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Operational design and pressure response of large-scale compressed air energy storage in porous formations

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With the rapid growth of energy production from intermittent renewable sources like wind and solar power plants, large-scale energy storage options are required to compensate for fluctuating power generation on different time scales. Compressed air energy storage (CAES) in porous formations is seen as a promising option for balancing short-term diurnal fluctuations. CAES is a power-to-power energy storage, which converts electricity to mechanical energy, i.e. highly pressurized air, and stores it in the subsurface. This study aims at designing the storage setup and quantifying the pressure response of a large-scale CAES operation in a porous sandstone formation, thus assessing the feasibility of this storage option. For this, numerical modelling of a synthetic site and a synthetic operational cycle is applied.
A hypothetic CAES scenario using a typical anticline structure in northern Germany was investigated. The top of the storage formation is at 700 m depth and the thickness is 20 m. The porosity and permeability were assumed to have a homogenous distribution with a value of 0.35 and 500 mD, respectively. According to the specifications of the Huntorf CAES power plant, a gas turbine producing 321 MW power with a minimum inlet pressure of 43 bars at an air mass flowrate of 417 kg/s was assumed. Pressure loss in the gas wells was accounted for using an analytical solution, which defines a minimum bottom hole pressure of 47 bars. Two daily extraction cycles of 6 hours each were set to the early morning and the late afternoon in order to bypass the massive solar energy production around noon. A two-year initial filling of the reservoir with air and ten years of daily cyclic operation were numerically simulated using the Eclipse E300 reservoir simulator.
The simulation results show that using 12 wells the storage formation with a permeability of 500 mD can support the required 6-hour continuous power output of 321MW, which corresponds an energy output of 3852 MWh per day. The average bottom hole pressure is 87 bars at the beginning of cyclic operation and reduces to 79 bars after 10 years. This pressure drop over time is caused by the open boundary conditions defined at the model edges and is not influenced by the cyclic operation. In the storage formation, the pressure response induced by the initial filling can be observed in the whole model domain, and a maximum pressure built-up of about 31 bars and 3 bars are observed near the wells and at a distance of 10 km from the wells, respectively. During the cyclic operation, however, pressure fluctuations of more than 1 bar can only be observed within the gas phase. Assuming formations with different permeabilities, a sensitivity analysis is carried out to find the number of wells required. Results show that the number of wells required does not linearly decrease with increasing permeability of the storage formation due to well interference during air extraction.