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Advanced computational modelling for drying processes – A review

Thijs Defraeye *

MeBioS, Department of Biosystems, University of Leuven, Willem de Croylaan 42, 3001 Heverlee, Belgium
Laboratory for Building Science and Technology, Swiss Federal Laboratories for Materials Testing and Research (Empa), Überlandstrasse 129, 8600 Dübendorf, Switzerland
Chair of Building Physics, Swiss Federal Institute of Technology Zurich (ETHZ), Wolfgang-Pauli-Strasse 15, 8093 Zürich, Switzerland

HIGHLIGHTS

- Understanding the product dehydration process is a key aspect in drying technology.
- Advanced modelling thereof plays an increasingly important role for developing next-generation drying technology.
- Dehydration modelling should be more energy-oriented.
- An integrated "nexus" modelling approach is needed to produce more energy-smart products.
- Multi-objective process optimisation requires development of more complete multiphysics models.

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ABSTRACT

Drying is one of the most complex and energy-consuming chemical unit operations. R&D efforts in drying technology have skyrocketed in the past decades, as new drivers emerged in this industry next to procuring prime product quality and high throughput, namely reduction of energy consumption and carbon footprint as well as improving food safety and security. Solutions are sought in optimising existing technologies or developing new ones which increase energy and resource efficiency, use renewable energy, recuperate waste heat and reduce product loss, thus also the embodied energy therein. Novel tools are required to push such technological innovations and their subsequent implementation. Particularly computer-aided drying process engineering has a large potential to develop next-generation drying technology, including more energy-smart and environmentally-friendly products and dryers systems. This review paper deals with rapidly emerging advanced computational methods for modelling dehydration of porous materials, particularly for foods. Drying is approached as a combined multiphysics, multiscale and multiphase problem. These advanced methods include computational fluid dynamics, several multiphysics modelling methods (e.g. conjugate modelling), multiscale modelling and modelling of material properties and the associated propagation of material property variability. Apart from the current challenges for each of these, future perspectives should be directed towards material property determination, model validation, more complete multiphysics models and more energy-oriented and integrated "nexus" modelling of the dehydration process. Development of more user-friendly, specialised software is paramount to bridge the current gap between modelling in research and industry by making it more attractive. These advanced computational methods show promising perspectives to aid developing next-generation sustainable and green drying technology, tailored to the new requirements for the future society, and are expected to play an increasingly important role in drying technology R&D.

Contents

* Address: MeBioS, Department of Biosystems, University of Leuven, Willem de Croylaan 42, 3001 Heverlee, Belgium. Tel.: +32 (0)16321618; fax: +32 (0)16322966.
E-mail addresses: thijs.defraeye@biw.kuleuven.be, thijs.defraeye@empa.ch

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1. Introduction

Drying (also dehydration or dewatering) implies removing moisture from natural or industrial materials down to a specific moisture content, while ensuring at the same time prime product quality, high throughput and minimal operational costs. Drying is applied amongst others for processing food, textile, paper, wood, ceramics, minerals, wastewater sludge, pharmaceutical products or biotechnological products [1]. As one of the most energy-intensive unit operations in industry, drying can use about 10–25% of the national energy consumption for industrial processes [1–3].

Though drying is a well-established unit operation in chemical engineering [4], the current dryers, with a typical lifetime of a few decades, were not designed for a world where energy usage has become an important part of the operational and lifecycle cost of a dryer and where the use of environmentally-friendly technology is strongly encouraged. The underlying drivers here are climate change, the limited amount of natural resources to produce energy, but especially the steep rise in global energy consumption (expected to increase with one third by 2035, [5]), due to the rapid industrial and demographic expansion in developing economies. Despite the fast progress in developing more sustainable, energy-smart drying technology in the past decades (Fig. 1), such efforts are expected to increase even more in the future. Here, evolutionary and revolutionary technological innovations, driven by the need to reduce energy demand and carbon footprint, particularly aim at improving energy efficiency, increasing the use of renewable energy and recuperating waste heat. At the same time however, innovative drying technologies should also strive to improve product quality but also to develop novel products [6]. Furthermore, material losses should be minimised (turndown ratio) in order to use our resources more efficiently and as a large amount of energy is embodied in dried products, which is lost indirectly in that way.

Due to these new boundary conditions and continuously emerging new feedstock, existing technologies are currently revised and optimised or intelligently combined (e.g. multistage and hybrid dryers; [7–10]), but also entirely new processes and equipment are developed. Several of these advanced innovative drying technologies and the accompanied R&D challenges have been discussed in literature [6,10–14]. Their successful integration in an industrial process chain is however often uncertain, as significant benefits compared to existing technology are required to find industrial acceptance. This originates from the large time-scales involved in this industry, which slows down implementation of new technologies and leads to long payback times [6]. As such, hardware replacement is often done in the context of retrofitting or upgrading existing dryer systems rather than implementing novel systems [13].

Optimising existing drying technologies or developing novel technological concepts requires a simultaneous leap forward in drying-process analysis methods, both experimental or numerical, in order to create more suitable means to fine-tune drying processes and to deal with the added complexity of these state-of-the-art technologies. Such methods are currently used to assist in: (1) design and performance assessment of dryer equipment and

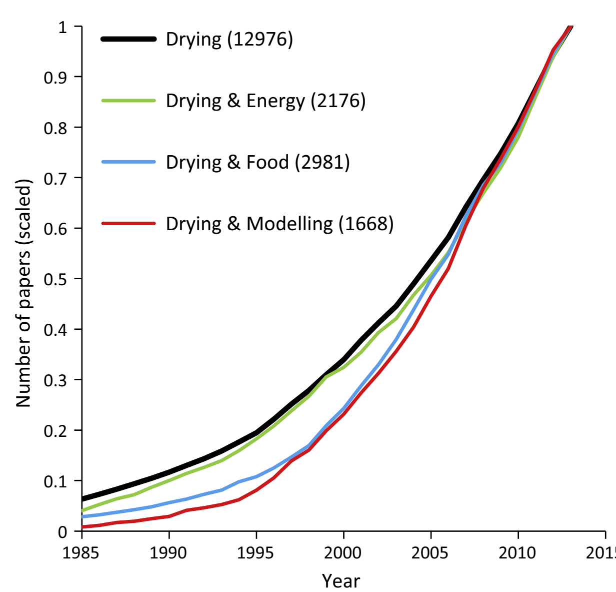

Fig. 1. Number of papers on drying technology and their relation to energy, food and modelling, obtained from Scopus for selected journals, as a function of time (up to 2013). The cumulative amount is shown and each curve is scaled with the total number of papers, which is indicated between brackets. Details on the exact search queries used to generate these statistics are given in Appendix A.