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Simulation of multiphase flows of binary mixtures under sub- and supercritical conditions

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Multiphase flows in a porous media under sub- and supercritical thermodynamic conditions take place in many natural and manmade processes. For example in deep regions of geothermal reservoirs where temperature reaches critical point of water, in gas-condensate fields where subject to critical conditions retrograde effects take place and even in underground CO2 storage processes at high formation pressure. Simulation of these processes is complicated due to degeneration of conservation laws under critical conditions and demands nonclassical mathematical models and methods.

A new mathematical model is proposed for effective simulation of binary mixture flows in wide range of pressure and temperature and under critical conditions. Transport equations and Darcy law are closed by a problem of conditional extremum for mixture properties calculation. This problem corresponds to maximum entropy condition in thermodynamic equilibrium. To define and solve the problem only one function – mixture thermodynamic potential - is needed. Such approach allows determining not only single-phase states and two-phase states of liquid-gas type as in classical models but also two-phase states of liquid-liquid type and three-phase states. As an example of the method efficiency water-carbon dioxide and some hydrocarbon phase diagrams were calculated.

The proposed model was implemented in a code for compositional hydrodynamic simulations. As opposed to classical approaches pressure, enthalpy and composition variables together with fully implicit method and cascade procedure are used. The code is capable of unstructured grids, heterogeneous porous media, relative permeability and capillary pressure dependence on temperature and pressure, multiphase diffusion, optional number of sink and sources, optional regions of saturation functions etc. There is advanced module for mixture properties design. The starting point for the simulation is cubic equation of state that is used for mixture thermodynamic potential – entropy – calculation in pressure, enthalpy and composition variables. A polynomial spline is implemented to save the potential for subsequent hydrodynamic simulations. At this stage the majority of complicated thermodynamic procedures are performed prior to hydrodynamic that results in sufficient acceleration of flows calculation.

The code was used for analysis of some nonisothermal flows in a porous media. Firstly a simulation of flows in deep layers of Campi Flegrei geothermal system was conducted. This system is fed with hot CO2-H2O binary mixture from deep underground magmatic source. Self-oscillation regime of the flow was found when subject to fixed rate of the flux from magmatic source the flow behavior is periodic in time. The oscillation can explain periodicity of the data measured at the surface. Secondly a simulation of CO2 injection in deep layer was performed. There were found injection parameters of underground liquefied CO2 zone formation. This effect may be useful for CO2 compact storage. Thirdly there was shown the code applicability to simulations of retrograde effects and cycling process in gas condensate field explorations.

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