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Short communication

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Joseph J. Biernacki *

Tennessee Technological University, Department of Chemical Engineering, PO Box 5013, Cookeville, TN 38505, United States

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ABSTRACT

The performance of portland cement concrete relies upon a series of complex events that begin with raw minerals and end many years after the concrete is placed. Between these points, the life of this dynamic material is dominated by chemical reactions called hydration. While much is known about hydration, unfortunately, there is no unifying theory that describes the kinetics (rates) of these complex transformations from anhydrous cement to hydrous cement paste. Other industries including metalugy, petrochemicals, pharmaceuticals and semiconductors have asserted process control by developing a fundamental, mechanistic understanding of the kinetics of the chemical reactions and phase transformations that define their products. Might the concrete industry be moving along a similar trajectory?

The cement and concrete industry is presently faced with a singular challenge, driven by our responsibility to the world community to produce a more sustainable and environmentally benign product: we *must* find new ways to reduce the lifecycle impact of concrete use on the environment. The answer to a more sustainable concrete infrastructure is, however, not likely a single product or technology, but rather a multiplicity of alternatives. Among the potential technologies are *designer* clinkers that have smaller carbon footprints, advanced admixtures that ultimately improve concrete lifecycle performance, and new protocols for more effective utilization of waste and by-product supplementary cementitious materials. Unfortunately, discovering and developing such technologies are difficult challenges with today's knowledge about hydration kinetics and how to engineer new cement-based materials.

The scientific community at large has invested heavily in the study of chemical kinetics; the discipline that quantifies how fast and by what pathway or mechanism a particular chemical or physical transformation takes place. Is it, however, so important to quantitatively understand the transition pathways and the rates at which they occur? Isn't the final result what matters? If the history of materials technology has anything to teach us then, yes, kinetics is a foundational, solution-enabling framework for the development of new and improved materials. Our understanding of kinetics has unlocked nature's resources and permitted mankind to take control of chemical and physical transformations in diverse areas of materials science including the nano-processing of thin film electronic devices, synthesis of advanced polymers and biomimetic materials and, yes, Portland cement.

Through kinetics, we now understand how to refine ores and to tailor the properties of metallurgical materials by controlling their solidification, crystallization and solid-state phase transformations. This knowledge has given us super-alloys, stainless steel, lightweight alloys, corrosion resistant metals and high temperature refractory metallurgy. Understanding the kinetics of organic interactions now enables us to hypothesize the structure of macromolecules and pharmaceuticals never before synthesized and to construct and test those molecules at will. This has lead to mega-ton production of polymers, the invention of designer co-polymers, liquid crystals, strong lightweight matrix materials for composites and new drugs. Without kinetic control of low-level doping of semiconducting materials, modern computers as we know them would be impossible. Detailed knowledge of how fast various dopants react with and move through semiconductors such as silicon, spawned what is without debate mankind's single most rapid intellectual transformation and has propelled us into the "Communication Age" of cell technology and satellites that have imaged virtually every inch of the plant. And, it is through kinetic control that modern man has converted our most controversial resource into energy that has powered the 20th Century — without knowledge of chemical kinetics, modern crude oil processing would be impossible. Kinetic control of petrochemical reactions permits our refineries to be *agile machines* that can move between product distributions in response to rapidly changing market demands, crude prices and availability, and changing chemistry of crude resources.

So what does all of this have to do with Portland cement concrete? Consider a few examples of how kinetics matter for the concrete

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* Tel.: +1 931 372 3667; fax: +1 931 372 6352.
E-mail address: jbiernacki@tntech.edu.

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