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First field results on the technical risks and effectiveness of mitigation measures for the full scale HT-ATES demonstration project in Middenmeer

Peter Oerlemans[1], Benno Drijver[1], Mariëlle Koenen[2], Joris Koornneef[2], Dorien Dinkelman[2], Wim Bos[3], Bas Godschalk[1]

[1] IF Technology BV, Velperweg 37, 6824 BE Arnhem, the Netherlands

[2] TNO, Applied Geosciences, 3584CB Utrecht, the Netherlands

[3] ECW Energy, Agriport 109, 1775 TA Middenmeer, the Netherlands

p.oerlemans@iftechnology.nl

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ABSTRACT

In Middenmeer, the Netherlands, a HT-ATES demonstration project was made and started operating in May 2021. Because of the high storage temperatures and limited experience with this technology, extra attention was paid to the identification and mitigation of possible risks. This paper is focussed on three major technical/economical risks. Scaling and clogging by carbonate precipitation (risk 1), is mitigated by adding CO_2 before heating. Based on the monitoring results, that show no indications for scaling, this method has been effective. The high flow velocities applied in this project, lead to an increased risk of sand production and well clogging by particles (risk 2). This risk was mitigated through the design, construction and development of the well and by installing filters to remove possible sand and fines from the extracted water before re-injection. During the first year of operation, these filters captured only limited amounts of particles. Additionally, no indications for well clogging were found in the monitoring data. Heat losses through the well casing (risk 3) are higher than expected. Because these losses strongly depend on the residence time between the storage aquifer and the surface installations, increasing the flow rates during storage and recovery of heat will limit these heat losses.

1. INTRODUCTION

From both a climatological and geopolitical point of view, the transition away from fossil energy sources towards sustainable ones is essential. To reduce greenhouse gas emissions related to space heating in the built environment and the horticulture industry a transition to alternative heat sources, like geothermal, solar and residual heat, is required. However, the supply pattern of these alternative heat sources typically shows a mismatch with the heat demand pattern: in the summer period more heat is available then required and the opposite is true in the winter period. Large scale seasonal heat storage can solve this mismatch by storing heat when there is an excess and then recovering it in the cold season. By means of heat storage, more sustainable heat is produced and provided to the consumers, which improves the business cases of geothermal, solar and residual sources and enables their economical and large-scale implementation. Therefore, large scale heat buffering is expected to play a key role in the sustainable heating systems of the future.

A technology with major potential for large scale seasonal heat storage is High Temperature Aquifer Thermal Energy Storage (HT-ATES). Using the subsurface as a storage medium and exploiting its isolating properties and very large volume, HT-ATES allows for the relatively cost-effective large-scale buffering of heat up to 90 °C in aquifers.

In the Netherlands, over 2,500 Low Temperature ATES systems (LT-ATES, <25 °C) have been realized in the permeable, unconsolidated subsurface, providing sustainable cold (direct cooling) and heat (using heat pumps) to the built environment. The mature LT-ATES sector (over three decades old) offers the vital basis for the development of the HT-ATES variant, especially for the depth range of 0 – 500 mbgl where both the legal and geological setting is similar as for LT-ATES. However, due to the strongly increased temperatures (natural groundwater is typically 10 – 20 °C), some major risks and challenges arise for HT-ATES from a technical point of view.

An important step in the mitigation of these risks and the technical advancement of HT-ATES as a technology was facilitated by the Geothermica HEATSTORE research program, where various Underground Thermal Energy Storage (UTES) technologies were investigated and implemented (www.heatstore.eu). Between 2018 and 2021, a full scale HT-ATES demonstration project was realized as a part of the HEATSTORE project by ECW Energy in Middenmeer, the Netherlands. During the development process, an inventory of the main risks and options for their mitigation was made (Van Unen et al., 2020). Subsequently, various risks were addressed, innovations were applied and monitoring activities were performed to develop effective mitigation strategies for the technical challenges that HT-ATES faced.

In this paper, we report on three major technical/economical risks for the HT-ATES system and how they have been addressed at the Middenmeer demonstration project: 1) scaling by carbonate precipitation, 2) flow rates of the wells in relation to sand production and well clogging by particles , and 3) heat losses through the hot well casing. Additional risks are described briefly. We show how these risks have been investigated in the first stage and mitigated through the design and operational phases of the HT-ATES system. Finally we evaluate the effectiveness of these measures using the detailed monitoring data sets of the first year of operation (2021-2022) and show that, at least for the first year, these technical risks have been successfully mitigated.

2. BACKGROUND: HT-ATES IN MIDDENMEER

2.1 Storing deep geothermal heat with HT-ATES

ECW Energy is the largest geothermal operator of the Netherlands, operating 5 deep geothermal doublets which produced 520 GWh of sustainable heat in 2019 (Godschalk et al., 2021). The produced heat is provided to large-scale greenhouse areas in the province of North-Holland in the Netherlands. One of those greenhouse areas is Agriport A7 in Middenmeer. The deep geothermal heat production is decreased in summer due to limited heat demand. However, during the winter period, the heat demand is higher than the production capacity of the deep geothermal wells, triggering fossil fuel heating systems to become active. By storing surplus geothermal heat with HT-ATES during the summer and recovering it in winter, ECW Energy strives to increase the yearly amount of sustainable heat that is provided to the greenhouses and reduce their dependency on fossil fuels and associated emissions.

2.2 Timeline of HT-ATES development

Ahead of the initiation of the HEATSTORE program, a Water permit was granted for HT-ATES application in 2018. A test drilling and related tests were performed in 2019, providing essential and detailed information about the subsurface conditions. Location specific risks were identified and investigated in detail. The test well was equipped as a monitoring well to enable monitoring of the impact of heat storage on the subsurface during the HT-ATES operation. In 2020 the HT-ATES well and surface facilities were designed, taking into account the test drilling results. The wells were drilled in 2020 and the surface installation was realized in Q1 of 2021. After a few weeks of successful testing, the HT-ATES was formally taken into operation on May 31st 2021, charging heat with a flow rate of 150 m^3/h (12 MW) right after the start. Frequent measurements were performed during the first heat storage and recovery cycle between 2021 and 2022, facilitating risk assessment, research and system management.

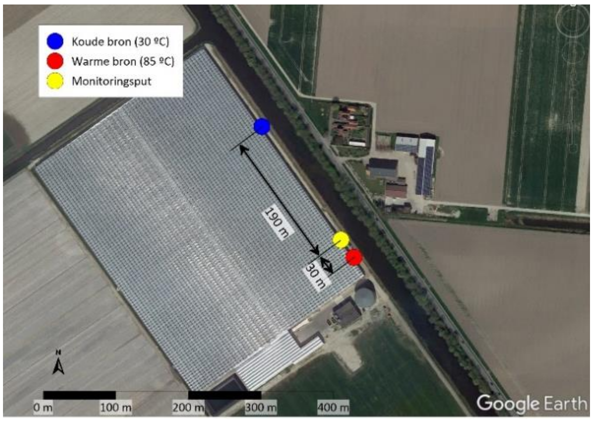

Figure 1: Satellite view of the well locations of the hot well (red), relative cold well (blue) and monitoring well (yellow).

2.3 The HT-ATES well system

Figure 1 shows that the wells of the HT-ATES doublet system are located 220 m apart and the monitoring well (former test drilling) is 30 m from the hot well to enable monitoring of subsurface effects in the hot zone.

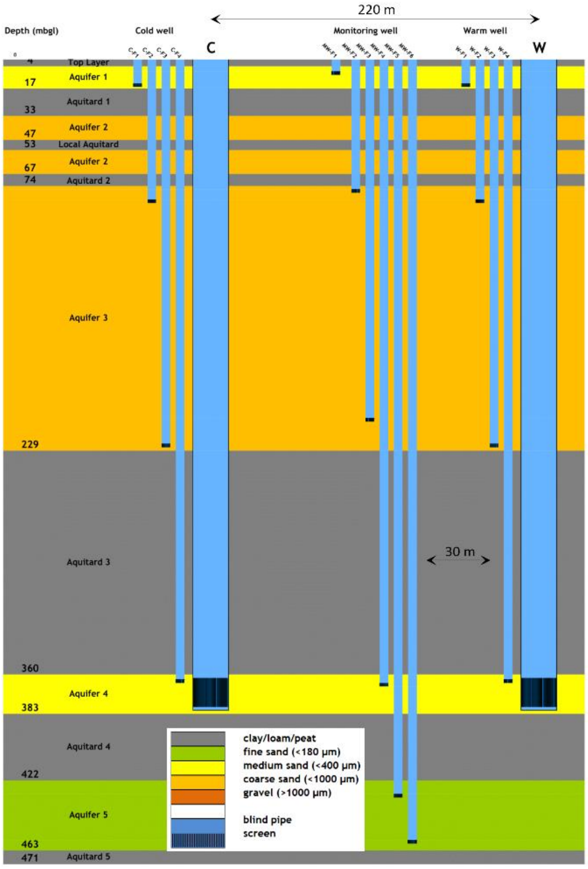

Figure 2: Schematic cross-section through the subsurface along the wells (not to scale). Coarse/medium coarse and fine sands in orange/yellow/green. Clay layers in grey. Blind pipes of the wells and piezometers indicated in blue, well/piezometer screens hatched black.

Well screens of the HT-ATES doublet system are placed in an aquifer at ~ 360 – 383 mbgl in the Maassluis formation (see Figure 2 for cross-section). All three boreholes are equipped with piezometers for groundwater sampling and fibre-optic cables for Distributed Temperature Sensing (DTS) with high frequency along the full length of the boreholes. During charging of heat, groundwater is pumped from the cold well, heated at the surface facilities, using deep geothermal heat, and reinjected in the hot well at ~ 85 ºC with a maximum flow rate of 150 m^3/h. The storage aquifer consists of medium coarse sand and is located between thick clay layers, so that the stored heat is forced to spread outwards and significant heat losses to shallower or deeper layers are prevented.

The temperature distribution after 20 years of HT-ATES operation was simulated with the Heat and Solute Transport software HST3D (Kipp, 1997) and is shown in Figure 3. The results represent a worst-case scenario of the thermal effects of the HT-ATES, using larger storage volumes than planned.

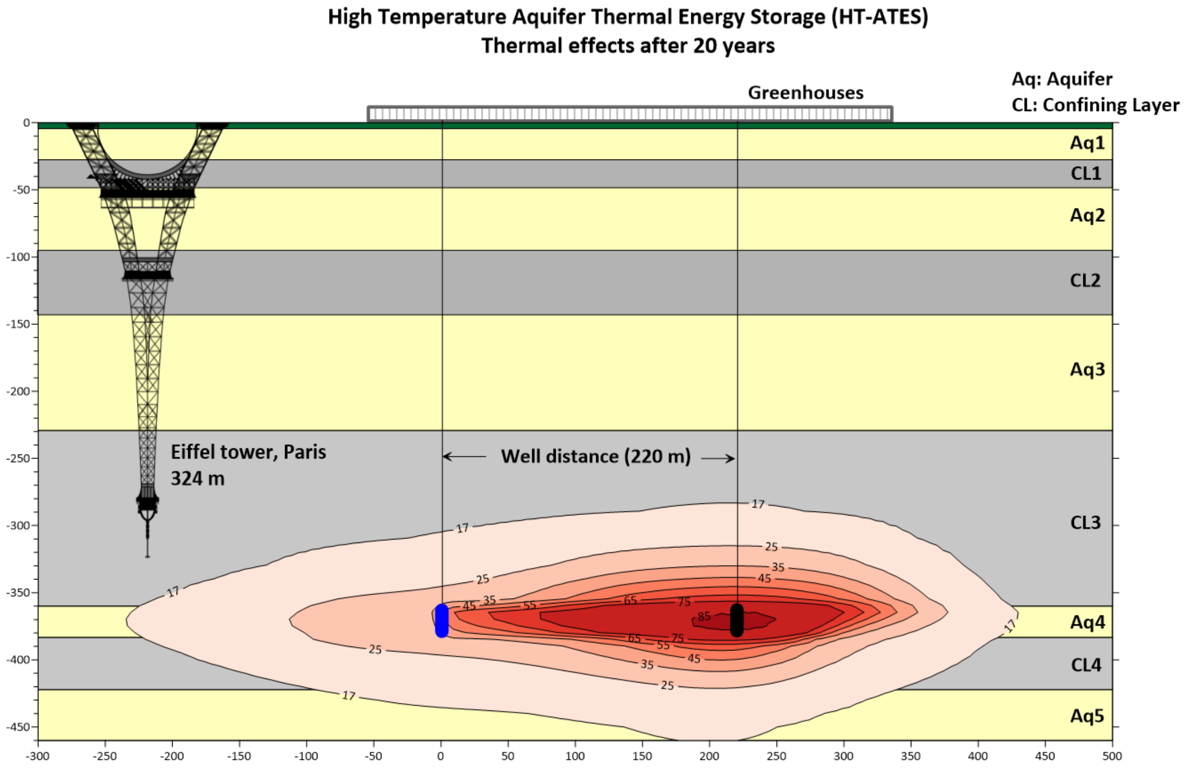

Figure 3: Simulated temperatures (°C) in the subsurface after heat storage in year 20 for a worst-case scenario. The heat is stored in a 23 m thick sand layer that is located deeper than the height of the Eiffel tower. A thick clay layer overlies the storage aquifer and prevents significant heat losses to shallower aquifers. The relative cold well (blue) and hot well (black) are indicated with thick lines which are not to scale.

3. MATERIALS AND METHODS

This paper focusses on the assessment, mitigation and evaluation of three major risks for the successful operation of the HT-ATES system in Middenmeer. Note that the following numbering of these risks is consistently applied from here onwards.

<u>(1) Risk of well clogging by carbonate precipitation:</u> Well clogging by carbonate precipitation and scaling, caused by the supersaturation with respect to calcite and other carbonate minerals as the groundwater is heated. Water treatment methods have had varying degrees of success in the past (Drijver, 2011). For this project, the addition of CO_2 to lower the pH and decrease carbonate saturation was selected as treatment method. It is the first time that this method is applied in a full scale HT-ATES plant.

<u>(2) Risk of well clogging by particles and sand production:</u> Based on the results of a number of tests, that were performed in the test well, the HT-ATES wells were designed for much higher flow rates than ATES well design standards indicate (Drijver et al., 2020). This allowed for a design with increased flow rates, which was essential for the economic feasibility of HT-ATES at the site. Possible risks of the high flow velocities are well clogging by particles and sand production (short term), and wear/damage to pipes and equipment and caving/subsidence around the screens by sand production (longer term).

<u>(3) Risk of heat losses through well casing:</u> During the transport of hot water from the surface to the storage aquifer (and back) through the well pipes, heat is lost to the colder surroundings of the well casing. This process decreases the thermal recovery efficiency of the HT-ATES system, and needs to be assessed. A more

extensive evaluation of the temperature measurements at the monitoring well and thermal evolution within the storage aquifer is reported by TNO (Dinkelman et al., 2022, this issue).

For each of these risks, its assessment during/after the test drilling is described first, followed by the mitigation measures taken in the design and operational phases to limit the risks to an acceptable level and/or keep track of how they change during operation. The resulting monitoring data and the evaluation of risks after cycle 1 are shown and discussed in the section 'Results and Discussion'.

3.1 (1) Risk of well clogging by calcite precipitation

Risk assessment during/after the test drilling:

The risk of well clogging by carbonate precipitation was investigated by sampling groundwater from the storage aquifer to define the chemical composition. IF Technology used PHREEQC to simulate the initial saturation with respect to various carbonates under natural conditions and the chemical changes upon heating. Additionally, TNO performed lab tests to research the processes of calcite precipitation and crystal growth by increasing temperatures of natural groundwater samples obtained from the ECW test drilling (Dijkstra et al., 2020). The results indicated a high risk of carbonate precipitation at the HT-ATES, if no measures are taken. Based on these findings, it was decided to apply water treatment by addition of CO_2 (acidification) in Middenmeer to prevent scaling and clogging.

Measures in the system design to mitigate this risk:

- A CO_2-dosing unit was added to the surface facilities, by which the CO_2-dosing can be automatically regulated based on the flow rate and temperature changes.

- Monitoring equipment is installed in the surface facilities, to allow investigation of the parameters that relate to carbonate equilibrium: temperature, pressure and pH are registered with high frequency at various locations in the groundwater circuit. The pressures in the well and on both sides of the heat exchanger are indicative for clogging and the effectiveness of the CO_2-dosing unit can be checked using the pH and temperature measurements in the circuit. Additionally, a sampling loop was designed and realized to facilitate optional water sampling for research of other parameters.

Risk mitigation activities during operation:

- Direct indicators of scaling are an increased hydraulic resistance in the clogged components. Past experiences show, that the most critical items are the heat exchanger and the hot well (e.g. Sanner, 1999). Therefore, the pressure loss over the heat exchanger and the injection pressure in the hot well were monitored.

- Both during heat storage and heat recovery, groundwater samples were taken and analysed for relevant parameters.

3.2 (2) Risk of well clogging by sand production

Risk assessment during/after the test drilling:

The risk of sand production and well clogging by particles was investigated using the test well. When the test drilling results are combined with the Dutch guidelines for ATES wells design (which aim to limit these risks in production wells), the maximum flow rate for a HT-ATES well in the storage aquifer was too low for a viable business case. Experiences and theory from the oil and gas industry suggested, that the maximum acceptable flow velocity may increase with depth (Drijver et al., 2020) so that higher flow rates might be feasible. Therefore, the risk of sand production and well clogging by particles was further investigated at the test well.

The NVOE-guideline for ATES systems in the Netherlands (NVOE, 2006) prescribes that the maximum flow velocity (v_{max}, in m/h) on the borehole wall is 2 times the hydraulic conductivity (k, in m/d) of the aquifer formation:

$$v_{max} = 2 * k / 24 \qquad [1]$$

Hence the maximum flow rate of a well (Q_{max}, in m^3/h) is determined by the hydraulic conductivity (k, in m/d), the length of well screen (H, in m) and the borehole radius (r, in m).

$$Q_{max} = v_{max} * 2\pi * r * H \qquad [2]$$

Or

$$Q_{max} = \pi/6 * k * r * H \qquad [3]$$

Production tests were performed where the flow rates were increased up to 2.44 times the maximum flow rate from the guideline. Higher flow rates could not be tested because of practical limitations. The results showed no significant sand production, indicating that the guidelines may be exceeded without significant risks of sand production (IF Technology, 2019). Furthermore the MFI and the concentration of fines in the extracted water met the criteria for ATES wells, suggesting a limited risk of well clogging by particles. Based on these results, flow velocities up to 2.44 times the value that follows from the design guidelines seem to be safe. Probably, higher flow velocities are also feasible, but this could not be tested in the test well. Based on these findings, it was decided to design the HT-ATES wells for a maximum flow rate of 150 m^3/h, which was sufficient for a healthy business case.

Measures in the system design to mitigate this risk:

- Sand filters were installed in the surface facilities to remove all sand and fines from the water produced by the well. This prevents produced particles from entering the injection well where they may cause clogging. It also facilitates the visual inspection of the amount of produced sand, fines and possible precipitates after replacement.

- Installation of pressure gauges on both sides of the sand filters to facilitate monitoring of the pressure drop over the filters as an indicator for clogging of the filters.

- Installation of pressure gauges in the wells as a general indicator for well clogging.

Risk mitigation activities during operation:

- Frequent checking of the pressures in the wells and pressure difference over the sand filters to check for indications of clogging.

- Removal and visual inspection of the sand filters after each loading cycle and unloading cycle, to evaluate how much sand and fines had been captured and assess the corresponding risks.

3.3 (3) Risk of heat losses through well casing

Risk assessment during/after the test drilling:

The risk of heat losses through well casing were assessed after the test drilling, through numerical simulation of the heat transport around the casing of the hot well during the flow of hot water through the casing (IF Technology, 2021). During the design phase, different types of backfilling material were considered for the future HT-ATES wells. Standard materials like gravel and clay were compared with spherelite, as this latter material has a lower thermal conductivity and would limit the heat losses through the hot well casing.

Measures in the system design to mitigate this risk were:

- DTS cables were attached to the outside of the well casing during the installation of the HT-ATES wells to facilitate high frequency (every 10 min) monitoring of temperatures in the direct vicinity of the well casing.

- Thermometers were installed in the surface pipe circuit on both sides of the heat exchanger, to facilitate monitoring of the temperature of the heated water.

- The simulations showed smaller heat losses when spherelite was used (1.6%) compared to sand/clay as backfilling material (2.5/2.3%), but the material was too expensive for the difference it made. To prevent heat losses by both horizontal groundwater flow and temperature-driven vertical flow along the casing to some extent, it was decided to apply an alternation of sand and clay layers in the backfilling material for the optimal balance between backfilling material costs and heat losses through the well casing.

3.4 Other risks for HT-ATES

Other risks that were identified:

- Material stress and corrosion risks of the HT-ATES system components due to high temperatures, pressures, salinity and addition of CO_2. This risk is managed by selecting stress and corrosion resistant material for the well and piping (corrosion-insensitive Fiberglass Reinforced Epoxy was applied) the heat exchanger (Titanium) and pumps (coated pumps that are also used to pump highly saline water in deep geothermal doublets).

- Risks regarding the changes in groundwater composition to HT-ATES. More insights are obtained in the chemical, gas and microbial composition changes of the groundwater through frequent sampling and analysis of groundwater from the storage aquifer.

- Heat demand of the client and future energy prices.

- Increased concentrations of dissolved gasses, due to CO_2-dosage and methane formation in the storage aquifer. This is

4. RESULTS AND DISCUSSION

This section shows the field data related to risks (1), (2) and (3) and evaluates the effectiveness of the mitigation measures applied.

4.1 Well clogging by carbonate precipitation

To manage the risk of clogging by carbonate precipitates upon heating, water treatment was included in the design. Based on the groundwater composition from the storage aquifer and hydrogeochemical calculations with PHREEQC, the amount of CO_2 was calculated that had to be added to ensure that the calcite saturation index (SI_{cc}) after heating was equal to that of the natural groundwater. The dosage in the software of the HT-ATES system is calculated, based on the flow rate, temperature difference (before and after heating) and the calculation results (required CO_2-dosage for heating from 15.5 to 85 ºC from the model results).

Monitoring results showed that there were no indications of clogging of the warm well or increases in the pressure difference over the heat exchangers. Furthermore the CO_2-concentration that was measured in the monitoring well after breakthrough of the stored heat, was almost exactly equal to the sum of the initial concentration and the applied dosage, which shows that the CO_2 that was added has not reacted. These results show that the water treatment - one of the critical components of the HT-ATES system - has functioned properly.

Although scaling has been prevented, there are still some questions left. One of the remaining risks with respect to water treatment is the possibility of a rising hardness of the groundwater over subsequent cycles, leading to a strong increase in the required (carbonic) acid dosage. This hardening can be reduced by decreasing the CO_2-dosage, but this would increase the risk of scaling. However, because of the complex interaction of different chemical processes like reaction kinetics and inhibition, the calculated CO_2-dosage is no more than a theoretical value and may be too high. Therefore, a controlled reduction of the applied dosage (together with strict monitoring of scaling indicators) is currently being implemented. In case this appears to be insufficient (undesirable increase in the required dosage), there is an additional option to remove part of the CO_2 by degassing during heat recovery before the cooled groundwater is injected into the cold well (e.g. Sanner, 1999). Future monitoring results in combination with reactive transport simulations are needed to see how this will develop.

4.2 Well clogging by sand production

During the realization of the HT-ATES wells, additional well performance tests were performed to further investigate risks of sand production. The results of these tests showed that:

- The quality of the well was very high, based on the low skin factor that was found. In the test drilling the specific capacity in different tests was between 28 and 33% of the theoretical value for a well without skin and in the HT-ATES wells this was 95 and 100%. This success is partly explained by changes to drilling fluid. Salt water from the storage aquifer (extracted from the test well) was used instead of rainwater from a water basin, limiting the swelling of clays and corresponding negative effects on the well quality. Also, the drilling fluid was less dense and a smaller overpressure was used during drilling. Furthermore, the test drilling is much deeper than the HT-ATES wells so that there was more time between reaching the storage aquifer and final depth than in the wells. All these factors together resulted in a limited amount of skin in the HT-ATES wells when compared to the test well.

- The flow rate during well developments was increased in steps up to a factor 3.8 times the maximum flow rate from the ATES design guidelines, still without significant amounts of sand production. This provided extra proof that the risks for sand production at high flow velocities was limited (Drijver et al., 2020).

During the first operational cycle (2021-2022), the pressure differences over the sand filters did not show consistent and significant increases during either the loading or unloading phase. The sand filters were replaced and visually inspected at the end of the both phases. The filters were practically clean after the first loading phase. The filters from the unloading phase show higher but still very limited amounts of sand and fines (Figure 4). The increased amount of sand produced during the unloading phase may be caused by the more frequent switching (on/off and changes in flow rate) of the pump during heat recovery (demand-controlled). Alternatively or additionally, the higher temperature and/or slightly different water composition (mainly more acidic due to CO_2-dosing) may have caused some particle mobilization.

Furthermore, pressure measurements inside the warm and cold wells show an almost perfect correlation between flow rate and pressure when temperatures are (more or less) constant. In the cold well the correlation is very good during both loading and unloading. In the warm well there is a good correlation during loading, but during unloading it is disturbed because the extraction temperature decreases with time. These results also show that well clogging is insignificant.

Figure 4: Picture of the sand caught in the 'bag filters' of the system during the unloading phase. A limited amount of very fine sands/ silts seem to have been produced.

Based on these observations, the relatively high flow rates seem not to lead to significant risks of sand production or well clogging by particles. The limited amount of produced sand and fines is effectively removed by the sand filters in the surface facilities. The mitigation measure of monitoring pressures over the wells, sand filters and visual inspection of used sand filters after each loading/unloading phase is continued in the future to create a more long-term image of this risk.

4.3 Heat losses through the hot well casing

Monitoring data from the first year show that 9,231 MWh of heat has been charged and 2,469 MWh (27% of the stored heat) has been recovered. This percentage is typically low in the first year, because the subsurface is still cold, and will strongly improve in subsequent years (e.g. Sauty et al., 1982). Furthermore, the temperature of the water that in re-injected into the cold well after heat recovery (~30 ºC) is higher than the initial groundwater temperature in the storage aquifer (~15.5 ºC), so that part of the added heat is not recovered.

Model calculations before the start of operation had predicted that 34% of the stored heat would be recovered in the first year and that this would rise to 58% in year 3, 70% in year 5 and 78% in year 10. However, in these model calculations a stored volume of 220,000 m^3 of hot water had been assumed, while the actual stored volume was ~115,000 m^3. Given the fact, that a smaller stored volume leads to an increase in the surface area over volume ratio of the hot bubble, which causes the relative heat losses to increase (Doughty et al., 1982; Bloemendal and Hartog, 2018), the 27% heat recovery seems 'not too bad'. Furthermore, heat losses through the hot well casing were not included in the model calculations: separate model calculations suggested losses of 2.3-2.5%.

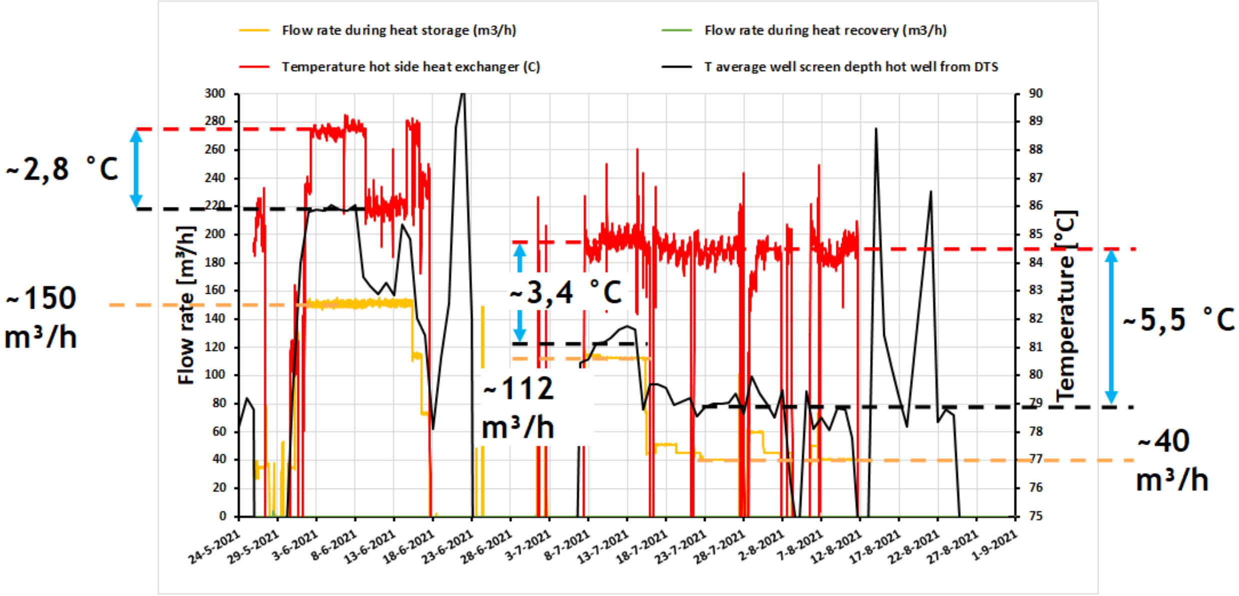

Figure 5: Comparison between the temperatures measured on the hot side of the heat exchanger (red line) and at the depth of the well screen of the hot well (black line: DTS measurement results). For different flow rates, the temperature loss is indicated that follows from the monitoring data.

The DTS-cables that were installed in the HT-ATES and monitoring wells, enable detailed monitoring of the temperature at reservoir depth. Temperature losses in the trajectory between the heat exchanger and the storage aquifer were analysed by comparing the results of temperature measurements with DTS and the temperature sensor on the hot side of the heat exchanger (Figure 5). It is important to stress that the DTS results may contain some inaccuracies/disturbances (Dinkelman et al. 2022).

The results clearly show that the temperature losses during injection of water that was heated to around 85 ºC strongly depends on the flow rate. When the flow rate is high, the residence time between the heat exchanger and the storage aquifer is relatively small and there is little time for the heated water too lose heat. When the flow rate decreases, residence time and associated temperature losses increase.

For three intervals with different flow rates during the loading phase a rough estimate of the temperature loss was derived from the monitoring data (Figure 5) and plotted in a graph (Figure 6). This graph confirms the increased temperature loss for lower flow rates. However, temperature loss will not only depend on flow rate and injection temperature, but also on previous heat losses. At the end of a long period of heat storage, the surroundings of the well casing will be warmer than at the start of the heat storage period and that reduces heat losses.

Another estimate of the temperature losses was made by using the pressure decline in time after stopping of heat loading. This gradual pressure decline is explained by a decreasing temperature in the well - caused by heat losses - resulting in a reduction of the density and a decreasing hydraulic head. In that way the pressure decline in time is an indicator for the increasing temperature loss with time.

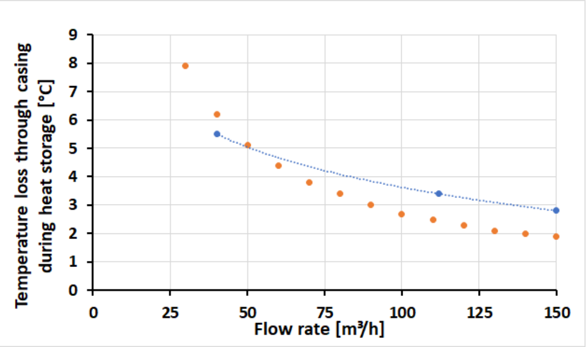

Figure 6: Graph showing the relation between flow rate and the derived temperature loss in the trajectory between the heat exchanger and the storage reservoir. Blue dots are based on Figure 5. Orange dots were derived from the gradual pressure decline after stopping of heat loading.

Based on the monitoring data, the average flow rate during heat storage was 86 m³/h. The relations shown in Figure 5 lead to an estimated temperature loss between 3.2 and 3.9 °C for that flow rate. Assuming 3.5 °C temperature loss, results in an estimated loss of 4.8% of the added heat during heat storage. During heat recovery, the average flow rate was 69 m³/h and the average extraction temperature was ~ 57 °C. The estimated heat loss during heat recovery was 2.8% of the stored heat.

Additionally, there is some heat loss each time the pump is stopped. When it is assumed that all heat is lost after a stop (worst-case estimate), then this results in an additional 1.3% of heat loss. Altogether, this results in a total estimated heat loss between the heat exchanger and the storage aquifer of 8.9%, which is much higher than suggested by previous modelling results (IF Technology, 2021). Possible explanations for this difference are a much smaller storage volume than designed for (calculations were performed during design), the influence of flow rate and relatively large losses in the first year (when the subsurface is still cold).

Based on the results, temperature losses can be reduced by using high flow rates and limiting the number of stops. An option that can be considered to reduce temperature losses due to stops is to pump one volume of cold water into the hot well at the end of each heat storage period.

5. CONCLUSIONS

5.1 Water treatment

To prevent scaling and associated clogging of wells and heat exchangers due to the precipitation of carbonates upon heating, it was decided to incorporate water treatment in the ECW HT-ATES system. The selected water treatment method is dosage of CO_2. The dosage was calculated based on the composition of groundwater sampled from the test well. Monitoring results from the first cycle show that there are no indications for clogging. It is concluded that the water treatment has functioned properly. However, further work is required to investigate if the CO_2-dosage can be reduced in order to limit hardening of the groundwater and the associated consequences for water treatment (increase in required CO_2-dosage) and gas pressures.

5.2 Sand production in the wells

In the ECW HT-ATES project flow rates are significantly higher than indicated by the ATES well design standards. Possible risks, associated with the resulting high flow velocities are well clogging by particles and sand production. The results of practical tests in the test well were favourable, but these test were of relatively short duration. Therefore, some uncertainty on the effects on the longer term remained.

Monitoring results from the first cycle have shown that the production of sand and fines during the heat storage and heat recovery periods has been limited. Furthermore, no indications were found for notable clogging of the wells or sand filters. Therefore, the results from the first cycle can be seen as a confirmation of the results from the tests in the test well.

5.3 Heat losses through the hot well casing

During transport of hot water from the heat exchanger to the reservoir (during heat storage) and back (during heat recovery), temperature losses occur through the pipes and the well casings. Based on the monitoring data a rough estimate of these temperature losses was made. During heat storage and heat recovery the estimated heat loss is 4.8 and 2.8%. Heat losses due to stops are estimated at 1.3%. The total energy loss through the piping (small part) and well casings (largest part) adds up to 8.9%, which is significantly higher than expected beforehand. Since temperature losses are related to residence time, increasing the flow rate during storage and recovery of heat helps to reduce these temperature losses.

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