Numerical Analysis of an Ultrasonic Technology for Food Dehydration Process Intensification

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Abstract

Introduction: Industrial processes assisted by high-power ultrasound have become an attractive field for industries because of its sustainability (low energy consumption, non-pollutant processes). These processes are based on the proper exploitation of the nonlinear effects associated to finite-amplitude-wave propagation that are able to enhance mass transfer processes in food dehydration.
In this work, the design of a new high-power ultrasonic transducer for food dehydration intensification and the effects produced on food samples located inside a dehydration chamber have been performed using COMSOL Multiphysics®.

Use of COMSOL Multiphysics: The mathematical model, including the Structural Mechanics Module, the Acoustics Module and the multiphysics analysis of COMSOL® allowed us to determine the influence of the different constitutive parts of the transducer, as well as the generated ultrasonic field inside a dehydration chamber where the samples were placed. The transducer is composed by a four piezoelectric ceramics stack tuned into a thickness vibration mode, two attached steel masses (Figure 1) and a mechanical amplifier (or horn) vibrating in an extensional mode. The stepped-grooved circular plate transducer is bolted at the horn's tip, and has an operational mode with a seven nodal circles (Figure 2). The whole system's mechanical behavior has been studied, considering the masses, horn and radiator as linear elastic materials, and obtaining the transducer's operational mode around 25 kHz (Figure 3).
This kind of extensive radiator may produce a high power acoustic field in air due to the good impedance matching achieved between the radiating plate and the gas medium, and a coherent ultrasonic radiation because of the ½ wavelength steps of the radiating surface.
A multiphysics analysis allows us to study the interaction between the structure and the fluid media, in this case, air at 15 °C, and considered as a thermo-viscous fluid. The transducer generates an ultrasonic field inside a dehydration chamber that depends on the chamber characteristics (dimensions, thickness and acoustic reflectivity), the fluid properties and structure-fluid interaction.
Finally, in order to simulate the effect of placing a food sample inside the chamber, a new calculation has been done, reducing the sample to a fluid characterized by its physical characteristics like porosity, flux resistance and density, so it is possible to determine how the sample absorbs the acoustic energy and, by a parametric study, find the places inside the chamber where the acoustic absorption of the food sample is the highest.

Results: After the numerical analysis, a high-power ultrasonic transducer with an operational mode at 24931 Hz was designed and the ultrasonic field inside a dehydration chamber was obtained. The most efficient location to place the samples was near the axis at a distance around 0.5 m from the plate transducer (Figure 4).

Conclusion: The main objective of this work is to present the mechanical and acoustic analysis done using COMSOL Multiphysics over this new high power ultrasonic transducer for food dehydration process intensification, as well as the parametric study of the sample location inside the chamber, in order to optimize the system efficiency.

Reference

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Figures used in the abstract

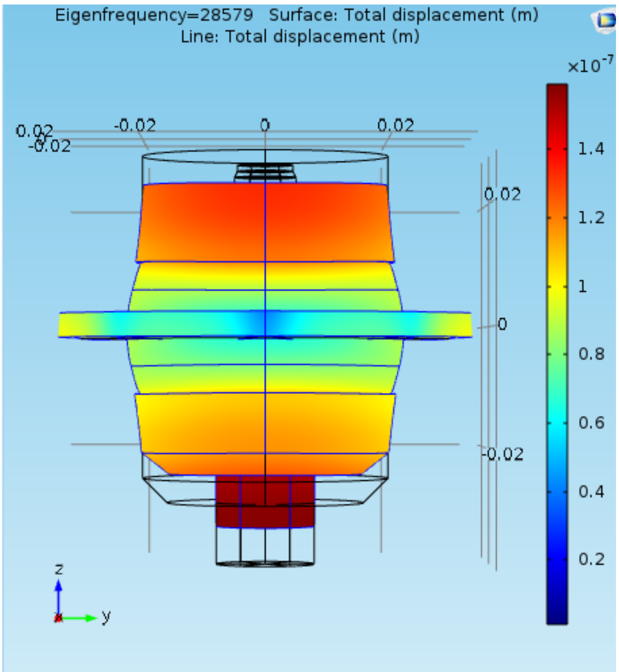

Figure 1: Extensional mode of the sandwich transducer.

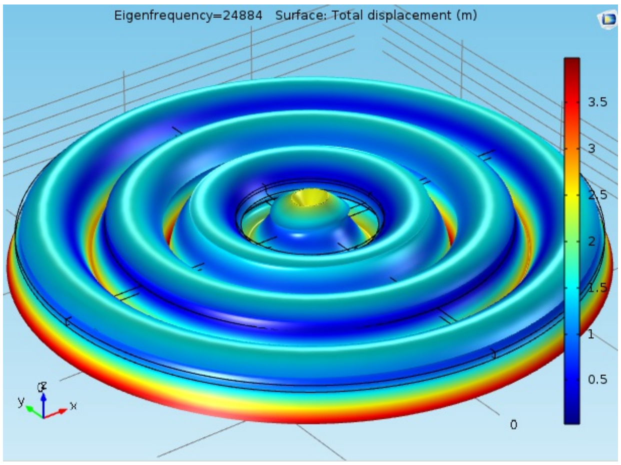

Figure 2: Seve nodal circles mode of the circular plate radiator.

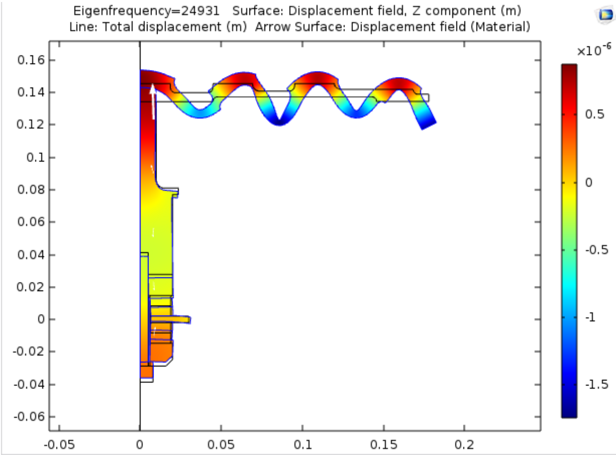

Figure 3: Operational mode of the whole system.

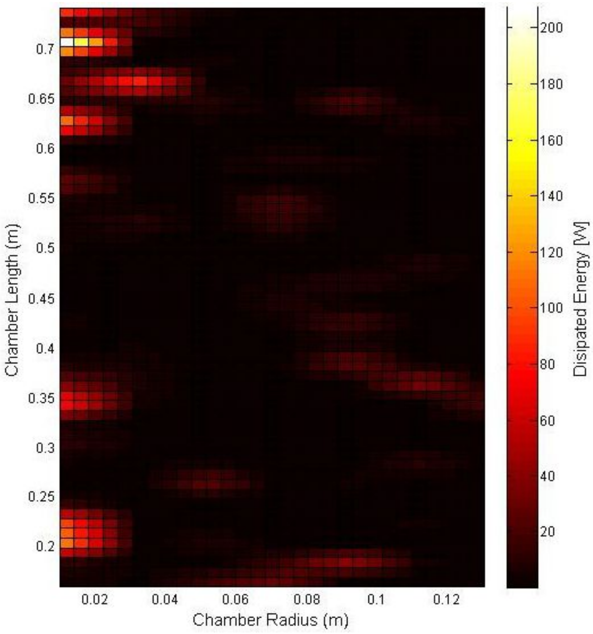

Figure 4: Food sample absorption field.