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The interaction of fluid mechanics and heat transfer

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The practice of heat transfer has undergone a profound change in recent years, primarily because of the rapid increase in the capability of computers. Heat exchangers are now designed and even constructed almost exclusively with dedicated software. An unfortunate corollary is the virtual discontinuation of research and development on heat transfer itself in both industry and academia.

On the other hand, heat transfer science continues to have a vibrant and essential internal role in most of the new products and processes, for example in biomedical technology and the cooling of supercomputers. For that reason it may be expected to retain its place in the curriculum of chemical engineering.

In natural convection, heat transfer is intimately and irrevocably coupled with the fluid motion. In forced convection heat transfer is uncoupled from, but primarily dependent upon the detailed field of flow. Recent developments in our ability to predict and describe fluid flow have allowed or inspired even more dramatic improvements in the understanding, prediction, enhancement and control of heat transfer. Many of these advances in the science of fluid mechanics and heat transfer are related to the growth in the capability of computers, but they are more often direct consequences of the development of clever, new special purpose algorithms by the individual investigator. The 10 papers of this special issue were solicited and primarily chosen to illustrate rather than discuss current interactions between fluid mechanics and heat transfer.

The most straightforward illustration of such an interaction is provided by the paper by Heng et al. on turbulent forced convection in round tubes. The essentially exact numerical predictions of turbulent flow with no explicit empiricism by direct numerical simulation (DNS), albeit for a very narrow range of conditions, have been combined with theoretically based asymptotic expressions to produce very general and nearly exact correlating equations for the field of flow. These expressions have in turn allowed the development of greatly improved expressions for the prediction of forced convection. The latter predictions have revealed gross numerical and functional errors in the existing correlations in the literature and current software for design.

The next four papers are concerned with the modeling and prediction of the Czochralski process, which is the principal one used to produce pure silicon crystals for microchips. This process involves thermal conduction, thermal radiation, independent rotation of the crucible and crystal, a free liquid surface and oscillatory natural convection. The first three papers describe progress in the theoretical prediction of the velocity and temperature fields. The requirement of over 2 months of computational time for a single set of conditions, even for somewhat idealized conditions, demonstrates the difficulty of this task. The fourth paper on Czochralski crystallization presents new experimental data to guide and test the various predictive methods.

The final five papers are concerned with some aspect of combustion – a subject in which chemical reactions and mass transfer are coupled with both fluid mechanics and heat transfer. The paper by Shinoda et al. describes both theoretically and experimentally the surprisingly complex characteristics of a combined double-spiral heat exchanger and reactor designed to carry out the combustion of very low heating value gases or the catalytic incineration of contaminants in air for working or living spaces. On the other hand, the paper by Kansuntisukmongkol et al. presents experimental data in support of theoretical prediction of the characteristics of a novel, thermally stabilized burner for premixed gases. The paper by Kim and Lior focusses on the prediction of radiative transfer within this type of burner when it is used for the combustion of powdered and dispersed coal, while that of Fan it al. explores the effects of modified patterns of flow on the combustion of coal in a more conventional furnace. Finally the paper by West and Lombardo describes the burnout of the binder from injection-molded ceramics, a process that involves thermal conduction, mass transfer and solid-phase reactions as well as the flow of the gaseous products of combustion.

I am proud but also somewhat embarrassed by my personal involvement with eight of the 10 papers of this issue. In

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addition to being a co-author of five, three others are co-authored by current or former associates. This unplanned and unintended confluence is simply a consequence of a greater responsiveness of my present and former associates to a perhaps insufficiently publicized call for papers. One fortuitous result has been my exemption from the reviewing process for five of them, a task graciously and efficiently assumed by Richard Darton. Finally, despite the somewhat limited scope of the papers and breadth of authorship, these 10 papers do appear to fulfill the original objective of illustrating the critical role of interaction with fluid mechanics in modern heat transfer.