Open-cell foam ultra-realistic microstructure model: a new generation workflow validated through experimental data and CFD simualtions

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Résumé

Over the past thirty years, the use of open-cell foams has significantly increased in various domains of the process industry, serving purposes from catalyst support in fixed bed reactors to particulate filters for molten metals. These foams, characterized by high porosity and large specific surface, are valued for the associated low pressure drops and high mass transfer coefficients. Commercially available foams are typically identified by their pore per inch (PPI) value, an approximation of the average pore diameter size, and porosity ϵ. However, limited is the knowledge regarding other geometric parameters such as Specific surface (SV) and tortuosity (
tau), their influence on foams performances.
The objective of this abstract is to introduce an ultra-realistic microstructure foam model and its digital workflows, which have been thoroughly tested and validated to replicate a wide variety of foam geometries. These virtual microstructures enable the computation of macro-geometric characteristics, thus facilitating the investigation of the relationship between macro-descriptors and foam performance, with the potential to optimize the geometric structure for different applications.

Several models have been proposed to represent the geometry of open-cell foams, including random Voronoi tessellations, which allow the generation of structures with similar levels of complexity. The workflow, starting from an initial set of random points (seeds), uses Voronoi algorithm to create an open cellular structure closely resembling that of ceramic or metallic foams. Morphological modifications of three-dimensional binary volumes composed of voxels are applied, within the plug im! environment (https://plugim.fr) to achieve realistic foam structures with macroscopic characteristics (ϵ, SV, and
tau) comparable to real foams.

To validate the virtual foams obtained through this workflow, x-ray tomography images of real foam samples are used to extract information regarding micro- and macroscopic geometric descriptors. In addition to the comparison of these descriptors, fluid flow performances are compared through pressure drop measurements from experimental setups and numerical simulations using Computational Fluid Dynamics (CFD), confirms the accuracy of the proposed workflow.

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The generation parameters of the workflow are adjusted to ensure that the resulting foam structures have macroscopic descriptors (ϵ, SV, and
tau) with a relative error of no more than 10% compared to the data extracted from tomography images. The comparison of pressure drops values obtained from experiments, CFD simulations, and literature correlations demonstrates the accuracy of the digital models in replicating foam behavior.
Therefore, the presented workflow provides an accurate representation of foam structures and their performance in terms of pressure drops, while maintaining computational efficiency. This approach allows the generation of a wide range of digital foam structures. The realistic foam microstructure model holds promise in advancing the understanding of transport phenomena within open-cell foams by exploring various cases and discerning the impact of geometric descriptors such as porosity and tortuosity through in-silico simulations. This research paves the way for further improvements in foam design and optimization to meet the specific requirements of diverse industrial applications.