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Stochastic Inversion of Pneumatic Cross-hole Tests and Barometric Pressure Fluctuations in Heterogeneous Unsaturated Formations

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The distributions of permeability and porosity are key factors that control airflow and gas phase transport in unsaturated formations. To understand the behavior of flow and transport in such formations, characterization procedure is a typical approach that has been widely applied to laboratories and fields. As is recognized by most investigations, this approach relies on accurate measurements, and more importantly, an adequate tool to interpret those measurements from experiments. This study presents a pneumatic inverse model that is capable to estimate the distributions of permeability (Ka) and porosity (n) with high resolution in heterogeneous unsaturated formations. Based on the concept of sequential successive linear estimator (SSLE), the developed model accounts for compressibility and density of air and estimates the geologic parameters using air pressure measurements from sequential cross-hole pneumatic pumping or injection tests. Four synthetic examples, including a one-dimensional well-posed, a horizontally two-dimensional, and two three-dimensional problems, are used to evaluate the developed model in estimating the distributions of permeability and porosity in unsaturated formations. Results of the numerical experiments are promising. The developed pneumatic inverse model can reconstruct the property (i.e., permeability and porosity) fields if the well-defined conditions are met. With relatively small number of available measurements, the proposed model can accurately capture the patterns and the magnitudes of estimated properties for unsaturated formations. Results of two complex three-dimensional examples show that the proposed model can map the fracture connectivity using relatively small number of subsurface pressure measurements and estimate and in shallow soil layers using spatial variations of barometric pressure.