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Conditions for the utilisation of low-enthalpy hydrogeothermal resources in Germany – an interdisciplinary approach

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ABSTRACT

The utilisation of geothermal energy is regarded as a promising possibility to cover a substantial part of mankind's increasing energy demand. Today the hydrogeothermal resources used in Germany for low temperature heat supply cover only a small part of the energy demand. A more widespread application is limited by a variety of factors of different nature and scale. Regional geological settings (supply) and consumer structures (demand) are well known with some degree of uncertainty and technical solutions for the exploitation of different resources are available. Because of the mentioned uncertainties reliable predictions for heat generation costs are difficult to obtain. They depend on very detailed location specific information, as the technological layout is strongly affected by the above mentioned parameters and their interaction.

Within an interdisciplinary working group of geoscientists, engineers, and economists the following topics and the coupling between various parameters was investigated:

- geologic-petrophysical characterisation of the resources,
- conditioning of the geothermal water cycle,
- long-term bebaviour of the utilised aquifers,
- economical analysis of drilling alternatives and various design plants
- optimisation of district beating systems
- energy-ecological and energy-economical analysis.

The investigations contribute to a better general understanding about mechanisms and processes during the exploitation of hydrothermal resources. Recommendations for the layout of geothermal heating plants and their operational regimes are derived. The tools developed show, that the utilisation can be competitive with the fossil fuel combustion of their alternatives. Environmental effects associated with the later are avoided to a great extent.

KEYWORDS

Geothermics, low-enthalpy, direct use, resource, economics, ecology, optimisation, Germany

Introduction

Currently the heating demand in Germany is four orders of magnitude higher than the present geothermal exploitation. Available geothermal resources are six orders of magnitude greater than what is utilised. During the last decades a number of efforts were made to develop a technology for utilising low-enthalpy hydrothermal resources for district heating (table 1). The constructions of the plants were more or less supported by public money. However, future technology for energy supply must be competitive with other alternatives under economic conditions. With respect to the future demand, the utilisation **of** low-enthalpy hydrothermal resources was investigated under technical, ecological, and economical aspects within a project supported by the German Ministry of Education, Science, Research and Technology (BMBF, contract no. BEO 0326969). This paper gives an overview **of** the results.

Method

Engineers, physicists, or economists, whose expertise ranges further than that of Earth scientists, are usually unaware of the potential **of** geothermal energy. **On** the other hand it is insufficient to assume the enormous potentials of geothermal resources, as geoscientists often do, without a careful **look** at the economy and reliability of the technology. Thus, the main objective of the project was to bring together a group of engineers, physicists, economists, and geoscientists to work out an interdisciplinary approach to the topics involved. The contributions from the complex interacting disciplines cover the consideration of several scales as follows:

The reliable potential **of** hydrogeothermal energy in Germany is about **1** magnitude higher than the demand. However, there is no common technological layout on the regional German scale because it is affected by local factors. The given geological setting and the possible heat supply for a district heating loop, then determines the economy. At the lower end of the scale the feasibility is constrained by processes in the pore space. The variation of each parameter in space and time adds up to a general uncertainty in this interdisciplinary evaluation. Therefore, all topics investigated cover the complete range from detailed specific studies with local implications up to general investigations of relationships between the disciplines with their global implications.

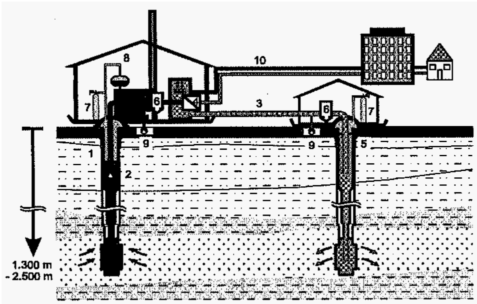

Figure 1: Concept of thermal water cycle for high saline water with production well (1), production pump (2). production tube (3), heat exchanger (4), injection well (5), filter (6), N_2-inertgas-(7) and pressure control system (8), slop disposal (9), and district heating loop (10).

Experience in operation

Since 1984 a number of plants are in operation in Germany and Switzerland (table 1). All plants provide sufficient energy to their customers. There have been no major problems in plant operations due to insufficient technical solutions for possible difficulties based on undeground properties. Observed problem are mainly: failures in the district heat system, the technical surface completion of the plant or at the subsurface water pumps (figure 1). Nevertheless, there still exists a potential for optimisation of the whole system with respect to reliability and economics.

Geological-petrophysical characterisation of the hydrothermal reservoirs

In Germany nowadays low enthalpy thermal waters with temperatures between 40 and 100 °C, realisable flow rates between 50 and 100 m^3/h and productivity greater than 50 $m^3h^{-1}MPa^{-1}$ form the hydrothermal reserves. A sufficient lateral extent and an easy re-injection of the water into the aquifers are additional requirements for efficient economic exploitation. Therefore the usage is restricted to certain geologic conditions and special reservoir properties.

Table I: Parameters of plants for hydrothermal heat production in the North German Basin (Waren, Neubrandenburg, and Neustadt Glewe), in the Bavarian Molasse Basin (Erding with a one well system), and in the Southern Part of the Upper Rhine Graben (Riehen, Switzerland) (HUENGES et al. 1998).

Location operational (modernised)	Installed power [MW] total	geothermal	Heat supply (per year) [GWh] total	geoth.	Depth of production and reinjection wells [m]	Flow-rate [m³/h]	Temperature [°C]
Waren 1984 (94-95)	52	16	134 (1995)	8.5 (1995)	1566/1470	60	62
Neubrandenburg 1988 (92-94)	15.4	35	20 (1995)	9 (1995)	1270/1285	100	54
Neustadt-Glewe 1995	169	65	162 (1996)	13.7 (1996)	2250/2303	120	98
1998	18	45	52 (planned)	28 (planned)	2350	864	65
Riehen (Switzerland) 1994	15.1	2.75	30.4 (96/97)	12.7 (96/97)	1547/1247	72	66

Potential reservoirs are Cretaceous, Jurassic, and Triassic sandstones in the North German Basin in a depth range between 1000 and 3000 m. Detailed geologic and petrophysical investigations of these reservoir rocks, temperature conditions, chemical and microbiological analysis of the formation waters and the estimation of possible fluid-rock interactions were compiled (HOTH et al. 1997) to provide a basis for a locally successful technical exploitation.

Reservoir characterisation

Hydrothermal reservoirs, porous or fissured and/or cavernous rocks filled with thermal water, must be characterised to have a base for an evaluation of the feasibility of the utilisation of geothermal energy. The reservoir properties given in figure 2 are typical for the utilised reservoirs in the North German Basin.

The mean porosity should exceed 20 %, the effective permeability should be in the order of $0,5*10^{-12}$ m² and higher and the effective thickness of the utilised reservoir layer should be greater than 20 m. To understand possible processes e.g. fluid-rock-interactionsinformation on the pore space structure is essential. Typical pore radii of 25 µm contribute to the utilisable porosity of sandstones. The long time behaviour of rocks with lower mean pore radii must still be investigated.

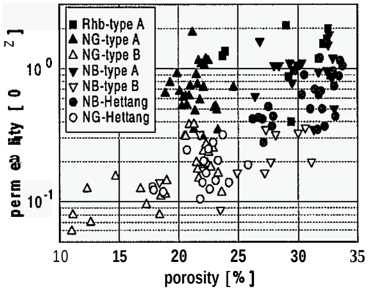

Figure 2: Crossplot of porosity and permeability of sand stones of Lias and Keuper** from **the bore holes Neubrandenburg (NB), Neustadt Glewe (NG), and Rheinsberg (Rhb) in the North German Basin. Type A: content of sheet silicates lower 5 % , Type B: content of sheet silicates higher 5 % (HOTH at al. 1997).

Adjacent rocks of the aquifers must also be included in the reservoir characterisation. They are important as so called cap rocks due to their sealing properties and their interaction with the thermal water. They may produce gas which can than be found in the thermal water.

Characterisation of the thermal water

The salinity of the thermal water in the North German Basin ranges from a low saline consistency up to highly concentrated saline fluids (HOTH et al. 1997) with concentrations greater than 280 g/l. A general depth dependence of the mineralisation of the thermal water exists only for Tertiary, Cretaceous, Jurassic, and Upper Triassic aquifers. Hereby, depth dependencies varying different to the trend are observed close to the surface (influence of meteoric waters) and close to salt structures.

The gas content varies locally, the measured total gas contents of the investigated brines reach values up to 10 vol. % (NAUMANN et al. 1999). The gas phase is dominated by N_2, CO_2 and CH_4, the concentrations of the minor constituents He, H_2, Ar and other gases are less than 1 vol. % each. The gas content must be predicted in advance and should be observed carefully as the production of free gas due to pressure release in the thermal water cycle could cause technical problems. In spite of hostile conditions in the aquifers bacteria were observed in the high saline, high temperature, and high pressure environment of the aquifers (KÖHLER et al. 1997). A reduction of the permeability within the reservoir may be the result of bacteria, as is reported elsewhere, e. g. in the Paris basin (HONEGGER et al. 1989).

Conditioning of the thermal water cycle

Because of the high salinity of the geothermal brines, the operation of thermal water cycles are usually designed with two bore holes: a production well and a re-injection well (figure 1). The initial Fe^{2+} content of the reducing Na-Cl-brines and the possible precipitation of iron hydroxides induced by oxygen **entry** between production and **re**-injection is of main technical importance. Due to the usual low oxygen-content in the natural reservoir general recommendations can be derived from oxygen-measurements during the operation of a plant:

- During normal operation and **high** flow rates (e. g. **> 40** m^3h^{-1} in Neustadt-Glewe) the diffusion of oxygen into the thermal water is negligible. Therefore, oxygen inflow prevention is only necessary in sensible reservoirs. During standstill of a plant the oxygen inflow must be prevented ***e.*** g. by pressurising the water cycle and/or protection by nitrogen.
- Injection of slop water (fig. **1,** component 9), i.e. water from the thermal water cycle with oxygen contact, must be performed with sufficient dilution.

Modelling of the long-term behaviour of the utilised aquifers

The evolution of utilised reservoirs, characterised by tectonic and sedimentary structures, was modelled in space and time, using a 3D-finite–elemente program (WENDEROTH et al. 1998). Varying physical properties **of** the fluids and rocks and varying production and injection concepts were used as input parameters. The following can be derived

- The life time of a plant is related to the distance between the production and injection well. Increasing distance leads to an over-proportional increase in the life time.
- The fluid flow through the reservoir is strongly influenced by the temperature dependent viscosity **of** the brines. Thus, **for** example, by neglecting this dependency a faster decrease **of** production temperature would be calculated.
- ***An*** optimised amount of thermal energy from a plant can be yielded using a multiple borehole concept. Under special conditions an inefficient working plant can be brought to economical operation using this concept.

Economical and ecological system analysis

Economical system analysis

The commercial feasibility, depends to a great extent on the cost for drilling and the completion **of** the wells. SIEBERTZ et al. (1998) investigated the realisation costs for drilling alternatives in hydrothermal reservoirs of the North German Basin in the depth range between 1500 and 2200 m. Costs of vertical and sidetrack wells were calculated. The increase of the sidetrack costs were then compared to the saving in technical surface completion. Within a 5 % divergence there was no difference between the total costs of all alternatives investigated.

Depending on the economic boundary conditions, completion **of** the plant including a fossil driven peak load equipment, and special district heating parameters, the costs were analysed in terms of capital expenditure, operational and consumable costs. The resulting heat production costs are strongly affected by the geological setting and decrease with increasing plant size. The figure **3** shows that geothermal heat production from Type II reservoir **seems** to be economic in comparison to conventional fossil heat production. While geothermal heat recovery in such cases is competitive with conventional energy supply the drawback

for a more widespread utilisation is a psychological barrier for the investor who has to wait some years for the economic win.

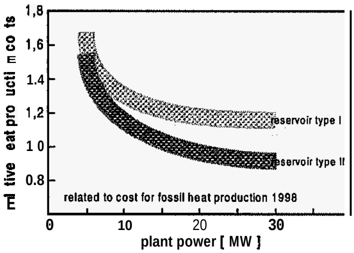

Figure 3: Quotient of calculated heat production costs of geothermal plants and conventional heated plants (= relative costs) as a function of plant power. Main difference in reservoir type is depth and temperature: type II is at greater depth and no additional heat pump is needed.

The heat production costs vary related to the reservoir productivity. In figure 4 depth and temperatures were kept constant.

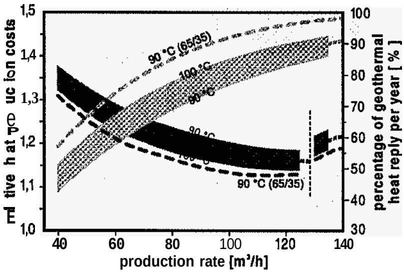

Figure 4: Quotient of calculated heat production costs of geothermal plants and conventional heated plants as a function of production rate and thermal water temperature (90 °C to 100 °C). The percentage of geothermal coverage of the yearly heat supply (30 GWh) is given in the lighter shaded graph. Calculations based on: peak power: 15 MW, district heating loop temperatures: 90/70 °C, (65/35 °C: dotted line) full load hours: 2000 h/a.

The peak load is covered by a fossil plant. Low production rates, for a given drilling depth and reservoir temperature, imply higher costs due to higher specific capital expenditures (e.g. for drilling). High flow rates result in a greater amount of geothermal heat supplied to the customer and less usage of the fossil **fuel** fired peak load system. This results in decreasing costs as long as the corresponding costs for completion (tubes, pumps, etc.) and operation (e. g. electricity) do not raise over proportional. **A** reduction of the district heating temperatures leads to a further increase in the economics of a plant significantly. The figure **4** shows the saving of peak load due to the possibility to enter a higher amount of geothermal energy into the district heating water loop. Optimised heating networks could significantly contribute to cost reduction.

Ecological system analysis

The exploitation of geothermal energy resources and the low temperature heat generation is regarded as a promising possibility of reducing the environmental impact of energy production.

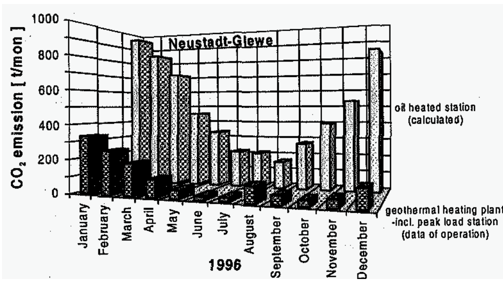

Figure 5: Comparison of CO_2-emissions derived from operation data of the Neustadt Glewe plant with calculated data for an equivalent oil heated station.

KAYSER & KALTSCHMITT (1998) performed a balancing method called life-cycle-analysis, which takes plant construction and disposal into account. Based on the same customer supply the emissions of CO_2-equivalents amount to 100 tons per TerraJoule [TJ] for a conventional oil heating station, 72 t/TJ for a gas heating station, 50 t/TJ for the Riehen geothermal plant, and 18 t/TJ for the Neustadt-Glewe plant. SCHALLENBERG et al. (1999) confm a quotient of ahout *20 %* CO_2-emission based on measured operation data of the Neustadt-Glewe plant in comparison to a conventional oil heating station, which was calculated for the same supply scenario. The figure 5 shows the comparison for the emissions during operation in a monthly resolution. Therefore, we conclude that geothermal energy can drastically contribute to an environmentally and climatically efficient energy supply.

Energy-economical analysis

The theoretical potential of geothermal **energy** in Germany is significantly higher than the yearly heat demand. Considering the technical scenarios, i.e. including all restrictions due to technical feasibility and the demand structure. KAYSER & KALTSCHMITT (1998) concluded that terrestrial heat is capable of covering quite a substantial part of the heat demand. While the present **use** of hydrothermal resources is approx. 0,5 PJ/year, this technical potential sums up to roughly 5000 PJ/year and is thus in the order of the yearly demand for warmth in Germany. The significance **of** the possible contribution of geothermal energy to the energy system in Germany is evident from these numbers but the future use **is** triggered by actual political and economical boundary conditions. The above mentioned end of the hydrocarbon era within the next century or with respect to special conditions in other countries, ***e.*** g. the Baltic states with **a** high demand on local energy, give other boundary conditions and increase the importance of geothermal energy.

Conclusions

The utilisation **of** low-enthalpy hydrothermal resources was investigated with an interdisciplinary approach of geoscientists, engineers and economists.

The geoscientific conditions for the utilisation of hydrothermal resources can be reduced to a number of parameters to characterise the reservoir and the thermal water within the temperature field of the resource. Some recommendations for a secure operation **of** the geothermal water cycle resulted from geochemistry. The long time behaviour **of a** plant was modelled numerically. It can be related to some geometric considerations of the bore hole set-up.

Data from running plants were compiled. With several plants in the North German Basin, in the Bavarian Molasse Basin and **in** the southern part of the Oberrheinthalgraben, operated by colleges in Switzerland, the technical feasibility is shown and similar experience to that of the French colleges was gained. Reliable technical solutions exist even for the highly concentrated geothermal brines of the very permeable but sensitive sandstone aquifers in North Germany and can be controlled over years.

Life cycle analysis and observation of geothermal plants during operation showed a very significant reduction of CO_2 emissions in comparison to fossil heat production. However, the economical evaluation leads to a restriction in the application of hydrogeothermal energy to existing district heating systems and similar customer structures. It is therefore important to continue interdisciplinary investigations on the potential **of** geothermal energy with special emphasis on the reliability, variability and scale of the considered parameters. The future market for hydrothermal heat production lies at the end of the hydrocarbon era.

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