PROCEEDINGS, Twenty-Fourth Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, January 25-27, 1999
SGP-TR-162

LONGTIME STUDY OF GEOTHERMAL DATA FROM A LOW ENTHALPHY GEOTHERMAL HEAT PLANT.

Per-Gunnar Alm

Lund University
Dept. of Engineering Geology
Lund, Sweden
Per-Gunnar.Alm@tg.lth.se

ABSTRACT

This paper presents a case study of a geothermal heat plant in southern Sweden where data of geothermal properties are collected daily. The plant has been in operation for more than thirteen years. By daily collecting and processing the geothermal data, it has been possible to minimize the standstill of the plant due to unexpected problems in the production and injection wells. A study of the geothermal properties has also made it possible to follow the long time changes within the geothermal reservoir.

INTRODUCTION

Scania is the south most province of Sweden. The largest city in the province is Malmö, the third biggest city in Sweden. Some twenty kilometers to the north of Malmö is the university town of Lund located. In Lund, the first geothermal heat plant in Sweden has been in operation since 1985.

The district heating in Lund was introduced in the city 1963 and in 1986 more than 80% of the total heat demand were met by district heating. In the beginning of 1980's the oil dependency for the district heating system was 100%. The Dept. of Engineering Geology, Lund University together with the authorities of Lund started in 1983 a project for utilization of the geothermal reservoir beneath Lund. Even if the geothermal resource is a reservoir of low temperature, the development of more efficient heat pumps to a lower cost made it economically possible to utilize the resource.

As an effect of the geothermal plant the oil dependency started to decline in 1985. During the first ten years the oil savings were more than 300,000 m^3. Today, the dependency has almost vanished.
The main heat sources are a combination of geothermal energy, natural gas and electric boiler. Of these three, the geothermal energy is major single producer. Today, the geothermal plant stands for approximately 45% of the total heat production in Lund.

The environmental benefits to the city of Lund and its surroundings are notable. Since the start of the geothermal plant in January 1985, the nitrogen oxide and sulfur pollution had been reduced to a minimum. The discharge of dust and carbon dioxide has also been reduced.

THE GEOTHERMAL RESERVOIR

The main part of Sweden, approximately 75%, belongs to the Russian plate (the Baltic shield), which consists mostly of granites and gneiss. The southwest part of Scania, the south most province of Sweden, belongs, in a geological sense to the Danish-Polish embayment. Sedimentary rocks, of geothermal interest, are therefor located mainly in this part of Sweden.
In the Landskrona basin, in which the Lund reservoir is located, the sediments resting directly on top of the basement are of the Mesozoic era. In the Lund area, the oldest sediments are lower Triassic deposits.

The geothermal reservoir is a Campanian sandstone occurring between approximately 500 - 800 m below surface. The rather unconsolidated sandstone is interbedded with impermeable lenses of shale. Due to the variation of the reservoir, the wells are all drilled to different total depths. For the same reason, the length of the screens and gravel pack also vary. Both the production and re-injection wells used in the geothermal plant are drilled to approximately 700 m. The temperature of the reservoir is 21-22°C. The production capacity of each well is at least 150 l/sec.

Table 1. The total depth and screen interval in wells located within the geothermal field of Lund.

Production well	Total depth (m)	Screen interval (m)
Skälsåker 1	701	594 - 657
Skälsåker 2	668	582 - 668
Hansagården 1	706	609 - 709
Hansagården 2	691	605 - 695
Injection well		
Värpinge 1	763	602 – 682
Värpinge 2	658	514 - 649
Värpinge 3	630	504 – 629
Värpinge 4	672	511 – 658
Värpinge 5	671	650 – 770
Värpinge 6	766	573 - 675

During 1982 and 1983 two investigation boreholes were drilled outside the town, in areas were the reservoir characteristics were supposed to differ. In connection with the drilling of the boreholes the department carried out an extensive test and sampling program. The purpose was to describe the reservoir and the composition of the geothermal fluid. From the tests it was noted that a minor gas production occurred at 1 atm and 25 ºC (2.5% of produced water volume). The geothermal pipe system is kept at an over pressure (more than 3.5 bar) so there will be no release of gas during the operation of the geothermal plant.
The minimum distance between the production area and the re-injection area of the reservoir is about 2000 m. The distance has been selected on the bases of thermodynamic numeric modeling. With this distance, the thermal breakthrough is calculated not to occur until after 25 years of operation.

THE GEOTHERMAL PLANT

Since the water, pumped from the reservoir, has a low temperature the heat can not be directly exchanged to the district heating net. Heat pumps are used to increase the temperature before the heat exchange takes place. The geothermal heat plant in Lund was built in two stages. During the first stage, which took place during 1984, two productions and two re-injection wells were drilled. The plant was taken into operation in the beginning of 1985. This first stage used a heat pump with a maximum capacity of 20 MW. The result of this first stage was so promising that the second stage was started practically immediately. The second stage consisted of two more production wells and three re-injection wells and was taken into operation at the end of 1985. The heat pump of this second stage had a maximum capacity of 27 MW. This gives the geothermal heat plant a total capacity of 47 MW.

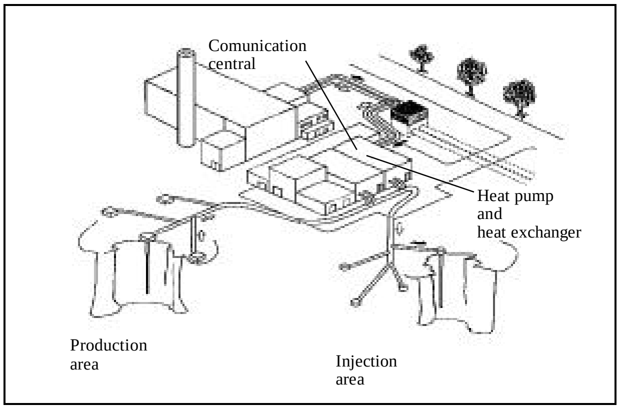

Figure 1. Principle figure showing the geothermal heat plant in Lund.

The design of the various wells differs depending on at what stage they were drilled. During the first stage all the wells in the reservoir were drilled as straight boreholes. During the second stage the wells were mostly drilled deviated. The two production wells were drilled from the same location and the same technique was used drilling the three injection wells where one is a straight borehole and the other two were done as deviated boreholes.

The production wells have been fitted with a continuously slotted screen, starting at about 600 m below surface, depending on well. Figure 1 shows a schematic figure of the plant design and figure 2 shows the principle design of the heat pumps.

Today, there are eleven wells in the geothermal field. Only ten wells are used for the plant. Of these there are four production wells divided in two production areas, two wells in each. On the injection side of the field are six re-injection wells located. Since the start of the plant the heat pumps have shown a very high degree of availability, often about 97-98% per year. The coefficient of performance (COP) has also been good, improving over the years, from approximately 2.5 in the beginning to today's value of around 3.3.

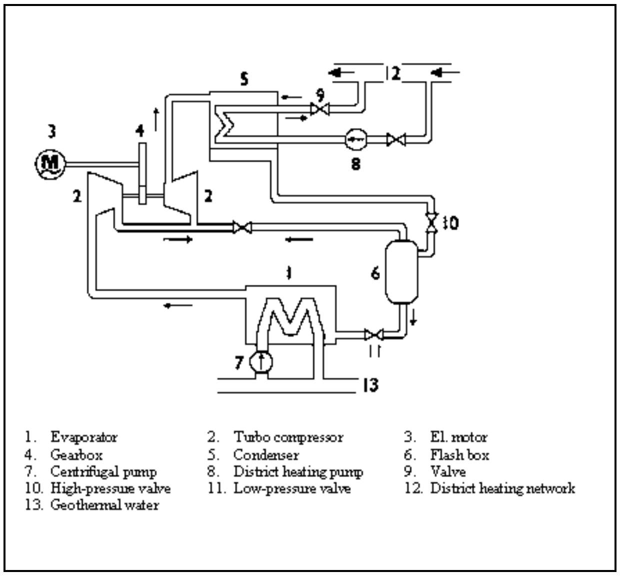

Figure 2. The principle design of the geothermal heat plant with heat pumps./Alm, Bjelm, 1995/

Due to the low temperature of the geothermal water, the geothermal plant operates with two heat-pumps. The incoming geothermal water is pumped to a first heat pump where a part of the heat of the geothermal water is extracted. Thereafter is the second heat pump used for the rest of the heat extraction. The temperature of the water leaving the heat pumps is approximately 80-85 °C. The return temperature from the district heating net is about 50 °C. The geothermal water is leaving the geothermal plant and is re-injected at a temperature of about 4-5 °C depending on time of the year. During the summer month when there is a smaller heat demand in the city, geothermal water with a higher temperature is re-injected.

THE PARAMETERS

To optimize the operation of the geothermal system, like the flow rate, the draw down, etc. a monitoring system is used. The system consists of sensors located in the wells and pump houses. All sensor readings are done on a monitoring panel in the communication central at the heat pump building. The registered parameters are printed out on paper twice every day and stored for future processing.

The monitoring system at the central is also used for checking other parameters than the geothermal ones, for instance the heat in the various part of the district heating net is also shown. In this paper however, only parameters from the geothermal side of the plant will be presented.

Every day since the geothermal heat plant was taken into regular use, geothermal parameters of importance have been monitored.

Approximately the same parameters are registered in all the wells. A total of 30 registrations are made simultaneously. Normally this is done twice every day but only one reading per day is used for statistical analyses. Besides the parameters registered in each well the ***total production flow per hour*** and the ***total injection flow per hour*** is also registered every day.

- The parameters registered on the production side are the ***temperature***, the ***draw down*** and the ***flow rate***. The ***pressure*** within the pipe system is also registered for the two production areas.
- The parameters on the injection side of the system are the ***injection pressure*** and the ***flow rate***. In some wells, the ***injection temperature*** is also recorded.

Regularly sampling of the incoming geothermal water is also done. One of the analyses that is done is salinity tests to see that no dramatic change of salinity occurs. This can in that case be an indication of activating newer parts of the reservoir.

Accompanying the drilling operations several geophysical well logs were run, which are used as zero-values of the geothermal reservoir. One of the first test wells that was drilled into the geothermal reservoir is located in the center of the re-injection area. This has made this well a perfect reference well, and various logs have been run into it during the years after the plant was started.

Regular readings

Here will be shown some diagrams of the parameters from some of the wells within the geothermal field. The “spikes’” that can be seen in the diagrams are some cases an effect of natural stops of the system, but mostly “noise” in the sensors.

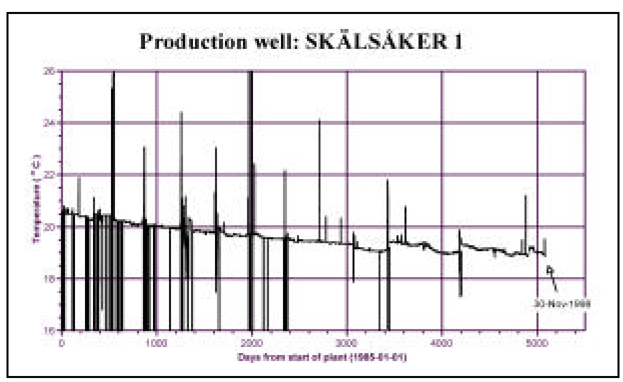

Figure 3. Temperature recorded in the production well Skälsåker 1.

Figure 3 shows the temperature variations of the geothermal water measured at the well head. As can be seen, there is a continuously decline of temperature. The same trend can also be found in the other production wells.

From the temperature recordings it can be calculated that there exist a temperature decline of approximately 0.33 °C per 2 years in the first 10 years of operation. In later years the temperature decline has been smaller about 0.24 °C per 2 years.

Figure 4 and 5 shows the flow rate and draw down in another production well.

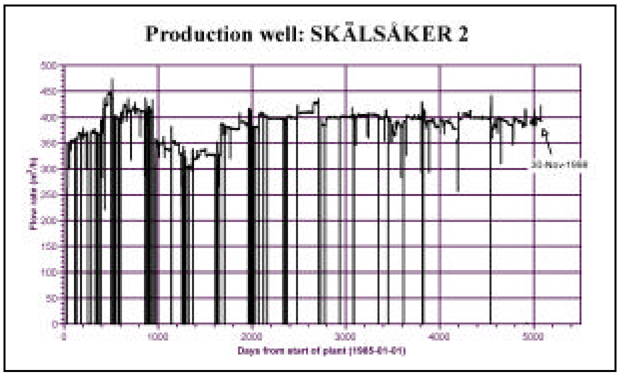

Figure 4. The flow rate recorded in the production well Skälsåker 2.

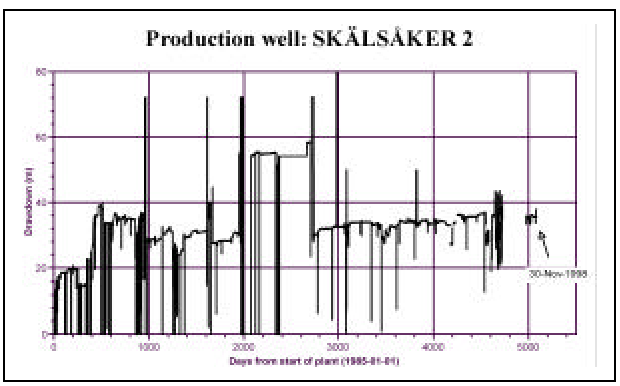

Figure 5. The draw down recorded in the production well Skälsåker 2.

These parameters are closely related. An increase in flow rate will normally result in an increase of draw down. By combining the flow rate and the draw down for a well. The specific production capacity for the well can be calculated as

$$\text{Specific Production capacity} = \frac{Flowrate}{Drawdown}$$

In the same way, the specific injection capacity will depend on the flow rate and injection pressure.

Presented in a diagram, figure 6, it can be used to monitor the status of the wells.

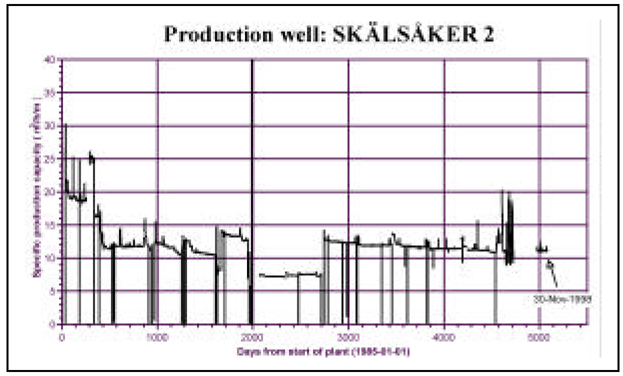

Figure 6. The specific production capacity calculated for the production well Skälsåker 2.

The specific production capacity can be seen as a relative index of the condition of the well. A declining value of the specific capacity indicates a declining performance of the well. This can be due to a need of increasing the draw down to keep up the flow rate or a need to reduce the flow rate in order not to have a to big draw down.

One of the most important parameters to study is the pressure in the injection wells. The pressure in these wells follows a cycle of increasing and reducing pressure. See figure 7. Directly after the re-injection wells were taken into operation, the pressure started slowly to buildup from initially about 2.5-3 bar to about 5-5.5 bar. Then, the wells were closed and the flow direction in the wells was reversed. This was done by mammoth pumping the well (airlifting the water) for some hours. This change of flow direction creates a re-arrangement of the gravel outside the screens. Thereafter the pressure had dropped to the initial value and the wells were used again. The same pressure buildup was noted in all the re-injection wells. The maintenance of the re-injection wells is done when the pressure has increased to 5.5-6 bar. This pressure buildup has been described in earlier papers /Alm 1996/.

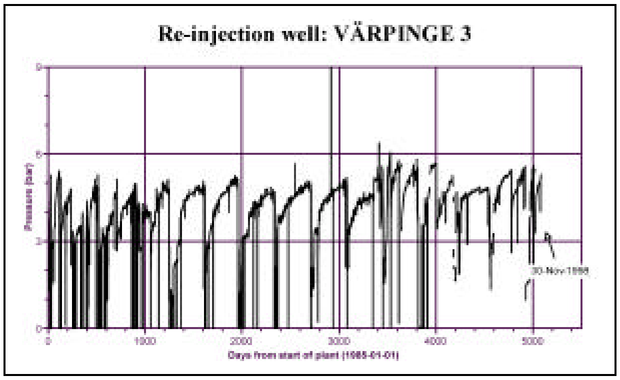

Figure 7. Injection pressure recorded in the re-injection well Värpinge 3.

If we look at the specific injection capacity for the same well, figure 8, there is some variation in the specific injection capacity. A decline can be noted as the pressure builds-up, but the important thing is that the overall trend for the well is not declining. (Compare with the first part of figure 11, where the trend was clearly declining.)

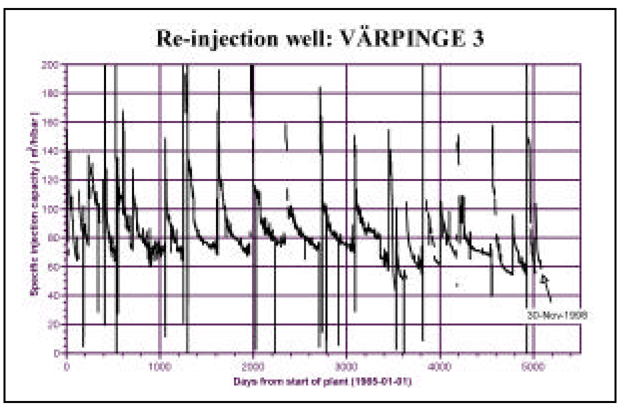

Figure 8. The specific Injection capacity calculated for there- injection well Värpinge 3.

Geophysical well logging

During the service periods, in the summer, when parts or the complete well system, is shut down it is possible to run logs in the closed wells. A reason for doing these logs is to record the injection and thermal changes within the reservoir. The log that is mostly run on these occasions is the temperature log. Figure 9 shows a temperature log run in one of the re-injection wells. The figure also has a marked depth showing the location of the screens.

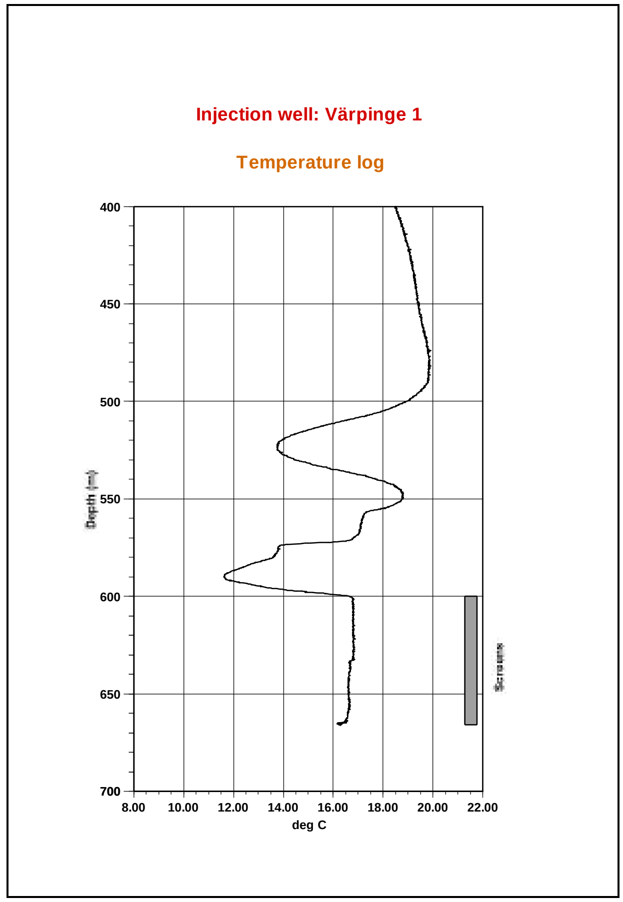

Figure 9. Temperature log run in the center of the injection area.

In the temperature log above it can be seen that the temperature sensor has reached the total depth inside the screened section. Within the screens the temperature is almost constant. This is a good indication that the inflow of the return water takes place over the complete section.

Temperature variations can be read above the screens and outside the injection pipe (casing). Since the screens in the wells were located at different depth, see table 1, the reservoir above the screens in Värpinge 1 is also used for water injection by other re-injection wells. Here it clearly shows that the reservoir is laminated with thick porous sections interbedded with finer parts with less permeability. These are the parts with a higher temperature. In these parts, heat transfer is carried out to a greater extent by conduction.

The relative high temperature that was recorded inside the screens on this log is because the recording was done in the summer. During summer time the returning geothermal water has a higher temperature due to the smaller heat demand in this period. See also figure 10, which shows the injection temperature for three of the wells. Here it can clearly be seen a yearly cycling of the injection temperature. These wells were all drilled during the second stage therefor the missing data for the first year.

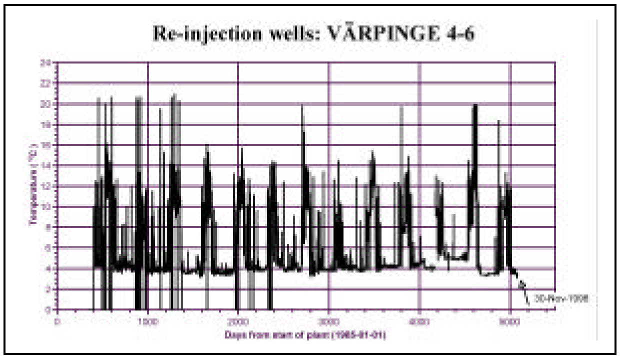

Figure 10. The temperature variation of the returning geothermal water since the start of the plant.

One of the re-injection wells, Värpinge 6, showed for many years a declining injection capacity. The injection flow rate had to be lowered over the years to keep a reasonably low injection pressure. By regular stimulation (reversing the flow direction) the negative trend has stopped. As can be seen in figure 11, the re-injection well Värpinge 6 has benefited from various stimulations and has indeed increased its performance. For many years this well was seen as one well with declining performance / Alm, 1996/.

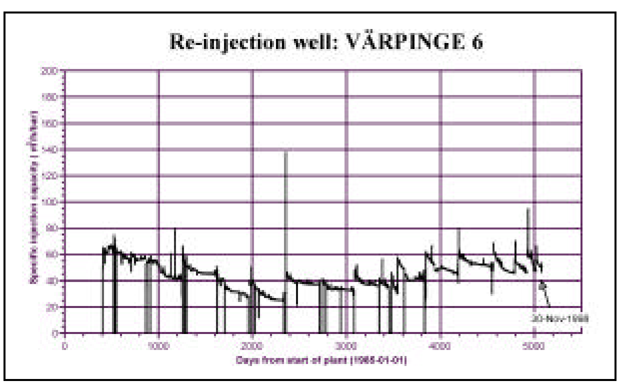

Figure 11. The Specific injection capacity of the re-injection well Värpinge 6.

As has been described in earlier papers the monitoring system can and is used to predict problems moreover to maintain the reservoir and wells in advance to minimize standstills of the geothermal plant.

CONCLUSIONS

It can be concluded that the geothermal heat plant in Lund has been a success since it was first started in the beginning of 1985. It can further be concluded that the monitoring system in the geothermal plant has been and still is of importance for the daily operation of the plant. Not only is it used to decide at what time maintenance has to be done in the wells, but it also gives a prediction of the amount of heat that can be extracted from the geothermal field in the future.

There is however one important thing that has to be stressed about the monitoring system. The various sensors have to be correctly calibrated if they are replaced or changed to a different location (i.e., depth) during any well maintenance.

REFERENCES

Alm, P-G; (1992)
"The use of a monitoring system in geothermal wells." Presented at the 10th International Energy Agency (IEA) Annex VI Expert meeting in Lund, Sweden 27th - 30th April 1992.

Alm, Per-Gunnar, Bjelm, Leif (1995),
"Geothermal Energy in Scania. A summary of Research Activities and Results within the National Program for Geothermal Energy in Sedimentary rocks, 1977 - 1994" Lund University, Lund Institute of Technology, Dept. of Engineering Geology. Lund, Sweden.
ISRN:LUTVDG/TVTG – 3042—SE.

Alm, Per-Gunnar (1996),
"Pressure Build-Up in Geothermal Re-Injection Wells." PROCEEDINGS, Twenty-First Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, January 22-24, 1996
SGP-TR-151