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Entropy Production in Convective Hydrothermal Systems

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Exploring hydrothermal reservoirs requires reliable estimates of subsurface temperatures to delineate favorable locations of boreholes. It is therefore of fundamental and practical importance to understand the thermodynamic behavior of the system in order to predict its performance with numerical studies. To this end, the thermodynamic measure of entropy production is considered as a useful abstraction tool to characterize the convective state of a system since it accounts for dissipative heat processes and gives insight into the system's average behavior in a statistical sense. Solving the underlying conservation principles of a convective hydrothermal system is sensitive to initial conditions and boundary conditions which in turn are prone to uncertain knowledge in subsurface parameters. There exist multiple numerical solutions to the mathematical description of a convective system and the prediction becomes even more challenging as the vigor of convection increases. Thus, the variety of possible modes contained in such highly non-linear problems needs to be quantified. A synthetic study is carried out to simulate fluid flow and heat transfer in a finite porous layer heated from below. Various two-dimensional models are created such that their corresponding Rayleigh numbers lie in a range from the sub-critical linear to the supercritical non-linear regime, that is purely conductive to convection-dominated systems. Entropy production is found to describe the transient evolution of convective processes fairly well and can be used to identify thermodynamic equilibrium. Additionally, varying the aspect ratio for each Rayleigh number shows that the variety of realized convection modes increases with both larger aspect ratio and higher Rayleigh number. This phenomenon is also reflected by an enlarged spread of entropy production for the realized modes. Consequently, the Rayleigh number can be correlated to the magnitude of entropy production. In cases of moderate Rayleigh number and moderate aspect ratio, entropy production even enables to predict a preferred convection mode for a model with homogeneous parameter distribution. As a general rule, the thermodynamic measure of entropy production can be used to analyze uncertainties accompanied by modelling convective hydrothermal systems. Without considering any probability distributions of input data, this synthetic study shows that a higher entropy production implies a lower ability to uniquely predict the convection pattern. This in turn means that the uncertainty in estimating subsurface temperatures is higher.