Microwave Assisted Vacuum Drying Processing: Magnetron vs Solid State A Case Study of Apple Drying

COMSOL CONFERENCE 2018 LAUSANNE

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Introduction: Lyophilization is a vacuum based process to remove water content in food products for preservation. This process yields inhibition of microbial growth, extended shelf life of food and less weight and volume for transportation. Heat is provided to shortening the process. The treatment must be run gently to avoid damaging of the products, thus temperature should be maintained low. Assisting the process with microwaves, it is possible to convert energy directly in the material with high selectivity since water is the main absorber. Energy transfer rate is not related to temperature gradients. In order to achieve very high uniformity, it is fundamental to compare different MW technologies by assessing their performances.

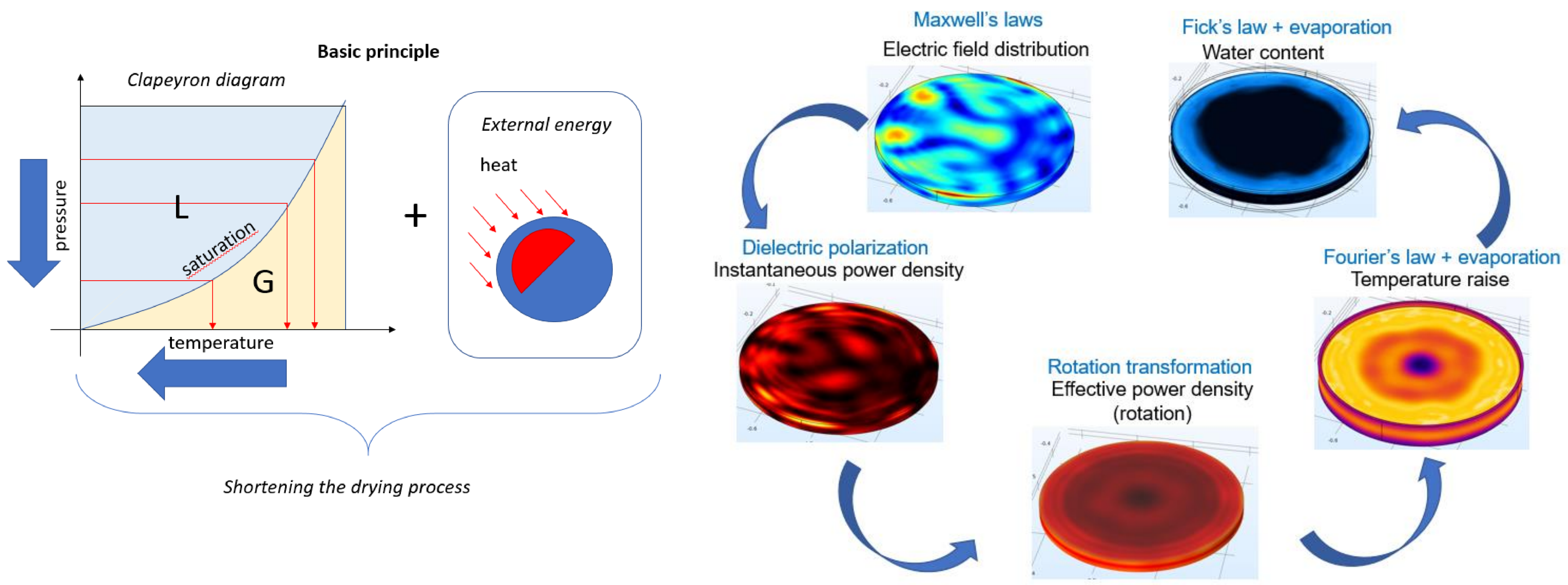


Figure 1. Schematic representation of the microwave vacuum drying process

Computational methods: The model has been implemented given specific BCs, ICs and Governing Equations.

Boundary conditions	Initial conditions
RF Electromagnetics	**RF Electromagnetics**
$n \times E = 0$ Perfect Electric Conductor	$E(x,y,z) = 0$ Absence of field
$S = \frac{\int_{\partial\Omega}(E - E_1)\cdot E_1}{\int_{\partial\Omega} E_1 \cdot E_1}$; TE_{10} EM propagation mode	**Heat transfer**
Heat transfer	$T(x,y,z) = 20°C$ Environmental temperature
$q = h(T_{ext} - T)$ Low level natural convection	**Vacuum drying**
Vacuum drying	$\theta_L(x,y,z) = 0.84$ Fresh product water content
$n \cdot c\Delta\theta_L = 0$ No flux of θ_L. B.C. is already included as mass depletion due to evaporation (sink term).	These conditions are necessary to compute the numerical solution of the PDE equations which are associated to each physics, and to guarantee uniqueness of results.

Table 1. Boundary and initial conditions of the vacuum drying process

Physical coupling: Depending on the different evolution time scales (e.g. electromagnetic waves and thermal inertia), and given certain direct relations (e.g. loss of heat and water due to evaporation) or indirect interrelations between interfaces (e.g. material properties change), and including the characteristics of the process (e.g. rotation) and technology degrees of freedom (e.g. frequency shift, phase shift) we can define the schema as follows.

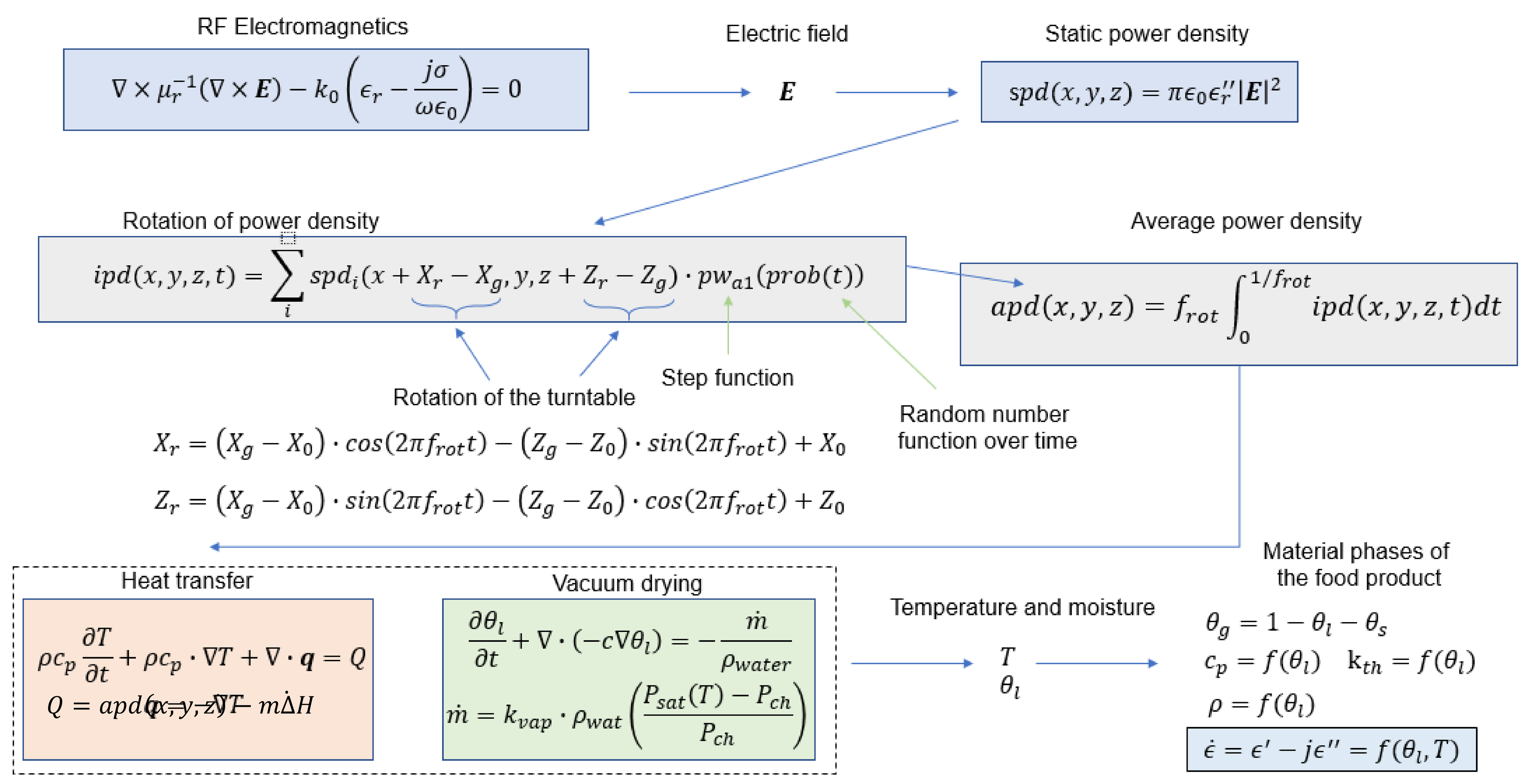


Figure 2. Schematics of couplings between the physical interfaces

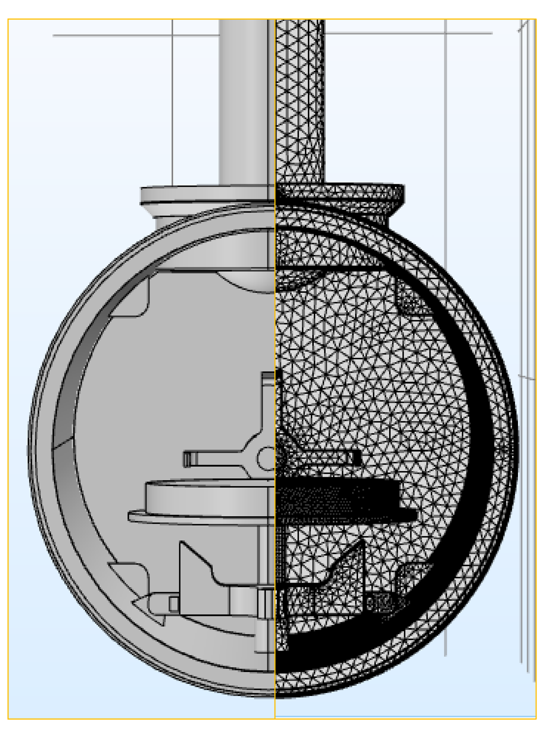
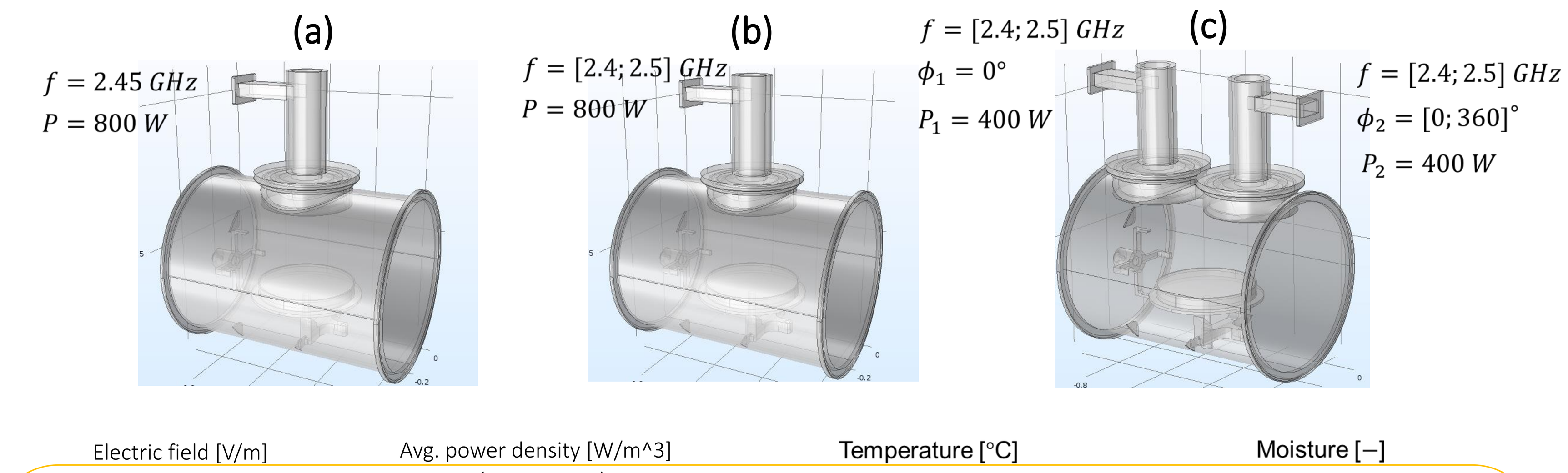


Figure 3. Implemented geometry and mesh

Figure 4. Real chamber in laboratory

Results: The model has been used to compare the performances of (a) Magnetron based system; (b) One port solid-state based system (c) Two ports solid-state based system.



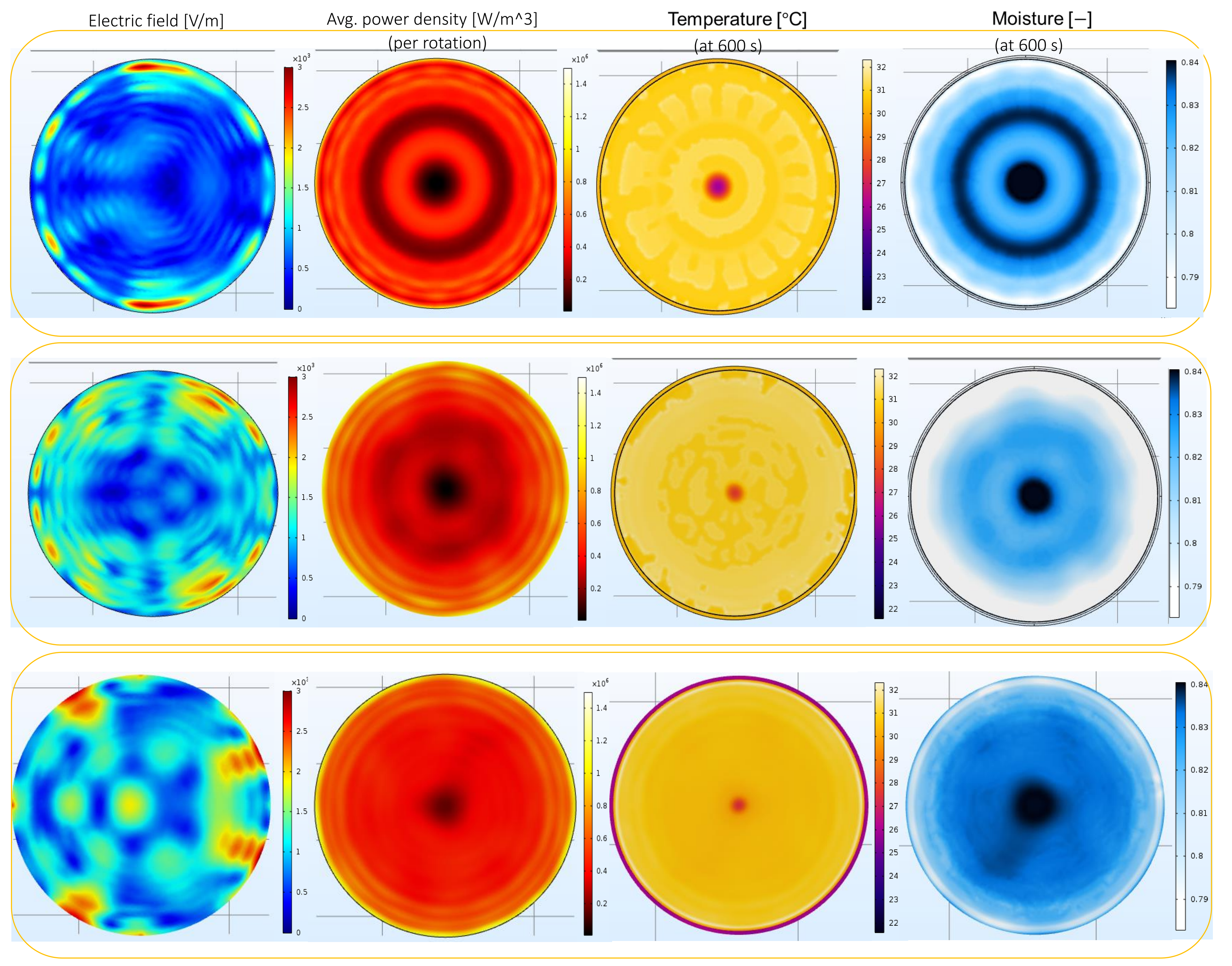


Figure 4. Field pattern distributions

Discussion: Solid state microwave sources improve greatly the performances in terms of uniformity with respect to classical magnetron technology. In particular, multiport systems increase homogeneity by maximizing the number of degrees of freedom in terms of reconfigurable electric field patterns.

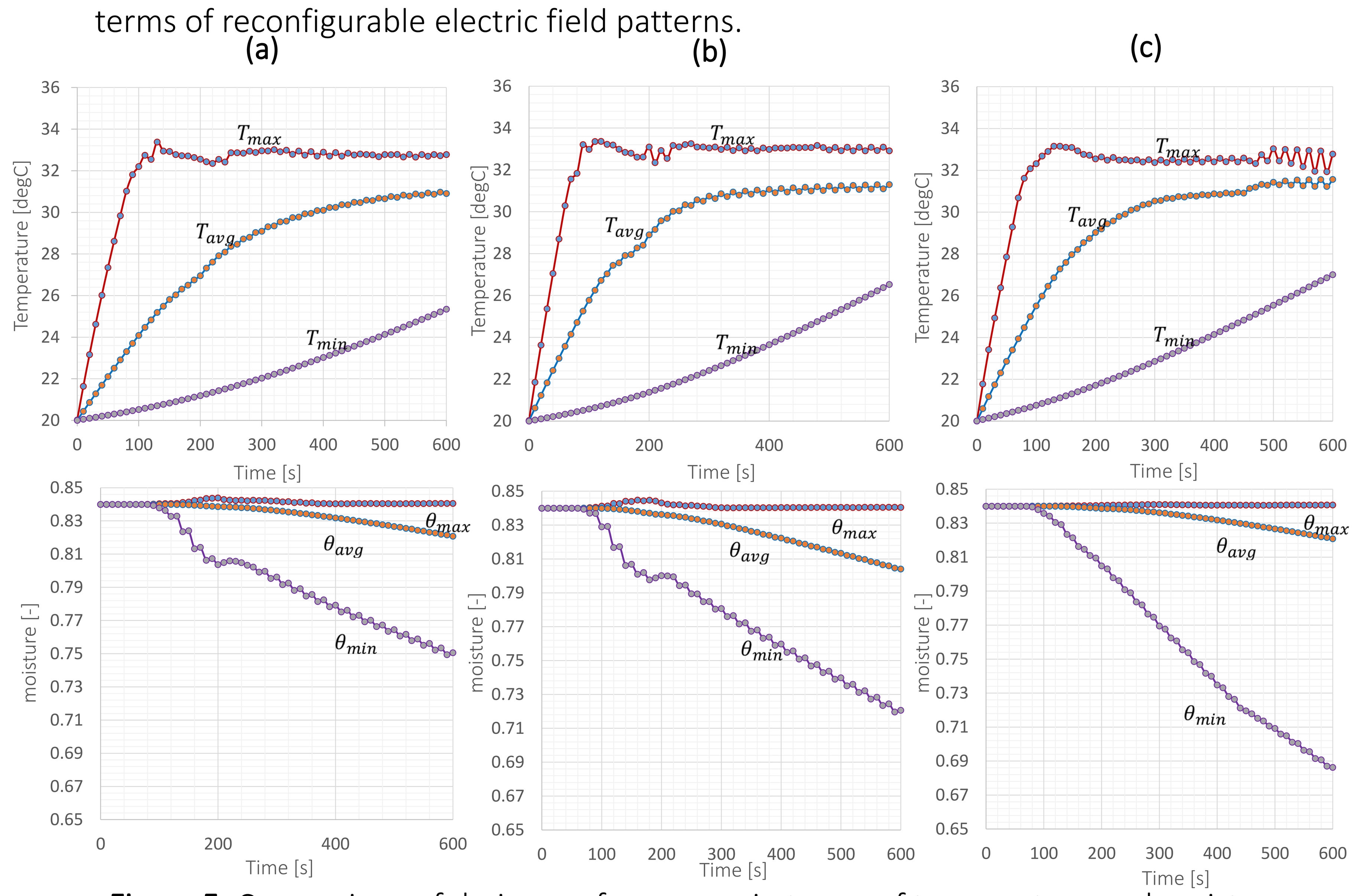


Figure 5. Comparison of drying performances in terms of temperature and moisture

Conclusions: COMSOL Multiphysics® Software is a valuable tool to assess the performances of different products which are characterized by specific technologies and to design high quality optimized devices. The current analysis has confirmed the capability to improve greatly microwave heating performances for lyophilization by adopting solid state MW amplifiers to perform high-quality vacuum drying processes.

References:

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