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Intelligent Energy Europe

IGEIA

Integration of Geothermal Energy into Industrial Applications

Deliverable 10 - Sweden

Preliminary design of a seasonal heat storage for ITT Flygt, Emmaboda, Sweden

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1 Introduction

The foundry at ITT Flygt encounters a large consumption of electricity with a high waste heat potential. The plant is run some 4 400 hours a year and a large amount, approximately 10 GWh of heat, is disposed to the atmosphere at all times. Even if some already is recovered at winter time, approx. 2 GWh, there is still room for a more efficient utilization of this heat source, hence replacing heat that today is delivered by a district heating system.

At present the project is preliminary designed. In this report a project overview is given describing the system, mainly from a technical and economical point of view.

2 Geological situation

2.1 Localization

Since the geological conditions are similar all over the factory area, the only criteria are that the storage should be located in connection to the existing local DH system, that the storage will not interfere with the factory activities during construction, and that it will not create an obstacle for future usage of the ground at site.

From these criteria the best choice is that the boreholes are placed to the area with grass and asphalt close to the dam, see enclosure 1.

2.2 Hydrogeological conditions

The hydrogeological conditions at the site have been documented by two investigation boreholes. The main results from these are summarized as follows:

- The soil consists of 7-8 m of till
- The bedrock down to 200 m consists of diorite (55 %) gneiss and granites (25 %) and amphibolites (20 %)
- The upper 2-3 m of the rock is fractured and unstable, which means that casing has to be drilled to some 12 m.

- Ground water bearing zones were penetrated at a depth of 35-40 m in both holes and at 70 m in one hole.
- The ground water level in rock is approx. 2 m below the ground surface
- The hydraulic conductivity measured by a capacity test in the borehole with two water bearing fracture zones is approx. 1 x 10^{-6} m/s.

2.3 Drilling ability

No drilling problems occurred caused by instable rock or hardly penetration zones. This indicates a good drilling ability down to at least 200 m.

2.4 Thermal properties of the rock

The thermal properties have been measured by two thermal response tests (TRT:s).

The measurements show the following results:

- The ambient temperature in the rock mass is +8°C and the geothermal gradient is 1, 5°C/100 m.
- The thermal conductivity of the rock mass is 3, 2 W/m,K in average (3,0 for one hole and 3, 4 for the other hole).
- The heat capacity is 0, 6 kWh/m^3 x °C.
- The thermal resistance with water filled boreholes and single U-pipes is 0,06 K(W/m)

3 Principle of geothermal system

3.1 Objectives

The main objective is to create a commercial project where a seasonal Borehole Thermal Energy Storage (BTES) is used to improve the utilization of waste heat from the foundry.

The available heat for storage is currently in the order of 3 800 MWh annually. The goal is to recover at least 2 600 MWh of that heat and hence reduce the bought heat from the external district heating system with the same amount.

A second goal is to increase the direct utilization of waste heat during the winter season by adding a couple of heat pumps to the system. These will allow low temperature waste heat sources to be used for space heating in winter.

3.2 Waste heat available for storage

The energy situation described in report D8 (*Sweco, 2008*) clearly indicates that there are three heat sources available for seasonal storage, mainly from summer to be utilised in winter. These sources are

1. Direct heat exchanging from the ovens (as currently)

2. Heat from the cooling tunnel (by usage of a heat pump)

3. Heat from the reservoir (by using a heat pump)

A seasonal storage would indeed even out the peaky temperature situation in the internal DH net. Calculated amount of energy that can be stored directly from the ovens will be in the order 1 200 MWh. The storage temperature will in this case be +60°C as an average.

3.3 Current system

The current system is described in report D8 (*Sweco,* 2008) and is principally shown in enclosure 2.

The preliminary designed system is principally shown in enclosure 3.

As shown, the main source of heat for storage is the ovens. These are currently chilled in two steps.

In the first step heat from the ovens is transferred to the local DH system through HEX 2. In the second step the ovens is chilled by a cooling tower through HEX 3.

In between HEX 3 and the cooling tower there is a water basin that evens out the temperature swings from the ovens.

The water basin also serves as a cooling medium for compressed air production the year around and some other minor processes. (These functions are not shown in the figure).

A major part of the heat needed for space heating at the factory is currently supplied by district heating through HEX 1.

3.4 Planned change of current system

3.4.1 Additional components

To allow a better waste heat recovery the existing system is planned to have following new components (for illustration, see enclosure 3).

- A heat pump (HP1) for utilization of heat from the cooling tunnel (TF101).
- A heat pump (HP2) for utilization of heat from the water basin.
- Seasonal borehole thermal energy storage (BTES) for storage of waste heat during the summer season to be recovered during the winter season.

3.4.2 Functional description

The factory has already an advanced controlling system with a lot of monitoring equipment. With the additional new components for an increased recovery of waste heat the controlling and monitoring system has to be extended.

As can be seen from enclosure 3, the connections to the local DH are such that heat can be delivered to both the supply and the return pipe of the net. The primary source will always be the direct heat recovery from the ovens (HEX2) followed by the heat pumps for temperature increase. All surplus heat, not used in the local DH will then be stored in the underground at the highest temperature level possible.

Discharging the storage will always be done to the return pipe. With such a connection only peak loads, if any, have to be covered by the regional DH (HEX1).

The storage will have separate sections with an “inner core” of high temperature and an “outer mantle” for less high temperature. The functional objective with this design is to adjust the production temperature to the actual heat demand and to occasionally allow a short term storage function.

The system will have the following main modes of operation

Winter

- At extreme cold weather the heat recovery system is primarily used for basal load followed by BTES supply. Secondary external DH is used for peak shaving. During nights and weekends the BTES will be the prime supplier of heat.

- At moderate cold weather all heat is expected to be delivered by the new system. A short occurrence of excess of heat daytime is stored in BTES and recovered during nights and weekends.

- At mild weather all heat is supplied by the recovery system. Excess of heat is short term stored in BTES and used if required.

Spring and autumn

During these seasons all heat needed is covered by the direct use of waste heat day time and by the BTES night time. All surplus heat is stored in the BTES.

Summer

Heat is only used for preparation of hot tap water. Almost all surplus heat is stored in the BTES which is expected to be fully charged at the end of September.

4 Performance of the system

4.1 Energy demand

4.1.1 Heat and heat load demands

The two latest years, that has been mild winters, the internal DH system has distributed approx. 8 000 MWh of heat annually. Of this some 4 000 MWh was waste heat recovered from the ovens with the existing recovery system.

The maximum heat load demand is according to the measurements around 3 800 kW at -18°C and during night time when there was no supply of waste heat. The same measurements show a demand of 2 200 kW at -10°C and 800 kW at zero outdoor temperature.

4.2 System design

The designed new system has a maximum load capacity of 2 200 kW, which means that the system would be capable to cover all heat needed down to -10°C. The need for peak shaving with the external DH seems therefore to be very small.

4.2.1 Additional components

The additional components have been dimensioned as follows (for illustration, see enclosure 3):

- HP1 for utilization of heat from the cooling. It will lift the temperature from +30-35 to +60-65°C .
- HP2 for utilization of heat from the water basin. It will lift the temperature from +20-35 to +60-65°C.
- The seasonal BTES system is designed for storage of 3 800 MWh annually at a temperature around +60-65°C (maximum +70°C). The temperature after recovery is +40°C.

4.2.2 Supply and return temperatures

The measurements from 2006-2007 indicate that the current supply temperature in the local DH system is at around +55°C during the coldest days of the winter. However, most of the winter season it is kept below +45°C, see enclosure 4. These are all temperatures that can be directly supplied by the heat recovery system.

The return temperature is in general some 10°C lower and kept within the frame of +30-40°C. This indicates that the BTES easily can produce heat down to at least +40°C, maybe lower.

4.2.3 Potential for an increased recovery

The measurements have shown that there will be around approx. 3 000 MWh surplus heat that can be stored during the summer season (May-September). During autumn and spring there is another 800 MWh excess of heat supplied to the BTES mainly with a short term function. Hence, some 3 800 MWh is estimated to be stored.

The potential for an increased direct use by the heat pumps is estimated to 3 000 MWh, although at present only 2 200 MWh can be utilized. It shall be noted that some 1 500 MWh of heat will be additionally produced by the heat pumps during summer to be stored in the BTES.

4.2.4 Seasonal storage system

To decrease the thermal resistance another type of borehole heat exchanger (BHE) is planned. This new BHE is estimated to reduce the resistance down to some 0,01 K(W/m). A principal figure of the BHE design is shown in enclosure 5.

For the design a mathematical simulation model by the name of EED (Earth Energy Design) has been used.

In this model the number of boreholes, depth and type of borehole heat exchanger, storage configuration, flow, energy loads etc can be varied. This creates the possibility to optimize the storage with respect to size, temperatures and the underground thermal properties.

The simulation shows that it takes 140 boreholes á 150 m with a rectangular shape and a hole distance of 5 m to create a storage for 3 000 MWh.

The extra 800 MWh for short term storage during the winter does not take any extra holes. This energy lies on top with a higher degree of quality.

Taken into account that the average time for storage is six months, and that the storage working temperature is +60/40°C, the storage losses will be in the order 1 200 MWh. Hence, 2 600 MWh will be recovered and utilized.

The storage will be able to deliver a load capacity of some 1 100 kW at the start of the winter season. At the end of winter the capacity may drop down to some 100 kW. However, pulses of short term storage can drastically increase this number if required.

4.3 Energetic performance

Using the borehole storage, the amount of energy that can be directly obtained from the ovens will increase from approximately 4 000 MWh to 6 300 MWh per year. Out of these, 2 300 MWh is stored into the BTES and 4 000 MWh used directly in the internal DH system.

HP1 in enclosure 3 is estimated to produce some 1 900 MWh of heat annually at a COP of 3,6. This translates to about 530 MWh of electricity being used for this heat production.

HP2 in enclosure 3 is estimated to produce around 1 800 MWh of heat at COP of 4,2. This translates to about 430 MWh of electricity being used for this heat production.

Of the 3 700 MWh of heat produced by the heat pumps, 1 500 MWh is stored into the BTES and 2 200 MWh used directly in the internal DH system.

In total, 3 800 MWh of heat will be stored in the BTES system each year. It is calculated that 2 600 MWh will be recovered and used directly in the internal DH system, giving the storage a recovery factor of circa 2/3. The amount of electricity used for the circulation in the BTES system is estimated to 60 MWh (COP ~ 40).

When using the heat pumps and the BTES, the need for cooling the ovens is reduced by about 5 000 MWh, mainly during summer. The energy cost for providing this cooling is not known today. However, it has been roughly estimated that 150 MWh of electricity will be saved by reducing the amount of cooling summertime.

All together, the heat pumps and the BTES system will deliver an extra 4 800 MWh of heat to the internal DH system. At the same time, the use of electricity will increase with about 900 MWh, giving the system an overall SPF of 5,3.

4.4 Environmental balance

4.4.1 Technical fundamentals

The environmental evaluation is based on the following technical properties of the system

- The heat carrier between the BTES and the local district heating consists of water in closed loop that has no physical contact to other flowing media in system except the ground water in the rock.

- The water will have no additives and will consist of local tap water.

- The flow will be steered by one or several frequency controlled circulation pumps. The pressure will be low, approx. 2 bar as a maximum.

- The rock around the boreholes will be heated up to maximum +70°C. The highest temperatures will occur close to each one of the boreholes. The highest average temperature of rock mass will be +60°C fully charged, and +40°C as lowest at fully discharged.

4.4.2 Impact on the ground water level

During construction a temporary lowering of the ground water in the rock is expected. However, the rock has a low permeability. Hence, the disturbance will be limited to a few hundred meters.

Once constructed and set into operation a slight level change may occur due to the changes in temperatures.

4.4.3 Impact on ground water chemistry

The tap water used as heat carrier is oxidized and may to some extent mix with a slightly reduced ground water that occurs in fractured part of the rock.

If so, iron and manganese in solution may precipitate in the fissures and clog these. However, the amount of precipitates is estimated to be very low, but on a very long view, the local permeability of the rock may be locally decreased. The surrounding areas will not be affected.

The type of borehole heat exchanger used will allow hot water to have direct contact with the borehole walls. In theory, some of the minerals would get into solution in the water. However, results from internationally performed research on this subject clearly shows that the risk for such processes is very low with actual types of rocks and temperatures (IEA-ECES-Annex 6)

4.4.4 Impact on the underground microbiology

The IEA research also shows that an increase of temperature to +70°C will kill all bacteria in the centre of the storage. Along the sides with temperatures on +45°C and less, the micro fauna will adopt with new species of mainly iron-, sulphur-, methane-, and nitrogen bacteria.

The most important result of the research is that an increased temperature will not lead to an increased growth of bacteria. The growth is only controlled by the access to nutrients, mainly organic coal.

It shall also be considered that the natural bacteria fauna will be return once the storage is shut down and the rock is slowly chilled down to ambient temperature.

4.4.5 Spreading of heat

Heat that is stored in the rock mass can be transported away with the flow of ground water.

The two investigations holes suggest that there are a couple of fracture zones that I theory may displace some of heat stored. However, the capacity test shows that the flow of water is marginal and hence, no such transport is expected. This is based on the facts that the ground water gradient is very small (approx. 1/100), as well as the hydraulic conductivity of the single fractures that occurred (10^{-6} m/s). In theory these figures suggest a movement of less than 0,5m/ year. Hence, the movement of ground water will not spread the heat from the storage more uttermost marginally.

4.4.6 Impact on the surface

Inside the storage area there is a grass surface and asphalt surface and close by a damming of a river (Lyckebyån)

The calculated losses from the storage is 1 200 MWh annually. This heat will mainly reach the surface at storage area, approx. 5 000 m^2

Theoretically estimated the heat losses at surface will be in the order of 30 W/m^2. This is about 500 times more than the natural heat flux from the underground (0, 06 W/m^2) caused by the geothermal gradient. A consequence of the increased heat flux would be that the surface will be unfrozen during winter and that snow will be melted quicker than in the surroundings.

The area with grass will potentially have an increased time of growing and may even grow in the winter. The nearby dam will probably not be affected at all since heat that leaks out here will be mixed with the flow of water through the dam.

4.4.7 CO_2 reduction

As stated above, there are no expected local environmental concerns or impacts installing and operate a BTES system. On the contrary, the system would be of benefit for the environment by saving thermal energy that can be used else where.

As explained in the D8 report (*Sweco, 2008*), ITT Flygt can prohibit the release of about 350 kg CO_2 per MWh that is not bought from the regional DH system of Emmaboda.

If 4 800 MWh of regional DH energy is allocated for use elsewhere, the release of CO_2 to the atmosphere will be reduced by about 1 700 tonnes each year.

For producing these 4 800 MWh of heating, an additional 900 MWh of electricity is used. Since “green” electricity is specifically used for running the system there will be no emissions of CO2 or other environmental harmful substances.

5 Financial balance

5.1 Investment costs

The investment has been calculated to approx. 10,6 Million SEK split into the following items

- Heat pump HP1, installation and side equipments included, 1 700 Thousand SEK
- Heat pump HP2, installation and side equipments included, 1 200 Thousand SEK
- BTES, borehole heat exchanger piping system and heat exchangers included, 6 500 Thousand SEK
- Controlling system and electricity, 1 200 Thousand SEK

5.2 Operating costs

The investment is estimated to reduce the dependence of district heating with 4 800 MWh annually. Of this reduction the BTES will supply 2 600, while 2 200 will be produced directly by the two heat pumps.

The economic value of the reduction is with the present price of district heating 2 250 Thousand SEK annually (470 SEK/MWh).

For running the system, mainly the heat pumps, 900 MWh (+ BTES el) of additional electricity is used. The present annual cost for this is 400 Thousand SEK (450 SEK/MWh).

The maintenance and operating costs are estimated to 20 Thousand SEK per year.

Based on these figures, the annual savings will be 1 830 Thousand SEK.

5.3 Pay-back time

The net investment is 10 600 Thousand SEK and the annual savings 1 830 Thousand SEK.

Using the net investment the straight pay back will be in the order of 5,8 years.

Future energy prices will increase the profitability as long as the price of electricity stays on the same level as the price of district heating.

It is also of value to know, that the operation and maintenance cost for running the BTES is practically none and that the investment in BTES can be written off on a very long period of time. The technical lifetime of the BTES part of the investment is commonly set to 40 years or more.

6 Conclusions

The objective is to make the recovery of waste heat from the foundry more efficient by using a Borehole Thermal Energy Storage (BTES) and by using heat pumps in the system.

The BTES system consists of 140 boreholes at a depth of 150 m. The boreholes act as a heat exchanger to rock mass of some 600 000 m^3.

In the storage, waste heat is seasonally stored from the summer to the winter season. The storage is heated to approx. +60°C at the end of summer and recovered again during winter. The temperature of the storage will then be approx. +40°C.

The storage will also be used for short term storage of heat during part of winter. Recharge of heat will then take place when the foundry is in operation and recovery at nights and week ends.

Based on measurements performed the two latest years it has been calculated that 3 800 MWh of waste heat can be stored. By using a simulation model, Earth Energy Design (EED), it is estimated that at least 2 600 MWh (68 %) can be recovered. The rest are heat losses from the storage.

Except for the storage, the system contains two heat pumps, with the function to increase the temperature on waste heat that is not warm enough for a direct utilization. The heat pumps will add another 2 200 MWh to the recovery.

All together, the system will replace approx. 4 800 MWh of bought district heat annually at an SPF of 7, 3. With the current energy prices the investment, roughly 10, 6 Million SEK, will be paid back within 5, 5 years.

Since “green” electricity is used for running the system there will be no emissions of CO2 or other environmental harmful substances. In fact, the project will reduce emission of CO2 with approx. 1 700 tons per year. This calculation is based on that the energy savings will replace burning of oil elsewhere in the Emmaboda community.

An environmental assessment study indicates that the BTES system will not cause any local impact on the nearby surroundings.

7 References

Sweco, 2008: IGEIA, Deliverable 8, www.saunier-associes.com/igeia

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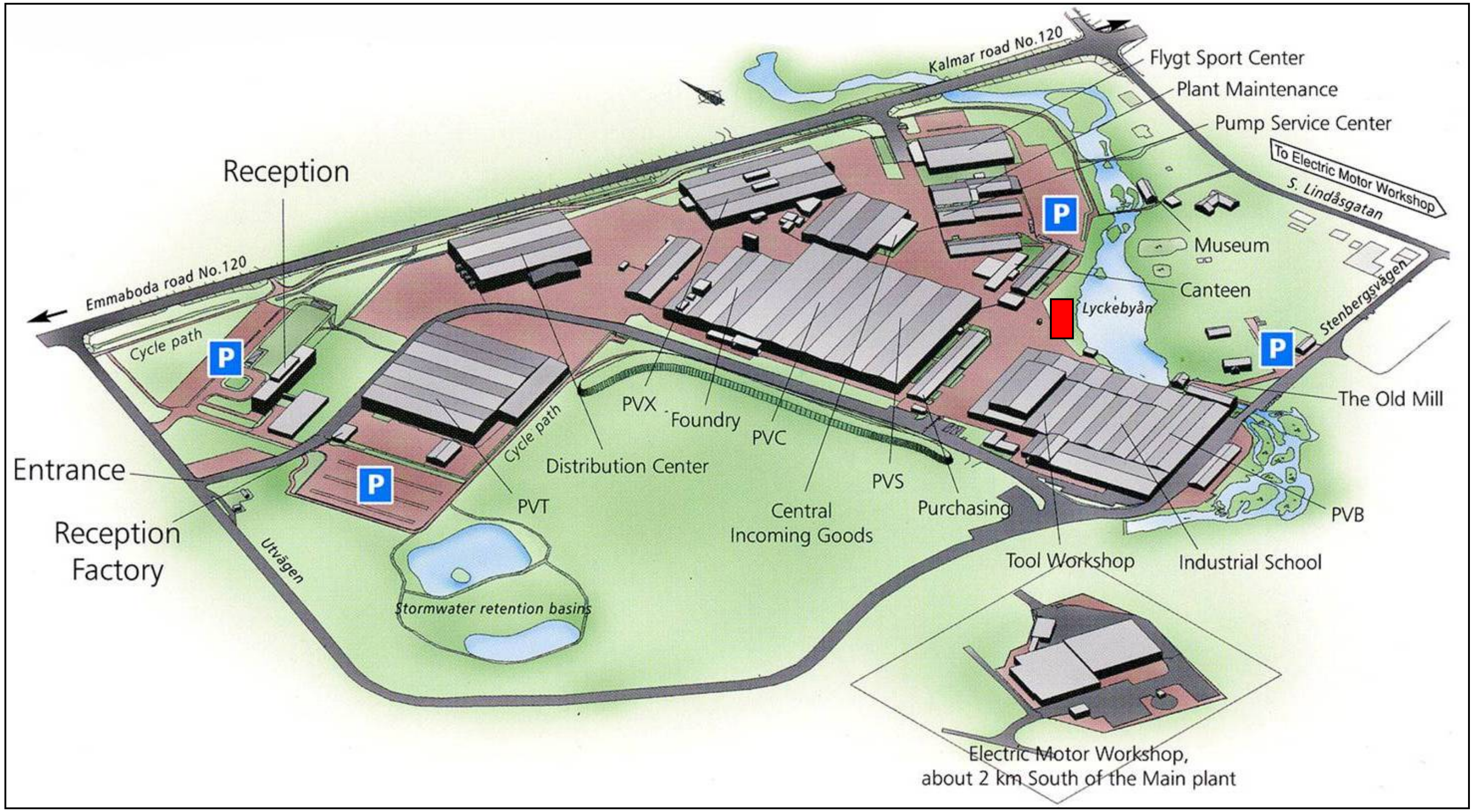
for ITT Flygt, Emmaboda, Sweden

Enclosure 1

Location of BTES



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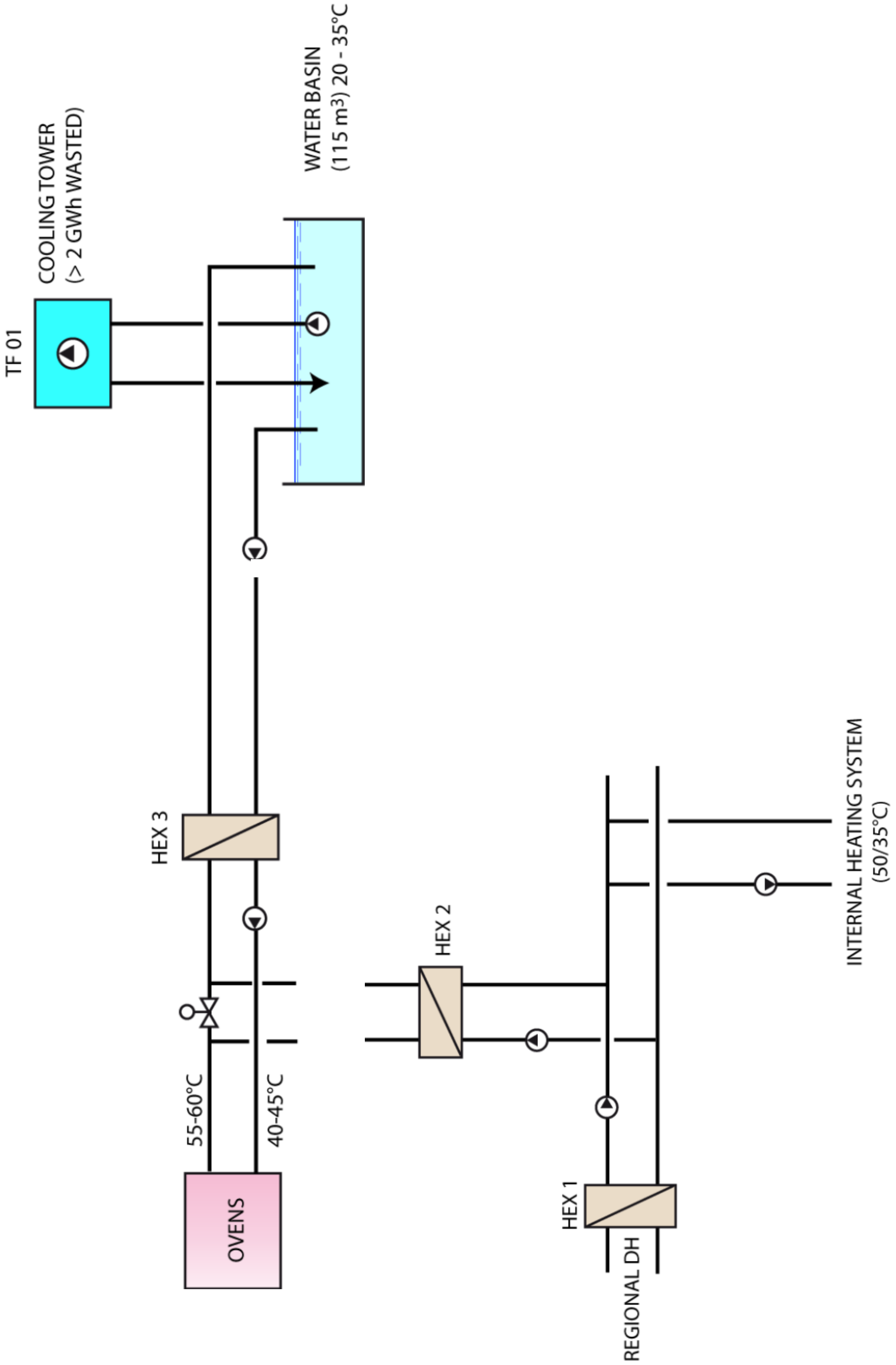
Enclosure 2

Current system



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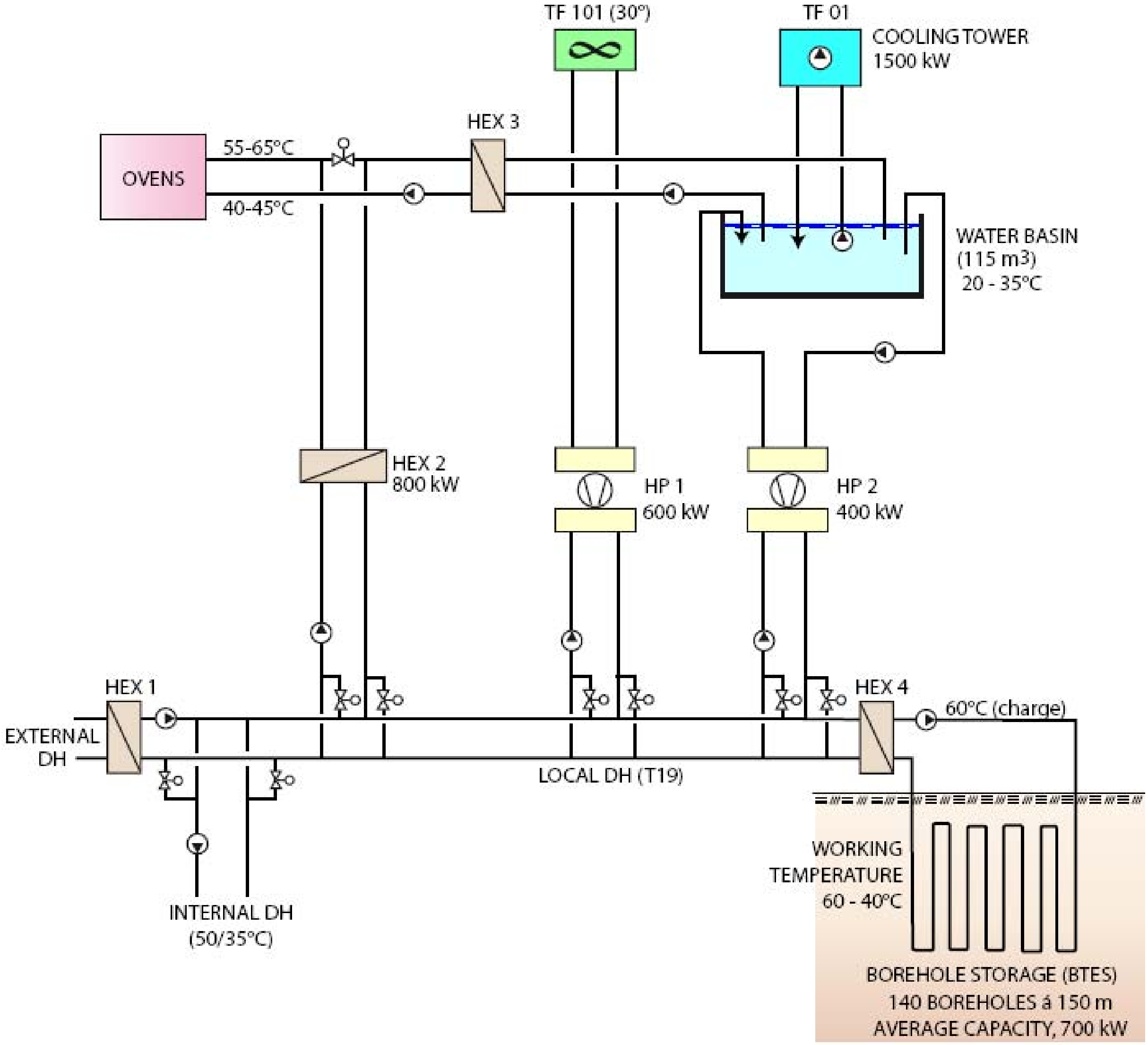
Enclosure 3

Preliminary design of geothermal system



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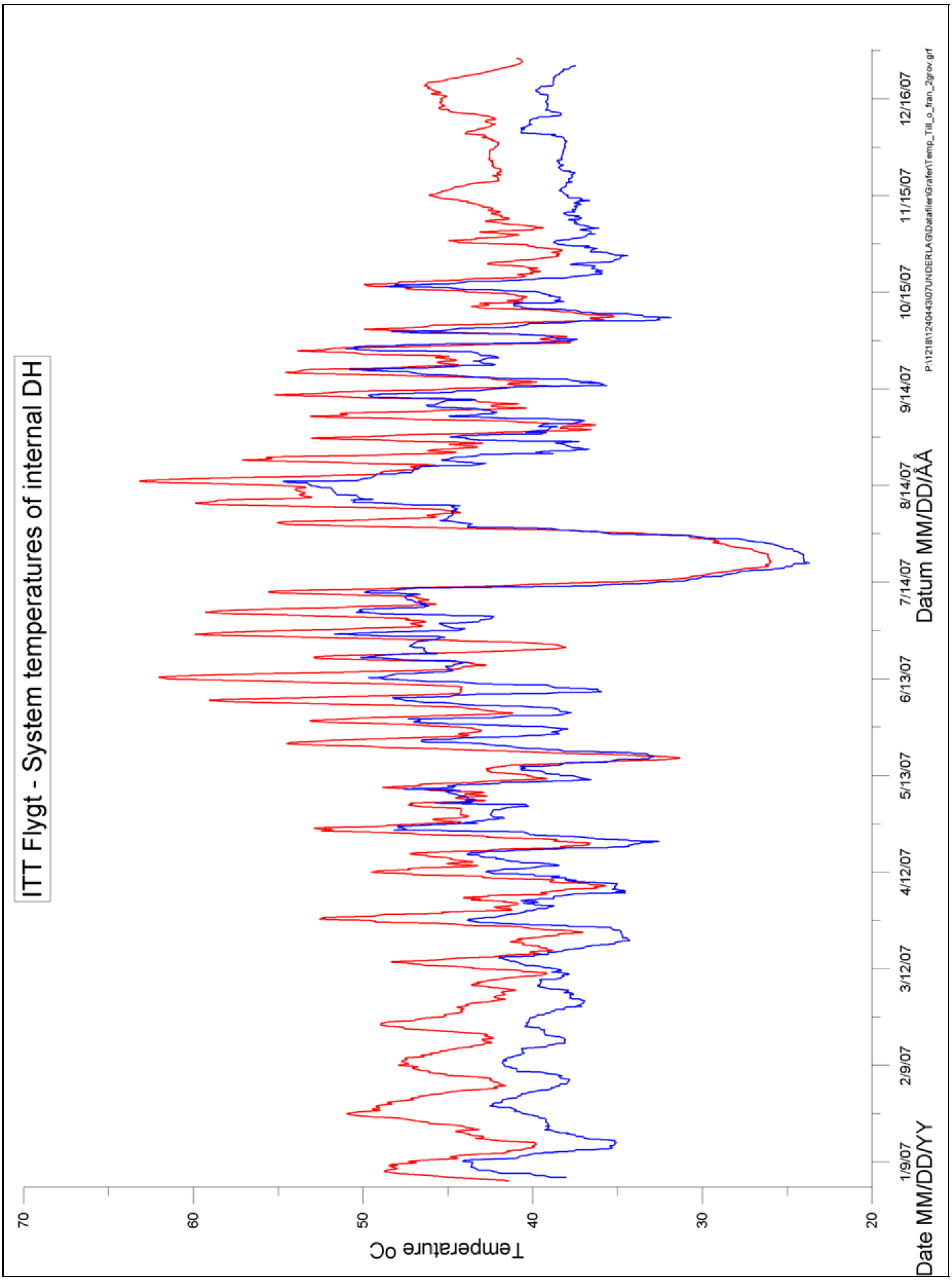
Deliverable D10

BTES for efficient utilization of waste heat Preliminary design

Supply- and return temperature T19



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BTES for efficient utilization of waste heat
Preliminary design

Enclosure 5

Design of Borehole Heat Exchanger