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A large-scale borehole heat store during five years of operation

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ABSTRACT

The borehole heat store in Luleå, Sweden, was built in 1982/83. The store consists of 115,000 m^3 of chrystalline rock. The rock volume is perforated by 120 boreholes to a depth of 65 m of which 3.5 m penetrate the soil. The total active borehole length is 7380 m. The rock temperature varies between 30 to 60 ^oC during the year. During six months of the summer season 2.0 GWh is charged of which 50% is recovered during the winter season. The extracted heat is utilized for space heating of one of the university buildings.

The research project includes evaluation of the construction work and five years of operation. The measurement programme was completed in May 1988. A final report will be published in the autumn of 1988. The storage system is now in its 6th charging period.

This paper gives a brief description of the plant. Experiences from the operation period and operation data of the plant are given.

1 INTRODUCTION

As part of the Swedish energy policy the Swedish Council for Building Research (BFR) gives financial support to seasonal heat storage research. The research was initially concentrated on waste heat storage but the long-term aim of the research programme is to store solar heat during the summer for space heating in the winter. There are other advantages with seasonal heat storage. A large-scale heat storage system reduces the construction cost of the heat production plant since its peak capacity need is reduced by the storage system. There are also environmental advantages since the emissions from the the heat plant to the air is reduced.

The borehole heat store in Luleå was built in 1982/83 for experiments and demonstrations and to get experiences for future heat stores. The store is located close to Luleå University of Technology. The store is owned and operated by the Public Works of Luleå, distributers of heat and electricity to the main part of the city, with a population of 70,000.

The research is conducted by WREL at Luleå University of Technology.

1.1 The borehole heat store

A borehole heat store is a rock volume, perforated by some hundreds of vertical boreholes. The store is usually covered with a soil layer through which the drillings are carried out. The heat is stored in the heated rock volume. The boreholes work as heat exchangers. The rock volume is heated by hot water circulation in the boreholes. When heat is extracted cold water is circulated. The low heat conductivities of soils and rocks make it possible to store the heat with relatively small heat losses in large storage volumes.

The heat capacity of granite and gneiss is about 0.6 kWh/m^3,^{o}C. Thus a 40^{o}C temperature rise of 1000 m^3 of rock means that 24,000 kWh is charged. This is the annual heat demand of a one-family house in northern Europe. Figure 1 shows the storage capacity as a function of storage volume.

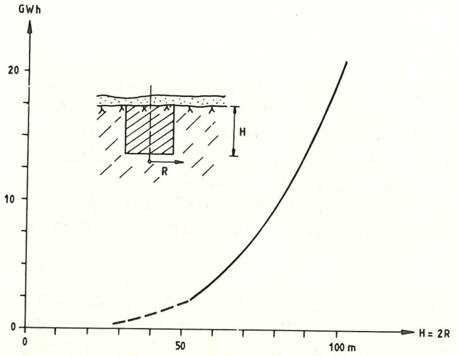

Figure 1. Storage capacity as a function of storage volume. The store is constructed in granite with a temperature difference of 35^{o}C.

2 THE HEAT STORE IN LULEÅ

Waste heat from a gas fired co-generation plant is transferred to the store by the district heating net which deliver the heat at a temperature of 70 to 80 ^{o}C. The storage system is separated from the district heating system by a heat exchanger. During the winter one of the buildings at the university is heated by the storage system. Two heat pumps, each of 200 kW, are partly used during heat extraction.

The rock volume of the store is 115,000 m^3 which is less than an optimum full-size store which will have an energy effiency of 90%. The volume is nevertheless sufficient to give relevant experience of construction and operation.

2.1 Technical design

The shape of the store is shown in Figure 2, and storage data are listed in Table 1. Detailed information is given in Nordell (1987).

TABLE 1. HEAT STORAGE DATA

Bedrock	granite and gneiss
Number of boreholes	120
Borehole separation	4 m
Storage land area	1500 m^2 (36 x 44m)
Depth of boreholes	65 m
Soil cover	2 - 6 m
Diameter of boreholes	152 mm (6")
Rock storage volume	115,000 m^3
Circulation system	open
Injected energy	2.0 GWh
Extracted energy	1.0 GWh
Fluid maximum temp.	80 ^{o}C
Fluid minimum temp.	10 ^{o}C
Heat pumps	2 x 200 kW

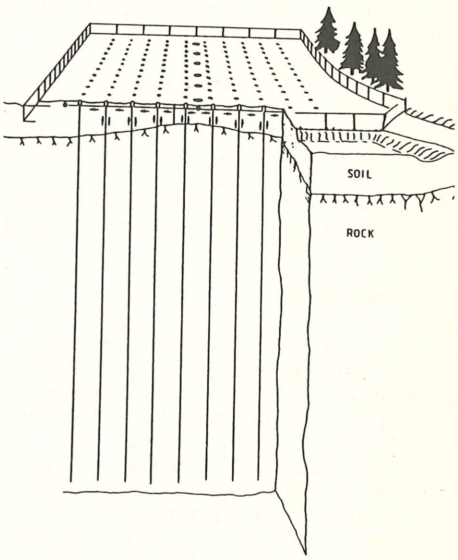

Figure 2. Section of the borehole heat store in Luleå.

The boreholes are placed in a square system with a spacing of 4 m. When injecting heat hot water flows from a central pipe into 24 parallel lines, each of five boreholes connected in series, to collecting pipes at the long sides of the store. When recovering the heat the flow is reversed. The flow direction within the store leads to a temperature stratification of the storage volume.

A pipe in each borehole conducts the circulating water to the bottom of the borehole. The water leaves the pipe and flows upwards thru the borehole to the bedrock surface where another pipe is conducting the water to the next borehole. Thus, the circulating water is directly in contact with the rock in the boreoles.

2.2 Construction

The pre-investigation included seismic profiling, core drillings and water injection tests. The thermal properties of soil and rock were determined in laboratory tests.

The drillings (8000 m, diameter 152 mm) were carried out during five months, including the coldest months of the year. Cold winter days meant tough conditions for men and equipment but they also meant hard stable ground for the down-the-hole drilling equip-ment.

The outdoor installations comprised 10,000 m of plastic pipes in and between the boreholes, collection pipes and the heat culvert between the store and the indoor heat exchanger.

The indoor installations meant conventional installation work of heat pumps, heat exchanger, pumps and pipes.

The total construction cost was 6.7 MSEK (US$ 1.1 M) in 1983, see (Nordell, 1985, 1987) and (Hellström, 1988).

2.3 Research programme

Within the research programme design, construction and operation are evaluated. Geological pre-investigations were included in the research project. Pumping tests were carried out as part of the geohydrological investigation. Groundwater chemistry and thermal expansion of the rock were studied. Calculation models have been made to simulate the thermal behaviour of the heat store. A special study has been made on the drillings to give basic data for development of future drilling equipment. Charged and recovered energy are recorded and the rock temperature is measured in 40 points at different depths within and outside the heat store. The research programme includes the first five years of operation. See (Nordell, 1987).

3 RESULTS AND EXPERIENCES

The store has been in operation since July, 1983 and is now in the charging mode of the sixth cycle. The operation of the heat storage system has meant very little maintenance and overhauling and the store is a reliable part of the heating system. The heat pumps which are used to extract about 20% of the energy have been the major problem.

The interaction between hot water and rock could have caused scaling problems in the pipes and in the heat exchanger but no such problems have occurred.

The thermal expansion of the rock volume has been measured by levelling the up-lift. Obviously the up-lift depends on the rock temperature, and the maximum up-lift was 18 mm compared to a theoretical value of 25 mm for homogeneous rock.

The drilling study show that the soil drilling cost was 40% of the total drilling cost. Measurements done show that the mean value of the borehole deviation from a vertical line was 5.7 m at a depth of 65 m. The maximum deviation occured in a temperature measurement hole which deviated 20 m at a depth of 100 m.

The length of the cycles have varied considerably, see Table 2, during the five years of operation. The first year the charging period was seven months as we wanted to heat the store as much as possible from its initial temperature of 3.5 ^{o}C. Varying length of the cycles during the next four years depend on the climate.

TABLE 2. CHARGING AND EXTRACTING DATA IN LULEÅ

Period	Duration (days)	Inj./Extr. (kW)	(MWh)	Recovery (%)
83-07-04 - 84-01-26	207	845	4196	
84-01-27 - 84-06-08	134	-150	-483	11.5
84-06-08 - 84-11-06	152	553	2018	
84-11-06 - 85-05-21	197	-278	-1013	50.2
85-05-22 - 85-11-27	190	573	2612	
85-11-28 - 86-06-16	201	-200	-967	37.0
86-06-16 - 86-10-15	122	655	1919	
86-10-16 - 87-06-04	232	-200	-1112	57.9
87-06-04 - 87-11-27	177	592	2515	
87-11-27 - 88-05-31	187	-195	-877	34.9

Table 2 shows that long charging periods increase the charged heat but the extraction period gets shorter and the extracted heat is reduced. Except from the first year of operation the annually charged and extracted heat show an undulating curve, see Figure 3. The heat input and output are shown in Figure 4.

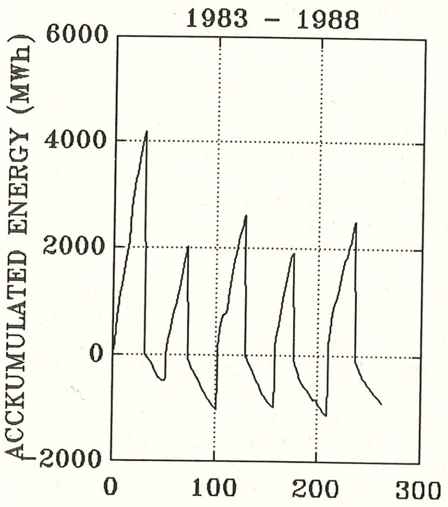

Figure 3. Charged and extracted heat during 5 years of operation

Under "steady-state" conditions the store was expected to recieve 2700 MWh and deliver 1600 MWh during each cycle. This has not been obtained.

Mean values of the four latest years of operation show that 2266 MWh (84%) has been charged and 992 MWh (62%) has been recovered. The maximum values are 2612 and 1112 MWh, see Table 2.

Preliminary simulations of the first four cycles have shown that the heat transfer between the circulated water and the borehole wall is poor during heat extraction periods. The calculations made before the store was designed assumed that the pipes in the boreholes were placed in a concentric position. There are no arrangements to keep the pipe in this favourable position. Thus, the plastic pipe is most likely to lie against the borehole wall and thereby partly reducing the heat transfer area available to the heat carrier fluid. This problem is most pronounced during extraction periods when the flow conditions are close to the laminar regime.

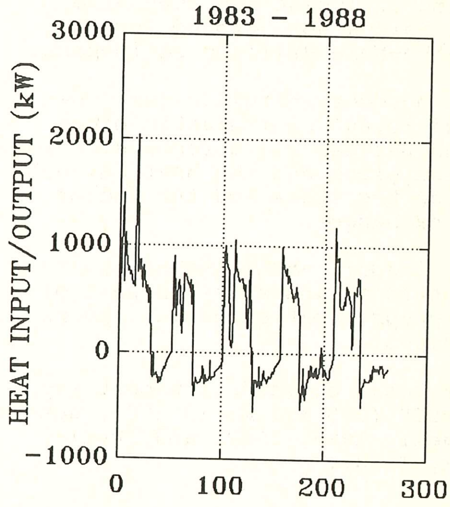

Figure 4. Heat input and output during 5 years of operation

The water flow rate is 0.0125 m^3/s during the charging periods which is 40% higher than during the extraction periods. The low flow rates during extraction periods is a system design problem since the flow rate is linked to the flow rate of the heating system of the heated building. The leaving temperature from the store is shown in Figure 5.

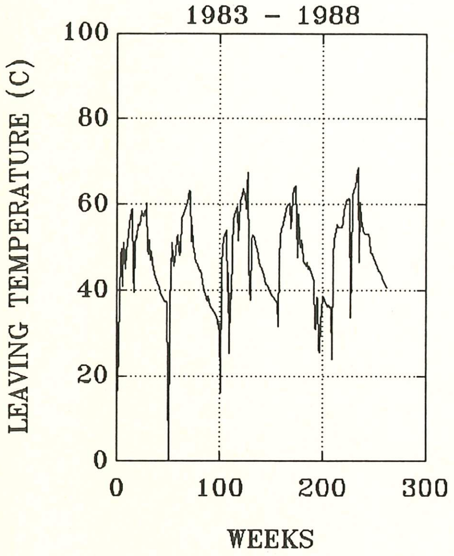

Figure 5. Leaving water temperature during 1983-1988.

4 DISCUSSION AND CONCLUSIONS

Although the store has a lot of built-in faulties in design, construction and operation, the heat storage system has been a reliable part of the heating system. The Public Works of Luleå are satisfied with the operation of the store which has meant very little overhauling and maintenance.

Most of the misstakes contributed to the unnecessary high construcion cost but some of the faulties result in a reduced capacity of the store. We did not have present know-how in 1982 but some of the faulties should have been considered when the store was built.

1/ The geometry of the store should have been different. It is shown by Hellström (1988) that the total construction cost is reduced by 13% only by drilling the boreholes to a depth of 125 m. This means that the number of boreholes is reduced to 64.

2/ The pipes in the boreholes should have been placed in a concentric position to achieve a better heat transfer between the fluid and the rock.

Today it is possible to design and construct a well-functioning borehole heat store as a part of a heating system. Long-term problems with this technology are not yet known since no borehole heat store has been in operation for more than 5 years.

In general the calculated heat cost is not yet low enough to encourage heat producing companies to install heat stores in their systems. However, continued research will improve the storage system and reduce the cost.

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