Topic: Sensible TES

Long-term Performance of the HT-BTES in Emmaboda, Sweden

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SUMMARY

The Emmaboda HT-BTES was taken into operation 2010. Since then ~10 GWh has been stored, only a fraction has been extracted, and a storage temperature of 40-45 ^{o}C has been reached. The purpose of the BTES is to utilize waste heat from the industrial processes. Heat sources have been added annually and in 2015 the predicted heat injection (3.6 GWh/year) will be reached. Performed simulations are based on actual heat injection and extraction. The simulation model can reasonably well predict the future operation of the BTES. Initial problems with circulating the heat carrier at a slight vacuum pressure have been solved by using vacuum pumps to degas the fluid. The BTES has reduced the amount of bought district heating by approximately 4 GWh/year. To improve the system further, and reduce heat losses, it is suggested that a heat pump should be installed for heat extraction.

INTRODUCTION

The high temperature borehole storage (HT-BTES) is an integrated part of the energy system at the Xylem Water Solutions AB in Emmaboda, Sweden. The location of the storage is shown in Fig 1.

Figure 1 The Xylem manufacturing plant at Emmaboda, Sweden. The location of the heat storage and its culvert is marked red

The company manufactures submersible pumps and mixers and handles the whole production flow, from molten metal to finished products. The industry is operated 4400 hours per year and large amount of waste heat, from various heat sources, is generated by the production e.g. cooling processes. The storage concept, the anticipated economics, and the result of environmental assessment issues were first described in Andersson et al (2009). The storage system was then constructed during the winter season and spring 2009-10 and taken into operation during the summer 2010. The design and construction of the storage as well as initial technical problems and solutions are described in Andersson et al (2012). In 2013 the HT-BTES system was chosen for a long term evaluation to be carried out by Luleå University. This "evaluation project" will be finalised in June 2015.

OBJECTIVES

The long term objective is to successfully demonstrate how the underground can be used for seasonal storage of waste heat and in this way conserve thermal energy. The objective with the evaluation project is to document and analyse the thermal function of the storage system.

THE BTES SYSTEM

Location of the store

The HT- BTES is located in a park with a small river separating the storage from the factory area. There is also an old dam, which was once built for the old mill of the area, see Fig 1. An insulated culvert pipe (red line) which is crossing the river connects the BTES to the heating system of the factory area.

The system consists of 140 boreholes drilled within a rectangular area to a depth of 150 m, with a borehole spacing of 4 m, see Fig 2. The storage is divided into 7 sections á 20 boreholes. These sections A-G are individually opened or closed, for injection or extraction of heat depending on the storage temperature.

Two holes are drilled for temperature measurements in the ground. One is located outside the storage area (GT3) while the other hole is located in section E (GT1/2).

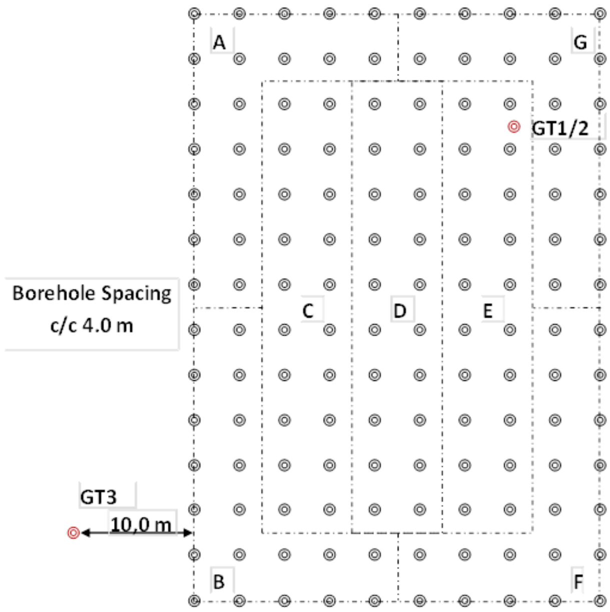


Figure 2 Plan of drilled boreholes. The seven sections and the location of the 140 boreholes and monitoring holes are indicated. The red rings show the location of measurement holes.

Site investigations

Site investigations and design of the project were carried out in 2009 (Andersson 2010). Initially two test holes were made, each one 150 m deep in order to analyse the geological, hydrogeological, and drilling conditions at site. Based on that information, the borehole field was somewhat adjusted, hoping to avoid as much water holding fracture systems as possible and deep drilling with casing. The drillings showed that the 5-10 m overburden mainly consists of glacial till. The bedrock mass mainly consists of granodiorite, structured as an anticlinal. Some thin dykes of amphibolite occur as well as one minor layer of magnetite.

A Thermal Response Test (TRT) was made in one of the test holes. The thermal conductivity was found to be 3.0 W/m, K, which agreed with the two older tests which were made on the other side of the dam and showed 2.8 and 3.2 W/m, K. The tests showed an average rock temperature of +8°C. The new test was performed on a prototype borehole heat exchanger (BHE) that gave a very low thermal resistance (0.02 K/ $W^{-1}m^{-1}$). A modification of that BHE was later developed, see further next chapter.

New BHE

The new BHE consists of a coaxial thick plastic tube which is thermally insulated by stagnant water. The circulated water which is circulated through the borehole is in direct contact with the borehole wall, see Fig 3. The open circulation system means that if the bedrock wall is "fracture-free" the heat carrier is circulated as if it was a closed system. In boreholes that are drilled through permeable fractures, the water (heat carrier) will also move in the fractures. In a few cases this circulation was found to short cut two or several boreholes especially in the left upper corner of storage shown in Fig 4. This secondary circulation will enhance the heat transfer but may also be a part of the water chemistry problems decribed later.

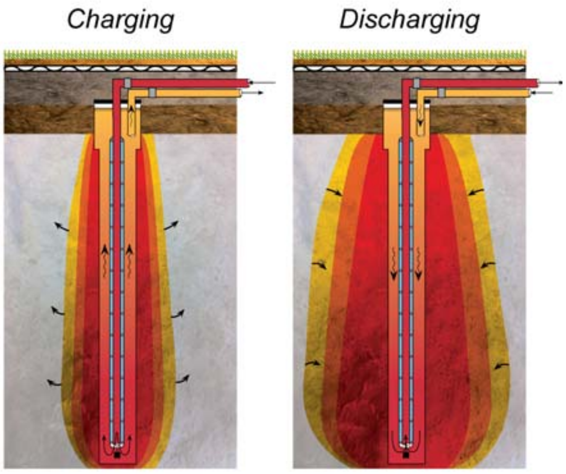


Figure 3 The Borehole Heat Exchanger.

Figure 4 Piping of the Emmaboda BTES in 2010. The manifolds of some of the seven sections á 20 boreholes can be seen.

Heat Sources

The BTES is linked to an internal heating system (IHS) to which a number of waste heat sources are connected. The IHS is supplied by heat from an external district heating system (DH). At the time BTES was constructed some 7 GWh a year of heat was bought from the DH and only ~1.5 GWh of waste heat from the foundry was recovered to the IHS, while the rest was wasted into the atmosphere. Since then, more heat sources have been gradually added, Table 1. These are mainly by support of heat pumps. Currently (early 2015), most of the potential heat sources have been linked to the IHS and directly used for space heating in the winter. When the demand for space heating is lower than the waste heat production the surplus heat is stored in the BTES. The maximum amount of surplus heat is available in the summer.

Table 1 Heat sources connected to the internal heating system (IHS) at Xylem

Heat Sources	Power (kW)	Available Annual Energy (MWh)	Max Temp. (°C)
H/C HP Foundry	550	3000	58
HX Owen Foundry	450	1000	63
H/C HP Paint shop	150	400	72
H/C HP Server Halls 1-2	90	500	72
H/C HP UPS (Battery Backup)	15	80	65
H/C HP Server Halls 3	60	400	72
H/C HP Evaporator	20	50	65
H/C HP Compressor Central	170	1200	72
HX Compressor 1	120	700	90
HX Compressor 2	90	350	90
H/C HP Testing 2	80	200	72
H/C HP Curing oven	90	450	72
HX Compressor Central	100	100	90
Sum	**1985***	**8430**	

*/ The heat powers are not all available at the same time. H/C HP = heating/cooling heat pump. HX =heat exchanger.

The storage was designed for an annual heat injection of 3600 MWh during the summer, of which 2600 MWh was predicted to be recovered and used for space heating during the winter. However, the planned heat injection has been much lower than predicted and it took until the late autumn 2014 before the full capacity of heat injection was reached.

RESULTS

Energy

The heat injection has been annually increased as increasingly more heat sources has been added to the system; 581 MWh (2010), 1845 MWh (2011), 2149 MWh (2012), 2377 MWh (2013), 3271 MWh (2014) and 91 MWh until March 2015. During 2015 we expect to reach the heat injection that the storage was designed for. The recorded energy values are based on measurements of water flow rate and water temperature difference between inlet and outlet temperature to the storage system. These measurements are usually recorded every 5 minutes. Monthly mean injection and extraction powers from July 2010 to March 2015 are shown in

Fig 5. The total amounts of injected and extracted heat during this period were 10 314 and 174 MWh respectively.

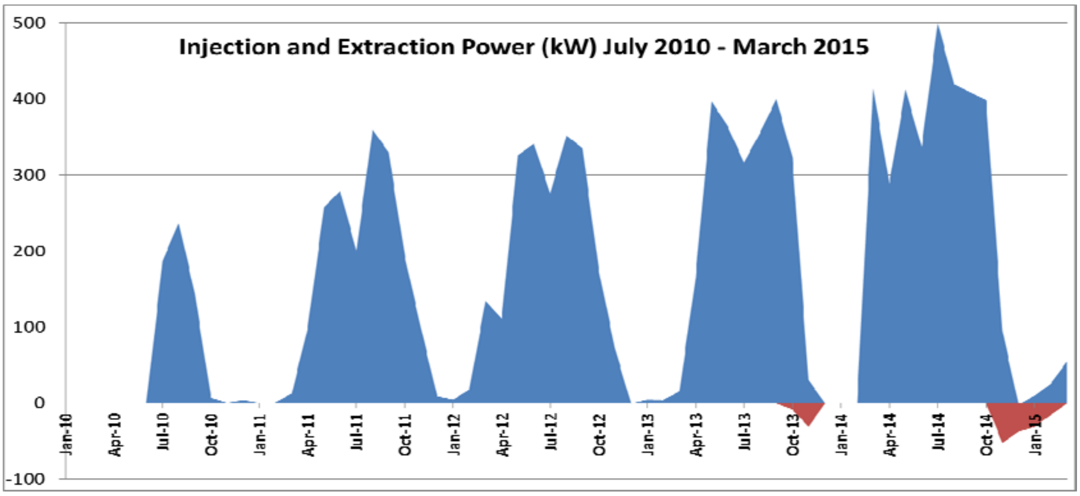


Figure 5 Monthly heat injection power (blue) and extraction power (red) at the Emmaboda Storage from the start in July 2010 until March 2015.

Storage Temperature

Two ground measurements are made in a borehole inside the storage volume (GT1 at 117 m depth and GT2 at 70 m depth) and another is made in GT3, 10 m outside of the storage volume, at a depth of 100 m, see Fig 2. Fig 6 shows that it is hardly any difference between 70 m depth and 117 m depth in borehole GT1, while the temperature outside the storage volume is considerably lower. The periodicity of the heat injection is also seen more clearly within the storage volume while it is strongly damped outside the storage volume.

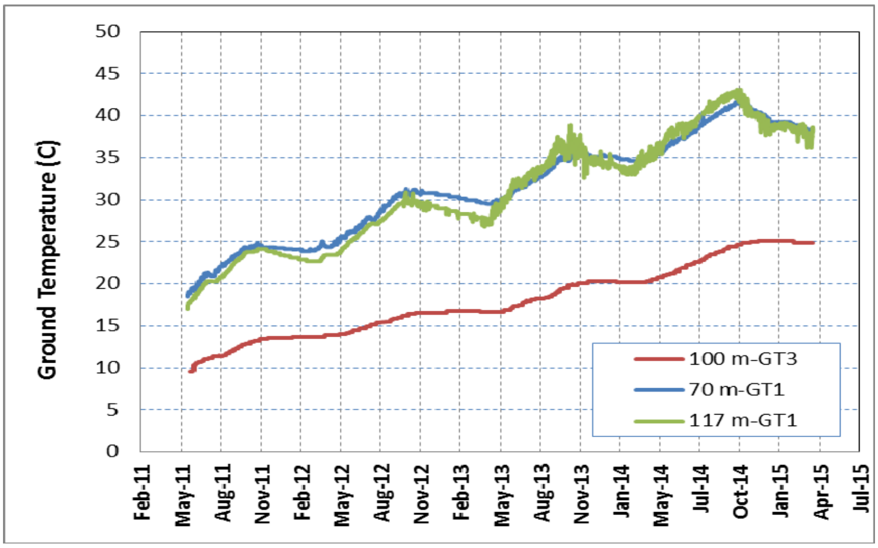


Figure 6 Measured storage temperature (GT1) 70 m and 117 m below ground surface and GT3 at a depth of 100 m, 10 m outside the storage volume.

The heat carrier and water chemistry

As earlier described, the heat carrier is in principal groundwater that is circulated under vacuum conditions through the storage. Since the flow loop is in hydraulic connection to the groundwater in the rock, the pressure in the circulation loop is primarily controlled by the groundwater level and secondly by friction losses through the system. The groundwater level is more or less steady over the year. This is a result of favourable hydrogeological conditions where the water level of the regulating dam relates to the groundwater level in the rock.

The friction loss over the storage is approx. 35 kPa at full flow rate (19 l/s) and all sections opened. This figure has been steady since the beginning and indicates that no severe clogging by precipitation of carbonates or iron has occurred. The friction losses all together in the loop are approx. 120 kPa. The vacuum pressure at the suction side of the pump is around -70 kPa as lowest, creating a risk for boiling at that point.

The vacuum pressure is one reason for gas production in the loop, the increased temperature another. Gas is almost constantly released from the fluid especially on the supply side of the pump (at heat injection), much less on the return side. To separate the gas, two vacuum pumps are applied, one on each main manifold. The one at the supply side has so far disposed approx. 60 m^3 of gas up till now, while the one on the return line disposed only approx. 6 m^3.

The chemistry of the heat carrier is an important issue to follow since an unfavourable chemical development may cause operational problems with corrosion and clogging. In Fig 7 the pH, the content of oxygen and the content of dissolved iron are shown, reflecting the potential for corrosion and precipitation of carbonates and iron hydroxides.

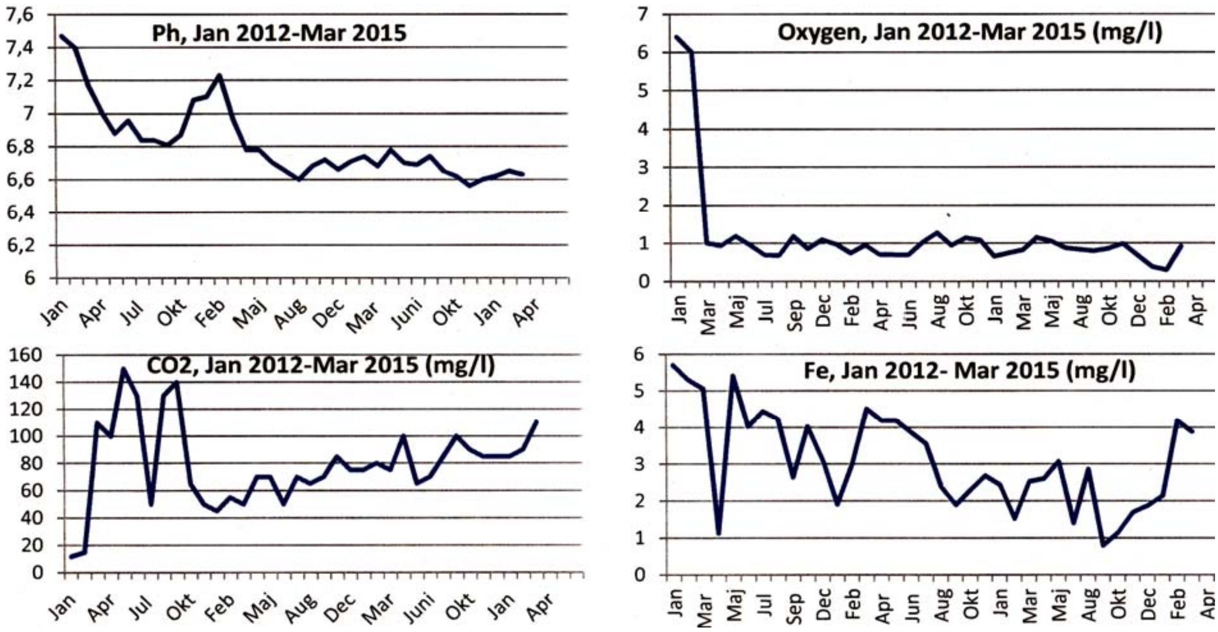
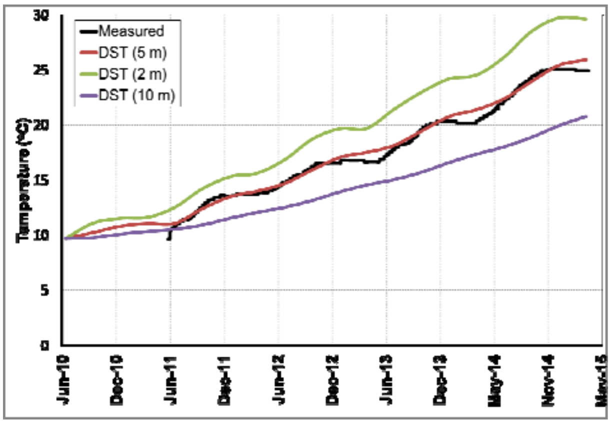


Figure 7 Chemical developments of some compounds of the heat carrier

As can be seen in Fig 7, the oxygen content has been kept at approx. 1 mg/l since March 2012. The pH has steadily grown lower as a result of increased storage temperature (from 20 to slightly above 40^{o}C during the period). For the same reason the CO_2 has increased, while the content of dissolved iron shows a decreasing trend.

Thermal development - actual and simulated

Performed simulations were made with DSTwin (Hellström, Sanner 2001). This model simplifies the storage geometry and e.g. includes no details about the boreholes and the pipe system. However, it calculates the global thermal process with sufficient accuracy. When the simulated ground temperatures are compared with measured temperatures it shows that the storage temperature is ~4^{o}C greater than the simulated temperatures. Fig 8 (Left) shows the temperature at GT3, which is located at 100 m depth 10 m outside the storage volume (see Fig 2). Since the measured temperature was ~4°C greater than the calculated, it was investigated if this difference could be the result of borehole deviation i.e. that the measurement point was not located where it should. So, the other two curves show the same measurement point as if it was located not 10 m but 5 m and 2 m outside of the storage volume. It is not unusual that a "vertically" drilled borehole deviates up to 10 m from the supposed vertical line. In this case it seems like a deviation of 5 m gives the best fit. Fig 8 (Right) shows the measured and calculated temperatures within the storage volume. In this case the simulated storage temperature is more or less the same within the storage volume and cannot be explained by dislocation of the temperature gauge. This temperature deviation is a rather a result of the simplified simulation model.



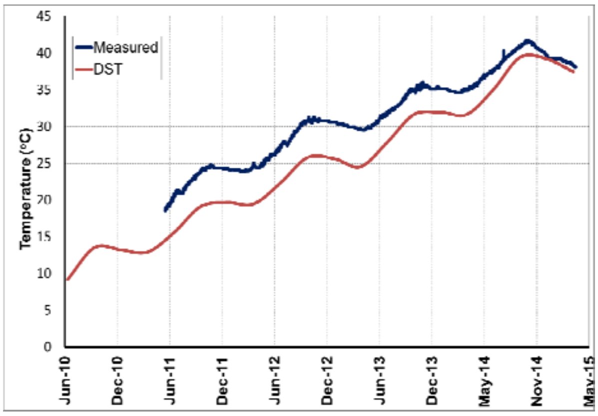


Figure 8 Left/ Measured and calculated ground temperatures at 100 m depth (GT3). The wavy centre line (black) shows measured temperature. The purple line indicates the simulated temperature at the presumed location of GT3, 10 m outside the storage volume. The other two curves show simulated temperatures at 2 and 5 m outside the storage volume. Right/ Measured and calculated ground temperature at 70 m depth (GT1). The simulated temperature is ~4^{o}C lower than the measured temperature.

DISCUSSION

After some functional problems, mainly due to problems with gas in the heat carrier the first two years of operation, the BTES system now works successfully. Still, corrosion of steel pipes in the system and precipitation of carbonates (scaling) and solid iron compounds should be considered as potential future problems. However, the development of the chemistry of the heat carrier fluid indicates that no severe corrosion should be expected in the nearby future. This is mainly due to a continuous low content of oxygen. An increased content of CO_2 works the other way as an increased storage temperature does. The vacuum pressure is around –70 kPa at the current storage temperature (around 40^{o}C). This is close to the boiling point and an increased temperature may cause the water to boil at the suction side of the circulation pump. These are both reasons to consider a lower storage working temperature than designed and to use a heat pump for the major part of heat recovery from the store.

After investigating the difference between measured and simulated ground temperatures (where the measured temperature is greater than simulated) it was found that the only reasonable explanation is that the temperature gauge (GT3) is located not 10 m but rather 5 m from the storage volume. It is more or less normal that boreholes deviate 5-10 m from planned vertical line location. Even if the measurement hole would be vertical, the borehole of the storage could deviate in the direction of the measurement hole. It is possible to drill more accurately but it is usually not required (requested) in this type of drillings. The too low temperature within the storage volume is because of the simplified model used, which solves the global problem well but not the details within the storage.

CONCLUSIONS

The concept of HT-BTES for a more efficient usage of bought thermal energy has shown to result in several benefits such as a considerable increase of heat conservation from the industrial processes (some 4 GWh/year so far) and an improved indoor working environment, especially in the foundry (comfort cooling).

Performed simulations show that we can rather well predict the future temperature development of the storage volume. In 2015 the planned rate of heat injection (3600 MWh/year) will be reached for the first time, and thereafter. This means that the BTES will need still a few years to reach steady state in its operation i.e. with an annual heat extraction of 2600 MWh.

Lessons from the chemical measurements and the functional experiences are that a lower storage working temperature than designed should be considered. This is due to an increased risk for scaling and corrosion with an increased temperature, as well an increased risk for boiling at the existing vacuum pressure.

A heat pump for heat extraction from the storage combined with a lower working temperature would increase the efficiency of the storage; reduce the potential problems with scaling and corrosion; and reduce the risk for boiling at the suction side of the circulation pump.

ACKNOWLEDGEMENT

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