Modeling of Microwave Heating of a Rotating Object

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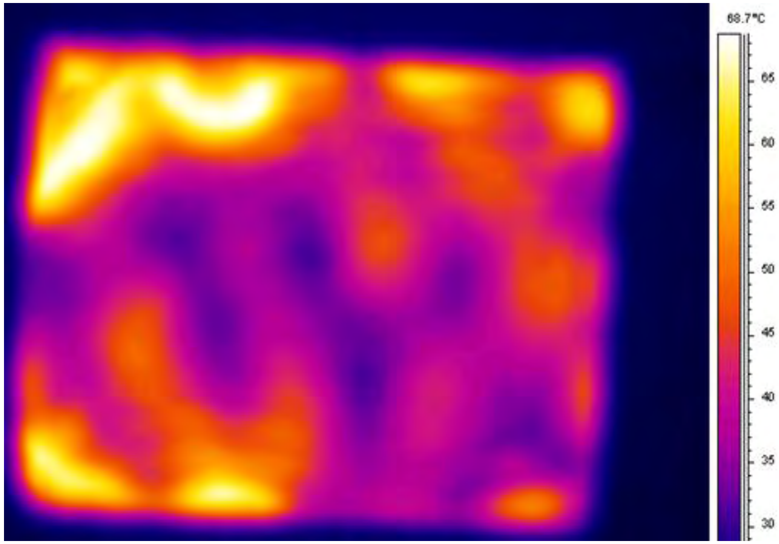
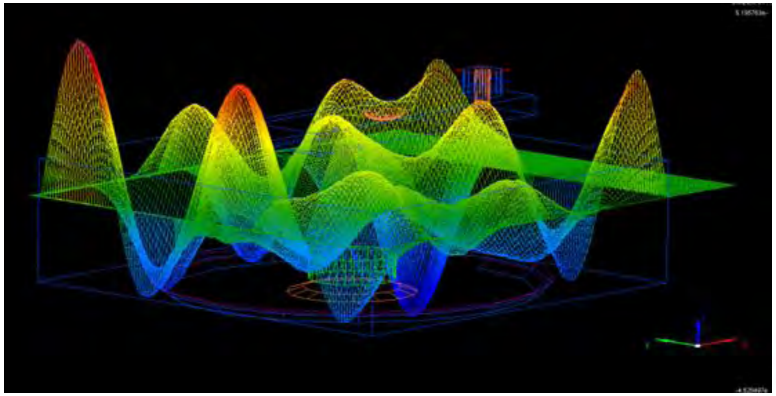
Outline

- Background
- Objectives
- Simulation
- Experimental study
- Results
- Conclusion

Uneven heating in microwave ovens

- Microwave ovens heat food unevenly
- Caused by the standing wave pattern



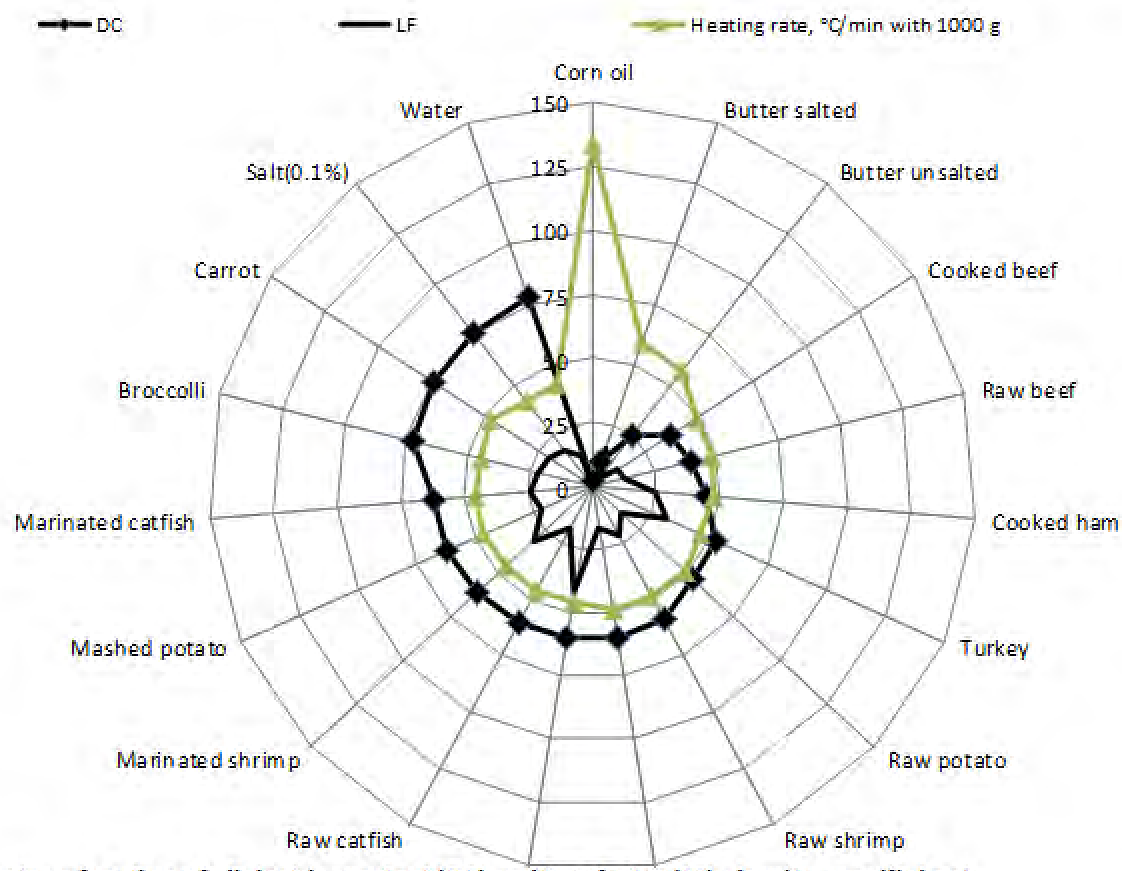


Factors influencing heating patterns

- Oven features
  - Size and shape of cavity and waveguide
  - Age of magnetron

- Food properties
  - Size and shape of food
  - Constituents
    - Dielectric properties
    - Thermal properties

Effect of food properties



Heating rates a function of dielectric constant (DC) and Loss factor (LF), density, specific heat

Consequences of uneven microwave heating

- **Food borne illness outbreaks**
  - Frozen food (esp Not ready to eat food NRTE)
    - Raw and semi-cooked ingredients

Need for modeling microwave ovens

- Predictive microbiology
- Packaging design
- Food Design

Review of literature

- Finite Difference Time Domain using Quickwave by Kopyt and Celuch (2003).
  - Transient positions
  - External software (MATLAB)

- Geedipalli et al (2007) – Finite Element using ANSYS and FIDAP
  - One way coupling

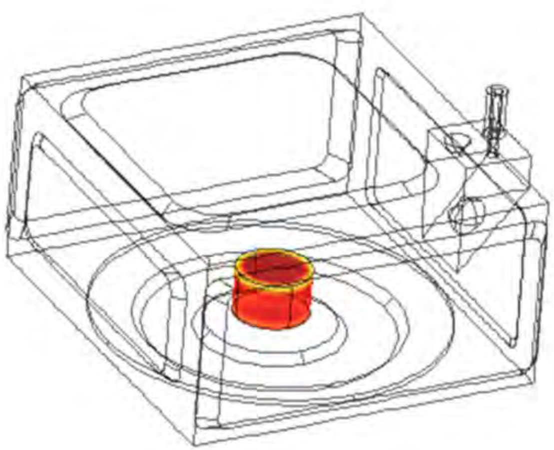
- Chatterjee et al. (2007) - Finite Volume based FLUENT.
  - Symmetrical uniform field

Objectives

- Simulate the rotation of a cylindrical body in a microwave oven using COMSOL Multiphysics 4.2
- Validate the model using a gellan gel cylinder.

Geometric model

- Based on the Panasonic Model No. NN-SD767W.
  - Rated at 1100 W
  - Actual power output (~900 W)
  - Coaxial port

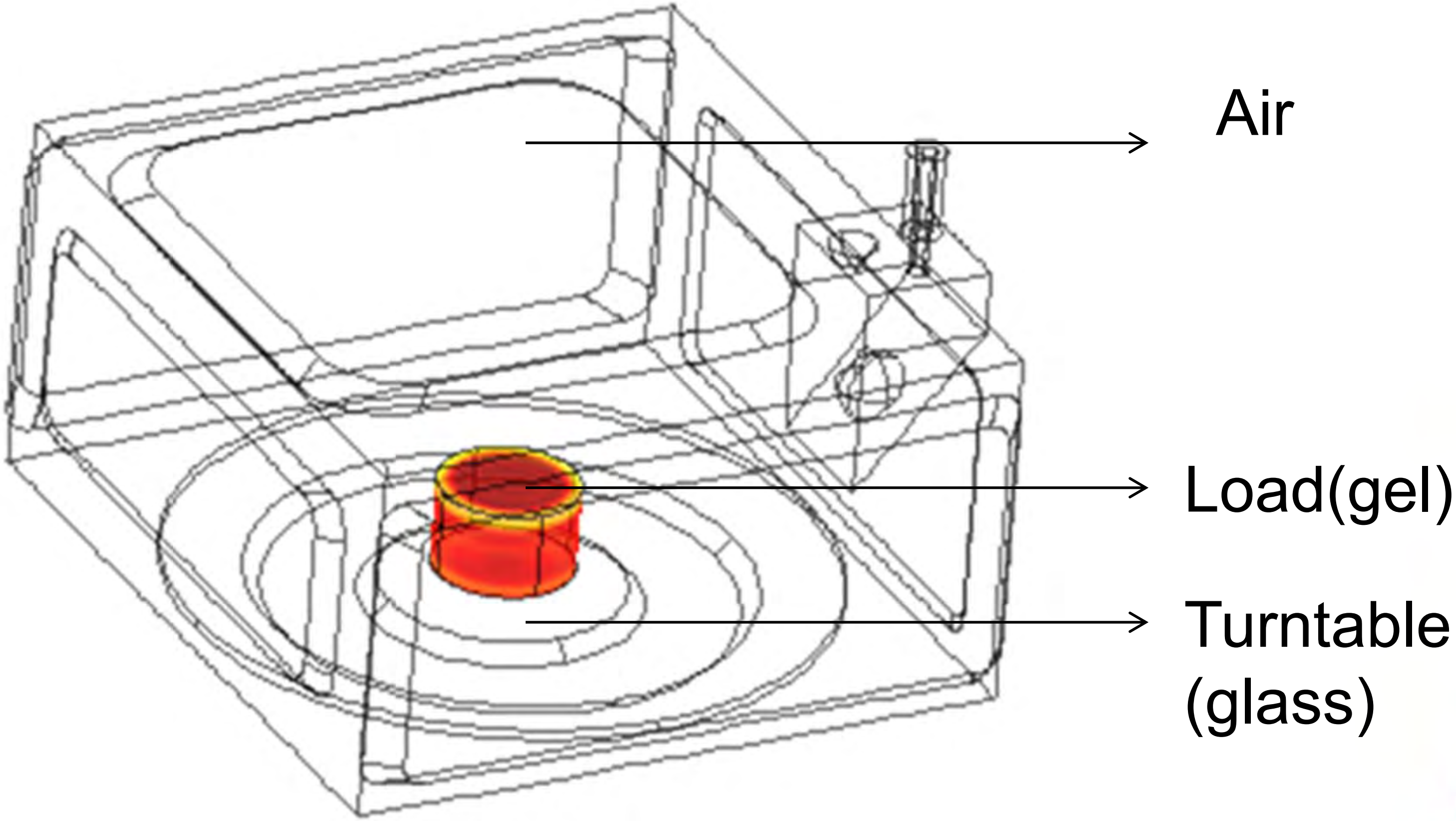


Properties

Properties	Gellan gel *	Glass
Specific heat, J/kg/K	4160	0.55
Density, kg/m^3	1010	2050
Thermal conductivity, W/mK	0.53	0.1
Dielectric constant	$-0.23T+81.103$	4
Loss factor	$0.0019T^2-0.264T+18.033$	0

*Measured at University of Nebraska – Lincoln and the Oklahama State University

Domains



Physics used

- Microwave heating (mh)

$$\nabla\times\mu_r^{-1}(\nabla\times\mathbf{E})-(\frac{2\pi f}{c})^2\left(\epsilon_r-i\,\epsilon''\right)\mathbf{E}=0$$

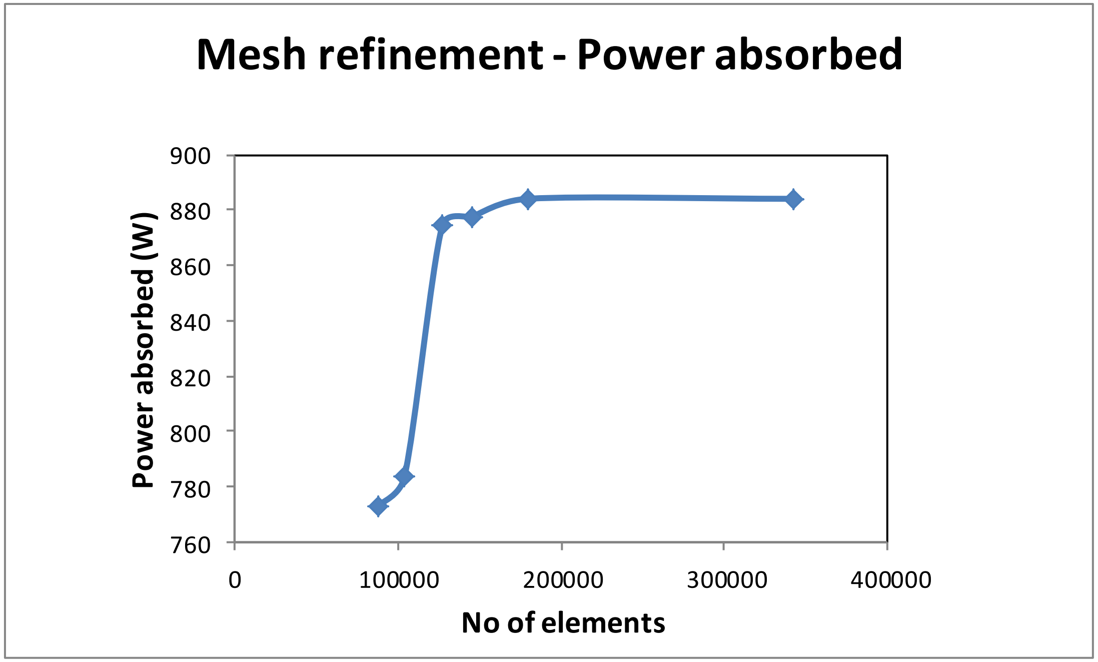
- Moving mesh (ale)
  - Prescribed movement of turntable and load

$$dx=\cos(2\,\pi\;N\,t)\,X-\sin(2\;\pi\,N\,t)\,Y-X$$
$$dy=\sin(2\,\pi\;N\,t)X+\cos(2\;\pi\,N\,t)\,Y-Y$$

  - Free deformation in the air domain

Meshing

- Mesh independence studies
  - Thumb rule (10 elements per wavelength)



Study and solver

- Frequency Transient study
  - Simulated for 30 s of heating
  - Segregated solver
    - Electromagnetic field (E)
    - Heating (T)
    - Moving mesh (xyz)

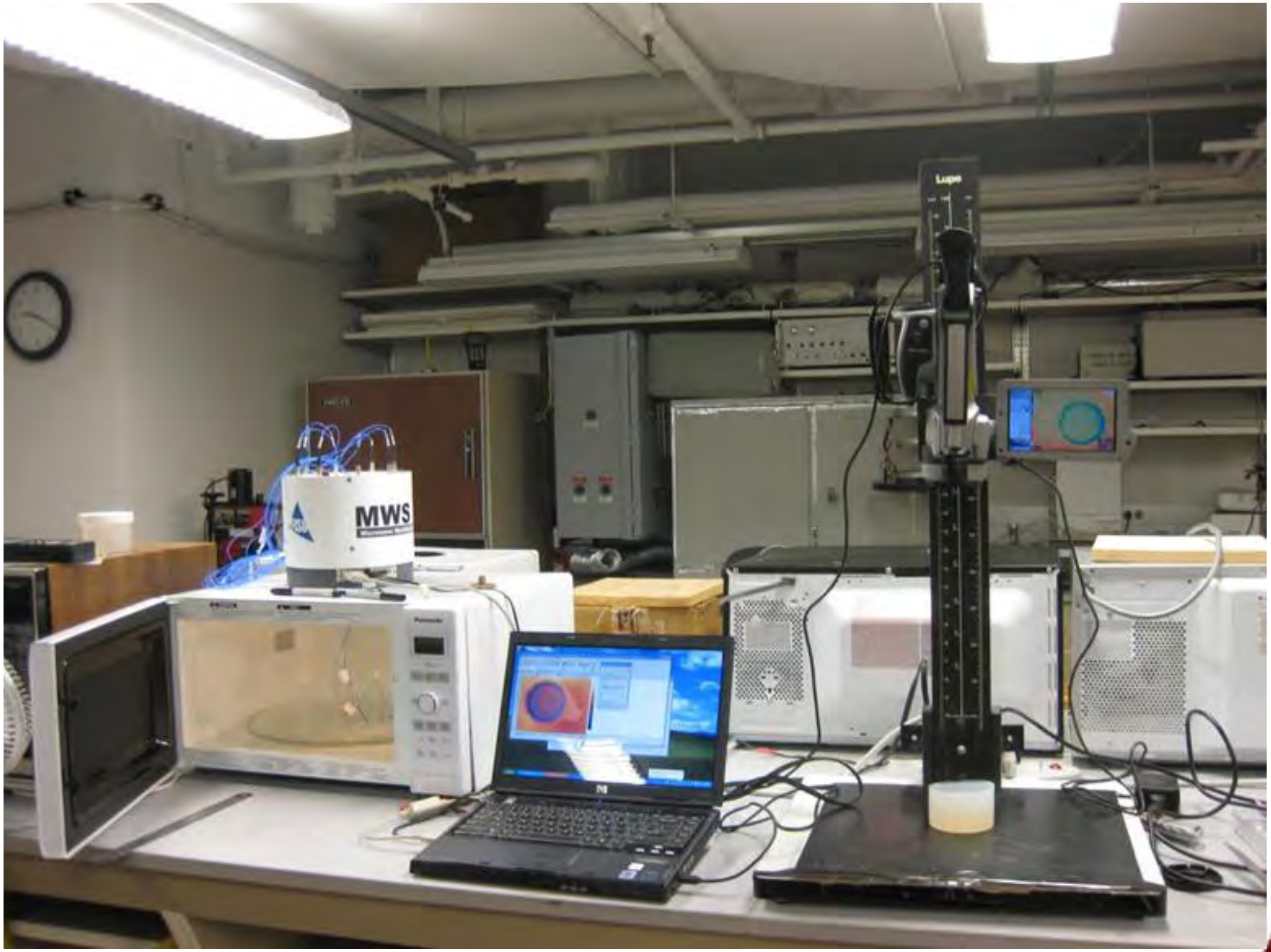
Solving time

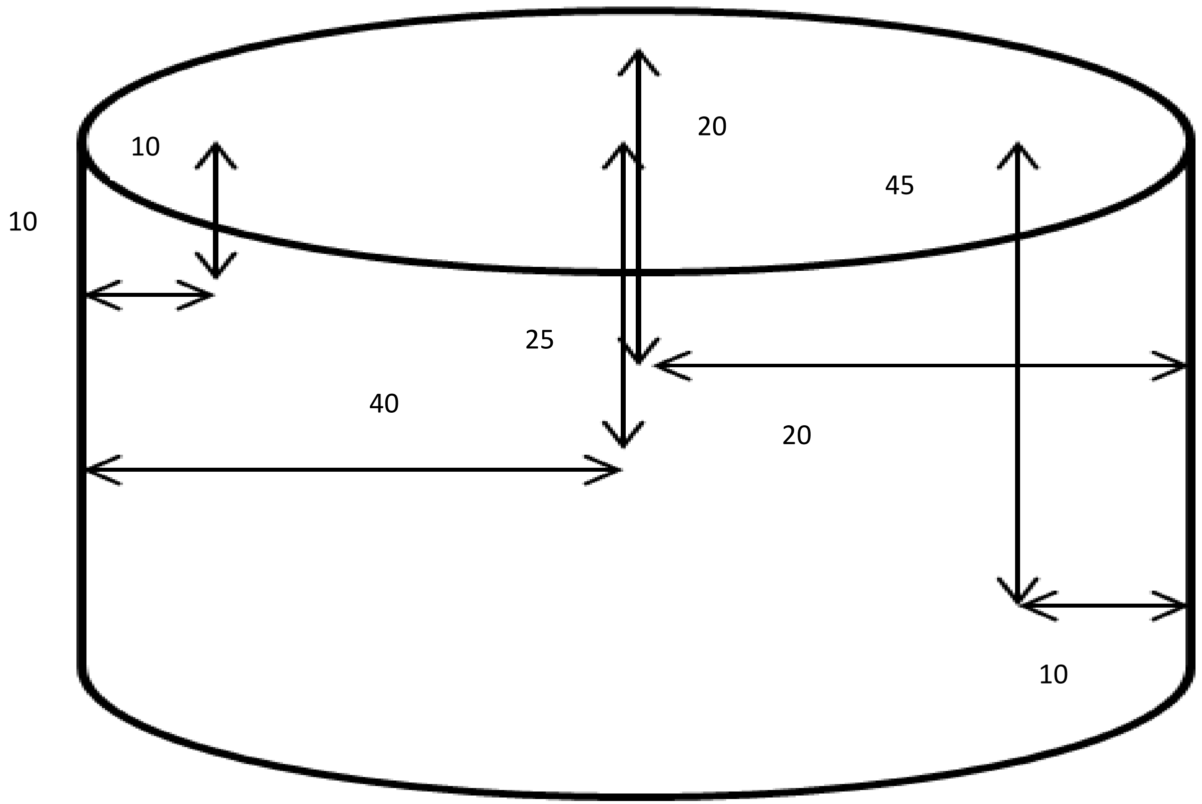
- Desktop computer – 7760 s
  - 8 GB RAM

- Cluster computing – 3599 s
  - 32 GB RAM
  - 8 nodes

Experimental validation

- 1% gellan gel (80 mm diameter and 50 mm height)
- Validation
  - 4 fiber optic sensors for different locations
  - Thermal imaging camera from FLIR systems


MWS
Lupe


20
10
45
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25
40
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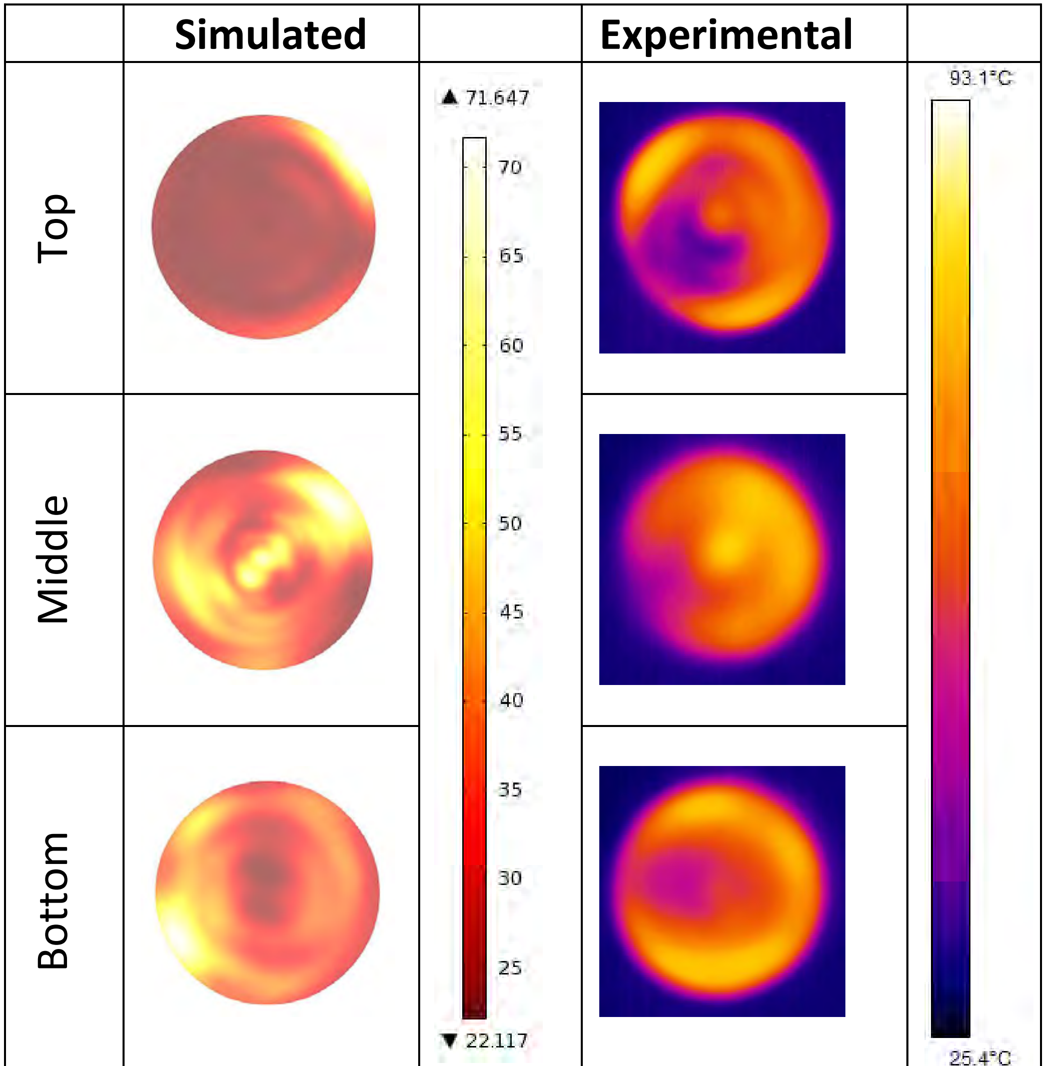
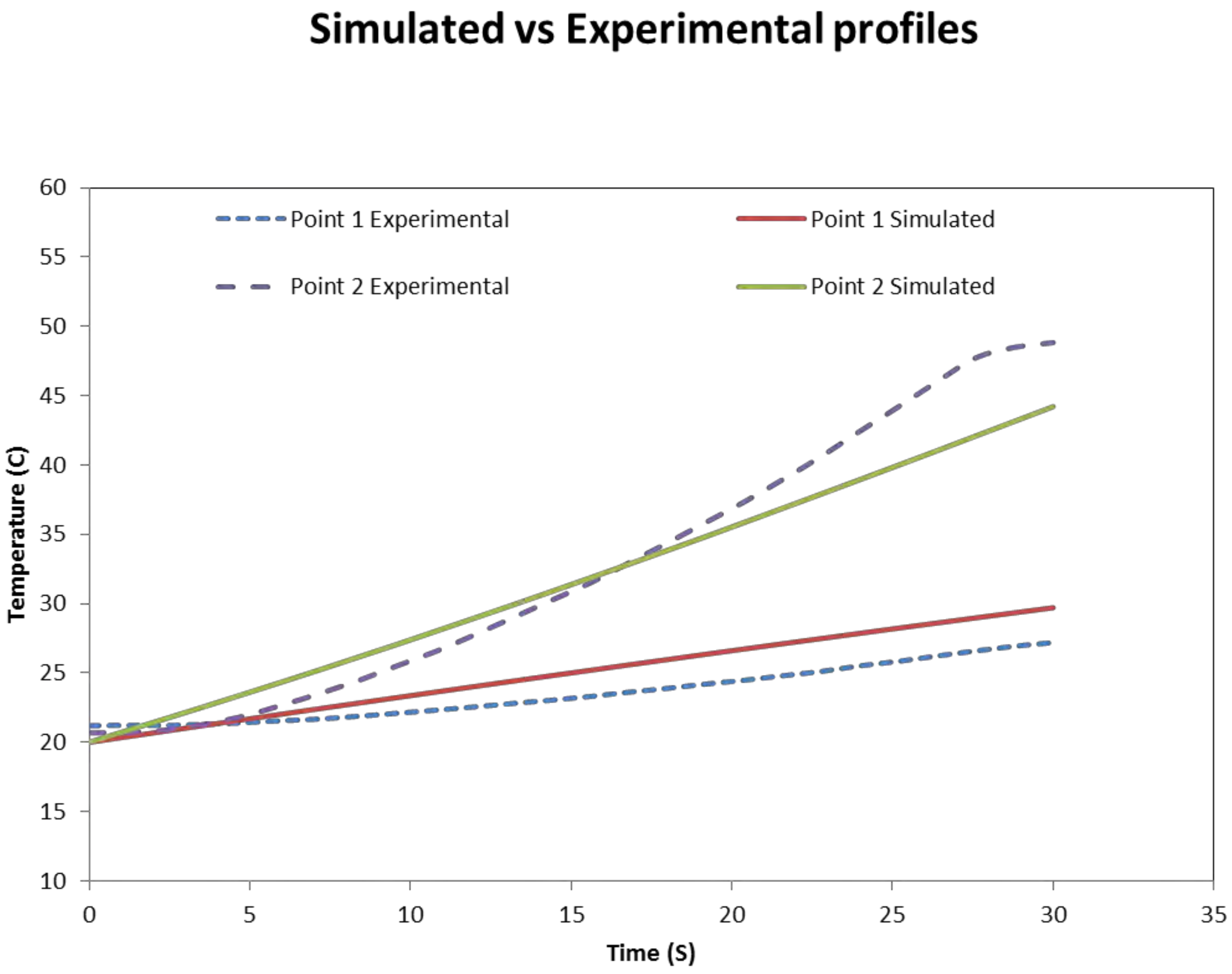
10

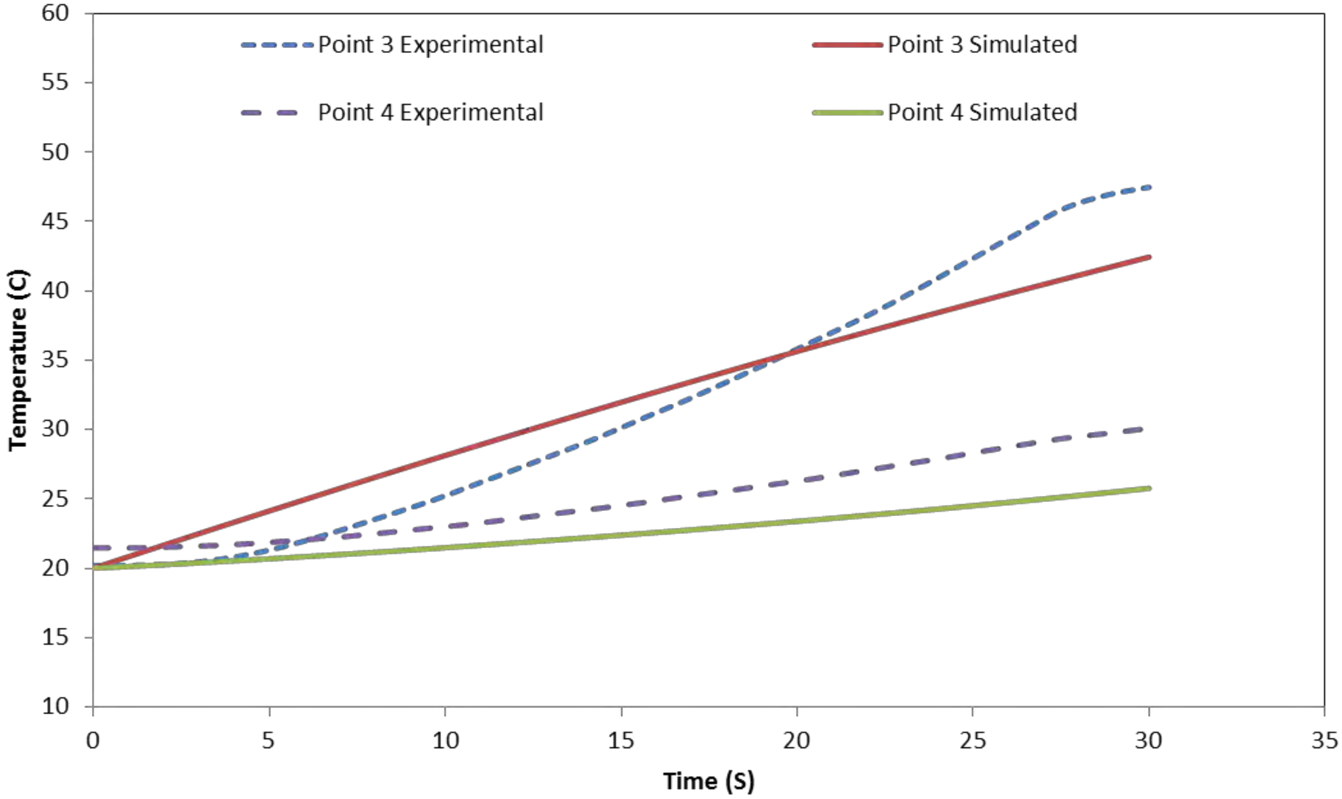
Stationary image



Stationary transient

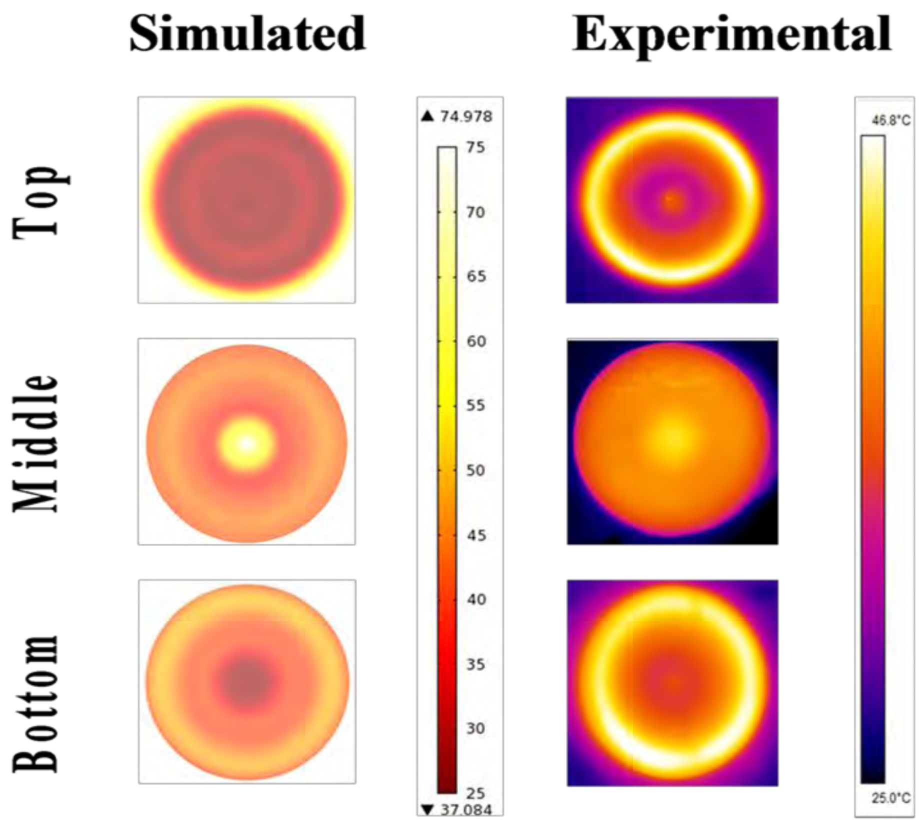


Simulated vs Experimental profiles

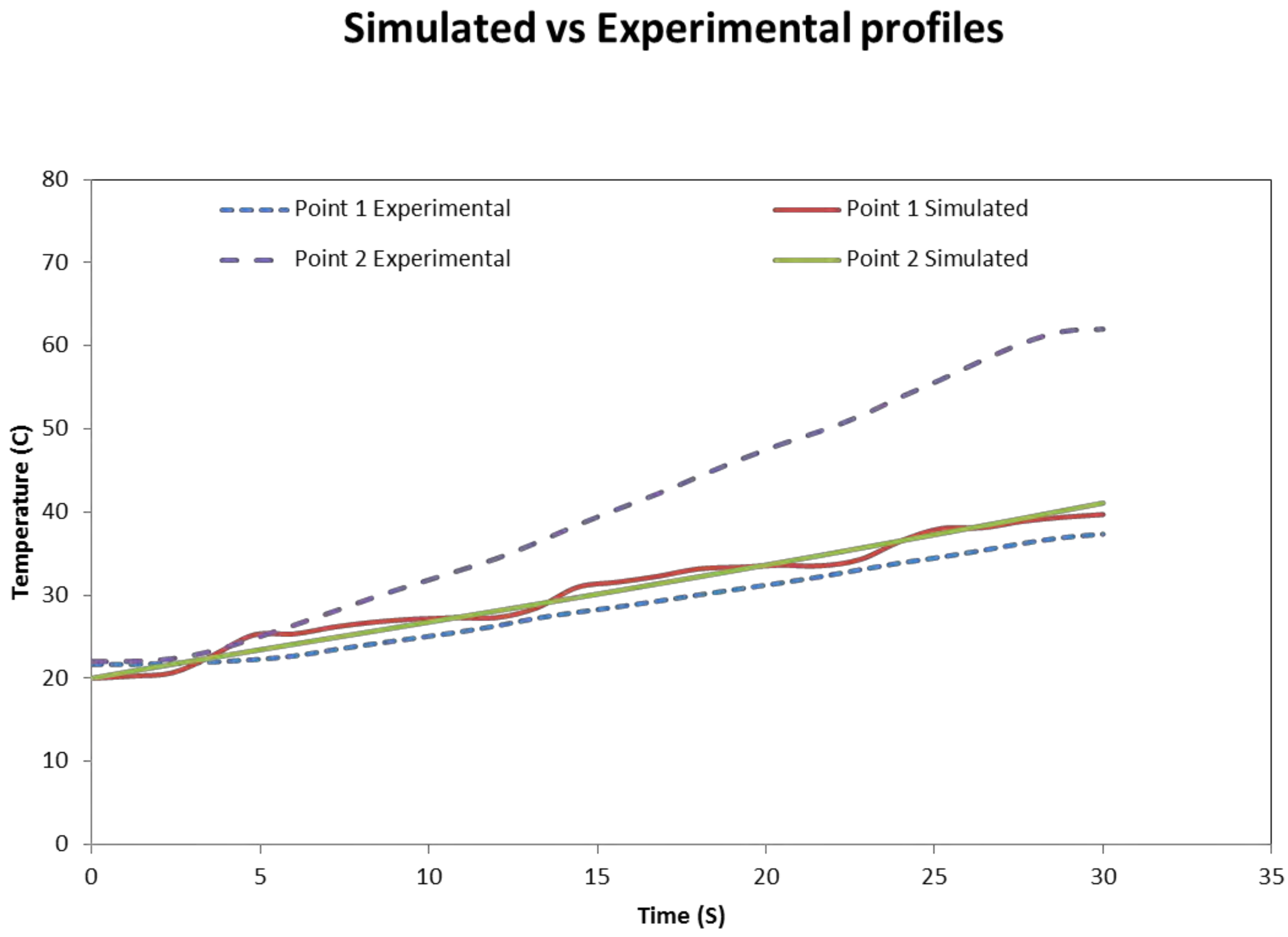


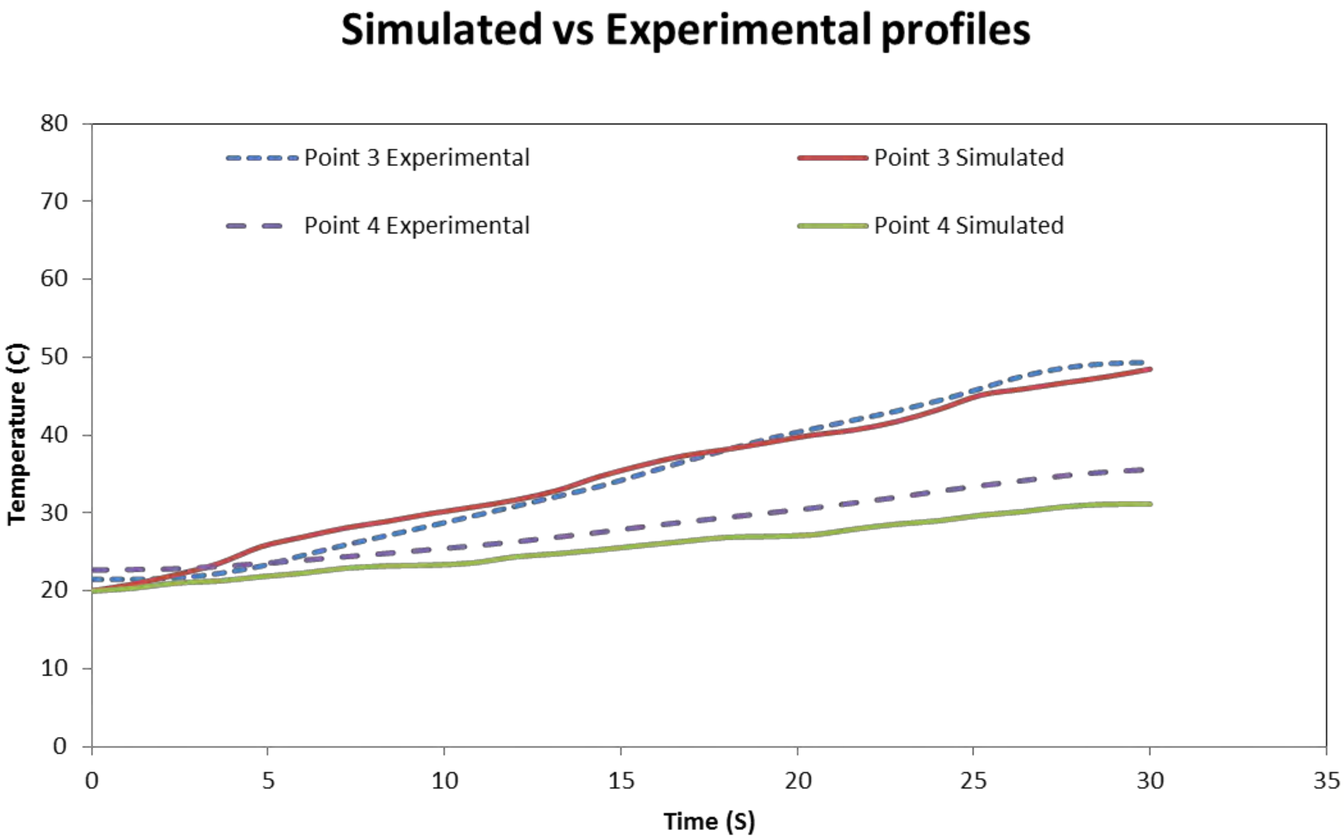
Stationary RMSE 1.22 C

Profile comparison - rotation



Rotating transient





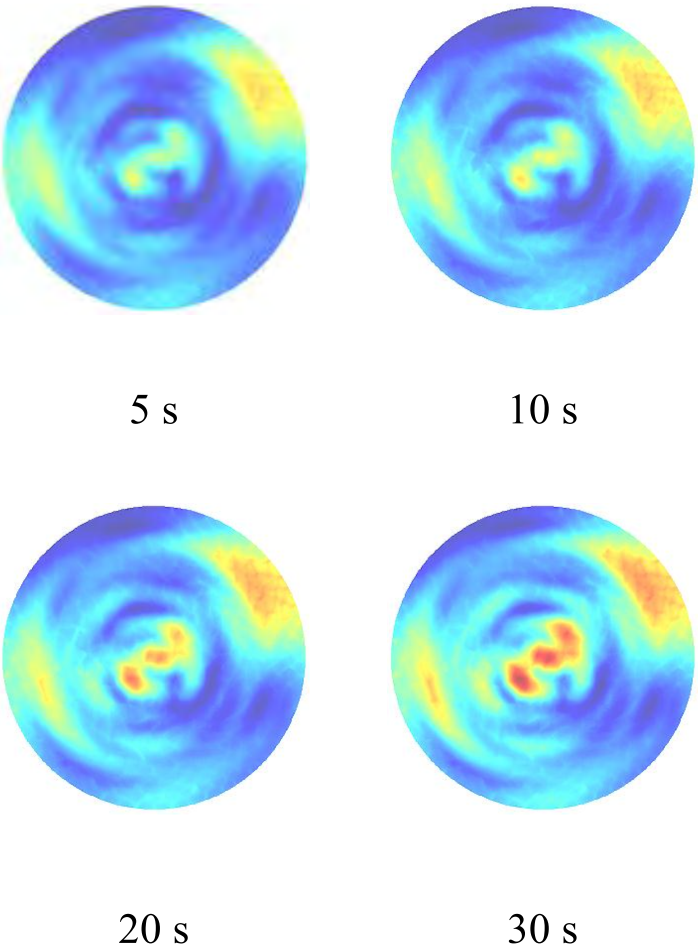
Stationary RMSE 2.34 C

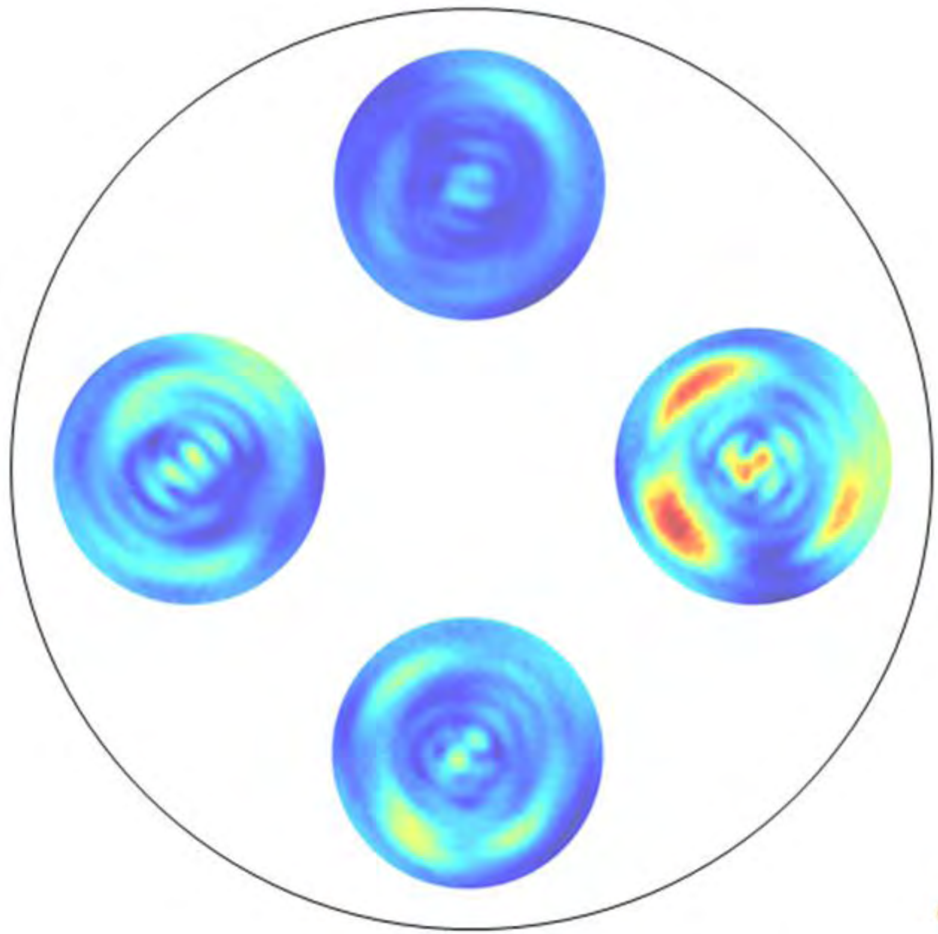
Two-way coupling issues in COMSOL

- No change of electromagnetic field with change in temperature.

- Original field and temperature properties are used for temperature prediction.

Power absorption (W)





Conclusion

- A reasonable agreement between the model and the experimental results was found based on the transient temperature profiles.

- COMSOL does not couple moving mesh (ale) and microwave heating (mh).

- The results while seeming to agree with the experimental values do raise concerns because of the non changing of the electromagnetic field with temperature.

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Questions?

Thank you