NATURAL CONVECTION IN SALINE AQUIFERS WITH HETEROGENEOUS PERMEABILITY

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Convective effects produced by the hydrodynamic instability known as the Rayleigh-Benard convection result in the most effective form of sequestration of CO2 by solubility trapping. In addition to providing an efficient trapping mechanism on t heir own convective effects further facilitate the more permanent form of mineral trapping which generally requires CO2 to be in the dissolved state in order for the mineral reactions to proceed. Characterization of the flux of CO2-rich phase into brine requires the understanding of the conditions necessary for the existence and sustenance of convective instability.
We present a theoretical basis for quantifying the effect of heterogeneous permeability on t he Rayleigh-Benard natural convection. We employ an advanced perturbation approach based on t he dominant mode projection method. This approach is compared in detail with other methods used in the past for this problem such as spectral and non-modal analysis. The stability problem is transformed with a special similarity transformation onto a basis where the evolution operator has a small spectral radius. This helps reduce the sensitive dependence on initial conditions and provides us with a proper initial perturbation profile. A dominant mode solution is then obtained in a semi-analytical form for external forcing in the form of permeability heterogeneity. Critical length and time scales of instability are obtained to determine systematically the resonance or damping of the unstable spectra with respect to the forced permeability modes. It is observed that heterogeneity related forcing increases significantly the band of unstable modes for small permeability modes with small variances. A bifurcation occurs when the system is forced with higher permeability modes and variances, which splits the spectrum into isolated regions of uns table modes. We explain this behavior in terms of the coupling of heterogeneity related vorticity and that arising from unfavorable density effects. High accuracy spectral solution of the nonlinear behavior is obtained for longer times, which describes the effect of the interaction of homogenous modes with heterogeneity on the long term flux of CO2 into brine.