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Simulation of high-temperature water-CO2 flows in porous media

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Coupled water and carbon dioxide flows in porous media can take place both in natural volcanic environments and in industrial processes, for example, underground carbon dioxide storage or geothermal energy recovery. Pressures and temperatures in these flows can considerably exceed their values in critical point of water. Nowadays there are no adequate mathematical models that can in aggregate describe both water and water-carbon dioxide mixture properties in sub- and supercritical regions and the dynamics of their flows in such conditions. Thereby the influence of critical conditions on water flows in porous media is not well understood.

In the paper cubic equation of state is used to describe water-carbon dioxide mixture in wide range of conditions including critical conditions for mixture. The equation generalizes well known Peng-Robinson equation and can be used to describe properties not only of hydrocarbons but also of carbon-dioxide and water. The real mixture properties measurements are used to determine the equation coefficients. Comparison between experimental measurements and data calculated via the equation of state shows a good agreement between the data. For example the error in water density calculation is less than 10% in the whole range of pressure-enthalpy conditions. Effective and fast algorithms for phase equilibrium calculation via pressure, enthalpy and mixture composition where developed. These thermodynamic variables are the most suitable for trans-critical flow simulations.

The developed numerical model that is based on mass and energy conservation laws was used to study hydrothermal system in Solfatara volcano (Campi Flegrei). The flows in porous media that take place in the system are forced by presence of magmatic chamber located at depth of 9 km. Magma degassing makes a hot supercritical plume of water-carbon dioxide mixture that ascends to shallow layers where magmatic fluid mixes with cold meteoric water. The model assumes a source of supercritical fluid located at depth of 4 km. The problem is studied in 1D and 3D cases. In 1D case the transition from supercritical to subcritical flow occurs at a single temporal value when water critical conditions are reached. At this time intense phase transfer process starts and two-phase flow region rapidly develops and expands in both upper and lower directions. In 3D case the water critical temperature and pressure exist permanently after the first time they are reached in the flow. As the system approaches a steady state there is a continuous transition from supercritical fluid to vapor single-phase flow above the source region. The two-phase flow zones develop only in peripheral regions where the hot plume interacts with cold meteoric water.

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