Long-term experience from a heatpump plant in Lund, Sweden, using a low-temperature geothermal aquifer

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ABSTRACT

All heat from the heat pumps is supplied to the district heating network for the town of Lund. The plant is operating at base load and covers almost 50% of the total heat demand, equal to 300 GWh/a. Experiences of the operation of the heat pump plant will be reported. Due to environmental reasons the cooling media of the two heat pumps will be changed from R500 to R134A in 1994 and 1995 respectively. The anticipated results of the conversion will also be presented in the paper.

In late 1984 the first heat pump unit was connected to the geothermal wells and about one year later another heat pump unit was connected. In total 9 wells to about 700 meters of depth were drilled and completed **as** huge groundwater wells. Four wells are dedicated for production and the rest for injection. The water production capacity from the wells is 100 - 140 l/sec and the reservoir temperature was initially about 22 - 23°C. The total thermal output from the heat pump units is 47 MW (Bjelm *et al.* 1984).

The reservoir rock belongs to Campanian of Cretaceous age and is a rather homogeneous calcareous sandstone. Thorough hydraulic, thermal and chemical investigations were carried out during **a** full scale study where well materials and final well construction was defined. The subsurface reservoir reactions have been monitored since start-up and some results are discussed in the article. Furthermore, certain well and filter behaviours and reservoir technological experiences are presented.

Key words: district heating, heat pump, Sweden

1. INTRODUCTION

Lunds Energi AB is a municipally owned company distributing electricity and natural gas. It also produces and distributes district heating for the town of Lund and its vicinity. The municipality of Lund has about 90 000 inhabitants of which 75% live in the town of Lund. The town is well known for its old university and is today also a centre for a number of major industries such **as** packing, pharmaceutical articles and medical equipment and heat exchanger, to mention some.

The introduction of district heating in Lund goes back to the early 1960s. The main reason for the municipality to be involved in this activity was to offer heat at **a** reasonable price and simultaneously to improve the local air quality. At the same time a better fuel economy and a combined heat and power production could be obtained. The district heating system was expanded quite fast and covers today about 80% of the heat demand of the town. Low heat density areas with single family houses are today mainly heated by natural gas, also supplied by Lunds Energi AB. The energy demand of the district heating system is now almost constant from one year to another. Energy conservation in existing buildings can compensate for the expansion of the system at least for another decade.

2. HISTORICAL BACKGROUND

Information from the Department of Engineering Geology at Lund University of Technology started the development work. A feasibility study on the possibilities of using geothermal energy for the production of district heating started in 1983.

Temperature requirements for base load of the district heating system is 80-85°C. An optimisation study showed that it would not be economic to drill deeper to find higher temperatures for the geothermal energy. Instead the optimal system would include the installation of heat pumps for lifting the low temperature to the required level. (Lund University of Technology and others 1982-84)

The ambition to supply heat to the subscribers at lowest possible cost was the main reason for the geothermal project. Just as important was the objective to reduce oil dependency and to decrease sulphur and nitrogen oxide emissions. The project was also influenced by the success of large heat pumps that occurred in Sweden during the early 1980s.

In 1984 the first stage of a full scale geothermal project started. Two production wells and two injection wells were drilled down to a depth of 600 - 700 meters. A heat pump plant with a thermal capacity of 20 MW was built and taken into operation in December 1984.

Evaluation of the project during 1985 showed that the installations fulfilled the requirements and in many ways exceeded expectations. Later the same year the next stage was initiated. This included another two production wells and three injection wells.

Simultaneously a second heat pump was installed with a capacity of 27 MW. This second unit was commissioned in March 1986.

After eight years of successful operation it was decided in 1993 to change the cooling media of the heat pumps from R500 to the more environmentally friendly R134A. This conversion is carried out because it has been found that leakage of R500 influences the properties of the ozone layer in the atmosphere. National restrictions have been implemented regarding the use of the old type of cooling media. The change to the new cooling media also includes reconstruction of the heat pump, especially the compressors. Conversion of the two machines will be made in the summer of 1994 and 1995 respectively.

3. HYDROGEOLOGICAL AND GEOTHERMAL BACKGROUND

The Department of Engineering Geology at Lund University of Technology carried out all preinvestigations for the project. These were conducted during 1983 and 1984 when two preinvestigation wells were drilled and tested by means of, among other tasks, test pumping, chemical tests and corrosion studies.

The wells penetrated the so called Campanian sandstone of Cretaceous age at depths between 600 - 800 metres below surface. The sands contain a major confined aquifer which is some 5 - 7 km wide and the length is at least 100 km. The water has a TDS of around 6000 ppm. The main constituents are sodium and potassium chlorides and the content of iron is quite high, about 60-70 ppm. At rest the aquifer pressure level is at ground level or in some areas slightly above.

The sands are rather coarse grained, well sorted and virtually without cementation. The permeability is therefore very good. The initial temperature was around 23°C.

The test pumpings revealed **a** transmissivity of 3-5 x 10^{-3} m^2/sec. As an example, when producing around 100 l/sec, the drawdown in a production well is only around 35 metres. The testpumpings could also confirm that it would be possible, from a sustainable point of view, to take out more than 100 litres per second per well. With an estimated temperature drop of about 18°C over the heat pumps, the energy requirement set by the community could be met.

For the first plant four wells, two for production and two for injection, were recommended. On basis of the preinvestigations it was concluded that more than 20 MW per well couple can be extracted. In this case a temperature lowering of 18°C and a flow of about 110 - 120 litres/second was assumed.

Today, 1994, almost ten years after the first plant was set in operation the wells and the aquifer have behaved completely according to assumptions. A slight temperature decrease of maybe 1-2°C has occurred and the drawdown in the vicinity of the wells varies during the year due to different seasonal loads. As the water is reinjected a couple of kilometres away there is no depletion of water.

In spite of the fact that about 500 litres/second is reinjected there has been no sign what so ever of particle clogging. The wells are obviously successfully constructed.

The yearly stimulation is a maintenance effort introduced in order to "repack" the gravel pack that surrounds all the well filters. The injection pressure increase after one season of injection is about *6* bar. After the stimulation the injection pressure drops to about 3,5 bar. The seasonal injection pressure changes are shown in Figure 1. The stimulation procedure is very simple. It is performed by means of a common air lift operation for a couple of hours once a year. Only the injection wells are stimulated and no particles are removed during the airlift operation. The change in pressure is believed to occur because of change in gravel packing porosity due to dilatant grain processes.

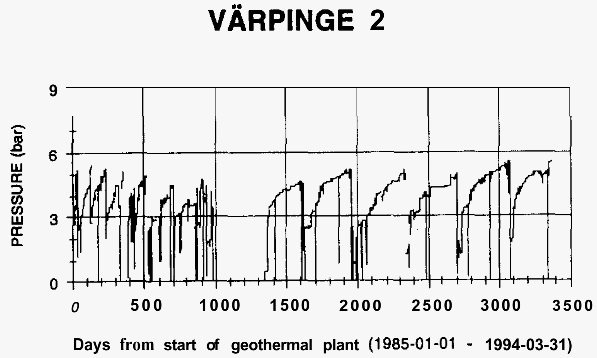
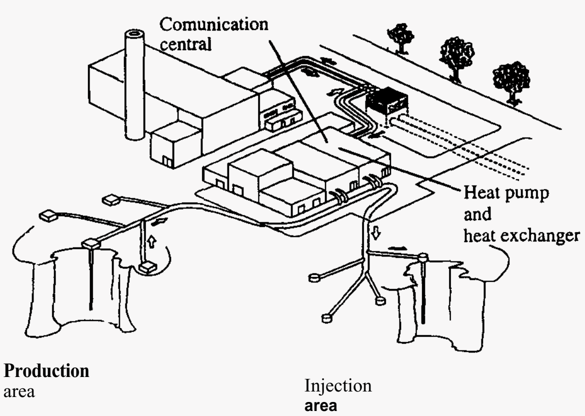


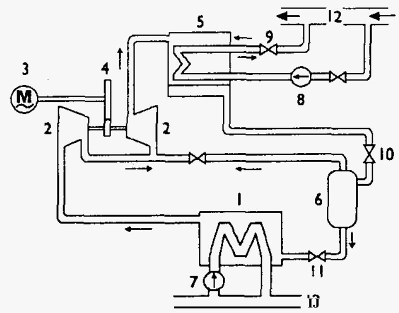
Figure 1. The pressure variation in the re-injection well Varpinge 2. Recorded since the start of the geothermal plant.

4. THE PLANT

4.1 Technical principles

The heat pumps operate according to the same principles as a refrigerator. A cooling medium is circulated in a closed circuit. In the evaporator the cooling medium is boiled at low pressure by the geothermal water. An electrically driven turbine compressor increases the pressure of the gas and therefore also the temperature. In a condenser the gas is cooled by the district heating water and brought back to the liquid phase again. The pressure is decreased in a reduction valve, the cooling medium **is** brought back to the evaporator and the circuit is closed. Figure 2 shows a flow diagram of the entire plant, and of the heat pump.





1. Evaporator
2. Turbo compressor
3. Electric motor
4. Gearbox
5. Condenser
6. Flash box
7. Centrifugal pump
8. District heating pump
9. Valve
10. High-pressure valve
11. Low-pressure valve
12. District heating network
13. Geothermal water

Figure 2. Flow diagram of the entire geothermal plant and of the heat pump.

At the location of the heat pumps a combined heat and power plant with a natural gas fired turbine is installed. This plant has a capacity of 37 MW of heat and 22 MW electrical output. At the plant there are also two electrical, three oil fired and one gas fired hot water boilers with a total capacity of 375 MW.

Figure 3 presents a typical duration curve for the district heating load during a normal year.

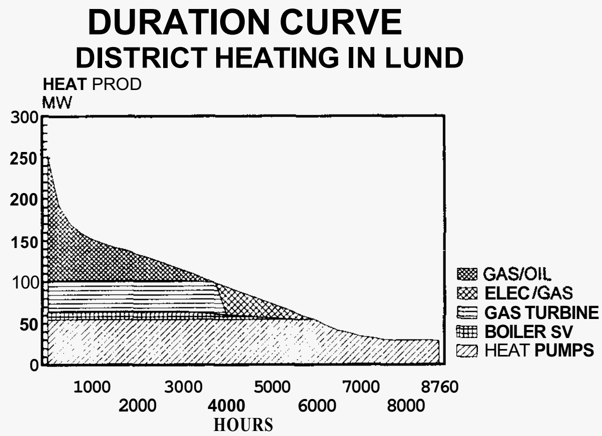


Figure 3. A typical duration curve for the district heating load during a normal year.

Technical data for the heat pump installation can be summarised as follows:

	Heat pump 1	Heat pump 2
Heat capacity (MW)	20	27
Compressor	2-stage turbo	2-stage turbo
Cooling medium	R500	R500
Elec. motor	10 kV, 6.5 MW	10 kV, 9.0 MW
Condenser	Tube	Tube
Design temp. (°C)	120	120
Evaporator	Tube	Tube
Material	Titanium	Titanium
Design temp. (°C)	65	50
Manufacturer	ABB-Stal	ABB-Stal

4.2 Operation experience

Almost ten years of operation of the geothermal and the heat pump system has proven that assumptions and expectations have been fulfilled and exceeded. In spite of the highly corrosive geothermal water only minor problems have occurred. The submersible well pumps are renovated every second year as a precaution and as a maintenance effort. Only once a pump has failed under operation.

In spite of environmental problems concerning leakage of freon the geothermal project has led to a considerable improvement on emissions from the district heating production. Figure 5 shows emissions of sulphur and nitrogen oxides from the district heating production. The increase after 91/92 is due to the installation of a gas turbine for electric production.

TABLE 1. Geothermal heat pump operation results

	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
Heat production (GWh)	1.4	129.2	261.1	326.9	296.6	318.3	302.4	319.4	316.3	351.1
Total heat factor	2.72	2.58	2.69	2.92	2.92	2.95	3.01	3.12	3.09	3.06
Number of starts	6	68	175	140	86	76	126	78	110	56
Availability (%)		99.1	89	95.8	87.2	97.4	97	99.1	99.2	99.3

Operation of the heat pump has demonstrated a high degree of availability. Minor problems with the computer controlled system caused several stops during the first years. A collapse of one electrical motor occurred in the autumn of 1990 causing a longer stop and the necessity of a replacement. The heat factor of the heat pumps has improved and is at a higher level than expected. Table 1 gives a summary of operation results year by year.

The most difficult problem with the heat pumps is the leakage of freon gas. In 1987 the negative influence on the ozone layer caused by the chlorine in freon especially CFC was world wide reported. Several actions have been taken since then to reduce freon leakage. Evacuation systems were installed along with leak detection systems. Leakage can still not be totally avoided. Leakage has been lowered from year to year. In 1990 a small leakage occurred that was not detected until after one month. This caused an increase of losses this year up to 4.5 tons. Figure 4 shows the annual freon losses year by year.

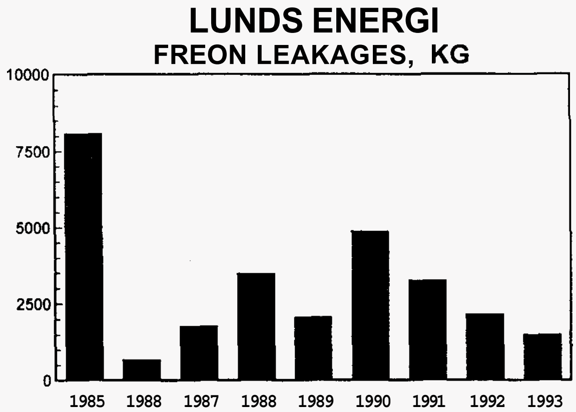


Figure 4. Annual freon losses from 1985 to 1993.

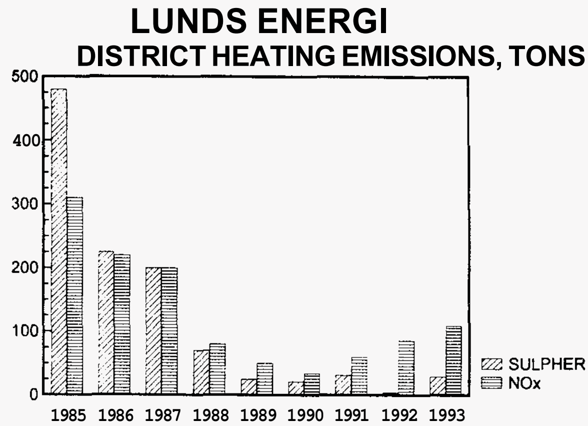


Figure 5. District heating emissions of sulpher and NOx from 1985 to 1993.

Another initial goal was to decrease oil dependency. Figure 6 shows the production mixture year by year from 1975 up till present. As shown in the figure a 100% oil dependency has now changed to a negligible use of oil.

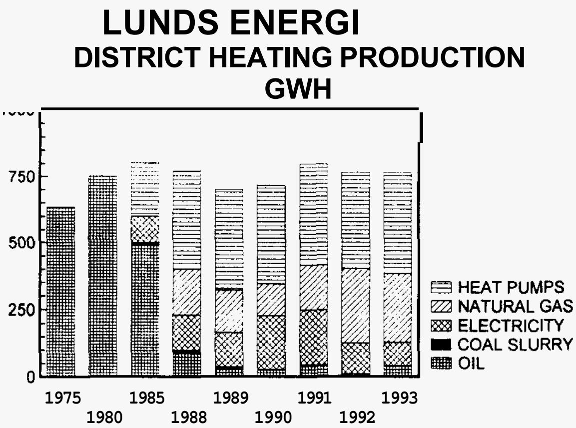


Figure 6. District heating production mixture from 1975 to 1993

4.3. Investments and operational results

No government subsides were given to the project. The Swedish National Energy Board gave financial support including a conditional loan of 16.5 MSEK (2.2 million USD). If the expected economic result of the project could not be achieved the loan had only to be paid back partly. However, this never became necessary.

Approximately 110 MSEK (14 M USD) have been invested in the plant. The main part of this was made 1985 and 1986. The conversion costs including new cooling media has been estimated to 25 MSEK. Due to lower oil prices from 1986 the profitability of the project has not been as good as expected. Assuming an economic life time of 15 years the total operational costs have been the same as if existing oil and gas fired boilers had been used.

After the Swedish government's introduction of environment taxes on sulphur in 1991, CO_2 and NO in 1992 this situation has changed dramatically. The tax (1994) for C02 is 45 USD/ton, for sulphur 4 USD/kg and for NO 5 USD/kg. Assuming energy costs valid today we now calculate on having the investment paid back before year 1995 - i.e. after less than ten years.

5. CONCLUSIONS

In spite of possible risks with well and formation deterioration, sometimes involved in the use of geothermal energy, the project in Lund has been a success. The technical problems encountered have not been related to geothermal energy as such but to general technical problems which have been possible to solve when they have occurred. Heat costs have not been higher but on the other hand not lower than they would have been in a case without geothermal energy. In the next ten years however heat costs will be substantially lower.

Emissions to the environment as well as the oil dependency has been reduced to a minimum.

It is therefore possible to recommend other municipalities with equal or similar prerequisites to study the use of geothermal energy for district heating systems or for other low temperature heating purposes.

6. REFERENCES

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