Reutilization of Mine Water for Heating and cooling in the Abandoned Colliery Dannenbaum in Bochum

Gregor Bussmann*[1], Kirsten Appelhans[1], Florian Hahn[1], Felix Jagert[1], Rolf Bracke[1], Torsten Seidel[2] and Christoph König[2]

[1] International Geothermal Centre (GZB), Bochum, Germany

[2] delta-h Ingenieurgesellschaft, Witten, Germany

*gregor.bussmann@hs-bochum.de

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ABSTRACT

Within this pilot project, it is planned to provide the heating and cooling supply for the redeveloped commercial area Mark 51°7 (former Opel plant 1) by using the thermal source of mine water from the abandoned colliery Dannenbaum, that is located below the area.

After the closure of the Dannenbaum colliery (1859 - 1958), the shafts were filled and the mine was flooded to above the 4th level, up to approx. -190 m above sea level. For the realization of mine water utilization, the subsurface infrastructures of the former Dannenbaum colliery are to be developed via production and injection wells using directional drilling technology. For the heat supply, a well has to be drilled into the 8th level at -693 m NHN with projected undisturbed temperature up to 37°C. For cooling purposes, a second well has to be drilled into the 4th level at a depth of 334 m below ground with predicted temperatures of approx. 18°C. The necessary measures for the project are a low-temperature heating and cooling grid (low-ex), a mine development via two or more directional boreholes and a heating and cooling centre with reversible heat pump system. The proposed mine water usage for heating and cooling supply has not been realized in Germany so far.

The pumped mine water can not be used directly, but must be raised or lowered by means of a heat pump / cooling machine to a temperature level of 48°C in the heating case and 10°C in the cooling case that can be used by the customer. At this stage of the project, it is planned to provide the base load with a maximum of 6,704 MWh of heating and 4,735 MWh of cooling via mine water utilization, whereby seasonal performance factors of 4.79 in the heating case and 4.40 in the cooling case can be achieved.

By means of a multi-level thermal-hydraulic modeling concept, the operation of the mine reservoir was simulated over a period of more than 600 months, taking into account the influence of the existing mine water drainage of the RAG. It could be shown that a short circuit between the injection and extraction of mine water does not take place and that the mine can sustainably provide the heat and cold volumes over a period of 50 a.

1. INTRODUCTION

The presented pilot project will take place at the "Mark 51°7" location, which covers the area of the former Opel plant 1 in Bochum (Germany) (Figure 1). By the FUW GmbH (Stadtwerke Bochum group) an energy supply concept has been drafted. Accordingly, heating & cooling of about 40% of the area shall be supplied by using the thermal source of mine water from the former mine Dannenbaum (that lies below the area) with the support of a heat pump system. The overall investment consists of three elements:

- Installation of a low-temperature heating & cooling grid (low-ex).
- Geothermal development of the mine building via two or more directional boreholes.
- Construction of the heating & cooling centre with reversible heat pump system.

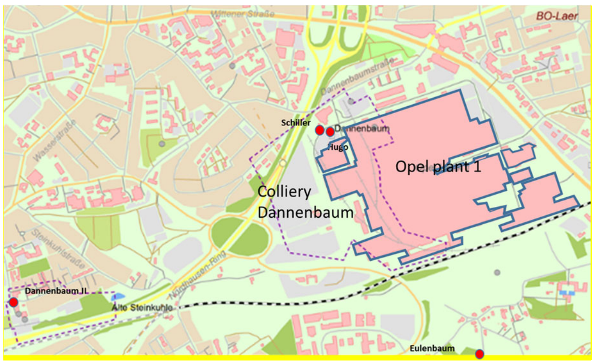

Figure 1: Former Opel plant 1 and Dannenbaum Colliery with shafts Schiller, Hugo, Eulen-baum and Dannenbaum II in Bochum-Laer, Germany (modified according to www.ruhrkohlenrevier.de).

The proposed usage of mine water via an open doublet system with regeneration of the heat reservoir has not yet been realised in Germany. The heating and cooling network at Mark 51°7 is to be established as 5th Generation District Heating and Cooling grid. 5GDHC has a huge potential for scaling-up and rolling out in Germany, and specifically in the Ruhr area, considering the large existing DH networks (mainly 2nd and 3rd generation) which can be upgraded to 5G. The special model character of the project will be emphasized by a comprehensive scientific support program, which includes thermo-hydraulic-density modelling, a comprehensive sensitivity analysis and a monitoring concept. This will allow for a better assessment of economic, technical and environmental risks of future projects.

2. HISTORICAL DEVELOPMENT OF THE SITE

2.1 Dannenbaum colliery

The first coal mining on the site occured already in the 14th century. The Dannenbaum colliery started operations in 1736. There are various principal adit levels and other pits documented. The entire area is characterized by near-surface mining. In 1859 shaft Schiller, 1873 shaft Dannenbaum II, 1888 shaft Hugo and 1899 shaft Eulenbaum were established (Figure 1). The mine layout consists in total of eight levels, which are listed in Table 1 with a specification of the depth (Huske, 2006).

Table 1: Depth of the levels of Dannenbaum colliery.

	m asl	depth (m)
Topographic surface	114	
Isabella principal adit	+88	26
level 1	+69	45
level 2	-11	125
level 3	-97	211
level 4	-212	326
level 5	-380	494
level 6	-489	603
level 7	-511	625
level 8	-696	810

In the 20th century, due to operational optimization, the Dannenbaum colliery was merged with the neighbouring collieries Prinz Regent and Friedlicher Nachbar via connecting galleries on some levels. The three collieries were aggregated to one water management province, called Friedlicher Nachbar. Figure 2 shows the entire mine layout of the 4th level (blue) and the 8th level (red).

In 1958, the final closure of the mine took place. Afterwards the shafts were backfilled and the mine were partly flooded. The current mine water level corresponds to the pumping level of the dewatering location of the former colliery Friedlicher Nachbar. The German coal mining company RAG is pumping mine water from a depth of -190 m asl with an annual volume of 5.9 million m³ (as of 2017) at this site and discharging it into the Ruhr River.

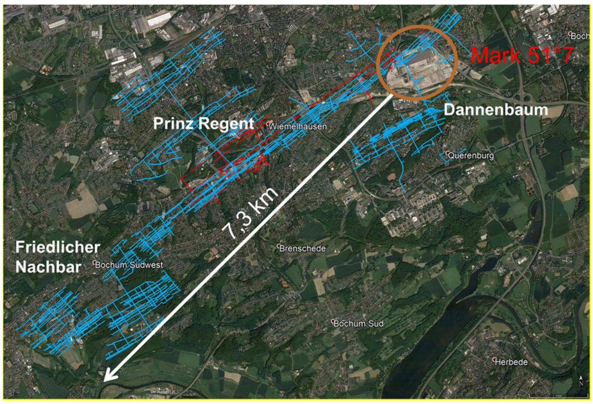

Figure 2: Mine layout of collieries Dannenbaum, Prinz Regent and Friedlicher Nachbar at the 4th level (blue) and at the 8th level (red) (GZB).

2.2 Opel plant 1

Due to the construction of Opel plant I in Bochum, the well-developed site of the abandoned Dannenbaum colliery was reused. Vehicle production took place between the opening in October 1962 until the complete closure of the plant at the end of 2014. The opel site is shown in the Figure 1. The blue framed areas are factory buildings, which were mostly dismantled.

2.3 Industrial, Technology and Knowledge Campus Mark 51°7

For the preparation and marketing of the area the Bochum Perspektive 2022 GmbH has been founded. A private company formed by the shareholders Adam Opel AG (49% share) and the urban economic development company Bochum (WEG 51% share). The property areas of Adam Opel AG were taken over on 01.07.2015. Figure 3 shows the development plan 947 as of December 2015 of the city of Bochum.

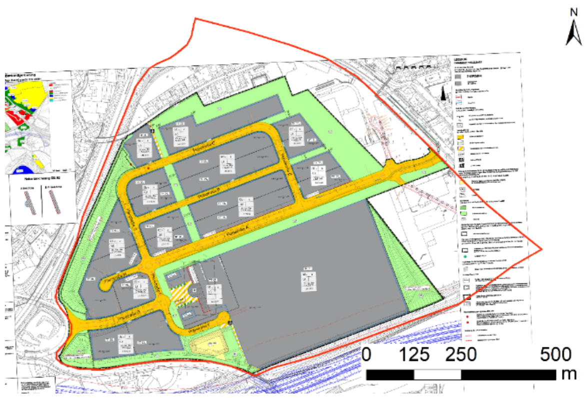

Figure 3: Development plan Mark 51°7 (Stadt Bochum, 2019).

MARK 51°7 will be an industrial, technology and knowledge campus that addresses the needs of future work environments and enables companies to provide a highly attractive work climate for their employees all in the spirit of work-life-blending. This creates an area of networked production and microservices that integrates companies, customers, employees and residents alike. MARK 51°7 will become the succinctly designed entrance gate to Bochum. An impressive architecture, attractively designed squares and green spaces open the formerly closed off private area (Bochum Perspektive 2022 GmbH).

3. CONCEPT

3.1 Development of the mine water reservoir

As part of the planned heating and cooling supply on the Mark 51°7 site, mine water of the abandoned Dannenbaum colliery is to be used innovatively as a geothermal energy source. Presently, the mine is flooded above the 4th level, at least up to -190 m asl (cf. Chapter 2.1). It is assumed that within the mine building, due to the increased geothermal gradient of the Ruhr carbon an undisturbed temperature level of approx. 37°C (Leonhardt, 1983) can be anticipated on the 8th level at a depth of -693 m asl, which can be used for heating production. For the 4th level at a depth of – 226 m asl, according to the measured water temperatures of Friedlicher Nachbar, a temperature of 18°C is expected, which can be used for cooling.

Because the formerly shafts are backfilled, the mine building has to be developed hydraulically via directional wells. For this purpose, a well is to be drilled into the 8th level at a depth of 816 m below ground. A second well is to be drilled into the 4th level at a depth of 334 m below ground. It is envisaged that during the winter months, the up to 37°C "hot" mine water is to be supplied by means of a submerged centrifugal pump from the 8th level to the corresponding heat pump system. The mine water cooled down by the heat pumps is to be reinjected into the 4th level with an injection temperature of approx. 18°C (Figure 4).

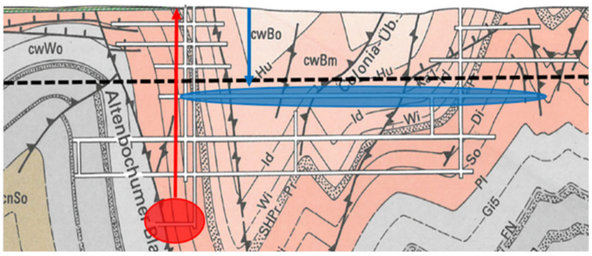

Figure 4: Mine water use in winter (modified according to the Geological Map 4509 Bochum).

In summer, this process is reversible and the "cold" mine water from the 4th level is lifted by means of a submerged centrifugal pump, heated by the active cooling mode of the heat pumps (reversible operation) up to 40°C and then reinjected into the 8th level (Figure 5), so that a regeneration of the heat reservoir can take place here.

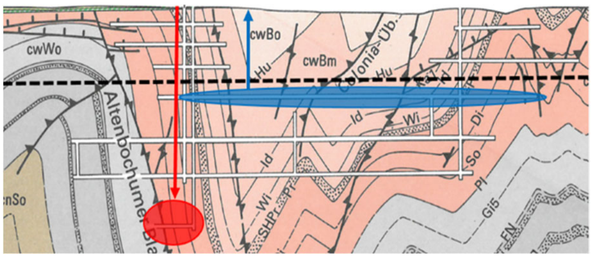

Figure 5: Mine water use in summer (modified according to the Geological Map 4509 Bochum).

The challenge of the directional drilling technique is to drill exactly in the underground galleries (Figure 6) at the desired level. The diameters of the galleries are in the range of approx. 3 - 4 m.

Figure 6: Typical gallery of Dannenbaum colliery.

The following selection criteria were used to localize the appropriate target points within the galleries:

- Minimum distance between start and target point.
- Largest possible cross-sectional area (e.g. intersection of galleries).
- Sandstone as surrounding gallery rock (highest residual strength).
- No intersection of geological fault zones and galleries and excavation-damaged zones of the higher level.

Figure 7 below shows a target range of the 8th level that meets all selection criteria.

Figure 7 Target point in the 8th level.

3.2 Heating and cooling network

Due to the new construction with the implementation of the EU Buildings Directive of 2010, it is possible to minimize the energy requirements and grid temperatures accordingly. The establishment of 5th Generation District Heating and Cooling in the area Mark 51°7 could be considered. The area relevant to the low-ex-grid includes the northern (section II east) and eastern part (section III) of Mark 51°7 (Figure 8). For the southern (BA I) and western part, an energy concept has already been implemented or other supply concepts are being pursued.

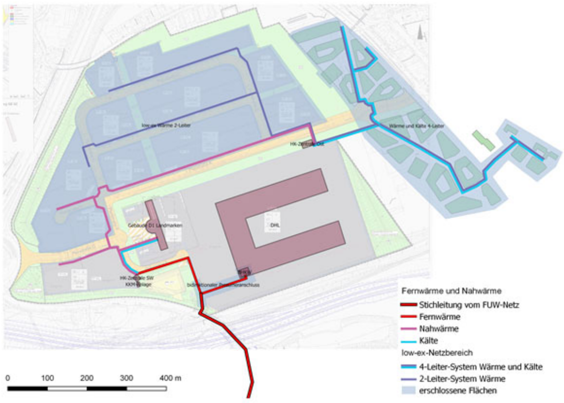

Figure 8: Grid scheme of mark 51°7 changed according Development plan (Stadt Bochum, 2019).

The pumped mine water cannot be used directly, but must be raised or lowered by means of a heat pump / cooling machine to a temperature level that can be used by the customer. In the plant, the following temperature values are relevant for heat pump or chiller operation:

- Heating case
  Mine water from 8th level with up to 37°C, after heat exchanger up to 35°C;
  raise with heat pump by min. 13 K to 48 ° C.
- Cooling case
  Mine water from 4th level with 18°C, after heat exchanger 20°C;
  lower with cooling machine by 10 K to 10°C.

The temperature rise of the heat pump / cooling machine is lower in both cases than in standardized applications. Very high seasonal performance factors can be achieved, if the machines used are adapted to these temperatures. The energy demand figures were calculated on the basis of the building area, floor height, density characteristics, energy standard and expected usage. The following Figures 9 and 10 show annual load duration curve for the heating and cooling case (maximum variant).

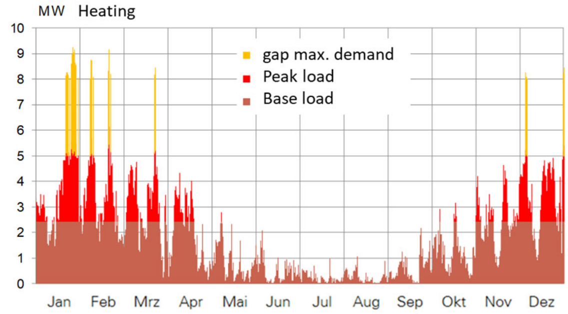

Figure 9: Annual load duration curve for the heating case with base and peak load (Gertec GmbH, 2018).

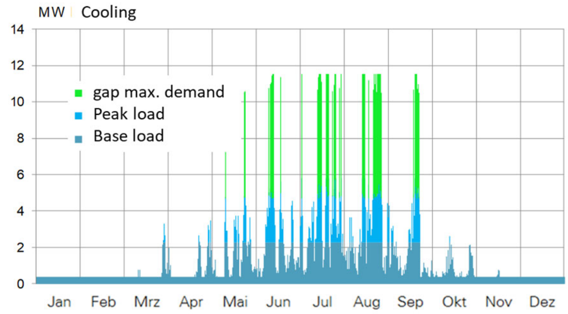

Figure 10: Annual load duration curve for the cooling case with base and peak load (Gertec GmbH, 2018).

In the present case, it is planned to provide the base load with a maximum of 6,704 MWh of heating and 4,735 MWh of cooling via mine water utilization. This can be achieved by taking into account the electrical power requirement for submerged pump and heat pump / cooling machine seasonal performance factors of 4.79 in the heating case and 4.40 in the cooling case. The remaining peak heat requirement is exceeded by the upstream local heating network provided nearby.

3.3 Coupling of the systems

The development concept for mine water usage with the time characteristic and the magnitude of the energy flows for the feed-in and feed-out into the mine building will be adjusted according to the scenario of heating and cooling supply described in chapter 3.2 on the basis of the determined demand of energy and the temperature drop in the planned supply grid.

An iterative alignment process takes place between the mine water concept and the above-ground spatial and technical specifications. These include the diameter of the wells, the location of the starting points (drill site), the heating and cooling plant and the heat and cooling grid as well as the dimensioning of the individual plant components such as pumps, pipelines, process measuring and control technology devices etc. Important for the dimensioning are, in particular, the volume flows and the temperature differences between flow and return of the grid.

By means of an underground model and numerical thermal-hydraulic simulations (see chapter 4), the developed mine water utilization concept is validated, whereby the extent to which the selected target points of the wells in the mine building under the thermal and hydraulic conditions of the subsurface can sustainably provide the heat and cold volumes over a period of 50 a is considered.

4. NUMERICAL MODELLING

4.1 Modelling concept

The existing mine maps of the former collieries Dannenbaum / Prinz Regent were completely digitized and transferred to a 3D subsurface model (Figure 11). In a multi-level modeling concept (Figure 12), the planned mine water utilization is numerically investigated. In this context, the possible influence of the exclusive mine water utilization with regeneration of the heat reservoir in connection with the existing mine water drainage measures of the RAG is also determined.

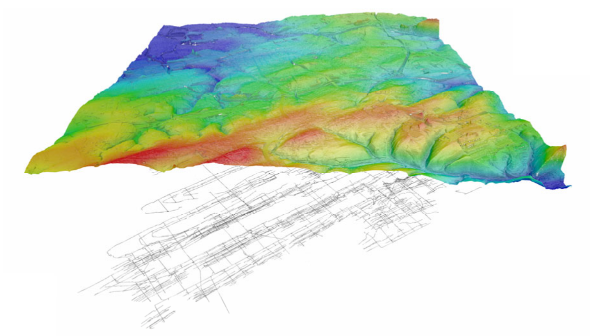

Figure 11: 3D subsurface model with the completely digitized mine layout (delta-h).

Due to the greatly increased groundwater flow in the associated mine buildings and due to the complex, clearly anthropogenically dominated surface drainage system, the hydraulic and hydrogeological interactions are far greater than in the natural environment. A simple reduction of the model area of hydrogeological simulations along drainage systems, water divides and wells is not expedient for the complex problem with very large boundary conditions. The system to be modeled must be integrated into the larger regional context. In addition to the regional model scale, material parameters can be estimated via near-field considerations and failure considerations are initiated. In addition to the problem of the definition of boundary conditions, the permeabilities of the fractured carboniferous rocks and of the fault zones are of major influence for the prognosis of the energy propagation from the mines. By means of small-scale local models, the propagation in the local area of galleries and shafts can be mapped and conclusions can be drawn from fracture distributions to permeability values.

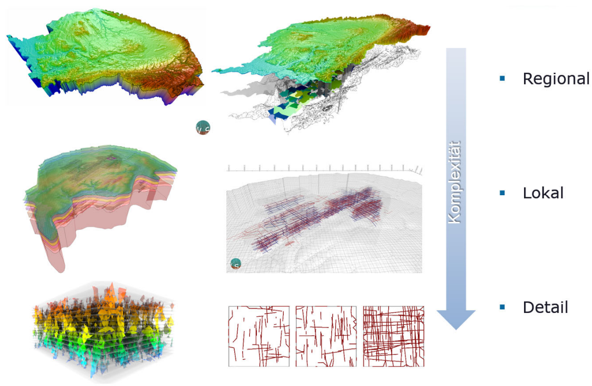

Figure 12: 3-level modelling concept (delta-h).

4.2 First results of numerical modelling

Density-dependent flow and heat transfer calculations were carried out, which simulate the operation of the mine reservoir over a period of more than 600 months. In figure 13 the flow field is shown as streaks and with water table contour for the winter and summer phase. The color graduation corresponds to the calculated temperature after 50 years.

The state in the summer phase differs from the winter phase mainly locally in the periphery of the injection and extraction node points. In particular, the inflow to the 4th level in the extraction zone can be seen in the streaks illustration (Figure 13). A direct bypass or short circuit between the injection and extraction area is not recognizable in both states.

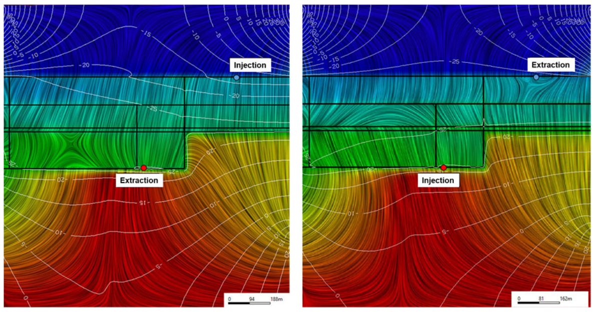

Figure 13: Streaks illustration and water table contour of the flow field, temperature distribution as color graduation for winter phase (left) and summer phase (right) (delta-h).

Also, for the temperature distribution over the entire modelling period, the interventions of the mine water use overlap with the dominant temperature field, which results from the natural geothermal gradient with the depth and the strong drainage effect of the mine. Preliminary results show that due to the drainage effect the temperatures within the galleries of the respective levels are very similar. In the 8th level, the temperatures are cooled significantly by the drainage effect compared to the predicted temperatures, due to the natural thermal gradient. However, a larger proportion of this temperature reduction is compensated by the mine water utilization and the related regeneration in the summer again.

5. CONCLUSIONS

The current state of investigation suggests, that under the currently determined boundary conditions a technical realization of the mine water utilization concept for heating and cooling in the abandoned colliery Dannenbaum in Bochum is possible by using directional drilling and implementation of a low-ex grid. The first results of the numerical thermal-hydraulic simulations show that the flooded mine reservoir on the basis of the selected thermal and hydraulic conditions of the subsurface, the determined demand of energy and the temperature distribution in the planned supply grid sustainably provide the heat and cold volumes over a period of 50 a.

In the upcoming project phase, it is foreseen to develop the mine galleries successive via directional drilling and to determine the subsurface data on the yield, the temperature and the hydrochemical composition of the minewater via pump tests. Based on this, the numerical model is validated.

In the case of a successful technical implementation of the wells and the low-ex grid there is a great potential for a transferability to other mining sites.

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