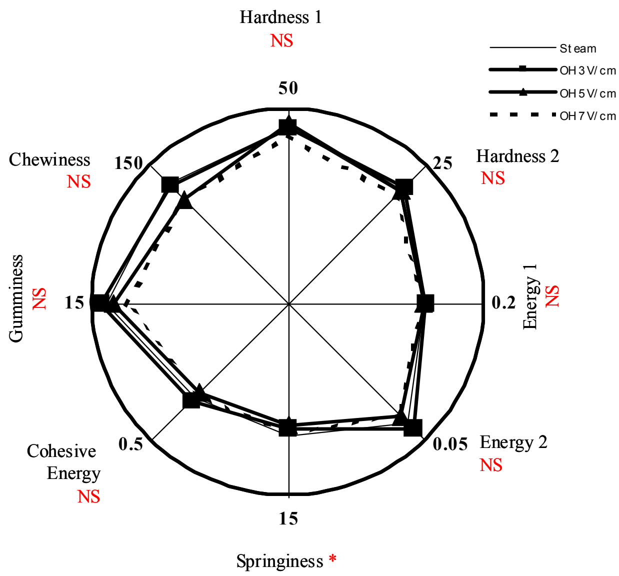


Figure 4. Texture profile analysis results for steam and OH meat emulsions heated to similar end point temperatures attributes no definite trends emerged one way or the other. In many cases no significant differences were noted. Early results, using a non-optimized OH system suggested colour differences consistent with a less well done appearance in meats cooked to similar end point temperatures particularly with more rapid ohmic heating protocols. However, when the cooking system was further developed and heat losses were reduced with appropriate holding times incorporated, these differences were no longer observed. Overall across all RF/OH experiments when colour differences did occur, they were minor.

*Flavour:*

Various analyses including GC and Tbars were conducted on some products. Some differences were noted though they were very slight and unlikely to have an impact on sensory perception. Rates of oxidation in beef and turkey were slightly less in RF compared to steam cooked but this difference was so small that it was unlikely to be detected by sensory analysis. No major qualitative differences were noted in sulphur volatiles in RF vs. steam cooked samples.

## VII. Conclusion

When product quality in OH or RF cooked meats was compared to steam cooked in many products/attributes no differences were detected. Where differences were noted they were generally subtle and it was not possible to tell whether these differences were due to the heating mechanism or the extent of heating. Results suggest that OH and RF cooking are certainly capable of producing meat products that are of comparable quality to conventionally cooked samples while non-comminuted meat products are likely to have a higher yield compared to conventionally cooked samples.

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