Numerical Modeling of Multiple Length and Time Scales in Thermal Transport Processes

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A particularly important aspect in many thermal processes and systems is that of mathematical and numerical modeling of different length and time scales that arise. For example, numerical simulation of environmental flows, such as buoyant plumes generated by large fires and thermal energy discharges from power plants and industries into the ambient medium, involve very different length scales close to the source and those far downstream. Similarly, cooling of electronic components, which are generally at engineering length scales, is often efficiently achieved by the use of microchannel flows. Data centers involve servers and racks that are much larger in length scales as compared to individual components. Thus, different length scales and, correspondingly, different time scales are encountered. In manufacturing processes, these considerations are particularly critical. The basic transformations in the material being processed largely occur at the micro/nanoscale, whereas the devices being fabricated and the operating conditions are at the macro scale.

In all these cases, our interest from the simulation lies in the overall behavior of the system and the characteristics of the outputs achieved. These outputs may, for instance, be the quality and quantity of the resulting product, efficiency of heat removal, environmental effect, energy consumption, and fire spread. However, depending on the dimensions, different flow regimes arise with different underlying mechanisms, which demand different analyses and pose different challenges to experimentation. It is thus critical to model the different scales accurately and then couple these to obtain the overall model for the system or the process to obtain the inputs needed for design, prediction and optimization.

This talk presents a wide range of fundamental and practical problems where multiple length and time scales are of interest. It presents the modeling at different scales and then addresses the coupling of the different models to obtain the overall model and simulation for the system or process. Both numerical and experimental methods to obtain results at the small scales are considered. The challenges posed by model validation, different transport mechanisms and different governing equations and parameters are outlined. Several examples, from materials processing, environmental flows and electronic systems, are given to present the different approaches that may be adopted to achieve the desired level of accuracy, control and predictability.