Preface

This is a text and reference book on the fundamentals of flows in porous media and the key roles played by these advances in technologies that are important today and in the foreseeable future. The fundamental topic of flows in porous media is the vehicle for bringing together a long list of critically important issues from diverse fields such as energy, civil, biotechnology, chemical, and environmental engineering. This is an interdisciplinary book, because these many technological issues are being brought together with purpose: they are current and important, and are supported by a common scientific structure, the principles and behavior of flows in porous media.

Our first objective in writing this book was to present a new approach, in several respects. Unlike the most recent reference books on porous media, which catalogue in pure and relatively abstract terms the current position of fundamental research on porous media, our book invites the reader to see the real-life needs of today's engineering. The development of engineering science is driven not only by curiosity, but also by needs, objectives, and limitations. This need-based design approach characterizes not only our coverage of flow phenomena in porous media, but also the coverage of the fundamentals of the other disciplines that overlap in this book.

Energy engineering is an important interface because the environmental impact of energy conversion (e.g., power plants) is, in many cases, due to flows through subterranean porous layers. The latter also play the central role in energy exploration (e.g., petroleum, geothermal fluids, methane hydrate deposits). Yet the traditional approach to energy engineering starts from classical thermodynamics—the first and the second laws, and analyses of "thermodynamic systems," which are defined specifically to be distinct from their environments. Our view is considerably more inclusive. Energy engineering also means design, optimization, and the generation of optimal flow structure. Furthermore, realistic models of energy systems demand the combined treatment of installations and their flowing surroundings, more so when the installations are large and their spheres of impact greater. We apply these principles to the analysis and design of energy storage systems and fuel cells.

These examples highlight the connection between exergy, environment, and sustainable development.

Another new direction that is explored in our book is the impact that small-scale devices (compact heat exchangers, electronics) have on the very fundamentals of heat and fluid flow through porous media. Again, current technological needs dictate the development of fundamentals. The traditional treatment of porous media refers mainly to homogeneous and isotropic porous media, Darcy and Darcy-modified flow models, and local thermal equilibrium (one-temperature) heat transfer models. New and considerably more challenging are the models demanded by strikingly coarse porous structures where the representative elemental volume assumption fails, highly conductive structures where the local thermal equilibrium assumption fails, and heterogeneous media composed of porous domains and domains occupied by pure fluids.

Aerosol transport and collection in porous media (e.g., filters) is another area where environmental impact and a variety of modern technologies comes together for the purpose of developing and using new porous-medium models and results. Applications range from nuclear engineering, agricultural products, food technology, and semiconductor manufacturing, to environmental control in hospitals, museums, and large buildings in general. Porous filters are used to protect workers, occupants, and materials.

Biomedical engineering is another major area that bursts with activity, and enriches the understanding of vascularized flow structures as complex and designed (optimized) porous media. Vascularized tissues and the lung can be presented as porous media that function as mass and heat exchangers with flow structures optimized over many length scales, starting with microchannels. The lung can also be described as a porous structure functioning as a periodic aerosol filter. The modeling of heat transfer in living tissues, which is so important to designing heat-treatment and organ preservation techniques, depends greatly on descriptions of porous media with designed structure (e.g., dendritic channels, counterflow pairs).

Food technologies demand porous-media treatments that account for mesopores, water vapor flow, time-dependent flows, phase-change, and the movement of the two-phase interface through the porous structures. These phenomena are important in the drying and storing of grain, as well as in the thermal processing of food products. Energy-intensive processes such as drying and food processing rely not only on porous media but also on principles of energy engineering.

Civil engineering also demands the porous-media backbone of our book. One example is the modeling of environmental impact, such as, the spreading of pollutants. Energy conservation in buildings is also important, for example, the loss of heat through walls with porous inserts and small cavities. The transfer of chemical species and chemical reactions in concrete are critical to understanding and improving the durability and environmental safety of buildings. They govern the penetration of chloride through concrete, and the corrosion of the metallic structure that reinforces the concrete. Another example is the ionic decontamination by electrokinetic processes. The collection and distribution of water (cold or hot), sewage, rainwater, and so on, require increasingly more complex dendritic networks (larger, finer, multiple scales). Urban flows are porous structures that are designed. Such designs have a lot in common with the bioengineering applications mentioned above. Once again, conceptual connections are made not only with civil engineering and porous-media fundamentals, but also with living systems.

Electronics, and the miniaturization of structures that must be cooled intensively, is the technological frontier that, alone, demands the treatment presented in this book. Cooling is the technology that stops the march toward smaller scales, greater processing density, greater complexity, and superior global performance. We are seeing this not only in microscale heat transfer but also in the development of compact heat exchangers. For our treatment of porous media, the new opportunity stems from the need for smaller and smaller flow passages and fins in heat exchangers and electronics cooling. Smaller ducts mean higher heat transfer rates, and laminar flow. In the aggregate, however, macroscopic flow structures (heat exchangers) approach a limit that is much better suited for porous-medium modeling, and for the design of porous structure.

The need for considering the broad picture—the macroscopic system—is great and universal. No matter how successful we are in discovering and understanding small-scale phenomena and processes, we are forced to face the challenge of assembling these invisible elements into palpable devices. The challenge is to construct, that is, to assemble and to optimize while assembling. This challenge is becoming more difficult, because while the smallest scales are becoming smaller, the number of components and the complexity of the useful device (always macroscopic) become correspondingly greater.

This observation deserves emphasis, because it is widely overlooked in discussions of shrinking scales and "nanotechnology." Technology means a lot more than the new physics that may appear on the frontiers of progressively smaller scales. A technology is truly new when it is made useful in the form of devices (macroscopic constructs) that improve our lives. Usefulness demands that we must discover not only new physics, but also the strategy for connecting and packing the smallest-scale elements into devices for use at our macroscopic scales.

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