Abandoned mines as a source of heat and cold for quarter solutions

Timm Wunderlich[1], Lukas Oppelt[1], Tom Ebel[1], Thomas Grab[1], Tobias Fieback[1]

[1]*TU Bergakademie Freiberg, Chair for Technical Thermodynamics, Gustav-Zeuner-Straße 7, 09599 Freiberg, Germany*

Abstract

The communities bordering the former coal mining area of Lugau/Oelsnitz in south-west Saxony (Germany) were shaped by active mining for over 100 years. Structural change requires activities for aftercare, especially considering the possible leakage of mine water (if no countermeasures are taken) in 2032. In this context, the paper shows the investigation of using the mine water to be discharged as a thermal energy source. For the town of Gersdorf, 11 different residential buildings were simulated in MATLAB Simulink. The solutions were examined in terms of technical, economic, and ecological factors in relation to a local district heating network.

Keywords: Mine water, heat pump, district heating network, simulation, MATLAB

Introduction

In the Lugau/Oelsnitz, located in the south-west of the state of Saxony, area, a sedimentary package was formed during the Upper Carboniferous period approximately 305 million years ago, resulting in a thickness of up 200 m in the mining area hosting 12 economically viable coal seams. The first coal mining in this area began in 1831 and was subsequently expanded from 1844. The communities surrounding the former coalfield of Lugau/Oelsnitz have been shaped by active mining. Thus, making it one of the first hard coal mining areas in Germany during of the Industrial Revolution. Figure 1 shows the study area of about 70 km² – including of the municipalities of Oelsnitz (Erzgeb.), Gersdorf, Hohndorf and Lugau/Erzgeb., which are between the cities of Chemnitz and Zwickau and home to around 24,000 inhabitants. This suburban area developed around the mining sites and their surrounding vicinities became economic, cultural, and social centres of the area. [1]

During the 1950, at the peak of mining activities, coal mining operations extended for a total distance of approximately 140 km below the ground. The heading ways were located on 6 levels at different depths. The roadways on these levels can be considered hydraulic roadways. The lower-lying western minefield is separated from the higher-lying eastern minefield by the Pluto shaft fault. However, a connection between the two pit fields exists via the -146 m and the +25 m levels, due to the rising flood level indicating that the flooding level is balanced in the pit. The two pit fields are hydraulically connected via these levels. [2]

The excavation and extraction of coal and non-coal materials such as dead rocks, caused the land above these areas to sink. The mining-induced deformations at the surface, led to segregation processes in Oelsnitz of up to 17.34 meters. [3] Between 1859 and 1971, approximately 142 million tons of usable coal were extracted in the Lugau/Oelsnitz district [4]. As coal mining and dewatering discontinued approx. 150 million m³cavity began to flood. Due to subsidence and the sinking of the land, it is estimated that around 47 million m³ of free drifts and shafts are still present in the mining area, corresponding to 32 % of the raw mining volume. All other spaces are assumed to be filled with downfall of rocks. [1]

Since the closure of the mining activities in 1971, uncontrolled flooding has been occurring, with the flooding volume being determined by groundwater recharge. This average amount of flooding is expected to be 30 m³/h in 2032 and it´s estimated to be even higher due to the current deep inflows. This volume flow quantifies the annual average and is subject to seasonal fluctuations [5].

Due to the lack of monitoring and intervention measures in place, there was no data available on the current flooding level until the beginning of the millennium. Therefore, there was no possibility of actively influencing the flooding process. [1] However, in 2003, the State of Saxony established a mine water monitoring station (MWMS) in Oelsnitz (633 m below ground level) to monitor the flooding level and to check the water quality of the mine water. A second MWMS was set up in Gersdorf in 2014, which is located 674 m below ground level and focuses on data collection of the flooding level. [6]

In the southwest of the district is the community of Gersdorf which has the lowest valley elevation (+320 m meters above standard zero). If no preventive measures are taken, the mine water level is expected to rise and surface by 2032 due to subsidence. Near this area in the community are the former "Kaisergrubenschächt", which have been secured by mining as shown in Figure 1.

To prevent uncontrolled flooding due to escape of mine water, preventive measures must be taken, e. g. pumping out the inflowing mine water through a borehole.

Methods

Measures for aftercare are required for the regional structural change, especially due to the potential leakage of mine water from 2032. However, the municipalities in the area of interest, like most municipalities in Germany, still face challenges to implement renewable heating and cooling in the building sector. Some mine waters have temperatures above 20 °C which offers opportunities for combining technical and energy measures (renewable heating and cooling). The utilisation of mine water to produce energy has been discussed in detail by Grab *et al.* [7] and Oppelt *et al.* [8]. In addition, it is worth exploring the combination of necessary aftercare measures, e. g. pumping out the mine water, rehabilitating galleries, and renewable energy supply, particularly through energy supply networks such as heating and cooling grids to facilitate a climate-neutral energy local heating in the communities affected by structural change.

Two scenarios for a grid-connected supply are possible.

- supply with a cold network and corresponding heat pumps in the buildings
- supply using one or more large heat pumps directly to the buildings,

To calculate the potential, the mine water needs to be cooled down to a minimum

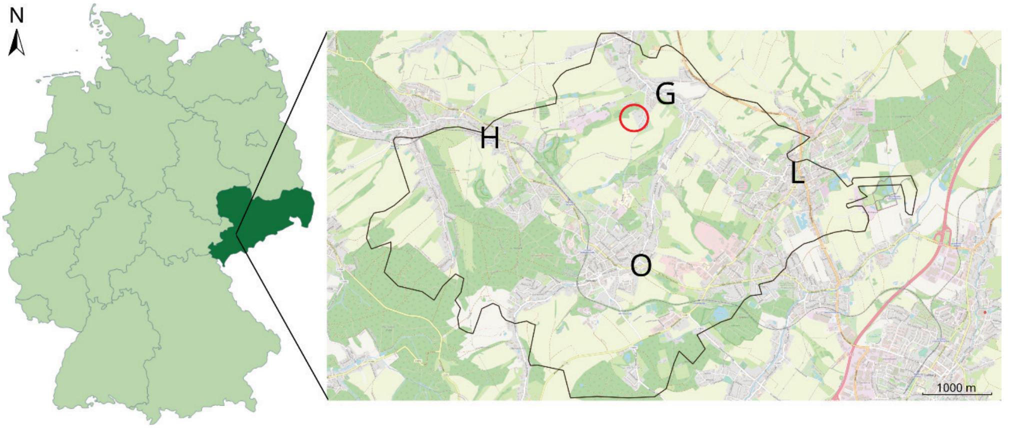

Figure 1 Black outlines the location of the mining area, the surrounding municipalities H-Hohndorf, O-Oelsnitz, L-Lugau, G-Gersdorf and the location of former "Kaisergrubenschächte" and object of investigation in Gersdorf marked in red

temperature. This extracts the heat from the water so that it can be utilised for a specific process later.

A maximum of 5°C (outward temperature) is set as the maximum possible cooling of the mine water. The mine water temperatures are set at 25 °C (655 m depth) resulting in an effective usable temperature range of 20 K. The calculation is made with 5 K, based on existing power plants. More data are shown in the following table 1. [5]

The heat potential of the mine water is given by the formula (1):

$$Q = V \times \rho \times cp \times \Delta T \quad (1)$$

Where rho is the density, cp the specific heat and ΔT the change in temperature. Table 1 provided all the other necessary data.

This potential represents the heat source compared to the above-ground consumers in the network (heat sink). With a constant source temperature of about 25 °C throughout the year, the house in the heat network can achieve a high annual coefficient of performance when using heat pumps in combination. [10]

Various terms are used for networks that operate with low temperatures. Along with the term "cold local heating network", terms such as energy networks or heat networks 5.0 are also in use. The main characteristic of these heat networks is that the network temperature with values between 5-40 °C (mostly 10-25°C) is insufficient for directly heating a building. Therefore, decentralised HPs must be installed in the building´s, which raise the heat from the network to the inlet temperature of the building energy system. Moreover, heat transfer stations in the buildings can facilitate the operation of the HP, allowing the same district network to meet the heating and cooling needs of the connected users (bidirectional supply). These networks can be used to meet cooling demand, such as by supplying chilled water for cooling purposes (i.e., free cooling) or to feed decentralized chillers with very high efficiency. In addition, the integration of renewable energy sources into these networks is facilitated. [11]

The Kaisergrubenschacht quarter in Gersdorf is situated on the formerly restricted area of the Kaisergrubenschacht I and II, covering an area of approx. 9.000 m². The district is planned to include 11 households and the mine water plant, resulting in a division of 12 plots. As the single houses are scheduled to be built after 2030, the legal framework for the construction adheres to the passive house standard.

Since the development plan has not been finalised, no specific statements can be made regarding the layer of the lots and/ or apartment composition. Therefore, three types of houses and two different roof shapes were selected within the framework of the project. Representing possible composition of the district; Furthermore, some residential units will have a basement representing the possible composition of the district. To make recommendations for optimal development, various buildings were simulated using MATLAB Simulink. Figure 2 shows the resulting building placement, two semi-detached houses are built in the northern part of the area, while bungalows are located in the southern due to the resulting shadows because of their height.

To represent a diverse occupant structure, various typical households were examined in

Table 1 *Parameters and calculated heat potentials of the mine water*

	Diameter	Value	Source
Conveying rate: at 300 m above sea level	m^3/h	32.5	[5]
Heat exchanger efficiency:		0,5	[9]
Transmittable heat output:	kW	94.67	
Transmittable energy quantity (8760 h/a)	MWh	829.3	

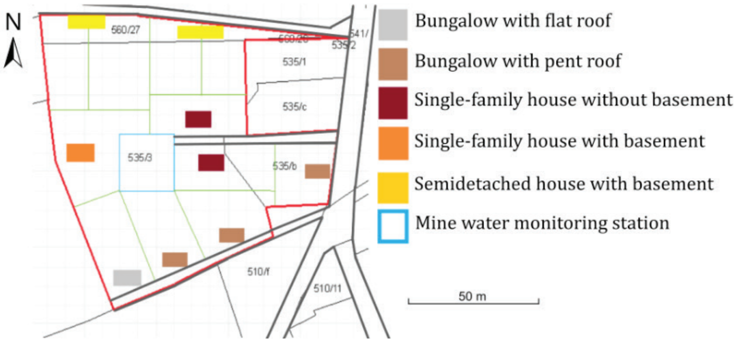

*Figure 2 Building distribution **and designation on the site under consideration***

detail. Various simulations were carried out for two to four-person households, each of which performs different activities.

Simulation settings

The simulations were carried out using the Simulink program and is an add-on to the MATLAB software. Additionally, the CARNOT Toolbox was employed, which is an application for Simulink developed by the University of Applied Sciences Aachen [12]. The toolbox provides ready-made blocks for designing technical systems such as thermodynamics, hydraulic, electrical, and chemical systems, and can be further customised by adjusting the specific parameters. The CARNOT blocks have been used to integrate fixed framework parameters and create interdependencies. The resulting models simulate the thermodynamic and hydraulic processes of the buildings [12].

Since no concrete building projects are planned, a modular approach was used to develop the models, allowing for easy adjustment of the model parameters and structure of relationships between the blocks. The parameters of the model can be easily adjusted and the structure of the individual relationships between the blocks can be changed. This allows for flexibility to adapt the models to future construction planning specifications with minimal effort. In addition, several input factors or framework conditions were incorporated into the model to obtain an authentic and realistic picture of the neighbourhood. The weather data used in the simulations originate from the German Weather Service data set for the Gersdorf site was used, which includes temperature, radiation values, wind direction and speed, relative humidity, cloud cover, and barometric data [13].

In the simulation, the building model comprises individual rooms, which are thermodynamically connected to the rest of the building and the outdoor environment through air exchange and wall surfaces allowing for heat transport within and from outside the building to be considered. Furthermore, different roof types, as well as the connection between the basement-ground floor and the ground floor, were considered in the simulation. Another important component in the simulation of the energy demand is the use of individual load profiles. Individual load profiles were used to represent the internal loads of the house in seconds, with the "LoadprofileGenerator" [14], [15] developed by N. PFLUGRADT which enables the creation of individual load profiles for different consumer scenarios. This allows extremely accurate simulations of the building components, including small electrical appliances.

The heat network purchase corresponds to the environmental energy required by the heat pumps, which in the neighbourhood concept is obtained from a local heating network that utilises mine water. However, if there´s a centralised heat supply, large heat pumps must be used to meet the heating and cooling requirements of the building.

In the respective scenarios, the annual heat grid demand is 41.035 kWh, which must be fulfilled by using mine water. Assuming a maximum mine water capacity of 95 kW and a continuous operation of 8760 h per year, the energy quantity that can be transferred is 829.309 kWh. Thus, MWMS II provides more energy per year than is consumed by the simulated neighbourhood. If the performance values of the decentralised grid are calculated using an average performance factor of 4.475 (the average of all annual performance factors of the neighbourhood buildings), the energy consumption of the MWMS II is much higher than that of the simulated quarter. A maximum capacity of 57 kW (27 kW heating/cooling and 30 kW domestic hot water), The heating network is allocated 44.3 kW of a maximum capacity of 57 kW (27 kW heating/cooling and 30 kW domestic hot water). Therefore, the power transfer at the heat exchanger of the MWMS II is the limiting factor for decentralised supply.

In the centralised example, the overall cost of the system is approx. 137,200 €, which includes the circulation pumps, heat exchangers, heat pumps, intermediate circuit, and other components. In contrast, the decentralised system cost does not include the expenses for heat pumps and intermediate circuits, which cost approx. 23,300 €.

The results for the central local heating network are listed in table 2 below.

Heat network supply

The average district heating costs are currently around 90 €/MWh [16]. Thus, the cost of the mine water system is noticeably less expensive than that of district heating. However, since grid pump electricity is not accounted for due to missing parameters, this computation is incomplete. As a result, the heating cost of the mine water system in the selected configuration is expected to be comparable to that of district heating. Nonetheless, through optimisation of the buildings and the selection of specially configured heat pumps, the heating cost can be significantly reduced.

Based on the calculated energy demand for the centralised and decentralised supply, the primary energy factor (PEF) of the buildings and systems can be estimated. neighbourhood considered in this study has a grid supply of 24,000 kWh, resulting in a total primary energy demand of 43,500 kWh per year. Considering the total energy reference area of the neighbourhood of 1,500 m², the average primary energy demand is calculated to be 28.7 kWh/m² per year. This value is significantly lower than the passive house requirements of 120 kWh/m² per year. In the case of the centralised supply option, the electricity consumption amounts to 19,700 kWh resulting in a primary energy demand of 23,600 kWh per year.

To supply the new quarter with power, it is estimated that a ring main of 250 m and a supply of 110 m will be required. The installation costs for decentralised local heating network amount to 99,500 €, whereas for a centralised local heating network amount to 196,300 €. It should be noted, that due to the passive house standard, a total output must be assumed, and thus only very small output diameters with a nominal diameter of DN 20 are sufficient to supply the buildings.

For the ecological assessment, a CO2 emission factor of 0.537 [t_{CO2}/MWh] was calculated based on current German grid electricity, among other factors.

Conclusions

It was shown how an after-use concept for the Gersdorf mining site in Saxony could look in the future. The concept includes the use of pumped mine water for the local heat supply of 11 surrounding houses, which consist of different building and household

Table 2 *Heat price for central district heating supply (calculated with German prices [16])*

Energy demand Heating [kWh]	Energy demand Cooling [kWh]	Energy demand TWW [kWh]	Electricity demand MineW. system [€/MWh]	Heat price [€/MWh]
20,133.5	41,882.1	31,093.3	19,565	80.92

types in passive house standards. The potential of the mine water to be pumped out was calculated, evaluated, and transferred into a demo case. Various simulations were carried out with different building and roof types and the option with or without a basement. As a further important component in the simulation of the energy demand, different load profiles of groups of people were included in the consideration. The supply of the buildings was investigated and calculated utilizing two variants of supply using centralised and decentralised network variants. The total costs of the centralised system would amount to approx. 353,650 €. This resulted in a heating price of 80.92 €/MWh and a CO_2 emission factor of 0.537 [t_{CO2}/MWh] for the centralised supply variant. The transmission capacity and energy supply of the mine water are completely sufficient for the district under consideration. The neighbourhood would have a very low primary energy demand and a very good CO_2 balance if the electrical energy for the heat pumps came from solar electricity from the roofs of the buildings under consideration. Finally, a significant improvement in the single-family house cooling demand can be achieved, if the buildings are cooled regeneratively in summer using the system.

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