Proceedings World Geothermal Congress 2010
Bali, Indonesia, 25-29 April 2010

Reservoir Cooling After 25 Years of Heat Production in the Lund Geothermal Heat Pump Project

Leif Bjelm and Per-Gunnar Alm

Engineering Geology, Lund University, PO Box 118, S-221 00 Lund, Sweden

Leif.Bjelm@tg.lth.se, Per-Gunnar.Alm@tg.lth.se

Keywords: Reservoir cooling, long term thermal development, direct use, logging, reflection seismic interpretation

ABSTRACT

After 25 years of heat extraction and reinjection of cold water to the reservoir the expected cooling is now at hand. About 550 l/s is extracted from 4 wells and subsequently reinjected into 5 wells. Yearly about 250 GWh of heat energy is produced to the district heating net. The distance between the production and injection areas is about 2 km.

The reservoir is an unconsolidated sandstone of Cretaceous age. It is a confined reservoir with a thickness of several hundred meters. The deposit is part of a complex delta formation sitting close to a major tectonic feature, which was active while sedimentation was going on.

The last few years repeated temperature and flowmeter logging has been carried out in the wells in order to evaluate the distribution of cold water within the reservoir. The cold water migration seems to follow certain layers within the delta deposit. A high-resolution reflection seismic campaign has recently been carried out and it is now possible to compare the layering revealed by seismic data and thermal layering determined by borehole logging. Also the thermo-hydraulic development after 25 years of use of the reservoir is discussed.

1. BACKGROUND

In Scania the southernmost province in Sweden, Figure 1, the thickest sedimentary deposits in Sweden are at hand. Except for the upper part of Palaeozoicum the sequence from Cambrium to Quaternary is rather complete.

Extensive exploration efforts for oil and gas, some 40 years ago, brought about geological data from more than 15 deep exploration wells. There is also data from about a couple of thousand kilometres of reflection seismic investigations. Based on this data the geothermal potential in sedimentary deposits was concluded by Engineering Geology in a series reports from 1977 to 1979.

Typically the resources occur as geothermal brines in sandstones of different ages. Reservoirs occur from about 550 m to about 2500 m of depth and the temperature range is from 20 °C to 85 °C. Six different geological formations have been identified as good geothermal reservoirs. A summary report was presented in 1995, Alm and Bjelm, (1995). At the deepest levels the total salt content can exceed 20%.

In 1978 attempts were made in Höllviken, southern Scania by VIAK AB, to use 65 °C geothermal water from a Triassic sandstone at about 1900 m depth. However the fairly low water productivity could not convince the community to use the resource for local district heating.

Figure 1: Sweden with Scania and Lund.

Then in 1980 Engineering Geology carried out a new exploration drilling in Landskrona, western Scania. The well was drilled as a combination of drilling equipment testing and geothermal exploration. The final depth was reached at around 1100 m revealing a very thick sequence, several hundred metres, of rather unconsolidated sandstones belonging to Campan of Upper Cretaceous age. The slim hole exploration well was not possible to test pump and the local energy company was not willing to release funding for drilling a proper test well. However the exploration drilling proved that very porous and thick sandstones occur at a certain distance southwest from the Romele horst dislocation zone. By means of extrapolating that finding some 15 km south-eastwards to the Lund area a similar reservoir situation should be at hand.

This geological concept was the base for the exploration drillings that started in Lund 1982. With some support from a couple of old seismic lines and nearby oil exploration wells two locations for geothermal exploration drilling were selected. The exploration programme was run in cooperation between Engineering Geology, Governmental energy research funds, Lund Energy Company and Atlas Copco. Late 1983 two test wells were completed and test pumped proving very favourable water production properties. As anticipated, the Campan sandstone was the formation at hand occurring from about 500 to at least 800 m of depth (Figure 5). In the reservoir the temperature is around 22 to 24 °C, a total salt content of about 6% and a productivity > 125 l/s at a drawdown of only 30-35 m. In other words those were the input parameters to the heat pump manufacturer, ASEA STAL, whom was asked to design the geothermal heat pump plant, Bjelm and Schärnell (1983). Late 1983 the Lund Energy Company and the Community Board decided to build the plant upon our proposal. In 1984 two production wells and two injection wells were drilled, completed and tested and the first heat pump was installed and connected late 1984. This was Phase 1 and during 1985 another two production wells and three injection wells were completed. With the installation of heat pump number two, Phase 2 was finished and Lund had a 45 MWt geothermal heat pump plant in operation at that time delivering about 40% of the district heating demand, about 350 GWh. The plant has been in operation since then and stands today for about 25% of the district heating demand.

2. GEOLOGICAL AND THERMOHYDRAULIC DESIGN CRITERIA

When geological and hydraulic data was at hand from the two exploration wells the first numeric thermohydraulic analyses were carried out. One objective was to determine the minimum distance between production wells and injection wells. The energy company requested stable temperature lifetime for about 20 years. Around 2 °C of temperature decline could be accepted after 20 years. Three cases were studied 1+1, 2+2 and 6+6 wells, Bjelm et al. (1983). The distance between each central point was set to 800, 1200 and 2000 m respectively. The first thermal response in the numeric model is seen after 10 years for those distances and after 20 years the production temperature has declined 1-2 °C which was according to the energy company request. Input for the numeric analyses were the following: reservoir thickness 150 m, top of reservoir at 550 m depth, production temperature 25 °C and reinjection temperature 5 °C. Flow rate was set to 100 l/s for each production well and all was to be reinjected. When the final well distribution was determined in 1984 and 1985 the selection became 4+5 wells and the distance between central points became around 2000 m, Figure 2. Production flow has since start been around 125 l/s per production well.

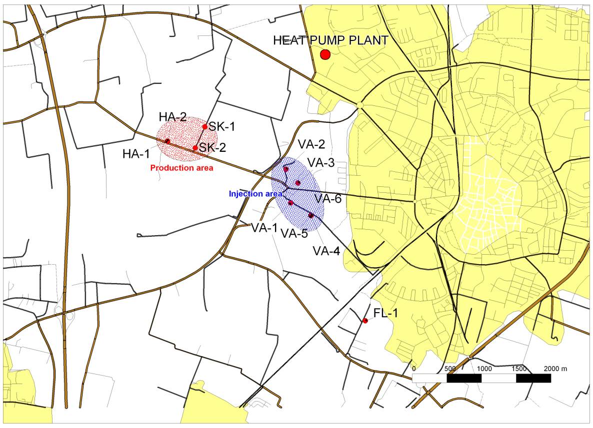

Figure 2: Map showing the location of the geothermal wells west of Lund.

3. RESERVOIR PROPERTIES, HYDRAULIC AND THERMAL RESPONSE

Cuttings exist from all wells and quite complete borehole loggings have been carried out in each well before and after well completion. Since the mid-1990s Engineering Geology has carried out borehole measurements such as temperature, gamma ray, calliper and lately also spinner flowmeter measurements in most of the wells. The main reason for this has been to follow the temperature development, the gravel pack condition and the well integrity.

Typical for the reservoir is its loosely deposited well-sorted sandstones, commonly with a medium grain size distribution. There is a well-developed stratification in the reservoir where siltstones and sometimes clay stones occur. From a geological point of view the reservoir is part of a delta deposit developed whilst there was tectonic activity in the nearby vicinity only a few kilometres to the northeast. The deposit belongs to Upper Cretaceous and the total thickness of the stratified sandstone sequence, Campan, is not penetrated at the site but can be as thick as 300 m. In case there will be more wells drilled within the project the aim is to determine the thickness of the sandy part.

Top of reservoir is at about 420 m depth in the injection area and around 560 m in the production area, Figure 2. The screened part of the wells commonly starts about 75 m below the top of the reservoir and is around 100 m long. An interpretation of a reflection seismic section, Line LUN002 in Figure 3, shows the geological setting and how layering has been influenced by tectonic movements (Figure 4).

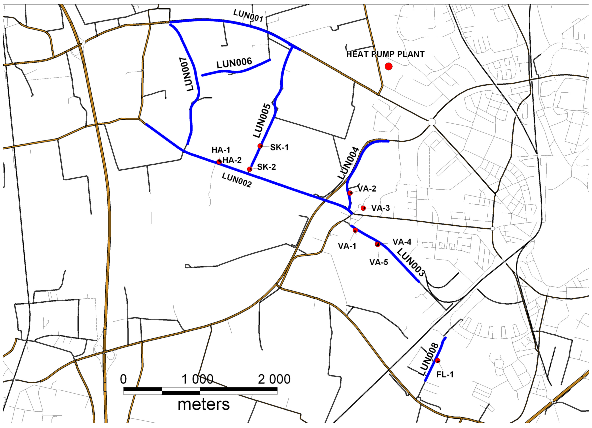

Figure 3: Map showing the location of the reflection seismic lines, west of Lund.

In 2008 a reflection seismic campaign was carried out in order to better understand the geologic conditions in the Lund geothermal field and eight lines were run, Figure 3, Bjelm and Alm (2009). In Figure 5 the well screens are indicated for three wells and the reflectors representing correlated layers are shown as markers. Inserted in the figure are also graphs showing the borehole temperature recorded 2007 and 2008. Ha-1 and H-2 wells and the Sk-2 well to the west in the section show how the cooling had progressed at that time. The Vä-2 well to the east is the injection well closest to the production wells.

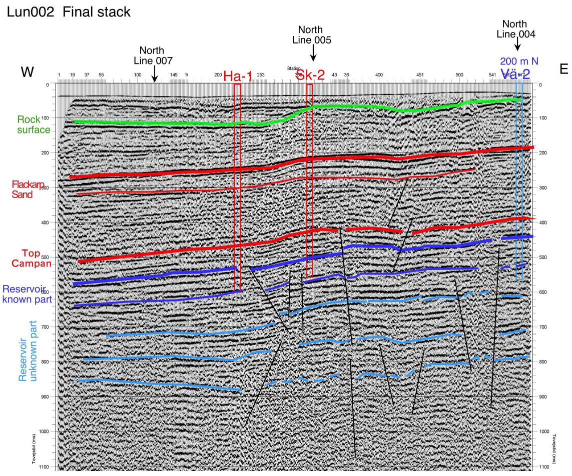

Figure 4: Interpretation of seismic line LUN002.

The initial temperature at start of operation 1985/86 was around 21-22 °C. A little more than 20 years later, 2007 and 2008, the temperature in Sk-2 had gone down to 13 °C in the upper part of the screened section but still around 16 °C in the lower part, Figure 5. The Ha-wells are about 500 m further away from the injection wells and consequently show much less temperature drop but at least one of the wells show an impact > 2 °C. An enlargement of Sk-2 is illustrated by Figure 6, showing how different the cooling has extended and developed in the reservoir due to layering and grain size distribution governing permeability properties.

For comparison the production temperature for all wells from start of operation in 1985 is shown in Figure 7. Sk-2 is closest to the injection wells Vä-2 and Vä-3 and as can be seen by the production temperature logs in Figure 7 there is a temperature impact in Sk-2 already after about 11 years. This is very much in accordance with the numeric pre-project modelling. The actual production temperature drop as per 2009 is however around 6 °C which is more than forecasted by earlier modelling. However this is explained by the fact that the distance to the two closest injection wells are only about 1400 m, which is less than the numeric modelling assumed.

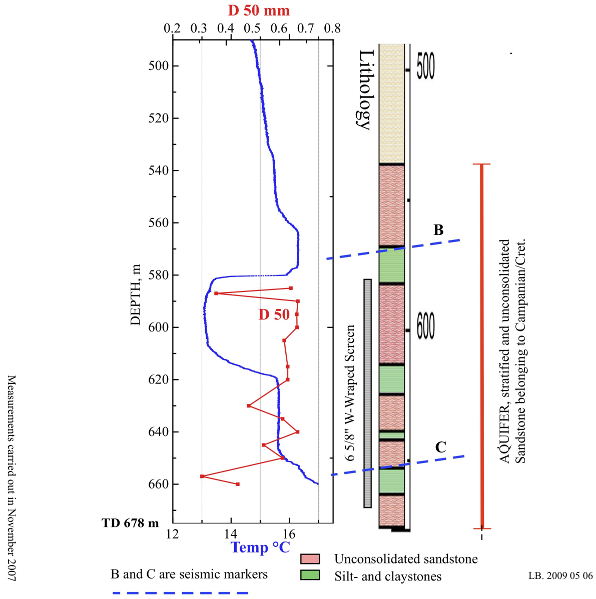

Figure 6: Enlargement of parts of well Sk-2, production well. Temperature status 2007, D50 grain size, layering and seismic markers.

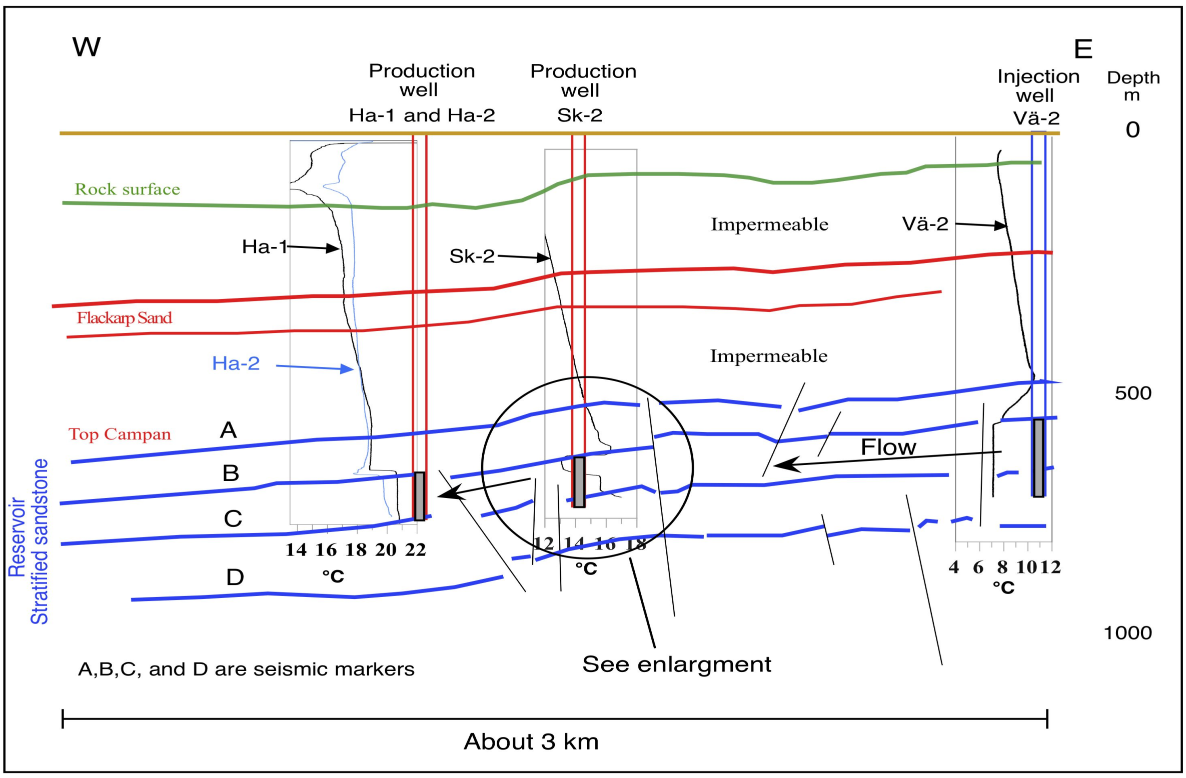

Figure 5: Section along seismic line LUN002. Included are screen positions, temperature logs and main geological markers.

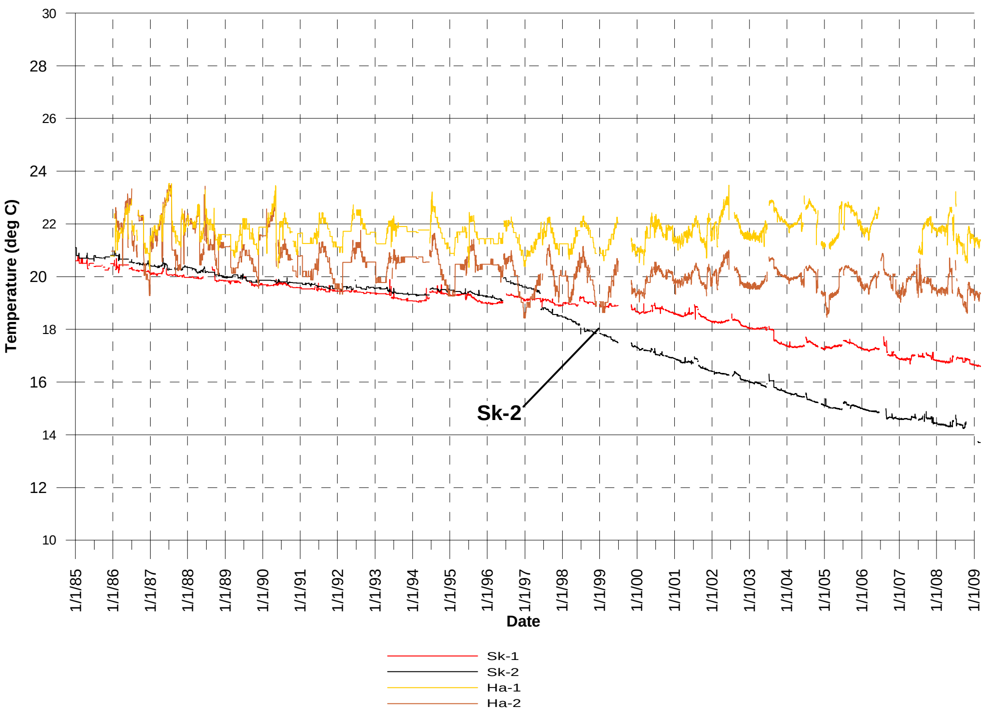

Figure 7: Production temperature for the wells since start of operation.

This provides a possibility to roughly estimate the velocity of the cooling expansion between Vä-2 and Sk-2. Distance is about 1400 m and time is 11 years. This gives, roughly, a velocity of 0.35 m/d or 4 x 10^{-6} m/s for the “cold front” movement. About 100 to 1000 times slower than the hydraulic conductivity in the reservoir. In reality it is a little more complicated but as an estimate based on a real case this is of practical interest.

It was not always possible to site the wells in accordance with the numeric modelling criteria. Farming, roads, power lines and buildings had also to be regarded.

4. WELL-DEVELOPMENT AND REHABILITATION

In the Lund geothermal reservoir all nine wells put into operation 1985-86 are still in use. Five are for injection and the rest for production of geothermal water. All wells are completed as gravel packed wire wrapped screened wells. The uniformity coefficient Cu value (d60/d10) of the formation sand is most commonly right below 2.5 and therefore the gravel packing completion was chosen. A 6 5/8” OD Johnson screen with a total length of around 100 m have been installed in most of the wells. Typical production rate is 100-125 l/s per well and all water is reinjected to the reservoir as the fluid has a salt content of around 6% making it impossible to be disposed elsewhere. Also, of course, thereby maintaining the reservoir pressure. The production temperature today, depending on from which well it comes, is from a little more than 14 °C to around 21 °C, see also Figure 7. Injection temperature is around 3.5 to 5 °C.

Injection pressure varies a little from well to well but generally increases as the production year proceeds. It varies from 4 bar to as much as 8 bar during a year. The difference from well to well is related to natural variations in geological conditions such as layering and formation particle grain size distribution. Some differences can also be related to how the well completion succeeded. The general increase in injection pressure during a typical production year has been the case from the very first years. It was anticipated and therefore all injection wells have pre-installed tubing from wellhead and some 80 m down the well casing. It was installed for airlifting the wells regularly as a means of rehabilitation if particle clogging should occur and to stimulate and repack the gravel pack if needed. Clogging has not occurred but repacking of the gravel pack by means of airlifting is taking place several times a year. Commonly the airlifting is mobilized when too high injection pressure so demands or in conjunction with general well maintenance work. The air-lift operation takes about one day per well to carry out.

5. PRODUCTION AND PERFORMANCE

Being a commercial operation, matters like availability and productivity are main issues. The geothermal plant has been successful in both aspects. Availability has been around or above 95% and energy delivery has met demands and expectations. However continuously tapping the stored geothermal heat energy eventually comes to a point where reservoir cooling is a fact. Such a development was indeed expected and taken into consideration at the beginning of the project. Thermohydraulic modelling gave basis for lifetime expectances, which more or less have been confirmed by the operation. Well or rather screen gravel pack stimulation with airlifting has become more common than expected but takes away only small amounts of production time. So altogether, cooling is the matter to consider and with fixed well positions there is only one thing to do if you want to maintain the production – drill more wells further away from the cooling area. Today one of the production wells is of special interest, Sk-2, as it has depleted rather significantly (Figure 7). The rest are not that affected yet but the cooling development is definitely around the corner.

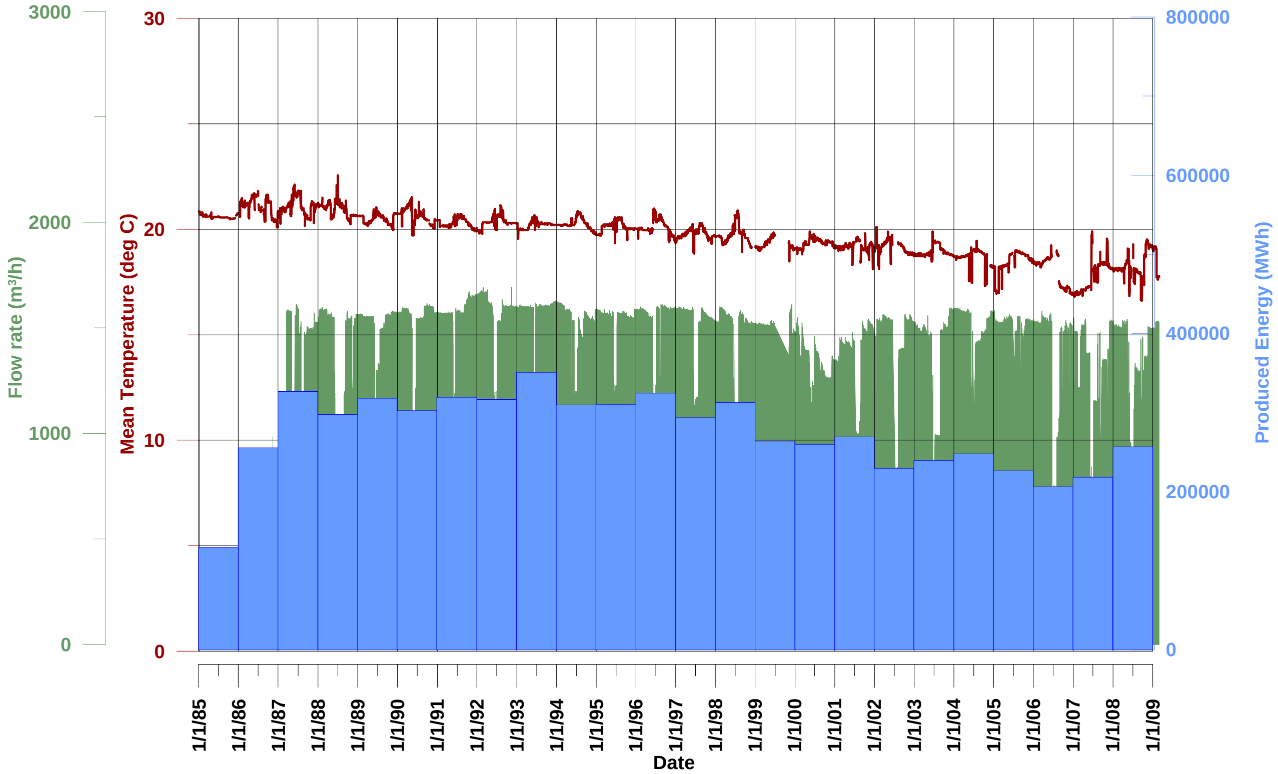

Figure 8: Relation between water production, mean water temperature and total energy production.

In order to show the geothermal plants production history a combined graph has been elaborated. In Figure 8 the relation between energy production, geothermal water production and mean temperature from start of operation in 1985 till 2009 is shown. The data represent all wells and heat pumps. Looking at the mean temperature development for all the four production wells the temperature drop is 2-3 °C. The energy production is going down somewhat as there is a temperature decline and a slight depletion in water extraction. But the change in energy production is also related to the fact that the Energy Company has introduced other energy sources for heat production than geothermal energy. The yearly heat energy production from geothermal energy is today about 250 GWh and the total heat energy production in the district heating net is 1000 GWh.

6. CONCLUSION

The Lund geothermal heat pump plant is a proof of how useful a geothermal resource can be when geological and technical energy production properties are complimentary. A large and already existing district heating net was a fundamental prerequisite giving the geothermal energy an opportunity to deliver the annual base load in the system. A very high availability and proven technology has rendered the owner a reliable energy production system based on shallow geothermal energy. The investment, around 110 MSEK in 1985, has most certainly been paid back several times. There is also a major environmental gain in replacing fossil fuel and cutting gas emissions significantly.

REFERENCES

Alm, Per-Gunnar and Bjelm, Leif: Geothermal Energy in Sweden, *Report*, Department of Engineering Geology, Lund Institute of Technology / Lund University, Sweden (1995).

Bjelm, L., Bennet, J., Claesson, J. and Hellström, G.: Unpublished internal reports. (1983)

Bjelm, Leif and Schärnell, Lennart: Large heat pump plants for district heating utilizing geothermal energy. Lund Institute of Technology, Dept. of Engineering Geology and Stal Laval Turbin AB, Finspong. International symposium on Geothermal Energy. Portland, USA. (1983).

Bjelm, Leif and Alm, Per-Gunnar: Reflektionsseismisk undersökning väster om Lund, Report, Department of Engineering Geology, Lund Institute of Technology / Lund University, Sweden (2009).