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Coupled Electromagnetic and Heat Transfer Simulations for RF Applicator Design for Efficient Heating of Materials

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Multiphysics CAE for Innovation ™

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Introduction

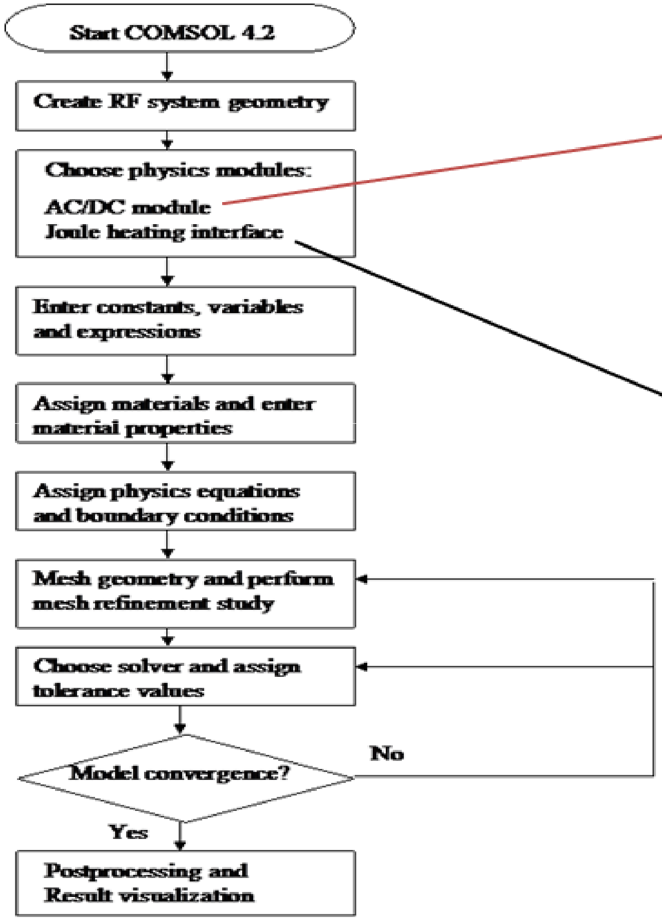
- Conventional heating of material wastes energy during heating due to inherent radiation, conduction and convection based heating mechanism.
- Radio frequency based electromagnetic heating is increasingly used for efficient heating in place of conventional heating methods
- The radio frequency based heating, requires efficient RF applicators for achieving uniformity of heat application
- The multiphysics coupling and parametric modeling capability of COMSOL for optimal design of applicator are highlighted.

RF heating

RF heating mechanism

- Water → H^+ and O^- = electric dipole
- RF Electric field applied → dipoles in water orient themselves to the field
- Rapidly changing oscillating electric field changes from (+) to (-) & back again several millions times per second → dipoles attempt to follow changing electric field → Frictional heat → Increase in temperature of water molecules
- Advantages of RF heating include heating uniformity, speed of heating, selective heating, reduced treatment time, increased productivity, rapid on/off of heating apparatus

Governing Equation



Quasi-static approximation (dim < λ/10)

$$\nabla\left(\sigma + j2\pi f\varepsilon_o\varepsilon''_m\right)\nabla V = 0$$

$$Q = 2\pi f\epsilon_0\epsilon_m''|\mathbf{E}|^2$$

RF power loss density

$$\frac{\partial T}{\partial t} = \nabla\alpha\nabla T + \frac{Q}{\rho C_p}$$

Heat equation

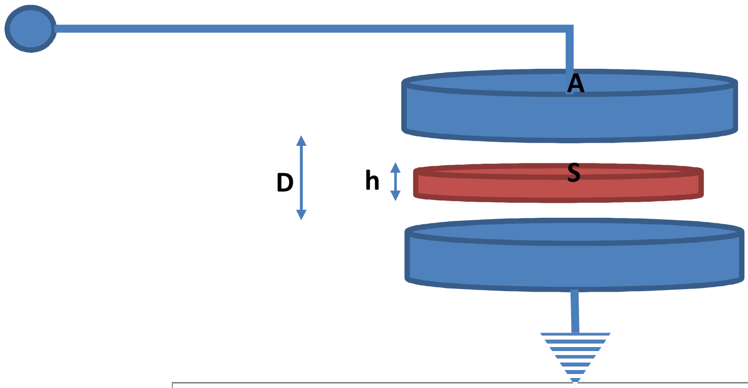
Power Uniformity Index

$$PUI = \frac{\frac{1}{V_{vol}}\int_{V_{vol}}\sqrt{(Q - Q_{av})^2}\,dV_{vol}}{Q_{av}}$$

DoE Design and Simulation

- A dielectric disk is considered for heating performance evaluation and an efficient RF applicator design with a better PUI is the objective of the DoE
- The uniformity of heat application(PUI) or electromagnetic energy distribution is used as metric to evaluate the efficiency of the RF heating applicator.
- Various factors of applicator design which will affect PUI as well as heating is studied
- COMSOL Multiphysics was selected for electrical, thermal and coupled electro thermal simulation. The AC/DC module was used for estimating the power uniformity index and optimization of electrode.

Results and Discussion



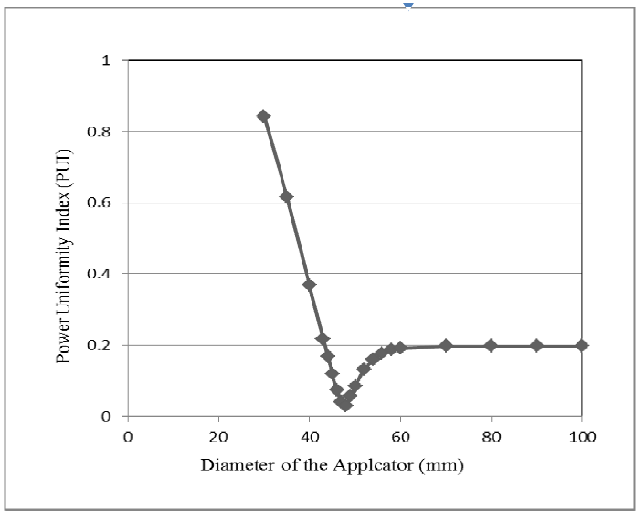
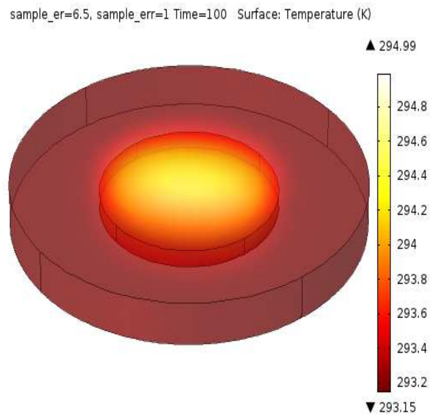
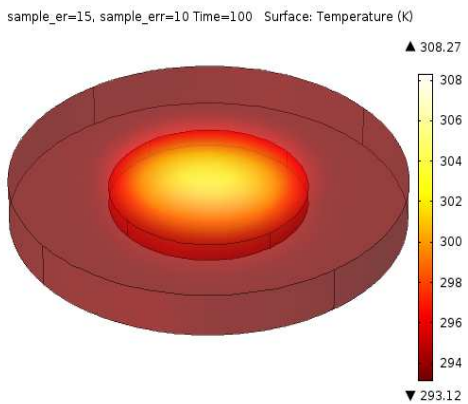


Figure 1. Power uniformity index as a function of the diameter of the applicator.

- The size of electrode was changed from 30 mm to 100 mm diameter and results are as shown in figure , for a electrode gap distance of 10 mm. The PUI was lower around the diameter of the dielectric disk and is lowest at around 48 mm. This is comparable to the size of the sample. An electrode size of 46 to 50 mm will provide us PUI of less than 0.1.

Results and Discussion





- An investigation performed to study the effect of material properties on the heat up performance using the microwave-heating module. The sample dielectric constant and loss factor varied from 6.5 to 15 and 1 to 10, respectively. The increase in dielectric constant and loss factor increases the heat buildup. The loss factor plays a significant role in the heat buildup. This simulation is to study the effect of material property on the performance.

Results and Discussion

- Also it is noted from experiments that PUI is also a function of inter electrode distance .
- Lower the gap distance lowest is the PUI.
- Also it is noted from experiments that PUI is also a function of shape of the material being heated with elliptical and cylindrical shapes offering lower PUI
- Based on the applicator design and heating performance optimization, a RF heating setup for dielectric disk was fabricated and experimentally evaluated for uniform heating. The results were in good agreement with prediction

Conclusion

- Electromagnetic RF heating provides an alternate and energy efficient heating method for processing of materials
- COMSOL multphysics tool is an useful tool for carrying out coupled Electromagnetic and Heat Transfer Simulations