State of the art of HT-ATES in The Netherlands

Benno Drijver[1], Guido Bakema[1], Peter Oerlemans[1,2].

[1] IF Technlogy, Velperweg 37, Arnhem, The Netherlands

[2] NIOO, Droevendaalsesteeg 10, Wageningen, The Netherlands

b.drijver@iftechnology

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ABSTRACT

Within the EU Geothermica program, the Heatstore research project has been started. Since Underground Heat Storage is expected to become one of the key elements in the energy transition, the aim of the Heatstore research project is to develop new technologies and knowledge on this topic. Globally, The Netherlands has a leading position in Aquifer Thermal Energy Storage (ATES) technology. Consequently, the Dutch contribution to the Heatstore project focusses on the design and realization of a new High Temperature ATES (HT-ATES) system in the Wieringermeer greenhouse area.

As a first step, IF Technology created an overview of the state of the art of HT-ATES in The Netherlands. In this paper, the main conclusions are described. Based on these conclusions, design rules are given for future HT-ATES systems. These design rules, both for underground aspects and for system integration, should contribute to a higher thermal efficiency.

1. INTRODUCTION

About half of the European energy consumption is used in heating and cooling and approximately 85% of this energy is produced from fossil fuels. The global community has set ambitious goals to reduce greenhouse gas emissions. A more widespread implementation of sustainable heat sources (e.g. geothermal, biomass, solar and waste-heat) is indispensable for achieving this objective. One of the main problems is that the heat demand and the availability of (sustainable) heat do not match. In the winter period, the heat demand is large and the availability of heat is limited, whereas in the summer season, much more heat is available than is needed for heating. Underground Thermal Energy Storage (UTES) is a promising technique to balance the discrepancy in thermal energy availability and demand. The ground has proven to be an ideal medium for storing heat in larger quantities and over longer time periods, like the yearly seasons. The two most common types of UTES are borehole thermal energy storage (BTES: closed loop systems that are used for thermal energy storage) and aquifer thermal energy storage (ATES: open loop systems that are used for thermal energy storage in aquifers).

In the major part of The Netherlands, the hydrogeological conditions for ATES are favourable and ATES is the most common type of UTES for large-scale projects (cooling/heating demand >100 kW). For such projects, ATES is favourable, because of its ability to pump large amounts of water and consequently store large quantities of thermal energy. At the end of 2016, about 2,200 permits for open-loop shallow geothermal energy systems were registered. The vast majority of these permits (on estimate > 90%) applies to ATES systems. With this large number of ATES projects, The Netherlands has a unique position in the world. Almost all of these ATES systems (> 99%) store heat (and cold) at temperatures below 30 ºC.

The focus of this paper is on High Temperature Aquifer Thermal Energy Storage (HT-ATES: storage of heat with temperatures >30 ºC). The application of HT-ATES has been limited in the past 20 years, mainly because of legal limitations, the poor business case (because of the competition with natural gas) and the decline of the application of CHP (Combined Heat and Power) installations. In the near future, the use of natural gas is expected to be strongly reduced in The Netherlands. Increasingly more new residential areas are built without a connection to the natural gas grid. As a consequence, the interest in more sustainable alternatives is increasing significantly.

HT-ATES is considered a promising technique for large-scale storage of heat from sustainable heat sources (e.g. deep geothermal systems or solar heat) or residual heat from the industry, waste incineration, power plants or CHPs. Especially in balancing supply and demand in district heating networks, HT-ATES has large potential.

In the framework of the HEATSTORE project, which is part of the European Union’s HORIZON 2020 GEOTHERMICA programme, an overview of HT-ATES experience in The Netherlands was made. The results will be made public in a separate report, that will become available on the website of the HEATSTORE project (www.heatstore.eu).

2. SCOPE

Here the lessons learned from the existing or former HT-ATES projects in The Netherlands are described with a focus on recovery efficiency, system integration and subsurface thermal effects. For an overview of medium-deep HT-ATES in other countries, see Holstenkamp et al. (2017).

Other important aspects of HT-ATES are the impact on groundwater composition, water treatment and material selection. The chemical and microbiological impact of the temperature changes in the underground was intensively studied and reported in the research program “Meer met Bodemenergie” (Hartog et al., 2013; Dinkla et al., 2012), the PhD project of Bonte (2013) and in several other research projects (Griebler et al., 2016; Possemiers et al., 2014; Jesußek et al., 2013; Brielmann et al., 2009). In work package 6 of HEATSTORE on environmental assessment, this research will be summarized.

The high storage temperatures may result in changes in the chemical composition of the groundwater. When high temperatures are stored, chemical treatment of the groundwater may be needed to prevent the precipitation of minerals in the system, which leads to scaling in wells, pipes and the heat exchanger (e.g. Drijver, 2011 and Sanner (ed.), 2009). The engineering aspects of the HT-ATES projects (including water treatment and selection of materials/components) are addressed in a separate report for work package 1.2 of the HEATSTORE project.

3. HT-ATES VERSUS MT-ATES

Within the HEATSTORE project, the term HT-ATES applies to storage of water between 30 and 95 °C. Based on added complexity of the technology (water treatment and material selection) at the high end of this temperature range, a subdivision is made in The Netherlands between HT-ATES projects that store heat of 30-60 °C (for the Dutch situation called medium temperature ATES: MT-ATES) and 60-90 °C. Higher temperatures have not been stored so far.

An advantage of MT-ATES over HT-ATES is that, due to the lower storage temperatures, the thermal losses in the subsurface - and the associated thermal effects - are smaller. Because the storage temperature is lower, there is usually no need for water treatment to prevent precipitation of minerals (in the heat exchanger, pipes and wells). Furthermore, the density difference between the stored warm water and the colder surrounding groundwater is smaller, restraining the tendency for density-driven groundwater flow. This means that aquifers with a higher permeability can be used, which is advantageous since there is more experience with these aquifers and the flow rate that can be achieved per well is higher. Another advantage is that at lower temperatures, less stringent requirements apply to the materials and components that are used in the system. Furthermore, the effects of temperature on the chemical and microbial groundwater composition are smaller.

A disadvantage of the MT-ATES with respect to HT-ATES is that the recovered heat has a lower temperature level and therefore has fewer possible applications. A heat pump can be used to raise the temperature to the desired level, but leads to additional investment and operational costs as well as electricity consumption. Furthermore, larger volumes of groundwater must be pumped to provide the same amount of heat.

The main advantages of HT-ATES over MT-ATES are that (1) high temperature heat can be used directly for heating (e.g. buildings, greenhouses) and is therefore useful for more applications and (2) more energy is stored per m³ groundwater, which reduces both the required flow rate and the subsurface space that is used.

4. PROJECTS

Table 1 contains an overview of MT-ATES and HT-ATES projects in The Netherlands. The Dutch HT-ATES projects have both been closed. It concerns the HT-ATES at the Utrecht University (1991: storage of 90 ºC heat from a CHP installation using ATES) (Figure 2) and a project at a health care institution in Zwammerdam in the late nineties (storage of 90 ºC heat from a CHP installation using ATES). Although the HT-ATES system performed well, the Zwammerdam project was stopped since it was not economically profitable to run. The project in Utrecht was stopped due to well problems and a mismatch between the temperature level required for the building heating system and the temperature level that the storage could provide.

All six MT-ATES systems are still operational. The Heuvelgalerie (1992) and Dolfinarium (1997) ATES systems have been operational for more than 20 years. Details on the MT-ATES and HT-ATES projects, can be found in the HEATSTORE report (Bakema and Drijver, 2018). Here we focus on the lessons learned in these projects.

5. LESSONS LEARNED

Recovery Efficiency

The measured recovery efficiency for all the HT-ATES systems was lower than designed. The main reasons are:

- The storage temperatures (warm well, cold well and cut-off temperatures) have in many cases not been well fitted to the building system or the other way around: the heating system in the building was not adapted to the extraction temperatures from the heat store.

- The storage volumes of the projects are lower than designed. For smaller storages, the impact of heat losses by thermal conduction and density driven flow is relatively large.

- The storage aquifers of some low temperature projects (Harderwijk and Eindhoven) are formations with very coarse sand. The combined effect of buoyancy flow and regional groundwater flow leads to a decrease of the recovery efficiency.

All the projects, except for Koppert Cress, were evaluated with the HST3D software (Kipp, 1987) or SWIP (the predecessor of HTS3D). The modelled recovery efficiency and temperature fields show good similarity with the measured values (Schout et al., 2014; Drijver, 2012; Heidemij Adviesbureau, 1992).

In general more than 50% of the stored energy in the HT-ATES projects was not used for heating. In addition to the negative influence this will have on the profitability of the HT-ATES project, also the authorities and other subsurface stakeholders will have their concerns about the thermal and environmental impact that is associated with these large heat losses. For future projects the recovery efficiency will have to be increased.

The recovery efficiency of an ATES system is governed by the energy losses that occur as a result of a number of processes. Doughty et al. (1982) and Bloemendal and Hartog (2018) give an overview of these processes. They include thermal conduction, dispersion, regional groundwater flow and density-driven flow (also referred to as ‘free convection’ or ‘buoyancy flow’). The case of a high ambient groundwater flow (which is usually not the case in the deep aquifers that are used for storage of high temperatures) is treated by Bloemendal and Olsthoorn (2018). The relative contribution of these processes to the magnitude of the heat losses is determined by a number of operational properties and the properties of the subsurface.

Table 1: Overview of MT-ATES and HT-ATES Projects in The Netherlands (heat storage >30 °C).

Project	Year of installation	Storage temperature [°C]	Storage capacity [MWh_t]	Heating power [MWt]
Utrecht University (closed)	1991	90	6,000	6,0
Heuvelgalerie Shopping Mall, Eindhoven	1992	32	3,300	1,8
Dolfinarium, Harderwijk	1997	40	7,650	4,7
Hooge Burch, Zwammerdam (closed)	1998	88	2,250	1,45
2 MW, Haarlem	2002	43	1,650	2,0
NIOO, Wageningen	2011	45	1,280	1,5
Van Duijn, Steenbergen	2016	40	2,000	2
Koppert Cress, Monster	2017	40	?	?

For HT-ATES systems (seasonal storage), based on a large number of model calculations, a relationship has been derived (Schout et al., 2014; IF Technology/SKB, 2012) between the recovery efficiency and (1) the stored volume of hot groundwater, (2) the well screen length / thickness of the aquifer, (3) the temperatures of the ambient and stored water and (4) the horizontal and vertical permeability of the storage aquifer. The assumptions that underly this relation are given in Schout et al. (2014). Since at least some of these assumptions are not valid in a real case, the recovery efficiency may differ in practice. The derived relation is especially useful to make a selection of the best aquifer for storage. For a proper assessment of the recovery efficiency in practice, numerical simulations are required.

Because the recovery efficiency depends on multiple parameters, it is not straightforward to give an optimal range of values for each of these parameters. However, with these remarks in mind, some general guidelines were derived, that contribute to a high thermal efficiency (60-70% or higher) in future HT-ATES systems:

Underground

- Presence of a confining layer

Because of the occurrence of buoyancy flow, the presence of a confining layer of sufficient thickness and vertical resistance is essential. This helps to minimize heat losses to overlying layers and reduces the thermal impact in overlying aquifers). In case of storage of 90 °C heat, a confining layer of 30 m thickness with a resistance of at least several thousand days is sufficient to prevent temperatures at the top of the confining clay layer >25 °C after 20 years of operation. The required thickness is somewhat smaller for storage of heat with lower temperatures (Drijver, 2012).

- Design HT-ATES with a sufficient size

For the Dutch target formations (Sand of Brussels and the Formations of Breda, Oosterhout and Maassluis) the design rules listed below could be defined, based on the following assumptions: aquifer transmissivity of at least 250 m²/d (to get economical feasible projects), horizontal hydraulic conductivity below 20 m/d (to reduce buoyancy flow).

- An indication for the minimum storage volume of a HT-ATES with a temperature of 90 °C is between 250.000 and 500.000 m³/season (this improves the recovery efficiency and the economical feasibility).

- In HT-ATES with a temperature of 50 °C, heat losses by buoyance flow are smaller and the minimum storage volume lies between 35.000 and 180.000 m³/season.

- Always perform a test drilling

The aquifers that are suitable for heat storage are often subject to limited research. This is mainly because these aquifers have (in most cases) not been attractive for drinking water extraction or low temperature cold/heat storage. Research through a test drilling is necessary to show where layers are located and which water quality they have. It is also desirable to perform a pumping test because the estimation of permeabilities based on grain sizes has shown to be potentially inaccurate.

- Calculate the recovery efficiency with a 3D hydrothermal model

The model schematization is also important. For example, a 3-dimensional thermal transport model is required to correctly calculate the effects of density-driven groundwater flow for multiple well HT-ATES systems (e.g. HST3D, Modflow/SEAWAT, FEFLOW).

The reliability of the predicted effects depends on the reliability of the input in the model. This concerns the usage pattern of the system (pumped water quantities, injection temperatures and variation over time), the properties of the wells (locations of wells, screen lengths and screen depths) and the hydrogeological properties of the subsurface (heterogeneity, permeability, layering).

System Integration

- Minimize the cut-off temperature

When heat is produced from the HT-ATES system, the temperature of the extracted groundwater typically drops significantly during the recovery period (typically the winter season). Ensure that the minimum usable temperature from the store (this is referred to as the "cut-off temperature") is as low as possible. At this cut-off temperature the required heating power can still be supplied under design conditions. The lower the cut-off temperature, the more stored heat can be recovered, which will improve the recovery efficiency. Lowering the cut-off temperature with 10 ºC can increase the recovery efficiency significantly (e.g. by 10 to 15 %).

- Use star-shaped well configurations

The HT-ATES well configuration normally consists of a doublet (one cold and one warm well). For large scale systems, more capacity is required and more wells will be needed. In a star-shape, the warm wells are placed in the middle and a ring of “cold” wells is placed around the warm wells. This is beneficial when the water that is injected in the cold wells has a higher temperature than the natural groundwater temperature in the storage aquifer. In that case, the cold wells can be used to separate the warm wells from the cold original groundwater and thereby reduce the heat losses (Drijver et al., 2012). Another advantage is that part of the heat losses from the warm wells will end up in the cold wells (so that less energy is required to heat up the water that is extracted from the cold wells to the storage temperature). In this configuration the cold wells will insulate the heat around the warm wells and efficiency will increase up to 10 %.

- Put the heat storage system at base load in winter time

The heat storage is a slow-reacting system because the heat usually comes from a large depth (e.g. 150-300 mbgl) and because pipe systems must be heated up. To minimize start-up losses and heating losses, it is recommended to use the heat storage as the base load of the heating system. This allows the heat storage to run almost continuously. In this way a significant part of the stored heat is recovered in the period immediately after storing the heat, which reduces the heat losses (and thus increases the recovery efficiency and reduces the thermal impact).

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