Data-driven reduced order modelling for crystallization processes

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A wide range of manufacturing methods and applications in food processing involve crystallisation processes. As crystal/microstructure formation determines both quality and function of frozen and freeze-dried products, a proper control of crystallisation conditions during processing is critical. In this context, mathematical models can help to design and optimise efficient crystallisation industrial processes.

However, these current approaches used to model crystallization processes usually lead to computationally involved numerical schemes, revealing the need for more efficient computational solutions: i.e., industrial applications, like real-time control and optimisation, require the development and implementation of process models that are capable to operate at faster time scales than the process itself.

In this work, we considered a Phase-field model that couples heat and mass transfer phenomena and describes the evolution of the solid/liquid interface, to describe and predict ice crystal formation in food model systems. Using this Phase Field model as reference, i.e., full model, we have then compared the performance of different data-driven methods: (i) Proper Orthogonal Decomposition (ii) Dynamic Mode Decomposition and (iii) and Deep Learning-based model reduction under a range of undercooling and seeding conditions.

Results obtained showed that data-driven reduced models, some of which include physics and process dynamics information, can describe the behavior of the crystallising system, including the effect of the degree of supercooling on the formed crystals morphology, accurately while reducing associated dimensionality and computational times.

Overall, this work demonstrates the potential of reduced order approaches for the modelling of phase change processes and also for the development of virtual tools that allow a “fast” (yet accurate) monitoring, design and optimisation of food manufacture operations, enabling a “real-time”, I4.0 framework in the food processing sector.