Multiphysics Modeling Of Electrohydrodynamic Drying - A Staggered Modeling Approach

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Abstract

Electrohydrodynamic (EHD) drying is a cutting-edge, non-thermal drying technique that leverages high electric field to enhance water removal from moist materials via corona wind generation. EHD drying encompasses two fundamental phenomena: corona wind generation and the drying process itself. These phenomena interact dynamically, substantially increasing the overall complexity of the EHD drying mechanism. A fully coupled multiphysics model capturing all interactions would be excessively complicated and computationally challenging due to the involvement of numerous physics.
To address this challenge, a staggered modeling approach was used: solving limited physics per stage, with the outcomes serving as boundary conditions for subsequent simulations. Corona wind was modeled first to characterize airflow, followed by thin-film drying to capture drying kinetics. The evaporation rate was then integrated with airflow to optimize dryer design.
A two-dimensional (2D) model was developed to simulate the EHD drying process, representing the frontal cross-section of a laboratory-scale EHD dryer. The simulation of corona wind generation was conducted in two stages. First, the corona discharge phenomenon was modeled by using the electrostatics (es) and charge transport (ct) physics from the plasma module and coupled using an electrode (el) multiphysics. The resulting electric field distribution was subsequently coupled with the turbulent flow (spf) physics to simulate the induced airflow. Finally, a statistical analysis was conducted to establish a correlation between the dimensionless EHD number and the Reynolds number.
The drying model used transport of diluted species (tds) and heat transfer (ht) physics to simulate water migration and evaporation, incorporating moisture migration theory for carbohydrate films. Simulated drying kinetics were validated experimentally, with mass transfer coefficients estimated via the optimization (opt) module.
Moisture transport inside the dryer was modeled using moisture transport in air (mt) and heat transfer (ht) within the heat and moisture (ham) multiphysics framework. Simulations focused on identifying moisture accumulation zones and used to explore optimum dryer geometry beyond the experimental set up.
This study demonstrates the application of a staggered multiphysics modeling approach for simulating EHD drying. By decoupling complex interactions, the method enables useful prediction of airflow, moisture transport, and drying kinetics, offering valuable insights for optimizing dryer design and performance. Additionally, this approach reduces computational demand, allowing faster solutions. The output of one model serves as a boundary condition for others, facilitating effective model integration. These results lay the groundwork for advancing scalable and energy-efficient EHD drying technologies.

Reference

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J. C. A. Ham et al., “A multi-scale analysis on electrohydrodynamic drying technology for bio-based & food products,” Trends Food Sci Technol, vol. 151, p. 104634, Sep. 2024, doi: 10.1016/J.TIFS.2024.104634.
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Figures used in the abstract

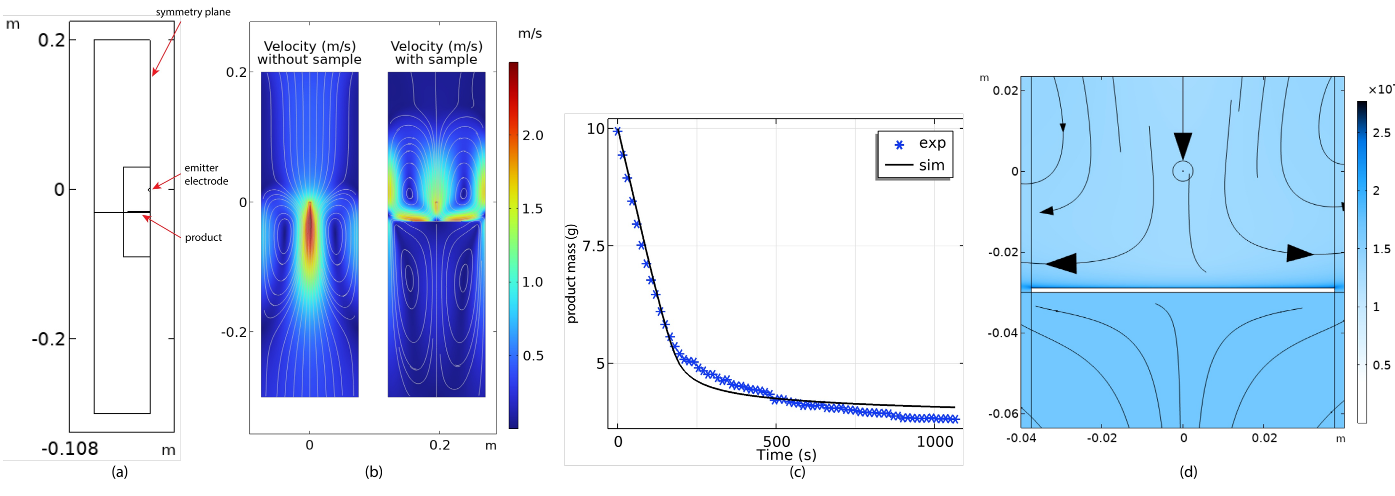

Figure 1 : Figure 1. (a) Geometry of EHD drying model, (b) Simulation results of corona wind generation, (c) Simulated and experimental drying kinetics, (d) Simulated moisture distribution in the dryer.