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Simulation and Optimization of Furnaces and Kilns for Nonferrous Metallurgical Engineering

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With 132 figures

Metallurgical Industry Press

Springer

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Based on an original Chinese edition:
《有色冶金炉窑仿真与优化》 (Youse Yejin Luyao Fangzhen Yu Youhua), Metallurgical Industry Press, 2001.

ISBN 978-7-5024-4636-9
Metallurgical Industry Press, Beijing

ISBN 978-3-642-00247-2 e-ISBN 978-3-642-00248-9
Springer Heidelberg Dordrecht London New York

Library of Congress Control Number: 2009920461

Cover design: Frido Steinen-Broo, Estudio Calamar, Spain

Printed on acid-free paper

Springer is part of Springer Science+Business Media(www.springer.com)

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图书在版编目（CIP）数据

有色冶金炉窑仿真与优化：英文 / 梅炽等著.—北京：冶金工业出版社，2010
（冶金反应工程学丛书）

ISBN 978-7-5024-4636-9

Ⅰ.有… Ⅱ.梅… Ⅲ.①有色冶金炉—计算机仿真—英文 ②有色冶金炉—最佳化—英文 Ⅳ.TF806

中国版本图书馆 CIP 数据核字(2010) 第 162201 号

ISBN 978-7-5024-4636-9	Metallurgical Industry Press, Beijing
ISBN 978-3-642-00247-2	Springer Heidelberg Dordrecht London New York
e-ISBN 978-3-540-00248-9	Springer Heidelberg Dordrecht London New York

Library of Congress Control Number: 2009920461

Cover design: Frido Steinen-Broo, Estudio Calamar, Spain

Printed on acid-free paper
199.00 元

Springer is part of Springer Science+Business Media（www.springer.com）
（仅限中国大陆地区销售）

Preface

Due to the tremendous variety of nonferrous metals and their processes of extraction, the furnaces and kilns used for nonferrous metallurgical engineering (FKNME) vary largely in terms of structure, heating mechanism and functionality. The incomplete statistics show that currently there are over one hundred types of FKNME around the world. Despite this wide variety, however, these FKNME share a few characteristics in common: first of all, most FKNME are heavily energy-consuming, with low energy utilization effectiveness usually ranging from 15% to 50%. The energy needed to extract nonferrous metals is approximated 2.5 to 25 times that for ferrous metals. China is facing an even bigger challenge in this area. The mean energy consumption rates in China are much higher than that of the most advanced indices in the world. Secondly, FKNME usually generate more toxic emissions such as sulfur dioxide, fluoride, chloride, arsenide,etc. Thirdly, the performance of the FKNME is often influenced by many factors, the effects of which are usually non-linear and considerable hysteresis can be found. These difficulties account for the relatively lower process controllability and lower automatization level of the FKNME.

It is clear, from the three common characteristics described above, that the FKNME practices are challenging for the industry and therefore deserve more strenuous investigation. For the purpose of effectively upgrading FKNME technologies and improving performance, it is imperative that the following issues be addressed and resolved. Firstly, the output should be maximized by improving the efficiencies of both thermal and production processes. Secondly, the quality control of the production should be more stringent so as to minimize contaminations in the products and the losses of the useful elements. Thirdly, a longer service life of the FKNME can be achieved by reducing the consumption of the refractory and other construction materials. The fourth and the fifth issues are respectively the reduction of the energy consumption and the pollution emissions. The last two issues are highly correlated; reducing energy consumption normally leads to reduction of emissions (such as SO_x, CO_2, NO_x, CO and soot). As a matter of fact, energy consumption can be similarly reduced by augmenting output rate, improving production quality and extending service life. These five issues, therefore, are linked to each other, and may be categorized as the three “highs” (output rate, quality and service life) and two “lows” (energy consumption and pollution emission). Essentially, achieving the objectives of technological upgrading and innovation for the FKNME are equivalent to achieving the overall systematic optimization among the “three highs and two lows”.

Back to the 1950s, G. L. Giomidovskij, a researcher from the former Soviet Union, conducted a series of primitive but quantitative investigations into the fluid flows, fuel combustion, heat transfer and mass transport as well as the physico-chemical reactions in a number of most frequently used FKNME. His work has had a far-reaching impact on the researches on the FKNME. However, due to the unavoidably limited research tools available to him—computation facilities, in particular—the results of his work, at best, provided general information. It was not until the 1970s that the investigations of the FKNME evolved from being limited within macro-phenomena and lumped, averaged information to exploring the micro-mechanism and obtaining fields information. Such change was mainly a result of extensive and rapid development of the computational fluid dynamics (CFD), as well as heat transfer and combustion techniques, thanks to the unprecedented development of the modern information and computer technologies.

As early as the 1980s, the author of this book began applying numerical simulation techniques to investigate the aluminum reduction cells that are among the most widely and frequently used FKNME. The optimized cell lining structures under different operation conditions and system setups were identified by carrying out numerical experiments, i.e., simulations. In the meantime, the research group led by the author used the same methodology to carry out a series of investigations, such as the optimization of the inner wall profiles of the resistance furnaces, and the temperature field prediction and the optimization of the soderberg electrode in the electro-thermal ore-smelting furnaces. The outcomes of these investigations have been proven to be much more effective and accurate than what could be achieved by using the “traditional” research methodology.

As the computation capacity has been continuously improved, the research interests of the group have been extended to the investigations of electric furnaces, flame furnaces, muffle furnaces, bath smelting furnaces and boilers. The research scope has also broadened from single-process simulations and single-objective optimizations to multi-process coupling simulations and multi-objective optimizations. Besides mathematical modeling, artificial intelligence modeling has also been adopted to enable more powerful simulations. Thanks to this progress, the research group has been able to develop various tools for industrial applications. These tools range from the CAD packages for FKNME optimization and decision-making support systems for operation optimization to the integrated FKNME operational management systems featuring unified platforms for monitoring, controlling and managing.

Throughout decades of investigations, a new research methodology for FKNME has gradually taken shape and been consistently used in recent years in the research group. This methodology, called the “hologram simulation”, requires at first building up a mathematical or artificial intelligence model for the furnace or kiln concerned. Based on this model, a computer code can be developed so that comprehensive and detailed simulation can be performed for the furnace or kiln. Details on the hologram simulation will be covered in Chapter 3. With the help of this hologram simulation tool, multi-objective optimization of the furnace or kiln can be accomplished by systematically carrying out numerical experiments with or without human intervention.

Many people have been involved in work reported in the book. The authors are much indebted to their colleagues and students who participated in the research activities. We would also thank colleagues and friends who contributed to the contents of this book with their ideas and suggestions. Moreover, our deep gratitude is given to Dr. Zhuo Chen for her great efforts in editing the whole book; and special thanks are given to Mr.&Mrs. Ames in Sheffield, U.K., Dr. Siow Yeow at Purdue University, U.S.A. and Prof. Chengping Zhang at Central South University for their careful proofreading of the manuscripts. Without all their work and help, this book would not have been accomplished.

It is our sincere hope that this book would serve as a bridge, helping to exchange academic ideas among the FKNME fellow researchers and developers around the world. We hope the work we have done is useful for colleagues in relative fields. Finally, we wish further development and success in the FKNME research, and we should much welcome any comments on the book that readers may care to send.

Mei Chi
May 2009

Contents

5 Hologram Simulation of Aluminum Reduction Cells 127

6 Simulation and Optimization of Electric Smelting Furnace 175

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