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Book review

SCALE-UP IN CHEMICAL ENGINEERING
Second, Completely Revised and Extended Edition

Marko Zlokarnik
Wiley-VCH Verlag GmbH& Co. KGaA, Weinheim, Germany
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Nowadays many chemical engineering research and design problems are too complicated to be solved by numerical mathematics. In this context, one only has to think of processes involving fluids with temperature-dependent physical properties or non-Newtonian flow behaviour. The scaling up of equipment needed for dealing with such physical systems often presents serious hindrances which can frequently be overcome only with the aid of partial similarity.

This book presents the dimensional analysis as the only secure foundation for scale-up in such a way that it can be immediately and easily understood, even without a mathematical background.

*Due to the increasing importance of biotechnology, which employs non-Newtonian fluids far more frequently than the chemical industry does, variable physical properties (e.g. temperature dependence, shear-dependence of viscosity) are treated in detail. It must be kept in mind that in scaling up such processes, apart from the geometrical and process-related similarity, the physical similarity also has to be considered (*from Preface to the 1st Edition). The author, Prof. Dr.-Ing. Marko Zlokarnik, studied chemical technology and obtained his Ph.D. in process engineering from RWTH Aachen University and was active in process engineering R&D at Bayer AG, Leverkusen, for 35 years. His work involved reaction apparatus design for chemical production facilities, which, apart from elucidation of reaction kinetics, also brought fundamental work on mixing technology and modelling with it. In the 70s, he developed an especially efficient biological wastewater treatment. From 1970 to 1990, he taught similarity theory at the Technical University of Clausthal-Zellerfeld, and then held the Bayer Foundation Chair of Chemical Technology at the University of Cologne. He served as chairman of the VDI-GVC committee on biological process engineering from 1979 to 1988, and in the course of his career has published 60 papers, 20 patents, and 5 books, receiving the Otto Bayer Gold Medal and the VDI Honorary Medal for his work.

Approaching the important task of the scale-up of processes from the laboratory to the production scale, this easily comprehensible and transparent book is divided into two main sections. The individual basic operations are presented that cover the field of mechanical, thermal, and chemical process engineering with respect to dimensional analysis and scale-up. The rules for scale-up are given and discussed for each operation. Other additions to this second edition are dimensional analysis of tableting processes, and a historical overview of dimensional analysis and modelling, while all the chapters have been updated to take the latest literature into account. Even in the **introductory part**, the author highlights the role of the chemical engineer during the industrial implementation of processes where mass, heat and momentum transfer exhibit a real influence on the chemical and/or microbial conversion of materials and that are considered scale-dependent. The first part details the theoretical principles, introducing the subject for readers without a profound prior knowledge of mathematics. It discusses the fundamentals of dimensional analysis, the treatment of temperature-dependent and rheological material properties and scale-up where model systems are not available or only partial similarity is obtainable.

Chapter 2, *Dimensional Analysis,* includes concepts and principles, illustrated with examples, regarding a dimension, a physical quantity, base and derived quantities, dimensional constants, dimensional systems, dimensional homogeneity of a physical constant, the Pi theorem.

Chapter 3, *Generation of Pi-sets by Matrix Transformation* details the dimensional analysis with

reference to the matrix or equivalence transformation, providing also numerical examples. **Chapter 4,** *Scale Invariance of the Pi-space – the Foundation of the Scale-up*, develops examples for scale-up fundament, taking into consideration the root of the concept of similarity based on dimensional analysis. It is detailed the scale-up procedure in the so-called *process point.*

Chapter 5, *Important Tips Concerning the Compilation of the problem Relevance List,* includes details on the treatment of universal physical constants and intermediate quantities, demonstrated by two examples. **Chapter 6,** *Important Aspects Concerning the Scale-up*, refers to the importance of choosing an appropriate model material system in order to adjust the process point of the pertinent pi-space in the model experiment, because the unavailability of this model can sometimes limit the application of the dimensional analysis. Also, the scale-up under conditions of partial similarity is discussed, based on appropriate examples. **Chapter 7,** *Preliminary Summary of the Scale-up Essentials,* reflects on the advantages of using dimensional analysis, the scope of applicability of dimensional analysis and some experimental techniques for scale-up, together with some considerations on model experiments carried out in the laboratory under changes of scale. **Chapter 8,** *Treatment of Physical Properties by Dimensional Analysis*, deals with this important aspect of the scale-up process, in relation with the dimensional-analytical treatment of variable material properties, presented for various situations and examples. Also, rheological standardization functions and process equations in Non-Newtonian fluids with diverse behaviour are argued in connection with scale-up. **Chapter 9,** *Reduction of the Pi-space*, recall the statement of the Pi-theorem that can be reduced to a simpler relationship if one succeeds in enlarging the base dimensions of the dimensional system. Also, the Rayleigh-Riabouchinsky controversy is evaluated based on some relevant examples.

Chapter 10, *Typical Problems and Mistakes in the Use of Dimensional Analysis*, deals with problems related to measuring techniques, by highlighting realities and examples from the area of stirring technology. **Chapter 11,** *Optimization of Process Conditions by Combining Process Characteristics*, exemplifies the possibility of process optimization with respect to the desirable objectives by the means of an appropriate combination of process characteristics. **Chapter 12,** *Selected Examples of the Dimensional-Analytical Treatment of processes in the Field of mechanical Unit Operations*, offers to the reader the possibility to become familiar with scale-up examples that present problems when model substances are not available. **Chapter 13,** *Selected Examples of the Dimensional-Analytical Treatment of Processes in the Field of Thermal Unit Operations*, underlines the difficulties that appear during the scale-up process that involve simultaneous mass and heat transfer in the same process, and includes seven examples that deal with heat transfer in mixing vessels, pipelines and bubble columns, mass transfer in surface aeration wastewater treatment ponds, in bulk-aerated mixing vessels and bubble columns that use injectors as gas dispersers. **Chapter 14,** *Selected Examples for the Dimensional-analytical Treatment of Processes in the Field of Chemical Unit Operations*, analyses the problems that appear in the scale-up of the chemical processes as a result of their complexity, which implies the rules of chemical thermodynamics and chemical reaction kinetics, together with mass and heat transfer, the actual residence time of the reaction partners in the reactor (for a continuous reaction process), homogeneous or heterogeneous systems, catalysis etc. **Chapter 15,** *Selected Examples for the Dimensional-Analytical Treatment of Processes within the Living World,* evaluates the possibility for scale-up of the processes in the living world, while the so-named scale invariance of dimensionless representation is considered as an advantage. Some examples illustrate rowing consideration from the viewpoint of dimensional analysis, as well other interesting aspects of the living world.

Chapter 16, *Brief Historic Survey on Dimensional Analysis and Scale-up*, reviews the important moments in the development of the dimensional analysis and scale-up and the personalities that contributed to this. It is emphasized the role of the dimensional analysis for the modern technology, and for the applications that envisage the evaluation of experiments which are necessary to scale-up industrial plants reliably.

Chapter 17, *Exercises on Scale-up and Solutions,* illustrates all these by several real-world examples, while 25 exercises plus solutions new to this edition aid to practice and monitor learning.

The interested reader, who is intending to solve a concrete problem but is not familiar with dimensional-analytical methodology, does not need to read this book from cover to cover in order to solve the problem in this way. Subsequently, the reader can scrutinize the examples given in the second part of this book and choose that example which helps to find a solution to the problem under consideration. In doing so, the task in hand can be solved in the dimensional-analytical way. Only the practical treatment of such problems facilitates understanding for the benefit and efficiency of these methods. Also, the *List of important, named pi-numbers*, included in the 18th chapter of the monograph provides a further help for the specialists.

Written by an expert with more than 40 years of experience in the industry, this book is specifically aimed at students as well as practicing engineers, chemists and process engineers already working in the field.

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