Coupled CFD-Structural Mechanics Simulation Of Deformation In Non-Rigid Polypropylene Food Packaging

Sadhan Jyoti Dutta[1], Olivier Rouaud[1], Patrice Dole[2], Alexandre Thillier[3], Sebastien Curet[1]

[1]Oniris, Nantes Université, CNRS, GEPEA, UMR 6144, F-44000 Nantes, France
[2]CTCPA, 64 Rue de la Géraudière, 44322 Nantes Cedex, France
[3]SAIREM - 82 Rue Elisée Reclus, 69150 Décines-Charpieu, Lyon, France

Abstract

Deformation of food packaging materials due to internal pressure buildup during sterilization is a critical concern for packaging integrity and product safety, particularly in non-rigid containers like polypropylene (PP) trays for ready-to-eat meals. (Dutta et al., 2024b). Internal pressure primarily results from water vapor generation and dry air expansion during heating (Dutta et al., 2024a). This causes inflation and displacement of the top polymer film. This displacement, especially near the heat seal, can indicate potential rupture. To our knowledge, no prior studies have addressed this. Hence, this study investigates numerically and experimentally the maximum PP film displacement using CFD and solid mechanics.

A CFD approach with injection of air into the PP tray through a small inlet was used to analyze the deformation and stress on the PP film, and pressure generated inside the tray. The multiphysics phenomena were investigated with COMSOL® 6.3 (CFD and Solid Mechanics modules). The internal airflow (laminar) was simulated using the compressible Navier-Stokes equations (time-dependent study), and the structural mechanics of the PP film was modeled using equations for deformable solids (time-dependent study).

A 2D model of the empty PP tray (filled with air) was chosen in COMSOL® (Figure 1) as a first approximation. Mechanical properties of the PP material (Young's modulus and Poisson ratio) were incorporated into the geometry. Using a parametric sweep for Young's modulus and Poisson ratio values, the best-fit values were chosen (Young's modulus (PP): 1.8476 GPa & Poisson ratio (PP): 0.42). Air properties were imported directly from the application library of COMSOL®. Parametric sweep on air flowrates (0.1 L/min, 0.15 L/min, and 0.6 L/min) was performed to investigate the maximum displacement of the PP film until its rupture as a relation to air flowrates. These values of air flowrates were chosen as these values were used during the experiments. The study was computed from 0 s to 100 s with mesh of 3190 triangular elements as this mesh gave accurate results.

Simulations showed the displacement of the PP film as a function of air flowrate (Figure 2). Simulation results are compared with experimental measurement of film displacement obtained from 2D image analysis. A 0.1 L/min air flowrate produced a maximum film displacement of 8.66 mm (10 mm in experiments) in 94 s, a 0.15 L/min air flowrate produced a maximum film displacement of 10.18 mm (10.83 mm in experiments) in 83 s, a 0.6 L/min air flowrate produced a maximum film displacement of 11.24 mm (10.79 mm in experiments) in 25 s. Simulated and experimental pressure values were also compared and matched well with a RMSE value of 0.015 bar.

This study lays the groundwork for future investigations involving heat treatment conditions, where water vapor generation from food will be explicitly considered to study its influence on the structural mechanics of PP food trays. The insights gained from this COMSOL®-based study can support the development of robust and efficient packaging designs suited for both conventional and non-conventional food processing applications. Future perspectives involve extending this 2D model to a 3D model.

Reference

Dutta, S. J. et al. CFD-based Approach For Prediction Of Headspace Pressure In Can During Thermal Sterilization Of Foods. COMSOL Conference 2024 (2024a). https://www.comsol.com/paper/cfd-based-approach-for-prediction-of-headspace-pressure-in-can-during-thermal-sterilization-of-foods-135292

Dutta, S. J. et al. Microwave Sterilization: Interlinking Numerical Modelling, Food Packaging, and Engineering Solutions. Food Engineering Reviews, 16(2), 192–224 (2024b). https://doi.org/10.1007/s12393-024-09370-w

Figures used in the abstract

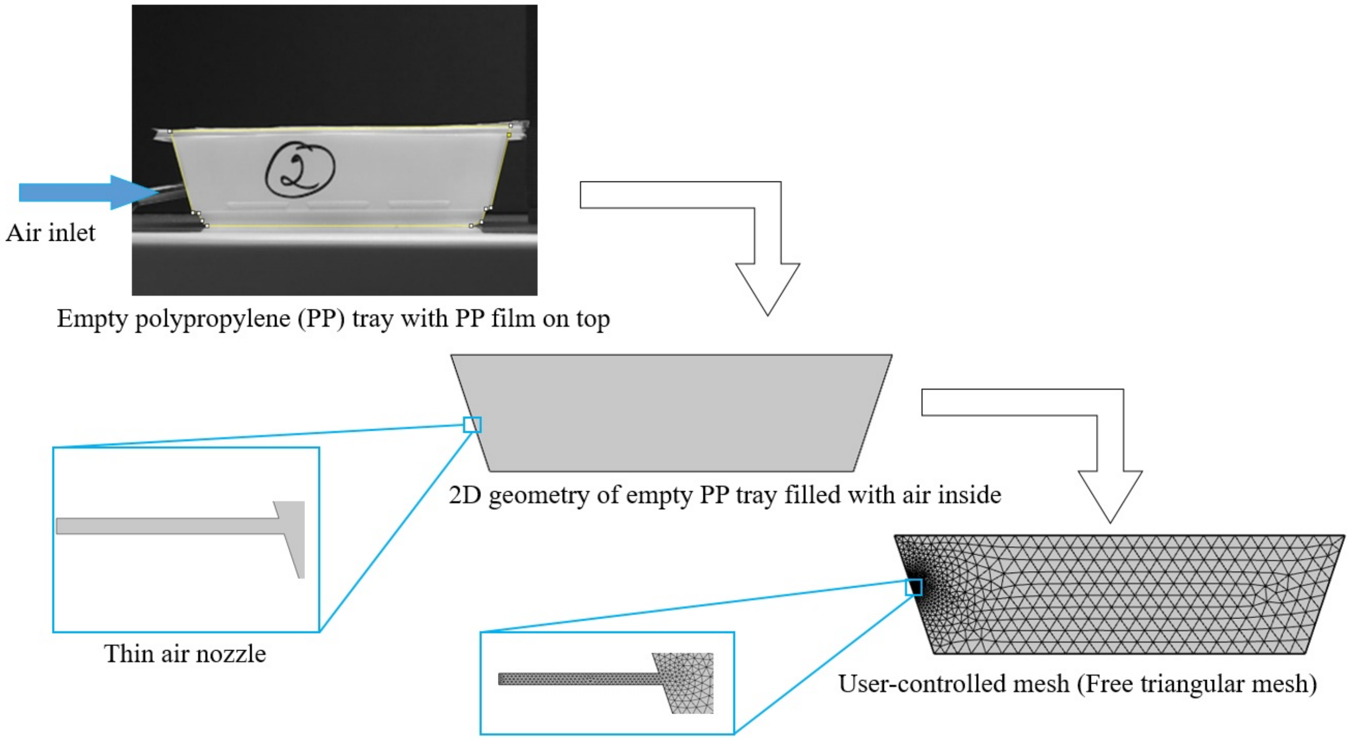

Figure 1 : Polypropylene (PP) food tray with PP film on top and meshing in COMSOL® Multiphysics 6.3.

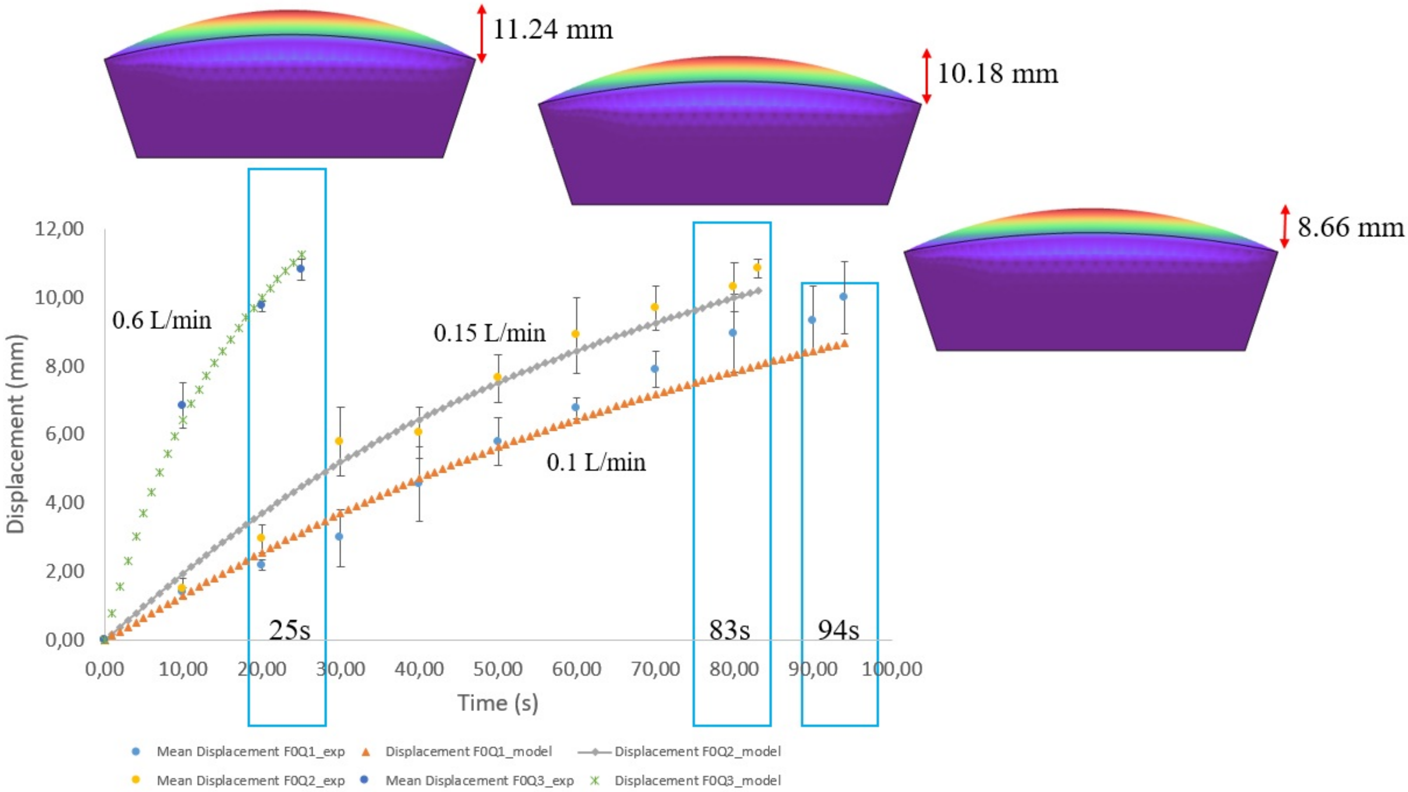

Figure 2 : Simulated and experimental displacement values of PP film from original position with respect to different air flowrates (0.1 L/min, 0.15 L/min, 0.6 L/min)