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A numerical modeling approach for capillary effects in systems with changing porosity

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Most commonly used numerical models of unsaturated porous media flow use a single capillary retention function which is specified at the start of the model run and alters capillary pressure only as a function of saturation. However, changes in porosity are common in geologic and industrial applications across a wide range of time scales. Consequently, numerical models of unsaturated media flow in these systems may become inaccurate over the course of a model run. In extreme cases, clearly unphysical results can occur, such as liquid water suspended in newly-created void spaces. In less extreme cases, the single retention function has a tendency to balance saturation to the same value throughout the region to which the function is applied, independent of any changes in the porous medium. Water in these cases tends to be drawn out of low-porosity regions into high-porosity areas to achieve this balance, but low-porosity porous media should generally be harder to drain and retain a higher saturation. Such inaccuracies tend to produce counterintuitive results, especially with volumetric water content, and can be compounded in scenarios where porosity changes are driven in part by that volumetric water content. One example where this problem may arise is in numerical modeling of high-temperature sources in salt, where brine/vapor interactions and fluid migration causes porosity changes in the salt via dissolution and precipitation.
To address these issues, we have developed new formulations for the retention function in which residual saturation and maximum capillary pressures are dynamically changed throughout the simulation as local porosity changes. The new functions are applied in the porous flow simulator Finite Element Heat and Mass (https://fehm.lanl.gov). In this approach, at a given saturation, capillary forces weaken as node porosity increases, and strengthen as porosity decreases. This approach eliminates the suspended water problem and increases the retention of water in low-porosity nodes. In salt test cases, model outputs are more intuitively reasonable and show strong differences from the initial-only retention curve cases, with dramatic changes in volumetric water content and a reduction in the severity of dissolution effects.

References

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