Book Review

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Book Review


JOHN W. RUDNICKI1,2

This is a short (239 pages including index and appendices), clearly written, and timely book. As the authors explain, “…this book contains what we see as the essentials of carbon storage modeling, with a focus on how systems and solutions can be simplified to provide useful solutions to practical questions.”

The book is not a survey of the field but, instead, provides an instructive treatment of the authors’ particular approach to the subject. This is not meant as a criticism since I found their perspective appealing. Their modeling philosophy espouses judicious approximation, careful study of analytical solutions, consideration of physical processes of most significance for the time and space scales of interest and efficient numerical solution. Of course, these are the ingredients of any good modeling but could be contrasted with direct application of a large computational model. Such models certainly have their place, but I think the authors would argue that for many geometric problems the disparity of time and length scales, uncertain geometries and properties, and incompletely known physics can favor a more incisive approach.

The book is self-contained, beginning with the basics and progressing to more complex models of realistic storage scenarios. The approach is mathematical. But readers for whom that description might be a deterrent will find much that is worthwhile in this book. Plentiful descriptive interludes and qualitative discussion of results will be of interest even to those for whom the math is murky. Indeed, the authors acknowledge that the reader may “not have followed all the mathematical details, [but] we hope that the modeling philosophies will stick with you.”

The first chapter gives a brief overview of the deleterious effects of increasing amounts of anthropomorphic emissions of CO2 on the atmosphere and the role geological storage can play in mitigating them. The second chapter is a précis of single phase flow in porous media, including an introduction to numerical methods. The third chapter extends the discussion to two phase flow. Since I knew little about two phase flow, I found this chapter particularly educational. Chapter 3 ends with a nice qualitative description of CO2 storage from injection to long times.

Although the CO2—brine system is used for examples in Chapters 2 and 3, it becomes the specific focus in Chapters 4–6. Chapter 4 is entitled Large scale models and begins with an in depth discussion of various time and spatial scales that are relevant to the problem. Navigating these is a persistent problem in geomechanics and the discussion here could serve as a model for other systems. The learning curve becomes much steeper beginning with this chapter. The equations and notation become more dense, particularly beginning with Section 4.5, and the chapter undoubtedly requires a much closer reading than I gave it.

Chapter 5, Solution approaches, includes application of both analytical solutions for idealized models and numerical solutions for more realistic ones. The section on analytical solutions illustrates the effects of different physical processes and compares solutions incorporating different levels of detail.

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For example, there is a comparison between a model that includes a capillary fringe and one that treats this as a sharp interface. Another example concerns prediction of plume extent. Counter to intuition, the large variation in prediction primarily results from the mobility ratio (relative mobility of brine and CO₂) rather than the porosity. The section on numerical methods is very concise and the authors acknowledge that “We have provided herein only a superficial and introductory exposition of some of the basic ideas”. The chapter closes with two example applications to realistic data for storage locations.

Chapter 6 is devoted to leakage, arguably the most important issue with geological storage. The treatment focuses on leakage through current or extinct wells (as opposed to leakage through the cap rock). The chapter contains an interesting comparison of the accuracy of three solution approaches, their efficiency and their ease of extension to more complex models (in this case, more wells). The chapter also briefly discusses comparison of predictions by 13 different groups for leakage. Although the predictions are certainly similar, the differences illustrate the uncertainty of modeling complex subsurface processes. A hypothetical example from the Wabamun Lake area in the Alberta Basin with 1,250 wells penetrating varying depths in 10 stratigraphic layers in the 50 × 50 km. region makes concrete the meaning of a density of 0.5 wells per square kilometer.

A prominent tool in the book is the use of Compression and Reconstruction operators, a terminology with which I was not familiar. The simplest example is Reduction of dimensionality, which appears in Chapter 2. For this case compression refers to integration of the three dimensional equations through the thickness of an aquifer layer to reduce the problem to two dimensions with some additional terms. Reconstruction involves restoring finer scale aspects of through-the-thickness variation. Obviously, Reconstruction is terribly non-unique but depends on the understanding of finer scale physical processes and available data about them in order to be useful. In this example, I appreciated the precise treatment for a topic that is often treated more heuristically. To me, compression is similar to what is often called up-scaling or averaging, although this may be too restrictive an interpretation. Much of the discussion of larger scale models is phrased in terms of compression and reconstruction. Although I can appreciate that this approach provides a concise symbolic description and a more systematic method of ensuring consistency between models at different scales, I found it a bit abstract. That said, the meaning does become clearer in applications for specific examples.

The authors suggest that the book could be used as a text. It could, but a good understanding of the material would require considerable amplification by the instructor, particularly for those without a strong mathematical or numerical methods background. Portions would, however, provide excellent ancillary materials for courses on hydrology, computational methods, or geomechanics modeling.

Although the book includes no problems, many could be based on filling in details or further exploration of applications of the solutions presented.

I do think the authors give short shrift to the effects of solid deformation. Fracture is included only by a simple pressure criterion. Creation or reactivation of faults or fractures will likely depend on stresses (and flow) in more complex ways. Localized deformation and inelastic deformation due to past production may alter permeability structure and the response to stress changes. Admittedly, this is more a reflection of my own interests than an omission. Thorough treatment of this aspect would likely require another book.

The book contains useful appendices but I found the referencing sometimes frustrating. For example, I had no idea what the Green and Ampt solution was and no reference was given. Certainly, I could have found out with a bit more effort on my part, but, for a book that is otherwise self-contained, it was an annoyance, albeit minor.

In summary, I enjoyed reading this book. I learned from it. Although the perspective is mathematical, the book has much for readers with diverse backgrounds. I agree with the authors that it fills a need on a timely subject. I appreciated its brevity. It is difficult to write a short book on a complex subject, but the authors have managed to balance the general and the specific. While acknowledging the complexities beyond the treatment here, they do not get sidetracked by them. They have distilled a great deal of expertise and experience into a treatment provides both an introduction to and insight into current modeling issues of CO₂ storage.