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GRAVEL PACK MAINTENANCE AND STIMULATION BY AIR LIFTING

Per-Gunnar Alm

Lund University, Engineering Geology, P.O. Box 118, S-22100 Lund, Sweden
Per-Gunnar.Alm@tg.lth.se

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ABSTRACT

This paper presents a case study on reducing pressure build-up in some injection wells in a geothermal heat plant in Sweden. The plant has been in operation for 25 years. Four production wells are used and after heat extraction the geothermal water is re-injected in 5 wells approximately 2 km from the production area. In the injection wells there is a build-up of injection pressure over time and the wells needs a regularly maintenance to reduce the pressure. This is performed by a regular reversal of the flow direction in the gravel and screen section of the wells. The water production during the stimulation is carried out by airlifting.

From the start of the plant in 1984, recordings of production and injection parameters such as pressure, temperature and flow rate has been done daily. Over the years geophysical logging has also been performed in both production and injection wells. Parameters that have been studied are for instance temperature and flow profile along the screen sections etc.

The pressure reduction by stimulating the gravel pack is recorded and the results are also shown by flowmeter logging before and after stimulation.

INTRODUCTION

Back in 1984 the first geothermal heat plant in Sweden, and so far the only existing, was built. After one year the plant was expanded to its present size.

The geothermal heat plant consists of 4 production and 5 injection wells. Heat exchanger is used to transfer heat from the geothermal water to the water in the district heating net in the city of Lund. 2 heat pumps, with a total effect of 47 MW, are used to raise the temperature to a level suitable for the net.

The geothermal reservoir is located in a sandstone formation, with its upper boundary at about 600 m. The wells are drilled to a depth of 650 - 800 m. The geothermal water temperature is about 21 °C and is re-injected to the reservoir at a temperature of 5-7 °C. The total water production rate from the four wells is about 1600 m^3/h.

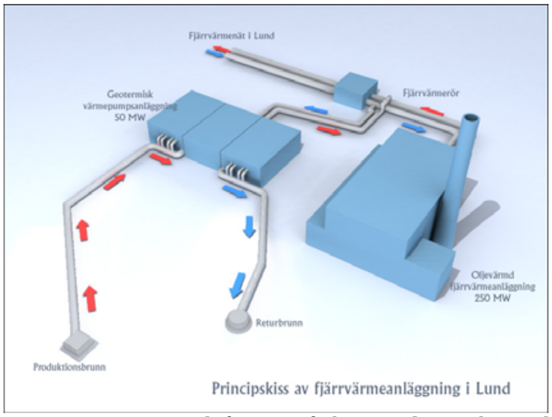

Figure 1: Principal figure of the Lund Geothermal Heat Plant.

Figure 1 shows a principal sketch of the geothermal plant while figure 2 shows the location of the wells just outside the city of Lund. The 4 production wells are located to the far west on the map. The distance between the production area and the injection area is approximately 2 km. The well furthest to the south is one exploration well drilled prior to the plant design.

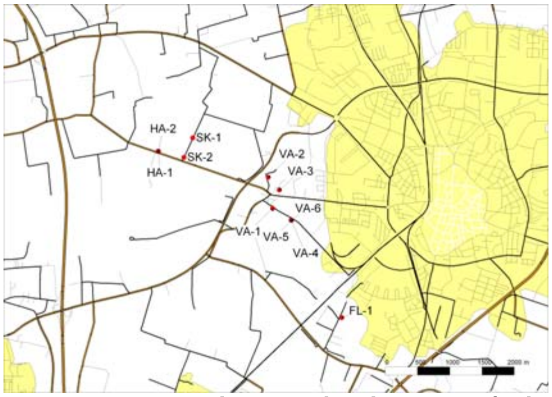

Figure 2: Map showing the location of the geothermal wells outside the city of Lund.

All the wells in the geothermal field are constructed basically the same the only differences are the submersible pumps in the production wells. Figure 3 shows the design of one of the injection wells.

The wells have a surface casing down through the soil layers. Then there is a main casing down to the top of the aquifer. Through the aquifer are installed Johnson filter screens with gravel pack outside. The length of the screened part differs but is in the range of 100 to 150 m. On the top of the wellhead, in the injection wells, a pipe is installed down to approx. 80 m below surface. The pipe is used during stimulation of the well enabling operation without having to uninstall the wellhead itself. The pipe also makes it possible to run geophysical logs in the wells during operation of the plant. By using a seal, where the logging cable run through, on top of the pipe logging can be carried out during injection of geothermal water and with full injection pressure.

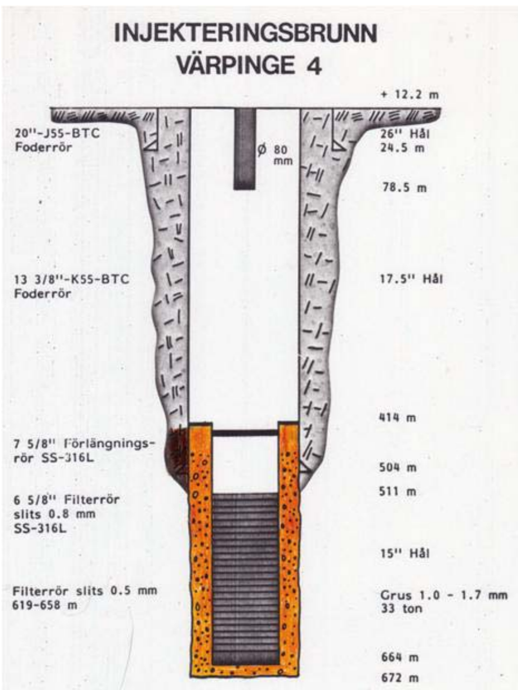

Figure 3: Design of one of the injection wells, Värpinge 4.

FLOWMETER LOGGING

During the lifetime of the plant geophysical logging have been performed regularly. One of all the parameters that have been recorded is the distribution of injection water in the screens of the injection wells. The logging equipment used in the logging operations is manufactured by Robertson Geologging Ltd and consists of a winch with 2000 m cable, a recording unit, a thermal printer and various sonds.

Here will be shown the result from flowmeter measurements in two of the injection well, Värpinge 2 and Värpinge 3. First a presentation of result from one of the regular measurements and then some results in connection with stimulation of the gravel pack surrounding the screens.

In the diagram showing the flowmeter log, figure 4 and 5, the following log curves are shown. To the left of the depth scale are 2 curves, the Natural Gamma Radiation (NGAM) and a curve showing the logging speed (CVEL). To the right of the depth scale is the flowmeter log curve presented as rotation per min (ROTN), i.e. the spinner rotation.
Note that the scale is from 0 to -700 RPM (Rotations per minute). The value -700 is actually positive, the sign is only an indication of rotation direction.

At the time of logging only about 1/3 of normal flow capacity was used. The reason for this was due to uncertainty of the spinner. It hadn't been tested at maximum flow rate before.The same flow rate was used in the two wells in order to get comparable results.

Two different types of zones have been marked in figure 4 and 5. In the case where there is no change in rotation speed (a more or less straight vertical line) the sond is passing in front of an impermeable zone, i.e. no water is entering the formation. The marked zones are all in the screened section of the wells. The curves however also shows values a bit up in the main casing above the screens. Besides the marking of the zones, % lines have been added to the log, 100% at the top of the screen and 0% at the bottom.

The drastic change in rotation speed of the spinner above and below the top of the screens is due to change in diameter. In the main casing as well as in the screens it is possible to discern the joints between each casing and screen section. This can be seen as small spikes on the flowmeter curve.

Värpinge 2

During logging, the flow rate was approximately 100 m^3/h.
On the flowmeter log several sections can be seen were injection water is entering the formation, see figure 4. This is marked with green color and those sections shows a slanting flow curve indicating outflow through the screen..

With a flow rate of approximately 1/3 of full capacity the flow log shows that the best section in the screens is at the top of it. The section is however not very thick only about 3 m. Another section with good injection capacity is between 549-590 m where almost 50% of the total injection takes place.
If the complete screened part of the well is studied the following sections can be discerned:

518-521 m	*out flow*
521-523 m	*no out flow*
523-541 m	*out flow*
541-549 m	*no out flow*
549-562 m	*out flow*
562-571 m	*no out flow*
571-590 m	*out flow*
590-599 m	*no out flow*
599-603 m	*out flow*
603-624 m	*no out flow*
624-634 m	*out flow*
634-636 m	*no out flow*
636-	*out flow*

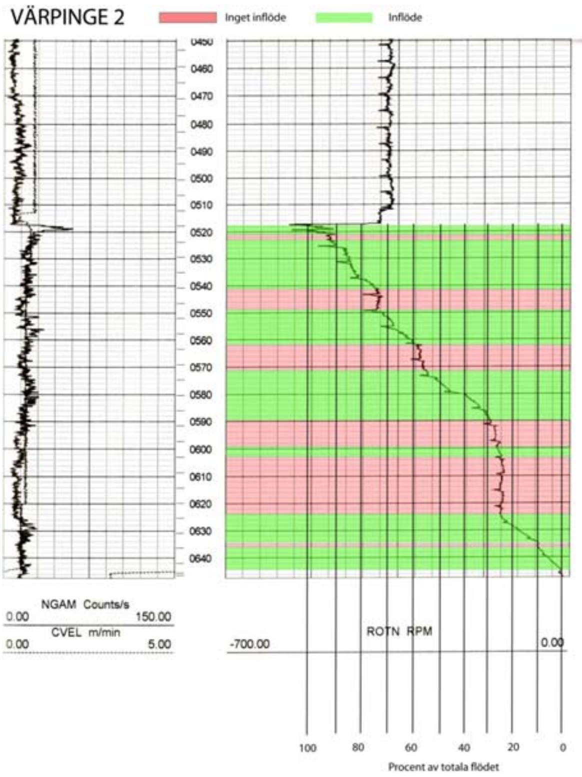

Figure 4: Flowmeter log for Värpinge 2 ran 16/09 2008.

If the outflow through the screen in the injection well, Värpinge 2, is calculated in percentages the result will be as in table 1.

Table 1. Outflow through the screens in Värpinge 2 presented in percentages.

Depth m below reference point	% of total flow	% of total flow / m
518 - 521	8	2.6
523 – 541	18	1.0
549 – 562	19	1.46
572 - 590	28	1.56
599 – 603	2	0.5
624 - 634	15	1.5
636 -	10	1.25

The table shows that the best part is the upper 3 m where there is the greatest outflow calculated per meter. It can also be seen that the upper four zones takes about 75 % of the total outflow.

<u>Värpinge 3</u>

Just like in Värpinge 2 flowmeter logging was done with about 1/3 of full injection capacity. The injection flow rate was 107 m^3/h.

The flow log shows that for this well there are two major intervals and some minor that receive injection water. The injection in Värpinge 3 seems however to be more evenly distributed over the complete screens compared to Värpinge 2. Also the % inflow per meter is more evenly distributed. There is however a part in the middle where the inflow is higher compared to the rest, see Figure 5.

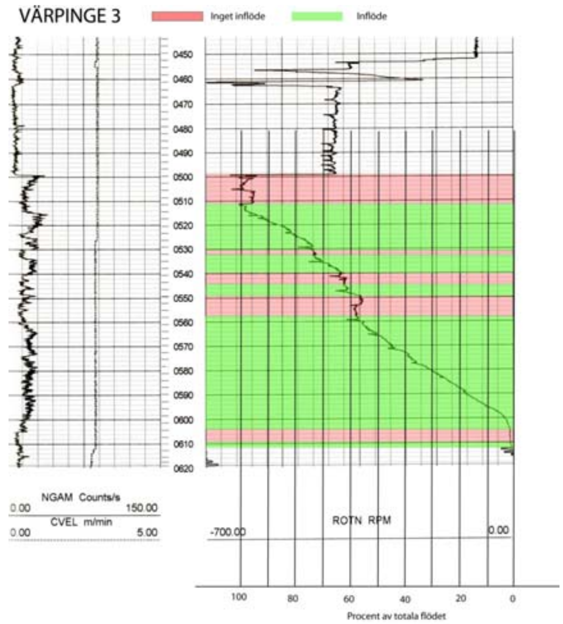

Figure 5: Flowmeter log for Värpinge 3 ran 19/09 2008.

When the complete screened part of the well is studied the following sections of the screen can be distinguished:

499-511 m	*no out flow*
511-530 m	*out flow*
530-532 m	*no out flow*
532-540 m	*out flow*
540-545 m	*no out flow*
545-549 m	*out flow*
549-558 m	*no out flow*
558-604 m	*out flow*
604-609 m	*no out flow*
609-611 m	*out flow*
611-	*uncertain*

If we do a calculation in percentage of the outflow through the screen in, Värpinge 3, the result will be as in table 2.

Here we can se that he last but one zone receives more than 50 % of the total out flow through the total screen. Not surprisingly this is also the thickest of the zones.

Table 2. Outflow through the screens in Värpinge 3 presented in percentages..

Depth m below reference point	% of total flow	% of total flow / m
511 - 530	26	1.37
532 - 540	11	1.38
545 - 549	6	1.5
558 - 604	55	1.2
609 - 611	2	1

PRESSURE BUILD-UP

Since the start of the heat plant a regular change in injection pressure have been noticed in the injection wells as can be seen in figure 6, showing the pressure variation over time in the injection well Värpinge 3. The diagram shows the variation from 1985 until 2009. This phenomenon has also been described in previous articles by Alm (1996 and 1999).

By stimulating the gravel pack in the injection wells it has been possible to control the pressure. After stimulation the pressure immediately drops to a lower level and thereafter starts to build up again. This can also be seen in the figure.

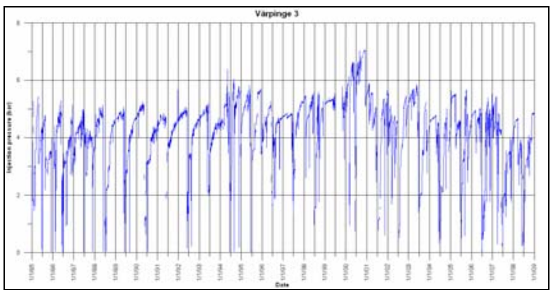

Figure 6: Change of injection pressure in Värpinge 3 since the start of the geothermal heat plant.

In the beginning of the plant the stimulation was carried out once a year but lately this operation has to be made on a regular basis throughout the year.

STIMULATION AND FLOW LOGGING

Stimulation of the gravel pack outside the screen is done by means of airlifting. The previously described pipe on the wellhead is connected to a 20 bar compressor. The produced (airlifted) geothermal water is released to a couple of ponds, thus avoiding the water going in to the heat plant. By vary the flow rate of air and pressure during the stimulation the water is forced to move up and down in the well and thereby also moving fort and back through the screen and gravel pack. Normally the stimulations take about one hour, i.e. until the ponds are full. Often this is done several times during a couple of days.

In order to study the effect of the gravel stimulation flow logging were performed both before and after stimulation. Here will be shown the result from stimulation in the injection wells described before.

Värpinge2

Both before and after the stimulation and flowmeter logging the well pressure was recorded. The injection pressure is registered at the heat plant station but the sensor is located in the wellhead. A pressure of 5.06 bars was recorded 14 June 2009 with a flow rate of 262.04 m^3/h. See also figure 7.

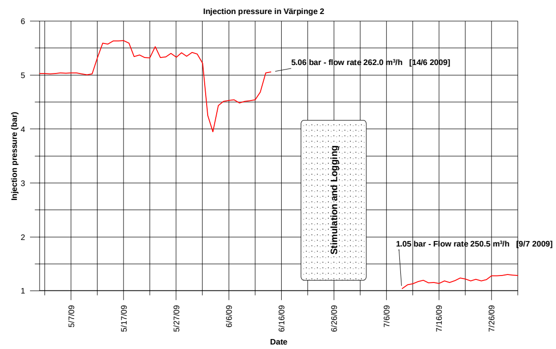

Figure 7: Diagram showing the injection pressure before and after stimulation in the well Värpinge 2.

After stimulation and logging, 9 July 2009, the pressure had decreased to 1.05 bars recorded at a flow rate of 250.47 m^3/h. As can be seen in the figure the stimulation had clearly an effect on the injection pressure but so far no information was available about which part of the 130 m long screen that was affected.

The log curves from the two measurements are presented in the same diagram; figure 8. The red logging curve represents the situation before stimulation and the blue one directly after the stimulation had taken place. Both logs were run at the same flow rate of 101 m^3/h.

The small lateral displacement of the curves above the screens is due to the fact that there is a small difference in flow rate between the two logging runs. As before the connection between the different screen sections can be seen as small spikes on the curves.

To study the influence of the stimulation, the gradient of the log curves has to be studied. The more flat the gradient is the more inflow takes place over that section. And by studying the change in gradient between the two measurement zones that have been afected can be detected.

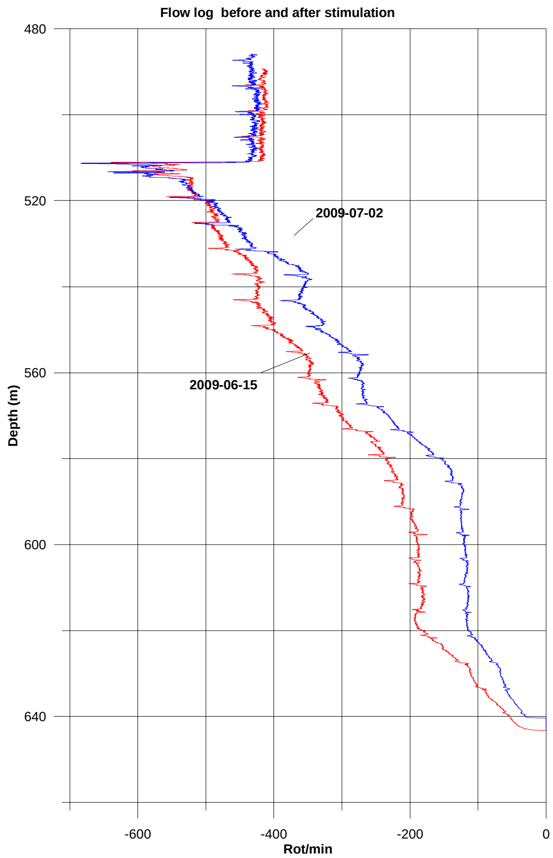

Figure 8: Flow log before and after stimulation recorded in Värpinge 2.

The upper two screens show a significant improvement compared to before stimulation. The gradient of the blue log curve is more flat in this part then on the red one. The next screen seems to have been unaffected since the log curve is almost parallel. The screen section below has been improved.

The screens below 555 m show no major change in the log curves and probably have not been affected by the stimulation.

If the logs in figure 8 are compared with the one in figure 4 it can be seen that there is a vertical displacement between the curves. This is due to a change of depth reference point.
But if only the shape of the curves are compared it can be seen that the second zone (counted from the top of the screens), in figure 4, which didn't had any out flow have been improved by the stimulation.
The other parts that have been affected are within the zone 523-541 m.

Värpinge 3

Just like in Värpinge 2 injection pressure was recorded at wellhead before and after stimulation. The 14 of June 2009, the injection pressure was 4.87 bars with a flow rate of 290.28 m^3/h. After stimulation and flowmeter logging the pressure had dropped to 1.88 bars at a flow rate of 250.66 m^3/h recorded the 9 of July 2009. See also figure 9.

The flowmeter logging, before stimulation, in Värpinge 3 was carried out with an injection flow rate of approx. 100 m^3/h. Approximately the same flow rate was used during logging after the stimulation.

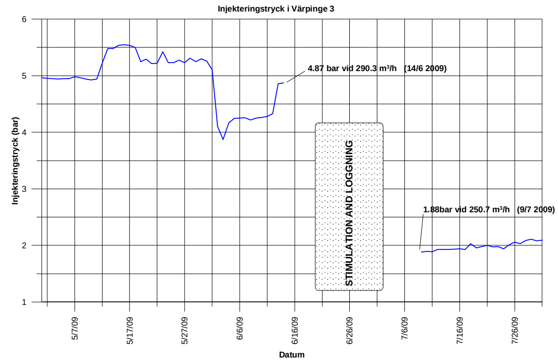

Figure 9: Diagram showing the injection pressure before and after stimulation in the well Värpinge 2.

Like in the case of Värpinge 2, the red logging curve represents the situation before stimulation and the blue one directly after the stimulation had finished.

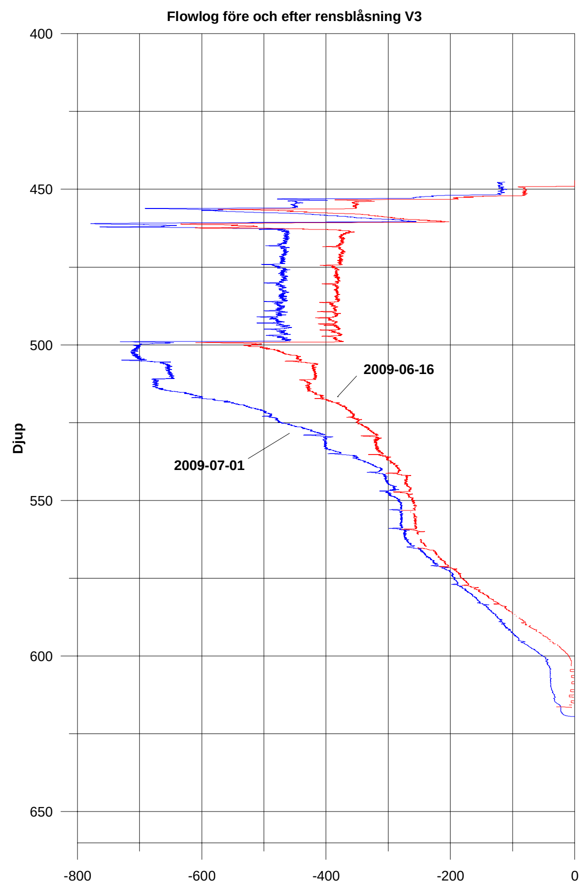

Figure 10 Flow log before and after stimulation recorded in Värpinge 3

The lateral displacement of the curves is just like in the case of Värpinge 2 due to difference in flow rate but in this case there is an additional displacement because the logging after stimulation was carried out in opposite direction compared to before stimulation.

When logging is done in the up direction there is an addition to the rotation speed. The speed of the sond going up gives an additional speed to the spinner and a reduction going down. Naturally the opposite would occur if instead of an injection a production takes place.

This additional effect on the rotation speed can also be seen if the figure 8 and 10 are compared. The blue curve in Värpinge 3 records generally a much higher speed after stimulation compared to Värpinge 2 where the logs have been ran in the same direction.

The stimulation seems to have had a negative influence on the top screen (starting at 500 m) since there is no out flow compared to before stimulation. The following 1 and a half screens haven't been affected. On the other hand the following 2 and a half screen show a significant improvement.
The next screen is unaffected, but the next 2 have been improved, the lowest however only to a small amount. Like in Värpinge 2 the screens in the lower part of the well doesn't show any improvement by the stimulation. This can be seen below 550 m were there isn't much change in gradient of the curve.

Comparing figure 10 and figure 5 shows that the parts of the gravel pack that have been affected all lays within the three upper zones with an out flow (figure 5).

CONCLUSIONS

By stimulating the gravel pack a reduction of injection pressure can be obtained. The figures showing the pressure situation at well head before and after stimulation clearly show this.

Flowmeter logging can be used to receive information on how much and which part of the gravel packed section that is affected by stimulation.

For the two injection wells in Lund, where the joints between the different screens are visible, it is actually possible to see how individual screens and gravel pack are affected by the stimulation.
With the used flow rate, about 1/3 of full capacity, it can be seen that it is mostly the upper part of the screened interval (some 45-50 m) that has gained by the gravel pack stimulation.

If logging with full injection capacity had shown that other parts of the screen further down also been affected by the stimulation is unclear. This is one thing that will be studied in connection with future stimulation of the wells.

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