Development of an Improved Model to Investigate Heating Potentials in Abandoned Mines Utilising Mine Water

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Abstract

Compared to the ambient, mine water has a natural constant temperature throughout the year. The heat energy stored in the water can contribute towards a more sustainable energy infrastructure in the mining regions. Although mines can have potentials of up to hundreds or thousands of megawatts, the methods of estimation are limited to either detailed numerical simulations or simplified analytical solutions. For small stakeholders, analytical solutions are often used as a basis for estimation. This paper will investigate the results of an analytical approach and ways to implement additional calculations, which are crucial for a realistic energy estimation.

Introduction

Although mine rehabilitation results in challenges, it can also hold unique opportunities. One of these opportunities is conditioned by the large body of mine water created by the flooding of the mining cavities. By contacting the surrounding ground, it naturally takes on its temperature in form of heat energy. With mine water geothermal systems having comparatively high contact areas, they consequently possess higher heat potentials particularly since conventional geothermal systems may be limited by the amount of ground they can effectively cover. The energy can be utilised by using heat pumps to supply space heating or hot water production. By providing an environmentally friendly, safe and stable heat supply, this alternative energy source could be a crucial component in enhancing a mining region's perceived attractiveness.

Before evaluating energy potentials, it has to be taken into account, how the energy from the mine -water can be utilised. At some locations it has to be pumped continuously to keep the level at a safe depth and prevent environmental damage. On the other hand, not every mining region needs to provide active water management. Drainage galleries may provide a safe and adequate method of dewatering, where the water could be used energetically analogous to the usage of the actively pumped water. In both cases, it is possible to estimate the energy potentials when the water flow rate and the temperatures are known. Although this accessible energy should be utilised as far as available, it is only a fraction of possible heat potentials of the mine, since not all mine workings are contacted by the flow of the water equally. To exploit the heat source more fully, dipole open-loop mine water geothermal systems can be deployed (Banks 2019). In such systems, mine water is extracted from one part of the mine, its heat is harnessed and subsequently, it is reinjected into another part of the mine. The resulting flow of the cooler water between the geothermal wells extracts heat energy from the rock which is contacted on its flow path. In comparison to heat extraction from active water management and gallery drainage, it brings the important advantage of being locational more flexible. This makes this method an attractive possibility to supply quarters with heat and cold.

Despite the mentioned advantages, higher costs are usually involved in making dipole open-loop mine water geothermal systems operational (Hoffmann 2014, Loredo 2011). Thus, special attention must be given to designing mine water systems appropriately. This prevents premature energy exhaustion of the mine water and the contacted rock over the lifetime of the system. Since calculating the amount of sustainable heat extraction with detailed numerical models is not feasible for many stakeholders concerned with mine rehabilitation, user-friendly approaches must be developed or expanded. Several analytical models are discussed in the literature, which can calculate the amount of sustainable heat extraction with comparatively simple input parameters (tunnel length, temperature level, etc.). However, the calculations often only focus on one heat regeneration mechanism at a time, i.e., the heat conduction in the rock or the geothermal heat flux. Additionally, there is no method of evaluating energy from water that might infiltrate the mine workings or gets transported indirectly to the geothermal wells of the dipole open-loop system. By bringing in energy from locations not directly influenced by the primary this mine water pumping cycle, can have a positive effect on the heat extraction potentials.

In this paper, a state-of-the-art analytical approach, together with its drawbacks and possible solutions is discussed. The foundation of the calculation was laid out by (Rodriguez 2009) and expanded by (Loredo 2017) in the project "Low-Carbon After Life" (Banks 2019) by implementing correlations for the Nusselt number and flow-coupling the heat transfer.

Model Analysis and Improvements

The analytical model uses a recurring calculation algorithm to estimate the outlet temperature of a mine water flow through a gallery. When entering the gallery, the mine water has a different temperature than the surrounding rock. Therefore, depending on the temperature, it takes up or transmits heat to the rock. The quantity of heat transmission between fluid and solid is dependent on their thermophysical properties as well as on the specified flow characteristics. An example case is given in Figure 1. Further calculations will be done referring to this example case with the specified major parameters.

Besides enabling fast calculations with few comparatively easy-to-estimate parameters, the algorithm has some drawbacks. First, the thermal influence radius, which is crucial in estimating the energy transmission through the rock mass, is calculated by implementing simplifications, which cannot be explained satisfactorily. Second, a constant mine water inlet temperature has to be specified, whereas, in a practical system, the reinjection temperature is dependent on the abstraction temperature and the heat extracted from the mine water. This leads to a varying amount of heat output, visualized in the given example in Figure 2. This effect is more pronounced in the early stages of system operation. Third, it considers only heat conduction through the rock as a heat regeneration mechanism for the mine water, while in reality, additional

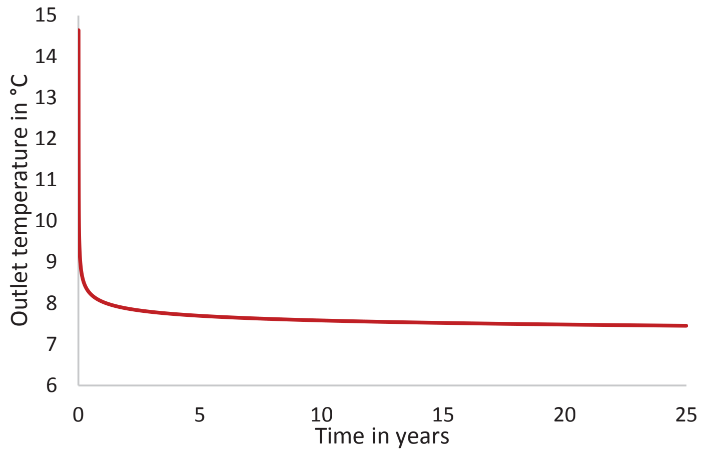

***Figure 1** Outlet temperature and thermal influence radius evolution for an example case and 25 years (gallery length = 1000 m, water reinjection temperature = 6 °C, rock temperature = 15 °C, volumetric flow rate = 5 L/s).*

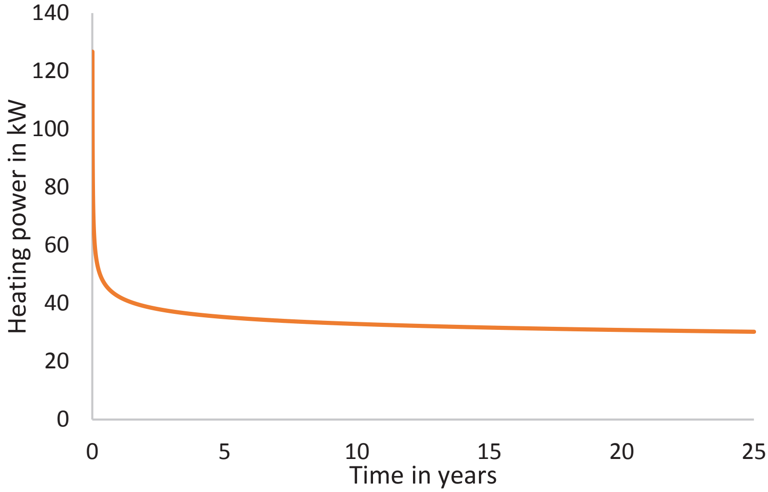

Figure 2 *Heating power evolution, calculated for the example case.*

water inflows are likely to occur, which yield increases in heating potentials. In addition, it's not possible to specify the geothermal heat flow and to consider the energy of the mine water.

While the structure of the solution made it possible to use it in accessible spreadsheets, ensuring a wide variety of potential users, an implementation in a numerical code can help to add another layer of calculation flexibility and implement improvements. At the same time the quick estimates with few input parameters are still possible so as to keep user accessibility.

To implement the system of formulae into a numerical code, the general programming language Python (V3.10) was used. Using the formulae as a foundation, several improvements can be worked into the syntax.

First, an improved version of thermal radius calculation was implemented. As suggested by (Loredo 2017) the logarithmic (Cooper 1946) approximation can be used to achieve a better foundation for this calculation. Thereby the thermal radius is obtained by specifying an incremental temperature change and calculating at which radius this displacement occurs. This temperature increment was set

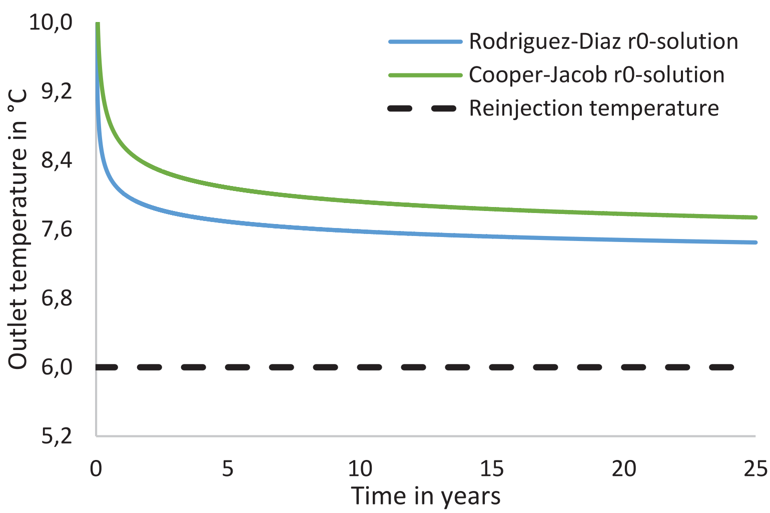

Figure 3 *Outlet temperature evolution for different calculation approaches of the thermal radius for 25 years for the example case.*

at a constant value of 0.01 K for the following calculations. A comparison between the two calculation approaches is shown in Figure 3.

The outlet temperatures display, that in total, more heat can be extracted from the gallery system. Since the thermophysical approach is more justifiable in the Cooper-Jacob approximation, it will be used for the continued calculations.

Since the heat output is a crucial parameter in designing a geothermal system, in the second step the code gets modified in order to allow specification of the heat power. This is done by coupling the entrance temperature into the mine gallery (mine water reinjection temperature) to a specified heating power and the outlet temperature (mine water abstraction temperature). If heat is constantly extracted, the temperature of the mine water will fall over time. To prevent chilling below a certain point, a critical reinjection temperature of 6 °C was defined, which is usually used as the lower limit for energetical utilisation of groundwater in Europe (LANUV 2018). Furthermore, chilling the water lower than that potentially causes technical problems in system operation. As soon as the calculated reinjection temperatures fall below this threshold, the calculation is terminated. For the specified case a constant heating power of 60 kW was used for the example calculation. The results are displayed in Figure 4.

Lastly, the influence of additional water inflow will be investigated. The value of the effect of water inflow is highly individual and dependent on the respective mine and the detailed location of water abstraction. Since the hydrodynamic information for closed mines may be very limited, the assumptions must be chosen with adequate caution. An investigation of the effect of inflowing water may be nonetheless reasonable if heat transport from the gallery wall alone is economically not sufficient for a mine water geothermal plant at a given location. In particular, if practical operation shows that a certain degree of additional water inflows is to be expected in most system locations (Oppelt 2021). The effect of this influence on the maximal possible heating power is displayed in Figure 5.

This maximum value is determined by observing at which heating power the critical reinjection temperature is undercut after 25 years. From the results, the conclusion can be made that even small mixing rates with inflowing water can lead to notable changes in the available heat potential. While being dependent on the volumetric flow rate of the system, even small mixing rations can lead up to severalfold increases in energetical potential. Since the potentials are most sensitive to this parameter, additional ways to characterize the amount of expectable inflow rates for future systems need to be discussed. The current model gives a foundation in which the results of further research could be implemented.

Conclusion and Outlook

While numerical methods of estimation of geothermal energy potentials in

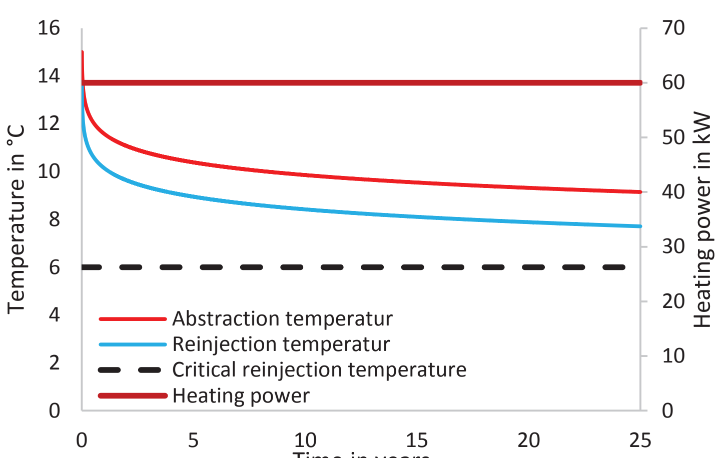

Figure 4 Temperature evolution with constant heating power of 60 kW and 25 years for the example case.

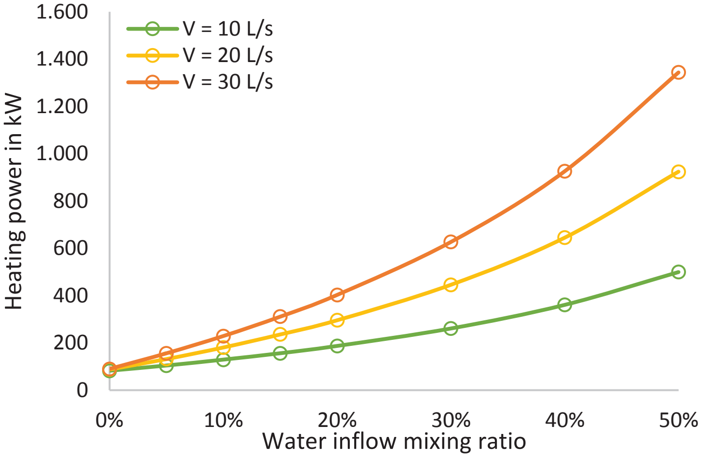

Figure 5 *Maximal heating power for three different volume flow rates at different water inflows and 25 years for the example case.*

mines provide detailed solutions to an increasing field of interest, the threshold of user accessibility often hinders more implementations on a larger scale. As a first step, this paper showed an approach to utilise a state-of-the-art analytical approach and how to compensate for the weak points by implementing the solution in an algorithm, where improvements can be built in more easily. The resulting calculation framework will work as a foundation where data from existing geothermal mine water plants can be implemented, in order to achieve more realistic estimations of the energetic potentials of mine water geothermal plants. Additionally, further research with a finite-difference-code will be conducted in order to compare the created analytical method to a numerical approach. Once the functionality of the potential calculation is validated, further research should focus also on the above ground distribution of the heat. Cold district heating networks might be suited optimally for transporting heat with minimal losses over long distances to consumers.

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