Utilisation of deep geothermal energy for heating purposes

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Abstract: The Hot-Dry-Rock-(HDR) technology allows a location-independent utilisation of geothermal heat, because aquifers in deep formations, i.e. layers filled with water, are not necessary. The flow paths for the circulating water in a depth of 4 km are created by hydraulic fracturing of existing gaps. Due to the fact that this new technology is quite cost-intensive, high annual load duration of the energy system above the surface is needed for an economic operation. Therefore, a process of electricity production by using low temperature steam (Organic-Rankine-Cycle (ORC) or Kalina-Cycle) or a plant for the supply of thermal heat and hot water could be installed. Under reference conditions the average geothermal heat output amounts to approx. 7 MW and the investment costs are nearly 30 million EUR. At present, a feasibility study is accomplished to verify the technical and economic feasibility as well as the standards and chances of this technology. This study is financed by the federal state of North Rhine-Westphalia and the European Union.

Keywords: geothermal energy; hot-dry-rock-technology; geothermal heating system; district heating; project ‘prometheus’ at location Bochum.


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1 Introduction

Based on an extension of district heating grids, the geothermal heat potential of the Hot-Dry-Rock-(HDR) technology amounts to approx. 2,500 PJ/a in Germany
This corresponds to 66% of the German low temperature heat demand. The development of this potential requires the demonstration of the technical and economic feasibility by the building of pilot plants. Such a plant for the integration of geothermal heat in an existing district heating net is planned in Bochum within the scope of the project ‘Prometheus’. That grid supplies the Ruhr-University Bochum (RUB), the University of Applied Sciences of Bochum (FHB), and the nearby university residential town (UW). The geothermal heat should cover the base load of these consumers. Since the HDR-technology is to a large extent, independent of the type of underground, the obtained results could be transferred to locations with comparable energy infrastructure and heat demand.

2 Hot-Dry-Rock technology

Geothermal energy represents a resources saving, climate protecting – regarding human dimensions – an inexhaustible energy source. Its important advantage is the continuous availability, not depending on intra-day or seasonal variations. In areas without volcanic activity like in Bochum, a drilling depth of about 3.5 to 4 km is required for the direct heat utilisation, because the temperature of the earth’s crust increases about 3 K per 100 m. Besides the temperature, underground conditions like the porosity and permeability of the formation are relevant for the geothermal usability.

The Hot-Dry-Rock technology allows the utilisation of geothermal energy, even no high-permeable rock formations exist at depth (Rummel and Kappelmeyer, 1993). Here, an underground geothermal heat exchanger must be stimulated between the two drill holes by high-pressure fluid injection (‘hydraulic fracturing’), i.e., existing fractures in the rock are widened and new are generated (Figure 1). During the operation of the plant, water is pressed into the injection borehole, circulates through the created heat exchanger, where it is heated, and finally pumped through the production well to the earth’s surface. Apart from the water injected, hot water from the underground contributes to the heat output which is conveyed to the district heating net at the surface.

Significant experiences concerning HDR technology were gained within the European HDR-demonstration project in Soultz-sous-Fœret (France) (Jung et al., 1998; Kaltschmitt, Huenges and Wolff, 1999; Baumgärtner et al., 2002). The advantage of this location is an anomaly of temperature which results in a temperature of nearly 200 °C at the depth of 5 km. Here, the aim is the production of electricity with a high duration because – in contrast to Bochum – consumers with an appropriate heat demand are missing. Moreover, a lot of projects work on utilisation of deep geothermal energy, but the main emphasis is focussed on electricity production too (Kaltschmitt and Schröder, 2002). The connection of HDR technology with exclusive heat utilisation has not been a subject of research and demonstration projects so far.

3 ‘Prometheus’-project: geothermal heat supply in Bochum

The realisation of a demonstration plant for geothermal heat supply at the location Bochum can be recommended due to two reasons: on the one hand the demand of a high rate of utilisation is fulfilled because of the existing all-season heat requirement, on the other hand additional capital costs can be avoided due to the existing district heating grid. Since the geothermal potential is to be assumed as representative for German conditions, a transferability of the obtained results is ensured.
3.1 Geo-scientific boundary conditions

In order to achieve an appropriate temperature for the heat supply of the consumers, the depth of the two boreholes is fixed to 4,000 metres. Here, the temperature of the rocks amounts to approx. 118 °C (Jung and Schellschmidt, 2003). The loss of temperature from the borehole foot to the borehole head is estimated to maximal 8 Kelvin, so that the thermal water reaches the surface with a minimum temperature of approximately 110 °C. Based on the experiences of the coal mining industry, it can be assumed that the underground shows a net of existing cracks and fissures and with it, a natural flow rate of thermal water. In connection with the probably advantageous suitability of the rocks (claystone and sandstone) regarding the process of hydraulic fracturing, flow rates of thermal water of approx. 30 l/s should be available (reference conditions). The high mineral content of the water (more than 300 g/l) requires special material qualities of the plant components that are in contact with the thermal water.
3.2 Energetic boundary conditions

At present, the consumers Ruhr-University Bochum, University of Applied Sciences Bochum, and the university residential town are supplied by district heating nets that are fed by one gas fired combined heat and power station. The annual heat consumption of approx. 60,000 persons amounts to nearly 295 GWh/a: 47% are caused by the RUB including the FHB, the remaining 53% by the UW (Table 1).

<table>
<thead>
<tr>
<th>Students/ Inhabitants</th>
<th>Heat consumption [GWh/a]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ruhr-University Bochum</td>
<td>37,000</td>
</tr>
<tr>
<td>University of Applied Sciences Bochum</td>
<td>5,000</td>
</tr>
<tr>
<td>University Residential Town</td>
<td>18,000</td>
</tr>
<tr>
<td>Total</td>
<td>60,000</td>
</tr>
<tr>
<td></td>
<td>295</td>
</tr>
</tbody>
</table>

Source: Gröne and Hampel, 2002; Stadtwerke Bochum Ltd., 2002

The minimal heat demand is about 8 MW (see Figure 4). Therefore, the intended high rate of utilisation – which is important for an economic operation of the geothermal plant – can be realised under reference conditions. As a consequence, the integration of a low temperature power generation process is not necessary. The location of the geothermal heating plant and the drillings will be in all probability in the south of the Ruhr University (Roth and Schneider, 2003). Therefore, the integration of the geothermal heating system in the existing energy infrastructure can be realised at the Technical Centre of the Ruhr-University (Figure 2). The existing combined heat and power station should cover the heat demand which exceeds the geothermal heat supply.

3.3 Phases of the project ‘Prometheus’

The entire project is divided into three phases. At present, a feasibility study (Phase I) regarding the contents of the entire project ‘Prometheus’ is accomplished. This study is supported by the federal state North Rhine-Westphalia and the European Union. Main
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3.4 Subject of the engineering studies of energy technology

While the geo scientists examine the underground boundary conditions in detail (keywords: geology, geophysics, hydrogeologie), the task of engineers is the creation of an optimal concept for the extraction, integration, distribution and utilisation of the geothermal heat. For this, the worksteps represented in Figure 3 are processed using the simulation programme TRNSYS. At first, the simulation of the existing heat demand is executed based on an estimated typical heat requirement curve in hourly resolution. The heat demand is divided into the different applications like heating (with heaters), ventilation and hot water (Kattenstein, Ziolek and Unger, 2001). The additional integration of the flow and return temperatures of the single applications, enables the computation of the return temperatures and heating water mass flow of the entire grid. Both latter parameters are used as initial data for the following simulation of the geothermal heat supply. In addition, this part of simulation is importantly influenced by the geo-scientific boundary conditions and the technical characteristics of the plant components. The used simulation tool enables the comparison of different technical concepts and the analysis of different boundary conditions for the heat demand and the geothermal potential. Analyses of the influence of different geothermal and economic initial parameters on the results (e.g., geothermal output and heat generation costs) are also accomplished.

4 Results of the engineering studies of energy technology

The simulation of the status quo of the heat supply and the future integration of the geothermal heat is based on hourly data of the heat demand for an average year of the Ruhr area, called Test Reference Year (TRY). These data are determined by measurements that are adapted to the TRY database by correlations. The measurements of the RUB and FHB were carried out by the Department five of the Ruhr-University, whereas the measurements of the UW were done by Stadtwerke Bochum Ltd.

The results of the division of the hourly data into the heat applications are shown in Figure 4. Regarding the RUB and FHB, heating and ventilation have to be differentiated. Their shares of the total annual heat demand of RUB and UW (140 GWh) amount to 41% (heaters) respectively: 53% (ventilation), while the remaining 6% are losses of the distribution net. The heat applications of the UW are heaters (64% of the total demand of
UW of 155 GWh/a and hot water (24%); because of the widely branched net, the losses of UW are with a number of 12% on a higher level.

**Figure 3** Boundary data, calculation process and results of the simulations of the heat demand and the geothermal heating system

The complete simulation of the status quo also requires the flow and return temperatures of the three applications depending on the outside temperature. Including the existing pipe structure and the regulation of the different applications in the simulation model, the hourly aggregated mass flow and the return temperature of the net can be calculated. The simulation results show high exactness reproducing the measured values (Figure 5). The estimated average return temperature amounts to 54 °C in the grid of RUB incl. FHB and 62 °C in the net of UW. Due to that, for maximisation of the geothermal output the future concept of operation of the geothermal plant should be designed for the exclusive geothermal supply of the RUB and FHB, as long as their demand is sufficient.
The system engineering must be divided into the components above and below the surface. The part below includes the drill holes, the net of fissures between the holes (i.e., the underground heat exchanger) and the submerged pump in the production well. The investment costs for this amount to nearly 14.6 million EUR in the reference case, from which the wells contribute the lion’s share with about 13.1 million EUR (including additional observation boreholes and insurance). For the service life of the underground system 20 years are estimated.
The system above consists of the elements of the geothermal cycle (pipelines, filters, slop system, pumps, etc., Figure 6), the elements of the heating water cycle (pipelines to the existing district heating net, circulation pump, regulation system, etc.) and the heat exchanger which connects both.

**Figure 6**  Schematic representation of the geothermal cycle

Under reference conditions, the geothermal heat could not permanently assure the needed flow temperatures of the net, so that a further heating system has to be included into the geothermal plant (see Figure 2). That could be a boiler fed by natural gas or biomass or alternatively the blending with the regular CHP plant flow. The costs of elements above the surface amount to nearly 2 million EUR. In consideration of additional expenditures for testing and research (5.7 million EUR) as well as planning and unforeseen events (also 6.7 million EUR), the overall investment costs for the geothermal heating plant come to approx. 29 million EUR (Figure 7).

**Figure 7**  Investment costs of the geothermal heating plant including surcharges for planning and unforeseen events (reference conditions, 100% ≈ 29 million EUR)
In the case of reference conditions, i.e., two wells with a depth of 4,000 m, the geothermal heat supply amounts to approx. 60 GWh/a. This corresponds to an average output of 7 MW and a share of 20% of the total annual demand (Figure 8). Thus, annual savings of 60 GWh of primary energy carriers and 11,500 t of greenhouse gases can be realised. These reductions are equivalent with 16% each compared with the existing district heating supply. For the building of the geothermal plant (dismantling is negligible), approx. 30 GWh of primary energy carriers are needed, so that the energetic amortisation is about half a year.

**Figure 8** Annual course of the heat demand of the consumers RUB, FHB and UW (295 GWh/a) as well as the geothermal output (58.4 GWh/a) and heating boiler output (3.5 GWh/a) in hourly resolution under reference conditions.

In consideration of an interest rate of 5%/a, a price increase rate of 3%/a and current energy prices, the specific costs of geothermal heat generation range between 65 to 70 EUR/MWh. Therefore, the price for the unchanged heat supply of the consumers by the CHP plant of approx. 45 EUR/MWh is exceeded significantly. The highest share of the geothermal heat generation costs show the investment costs (57%) and the costs in consequence of impairment of the existing supplier, i.e., the CHP plant (28%). The last-mentioned costs have to be paid by the operator of the geothermal plant, because the resulting price increase for the remaining district heating demand (12%) cannot be carried by the customers RUB and FHB as well as UW.

The mid and long term reductions of the investment costs of 15 to 25% could be achieved due to the building of a larger number of geothermal plants (Schaumann and Pohl, 2002; Federal Ministry for the Environment, 1999). That can result in a cost-effective operation of geothermal units, if the costs due to the interference of the operation of the existing supply system also decrease. This can be realised by the establishment of geothermal plants in cases, if the existing district heating systems are modernised.
Conclusions

The Hot-Dry-Rock technology enables the utilisation of deep geothermal energy widely independent of the geological conditions of the location. Therefore, a huge energy potential is offered by these techniques. An appropriate technical use on surface represents the heat supply of big consumers. Here, in particular the supply of an existing district heating nets is predestined in order to minimise the expenses for the plant on surface. The first step for the development of the enormous geothermal potential must be the construction of demonstration plants for the geothermal heat supply.

The location of Bochum is recommended for the realisation of such a demonstration plant because of the representative geological and geophysical conditions of the underground and the existing energy infrastructure. The present results of the feasibility study based on indirect examinations of the underground and computer simulations of the geothermal heat supply, confirmed the possibility to build the geothermal plant under controllable risks. The next step must be the drilling of one borehole to verify the underground conditions respectively, the present results. If the verification can be accomplished successfully the last step comprises the complete realisation of the geothermal plant – with the drilling of the second borehole, the stimulation of the underground heat exchanger and the plant construction on surface.

References


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