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Simulation of thermal effects during high and low frequency gas storage operations in porous formations

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Increasing the share of energy production from renewable sources will result in shortages in power supply on various timescales and magnitudes. Besides other options, porous media storage of chemical energy in the form of gases such as hydrogen (H2) or synthetic methane (CH4) as well as mechanical energy, i.e. in the form of a compressed air energy storage (CAES) could be employed to mitigate such shortages. A key difference between these storage options are the potential storage operation schemes in which they are used as a result of the different effective energy density in the subsurface. While CAES would most likely be employed in a high flow rate, high frequency storage scheme with daily cycles, H2 and CH4 storage sites are also suitable for longer, up to seasonal, withdrawal cycles with a lower periodicity.
The aim of this work is to compare different thermal effects as a result of H2, CH4, and compressed air energy storage operations. Besides advective-conductive heat transport in the fluid and solid phases, also the Joule-Thomson effect as a result of gas flow through the porous formation is analysed for the different storage options. For this the Joule-Thomson effect is implemented in the open source simulation software OpenGeoSys and numerical simulations of the different storage options are performed. For the simulations, synthetic but realistically parameterized storage sites are used. Besides using OpenGeoSys, the simulations are also compared to results obtained with the ECLIPSE reservoir simulator (© Schlumberger).
The simulations show that the heat introduced into the system by the gas injections is transported away from the injection wells mainly through heat conduction. Thus, the thermal perturbation is also present in the caprocks above and below the storage formation. Because of the low heat capacity of the injected gas, thermal effects are confined to the near well region. Temperature changes of more than 1 K are thus found within the first tens of meters around the injection well, if the stored gas is injected with a temperature difference of 25 K to ambient formation conditions. In case of a CAES or CH4 storage in a porous formation, the Joule-Thomson effect results in a temperature decrease during both injection and withdrawal cycles, which accumulates several meters away from the storage well, reaching about -5 K. In difference to this, a very slight temperature increase of about 1 K is found in case of H2 storage. This is due to H2 having a negative Joule-Thomson coefficient at the given reservoir conditions. In addition to the individual Joule-Thomson coefficients having different signs and magnitudes, the high cyclic storage operation of the compressed air energy storage results in an increased accumulation of the temperature perturbation compared with CH4 and H2 storage operations.