HEAT STORAGE IN ROCK
— MULTIPLE WELL SYSTEM

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HEAT STORAGE IN ROCK - MULTIPLE WELL SYSTEM

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1. INTRODUCTION

The multiple well heat storage system is primarily a seasonal storage. Its function is based on the heat conductivity and storage capacity properties of the rock.

The heat is transferred to or from the rock by means of a fluid, normally water, which is circulated through a great number of boreholes or wells. The boreholes are assumed not to be cased.

Fig. 1. Multiple well heat storage system. Principle sketch

The heat storage capacity of e.g. gneiss and granite is about 0.6 kWh/m$^3$°C, i.e. half of the corresponding figure for water. Hence, a multiple well heat storage system must have a volume
twice as large as e.g. a rock cavern with water and with the same storage capacity at the same temperature swing. Normal operation temperatures are assumed to be in the range of +10°C to +80°C.

2. FUNCTION

2.1 Circulation systems

The heat carrying fluid can be circulated through the wells in open or closed circulation systems. Fig. 2.

Fig. 2. Multiple well system. Circulation systems

In a closed circulation system, the fluid is circulated through U-shaped tubes inserted in the wells. The groundwater in the wells transfers the heat from the tube and the rock.

In the closed circulation system, the circulated fluid has no direct contact with the rock. Therefore, even if the storage is constructed in fissured rock, there will be no loss of water, nor will there be any problems concerning chemical precipitations in tubes, heat exchangers, etc.

On the other hand, a closed circulation system causes less favorable heat transfer characteristics because of the non-direct contact between the fluid and the rock.
Storage temperatures above +100°C can be used, provided the active part of the storage is at a sufficient depth under the ground surface. Fig. 3.

In an open circulation system the fluid is always water. The water is conducted through a tube down to the bottom of the well, where it is released in direct contact with the rock.

2.2 Hydrogeological conditions

A natural or superimposed groundwater flow may have a significant influence on the thermal behaviour and efficiency of a multiple well heat storage system. The ground water flow depends on the hydraulic conductivity and the hydraulic gradient.

A closed circulation system can be used even in fissured rock provided the hydraulic gradient is sufficiently low. Comprehensive investigations concerning the hydraulic conductivity of the Swedish bedrock indicate that generally the natural groundwater flow would not seriously affect a storage of a reasonable size.

An open circulation system implies a super-imposed hydraulic gradient because of the operation pressure. Hence, an open circulation system must always – if grouting, etc is to be avoided – be placed in non- or less fissured rock. However, preliminary calculations concerning acceptable water losses from the wells indicate a maximum permissible hydraulic conductivity which is normally found at least at a certain depth below the rock surface. The storage must then be placed below the fissured zone near the rock surface.
2.3 Thermal behaviour

The thermal behaviour of a multiple well heat storage system has been analyzed by means of the Continuous Heat Source Model for Ground Heat Storage. Simultaneous parameter studies related to the energy and temperature efficiency of the storage have been carried out. Parameters studied are size and shape of the storage, spacing between the wells, injection and extraction fluid temperature, thermal characteristics of the rock, etc. [11, 21].

The thermal behaviour during the heat injection and extraction periods is illustrated in fig. 4, based on the following main conditions:

- storage size: depth 100 m, diameter 100 m
- bedrock: granite with 5 m overburden
- spacing between the wells 4 m
- well diameter 150 mm
- closed circulation system
- max. fluid temperature +80°C
- min. fluid temperature +10°C
- heat injection and extraction rates and periods according to the upper part of fig. 4.

Fig. 4. Thermal behaviour of a multiple well heat storage system for the first three years
The diagram clearly shows the characteristic thermal behaviour of a multiple well system where the rock temperature, approximately equal over the entire storage volume, is steadily increasing or decreasing during the injection and extraction periods.

3. CONSTRUCTION COSTS

A pre-design of a full-scale multiple well heat storage system has shown that the storage can be constructed at low costs and with well known technology [C37]. Construction cost data have been collected and analyzed in order to make possible a cost comparison with other types of seasonal heat storages. The following storage systems have been studied:

- insulated steel tank with water
- rock cavern with water
- multiple well system (heat storage in solid rock)
- vertical pipe system (heat storage in clay)
- gravel-water-basin (excavated, insulated and refilled).

The cost information is given in fig. 5 as specific construction costs, i.e. costs per recovered kWh, as a function of the size of the storage and of the energy recovery factor \( \xi \). All cost data are based on the following assumptions:

- seasonal heat storage (only one storage cycle per year)
- \( T = 55^\circ \text{C} \) (\( T_{\max} = 85^\circ \text{C}, T_{\min} = 30^\circ \text{C} \))
- construction costs do not include costs for
  - land use
  - interest during the construction period
  - operation and maintenance
  - heat pumps
  - value added tax
- stationary heat losses are considered in respect to resultant lower storage capacity and consequently, higher specific construction costs. (The yearly cost of the heat loss itself is not considered.)
- transient heat losses are not considered (however, capitalized costs for transient heat losses may increase the specific construction cost with 0 - 4 % depending on storage type, size and energy costs).

As can be seen in fig. 5, a multiple well system implies considerably lower construction costs than other generally applicable systems.
Fig. 5. Specific construction costs for different types of seasonal heat storage systems.

Temperature swing 55°C

* disposable ground surface (pipe system in subsurface conduits)

** pipe system on or above ground surface

### Based on $\Delta T = 20^\circ C$ (The system is up to now only applied to $\Delta T = 10^\circ C$, but may be considered for $\Delta T$ up to $45^\circ C$).

4. FIELD TESTS

4.1 Downscaled storage

A multiple well storage downscaled 1:4 has been constructed on a test site in Luleå in the north of Sweden. The test is being carried out by the Department of Water Resources Engineering, University of Luleå.

The test simulates 5 years seasonal heat loading and reloading. The 5 years correspond to a test time of 120 days.

The test aims to justify the above mentioned theoretical studies \cite{11, 27}.

The test storage has 19 wells with an open circulation system for loading and reloading. The wells have a depth of 19 m of which 6 m are overburden. The wells are 1.3 m apart and have a diameter of 52 mm. The storage volume is 431 m$^3$. 
Fig. 6. Test site arrangements, Luleå

Fig. 7. Test site, Luleå
During loading, water with a temperature up to 65°C is circulated. The heat is taken from the district heating system. During reloading, water with a temperature down to 20°C is circulated. The amount of the injected and extracted heat is measured as well as the temperature distribution at 75 points in and outside the storage.

The test period is scheduled between 3 July and 31 October 1981.

At present, no evaluated data are available. However, preliminary studies of the test results indicate a good coincidence with the theoretical model. The test results indicate some deviation from the theoretical model concerning heat characteristics of the storage, probably due to convection of water through rock fissures.

Final test results will be reported early in 1982.

4.2 Full scale storage wells

Field tests encompassing a closed circulation system in three wells with a diameter of 150 mm and a depth of 100 m are in preparation at the hydraulic laboratory in Álvkarleby. The primary aim of the test is to solve practical problems concerning installation, tube material, etc. Heat transfer characteristics, etc, will be studied simultaneously.

The tests will be carried out by the Swedish State Power Board in cooperation with AIB, Consulting Engineers. Final test results will be reported in 1982.

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