Lecture Notes in Physics 771

Percolation Theory for Flow in Porous Media

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Preface to the Second Edition

Why would we wish to start a 2nd edition of “Percolation theory for flow in porous media” only two years after the first one was finished? There are essentially three reasons:

1) Reviews in the soil physics community have pointed out that the introductory material on percolation theory could have been more accessible. Our additional experience in teaching this material led us to believe that we could improve this aspect of the book. In the context of rewriting the first chapter, however, we also expanded the discussion of Bethe lattices and their relevance for “classical” exponents of percolation theory, thus giving more of a basis for the discussion of the relevance of hyperscaling. This addition, though it will not tend to make the book more accessible to hydrologists, was useful in making it a more complete reference, and these sections have been marked as being possible to omit in a first reading. It also forced a division of the first chapter into two. We hope that physicists without a background in percolation theory will now also find the introductory material somewhat more satisfactory.
2) We have done considerable further work on problems of electrical conductivity, thermal conductivity, and electromechanical coupling. The electrical conductivity may in more complex media than those addressed in the first edition lead to the relevance of nonuniversal exponents of percolation theory, while the thermal conductivity may be strongly affected by complex structures such as capillary bridges or pendular rings between grains. Neither of these subjects in morphology was discussed in detail in the first edition.

   Our additional research into the saturation dependence of the electrical conductivity appeared to confirm the relevance of universal scaling to a much wider range of materials than we knew about at the time of the first edition. However, a related subject long considered important in petroleum engineering is diagenesis, which was handled in some detail in Sahimi’s 1993 review. It is possible to make models of rock formation in which the connectivity of the pore space scarcely changes, while the width of the pores diminishes rapidly with diminishing porosity. Such models allow, at least in principle, the possibility of nonuniversal exponents of percolation theory.

   The reason that pendular structures could be relevant, especially to the thermal conductivity of geological porous media, is that the solid fraction generally has a higher thermal conductivity than the fluid phase (e.g., air or water), while the thermal resistance between neighboring grains may be quite high. Thus, small amounts of fluid at these junctions – pendular structures – may produce a rather large increase in the thermal conductivity, and this increase may have nothing to do with percolation theory as such, since the topology of the connected network might not initially change with increasing fluid content, although critical path analysis may still be useful for this problem. The large increase in material covered in the original Chap. 4 also led to its division into the current Chaps. 5 and 6.

3) We have recently addressed the problem of dispersion in porous media, which brings up the relevance of some additional topological aspects of percolation theory, in particular, the relationship of the tortuosity of the backbone cluster to the distribution of passage times. Because this was not addressed in the first edition, the introductory chapters mentioned the topic only briefly. As a consequence the preface to the first edition is now more dated as dispersion was implied to be a problem that could be omitted. In fact, inclusion of dispersion into the second edition has made a significant advance in the unity of the theoretical approach here.

We also bring in an additional problem (Sect. 11.4) addressing the question of how to generate a realistic prediction in horizontal and vertical K distributions for a topical waste management problem, which uses output parameters from a small-scale upscaling to generate appropriate input parameters in a large-scale upscaling. We hope it is useful to see how difficult practical problems in applying percolation theory at multiple scales might be managed.

In order to give the book a wider relevance, it is useful to embed the discussions of the relevance of universal exponents in a wider context. This is accomplished by looking at a wider range of models of porous media, a wider range of properties, and a wider range of experiments. As a consequence, the introductory review chapters needed to be rewritten in order to accommodate a more widely applicable theory.

Finally, it has been noted that solutions to the problems are not provided. It was our intention, except in the introductory chapters, to suggest mostly problems whose solutions could be published, so these problems have not yet been attempted.

Besides the people acknowledged in the first edition, one of us would like to thank the staff of the library at Wright State University.