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# The Neustadt-Glewe Geothermal Power Plant – Practical Experience in the Reinjection of Cooled Thermal Waters into Sandstone Aquifers

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## ABSTRACT

Germany has a considerable hydrogeothermal potential which is available for the environmentally sustainable and resource-saving production of heat. The example of the Neustadt-Glewe geothermal heating plant (GHP) is one more proof of the principle feasibility of energy production using deep and highly saline formation waters as heat source. Since the end of January 1995, operation of the GHP has been going on smoothly confirming the correctness of the selected technical and technological solutions. In 2003, the plant was extended by an additional cooling stage in the form of an upstream power generation unit. This paper presents the experience acquired in the exploration of the site, the planning, operation, and extension of the Neustadt-Glewe geothermal plant.

## 1. GEOTHERMAL RESOURCES IN GERMANY

In Germany, the utilization of deep geothermal resources is based on natural geothermal reservoirs with adequate geothermal deposits on the one side, and on rocks allowing hydrogeothermal energy production only after creation of artificially fractured systems on the other side. Regarding the natural reservoirs, porous rocks and secondarily fractured or cavernous rocks are of particular interest as potentially productive horizons. Such productive horizons, bearing 40 to 120 °C hot formation waters in depths ranging from 1,000 to 3,000 m, exist in large regions of Germany (Rockel, Hoth, and Seibt, 1997).

The economically efficient exploitation of these reservoirs requires large flowrates (50 – 100 m³/h/well at an economically justifiable drawdown). North Germany offers the most favourable geological conditions as very good pore reservoirs with high effective porosities (≥ 20 %) and a good cross-flow capacity ≥ $0.5 \times 10^{-12}$ m² ≅ 500 mD) do occur in many regions of the North German Basin. At present, three GHP are operated in northern Germany.

## 2.THE NEUSTADT-GLEWE GEOTHERMAL PLANT

The Neustadt-Glewe geothermal plant (cf. Fig. 1) was commissioned in January 1995 supplying exclusively in direct heat transition the base load of a district heating system amounting to a thermal output of approx. 11 MW, thus covering the demand of a major part of the town of Neustadt-Glewe. The installed geothermal capacity is 6 MW; a gas-fired boiler unit is operated to cover the peak-load. The site of Neustadt-Glewe is characterized by the hitherto deepest wells, the highest thermal water temperature and water mineralisation compared to all the other geothermal plants installed in Germany by now. In 2003, the plant was extended by a power generation unit (Menzel, Seibt and Kellner, 2000).

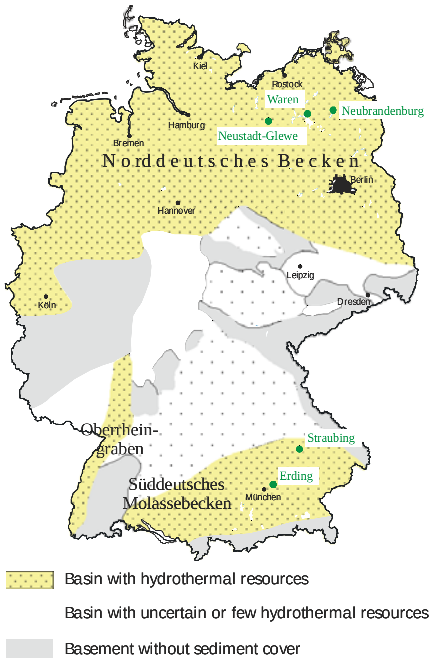


**Figure 1: Extension of natural geothermal pore reservoirs in Germany and location of the Neustadt-Glewe geothermal plant.**

### 2.1 Exploration and development

Thanks to the intensive oil and gas exploration in the North German Basin, the existence of reservoir rocks is generally known (Fig. 2). That is why the first step when selecting and exploring the adequate site implied the complex inquiry of all available geophysical and geological data for the investigated area focusing on: The regional geological conditions, extension and formation of reservoirs, temperature conditions, composition of the thermal waters. On this basis, a first estimate of the reservoir extension, the technically exploitable geothermal energy potential and potential methods of development was done. This first step was followed by a special vibro-seismic survey, then the drill site and the target horizons of the first well were planned. Through this well - drilled in 1989 – several sandstone horizons were explored and analysed with a complex investigation program (well logging, formation tests, laboratory investigations) for their suitability. These investigations form the essential prerequisite for a successful technical reservoir development or implementation of stimulation measures. This investigation

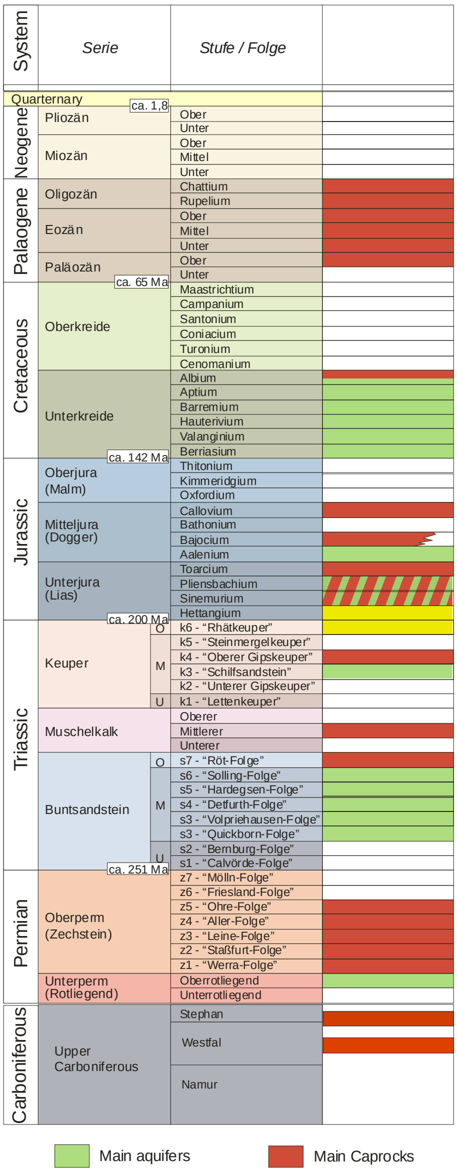


**Figure 2: Stratigraphic overview including the most important reservoir and cap rock sequences in the North German Basin; The producing interval of the Neustadt-Glewe site is marked in yellow.**

stage is therefore directly influencing the technical implementation and dimensioning of the future plant (Seibt, Horn, Möllmann and Brandt, 1994). Having drilled the 2nd well and completed testing, an Upper Triassic sandstone horizon was selected as the productive horizon which is characterised by the following parameters:

- depth: approx. 2200–2300 m; thickness: 40–60 m
- temperature: approx. 100 °C; formation water mineralisation: approx. 220 g/l
- porosity: 20–22 %; permeability: 0.5–1*$10^{-12}$ m²

The selected sandstone belongs to one of the most important reservoir horizons of the Mesozoic in northern Germany. The Upper Triassic "Rhätkeuper"- sandstones were deposited in a shallow marine environment. At the investigated site, these sandstones are mainly quartz-rich sandstones with quartz contents between 80 and 96%. Minor components are feldspar (1-5 %), carbonates (1-3 %), and clay minerals (up to 3%). Traces of pyrite and chlorite are also detected. Quartz is the main cement component, dolomite and kaolinite cements are only of minor importance.

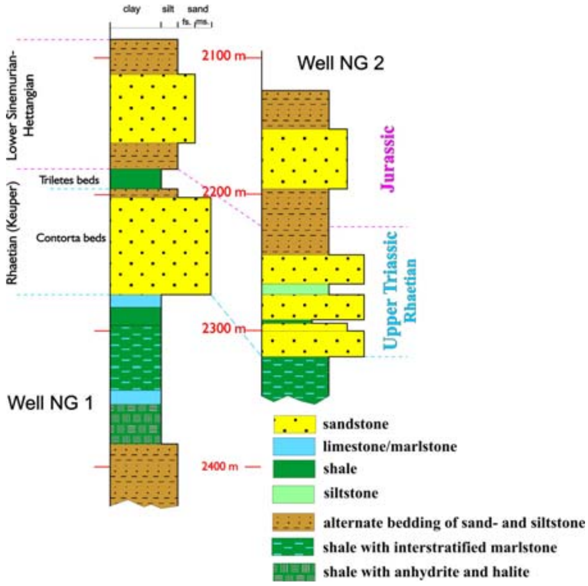


**Figure 3: Lithological cross-sections through the near-well reservoir sections of the two wells on the site of Neustadt-Glewe.**

From the very beginning, the wells drilled in 1989/90 exhibited a big difference between the production and the injection behaviour. While the required productivity > 100 m³ (h*MPa) could be proven in both wells, the injectivities remained far below the expectations. By means of stimulation measures a sufficient injectivity was achieved in the well NG 2 in a short-term test. However, these test results did not provide a sufficiently safe basis for the planning of the geothermal plant. Moreover, the effects of the 3-year standstill of the wells on the production and injection behaviour could not be assessed.

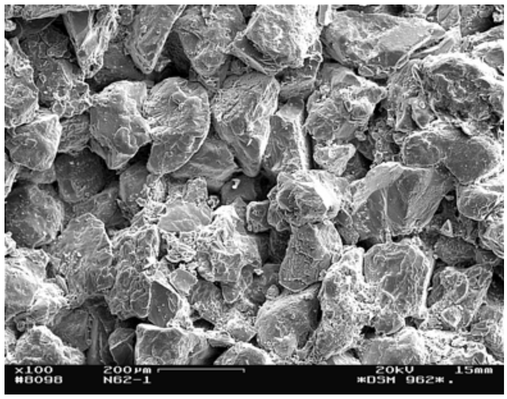


**Figure 4: Pore structure and signs of quartz cementation shown by SEM – sandstone of well NG 2.**

Consequently, testing was done again in 1993. Inspite of the extensive treatment measures, no satisfying results for the injection could be achieved in the well NG 1 – other than for production. Meanwhile, the well NG 2 proved its good injection behaviour which was tested last in 1990. These injection tests are explained in more detail in the Final Report on the EC-supported study "Improvement of the injectivity index of argillaceous sandstones" (Heederik et al., 1997). The comparison of the test results with the operating experience revealed that the behavior of the closed thermal water loop cannot be simulated definitely by injection tests.

### 2.2 Construction and operation

Based on the work done in 1993, the following decisions were made for the final well installation:

NG 1: installation as production well

NG 2: stabilization of the fragile reservoir section and installation as injection well

At first, the diameter of the protective casing in the production well was enlarged for installation of a submersible circulation pump. Subsequently, the pump was installed and the corrosion-protection system could be completed. Protection from corrosion is achieved by complete coating / lining of all surfaces, use of corrosion-resistant materials (glass fiber-reinforced casings), a protective fluid behind the production casings and the avoidance of the entry of oxygen by filling the system with an overpressurised protective gas (nitrogen).

Completion of the injection well began with the installation and gravel-packing of a wire-wrapped screen to support the unstable well wall. The perforated downhole section of the casing develops the upper part of the Contorta sandstones (Fig. 3) because their injectivity is absolutely necessary. The optimum solution was found to be the division of the reservoir into two sections. The underground screen head was installed without screen blanks along a casing length of 8 m only leaving open the perforation above. The screen head can be sealed inside allowing separate treatment for stimulation of both reservoir sections. The corrosion-protection system is analogous to that of the production well NG 1. Finally the performance of the two wells was tested, respectively. The results confirm the suitability of the wells to fulfil their tasks in the thermal water loop. The construction of the surface plant started in 1994. It was finalized successfully with the commissioning in 1995.

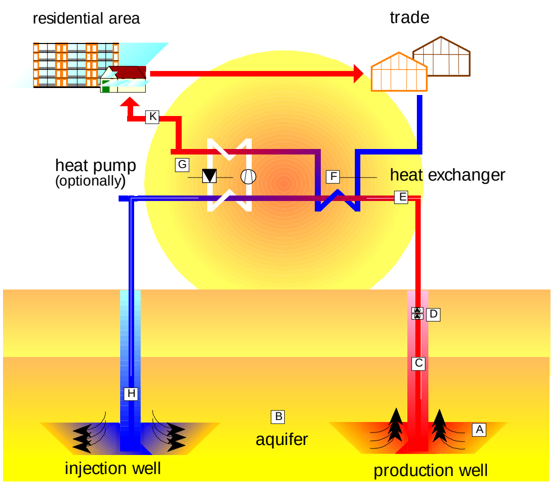


**Figure 5: Principle scheme and view of the central part of the Neustadt-Glewe GHP.**

The operation going on for 9 years now basically confirmed the plant concept; material and equipment resisted the high temperatures and the extremely high salt contents of the formation waters. Problems with the reinjection of the thermal waters which occurred over a short period of time were solved. Those problems were mainly caused by oxygen entry. Oxygen entered the otherwise closed system via a defective regulating valve over a short period of time in 1998, resulting in iron precipitation, which caused an increase of the injection pressure. After inspection of the injection well and intensification by soft acidising with HCl the injectivity could be restored to 100 %.

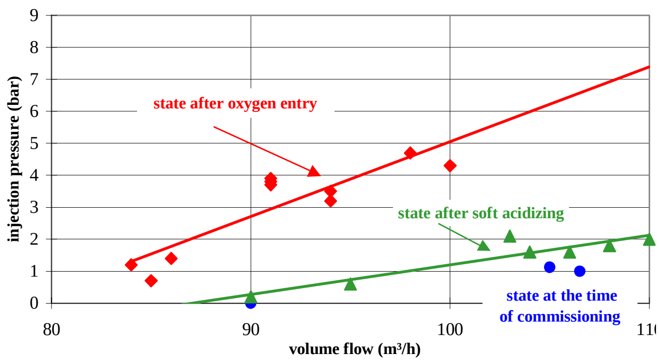


**Figure 6: Injection behaviour before and after intensification.**

The experience acquired during the long-term operation showed that in particular in case of this plant the entry of oxygen and ex-solving of gas from the thermal water must be avoided. Pressure maintenance and a nitrogen filling system allow for that. From this experience, the general requirement of special monitoring of the operation of such geothermal plants can be concluded (Seibt and Kellner, 2004).

### 2.3 Geothermal power generation

The geothermal potential of the site of Neustadt-Glewe which is available throughout the year in the same order of magnitude has not been fully used until 2003 due to the limited consumer potential and the specific characteristics of the demand on heat supply. Figure 7 shows that for an examplary year. On a few days only, the maximum thermal water flowrate is needed. In summer and in the transitional period, the submersible pump works basically at minimum speed producing approx. 40 $m^3$/h.

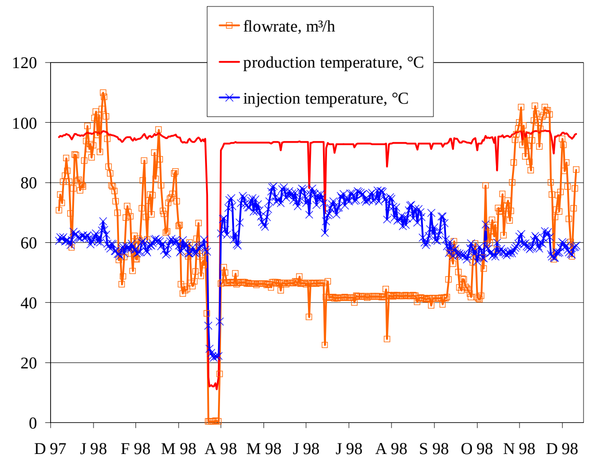


**Figure 7: Operating parameters of the thermal water loop for the year 1998.**

For that reason, the plant is extended by another cooling stage in the form of an upstream power generation unit. This demonstration plant is based on the well proven ORC (Organic Rankine Cycle) technique. Figure 8 shows the principle scheme.

Now, the mode of operation of the thermal water loop changes fundamentally. In the future, the maximum possible flowrate of 110 $m^3/h$ will be produced generally. The part of the thermal water which is not required for the supply of heat is fed into the ORC unit - via a surface pump - where it is cooled down to 68-70°C. The regulating variable for the splitting of the two thermal water flows and, thus, of the thermal water temperature after the mixing point is the given outdoor temperature-dependent temperature in the heating network after the direct heat exchanger.

Under full load and providing the conditions of dimensioning, the machine has a guaranteed rated power of 210 kW. It works on perfluoropentane ($C_5F_{12}$) which is expanded in a single-stage turbine.

An open evaporative cooling tower was selected for re-cooling, thus avoiding

- reductions of the output of the power plant as they occur with dry air coolers and at high outdoor temperatures in summer
- high power demand of the ventilators

and reducing the noise pollution of the environment.

The ORC unit was commissioned by the German Federal Minister for the Environment, Nature Conservation and Nuclear Safety on 12 November 2003.

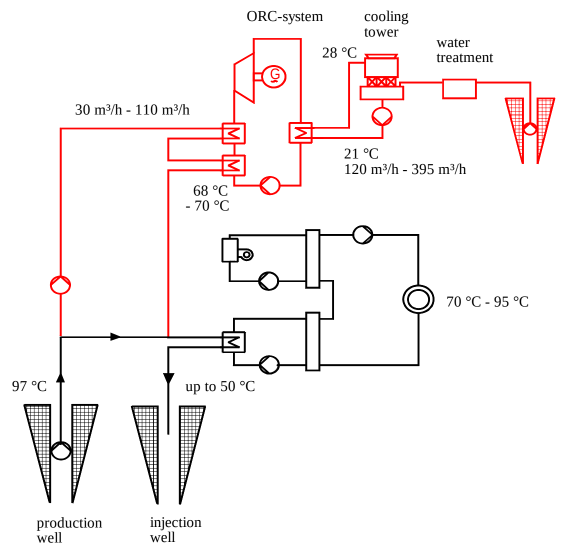


**Figure 8: Principle scheme of the Neustadt-Glewe geothermal plant after extension.**

The know-how gathered in the exploration, planning and long-term operation of the plant makes possible a broad application in other regions.

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