Scaling of continuous pulsed electric fields processes by means of dimension analysis and computational fluid dynamics

KNAPPERT J. (1), SCHOTTROFF F. (2), RIVERA J. (2), SIEMER C. (3), JER H. (2), RAUH C. (1)
1 Department of Food Biotechnology and Food Process Engineering, Technische Universit Berlin, Berlin, Germany
2 Institute of Food Technology, Department of Food Science and Technology, University of Natural Resources and Life Sciences (BOKU), Vienna, Austria
3 Elea Technology GmbH, Quakenbrck, Germany

Continuous pulsed electric fields (PEF) treatment is based on the application of high voltage electric fields (in the kV/cm-range) on a short time scale (µs-ms) to liquid food matrices or solid foods in a liquid carrier. It has recently been implemented in many sectors of the food industry, e.g., in potato processing or juice production to soften tissue, inactivate microorganisms or enhance mass transfer.
Due to the dependency of the electric field distribution on the electrode’s geometry, it is difficult to transfer knowledge from one to a different treatment chamber. Also, the characteristic flow patterns and temperature profiles in a pipe have a major impact on the effectiveness of the treatment. This makes upscaling of PEF treatments even more challenging. This knowledge gap is a major limitation in the implementation of PEF in the food industry, as process safety can only be guaranteed with the help of extensive experiments.
Computational fluid dynamics (CFD) simulation based on the balance equations for mass, momentum, energy, and free charge carriers is a suitable tool for visualizing local physical phenomena and thus investigating the influence of the geometry of the PEF chamber. However, a mechanistic approach to transfer the PEF process to other scales by means of CFD simulation is still missing. Therefore, based on the balance equations, dimensionless numbers were derived for continuous PEF treatment chambers. With this, the degrees of freedom for the scale-up were determined. CFD simulations were conducted on different scales to investigate if relevant treatment parameters behave as expected. The simulations were validated experimentally, using continuous PEF systems with throughputs from 1 to 100 L/h. The proposed study revealed that effects, for example the local heating, are more pronounced on larger scales even though, the derived numbers were kept constant. This can be attributed to physical properties of the food, for example the viscosity, which again influencing the flow properties. These overlapping effects lead to non-linearities in the scale-up. This study also shows at which scales such effects must be increasingly considered and thus provides important insights for the design of safe PEF processes on an industrial scale.