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Evaporation-driven transport and precipitation of salt in porous-media: A multi-domain approach

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Introduction: Evaporative salinization a major concern worldwide is observed across many environmental, agricultural and engineering applications. In the context of agriculture, salinization caused due to excess irrigation and use of artificial fertilizers in last few decades deteriorated productive land to a large extent. Many scientists have conducted experimental and numerical studies related to evaporative salinization [1, 2]. However, to our knowledge most of the performed numerical studies neglect the influence of atmospheric processes and free-flow pours-media interaction, which could play a significant role for salinization in a natural system. With our model concept we attempt to study and analyze the influence of atmospheric processes on dissolved salt transport, evaporation dynamics and salt-precipitation.

Evaporation is mainly driven by diffusion, related to the vapor pressure gradient across liquid-air interface and advection, related to the tangential wind velocity at the soil surface. Moreover, it is also affected by the complex interactions between the flow and transport processes in the atmosphere and the porous-medium. On the atmosphere side, it is influenced by wind velocity, air temperature, humidity, radiation etc. On the porous-medium side, it is strongly related to the advective and diffusive fluxes, heterogeneity in salinity distribution (causes osmosis) and salt precipitation (causes pore clogging). As discussed in [1] evaporation of saline solutions can be explained into three different stages.

Model: Our model is capable to handle coupled single-phase-compositional free and three-phase-compositional porous-media flow and transport. It is based on a two-domain approach, where non-isothermal sub-models are used for free-flow and porous-media sub-domains [3]. The sub-models are coupled using interface conditions ensuring continuity of mass, momentum and energy. This facilitates to describe evaporation independent of any boundary condition at the free-flow porous-media interface and the influence of atmospheric conditions on evaporation dynamics. The model is also capable to handle dissolved salt transport, osmosis, salt-precipitation and changes in porous-media properties (e.g. porosity and permeability). Numerical implementation is performed in the framework of DuMuX. Implicit Euler method is applied for time and BOX scheme is used for spatial discretization. The system is solved implicitly after incorporating the interface conditions.

Results: Numerical examples are setup to illustrate evolution of the evaporation rate, cumulative water loss, drying behavior, solute distribution, salinization and changes in porous media properties. The model is applicable to both non-saline and saline cases. Numerical experiments are undertaken for saturated and unsaturated systems with homogeneous and heterogeneous porous structures. The model concept is validated against the experimental data presented by [4].

References
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