Richards Examples

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1 Introduction

The Richards' equation describes slow fluid flow through a porous medium. This document outlines input-file examples for the Richards MOOSE code, drawing mainly upon the test suite. There are two other accompanying documents: (1) The theoretical and numerical foundations of the code, which also describes the notation used throughout this document; (2) The test suite, which describes the benchmark tests used to validate the code.

2 The examples

Each example is located in the *test* directory, which has path

`<install_dir>/trunk/elk/tests/richards`

or the *user* directory, which has path

`<install_dir>/trunk/elk/doc/richards/user`

2.1 Convergence and convergence criteria

As a general rule, the formulation of multiphase flow implemented in MOOSE is quite suitable to solve many different problems. However, there are some situations where the implementation is not optimal, such as the tracking of fronts. MOOSE may converge in these instances, but may take unacceptably short time steps, or it may not even converge at all. In these cases it is probably best to either modify the problem to something more suitable, or use another code.

For example, in simulations with sharp fronts, the user should ask whether it is truly necessary to accurately track the sharp front, or whether similar results could be taken by smoothing the fronts by using slightly different initial conditions, and/or by modifying the effective-saturation relationships, by making the van Genuchten parameter α smaller, for instance. If tracking sharp fronts is vital to the problem then a code specifically designed to solve such problems will do it better than MOOSE, or perhaps MOOSE could be used with an ALE front-tracking algorithm.

Below I list some general pointers that may help with problems that MOOSE is struggling with.

- Effective saturation curves that are too "flat" are not good. For example, the van Genuchten parameter $m = 0.6$ almost always gives better convergence than $m = 0.9$.

- Effective saturation curves that are too "low" are not good. For example, the van Genuchten parameter $\alpha = 10^{-6}\,\mathrm{Pa}^{-1}$ almost always gives better convergence than $\alpha = 10^{-3}\,\mathrm{Pa}^{-1}$. Compare, for instance, the tests `buckley_leverett/bl21.i` and `buckley_leverett/bl22.i`.

- Any discontinuities in the effective saturation, or its derivative, are bad. I suggest using van Genuchten parameter $\alpha \geq 0.5$ for problems with both saturated and unsaturated zones.

- Highly nonlinear relative permeability curves make convergence difficult in some cases. For instance, a "power" relative permeability curve with $n = 20$ is much worse numerically than with $n = 2$. See if you can reduce the nonlinearity in your curve.

- Any discontinuities in the relative permeability, or its derivative, are bad. For most curves coded into MOOSE this is not an issue, but I recommend the `RichardsRelPermVG1` curve over `RichardsRelPermVG`, since the former is smooth around $S_{\mathrm{eff}} = 1$. See `recharge_discharge/rd01.i` in the tests directory for an example of this. I also suggest using the "power" covers over the "VG" curves.

2.2 Two-phase, almost saturated

If a two-phase model has regions that are fully saturated with the "1" phase (typically this is water), then the residual for the "2" phase is zero. This means the "2"-phase pressure will not change in those regions, potentially violating $P_1 \leq P_2$. If the "2" phase subsequently infiltrates to these regions, an initially crazy P_2 might affect the results. This sometimes also holds for almost-saturated situations, depending on the exact simulation.

In these cases it is useful to add a penalty term to the residual to ensure that $P_1 \leq P_2$. An example can be found in the tests directory `pressure_pulse/pp22.i`. The choice of the *a* parameter is sometimes difficult: too big and the penalty term dominates the Darcy flow; too small and the penalty term does nothing. In both cases, convergence is poor as the penalty term switches on and off during the Newton-Raphson procedure. The documentation for `RichardsPPenalty` describes how to set *a* (run MOOSE with a --dump flag).

The penalty term should *not* be used unless absolutely necessary as it will lead to poorer convergence characteristics. In many cases it is not necessary.

2.3 An excavation

In the test directory `excav/ex01.i` and `excav/ex02.i` contains a single excavation, and the associated mass flux and mass balance.

2.4 Bounding porepressure

Occasionally it might be useful to bound porepressure. The test `buckley_leverett/bl22.i` has "bounds" that do this. Note that:

- The convergence is likely to be much slower when using bounds

- The -snes_type must be set to `vinewtonssls` (see the `[Preconditioning]` block of the aforementioned test.

- The command line must contain the argument --use-petsc-dm.