Preface

The author was born in Ghana in a little village called Kentikrono, now a suburb of Kumasi, the Ashanti capital. After a brief stint as an engineering cadet in the merchant marine corps of Ghana, he accepted a scholarship to study marine engineering in the former Soviet Union. Changing fields, he pursued studies in mechanical engineering in Moscow specializing in thermodynamics and heat engines where he redesigned a turbo-prop engine for hydrofoil application. He pursued graduate school in Canada, thereafter, and completed a MS in thermo-fluids mechanics at the University of New Brunswick with a thesis under J. E. S. Venart on energy conservation in greenhouses using thermal night curtains to prevent low-temperature nighttime infrared radiation heat losses through polyethylene roofs. He accepted a faculty position at the University of Guyana in South America, where his wife hails from, and taught undergraduate thermodynamics and heat transfer. His research in fluidized bed thermochemical conversion of rice hulls to provide bioenergy and utilization of the rice hull ash for cement applications earned him a faculty Fulbright award to the United States where he spent a year working in Dr. L. T. Fan's laboratory at the department of chemical engineering at Kansas State University. Upon an invitation to Canada, he joined Dr. Brimacombe's group at the Center for Metallurgical Process Engineering at the University of British Columbia, where he pursued a Ph.D. in rotary kilns under the sponsorship of Alcan Canada. His dissertation, *Rotary Kiln Transport Phenomena—Study of the Bed Motion and Heat Transfer*, supervised by P.V. Barr, presented some pioneering works on the application of granular flow theories for the modeling of particle velocity distribution in mineral processing kilns from which heat transfer within the kiln bed could be adequately and sufficiently solved.

After a brief stint as an Assistant Professor at Swarthmore College in Pennsylvania, he joined Solite Corporation, a rotary kiln lightweight aggregate manufacturing company in Virginia founded by Jane and John

Roberts (Swarthmore '39) as a research and production engineer. At Solite, he developed a two-part training manual on rotary kiln transport phenomena for project 10-10-10, an operational campaign promoted by John Roberts to increase production and product quality by 10% and also reduce fuel consumption by 10%. After Solite restructured in 1997, the author returned to Pennsylvania and joined Fuel and Combustion Technology (FCT) founded by colleagues from the UK, Peter Mullinger and Barrie Jenkins, who, having also completed their Ph.D. works on kiln combustion had developed methods of optimizing turbulent diffusion flame burners to match cement and lime kiln processes. When FCT's owner, Adelaide Brighton Cement, was acquired by Blue Circle Cement, the author joined the process group of Fuller-FL Schmidt (FFE) Minerals, now FLS Minerals in Bethlehem, PA, where he participated in works leading to the design of several large direct-fired mineral processing kilns including limestone calcination, vanadium extraction, soda ash production, and so on. He later worked for Harper International in Lancaster, NY, a lead provider of indirectly heated, high-temperature, rotary kilns employed for niche applications including inorganic materials. After Harper, he became a consultant to the industry providing process expertise including training to the rotary kiln community where he was dubbed "the kiln doctor." He is now a senior Research Scientist with the Agricultural Research Service of the USDA pursuing research in biofuels and bioenergy.

Rotary Kilns: Transport Phenomena and Transport Processes, is a culmination of the author's work in rotary kilns in both academic research and in industry. It captures the author's experiences in production, process design, commissioning, and more importantly, attempts to bridge the classroom and the rotary kiln industry. The focus of *Rotary Kilns: Transport Phenomena and Transport Processes* is to provide the process engineer and the researcher in this field of work some of the quantitative descriptions of the rotary kiln transport phenomenon including freeboard and bed process interactions. The latter combines the transverse bed motion and segregation of granular materials and the resultant effect of these phenomena on the bed heat transfer. Although other bed phenomena, such as axial segregation (sequential banding of small and large particles along the kiln length) and accretion (deposition or growth of material onto the refractory wall forming unwanted dams) are also not well understood, these are only qualitatively described. However, these phenomena can be better explained after careful elucidation of the transverse bed motion, segregation, and

heat transfer. The work has been divided into sequential topics beginning with the basic description of the rotary kiln operation followed by fluid flow in rotary kilns where the freeboard phenomenon is presented. Here the similarities of fluid flow in conduits are drawn to describe the characteristics of confined flows that manifest themselves in combustion and flames typical of the rotary kiln environment.

In Chapter 4 the granular flow phenomenon in rotary kilns is presented. In rotary kilns, often the material being processed is composed of granules, hence the underlying theories for such flows are important to the bed motion, gas-solids reactions, and solid-solid reactions that take place in the bed. With the knowledge of these flows, it is only prudent to cover mixing and segregation as they develop in rotary kilns. This is accomplished in Chapter 5. The severity of mixing phenomena impacts greatly on the quality of the product since it influences the thermal treatment of any granular material. Mixing and segregation determines the extent to which the rotary kiln can be classified as a continuous stirred reactor. The flame is the heart of direct-fired kilns, thus combustion and flame is treated in Chapter 6. The types of flames developed in rotary kilns depend on the flow distribution in the freeboard, which, in turn, determines the heat fluxes to the charged material and also emissions. Treatment of heat transfer in freeboard is therefore a logical sequence and this follows in Chapter 7 by a review of the fundamentals of process heat transfer. Many mathematical models have previously been applied to describe freeboard heat transfer in rotary kilns including one-dimensional zone models, and two- and three-dimensional computational fluid dynamics (CFD). Some of these are presented including recent developments. Freeboard treatment is followed by bed heat transfer in Chapter 8. Like fixed bed heat transfer, rotary kiln bed heat transfer is composed of particle-to-particle conduction, convection, and radiation. However, superimposed on this phenomenon is an *advective* transport component that is generated due to granular flow that sets apart rotary kiln heat transfer from packed bed heat transfer. Some existing packed bed models and their extension to rotary kilns are presented here. Following the bed heat transfer, the mass and energy balance is established in Chapter 9 by considering the kiln operation as a thermodynamic system that interacts with the atmosphere. A simple mass and energy balance is presented for a lime kiln. Having established all the above, it is only prudent to present some specific mineral processing applications for which the rotary kiln has been the main workhorse in Chapter 10.

Some of the processes discussed include lime making, cement making, carbothermic reduction kilns, and lightweight aggregate kilns.

The author is indebted to the many students both in the colleges he has taught and in industry where he has lectured. He is grateful to Solite Corporation, which gave him an unprecedented opportunity to test his theories and mathematical models on large rotary kiln processes in the early years. He is also indebted to FCT, FLS Minerals, Harper, and all the many members of the family of rotary kiln operators particularly Utelite Corporation, Graymont, Inc., and others who gave him an unparalleled education beyond the classroom. Finally, the author is indebted to Dr. Gus Nathan, Dr. Phillip Shaw, and Dr. Peter Cooke for the critical feedback they provided on the manuscript for this book.

A. A. Boateng, Ph.D.
Royersford, PA
aboaten1@gmail.com