Project 12 CiMPAS team from left to right. Raul Cruz, Sowmya Kasturi, Rika Takeda, Marie-Laure Delabre, Kris Tong, Aswathi Soni. Jeremy Smith was off site

FIET Project 12 update

Coaxially induced microwave pasteurisation and sterilisation system - CiMPAS process development

Authors: Marie-Laure Delabre[1], Aswathi Soni [2], Sowmya Katsuri[1], Steven LeMoan[1], Emma Rouyer[1], Jeremy Smith[1], Rika Takeda[1], Raul Cruz[1] and Kris Tong[3]

[1] School of Food and Advanced Technology Massey University, [2] NZ AgResearch, [3] Foodscope

Overview of technology:

There is global demand for highly nutritional, lightly processed, pre-packaged food with long shelf life and faultless food safety credentials (1). Coaxially induced microwave pasteurisation and sterilisation (CiMPAS) is a rapid process, so that the food products are exposed to high temperatures for much shorter periods than in conventional retorting, whilst still receiving the necessary thermal treatment. This offers greater retention of thermally labile compounds and improved sensory and nutritional properties of the food products. Our technology partner is Muegge, a German manufacturing company with state-of-the-art expertise in microwave technology. Muegge are a subsidiary of Meyer Burger GmBH and have developed a microwave-induced thermal processing unit currently residing at Massey University in Palmerston North. The equipment is similar to a retort and consists of a pressure vessel that holds the pre-packaged food products under water. The "core" heating of the food products is achieved by a series of antennae that emit microwave energy into the packaged products. This means the product is heated and cooled quickly to as close to as square curve as can be managed.

Validation methods:

Any thermal process for food disinfection requires validation for each combination of food, package, process and equipment. For conventional retorting, approved validation methods are available – here, conductive and convective heat transfer into the food can be predicted, with the location of cold spots at the geometric centre of the pack. However, microwaves generate volumetric, selective and rapid heat within the food that is not completely uniform, creating hot and cold spots in less predictable locations. Validation of microwave thermal treatment of a new food is likely to be a difficult and long-winded process unless proven techniques are available to track the time-temperature history of each part of that food, lest it be the cold spot. Developing these validation techniques is the task of this FIET project, and MPI is its implicit customer.

The accurate measurement of time and temperature in microwave heating is far from trivial and requires both a basic understanding of microwave dielectric heating effects and use of appropriate temperature monitoring devices. Classic metallic temperature probes will interact with the electromagnetic field. This FIET project will validate multiple techniques to allow a triangulation approach to validating application of microwave thermal technology to packaged foods.

1. Metallic temperature probes

Essential to validating conventional thermal processes, probes are placed in product in a specific position and temperature and time recorded throughout the thermal process. Mobile recording sensors may be used. Afterwards, these sensors are removed from packages and data is downloaded for analysis. A time-temperature curve is obtained from each probe to give an indication of the FO (time in minutes for the specified temperature that gives the same thermal lethality as as 121°C in one minute) achieved. The drawback to this method is the lack of visibility across the whole pack, with only the product temperature near the probe tip recorded. Also, due to the metallic structure of the probe, we needed to ensure there is no effect of the probe on microwave propagation through the food.

2. Optical temperature probes

Fibre optic temperature sensors are more appropriate for microwave applications, but only where the packaged food is moved very little – the fibre is fragile and passes out through the vessel wall.

3. Chemical marker as time/ temperature indicator

The chemical marker 4-hydroxy-5methyl-3(2H)-furanone (M-2) is the coloured product of a non enzymatic browning reaction between D-ribose and lysine. When foods are spiked with ribose and lysine, these precursors undergo Maillard reactions, resulting in the formation of M-2. The associated colour change gives an indication of accumulative time-temperature effects inside the food product during thermal processing. We have developed a gel food model using mashed potatoes supplemented with agar to obtain a firm texture, enabling the gel that is formed to be sliced lengthways to visualise the cold spots (lighter areas) inside the product. Different concentrations of agar have been tested to determine the optimum firmness. Special slicers have been designed by Raul Cruz and laser cut by the SFAT workshop (Figure 1.) to obtain clear slices. Processed product is sliced open and the image is analysed using the statistical computing software, R to give a heat map of the food.

4. Microbial inactivation

Inactivation of bacterial spores (*Geobacillus stearothermophilus* and *Clostridium sporogenes*) using CiMPAS were found to be comparable to that of thermal inactivation at 121°C. Challenge trials so far including two strains used for sporicidal testing showed that the variation (if present) in heat accumulation is not significant enough to show differences in spore inactivation at 121°C. Trials were conducted to understand the difference in thermal resistance of the spores when in different food matrices, indicating some products would reduce the resistance while others can increase; hence the validation would also cover some worst-case scenarios to ensure food safety.

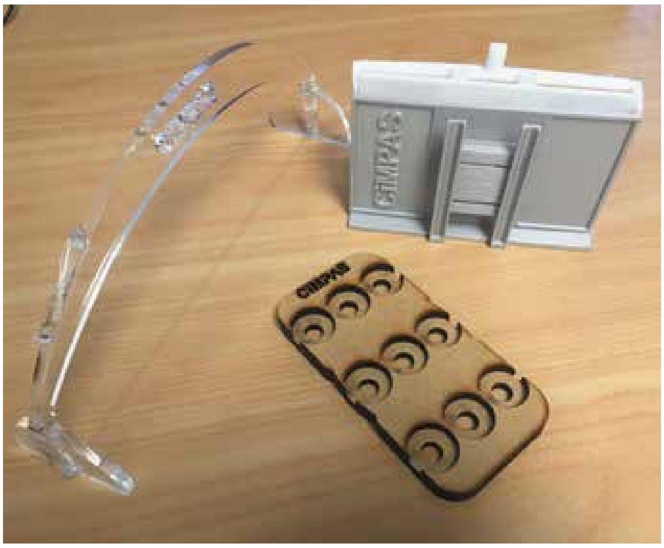

Figure 1: Tools developed to observe the time temperature distributions in model foods. From left; slicer for large gels, grid to adjust the aperture of the colorimeter to minimise external light reflection and consistent measurement location, right, slicer for food slab contained in tray

Improvement of microwave heating:

To optimise the uniformity of heating in the mashed potato food model, we have varied immersion water temperature, microwave power and profile, number and speed of passes under the antennae, holding time, and package size and dimension. Other parameters affecting heating are specific to the product such as the ability of the food to convert microwave energy to heat. The dielectric properties of the food govern the amount of heat generated in the product. They depend on the frequency, and on local temperature and chemical composition such as moisture and salts. The basic principle of energy conversion is that the electric field of electromagnetic radiation induces the agitation of polar molecules and ions in foods and heat is generated by the friction of molecules trying to align to the electromagnetic field. The real part of dielectric property is the dielectric constant (capability for storing energy in an electric field in the food) and the imaginary part is the dielectric loss, the ability to convert electric energy into heat. The dielectric constant and loss factor were measured in this project using an open-ended coaxial probe and a network analyser interfaced with a computer. The dielectric properties of 2% agar mashed potato model, spiked with ribose and lysine are illustrated in Figure 2. as a function of temperature. From the dielectric properties, we can easily

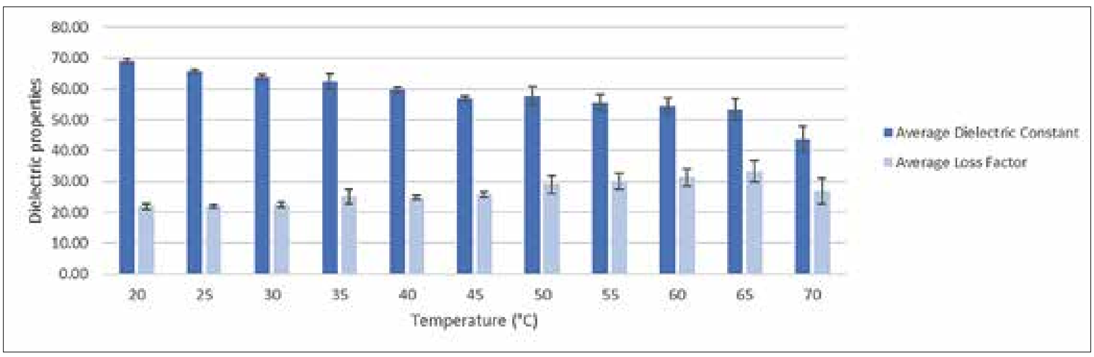

Figure 2: Dielectric constant and loss factors of mashed potatoes supplemented with 2% agar and spiked with D-ribose and lysine to measure the yield of the chemical marker M2. Error bars represent the standard deviation

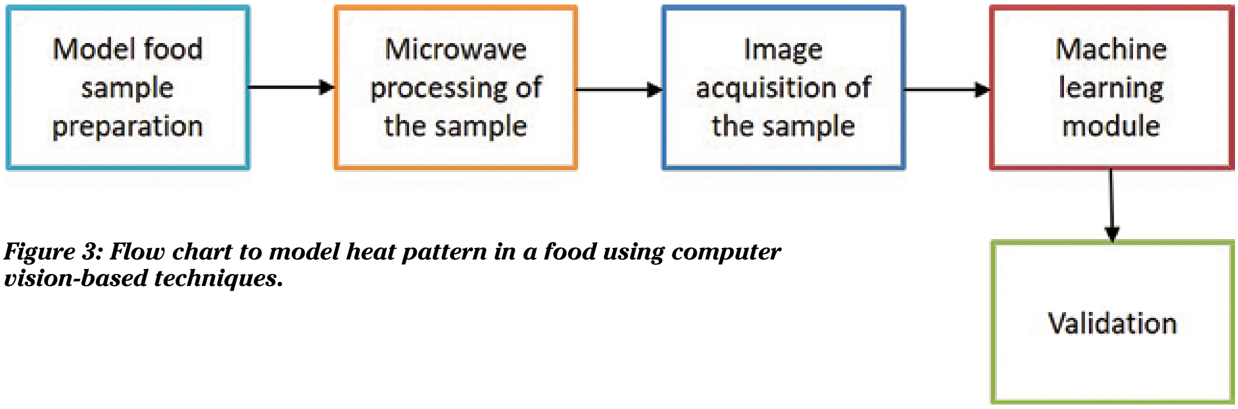

Figure 3: Flow chart to model heat pattern in a food using computer vision-based techniques.

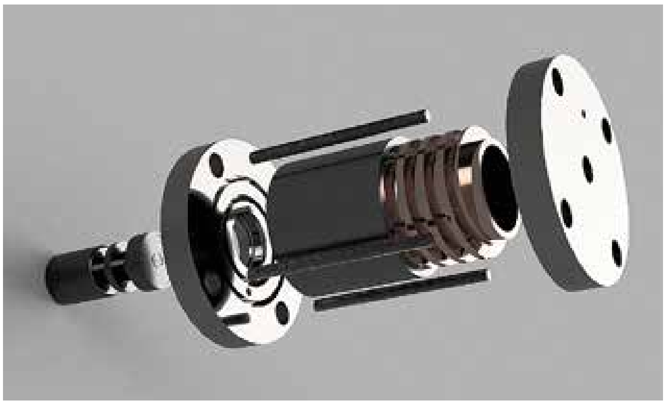

Figure 4: Pressurised chamber design to hold the coaxial probe for measurement of food dielectric properties up to 120°C.

calculate the power penetration depth (dp), defined as the distance at which the power density drops to 36.8 % from its value at the surface. Depth penetration is a good indicator of the ability of the food material to convert microwave energy to heat and a useful parameter when deciding package thickness for effective microwave heating. For example, we calculated that penetration depth in our food model is 19.9 mm at 20°C and decreases to 12.9 mm at 70°C. The CiMPAS design doubles penetration depth as the antennae emit microwave energy from above and below the food. All these measurements help to predict the microwave power to be applied to a food product without over processing and while retaining the organoleptic properties and nutrients.

Upcoming challenges:

The work has so far been carried out on homogenous model foods. The validation methods will need to become more sophisticated as the project next seeks to validate whole foods, such as fish fillets and pieces of meat. Current considerations include understanding and optimising temperature tracking and limitations of M-2 precursors or microbial spores that cannot be dosed evenly into these sorts of products.

Installation of fibre optic temperature probes, not attempted yet, will allow greater spatial resolution. They are less bulky than the current metallic probes, so more locations can be recorded in a pack. The probes can be inserted into whole foods with less disturbance to natural structure. However, these will be used as a verification technique in batch processing as the current cost may obviate industry adoption and they cannot be used in continuous systems.

Image analysis to uncover the heating history of a food will continue to be explored with PhD student Sowmya Kasturi, who is investigating the use of computer vision-based techniques in combination with deep learning networks to 3D model heating patterns, and data are being collected to investigate the potential of multispectral imaging as a validation technique. Preliminary studies conducted by Soni et al. (2) with the hyperspectral research team at AgResearch, have shown that non-destructive hyperspectral imaging can increase the limit of detection to identify colder regions in model food after CiMPAS processing in comparison to the efficiency of colourimetry (lightness values). Additionally, there are few dielectric data available in literature for foods at temperatures above 80°C. These data are necessary to develop a prediction model to sterilise any food by CiMPAS. We are currently designing a chamber allowing the measurement of dielectric properties at high temperatures and under pressure using a cylindrical jacketed stainless-steel sample holder connected to an oil bath that adjusts the temperature (Figure 4.).

As an output of this work we aim to commence developing prototype products with our industry partners with the ultimate goal to develop the validation pathway needed to commercialise these products and the Muegge CiMPAS equipment.

References

1- Soni, A., Smith, J., Thompson A., & Brightwell, G. (2020). Microwave-induced thermal sterilisation- A review on history, technical progress, advantages and challenges as compared to the conventional methods. Trends in Food Science & Technology, 97, 433-442.

2- Soni, A., Al-Sarayreh, M., Reis, M. M, Smith, J., Tong, K. and Brightwell, G. (2020). Identification of Cold Spots Using Non-Destructive Hyperspectral Imaging Technology in Model Food Processed by Coaxially Induced Microwave Pasteurisation and Sterilization. foods MDPI, 9, 837.

Food Industry Enabling Technologies (FIET) is funded by the Ministry for Business, Innovation and Employment and its purpose is to support new process developments that have the potential to add significant value to our national economy. The programme has six research partner organisations, Massey University (the host), Riddet Institute, University of Auckland, University of Otago, Plant and Food and AgResearch. Funding is $16.65m over six years (2015-2021) and targets pre-commercialisation activities. If you are interested in more information, then please contact either Dr Ross Holland (R.Holland1@massey.ac.nz) or Professor Richard Archer, Chief Technologist, (R.H.Archer@massey.ac.nz).