Microwave and RF Developments at Washington State University

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At the 3GMEA Conference in Cartagena, Spain, the Editor asked me to contribute an article to Ampere Newsletter. I decided to use this opportunity to provide a brief overview of our research and technology-transfer program related to microwave and radio frequency (RF) heating in food and agricultural post-harvest operations.

We initiated microwave and RF based food technology developments in 1995, right after I joined Washington State University (WSU) as an Assistant Professor. Over the past 21 years, our research and development efforts were mainly focused on three general themes:

1) Microwave assisted drying (at 2,450 MHz);
2) Radio frequency (27.12 MHz) treatment of dry agricultural products (including nuts and dry fruits) for pest and pathogen control;
3) Microwave-assisted (915 MHz) sterilization (processing temperature over 120°C) and pasteurization (processing temperature to 95°C) of pre-packaged ready-to-eat shelf-stable or chilled meals.

All these activities were multi-disciplinary and involved engineering design (supported by computer simulation), pilot-scale testing, scaling-up, and food safety and quality evaluation. The following provides a brief description on our activities for each of the three themes.

Microwave-assisted drying

Drying is one of the most energy intensive operations in the food and agriculture industries. Ideally, microwave internal heating of food particles combined with surface air drying should significantly reduce drying time and improve energy efficiency. But poor control of product temperature and heating uniformity are the two major technical issues that hinder the industrial application of microwave assisted drying processes. We studied using combination of a spouted bed with microwave heating to address these issues with a bench-scale unit[1]. Continued studies were successfully conducted on a pilot scale unit (10:1 from our bench top unit) by my former visiting professor in China in partnership with a food company (Haitong Food Group, Cixi, China)[2]. However, funding for drying research has been very limited, not only in United States but in other parts of the world, and the poor economics of using complicated technologies in a relatively low-value product industry hindered our efforts in promoting industrial applications.

RF-technology development for pest and pathogen control

This research program was originally supported by a $1.2M USDA grant under the Clinton Administration's Initiative for Future Agriculture and Food Systems Program. We then received an additional $0.6M from different funding sources, including a United States and Israel joint program, BARD. The initial goal was to explore applications of RF energy to replace dangerous chemical fumigation used in industrial post-harvest insect control for agricultural produce.

Our early research activities were focused in studying thermal inactivation kinetics for targeted insects at different life stages, selecting processing parameters, and conducting pilot-scale testing to validate developed process protocols, and using computer models to understand factors influencing RF heating uniformity (Fig. 1). We successfully scaled up and validated (with live insects inserted into fruits) the treatment using a 35 kW RF system in a processing plant[3, 4] (of the Diamond Walnut Company, California, USA). With new funding from the USDA of over $1.3M starting in 2013, we are expanding RF applications for the control of pathogens in food ingredients and dry bulk materials to support food companies in compliance with the Food Safety Modernization Act (FSMA), signed by President Obama in

2011. FSMA requires all food companies to develop validated pathogen control intervention methods by the year 2019.

My former students, research associates, and visiting professors have brought the expertise to China and started four active research RF groups at various universities including the Northwest University of Agriculture and Forestry, China Agriculture University, Shanghai Jiao Tong University, and Shanghai Ocean Universities.

Figure 1. Research associates and students conducting pilot scale testing at Washington State University (up) and industrial process validation in California.

Microwave-assisted processes for packaged meals

This is the most successful program in my laboratory, with the earliest supporter of our research being the US Army Natick Soldier Center of the US Department of Defense (DoD) in its search for new processing methods to produce high quality shelf-stable ready-to-eat meals for soldiers fighting in hostile environments. Traditional canning processes take a long time to complete the inactivation of pathogenic and spoilage spores in pre-packaged foods which severely damages food quality. Starting in 2001, the US Department of Defense's Duel Use Scientific and Technology (DUST) Program provided us a significant amount of funding to speed up our research and technology development activities. To fulfill the requirements of a 50% high quality cost share from the food industry, we formed an industrial consortium consisting of seven major United States food and packaging companies. These companies not only provided partial funding, but actively participated in discussions and planning for activities in different phases of the technology development.

In the United States, introduction of a new technology for industrial production of low-acid (pH>4.6) shelf-stable foods requires rigorous examination and acceptance from the US Food and Drug Administration (FDA) and the US Department of Agriculture Food Safety Inspection Services (USDA FSIS). With consistent support from DoD, DoE, USDA, and Food Companies, totaling more than $15 M over the past 20 years, we were able to bring the technology from concept development, through scaling-up, to regulatory acceptance, and finally industrial implementation.

Our research activities include developing computer simulation models to design effective 915 MHz single-mode cavities, developing new chemical markers method to determine heating patterns for validation of computer models and the determination of cold locations in packaged foods, creating methods for in-package temperature measurement in moving food packages, and developing microbial validation methods for regulatory acceptance of filed production processes.

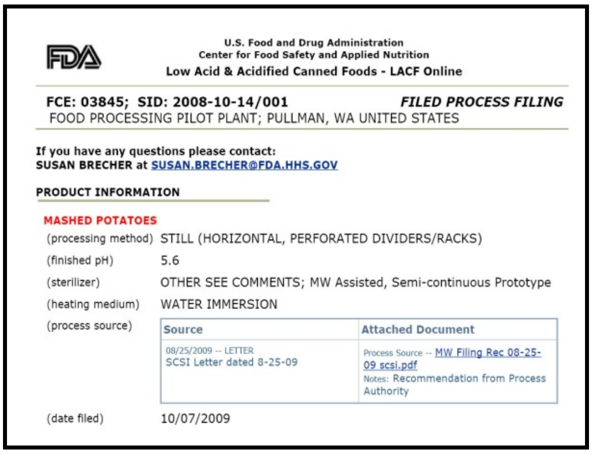
To support industrial implementation, we used computer simulation to study stability of heating patterns as influenced by possible changes in peak frequencies of generators, and evaluated accuracy of model temperature sensors in high power microwave systems. During the years, 18 PhD and 2 MS students, 17 postdoctoral fellows and visiting professors, and 5 full time engineers in my laboratory (Fig. 2) were heavily involved in various stages of the research program. Over 100 research scientists and experts from other departments (food science, mechanical engineering, and electrical engineering) of our university and from collaborating universities (University of

Tennessee and North Carolina State University), as well as from food companies and industrial associations (US National Food Productions Association, Seafood Product Association, and International Microwave Institute) also participated in part of the research activities.

Both technologies of microwave-assisted thermal sterilization (MATS) and pasteurization (MAP) are licensed to a start-up company named 915 Labs (www.915labs.com) for global commercialization (Fig. 3).

Figure 2. Students participating in the assembly of the 915 MHz pilot-scale microwave assisted thermal sterilization (MATS) system at Washington State University Food Processing Pilot Plant (up), and the machining of parts for the system.

Major engineering challenges and technical details of the technology development (as reflected in Figs. 4-6) have been reported[5]. Industry related MW and RF heating research, in particular for foods which require unique sanitary conditions, demands adequate infrastructure and substantial funding. We are fortunate to have received consistent supports from our university, federal funding agencies and the industry.



FDA

U.S. Food and Drug Administration
Center for Food Safety and Applied Nutrition
Low Acid & Acidified Canned Foods - LACF Online

FCE: 03845; SID: 2008-10-14/001 *FILED PROCESS FILING*
FOOD PROCESSING PILOT PLANT; PULLMAN, WA UNITED STATES

If you have any questions please contact:
SUSAN BRECHER at SUSAN.BRECHER@FDA.HHS.GOV

PRODUCT INFORMATION

MASHED POTATOES

(processing method)	STILL (HORIZONTAL, PERFORATED DIVIDERS/RACKS)		
(finished pH)	5.6		
(sterilizer)	OTHER SEE COMMENTS; MW Assisted, Semi-continuous Prototype		
(heating medium)	WATER IMMERSION		
(process source)		Source	Attached Document
		08/25/2009 -- LETTER SCSI Letter dated 8-25-09	Process Source -- MW Filing Rec 08-25-09 scsi.pdf Notes: Recommendation from Process Authority
(date filed)	10/07/2009		

Figure 3. The 3rd generation 915 MHz pilot scale MATS system (up). Two processes based on this system were filed and received FDA acceptance and clearance from USDA FSIS for shelf-stable meals. Above shows FDA document for a filed process.

Figure 4. A ready-to-eat meal produced by our pilot scale system.

Figure 5. Five-day boot camps for food and packaging companies gaining hands-on experience in using our new technologies. Participants shown above were developing meals processed by our pilot scale systems (2015).

Figure 6. US-Army soldiers participating in a sensory test on chilled meals processed with our MAPS system.

For further reading:

1. Feng, H., Tang, J. and Cavalieri, R.P. 1999. Combined microwave and spouted bed drying of diced apples: Effect of drying conditions on drying kinetics and product temperature, *Drying Technology* 17(10): 1981-1998.
2. Yan W., Zhang M., Huang L., Tang J., Mujumdar A.S., Sun J. 2010. Study of the optimization of puffing characteristics of potato cubes by spouted bed drying enhanced with microwave. *J. Sci. Food Agric.* 90: 1300-1307.
3. Wang S., Monzon, M., Johnson J.A., Mitcham E.J., Tang, J. 2007a. Industrial-scale radio frequency treatments for insect control in walnuts: II. Insect mortality and product quality. *Postharvest Biol. Technol.*, 45(2): 247-253.
4. Wang S., Monzon, A., Johnson J.A., Mitcham E.J., Tang, J b. 2007b. Industrial-scale radio frequency treatments for insect control in walnuts: I. Heating uniformity and energy efficiency. *Postharvest Biol. Technol*, 45(2): 240-246.
5. Tang, J. 2015. Unlocking potentials of microwaves for food safety and quality. *J. Food Science* 80(8): E1776-1793.

About the Author

Dr. Juming Tang is Regents Professor, Distinguished Chair of Food Engineering, and Chair of Biological Systems Engineering at Washington State University. He has trained 27 PhD students, and published over 290 peer reviewed scientific papers, 2 books and 24 book chapters.

Dr. Tang's laboratory has two licensed patents on 915 MHz single-mode microwave-assisted sterilization (MATS) and pasteurization (MAP) technologies for packaged foods.

Dr. Tang is past president of International Microwave Power Institute (IMPI) and past Chair of Institute of Food Technologists (IFT) FT Food Engineering Division. He received numerous awards, including 2010 IFT R&D Award, 2012 International Food Engineer Award of American Society of Agricultural and Biological Engineers (ASABE)/Nestle, 2014 Freezing Research Award from International Association for Food Protection/Frozen Food Foundation.

Dr. Tang is a fellow of IMPI, ASABE, and IFT.