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PRESSURE BUILD-UP IN GEOTHERMAL RE-INJECTION WELLS

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ABSTRACT

This paper presents a case study of pressure build-up in some geothermal re-injection wells in Sweden. The geothermal heat plant, in which the re-injection wells are used, has been in operation since the beginning of 1985. Each day since the start of the geothermal plant registration of the injection pressure has been done. The paper describes how a stimulation of the gravel pack outside the well screen can improve the hydraulic performance of the well. The stimulation is done by reversing the flow direction in the well. It is also shown how important it is to have a good well completion in order to receive a positive effect of well stimulation.
The paper give example of recordings from two different re-injection wells. The recordings from one of the re-injection wells show that there are serious problems in the well, while the other one shows "normal" hydraulic behavior.

INTRODUCTION

In the southern part of Sweden, outside the city of Lund, a shallow geothermal reservoir is located. The town has been using a local district heating system for many years. The department of Engineering Geology at the University, together with the authorities of Lund started a project in 1983 to use warm water, ~ 22 °C, from the reservoir. This resulted in a geothermal heat plant which was incorporated in the district heating network during 1984/1985. The geothermal system is connected to the district heating network by way of heat pumps and heat exchanger.

From the start of the geothermal plant a monitoring system has been used to monitor the daily temperature and pressure in each well. Several other physical parameters have also been recorded daily.

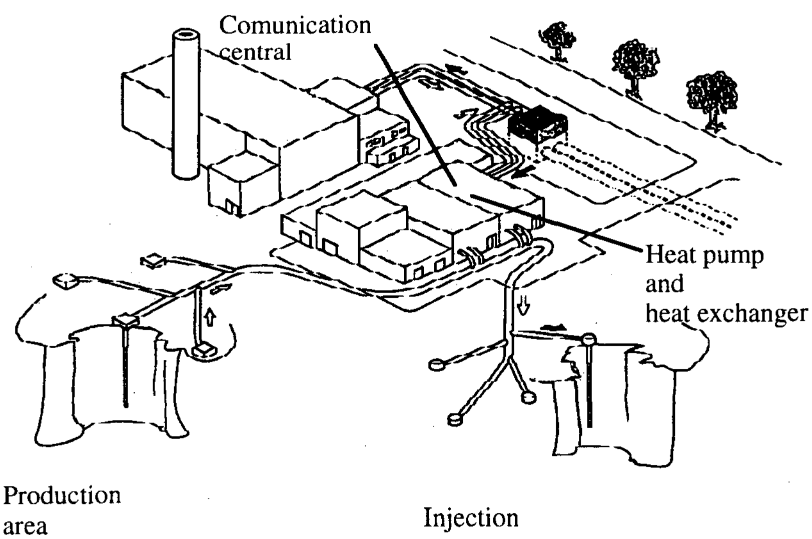

Figure 1. Schematic figure showing the geothermal plant in Lund. (modified from "Geotermi". Information paper from Lunds Energiverk).

The geothermal heat plant was built in two stages. During the first stage, two production and two re-injection wells were drilled. This part of the plant was taken into operating in the beginning of 1985.

The second stage, which was finished one year later, consists of two additional production wells and another three re-injection wells. To minimize the cost of the second stage, the drilling of the new wells were made from only two drill sites. One drill site for the two production wells and one for the three re-injection wells. As a result, one of the new production wells was drilled deviated and so were two of the re-injection wells.

Today, there are eleven wells drilled into the geothermal reservoir. A total of four production wells in two production areas and five re-injection wells. The additional two wells are exploration wells. Figure 1 shows a principal figure of the geothermal heat plant in Lund. The distance between the production area and the re-injection area is around 2000 m. The two heat pumps used in the geothermal plant have a maximum capacity of 20 MW resp. 27 MW. Production and injection values, recorded during a "normal" day are presented in table 1.

Production well	**Flow rate (m^3/h)**
Skälsåker 1	405
Skälsåker 2	390
Hansagården 1	402
Hansagården 2	385
Total production	1582
Injection well	**Flow rate (m^3/h)**
Värpinge 2	369
Värpinge 3	357
Värpinge 4	320
Värpinge 5	351
Värpinge 6	170
Total injection	1567

Table 1. Flow rates recorded in the geothermal wells. (April 11, 1990)

The difference in total production rate and total injection rate is not due to a leakage, but to the temperature difference of produced and injected water.

GEOLOGY OF THE GEOTHERMAL RESERVOIR

The geology of the southern province of Sweden, Scania, differs from the rest of Sweden. The main part of Sweden belongs to the Baltic shield, while the south-western part of Scania belongs to the Danish-Polish embayment. The bedrock of the Russian plate, which covers approximately 75% of Sweden, consists mostly of gneiss and granites. Therefore it is primarily in Scania, the southmost province, that sedimentary rocks, of geothermal interest, can be found.

The geothermal reservoir outside Lund is located in a Campainian sandstone at a depth of 500 - 800 meters. The sandstone is interbedded with impermeable shale lenses. The total depth of each well is approximately 700 m. Due to the variations in thickness and depth of the reservoir, the geothermal wells are drilled to different total depths. For the same reason, the length of the screens and gravel pack also varies. The temperature in the best part of the reservoir is 22-23 °C.

THE MONITORING SYSTEM

To be able to study the thermal and hydraulic status of each geothermal well a monitoring system is used. The system consists of sensors placed in the wells and pump houses. The sensors are connected to a monitoring panel in the communication central of the heat plant. Other parameters concerning the district heating net and heat pumps are also recorded at the central, but it is not within the scope of this article to describe these parameters.

More or less the same parameters are recorded in all the wells. A total of 30 registrations are made simultaneously. In addition to the parameters described below the total production flow and total injection flow are registered every day. Besides the daily registrations, water samples from the produced geothermal water are taken regularly for chemical analyses.

THE WELLS

In two exploration wells, different filter screens were tested. Other tests like production test etc. were also carried out. As a result from these tests, the screen types in the wells have been chosen to be continues slotted. The gravel pack outside the screen has been chosen to match the formation surrounding the borehole.

A schematic drawing of a typical production well is shown in figure 2. A production casing is installed down to approximately the top of the reservoir. Screen and production pipe are hanging in the lower part of the well. The space between the reservoir and screen is filled with a gravel pack.

In each production well, the following parameters are registered every day; *draw down*, *flow rate* and *temperature* of the geothermal water. The *pressure* in the pipe system from the production areas is also registered.

The design of the re-injection wells is in principle the same as for the production wells except for the pump, which is missing. A 'flushing' pipe has also been installed in each re-injection well. The pipe is approximately 70 meters long and it is used when the well is stimulated, as will be described below.

In the re-injection wells, the injection pressure and flow rate are registered at the same time as the data for the production side. The temperature of the injection water and pressure in the pipe before the three re-injection wells Värpinge 4, 5 and 6 are also registered.

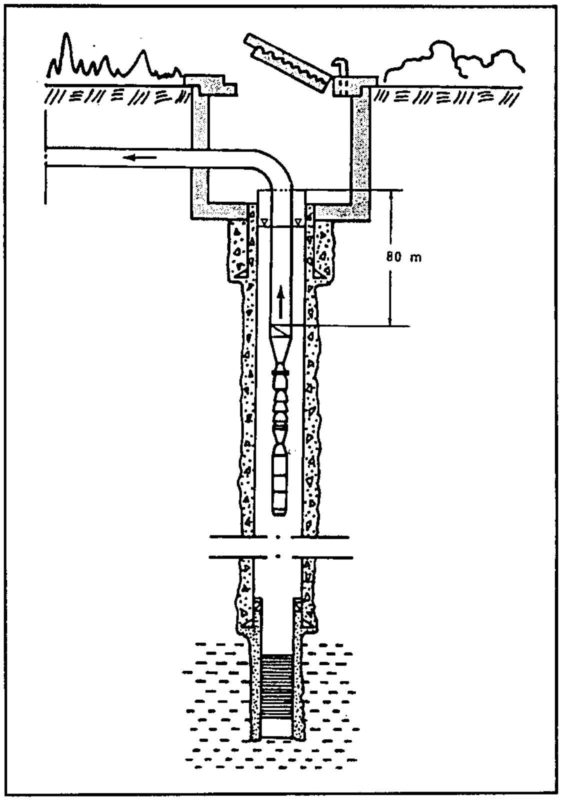

Figure 2. Principal design of a production well.

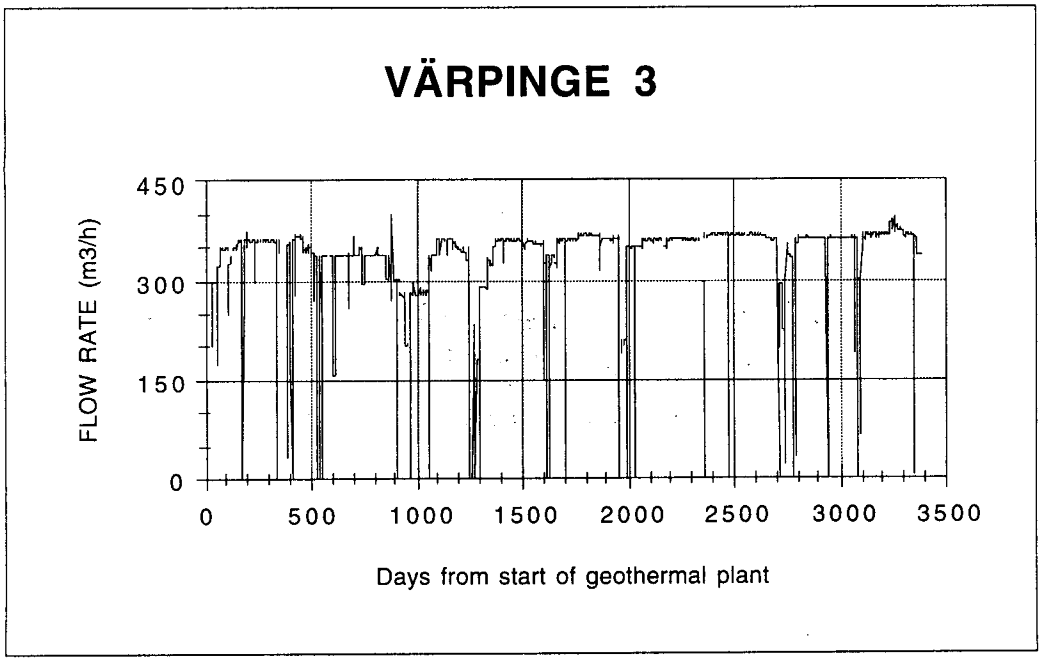

Figure 3. The flow rate of the injection water in the re-injection well Värpinge 3.

PRESSURE BUILD-UP

Figure 3 presents the injection flow rate in one of the re-injection wells, Värpinge 3. For the same well figure 4 shows the injection pressure. By combining the flow rate and injection pressure data, the specific injection capacity for the well, can be calculated according to the following expression.

$$\text{Specific injection capacity} = \frac{Q}{p}$$

where:

Q = flow rate (m^3/h)
p = injection pressure (bar)

The specific injection capacity for the well is shown in figure 5. As can be seen, in the figures, the flow rate is more or less constant, while the injection pressure is fluctuating. Shortly after the start of the plant, a rather rapid increase of the injection pressure was observed in the re-injection well.

Figure 6 shows the injection pressure in the well during the first year. Here the pressure increase can easily be seen. The fast increase of injection pressure was a phenomena that was observed in all re-injection wells. It was concluded that the continuously increasing injection pressure must be due to a change in the gravel pack outside the screens.

The pressure build-up resulted in a reduction of the hydraulic capacity in the wells and after approximately one month the injection was interrupted. This can be seen in figure 5, where the specific injection capacity dropped from a mean value of 120 - 130 at the beginning, to about 60 before the interruption.

In an attempt to rearrange the particles in the gravel pack, a flushing operation was started. Compressed air was connected to the flushing pipe and the well started to produce water. The air lifting of the water reversed the flow direction compared to normal injection. The reversed movement of fluid in the gravel pack rearranged the particles and the hydraulic capacity of the well was restored, as can be seen in figure 5. After the stimulation, the specific injection capacity was increased.

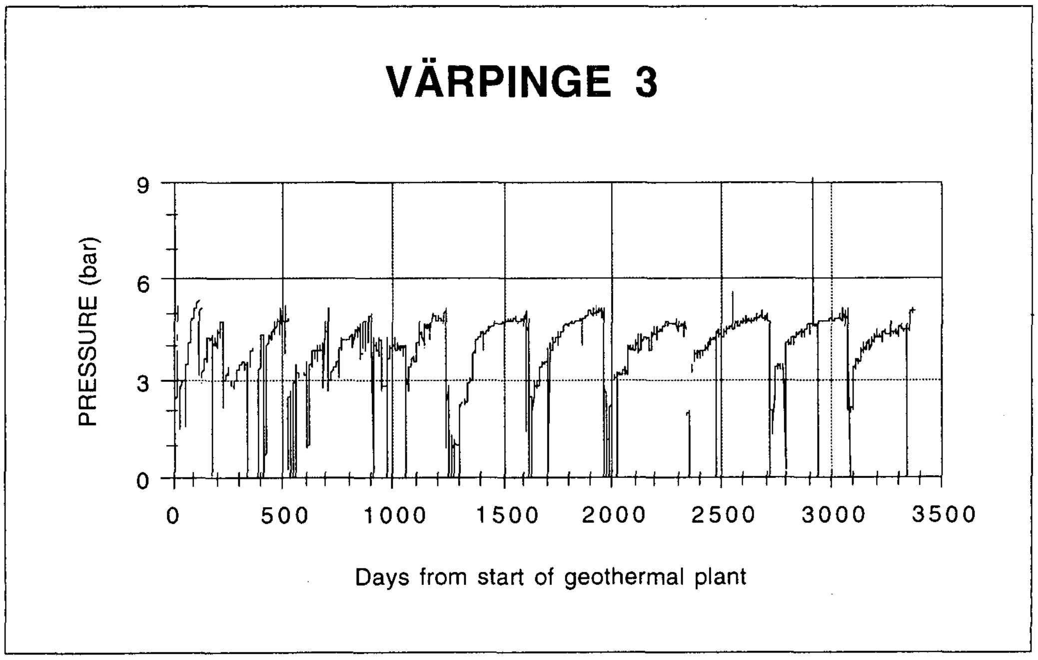

Figure 4. Injection pressure registered in re-injection well Värpinge 3.

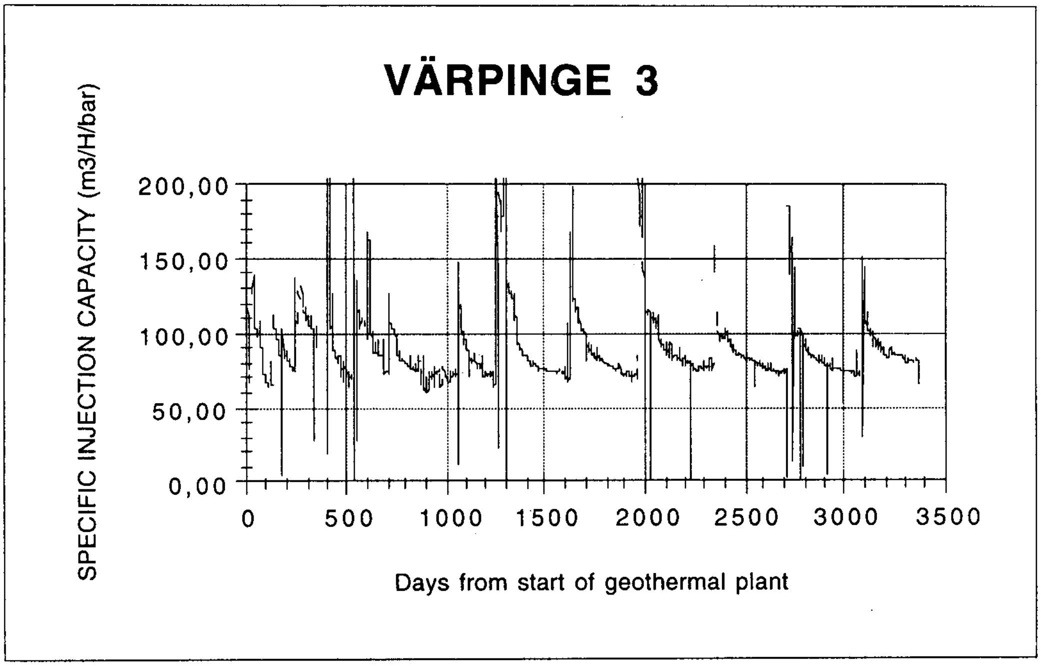

Figure 5. Specific injection capacity of re-injection well Värpinge 3.

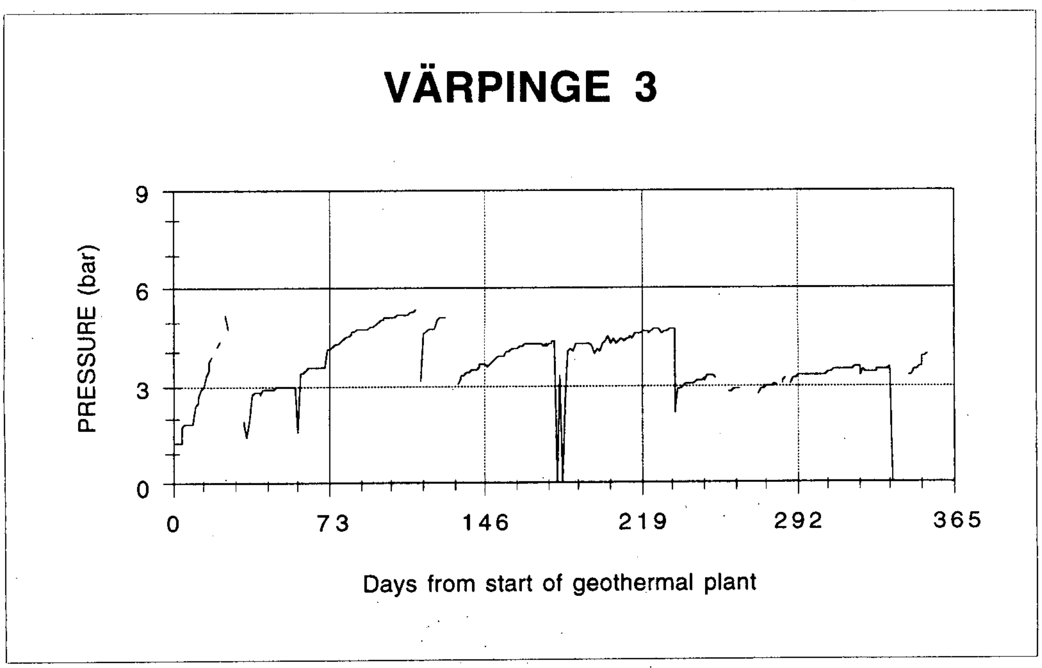

Figure 6. Injection pressure in re-injection well Värpinge 3 recorded during the first year.

During the first years, the flushing operation had to be made a couple of times each year. In figure 6 it can be seen that this was performed 3 times during the first 240 days of operation. In later years this has only been necessary once each year. The gravel pack is now rearranged in a more stable position and the pressure build up takes longer time. See right part of the diagram in figure 4.

Figure 4 shows that the injection pressure after the last stimulation has increased to a lower level than previous times. The specific injection capacity for the well also shows a some what higher value than before (figure 5). As can be seen in the diagram, the behavior of this well is very good. The stimulation of the well does directly increase the specific injection capacity to almost the double, before the capacity starts to decrease. However, the injection capacity never goes below a certain value. This means that over the years the well has not changed its 'over all' injection capacity.

We are now going to look at a well that behaves differently. As mentioned before some of the wells were drilled deviated. This can result in problems with screen and gravel pack installation. The re-injection well Värpinge 6, is one example. It is one of the re-injection well that was drilled in the second stage of the plant. That is the reason for the missing values in the beginning of the following diagrams.

It can be seen in figure 7, that the 'over all' specific injection capacity has decreased over the years. The trend of decreasing injection capacity can be noticed at a very early stage of the life of this well. During the last years it has been more stable and in fact increased a bit. Still the over all capacity value is much lower than for the other re-injection wells. See for instance Värpinge 3, figure 5. Today, the injection capacity value is about 40 compared to 80 for Värpinge 3, if the lowest value is used for Värpinge 3. Even at the start, the specific injection capacity of Värpinge 6 was lower, compared to the rest of the wells. The pressure build-up also differed. No gradual build-up occurred in the well, but the injection pressure increased more or less instantly to a high level.

Notable is also that the stimulation of this well has not the same effect as can be seen in Värpinge 3. After a stimulation in Värpinge 3 the specific injection capacity was almost doubled, but in Värpinge 6 no such effects can be seen.

Although the injection pressure is slightly higher than in the other wells, the pressure is more or less constant, even decreased a little at the end. See figure 8.

Stimulation of Värpinge 6 had no significant effect on the pressure build-up. After a stimulation, the injection pressure increased very rapidly to a high level. To be able to keep the injection pressure at a stable level, the flow rate has to be decreased. Compare the injection flow rate of Värpinge 3 and Värpinge 6, in table 1. In figure 7 it can be seen that it is only during the 3 - 4 latest years, that the decreasing trend has been stopped. It might be that the low flow rate that is maintained at this moment is the highest that can be used in this well.

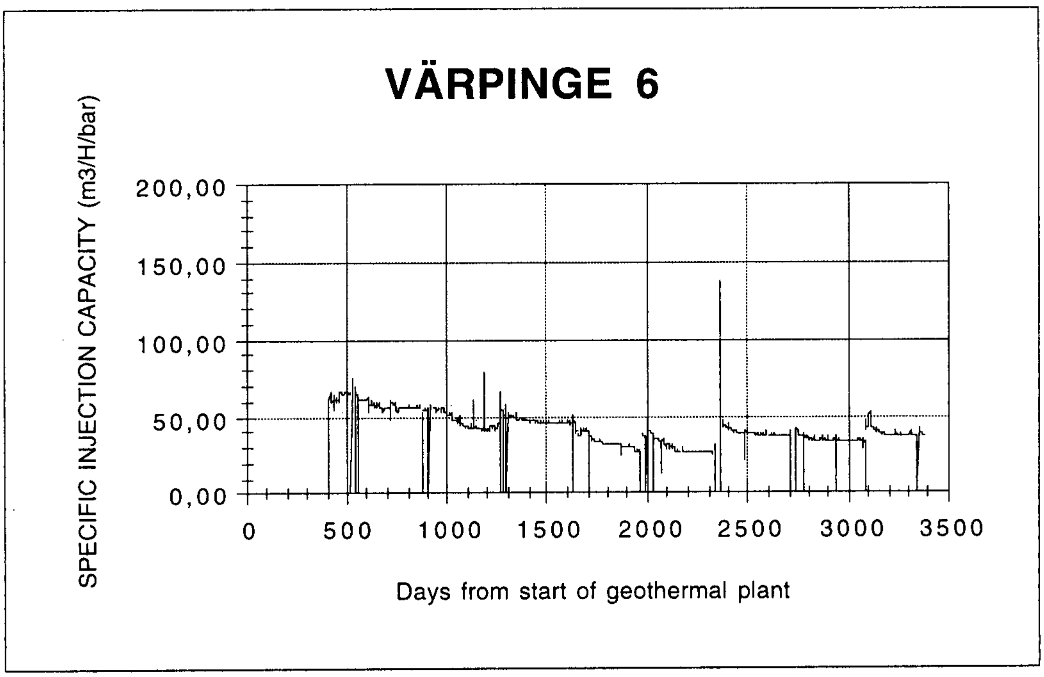

Figure 7. Specific injection capacity of re-injection well Värpinge 6.

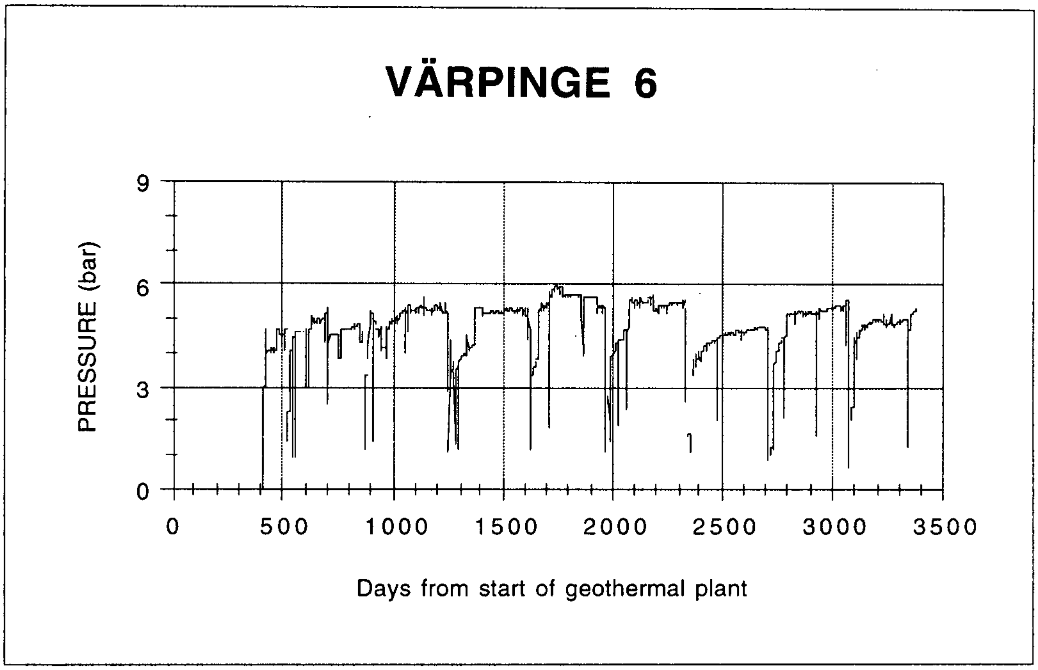

Figure 8. Injection pressure registered in re-injection well Värpinge 6.

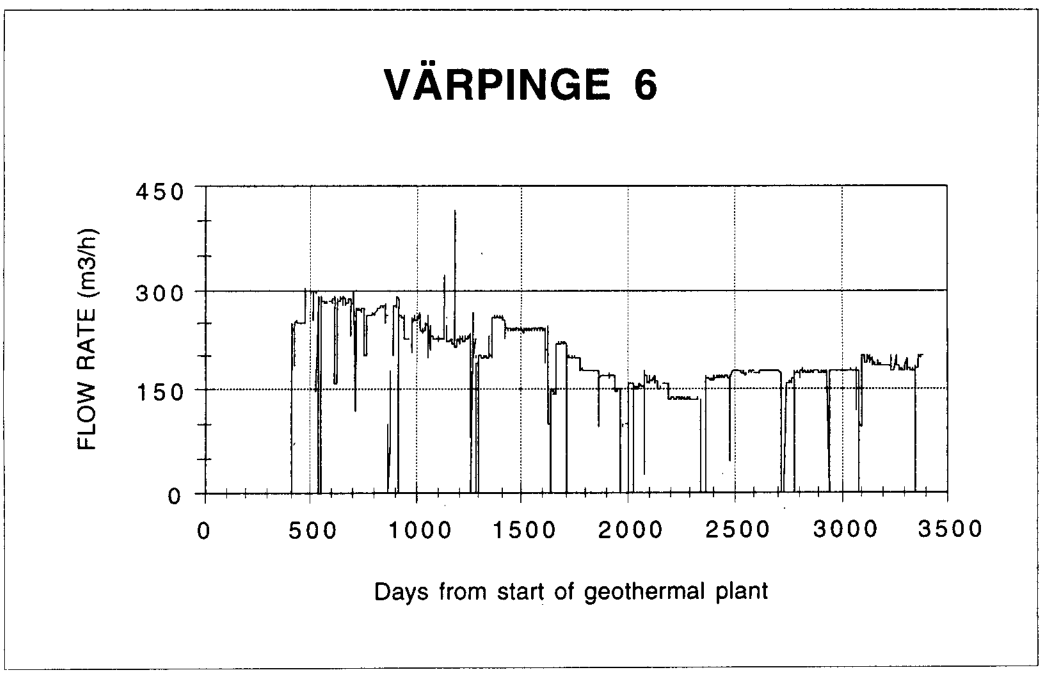

Figure 9. The flow rate of the injection water in the re-injection well Värpinge 6.

Värpinge 6 is the only well in the geothermal plant where the flow rate has to be decreased due to the increasing injection pressure.

CONCLUSIONS

The results from the geothermal field outside Lund shows that in some favourable cases a stimulation of a re-injection well can drastically decrease the injection pressure. It also looks like the stimulation has a longer effect as time goes on. Thus giving a higher specific injection capacity over a longer period of time.

The problem with screen and gavel pack installation in the re-injection well Värpinge 6 has clearly effected the specific injection capacity of that well. Stimulation of the well with reversed flow shows only minor improvement of the capacity. In cases like that, the only solution is often to operate the well with a lower injection flow rate.

Finally, it must be stressed how important it is that the sensors are installed and calibrated correctly. It is especially important with a re calibration if a sensor for some reason has been moved or replaced. If this is not done, unnecessary costly operations can be initiated due to erroneous interpretations of the readings from the sensors.

REFERENCES

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, P-G and Bjelm, L. (1994),
"Geotermisk energiutvinning ur sedimentärt berg. Slutrapportering av NUTEK Projekt nr 656 090-2." Avd för Teknisk Geologi, Lunds Tekniska Högskola.
ISRN:LUTVDG/TVTG -- 3038 -- SE.(In Swedish)

Alm, Per-Gunnar (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.

Lunds Energiverk (1984),
"Geotermi." Information paper. Lund. Sweden (In Swedish)