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Book review

NMR IMAGING IN CHEMICAL ENGINEERING

Siegfried Stapf and Song-I Han, (Editors),
Wiley-VCH Verlag GmbH& Co. KGaA, Weinheim, Germany,
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XXV + 620 pages

During the past decade, the application of Nuclear Magnetic Resonance (NMR) imaging techniques to problems of relevance to the process industries has been identified. The particular strengths of NMR techniques are their ability to distinguish between different chemical species and to yield information simultaneously on the structure, concentration distribution and flow processes occurring within a given process unit.

Nuclear Magnetic Resonance (NMR) has many applications in chemical analysis of molecules in solution and in bulk, in biomedical imaging, in imaging of solids in materials science, in imaging and analyzing transport phenomena in chemical engineering and geosciences, and in process, and product and quality control. Thus, the monograph edited by Siegfried Stapf and Song-I Han and written by distinguished professors and fellow researchers with internationally recognized experience in the field, is an excellent overview on NMR both on basic and complex levels. The book introduces important principles of NMR and, also, offers an in-depth view to many "real" engineering problems, providing thorough links to many applications.

The monograph includes fundamental aspects regarding NMR visualization and also advanced techniques in NMR imaging such as: 2D-characterization of the flow field, fast imaging techniques used to observe transient phenomena, basic contrast parameters, which reflect the heterogeneity of a sample with respect to the chemical and physical properties.

Gradient At Right-angles to Field (GARField), a bench-top permanent-magnet system, has found a niche application area in the characterization of drying and film forming from aqueous dispersion and in skin care. It allows an entry level route to routine coatings characterization.

The advantage of a recently proposed magnet geometry, which provides microscopic depth resolution by generating a magnetic field with an extremely uniform gradient, is highlighted. The potential use of the profiling technique is demonstrated in a number of applications, such as the measurement of moisture profiles, the effects of cosmetics on human skin, solvent ingression in polymers and the assessment of the state of paintings in the conservation of objects of interest to cultural heritage.

The main implications of the new remote detection methodology – in which the signal detection location is physically separated from the sample location where NMR or MRI information is encoded, are underlined, including the sensitivity enhancement as an important advantage, because it can be several orders of magnitude better in certain applications.

The recent development of a new 2D NMR technique which measures the correlation functions of relaxation and diffusion constraints is reviewed. It is considered that one of the key advantages of this technique lies in its simplicity and the significantly less stringent requirements in magnetic field strength and uniformly making it potentially suitable for broad applications in industrial processes as a monitoring and quality control device. Rheo-NMR is considered an area of research in which only a handful of people are able to take part. The applications concern polymer melts and demidilute solutions, colloidal glasses, lyotropic micelliar systems and liquid crystalline polymers.

The unmatched strength of the NMR technology is its versatility and specificity in probing and mapping parameters of practical interest. Most contributions to this book deal with application of NMR to deduce space – dependent information for the samples under study that refers, in most cases, to the distribution of different components. Diffusion in nanoporous materials and the guest molecules is implied. Upgrading of these molecules that means the transformation of the starting material to value-added products, is one of the key-issues of chemical engineering. Due to its ability to monitor the probable distribution of molecular displacements over macroscopic scales from hundreds of nanometers up to several millimeters, Pulse Field Gradient NMR (PFG NMR) is considered a most versatile technique for probing the internal structure of complex materials. Further developments of these techniques are considered dependent decisively on the attainability of higher resolutions, down to the sub-micrometer range. Application of Magnetic Resonance Imaging to the study of the filtration process is a versatile way for the quantitative description of the process. Density weighted MRI proved to be a powerful tool in material science research. Also, improved characterization of the morphological/microstructural properties of porous solids and the associated transport properties of fluids imbibed into these materials is crucial to the development of new porous materials, such as ceramics, so that magnetic resonance has been used extensively to study fluids in porous solids, including ceramics. Using the set of NMR-based measurement methods, it is possible to non-invasively and non-destructively characterize both the microstructural properties of the materials and relaxatori properties of fluids imbibed into these materials.

NMR has proven to be a valuable tool for formation evaluation by well logging, downhole fluid analysis and laboratory rock characterization. The decay due to diffusion in a internal field (DDIF) technique appears to be a useful experimental approach to the study of porous media. The DDIF technique has potential for the study of structure on the micron scale as a complement to existing methods, such as x-ray tomography or neutron scattering, to study porous media and other materials with internal structures that are important in many chemical engineering applications. A novel method to determine spatially resolved permeability distribution was presented using MRI to measure spatially resolved flow velocities, and estimated the permeability from the solution of an associated system and parameter identification problem. The bases for further studies of heterogeneous media and important processes that occur within such media, including these with chemical and biological changes that are affected by media structures are provided. Magnetic resonance imaging has enabled the development of a completely novel type of viscosimeter, based on the capacity of MRI to accurately measure velocity profiles in opaque liquid. Its potential applications include many systems of industrial relevance, such as polymer melt and slurries, in those facilities producing high value products that must meet critical rheological specifications, such as manufacturing plants producing engineering polymers, personal care products and processed foods.

Methodologies based on NMRI to study the flow of emulsion are highlighted. Methods to measure velocity, concentration were successfully implemented by researches and extended to other studies on the flow stability of emulsions, as well as for studies of flow-induced coalescence, flow effects on non-neutrally buoyant emulsions and suspensions, studies of shear-induced droplet migration; spatially-resolved measurement of the droplet size distribution; Rheo-NMR.

NMR is also unique in that the measurement is capable of probing structure and composition on all the length scales of importance in food systems, accounted directly for many of the sensory and processing properties that are observed. The information obtained from NMR can be used effectively to quantify quality parameters as well as provide vital information for understanding transport processes in production, storage and consumption. NMR methods have been demonstrated to provide data on the advective transport in capillary, packed bed and VF reactors.

The book focuses on NMR methods and hardware guided by applications to the areas of materials (from nanoporous materials to catalyst design, concrete building materials, functionalized ceramics and petroleum reservoir design), to uniphase and multiphase flows in chemical engineering and other complex fluids in complex geometries, and to transport phenomena in reactors to determine the efficacy of the mass transfer coefficient and to quantify the Residence Time Distribution.

NMR Imaging in Chemical Engineering comes to address a large audience from undergraduate to postgraduate students and faculty members, and also industrial researchers and decision makers who will not only gain a good understanding of the NMR theory and its diverse applications, but also will be able to address their particular problems *via* NMR.

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