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RECENT EXAMPLES FOR THE UTILISATION OF GEOTHERMAL AQUIFERS FOR HEAT OR COLD STORAGE OR IMPROVEMENT OF THE RESERVOIR CONDITIONS BY HEAT INJECTION (STORAGE AND COMBINED PRODUCTION/STORAGE PROJECTS IN GERMANY)

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ABSTRACT

In Germany, direct geothermal energy use is restricted to selected sites only, due to the geological and present economic conditions. The totally installed low-enthalpy geothermal heating plant capacity is 38.7 MW_t, and another **115** MW, are under construction or planned.
However, there is an increasing demand on long-term high-temperature energy storage which results from the peculiarities of combined heat and power generation. The experience gathered in geothermal reservoir engineering (injection, reservoir modelling, geochemical analysis) has proven the suitability of those aquifers for energy storage.

The present paper describes two up-to-date projects, namely

- aquifer cold and heat storage as essential part of the energy supply system of the buildings of the German Parliament in Berlin (first energy storage project in Germany which is under construction right now)
- improvement of the thermal yield from a low-enthalpy geothermal doublet being operated for 8 years now by increasing the temperature in the reservoir through injection of the excess and waste heat from a co-generation plant (project under planning for the Hannover **2000** World Exhibition).

AOUIFER THERMAL ENERGY STORAGE (ATES) - PRESENT SITUATION

The extent of both theoretical and practical investigations into the use of aquifers for seasonal energy storage has been increasing in the last 20 to 30 years.

Widely known and used in manifold ways for the validation of numerical models are the industrial-scale experiments of the Auburn University of Mobile, Alabama 1978/79 (Sykes et al., 1982) and **SPEOS** in Switzerland 1978-89 (Saugy et al., 1991).

In Europe, in particular in The Netherlands and Sweden, about two dozens of major aquifer heat and / or cold storage projects have been implemented in the 80s and 90s.

In Germany, licensing procedures have beed hindering in the beginning the broader application **of this** technology, which could be overcome after extensive investigations under the IEA project ,,Environmental and Chemical Aspects of Thermal Energy Storage in Aquifers and Water Treatment" (Wagner et al., 1991).

In a joint EU project ,,Seasonal Thermal Storage in Northwest Europe': several European partners investigated the geological-hydrogeological, energetic and economic conditions for the application of the procdure in their countries, respectively.

The demand for long-term heat storing reservoirs at a relatively high temperature level results from the specific conditions of combined heat and power generation with due consideration of the climatic conditions (little heat demand in summer with almost constant power demand). The energetic efficiency of the reservoir is here decisively influenced by the temperature level of the returned water, whch in return depends on the temperature of the fed-in water. For this very reason. geothermal reservoirs have been of special interest. These geothermal aquifers are generally deeper and their development is more expensive. **But,** along with the advantage of a usable higher temperature level the environmental impact is minimised in these depths, since drinking water horizons and the surface will not be affected.

In North Germany, geothermal reservoirs are generally mineralised and geologically separated from drinking water horizons by tight Rupelian clay layers.

PECULIARITIES AND GENERALISABILITIES OF RESERVOIR ENGINEERING

Same as in case of hydrothermal use including reinjection, the mass balance is maintained in aquifer storage systems. Reinjection is an essential condition of reservoir operation. However, for storage each well must be equipped properly both for production and injection. The analysis of potential (physical and chemical) effects on the reservoir and the injection behaviour through the temperature change is a condition for both procedures in terms of planning, such as protection from corrosion and ochre sedimentation in particular when utilising saliniferous waters.

In addition to the sole hydrothermal use of the aquifers for energy exploitation the following peculiarities occur when using them for energy storage:

- well installation: well design providing both for production and injection
- geochemical modelling with regard to cooling and heating of the reservoir fluids and the matrix
- additional specific points of interest in prognostic reservoir simulation
  - reservoir efficiency or recovery coefficient as the ratio of the stored over the recovered energy
  - temperature decline during re-production as essential parameter for the technological dimensioning
  - the influence of possibly existing natural groundwater flow
  - temperature distribution within the caprocks
  - optimisation of the technological regime.

All this calls for the iteratively coupled modelling regarding the surface energy demand and its variability in terms of quantity, temperature level and time for proper planning of the plant and efficient field management of the reservoir.

For geothermal reservoir simulation, different simulator codes have been used with due consideration of their specific advantages and disadvantages:

CFEST (Gupta et al., 1987) and TOUGH (Pruess, 1987) for reservoir simulation and field management using the intrinsic approaches of thermal conduction in the caprocks as a quasi 3D simulation - which reduces computing time - neglecting the complex three-dimensionality and
FEFLOW 3D (Diersch, 1996) for the prognosis and visualisation of possible effects on the ambiance with due consideration of the real geological-hydrogeological conchtions as detailed as possible.

In the following, two up-to-date examples of the utilisation of geothermal aquifers for heat storage Ire described.

LARGE-SCALE AQUIFER HEAT AND COLD STORAGE FOR THE BUILDINGS OF THE GERMAN PARLIAMENT IN BERLIN

On the location of the Reichstag project in Berlin (the building of the former Reichstag will be the seat of the German Parliament after 1999), excessive heat coming from the motor-driven cogeneration units is fed into a salt-water bearing aquifer lying about 300 m deep, and recovered and utilised at a temperature level ranging from 60 ... 20 °C (Luetzke, 1996). A second shallow aquifer cold energy reservoir in a depth of about 60 m serves for the cooling of the buildings. The ambient cold stored in winter is supplied in summer directly to the cold consumer61n the buildings (Fig. 1).

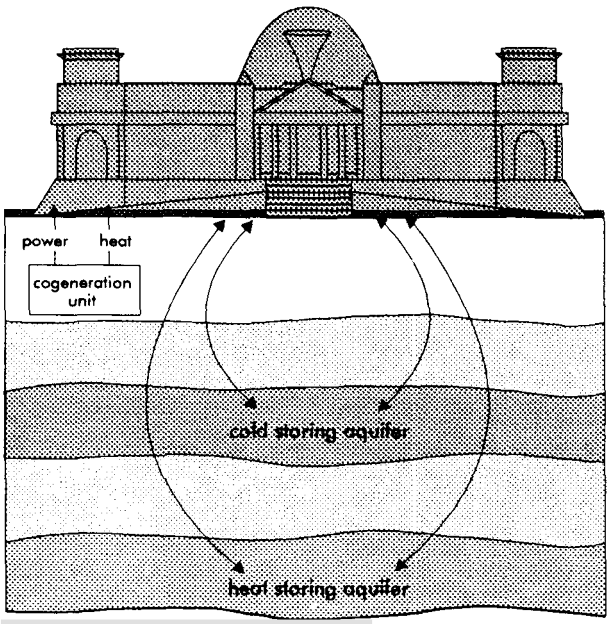


Figure 1. Aquifer energy storage and supply at the Berlin site

Within the framework of the preliminary geological investigations into the deep aquifer heat energy reservoir - which has been installed in a salt-water bearing aquifer for the very first time - an exploratory well was drilled in **1996** which was designed as to allow for including it as production well in the future reservoir installation (Fig. **2).**

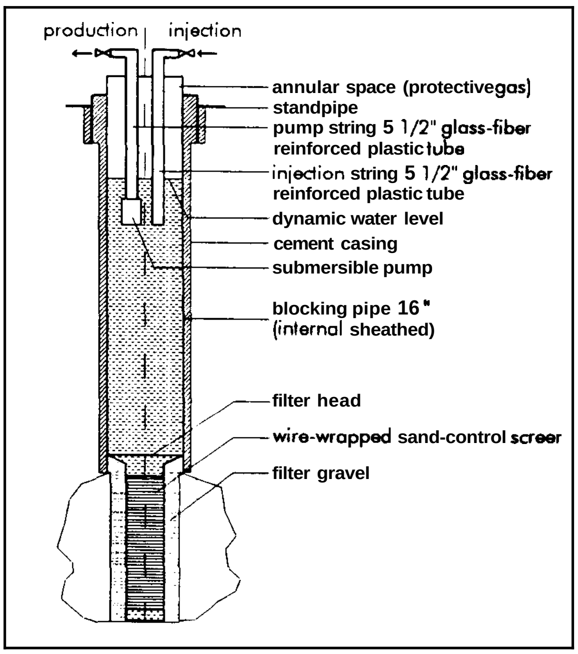


Figure **2.** Well drilled down for heat reservoir installation

In the course of the well investigations, several sandstone horizons with good reservoir properties and safe regional coverage were proven. **The** parameters of the selected productive horizon are as follows:

position of depth	**286 - 315** m
thickness	**29** m
porosity	**30 %**
permeability	$4.3 \cdot 10^{-12}$ m^2
production and injection rate	**> 100** m^3/h
mineralisation	**29 g/l**
initial reservoir temperature	**19.3 °C**
possible injection temperature	**70 °C**.

With the above parameters, the task of the exploratory drilling was fulfilled, thus confirming the geological and technical prerequisites for the utilisation of the aquifer as a heat reservoir (Seibt, Kabus, **1997).**

Simulation based on the obtained parameters served for

- the siting of the second well to prevent thermal breakthrough
- calculation of the well head changes as a function of the operational regime
- iterative optimisation of the regime (heat demand and surplus ⇔ regime of well operation ⇔ recoverable heat)
- calculation of the thermally influenced ambiance and the top layers.

Primarily, the theoretical reservoir efficiency of 0.86 may be estimated by simplifying analytically the charging and discharging processes and assuming the optimum regime with due consideration of the reservoir parameters according to Lauwerier **(1955).** For optimum integration of the reservoir in the supply system, several operational regimes implying up to 100 cycles per year were calculated on the basis of the obtained parameters and the simulation programme CFEST. The technological parameters (capacity of the block-type heat and power station, heat demand in Parliament conference periods and conference-free periods, direct heat exchange and heat pump use, integration of more consumers in the supplied area ...) represent numerous variables.
The optimum configuration - under overall energetic aspects - was found to be the following modelled case (Table 1). In Table 1 the charge and discharge parameters are summarised in a simplified manner for a block-type heating and power station with an overall capacity of **3,200** kW_{el}. In the period between 20 March and **21** December, predominantly energy storage is done at different temperature levels, and

from **22** December to **19** March, the stored energy is recovered.

date		day	„hot" well		,,cold well	
		d	m³/h	°C	m³/h	°C
03120-06/20	conference period	**63**	**13.52**	**67**	**-13.52**	**30**
	conference-free period	**29**	**3.33**	**67**	**-3.33**	**30**
06/21-09/23	conference period	**63**	**20.34**	**51**	**-20.34**	**30**
	conference-free period	**30**	**14.96**	**44**	**-14.96**	**30**
09124-12/21	conference period	**63**	**12.86**	**66**	**-12.86**	**30**
	conference-free period	**27**	**4.79**	**64**	**-4.79**	**30**
12122-03/19	conference period	**63**	**-39.62**	**43**	**39.62**	**32**
	conference-free period	**27**	**-61.23**	**43**	**61.23**	**32**

Table 1. Charge and discharge parameters

Fig. 3 gives the calculated reservoir temperatures over a simulation period of **5** years, after which the reservoir conditions will be stable. The recovery factor is expected to increase from initially **0.61** to **0.82** after **5** cycles.

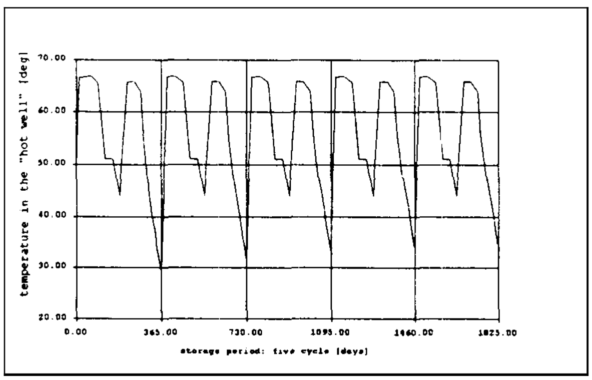


Figure **3.** Calculated reservoir temperatures over a period of **5 years**

The calculations of the warming-up of the top layer using a **3D** model with FEFLOW made clear that when injecting such an amount of heat a thermal impact on shallow sections or the groundwater can be absolutely excluded thanks to the **120** m thick Rupelian clay top layer, and even under unfavourable conditions no thermal breakthrough between the two wells (internal distance: **309** m) is to be expected.

Within the framework of the preparation of the project it proved to be necessary to implement a comprehensive programme of geoscientific investigations comprising in detail:

- the enquiry of the geological and hydrogeological conditions on the basis of the available documentation
- other geological exploration and pump test to increase the knowledge
- geohydrodynamic and geothermal simulation of the reservoir
- water chemistry
- microbiology
- botanics
- land-use planning
- the concept for the preservation of evidence and monitoring.

Due to the increased influence on shallow layers and competitive demands on the groundwater the level of investigations for the shallow aquifer (cold reservoir) was extremely higher compared to those done for the heat reservoir. Nevertheless, the results obtained in reservoir simulation for both aquifers concerning the cone of depression or elevation adjusting when operating the wells and the extent of the thermal impact on the aquifer and ambiance proved to be the basis of geochemical, microbiological, botanical and geotechnical investigations.

UTILISATION OF *AN* EXISTING GEOTHERMAL **LOW-ENTHALPY** SITE FOR WASTE HEAT STORAGE

The second project includes the extension of an existing hydrothermal plant in **NE** Germany by an aquifer energy storage system. Two production and injection wells each with a final depth of about 1 *00* m feed a district heat supply system since **1989** in direct heat transition supported by an absorption **heat** pump and a peak-load boiler plant.

Annually, about **5-10 GWh** of geothermal heat **are** supplied at a thermal water temperature of **54** °C, whereas due to lacking heat demand in summer, environment-benign effects *thanks* to the avoidance of emissions are reached almost exclusively in winter and in-between seasons.

So, the concept implies intermediate storage in the geothermal reservoir of the in summer excessive heat of a gas- and steam-turbine driven power station existing on the location, and central supply of geothermal heat in winter and in-between seasons - now at a higher temperature level. For this purpose, the direction of flow between the wells is reversed over a certain period of time.

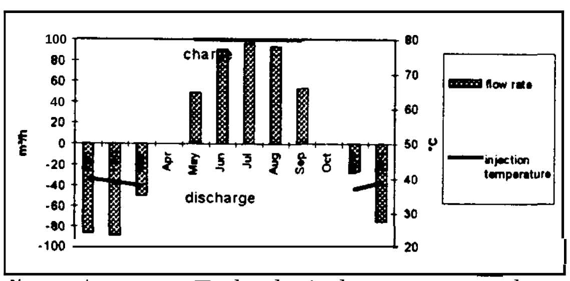
The thermal reservoir behaviour was simulated with the numerical simulator CFEST. Calculation was done on the basis of a **2D** model with due consideration of the heat exchange with the top layers. The following survey gives the relevant geological, thermo- and petrophysical parameters:

Parameter	Aquifer
thickness M, m	35
permeability $k_{=}$, µm²	0.9
permeability $k_{\perp}$, µm²	0.35
compressibility κ, 1/Pa	$3 \cdot 10^{-9}$
porosity n, %	25
dispersion δL, δT, m	5 and 0.5
mineralisation β, mg/l	130
thermal conductivity λ, W/mK	2.5
thermal capacity of fluid ρc, Ws/m³K	3913000
thermal capacity of matrix ρc, Ws/m³K	2400000
initial temperature T_0, °C	54

Table 2. Model parameters for the Neubrandenburg site

The model is discretised by 900 elements and 968 nodes covering an area of 2,500 m x 400 m. The internal distances between the nodes vary from 50 m to 0.5 m. Time control was effected with 12 switching operations per year as required by the technological regime.

In the course of the iterative calculation of excessive heat ⇔ reservoir behaviour ⇔ heat demand the optimum technological regime appeared to be in the annual cycle: 5 injection months, 2 storage months and 5 re-production months, as presented in Fig. 4.



'igure 4. Technological parameters of the Ne .l reservoir

Fig. 5 gives the well head temperatures of the „hot" well over a period of 5 years. The cooling-down around the cold section of the reservoir resulting from geothermal heat recovery over a period of several years was not considered here, as it does not exert any influence on the warm section of the reservoir.

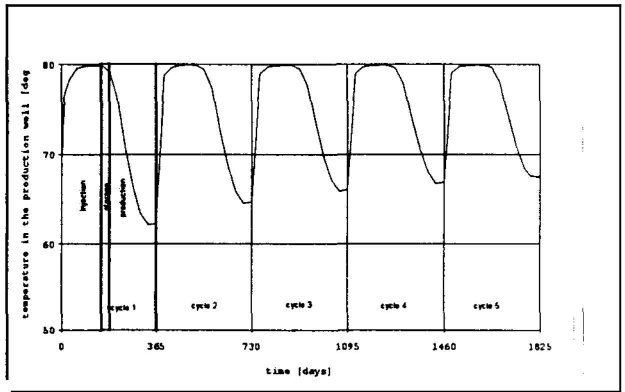


Figure 5. Temperature curves of the hot wells

With the growing number of cycles, the recovery factor increases as well which is shown in Fig. 6:

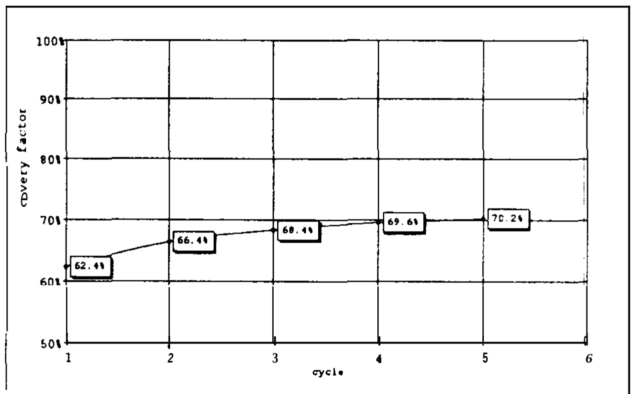


Figure 6. Calculated recovery factors

CONCLUSIONS

Aquifer heat storage does not represent a new technology. However, through the utilisation of geothermal saliniferous reservoirs, new perspectives are opened up, as storage is possible at an energetically more favourable, higher temperature level implying minimum environmental impact.

In Germany, a major project is being implemented for the new seat of the German Parliament in Berlin, more projects are under planning.

Preliminary geoscientific and engineering investigations showed that instruments of and experience gained from geothermal reservoir engineering are also suitable for the prognosis, planning and field management of ATES.

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