Assessment of short-term aquifer thermal energy storage for demand-side management perspectives

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Introduction

In the last decades, aquifer thermal energy storage (ATES) has been proven to be a reliable renewable energy source. Yet, most of the ATES running systems are designed for seasonal or monthly storage and recovery applications [1].
In the context of demand-side management, we have investigated the ability of such systems to perform short-term thermostatically-controlled load-shifting (storing thermal energy during off-peak periods and recovering it during peak periods) directly in aquifers at real-time, intraday and interday frequencies. In the present work, we mainly focused on the assessment of energy recovery rates for single low- (LT-) and high-temperature (HT-) ATES cycles at these specific frequencies.

Motivation

The main aim of our work is to consider short-term ATES for its potential for flexibility, with the implementation of two different strategies:

- **LT-ATES**: preheating/precooling aquifers (**T < 30 °C**) during off-peak periods, recovering the stored thermal energy during peak periods.
- **HT-ATES**: storing thermal energy at higher temperatures to retrieve heat (**T > 50 °C**) that can be directly used for space heating without the need for upgrading.

Shallow alluvial aquifers are suitable to perform short-term ATES [2]. This technique has a high development potential for demand-side management (DSM) applications.

The study site is typical of alluvial aquifers of Belgium, and is located along the Sambre River in Wallonia (**Figure 1**). Such alluvial aquifers are the **main target** for open-loop geothermal systems development in Wallonia, since they show the following properties:

- **Highly productive** (sandy to gravely aquifers).
- **Shallow** (easy to implement well-doublets).
- **Slow ambient groundwater flow** (low hydraulic gradient).

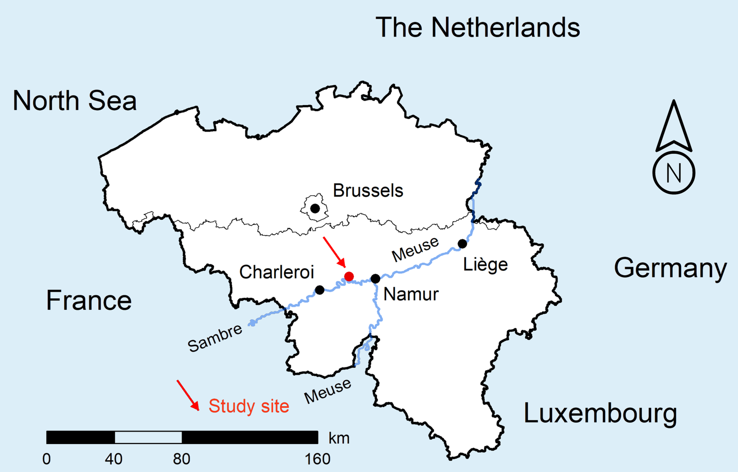

Figure 1. Location of the study site in Belgium (Wallonia). The largest cities built on alluvial deposits of the Sambre and Meuse Rivers are highlighted.

Methods

First, an ATES experiment was set up and performed on site. Then, a 3D subsurface flow numerical model was built and calibrated, with coupled heat transfer processes. With this model, 77 LT-ATES and HT-ATES simulations were run to assess the feasibility of short-term DSM applications.

1. Aquifer thermal energy storage experiment

The experiment is summarised at **Figure 2**. W1 and W2 are the well doublet used for our ATES experiment. PzA, PzB and PzC are observation wells used for monitoring the injected thermal plume. In addition, the plume extension was monitored through 4D electrical resistivity tomography (4D ERT) [3, 4].

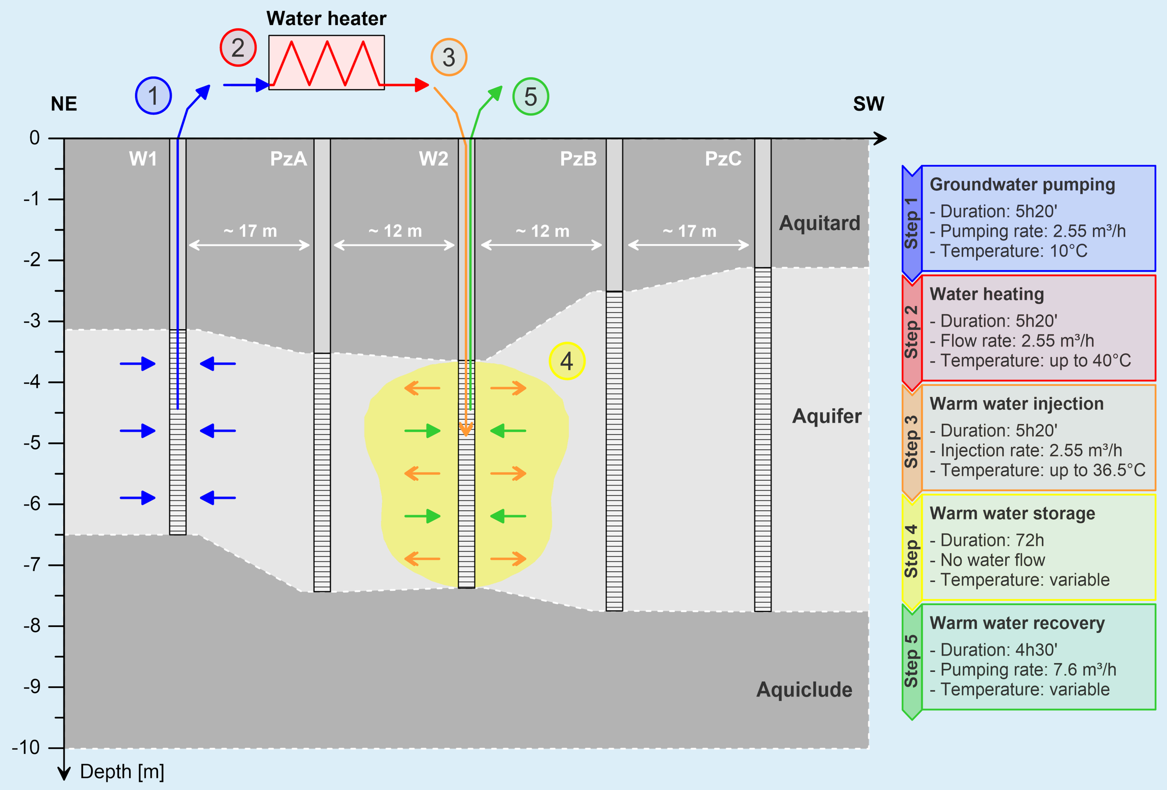

Figure 2. ATES well doublet experiment, modified after [5].

2. Subsurface flow and heat transfer model

The subsurface flow and heat transfer model was conceptualised and run with FEFLOW. Hydraulic and heat transport parameters were calibrated against field data collected during the ATES experiment (**Figure 3**).

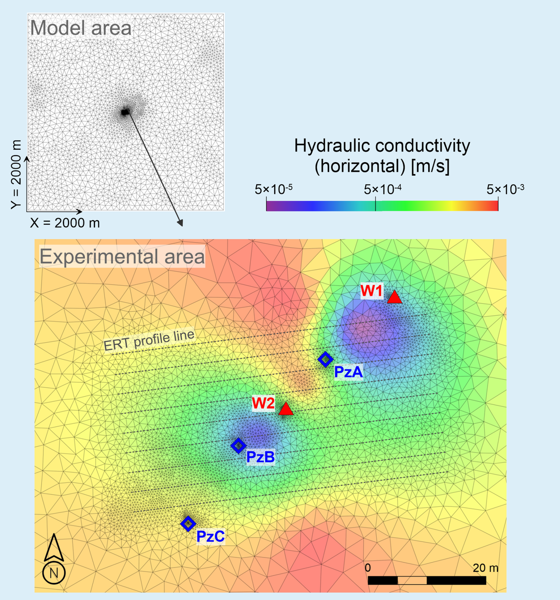

Figure 3. Horizontal discretisation of the subsurface flow and heat transfer numerical model. The calibrated hydraulic conductivity of the aquifer unit is exposed; it was calibrated with the pilot points method [6]. Vertically, the model is made of 16 layers.

Results

1. Model calibration

As seen from **Figure 4**, observed and simulated temperature curves are significantly different. Yet, the calibrated temperature breakthrough curve is assumed to be representative of the actual groundwater temperature, which was validated by the 4D ERT data. Heat loss through the injection well to the atmosphere, that was not simulated, is believed cause the observed curve offset.

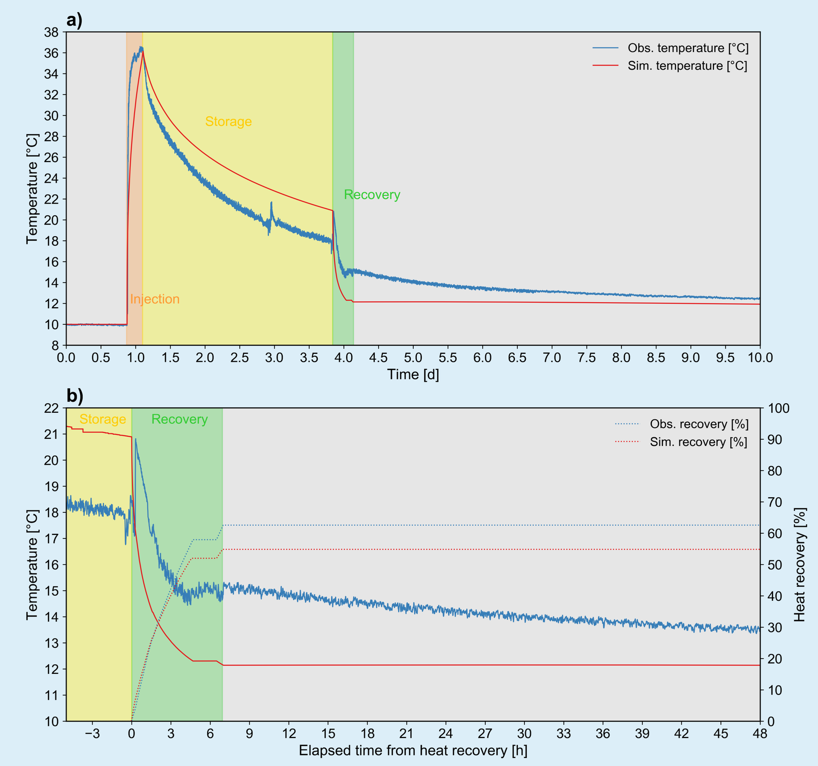

Figure 4. Observed and simulated temperature evolution in the injection well (W2) during the ATES experiment (a). The recovery phase is highlighted (b) with relevant observed and simulated heat recovery efficiency curves.

2. LT-ATES and HT-ATES simulations

With the calibrated model, the following simulations were run:

- LT-ATES ($-4 < \Delta T < 11$ K), that gave 78 to 87 % estimated energy recovery rates (**Figure 5**).
- HT-ATES ($\Delta T > 35$ K), resulting in 53 to 71 % energy recovery rates (**Figure 5**).

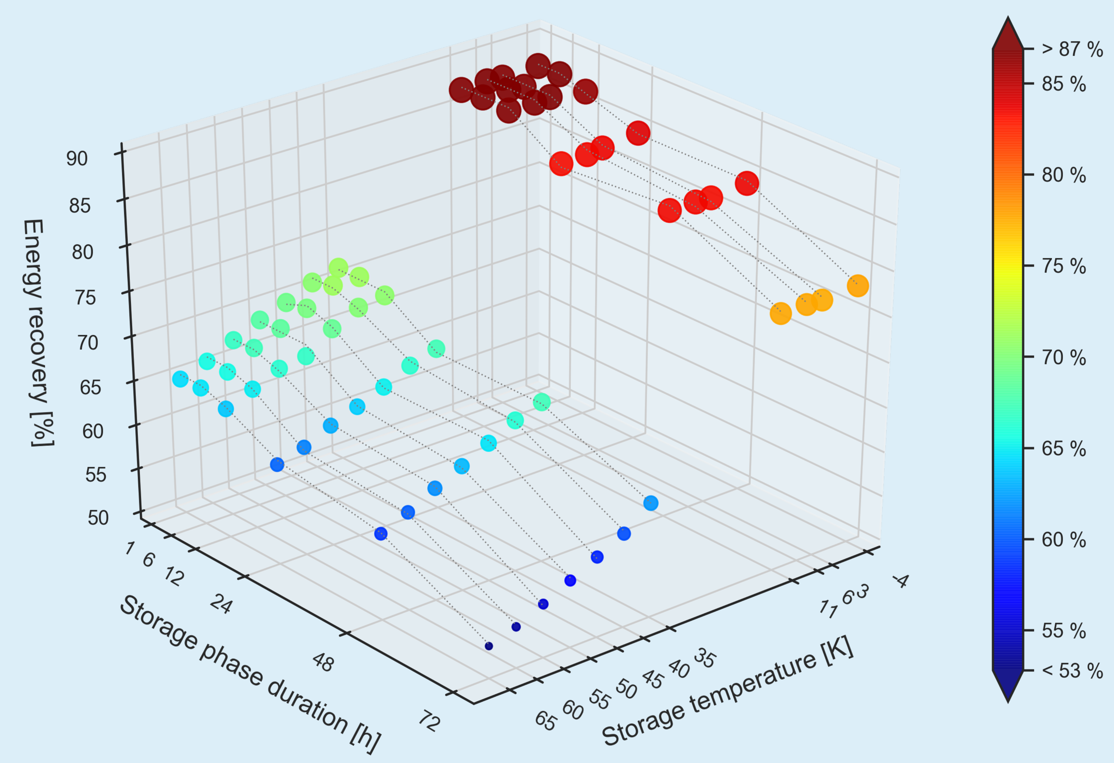

Figure 5. Energy recovery rates from the LT-ATES / HT-ATES simulated scenarios.

Recovering the absolute injected temperature is barely feasible with a single cycle, since:

- Energy recovery rates (η) are constant at real-time and intraday frequencies (Δt = 15 min, 1, 6 and 12 h).
- η decrease with longer storage duration (Δt = 24, 48 and 72 h).
- η decrease faster for HT-ATES compared to LT-ATES.

With energy recovery that was slightly underestimated for the simulated (and yet calibrated) real case ATES experiment, the simulated energy recovery of our scenarios are likely to have been underestimated too.

Conclusions

Our study shows that warm or cold water can be stored during off-peak periods, and can be recovered during peak periods with energy recovery rates likely up to 90%. Low-temperature storage shows higher energy recovery rates than high-temperature storage.

Short-term ATES should be further investigated for flexibility purposes by:

- Preheating/precooling aquifers to improve the performance of LT-ATES systems.
- Directly storing potentially useful heat for space heating or domestic hot water production, when considering HT-ATES.

Optimisation developments targeting enhanced thermal energy storage and recovery in space (system sizing), in time (cyclicality), and of absolute temperatures is underway (**see EGU2019-4159**).

References

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