Impact of aquifer properties and well configurations on ATES and open-loop shallow geothermal systems

Introduction

Aquifer Thermal Energy Storage (ATES) and open-loop unidirectional shallow geothermal systems can supply both heating and cooling. Both play an important role in providing a sustainable, and low-carbon solution for heating and cooling. Both use similar numbers of well pairs and have similar installation and operational costs. However, the seasonal reversal of ATES systems allows additional efficient energy storage (Bloemendal, 2015; Regnier et al, 2021), up to around 70-90% for well-balanced systems, whereas unidirectional open-loop systems rely on extracting energy relative to ambient aquifer temperature.

Here we explore several system measures of interest, including energy production and energy production per area, for a set of common aquifer properties and system design decisions to understand optimal conditions for shallow geothermal operations and compare ATES bidirectional to open-loop unidirectional systems. Optimal system conditions will depend on the perspective of involved sides and can be conflicting. E.g. developers likely prefer reducing installation costs, end-users likely prefer maximising energy cost savings and local planning councils likely prefer densest use (e.g. energy produced per m^2) of their land area. Results presented here can be used to support policy and design decisions and decide between open-loop or ATES systems. These results can also be used to reduce interference between neighbouring systems (Bakr et al, 2013).

Method

We set up a framework to simulate the impact of a wide range subsurface and design parameters to deduce their impact on ATES and open-loop system performance (Figure 1). Aquifer thickness, lateral permeability and permeability anisotropy are considered as main aquifer properties, and well lateral spacing and vertical offsetting of screened interval as main design decisions. The thickness of the injection and production interval can be dictated by aquifer permeability variations and/or be chosen by varying screen length.

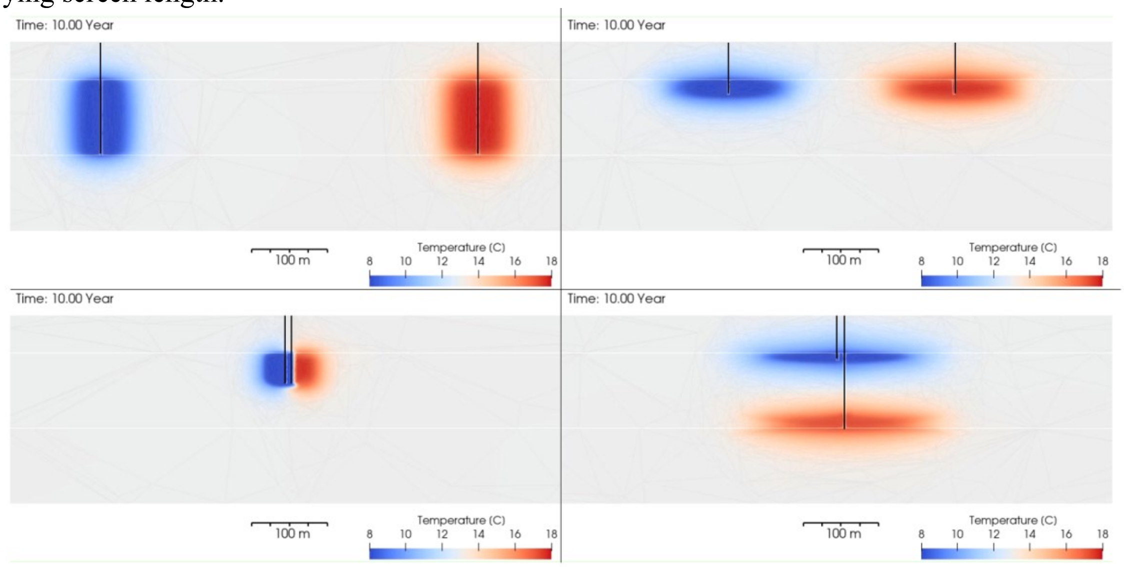

***Figure 1** Overview of four simulated different ATES scenarios, with different well spacings, screen length intervals and vertical screen offsetting. Top-left: wide well spacing and long screen intervals results in minimal interference and conductive losses and high energy production at cost of significant land use. Top-right: Reduced screen intervals yield wider and thinner thermal plumes that are more likely to interact and cause energy losses. Bottom-left: Very close well spacing and overlapping screen intervals are unlikely to be very efficient in any way. Bottom-right: Very close well spacing with vertical offsetting of screen intervals can reach high energy production combined with efficient land use.*

The parameters listed above are combined into dimensionless numbers, such as effective aspect ratio of the system and effective lateral spacing of wells to summarize and group different aquifers and possible shallow geothermal deployment designs. For a wide range of effective aspect ratios and effective well spacing ATES and open-loop system behaviour is predicted by flow simulation over a 10-year period and key performance indicators computed, including thermal efficiency, CO_2 savings, cool/warm plume sizes and stored energy density. The first two indicate the potential expected capacity, whereas the latter provide recommendations for best use of land area, especially if multiple shallow geothermal systems are planned in areas with high concentration of cooling and heating demand. Given heating and cooling demand, specific aquifer conditions and land area available for use, the predicted behaviour metrics will help design optimal deployments and show the potential for energy savings across multiple different settings.

Results

Results (Figure 2) indicate that ATES systems operating from very closely spaced warm and cool wells can yield energy production at similar level of widely spaced well pairs, mainly by vertically offsetting the well screens. Most ATES system, even when suboptimal in terms of energy produced, can produce more energy than theoretical maximum of open-loop system that operate without any thermal interference.

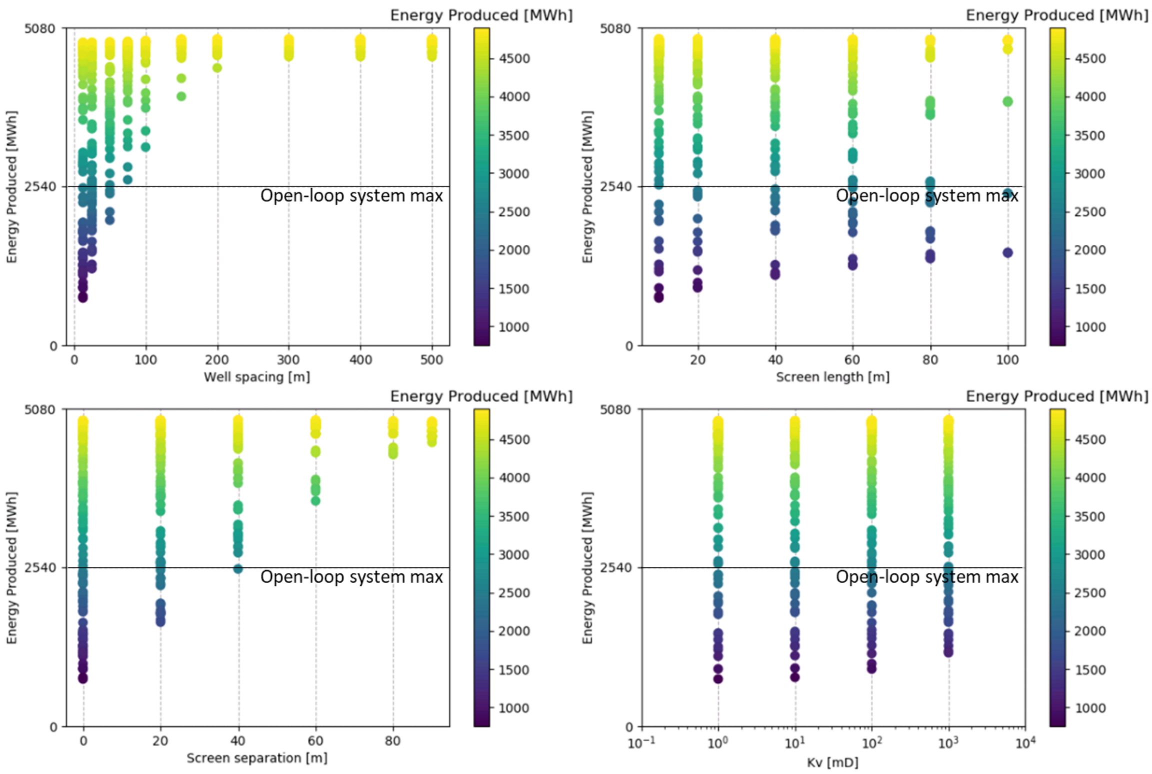

Figure 2 *Energy produced [MWh] during one heating cycle after 10 years of operation for 840 different simulated ATES systems. The theoretical maximum for open-loop system without thermal interaction is indicated by horizontal black line.*

Conclusions

Shallow geothermal systems for heating and cooling can produce large amounts of energy and play a key role in decarbonising. However optimal systems depend on the angle, of construction, use and planning. Here we present numerical results to support design decisions for shallow geothermal systems. Even at very close well spacing shallow geothermal systems can produce similar amounts of energy compared to wide spacing, by vertically offsetting screen intervals. This also reduces the footprint and risks of interfering with neighbouring systems. The added benefits of storing heat and cool in ATES systems result in higher energy production potential than open-loop unidirectional systems.

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References

Bloemendal, M., Olsthoorn, T., van de Ven, F. [2015]. Combining climatic and geohydrological preconditions as a method to determine world potential for Aquifer Thermal Energy Storage. *Science of the Total Environment*, **538**, 621–633. doi:10.1016/j.scitotenv.2015.07.084.

Regnier, G., Salinas, P., Jacquemyn, C., Jackson, M. [2022]. Numerical simulation of aquifer thermal energy storage using surface-based geologic modelling and dynamic mesh optimisation. *Hydrogeology Journal*, **30**, 1179–1198, doi:10.1007/s10040-022-02481-w.

Bakr, M., van Oostrom, N. & Sommer, W. [2013] Efficiency of and interference among multiple Aquifer Thermal Energy Storage systems; A Dutch case study. *Renewable Energy*, **60**, 53-62, doi:10.1016/j.renene.2013.04.004.