Experimental and Computational Study of Microwave Heating in Single-Stream Waste Processing

Megan C. Robinson[1], **Vadim V. Yakovlev**[2], **and Zoya Popović**[1]

[1] Department of Electrical, Computer and Energy Engineering, University of Colorado, Boulder, CO, USA
[2]Department of Mathematical Sciences, Worcester Polytechnic Institute, Worcester, MA, USA

Keywords: power combining, solid-state power amplifiers, temperature, waste breakdown

INTRODUCTION

Microwave heating of waste results in breakdown that can lead to conversion of waste to fuel [1]. Heating waste mixtures with microwave energy rather than incineration results in faster breakdown and can therefore be more efficient [2]. In this paper, we compare experimental and modeling results obtained for the heating rates of microwave processing of waste within a 1.4 L metal cavity. Three common waste materials with widely differing temperature-dependent electromagnetic and thermal material parameters are considered. As uniform heating is desired for chemical processing, spatial power combining is analyzed by comparing single and double solid-state excitation. We show that the heating efficacy is improved by volumetric combining inside the waste loading.

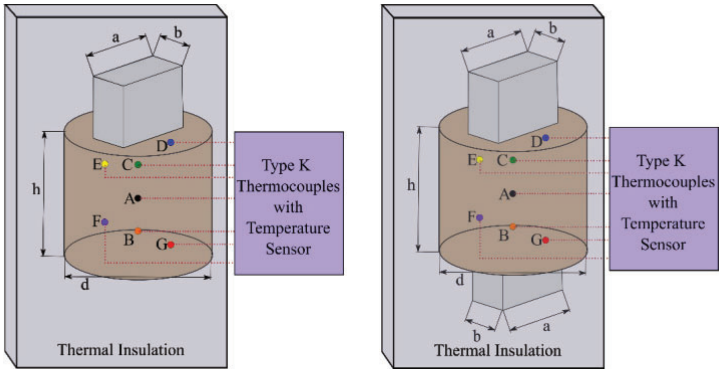
METHODOLOGY

The key goal of this work is to evaluate to what extent simulation tools with material properties found in the open literature can be used to model and predict heating and improve reactor design. We present a loaded cavity heating comparison of two circuit-combined and spatially combined 2.45-GHz 70-W efficient GaN solid-state power amplifiers (SSPAs) with controlled relative phase. EM and thermal parameters of several common materials are summarized in [3] and relevant properties given in Table 1.

The set up for both measurement and simulation is described in Fig. 1, with single port and two port excitations shown. The cavity size is chosen so that two 70-W sources at 2.45-GHz can deposit power throughout the volume for all three loadings. *QuickWave* [4] was used to simulate the microwave heating in the cavity filled with the three loadings characterized by temperature dependent material parameters.

RESULTS

The single-port excitation results are shown in Fig. 2. All loadings show higher simulated heating than measured. The hot spots are predicted in the simulation and line up with measurements for the higher permittivity materials. Since the reflection coefficient at the excitation ports changes with heating, the delivered power is kept constant in both simulations and measurements.



(a) (b)

Figure 1. Geometry of the S-band waveguide probes and loaded cavity, with d = 12.5cm, h = 11.2cm, a = 7.2cm, b = 3.6cm. Seven temperature sensors are at fixed positions A through G for all experiments. Single waveguide excitation (a); two waveguide probes used to excite electromagnetic fields in the cavity (b).

Table 1. Range of Material Parameters for the Three Investigated Materials

Material	ε_r	σ (S/m)	c (J/g °C)	ρ (g/mL)	K (mW/cm°C)
Paper (25-90° C)	2.3-2.7	0.025-.033	1.36	0.105	0.51-0.57
Bread (25-85° C)	3.1-4.1	0.05-0.1	2.47	0.19	0.95-2.8
Meat (15-65° C)	48.5-51.7	2.1-2.4	3.32	1.0	3.9-5.7

Fig. 3 shows the simulated and measured results for the dual excitation case. Heating appears more linear in simulation than measurement for the bread loading indicating some temperature effect is not being modeled realistically. This is potentially related to the PA circuit heating, or additional changes in impedance match. Asymmetry in the measured temperatures at points B and C indicate that probe placement and power at the two probes may be different.

DISCUSSION

Simulations adequately predict trends in temperature distribution; however, the delivered power and reflection coefficient differs in experiments. Lack of available data for material parameters depending on temperature is reflected in Table 1. This limits the simulation accuracy since the temperature-dependent properties are required at all points. The hottest regions contribute to the disagreement between simulated and measured heating duration.

CONCLUSION

Multiphysics simulations are in general agreement with experiments for single and dual port heating of single-stream waste in a solid-state excited microwave cavity. Notable disagreement of simulated and measured temperatures is explained by inadequacy of the literature data on the material parameters to the substances in the experiment. Measurement of the properties of the material in the experiment is preferable. The next step is an investigation of effects of material parameter variations.

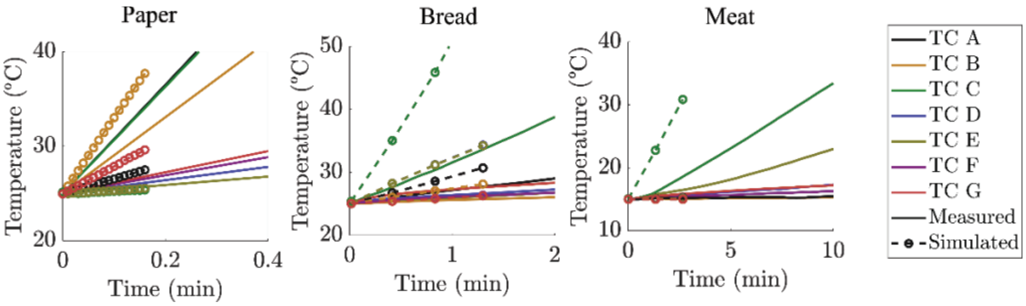


Figure 2. Measured and simulated temperature increase at seven temperature sensor locations (A to G); paper, bread, and meat loadings of the cavity with a single feed for 70 W of delivered power; the symbols show results from multiphysics simulations of heating rates at the thermocouple locations; right to left: paper, bread, and meat (hotdog) loadings.

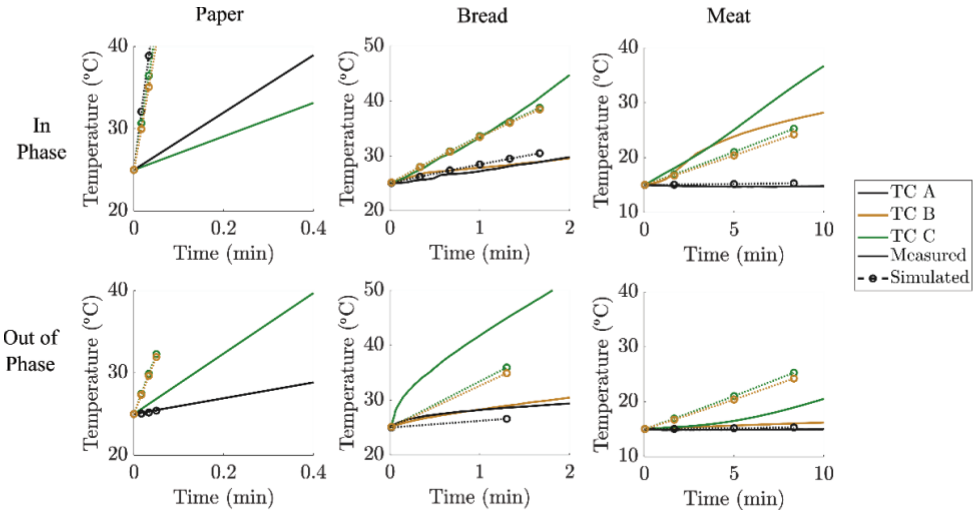


Figure 3. Measured and simulated temperature increase at three temperature sensor locations (A, B, & C) for paper, bread, and meat loadings of the cavity with two feeds for 70 W of delivered power; the symbols show results from multi-physics simulations of heating rates at the thermocouple locations; right to left: paper, bread, and meat (hotdog) loadings.

REFERENCES

[1] A. Sarkar and R. Chowdhury, "Co-pyrolysis of paper waste and mustard press cake in a semi-batch pyrolyzer optimization and bio-oil characterization," *Intern. Journal Green Energy*, vol. 13, no. 4, p. 373–382, 2014.

[2] Y. Fernandez, A. Arenillas, and J. Angel, "Microwave heating applied to pyrolysis," In: *Advances in Induction and Microwave Heating of Mineral and Organic Materials*, IntechOpen, London, U.K., 2011, doi: 10.5772/562.

[3] M.C. Robinson, V.V. Yakovlev, and Z. Popovic, "Circuit and spatial solid-state power combining for microwave waste mixture breakdown," *IEEE Microwave Theory and Tech*., submitted.

[4] *QuickWave*, QWED Sp. z o. o., 1998-2022, http://www.qwed.eu.