

CYLINDRICAL APPLICATOR FOR MICROWAVE HEATING OF FLUIDS

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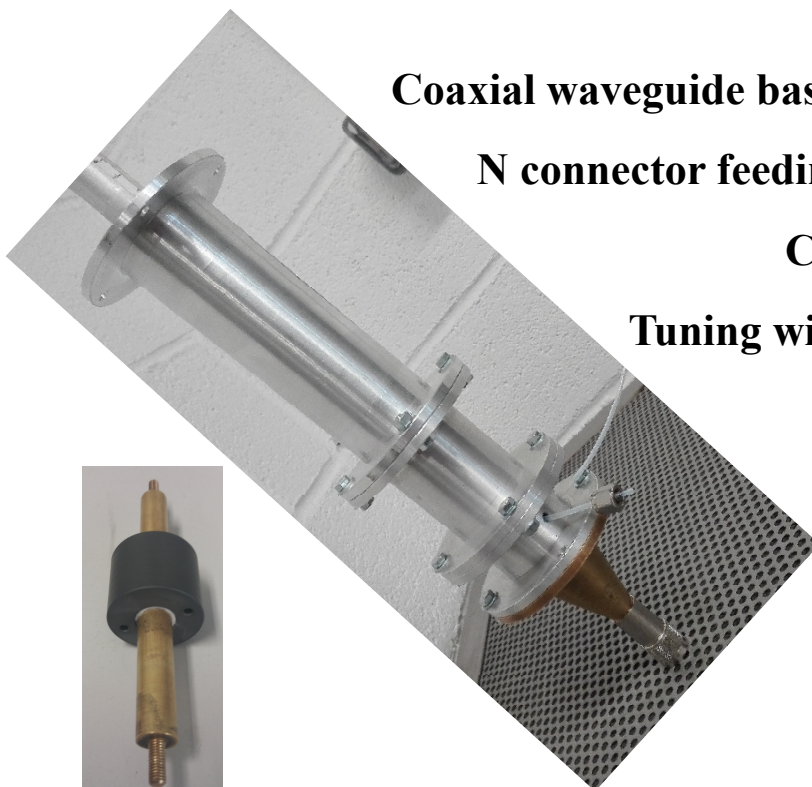
Objective

A tailor-made applicator for microwave processing of continuously flowing fluids

- More compact and more economical intensification process
- Miniaturization of reactor: less energy consumption, less raw material, less solvent in chemical process
- Microwave heating: heating volumetric and uniform. Also selective heating for polar dielectric

Description of Applicator

Important Characteristics



Coaxial waveguide based microwave structure

N connector feeding microwave generator

Compact ceramic reactor

Tuning with shorting sliding plate

Multiphysics Simulation

Electromagnetic Simulation

- **Governing equations**

$$\text{Maxwell-Faraday} : \text{rot.} \vec{E} = \frac{\partial \vec{B}}{\partial t} \quad (1)$$

$$\text{Maxwell-Ampère} : \text{rot.} \vec{H} = \frac{\partial \vec{D}}{\partial t} + \vec{J} \quad (2)$$

$$\text{Maxwell-Gauss} : \vec{\nabla} \cdot \vec{D} = \rho \quad (3)$$

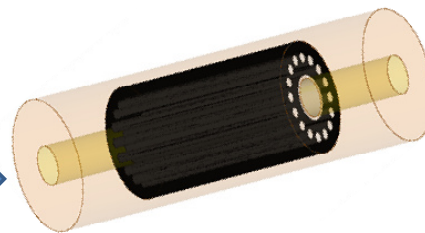
$$\text{Maxwell-Flux} : \vec{\nabla} \cdot \vec{B} = 0 \quad (4)$$

RF source



- **Domain of Simulation**

Compact Reactor

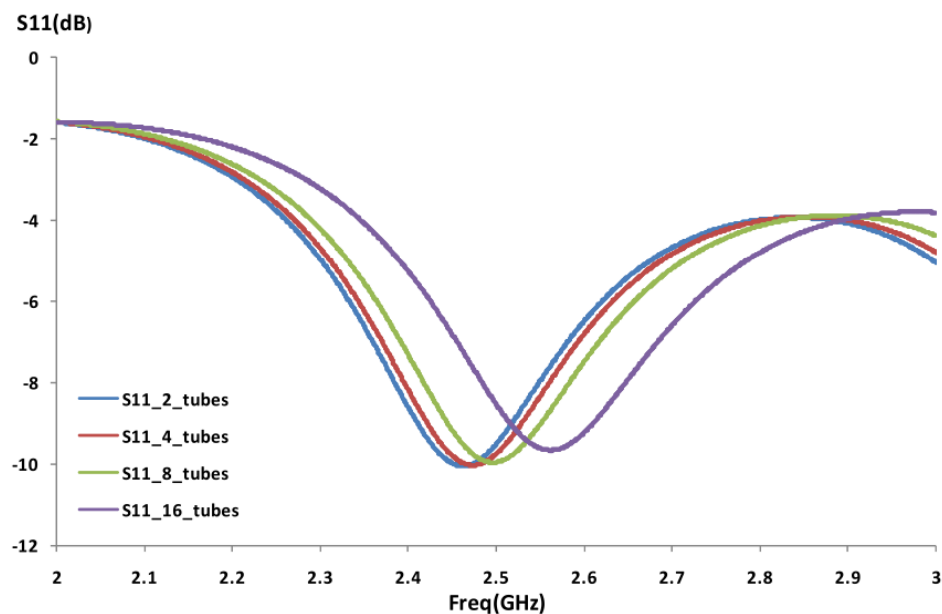


Shorting plate

Multiphysics Simulation

Electromagnetic Simulation

- **Electrical efficiency**

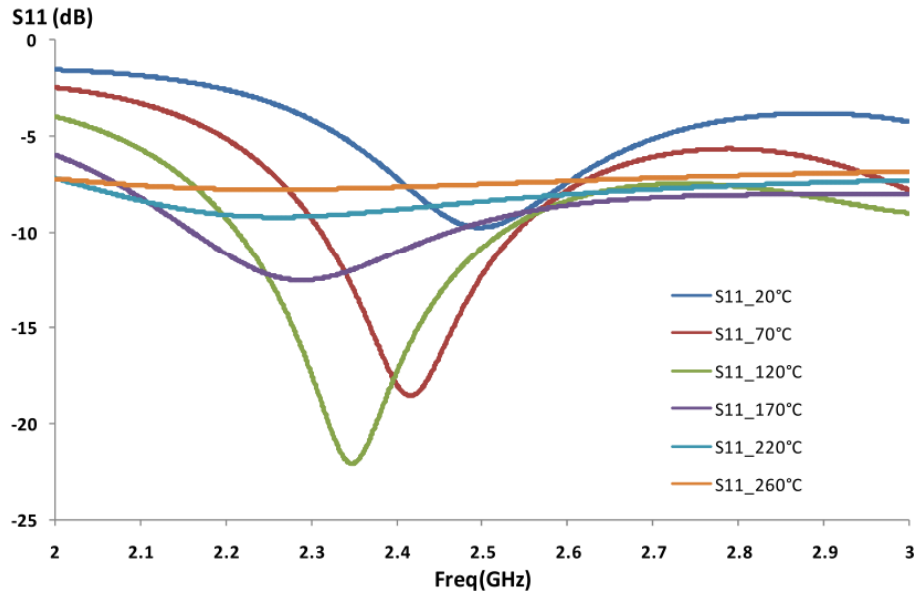


Between 80% et 90% power absorption depending on number of holes

Multiphysics Simulation

Electromagnetic Simulation

• Temperature influence on Electrical efficiency (2 holes)

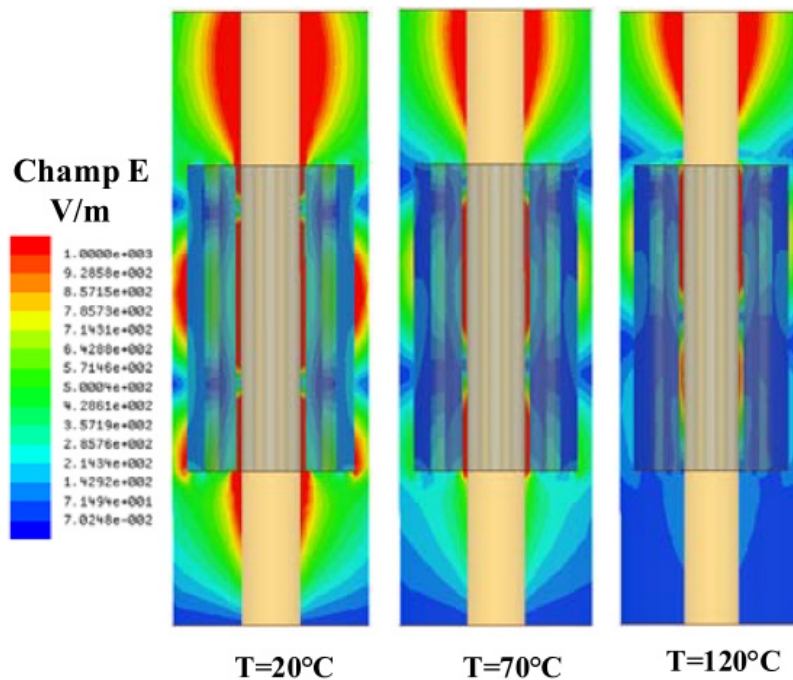


- ✓ Temperature increase improve power absorption until 200°C
- ✓ EM energy transfer change from resonant mode to leaky propagating mode

Multiphysics Simulation

Electromagnetic Simulation

• Temperature influence on Electrical efficiency (16 holes)



Multiphysics Simulation

Heat Transfer Simulation

• Governing equations

$$Q + \nabla \cdot (k \nabla T) = m C_p \frac{\partial T}{\partial t} + h S (T_{\text{ext}} - T) + \xi \sigma_B S (T_{\text{ext}}^4 - T^4)$$
$$Q = P_{\text{abs}}$$

- Q : Heat source (W)
m : Mass (kg)
C_p: Specific heat (J/kg.K)
T : Temperature (K)
T_{ext} : Ambient temperature (K)
k: Thermal conductivity,(W/m.K)
S : Surface between the material and the ambient air(m²)
h: Heat transfer coefficient(W/m²,K)
σ_B: Constant of Stefan-Boltzmann
P_{abs} : Absorption electromagnetic power (W)

Multiphysics Simulation

Heat Transfer Simulation

• Heating rate as function of RF generator's power

✓ *Reactor with 2 holes: RF source of 50W*

Time needed for temperature rises from 20°C to 150°C: 350S

✓ *Reactor with 2 holes: RF source of 300W*

Time needed for temperature rises from 20°C to 150°C: 60S

Reactor weight (g) : 140

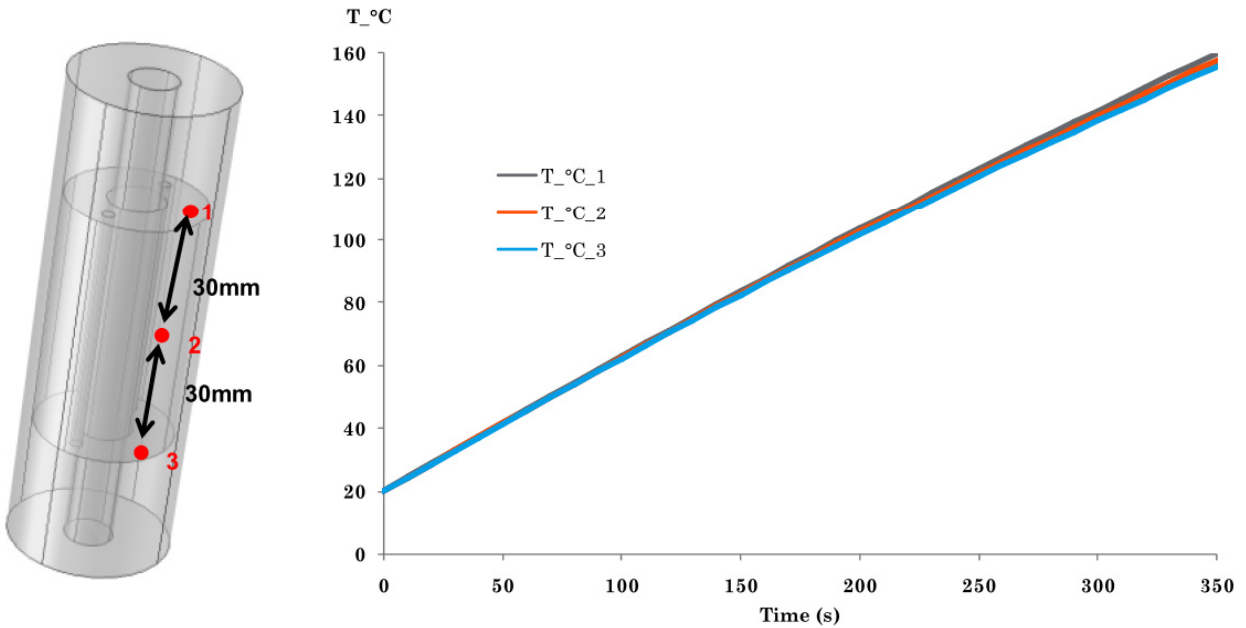
Nearly linear relation between power and time

Multiphysics Simulation

Heat Transfer Simulation

- **Homogeneity of microwave heating**

Temperature variation with RF source of 50W



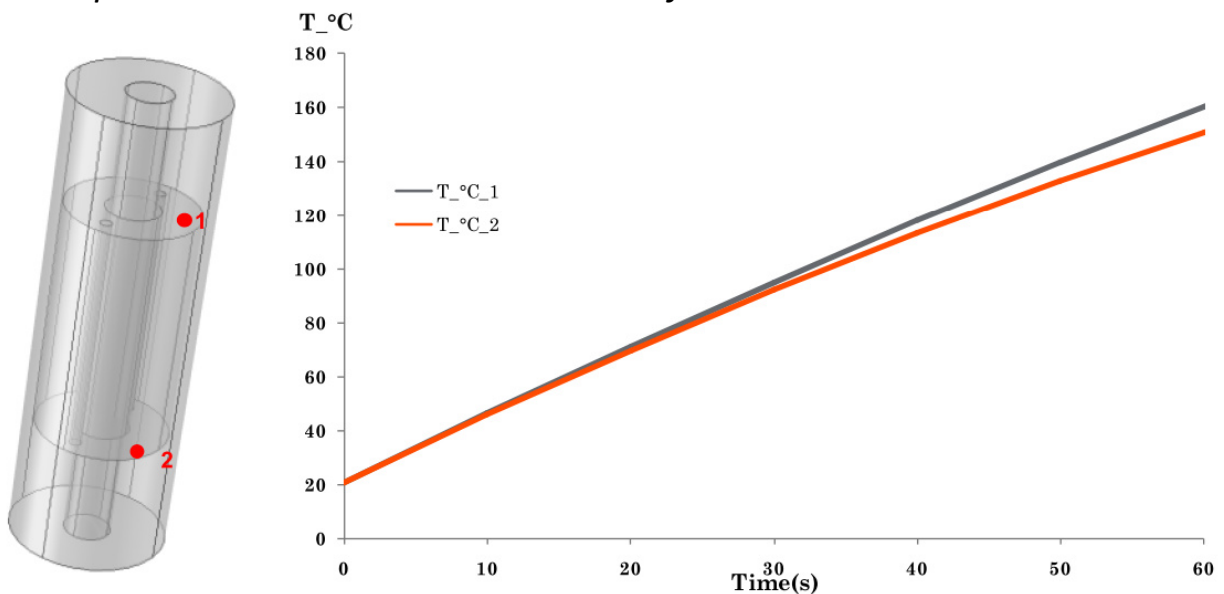
✓ Very small difference for 3 positions temperature

Multiphysics Simulation

Heat Transfer Simulation

- **Homogeneity of microwave heating**

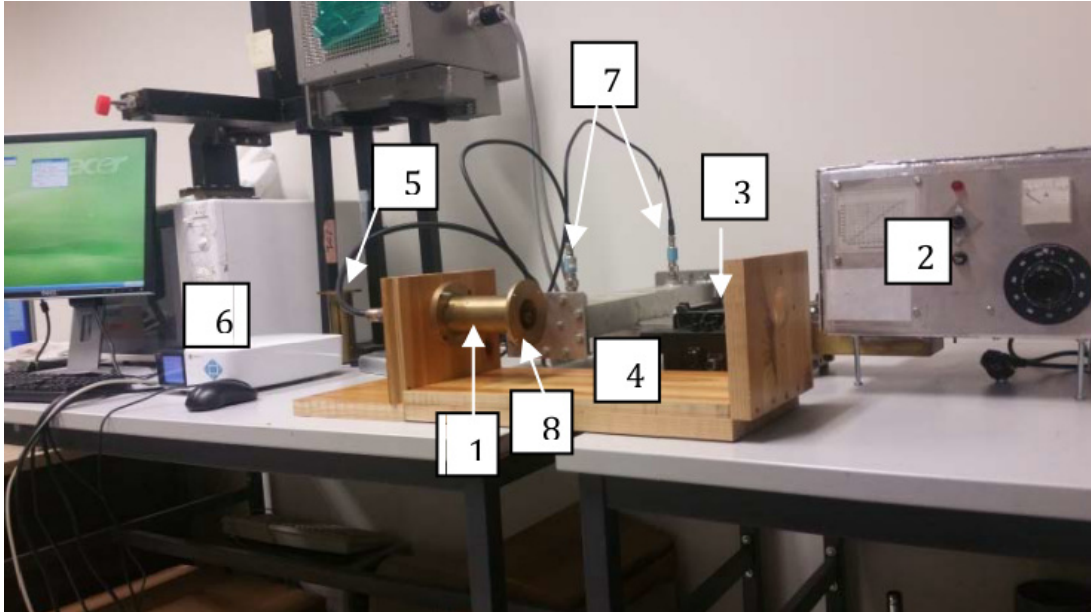
Temperature variation with RF source of 300W



✓ Larger difference from 80°C

Experimentation

Experimental Setup

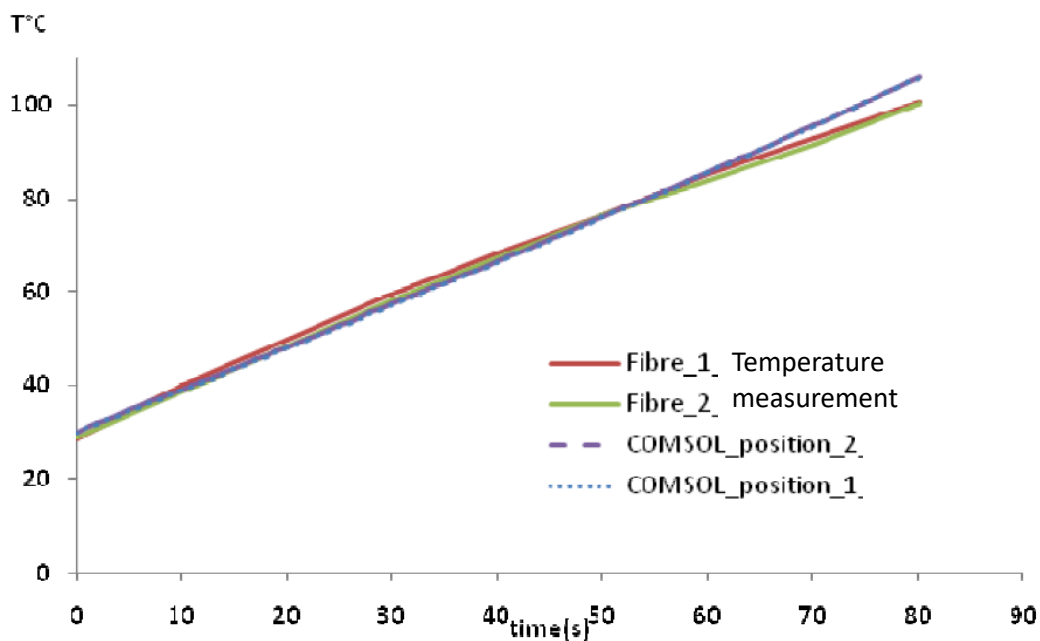


1. Coaxial cell with reactor inside. 2. Magnetron generator. 3. Circulator. 4. Directional coupler. 5. Waveguide to N connector Transition. 6. Optical fiber controller. 7. RF Sensor. 8. Shorting plate

Experimentation

Experimental Validation of COMSOL simulation

- **Microwave heating of 8 holes applicator with 85.8W power**

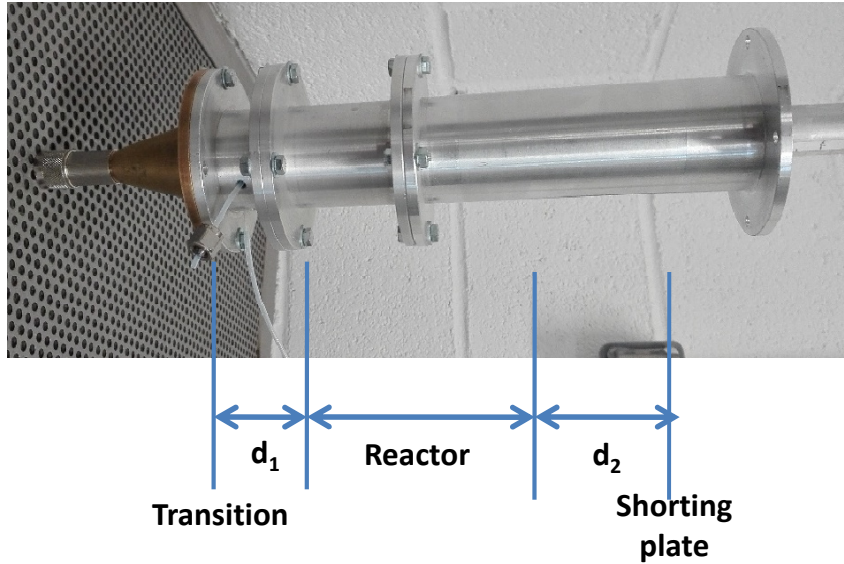


✓ Very close temperature variation between measurement and simulation

Experimentation

Optimization Work on Energy Transfer Efficiency

- **Parametrical study of applicator's return loss. Ambient T**

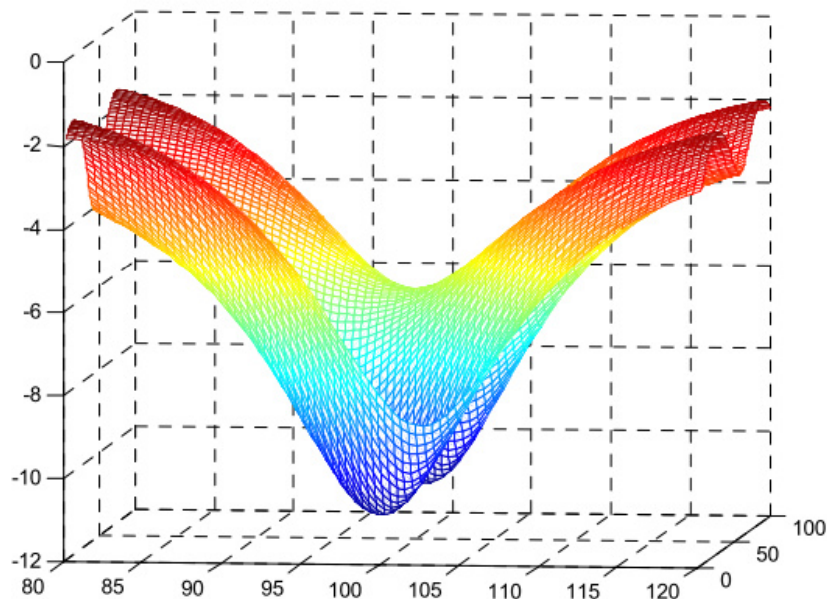


Two distances can influence the return loss

Experimentation

Optimization Work on Energy Transfer Efficiency

- **Return loss (reactor without hole) versus d_1 and d_2 (mm)**

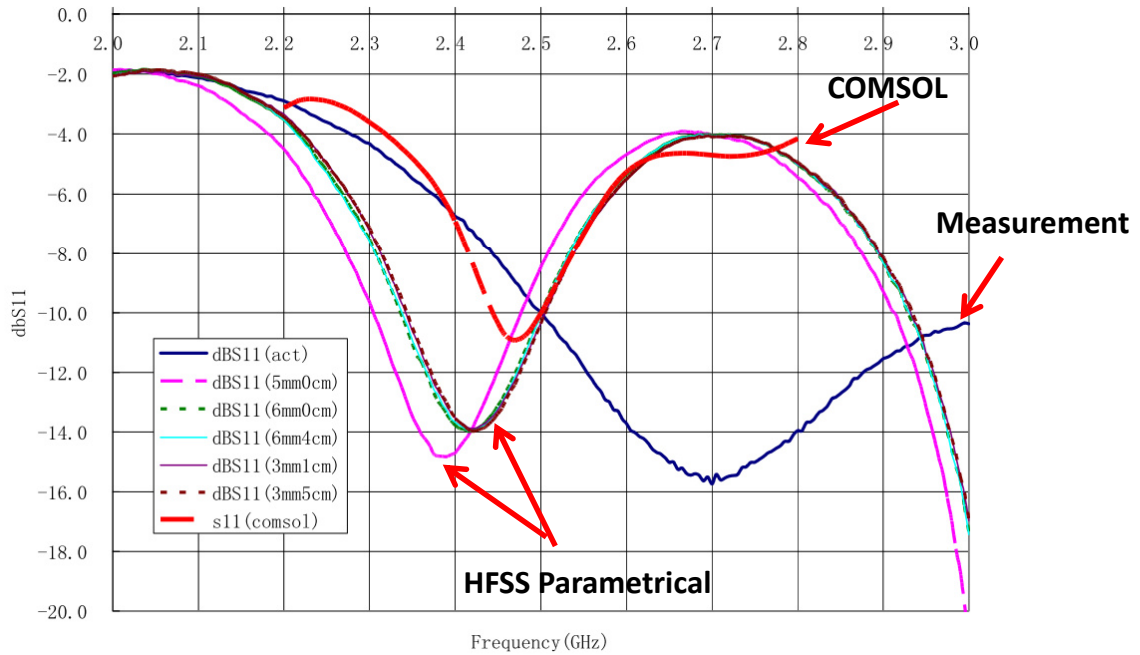


- ✓ Minimum exists
- ✓ Tuning very sensible

Experimentation

Optimization Work on Energy Transfer Efficiency

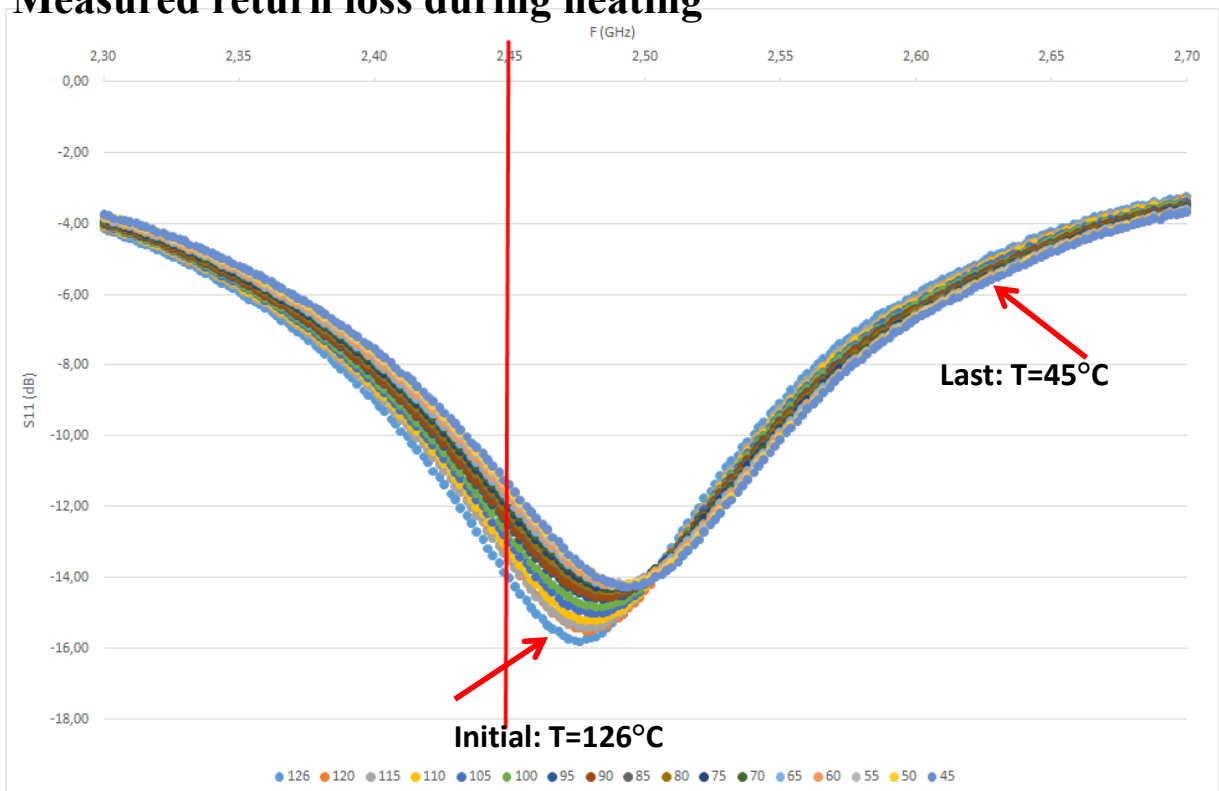
- Return loss (reactor without hole) study



Experimentation

Energy Transfer Efficiency during heating process

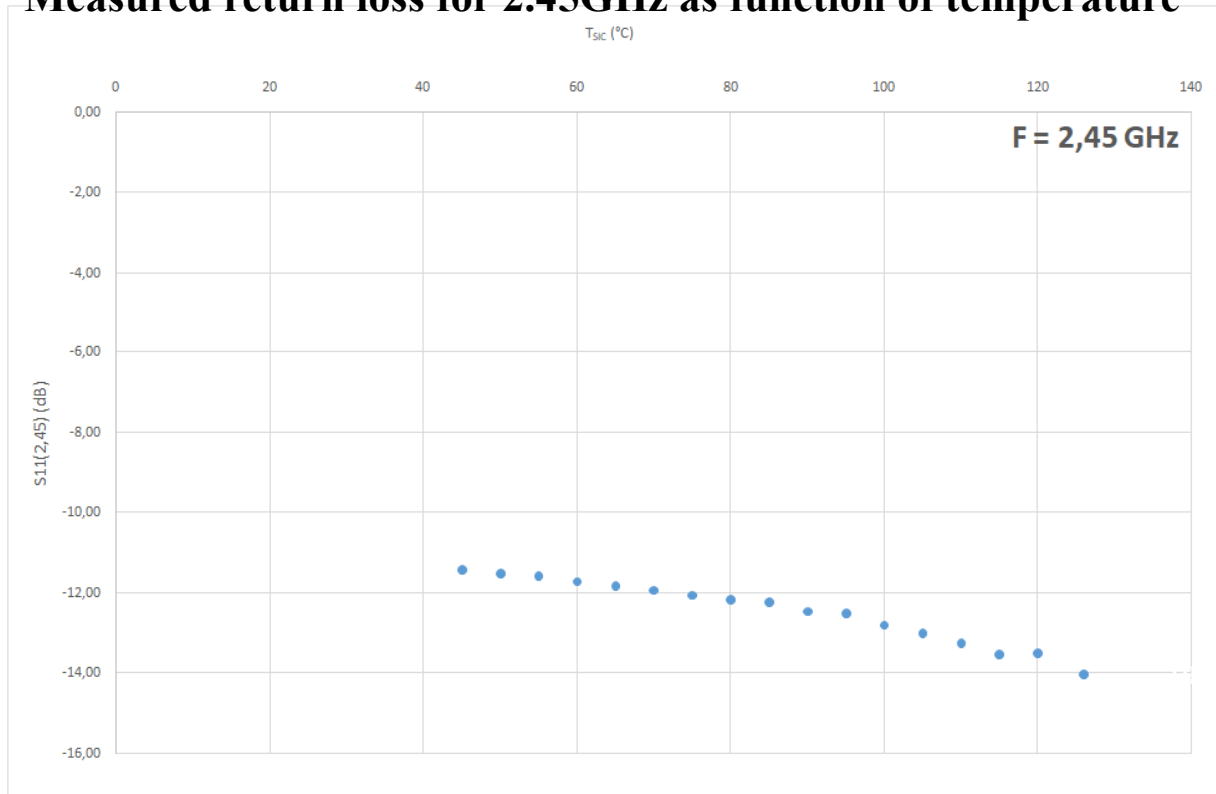
- Measured return loss during heating



Experimentation

Energy Transfer Efficiency during heating process

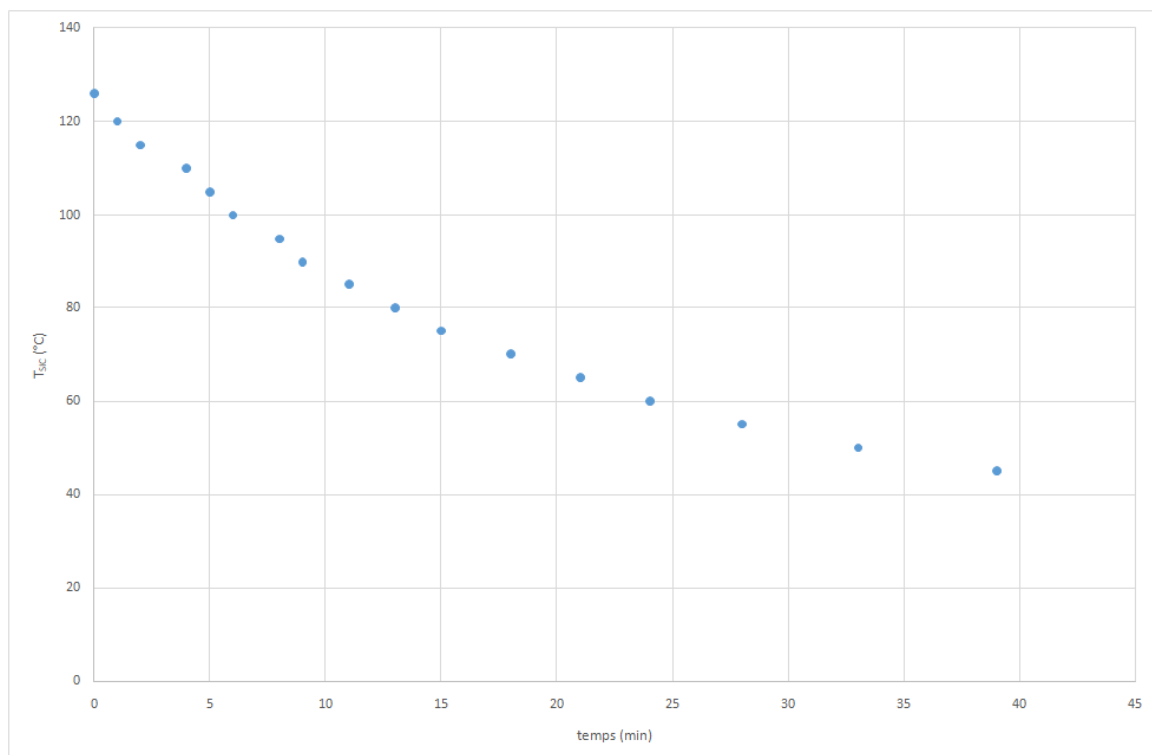
- **Measured return loss for 2.45GHz as function of temperature**



Experimentation

Temperature variation after MW heating

- **Temperature decrease rate when MW heating removed**



Conclusion

Work done

- Design of cylindrical applicator
- Study of energy transfer efficiency
- Study of heating rate
- Relation between heating rate and heating homogeneity and MW power
- Applicator optimization for energy efficiency
- Role of temperature

Thanks

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Thanks for your attentions!

