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Evaluating the Geothermal Potential of Abandoned Mine Workings: an Appropriate Approach Based on Geological and Technical Conditions

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Abstract The investigations established a qualitative assessment of the geothermal exploitation for geothermal fields based on geological, geohydraulic and mining criteria. This assessment should help companies with decisions on the extension of individual concessions. The options for use of the geothermal energy by potential consumers were not investigated. The assessment criteria included both the naturally existing voids in the rock mass and the anthropogenic voids created by mining activities. Both the degree of opening through existing shafts within the boundaries of the geothermal fields as well as the number of floors were used as a measurement for the voids created by human activities. The maximum depth of the shafts and floors are also important criteria for the regeneration of the heat content of the utilized mine water. The results of the assessments enabled the energy provider to make decisions on the exploitation of the corresponding mines and provided information for future detailed investigations.
Keywords ruhr region, abandoned mines, mine water, geothermal energy

Introduction

In the past decades, the Ruhr region in Germany has undergone dramatic structural change from a formerly strongly industrialized economic region to a cultural and technological service sector. According to resolutions of the German Federal Government, subsidized coal mining is to be abandoned in the year 2018. These areas are to be put to alternative use by converting the surface installations into commercial areas or tearing them down to build residential or commercial areas. With the termination of coal mining, the cost-intensive pumping of deep groundwater for the draining of mines is no longer required. To reduce the follow-up costs, the plan is to stop the pumping after shutting down a mine and to let the mine water rise in a controlled manner. This leads to the formation of a significant warm water reservoir in the mine because the water absorbs heat energy from the surrounding rock mass. The geothermal alternative use of the heat potential stored in the mine water can provide an economical and environment-friendly heat supply for local municipalities and commercial operations. Due to the legal prescriptions on the use of regenerative heating energy sources, the use of geothermal heat energy can also result in financial benefits (Rosner et al. 2006).

The technical feasibility of the geothermal utilization of mine water for the heat supply of residential and commercial buildings depends on the knowledge of various factors:

- Mining, geological and hydrogeological conditions;
- Caving of the mine, which enhances permeability;
- Depth of the mine, which influences rock mass temperature;
- Location of the shafts and distance to the users.

Several mines were investigated for an energy provider with respect to the utilization of geothermal energy based on a comprehensive evaluation of the lithologic, tectonic and hydrogeologic conditions and the hydrochemistry of the groundwater in the investigated area (Coldewey 1974, Hahne and Schmidt1982, Rudolph 2006).

Geothermal Utilization of Mine Water – State of the Technology

Abandoned and flooded mines represent a favorable prerequisite for the cost-effective exploitation of geothermal energy. Especially at average depths of approx. 100 m to 1500 m, there is an intense heat exchange between the rocks of the caved rock mass and the mine water. Due to the natural geothermal gradient, with an increase in temperature of approx. 3.6 °C/100 m of depth, flooded mines are considered as an infinite warm water reservoir. For example, the mean rock temperature in the central Ruhr area are ca. 42 ℃ at a depth of 1000 m and 64 ℃. at 1500 m (Patteisky 1954, Leonhardt 1983). The concept of using this heat potential was already explored in the 1950s. However, the implementation failed due to the surplus of inexpensive primary energy and emerging construction material problems.

Abandoned coal mines offer other benefits for geothermal alternative uses:

- Large volumes of rock and mine water with sufficient rock permeability;
- Favorable pore volumes in caved rock;
- Well-known mining, geological and hydrogeological conditions;
- Temperature of the mine water, generally above 20 ℃.;
- Existing shafts can be used for water pumping and infiltration.

In practice, two technical methods are generally used for the production of geothermal energy in abandoned mines. The suitability of a mine depends on the local above-ground demand situation and the market opportunity for existing and planned construction projects. With the single probe method, a closed geothermal probe system is installed in a shaft. Heat extraction from the water column standing in the shaft and the surrounding rock takes place through a heat transfer fluid in the pipe system. The advantage of the single probe is the uncomplicated installation in open shafts. However, because heat is only extracted from the immediate area of the probe, this method is principally suitable for the supply of smaller residential units near the shafts.

With the so-called doublet system, heat is extracted from the mine water and the cooled water is discharged into two shafts or wells that are separated by a certain distance. These shafts are connected to each other by mine openings, so that extensive heat flow takes place between the discharge site and the abstraction site, in which the water can be reheated. Additional boreholes or above-ground pipes to the discharge sites may be required to avoid a hydraulic short circuit, i.e. to prevent cooled water from flowing directly into the withdrawing well without being sufficiently heated beforehand. In addition, increased chemical reactions in the cooled, strongly mineralized mine water imposes greater requirements on the installation engineering.

The doublet system ensures the supply of a greater quantity of heat, whereby – in contrast to the single probe systems – the supply of larger residential units and commercial operations is possible.

Geothermal Potentials in the Investigated Area

A distinction must generally be made between shallow geothermal energy, which uses groundwater down to a depth of ca. 400 m, and deep geothermal energy at greater depths. Due to the minimal installation effort and moderate energy yield, shallow geothermal energy is usually used for the supply of private homes. Both closed methods (geothermal collectors, geothermal probes) and open systems (groundwater wells, heat and cold reservoirs) are used.

Deep geothermal energy, at greater depths, can achieve a greater energy yield by using tempered deep groundwater, whereby office buildings and industrial plants can be supplied. Again, both closed systems (deep geothermal probes) and open systems (hydrothermal use, petro-thermal use) are used. Due to the variable extraction depth, the extraction of tempered mine waters, as discussed here, takes an intermediate position between shallow and deep geothermal energy.

Methodology

Numerous documents and archives were screened and evaluated to estimate energy yields in the geothermal fields of the energy provider (Huske 2005). This estimation of geothermal exploitation was based on the following geological, tectonic and mining criteria (Rosneret al. 2006, European Union 2008):

- Geological conditions;
- Number of shafts in the geothermal field;
- Maximum depth of the shafts;
- Number of floors;
- Maximum depth of the floors;
- Expected total void volume.

The expected total void volume from the different void fractions (pores, joints, and anthropogenic voids) is an important criterion. In addition to natural porosity in the overburden, underground mining of hard coal causes pressure relief in the rock, whereby the rocks surrounding the openings are loosened. These lowered rock areas exhibit a higher degree of disruption than natural fractures caused by tectonic deformation, spanning an average of 2 m, up to a maximum of 8 m, into the rock mass. The sequence and number of the individual floor levels in a mine also influence the loosening of the rock mass. If a large number of floor levels occurs in a small space, it is probable that mining of the coal and the adjoining rock caused particularly strong lowering of the rock mass due to convergence. An elevated permeability can be expected in the caved areas, which increases the energy yield. The total quantity of the mined hard coal is therefore an indication of the size of the anthropogenic voids, among other things.

The existing shafts and sections also enable extensive water circulation and thereby exploitation of geothermal energy from heated mine water (Heitfeld et al. 2006).

In general, under certain conditions, some sites are more suitable than others for the use of geothermal energy. Concrete implementations require feasibility studies on individual sites in terms of the following influencing factors:

- Geological and hydrogeological conditions,
- Depth of the mine and the resulting rock mass temperature,
- Degree of excavation as well as caving of the mine workings and the resulting effective rock permeability,
- General options for the possible transport of heated mine water, or the infiltration of cooled water,
- Mining requirements on the shaft and on the still-existing mine workings,
- Sustainable relationship between heat extraction and heat replenishment,
- Location of the geothermal fields relative to potential geothermal energy consumers.

To assess these influential factors in terms of heat exploitation, the mines belonging to an energy provider were evaluated and represented in a matrix (Table 1):

Table 1 *Matrix for the qualitative assessment of geothermal exploitation in the geothermal fields of an energy provider.*

Geothermal field	Tectonics	Depth of the mine	Mining conditions	Overall assessment
1	+	+	+	++
2	+	+	+	++
3	+	+	+	++
4	+	O	+	+
5	O	+	+	+
6	O	+	O	O
7	+	Θ	O	O
8	+	Θ	O	O
9	Θ	O	Θ	Θ
10	O	Θ	Θ	Θ
11	O	Θ	Θ	Θ
12	Θ	Θ	Θ	Θ

++—*Very suitable;*+—*Well suitable;o—Moderately suitable;-—Poorly suitable;--——Very poorly suitable*

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