Energetic balancing of the cyclic operation of a high temperature aquifer storage

Jörg Meixner[a], Martin Jägle[b], Ingrid Stober[a], Thomas Kohl[a]

a. Karlsruhe Institute of Technology KIT, Institute for Applied Geosciences, Geothermal Research

b. Fraunhofer Institute for Physical Measurement Techniques IPM

joerg.meixner@kit.edu

Keywords: Aquifer thermal energy storage, energetic balancing, FE-modelling

ABSTRACT

The private sector energy consumption in Germany rather constantly accounts for about 50 % of the final energy production. More than 80% of this fraction is furthermore attributable to thermal energy. Thus high innovation and saving potentials arise for the heat market. Both are strongly required to meet national and international climate protection goals. A steady increase in renewable energies such as solar thermal systems helps to decentralize the heat market and to decrease CO_2 emissions. But common to many renewables is a seasonally phase-shifted supply and demand function. Heat demand is lowest in the summer months where heat production rates, e.g. of a solar thermal plant, commonly is peaking.

Cyclic storage of surplus heat in the summer is one possibility to close gaps in heat supply in the winter that are currently filled by the use of fossil fuels. Aquifer thermal energy storage systems, ATES, focus on storage and recovery of thermal energy by extraction and injection of groundwater from shallow seated aquifers (< 100 m). Because their applications are limited to areas with low groundwater flow velocities shallow seated Tertiary and Quaternary aquifers in the Upper Rhine Graben, URG, in Germany seem to be unsuitable for this technique. Mesozoic sediments, however, still are of interest since they locally occur in depth ranges of 500 – 1500 m, in suitable PT ranges for high temperature aquifer storage operations. Because pilot plants and field data are missing in the URG, a feasibility study based on geological and finite element, FE, modelling was conducted to 1) simulate a solar thermal heating plant that is coupled with a deep geothermal aquifer storage and 2) to assess the overall energy balances of different modes of storage operation. Various operating modes of the aquifer storage have been considered. "Static" scenarios with 175-day storage and production phases and constant volumetric flows allow quantification of maximum installed capacities, energies, and efficiencies achievable with the cyclic storage operation. "Dynamic" scenarios consider natural fluctuations of the global radiation during heat generation of a solar thermal plant. Sub-models for different volumetric flows, heat extraction rates, formation permeabilities, and borehole designs highlight sensitivity of individual, may site-specific, system parameters on the hydrogeological, geothermal, and economic outcomes of the FE modellings.

Following the maximum scenario of a "static" storage operation, up to 26 GWh_t per year can be produced from a deep geothermal aquifer storage (Figure 1) in the heating phase. In this scenario the annual heat demand of about 1000 households can be covered. The produced thermal energy corresponds to a heating oil equivalent of about 2.6 Mio l, which would need to be used to cover the annual heat demand.

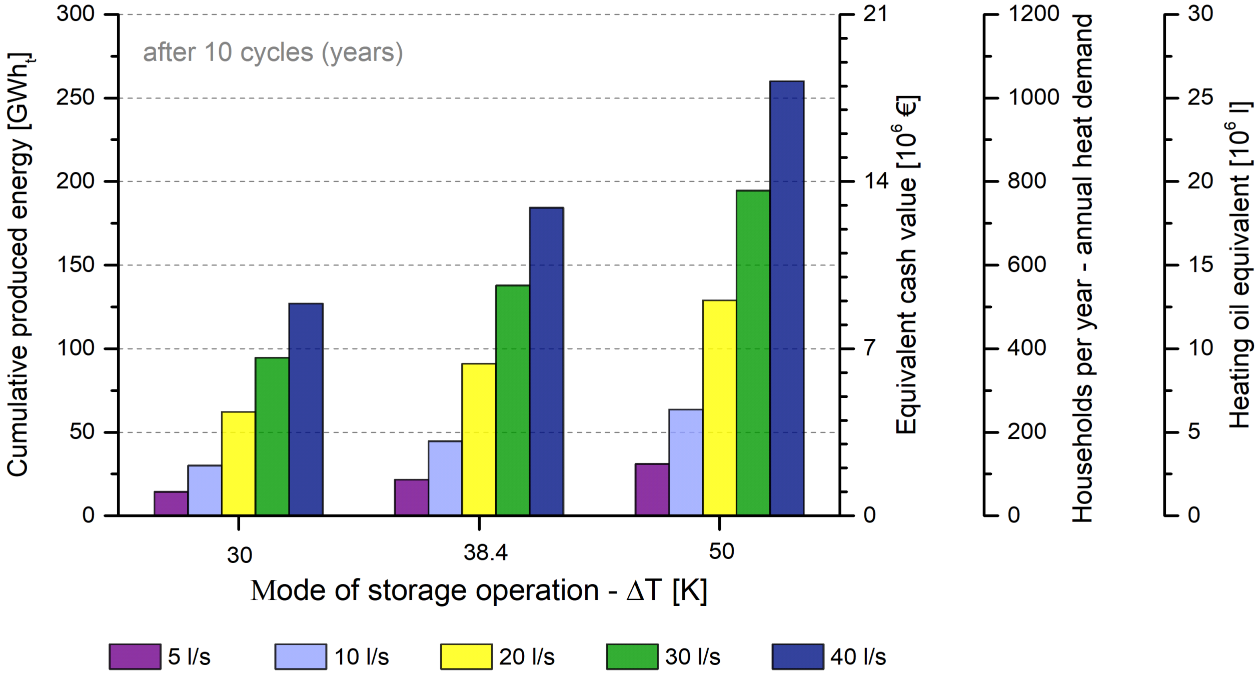

Figure 1 Comparison of the cumulative produced thermal energies after 10 years with 175-day storage-heating-cycles per year and for production rates of 5, 10, 20, 30, and 40 l s^{-1}. Additionally, three different modes of the storage operation are considered: each with constant injection temperatures during the storage phases of 80°C but with varying injection temperatures during the heating phases of 50 (left), 41.6 (middle), and 30°C (right).

The efficiency of different modes of the storage operation can be quantified by the recovery factor, the ratio between the stored and produced thermal energy. The modeled efficiencies in the static and dynamic models vary between 50 and 85 % and therefore range in the same order of magnitude as 1) the results obtained in comparable studies for shallow ATES systems (Schout et al., 2014; Xiao et al., 2016; e.g. Major et al., 2018) and 2) measured ones at the few demonstration projects in northern Germany (Sanner et al., 2005; Kabus et al., 2009).

Our results show, that cyclic operations of deep aquifer storages have the potential: 1) to store surplus heat in the subsurface with minor energetic losses; 2) to fill gaps in heat supply in the winter by surplus heat of the summer, which significantly increases the overall efficiency of different heat generation techniques; 3) to decrease the oil or gas consumption rate in the heating periods; 4) to reduce the CO_2 emissions related to the use of fossil energies.

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