Impacts of the use of the geological underground for thermal, electrical or material geoenery storage - prognosis of induced effects by scenario analysis

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New methods and technologies for energy storage are required for the transition to renewable energy sources, in Germany termed the “Energiewende”. Subsurface energy storage systems, such as salt caverns for hydrogen, compressed air and methane storage or porous formations for heat and gas storage offer the possibility of hosting large amounts of energy or substance. They can thus be utilized to store energy and dampen the intermittent nature of the renewable sources of energy production.

When employing these systems, an adequate system and process understanding is required in order to understand the subsurface formations intended for use as storage sites as well as to predict the complex and interacting effects on the storage formations, neighbouring formations and protected compartments like e.g. shallow ground water, soil, ecological functions and ultimately humans. This process understanding is the basis for assessing the potential of these storage options in the subsurface on the scale required to dampen production fluctuations, as well as to identify the risks connected with these uses. Special attention is turned on possible mutual influences of these intended storage options with existing or planned other uses of the subsurface. Figure 1 shows a schematic subsurface with possible types of use and their possible interactions. Interactions can be manifold and are transmitted by hydraulic, thermal, chemical or mechanical effects.

For achieving the above stated aims in this work realistic - however synthetic - scenarios for the use of the geological underground as an energy storage system are developed and parameterized. These scenarios are close to conditions prevailing in North Germany in the North German sedimentary basin. This basis shows both thick layers of sedimentary strata, which can host porous media storage sites, as well as salt structures close the land surface, which offer possibilities for cavern storage. Thus the types of energy storage investigated include gas storage of methane, compressed air and hydrogen.
in both salt caverns and porous formations, as well as heat storage in deeper (i.e. > 400 m depth) formations. The scenarios are parameterized using available data from literature or own measurements from the project work. The usage scenarios are derived by using typical energy demands and wind power plant generation cycles due to weather conditions, in order to obtain the required size and recharge/discharge rates of the geoenergy storages. The scenarios are then numerically simulated and interpreted with regard to induced effects, storage performance and sustainable use. In these simulations, the numerical simulator OpenGeoSys [2] is used in combination with geometry and meshing pre-processor tools specifically adapted for this purpose. OpenGeoSys is an open source scientific and process oriented numerical simulator, capable of representing coupled hydraulic, thermal, geomechanical and geochemical processes. The simulator is also specifically enhanced to be able to represent the required effects and induced processes occurring for these types of use. Using the simulated and interpreted scenarios, areas of influence of the individual influences can be mapped and their uncertainty assessed. This allows identifying the subsurface region used by the geoenergy storage site, which enables the assessment of mutual influences and competition for subsurface space. Based on these results, then also monitoring methods can be developed, which will allow to observe the storage options for adverse effects [3].

This presentation will demonstrate the procedure outlined by two geoenergy storage examples. In the first case, the storage of hydrogen gas in a porous formation is considered. Storage size, recharge and discharge rates are designed to compensate shortfalls in wind energy production, which prevails in northern Germany. The storage site is a sandstone layer in an anticlinal site, situated in about 600 m depth. The model was parameterized using site specific data, using both homogeneous and heterogeneous realizations. Hydrogen gas is injected and extracted through five wells, and nitrogen is used as a cushion gas. Well productions rates in this case can reach about 3 Million Nm³/d per well, providing the required electrical energy for about 1.5 Million people for one week. The synthetic storage site is operated on both short-term discharge and recharge cycles, as well as large demand cycles, representing highest outflow conditions. Effects of this storage are simulated in the subsurface, using a coupled thermal-hydraulic model. Induced hydraulic effects are a result of the induced overpressure within the storage formation. The propagation of the pressure signal does not strongly depend on the formation heterogeneity and thus shows approximately radial characteristics, with pressure changes of more than one bar in distances of less than 5 km from the injection wells. Thermal effects are limited to the vicinity of the injection wells. Conductive heat transport into the overlying barrier formations can be observed, causing temperature changes of more than 1 K in distances of less than 300 m in lateral and 30 m in vertical direction. The area of induced chemical effects is given by the distribution of the injected gas phase, which shows a strong dependence on formation heterogeneity, with a maximum reach of around 3 km from the injection wells and a covered area of about 4 km².

![Figure 2: Gas phase distribution (left) at the top of the eroded anticlinal structure, also showing the five wells. Maximum pressure increase (left) at the end of an injection period.](image)

The second example is demonstrating heat storage using borehole heat exchangers. For storing larger amounts of energy, injection and extraction temperatures of 90°C and 1°C are specified. The borehole heat exchanger and the near surroundings of the borehole are simulated using a highly refined grid.
This approach was verified using experimental data from a well defined test case [4]. Application to a setting with a 100 long borehole in an average depth of 500 m using heating and cooling periods of 6 months of heat injection and heat extraction, representing the summer and winter months, respectively, shows that about 75 MWh of energy are injected into the subsurface. If the subsurface is relatively impermeable (k = 10^{-13} m²; Case1), the heat is just transported by heat conduction in the porous medium. However, for higher permeabilities (k=5\times10^{-11} m²; Case2), thermal convection starts to have an effect on the stored heat, as heat is moving upwards and at the top of the formation away from the borehole. Thus storage efficiency is decreased, as this heat can not be recovered within a 6 month cycle of heat extraction. Recovery rates are low and on the order of 30% for the single borehole, increasing to 75% for an array of 19 borehole heat exchangers with 5 m spacing. Temperature changes are restricted to about 15 m from the boreholes after 5 years of cyclic operation. This distance increases, when convection is contributing to heat transport. Hydraulic effects on the subsurface are very small, as no water is injected or extracted. Chemical changes will be limited to the area of temperature increase.

Figure 3: Vertical temperature distribution along the borehole after 6 months of heat injection for low permeability (left) and high permeability (right) conditions.

References


