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Comparison of (semi)analytical and numerical simulations of underground gas storage

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With power production from renewable sources increasing constantly, offsets between available power supply and demand can result in energy storage requirements on different scales. The geologic subsurface can potentially supply high storage capacities in the form of mechanical, e.g. compressed air energy storage (CAES), or chemical energy storage using either hydrogen (H2) or synthetic methane (CH4). In a future energy system, loading and unloading of storage sites will vary strongly with time and depend on the future design of the energy system. Integrated models, which combine simulations of the subsurface storage operations with the operation of the associated power plants and the energy transmission system, have to be employed to investigate scenarios for an economical as well as ecological operation of these facilities. For these coupled simulations, multi-phase and multi-component reservoir simulations of the gas storage sites cannot be used, as very fast simulation times of the storage behaviour are required.

The aim of this work is to develop and investigate the applicability of an analytical gas storage model for the simulation of porous media compressed air energy storage operations for storage cycles with strongly varying flow rates and high temporal fluctuations. For the analytical simulation the reservoir gas flow is approximated using steady-state radial gas flow at the wells, and the reservoir pressure is adjusted based on the gas mass balance of the reservoir. For a better representation of more complex storage setups, multiple analytical solutions are superimposed to account for well interference. Limitations of well flow rates in case of pressure limit violations are also included for the analytical solutions. Results obtained by the analytical storage model are compared to results obtained using a numerical reservoir model (ECLIPSE). Realistic storage cycles in terms of duration, frequency and magnitude, which are obtained from energy system analysis in combination with a power plant analysis, are used for the comparisons.

The comparisons show that the analytical storage system simulations provide a reasonable estimate of the well pressures with differences being generally less than 0.5 bar in cases in which the storage site is operated at rates below the theoretical peak flow rates of the specific storage design and reservoir permeabilities are above 500 mD. With increasing well flow rates during withdrawal or injection periods and decreasing reservoir permeabilities the differences between the (semi) analytical tool and the numerical solution increase. The same is true for short storage cycles or strongly fluctuating storage flow rates. However, the (semi) analytical solution tends to overestimate the pressure build-up during injection periods and the pressure reduction during withdrawal periods, therefore providing a conservative estimate of the achievable well flow rates compared to the numerical simulations.