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PRINCIPLES, DESIGN AND OPERATION

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Industrial and Process Furnaces

Principles, Design and Operation

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Industrial and Process Furnaces

To the late Frank David Moles, who showed us a better way of thinking about furnaces, especially those where the product is directly heated by the flame.

Foreword

Furnaces have been used by humans for thousands of years and yet, beyond the basic chemical reactions and heat release calculations, engineers rarely have any formal training in relation to furnace design, combustion and their integration into industrial processes. It is therefore not surprising that the solution to issues of emissions, throughput and performance related problems have relied heavily on trial and error and experience. Within industry in general equipment would be more successful designed using the principals outlined in this book rather than relying on correlations and scale up factors that have little, or no scientific basis to support them.

In the early 1970s the authors set themselves the goal of applying more scientific methods to burner design than were currently used. This led to the realisation that heat release from flames needed to be closely matched to the process requirements and that this was intimately related to the design of the furnace itself. Now, more than ever before, the need to reduce ongoing energy costs and greenhouse gas emissions requires decisions to be made on the basis of knowledge rather than guesswork and past experience. This book, being one of only a few ever published on the subject, highlights the applicable science which can be used to take much of the guesswork out of furnace design. This book also emphasises the importance of ensuring that individual pieces of equipment are appropriate for the whole process and not simply selected on the basis of capacity or lowest capital cost.

Alcoa's alumina refineries operate a range of processes and equipment including boilers, rotary kilns, gas suspension alumina calciners and regenerative thermal oxidisers and, like many other industries, have needed to address emissions, throughput, performance and safety issues without a clear understanding of the science and underlying design basis. This makes it difficult to undertake reliable root cause analysis when problems occur.

In the early 1980s I was a mechanical engineer in Alcoa's Equipment Development Group. I had insufficient knowledge of, and certainly little experience with, combustion processes and was faced with having to address throughput and emissions related issues with alumina calciners. Fortunately I met the authors of this book, Peter Mullinger and Barrie Jenkins, and was delighted to discover that a scientific approach to furnace design is possible and methods are available to investigate and optimise many aspects of the combustion and associated processes.

It was highlighted through physical modelling of the flow patterns and acid alkali modelling of the combustion process mixing that both the throughput and emissions could be significantly improved by simply relocating fuel injection points. These modifications proved to be effective and have now been employed on all applicable alumina calciners at Alcoa's refineries around the world saving otherwise significant capital expenditure with potentially ineffective outcomes.

Since those early days the science as described in this book has been employed over a wide range of process issues, from the design of new equipment and in the solution of problems with existing equipment, positively impacting on performance and reliability. More recently there has been a major application in relation to the design of safety systems.

In particular the application of CFD modelling has highlighted to me that CFD doesn't replace the need for a deep understanding of the science of combustion and furnace heat transfer processes as there are many traps for the unwary and the uninformed.

Whether you are engaged in modelling, design of original equipment or equipment upgrades or operation of combustion and furnace heat transfer processes, this book provides much of the essential understanding required for success.

Greg Mills
Senior Consultant – Calcination
Technology Delivery Group
Alcoa World Alumina

Preface

This book has been more than 20 years in gestation; its lineage can be traced back to Barrie's lecturing at the University of Surrey in the late 1970s and early 1980s and Peter's first combustion course, provided internally to Rugby Cement's engineers in 1981.

We are not attempting to explain how to design any particular furnace but are advocating a more scientific approach to furnace design than the traditional methods of scaling from the last design. New approaches are essential if we are to make the advances needed to develop new processes for the twenty-first century and to significantly reduce industrial energy consumption and emissions.

We have worked together to improve the efficiency of furnaces since 1977, starting with rotary kilns in the cement industry when Roger Gates, Technical Director of Rugby Cement, allowed Peter Mullinger to try the techniques developed by the Fuels and Energy Research Group at the University of Surrey (FERGUS) on Rugby's South Ferriby No. 3 Kiln. This work was strongly encouraged by the plant manager, the late Jim Bowman. The project was an immediate success and led to significantly increased production and reduced fuel consumption. The success of that project encouraged Rugby to sign a research agreement with the late Frank Moles, founder of FERGUS, which committed Barrie Jenkins and the rest of the FERGUS team to support Rugby Cement's efforts to improve the production capacity, product quality and fuel economy of their 21 kilns.

Following time in senior technical management roles with a company supplying combustion equipment to the petrochemical industry, we founded our own business where we applied more scientific methods to combustion and heat transfer problems in all industries but principally those where the product was directly heated by the flame.

We commercialised techniques that had been successfully developed and used in-house by organisations such as British Gas, CEGB, and British Steel's Swinden Laboratories, Rotherham. We added acid/alkali modelling as a means of determining fuel/air mixing and flame shape, a technique that had seen little application outside of research institutions at that time.

We built a successful business on this philosophy that continues today, managed by our successors. During the time we managed it we applied these techniques to over 250 projects in a wide range of furnace types in the alumina, cement, ceramic, chrome, copper, lead, lime, steel, mineral sands, nickel, petrochemical, pulp and paper and even the nuclear industry.

The idea for this book arose from the short course we provided on behalf of the International Kiln Association to industry and to the Portland Cement Association where we were regularly asked to recommend a book. We would have suggested

Professor Thring's book *The Science of Flames and Furnaces* but it was long out of print so all that we could offer were the course notes. We hope that this book goes some way to filling the gap. It is the culmination of 30 years of working together, albeit for the last few years from across the globe.

Peter Mullinger
Barrie Jenkins

Acknowledgements

Over the years it has been our privilege to work with many engineers, process operators and other people who have encouraged and cooperated with us. Those who are mentioned below are but a small selection, whose influence has strongly encouraged the preparation of this book or who have directly contributed to it. Of special influence was the late Frank Moles, founder of the Fuels and Energy Research Group at the University of Surrey (FERGUS), who changed our thinking about industrial combustion, and Roger Gates, Technical Director of Rugby Cement, who allowed us to implement Frank's and our ideas on the company's plants.

We would like to thank many of the engineers at the former Midlands Research Station of British Gas, especially Neil Fricker, Malcolm Hogarth, Mike Page, Rachel Palmer, Jeff Rhine and Bob Tucker all of whom encouraged us to found Fuel and Combustion Technology Ltd (FCT) in 1984 and to apply modelling techniques to industrial combustion and heat transfer problems. We believe that we were the first to use these techniques commercially on a large scale.

We owe a special debt of gratitude to those who were brave enough to give us our early work at FCT, including Len May, Terry Henshaw and John Salisbury of ARC Ltd, Erik Morgensen and Lars Christiansen of Haldor Topsoe A/S, Greg Mills of Alcoa Australia, Ian Flower and Con Manias of Adelaide Brighton Cement, Philip Alsop of PT Semen Cibinong, Terry Adams and Peter Gorog of the Weyerhaeuser Company, all of whom were very influential in providing FCT with its early projects.

Peter Mullinger would also particularly like to thank Emeritus Professor Sam Luxton, who strongly supported his change of direction to an academic career in 1999. Without that change, it is unlikely that time would have ever been available to complete this task. Peter would also like to thank his colleagues at the University of Adelaide who either contributed directly to the book or who covered his teaching duties during the first half of 2005 and first half of 2007, when the majority of this book was written, in particular Prof. Keith King, Dr Peter Ashman, Prof. Gus Nathan and Dr Yung Ngothai, A.Prof. Dzuy Nguyen and A.Prof. Brian O'Neill.

We should also like to thank those commercial companies who provided data, photographs and drawings (who are acknowledged in the captions) but special thanks are due to Adam Langman, who tuned our woeful sketches into artistic masterpieces and Dave Crawley of DCDesign Services, who produced the process and instrument drawings and flow diagrams. Grateful thanks are also due to Dr Christine Bertrand, Mr Dennis Butcher and Dr John Smart for their invaluable contribution to the sections on 'CFD modelling', 'Furnace control and safety' and 'NO_x formation and control' respectively.

We hope that the errors are minimal, but there would be many more if it were not for the excellent proofreading of Victoria Jenkins and Sheila Kelly, to whom very special thanks are due. We could not have managed without you. Sheila, in particular, has read every word but maintains that it is not as much fun as Harry Potter!

Finally to all those who attended our industrial combustion short courses and asked, 'What book is available?' It is available at last; we hope that you won't be disappointed.

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