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Drying: a fascinating unit operation

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This special issue contains a selection of papers presented at the 12th International Drying Symposium, held from 28 to 31 August 2000, in Noorwijkerhout, The Netherlands. Other selections are presented in special issues of Drying Technology [1,2]. The proceedings are published by Elsevier Science [3]. The final programme and some background information can be found at website http://www.ids2000.tue.nl. In this journal, it might be worthwhile to make a few statements about drying in the context of chemical engineering.

In 1972, Keey [4] wrote in the preface to his first book: "Drying is a commonly practised art, but a neglected science, at least by workers whose mother-tongue is English." And in Chapter 1 of his book: "The reasons for drying are almost as diverse as the materials that are dried." And one more statement: "The diversity of purpose is matched by the diversity of methods." Now, three decades later, the diversity has not decreased; but what about the art and science?

For extending drying as a science, the development of a "drying community" was very important. The following initiatives in the past have been invaluable: organising of the International Drying Symposia by Arun Mujumdar, start of the journal Drying Technology, and the publication of a series of handbooks and monographs. As a result of the founding of national working parties on drying in a number of countries, the EFChE has incorporated a Working Party on Drying. All these initiatives have roused great interest, enthusiastic participation and cooperation from workers in the field, all coming from a very diverse world. Meanwhile, the International Drying Symposium has found a firm basis in the International Advisory Panel.

In many respects, drying remains still an art, but its character is changing from alchemy and craftsmanship to inspired virtuosity. The science of drying is no longer neglected; it is flowering. However, both in the world of drying itself and in that of chemical engineering, appreciation and application still have considerable room for improvement. For this reason, we will touch upon a few aspects of drying in general, and indicate some developments in technology and science, which we hope will serve as an appetiser for the contributions in this issue.

Drying is one of the largest energy consumers in industry. Recent data show that 10–15% of the total industrial energy use is consumed in drying operations. Preserving foods by drying, one of the oldest applications, is still of growing interest for the manufacture of both final and intermediate products. In an economy that is becoming increasingly global, the distribution of agricultural and other life science products is growing as well, and often drying processes are needed to insure transport and storage stability. Many dried products are in the form of powders, obtained from drying atomised liquid feeds (e.g. spray drying). However, products that are shaped either naturally or artificially form an important part of the materials to be dried. Examples are the drying of wood, of clay brick forms, and of paper. While visiting drying facilities, one is often impressed by the size of the equipment. This can be the result of limited rates of heat and mass transfer, from a low volume fraction of the dried product, or a limited capacity of water uptake by the drying gas.

For some simple products, drying is considered to be relatively easy; one has a solid, liquid or slurry which has to be turned into a dry solid. The main concerns in design are the mass and energy balances and the creation of sufficient contact area between product and heating medium in order to keep the equipment size within reasonable bounds. Next to that, product separation from the drying gas and emission prevention are aspects to be taken into account. In contrast to this, there are many products and processes where several additional requirements and physicochemical phenomena play an important role, making process design and operation often empirical rather than knowledge-driven. For many powders, a large range of *quality aspects* are set, e.g. moisture content, bulk density, particle size distribution, flowability, wettability, dust formation and more specific aspects such as colour, flavour, brittleness. In drying wood, pasta or extruded clay forms, the dried product should be free of cracks. Dried fruits and vegetables should have

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a good consumer appeal upon rehydration. Dried enzymes should still be active, or in some products they should be inactivated. In drying coffee extracts, one strives to contain as much as possible the volatile flavour compounds; in drying polymers one wants removal of solvents and monomers. All this shows that very often the drying process is much more than just removal of water (or solvent); it is simultaneously the creation of many product properties. The decrease of the time-to-market, along with an increase in the diversity of products, puts a stress on process and product development. This is one reason for trying to give a more scientific basis to the creation of dried product properties. The awareness of our environment forces us to focus on reducing energy consumption and associated CO_2 production, and on minimising product emissions. This leads to innovations of drying media such as steam drying, alternative thermal cycles such as chemical regeneration of drying gas, and improved control strategies. Saving energy by process modifications can conflict with the other goals such as quality aspects; the only way out here is through use of more detailed knowledge of all aspects of the drying process.

Drying research is an outstanding example of a field where a very high level of integration is needed. The main aspects to be dealt with are the highly non-linear physical phenomena inside drying materials, the non-homogenous distribution of temperature and humidity inside driers, equipment selection, design and control, and final product quality. One of the challenges for drying research still is the incorporation of the knowledge of basic thermodynamics and transport phenomena into the description of phase equilibria and drying kinetics. A generally accepted framework in the chemical engineering world may also apply to the drying community. Alongside excellent research work, we still see a considerable part of the drying literature that uses semi-empirical expressions and unstructured models. On the equipment scale, there are parallels between adsorption columns and deep-bed driers, which could be explored more. Many drying materials are porous, and contain for part of the drying process at least two phases and often three: liquid, gas and humid solid. The progress made within the drying field in the description of this multiphase, often non-isothermal transport, can be of inspiration to the chemical engineering field. Also the quantitative description of the internal morphology of materials to be dried and the successful applications of averaging methods can lead to cross-breeding between the two fields. Besides, a remarkable development has taken place in the modelling of shrinkage and deformation during drying, which may be of value in other process technologies too. Process intensification is sought by improved mass and heat transfer, as in the novel process of pulsed combustion drying. Steam drying as one of the environmentally friendly drying technologies can now be rationally compared to air drying because of a sound theoretical basis.

Next to advanced models the experimental work presented at IDS2000 also shows considerable ingenuity, integrating knowledge and methods from widely different fields. We hope that this special edition will bring the experts on chemical engineering and drying science closer together.

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