Energiewende und Klimaschutz: analog und digital

WellboreKit: A coupled-dynamic thermohydro-chemical wellbore model for two-phase multicomponent geothermal fluids

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Fluid pressure and temperature enter into a variety of geothermal production-operation calculations, including well drilling and completion, stimulation, controlling mineral scaling, and analyzing pressure-transient test data. The availability of reliable downhole pressure data during hydraulic tests are of crucial importance for interpreting the behaviour of the underground system. For that purposes, high salt and non-condensable gas content in geothermal wellbores may lead to inaccurate pressure, temperature, and mineral saturation index (precipitation/dissolution) calculation. However, due to the complexity of describing this effect, it is normally simplified in the modeling process.

Practically, mineral precipitations (scales) on wellbore casing reduce steam flow-rate which lower the well productivity. In order to recover the productivity, power producers have to remove the scales by well workover. The cost of workover descaling in the wellbore casing is about 100 K to 500 K USD depending on the mineral scales location. Thus, a Thermohydro-Chemical (THC) calculation to predict precipitation amount with regard to time is of great importance to control maintenance cost of wells. This will result trade-off between well productivity and maintenance cost, optimizing the plant operation. Nevertheless, to the Author knowledge, no THC wellbore simulator has been devised currently to simulate multicomponent geofluid with chemical reactions to predict mineral precipitation.

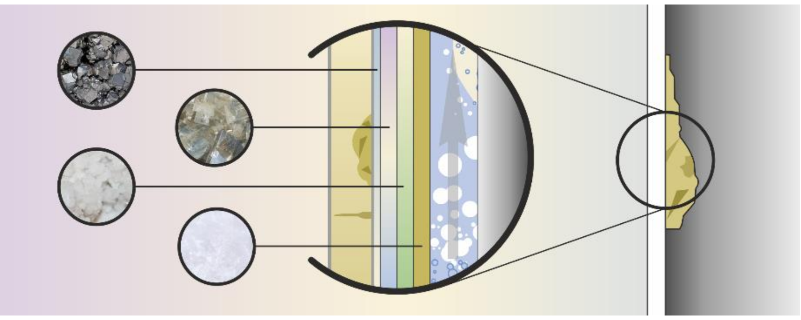

Figure 1 Mineral scales deposit on wellbore tube comprises of layers depending on its solubility. The equation of state for geofluids is implemented in wellbore simulator coupled with geochemical solvers to predict scaling phenomena inside the tubes.

We developed WellboreKit, a model for calculating THC behavior during de-/pressurization of a two-phase multicomponent geothermal fluid in deep wellbore as illustrated in Figure 1. Here, we implemented sequential coupling between transport and de-/compression with a thermal load of a two-phase multi-component geothermal fluid. The thermodynamical and transport properties for H2O - salt (NaCl, $CaCl_2$, KCl, $MgCl_2$, $NaHCO_3$) - gas (CO_2, N_2, CH_4, H_2S) mixtures are calculated using the fugacity-activity, three-region Equation of State solver, GEOSKIT. The solver has been validated with experimental data from literature and online field-measurements applying pressure, temperature, and ionic-strength range of 0.5 – 50 MPa, 32 – 177 °C, and 0 – 8.1 mol/kgw. Figure 2 shows good agreement of GEOSKIT and measurement data for H_2O-CO_2-CH_4 system, confirming reliability of the approach.

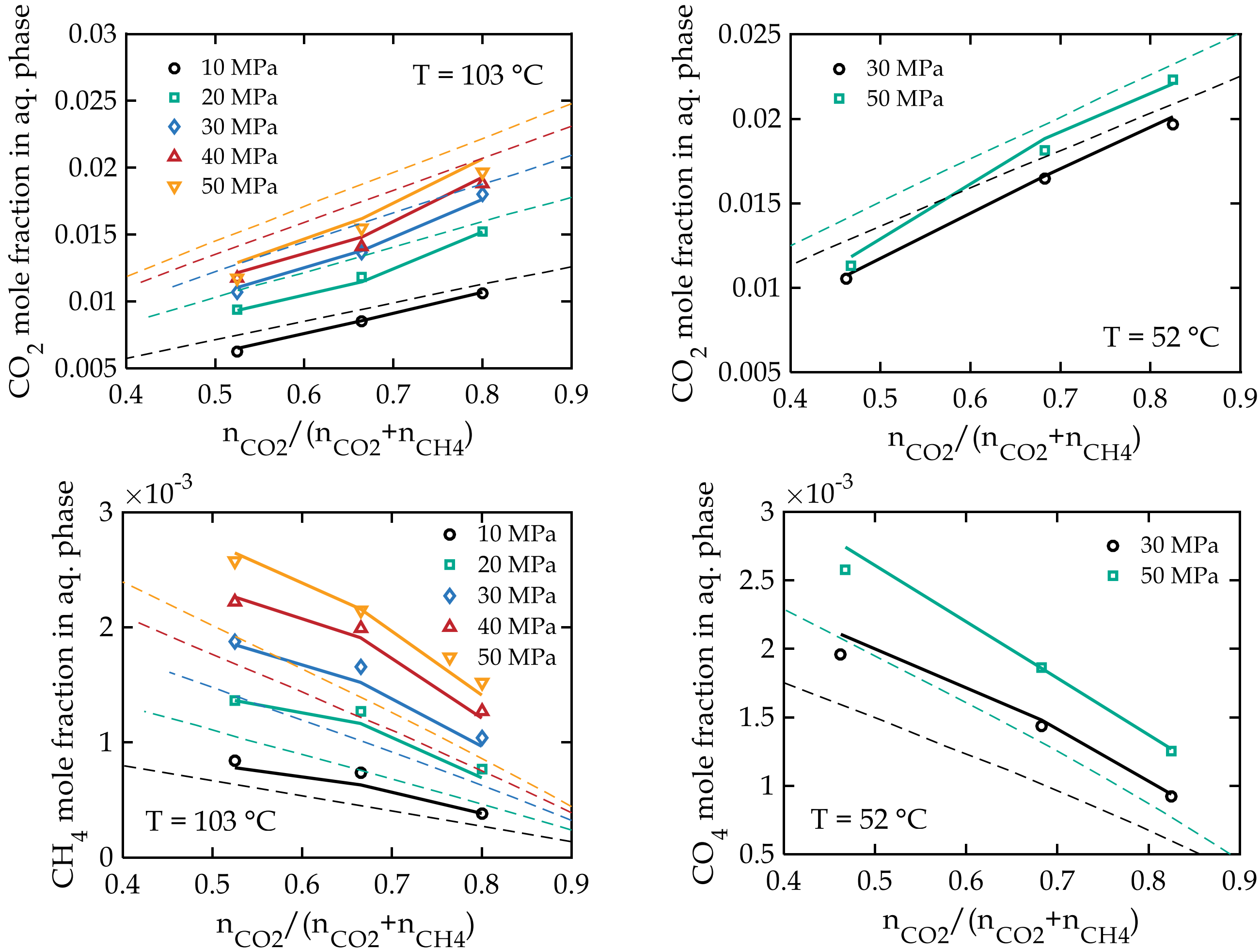

Figure 2 Aqueous mole fraction of CO_2 and CH_4 varying with CO_2 mole-fraction in dry non-aqueous phase: Experimental data (unfilled circles 10 MPa; unfilled squares 20 MPa; unfilled diamonds 30 MPa; unfilled upward triangles 40 MPa; unfilled downward triangles 50 MPa) are compared with calculated values from GEOSKIT (solid lines) and PhreeqC 3.2 results (dashed lines).

The fluid flow is described by a heterogeneous drift-flux model, which is solved using the Elmer FEM. An operator splitting algorithm is applied to couple PhreeqC for calculating chemical reaction as depicted in Figure 2.

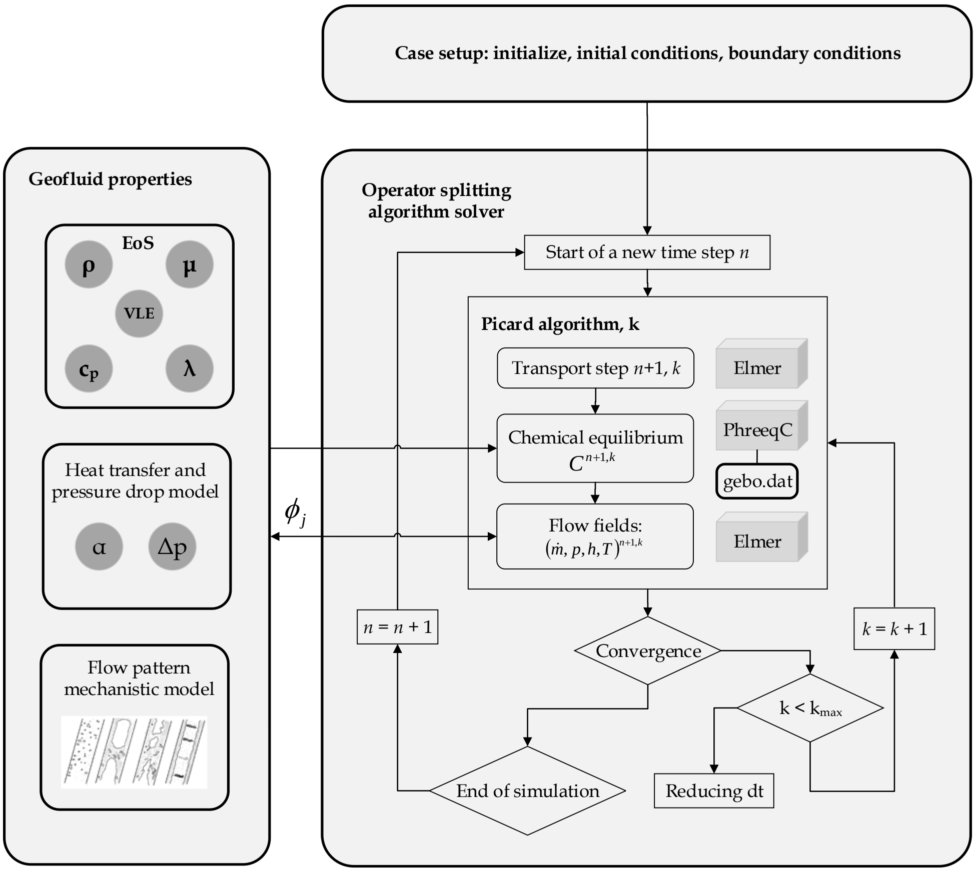

Figure 3 WellboreKit calculation procedure.

Once the boundary conditions have been set, each solver step for a specified time step, consists of the following major sub-steps:

1. Aqueous species transport is calculated in Elmer to obtain species concentration at each cell along the well path. For definite salt and gas concentrations at each cell, chemical equilibrium is solved in PhreeqC to compute saturation index of minerals which is then used to determine mineral scaling and to calculate the dissolved salt concentration in the aqueous phase.
2. Thermodynamic properties, i.e., aqueous and non-aqueous enthalpy h^{AQ}, h^{NA}; density ρ^{AQ}, ρ^{NA}; viscosity μ^{AQ}, μ^{NA}; thermal conductivity $\lambda^{AQ}, \lambda^{NA}$; gas fugacity ϕ_j, and quality x, are determined using the equation of state described before as a function of the pressure p(z), enthalpy h(z), and the salt b_i (z) and gas molality b_j (z), and gas mole fraction y_j (z).

3. Void fraction with constitutive relations, i.e. heat transfer coefficient α, wall shear $\left(\frac{dp}{dz}\right)_f$, and hydrostatic pressure gradient $\left(\frac{dp}{dz}\right)_h$ are determined, based on the flow-pattern map, mechanistic flow model, which is the used to calculate the effective two-phase thermodynamic properties.
4. Geofluid heat and mass transfer, pressure drop, and species transport are solved in Elmer.

From Elmer calculation we retrieve new pressure, temperature, species concentration, and gas fugacity fields, which are sent to PhreeqC for the equilibrium at the next time step.

Application of the model associated with geofluid flow in wellbores is depicted in Figure 3. Specifically, we discuss issues with downhole scaling in reinjection wellbores. We simulated barite precipitation which is typical scale in deep geothermal systems. The simulated geofluid comprises aqueous barium sulfate $Na^+/Ca^+/Ba^{2+}/Cl^-/SO4^{2-}$ with concentration of 1.105/0.015/1.4E-4/1.408/1.4E-4 mol/kgw, respectively.

As shown in Figure 4a and 4c, we can recognize that the precipitation proportionally increases with lower reinjection temperature and higher injection rate. In Figure 4b and 4d, we can observe the hydraulic diameter reduction inside wellbore due to precipitation explained previously. The simulation was performed in chemical equilibrium for one month reinjection period. As observed in Figure 4b, for the reinjection temperature of 40 °C, the wellbore is blocked after 16 days at depth of approximately 800 m. This results denote first scaling analysis which needs to be validated with measurement data. Thus, presently, only qualitative conclusions can be made which provides useful information concerning downhole scaling with regard to time.

Having demonstrated the scaling prognosis in the single-phase, chemical equilibrated reinjection case, we plan to run the case with kinetic chemical reactions, grain mechanics and two-phase geofluid in the production case.

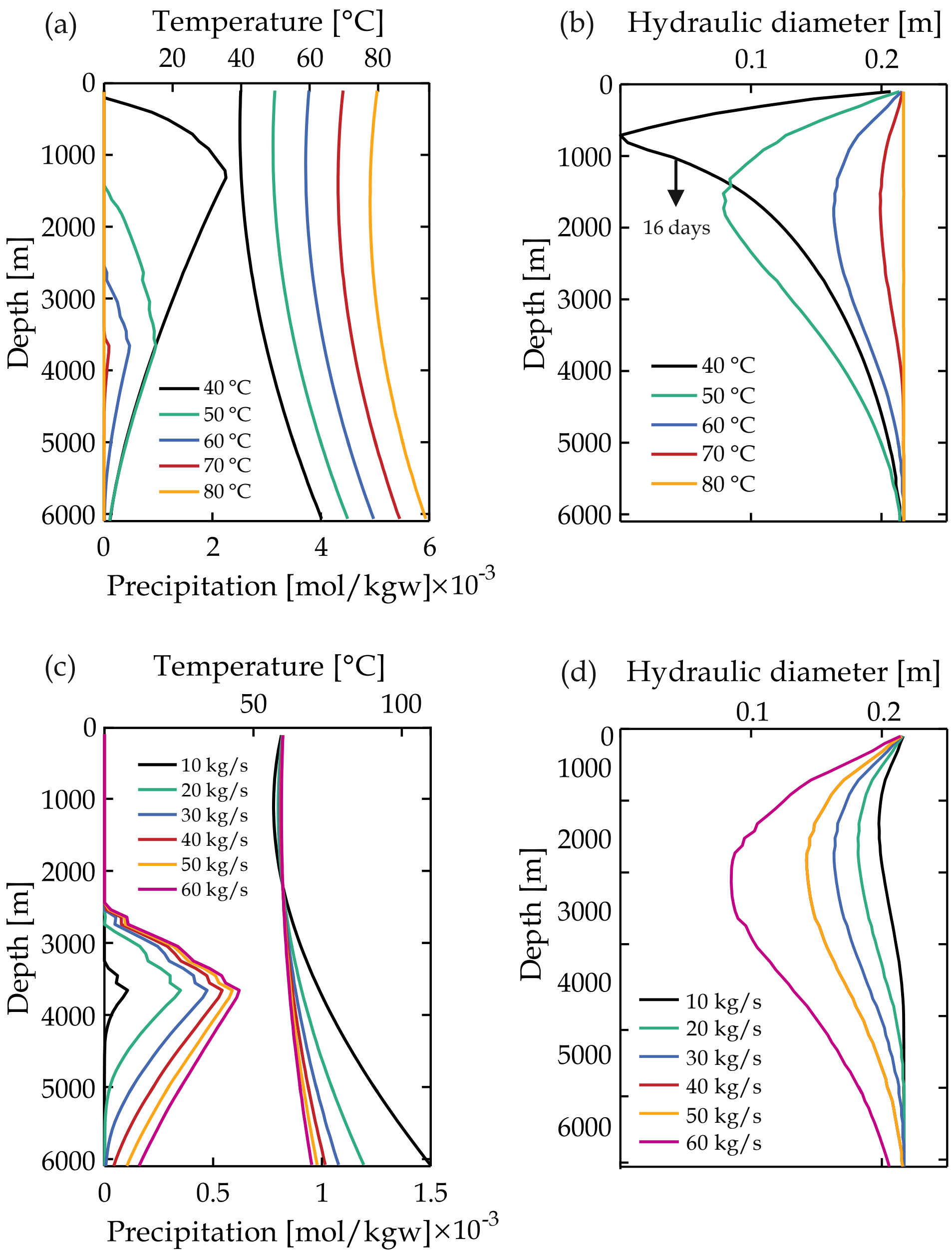

Figure 4 Evolution of precipitation amount, temperature, and hydraulic diameter with regard to reinjection temperature (a, b) and reinjection rate (c, d) at 1 month period. At varying reinjection temperature, the reinjection rate is kept constant at 30 kg/s. While, at varying reinjection rate, the reinjection temperature is kept constant at 60 °C.

By using WellboreKit, a robust, unique wellbore flow simulator, it is expected to analyze individual two-phase, multicomponent well dynamics, such as the effects of casing and reservoir issues, predict the actual results measured after a flow test or workover due to downhole scaling. The simulator is useful to be practically used in worldwide geothermal industry to optimize plants operation, particularly for deep geothermal systems.