HT-MTES: Seasonal heat storage in abandoned coal mine

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ABSTRACT

At the end of 2018, the last operative coal mine in Germany, which is Prosper-Haniel, is going to be closed down, plugged and abandoned. Large amounts of subsurface infrastructure, resembled mainly by open parts of former galleries and mining faces are going to be flooded after the mine is closed down and therefore have the potential to become an enormous geothermal reservoir for seasonal heat storage. During the summer non used heat from solar thermal power plants, garbage incineration, combined heat and power (CHP) plants or industrial production processes can be stored within dedicated drifts of the mine. During the winter season this surplus heat can be extracted and directly utilized in single construction complexes and in city areas, which are not connected to the existing district heating grid. The development and advancement of innovative (underground) storage technologies is identified as one of the central key technologies, which are necessary to enhance the utilization of renewable energy sources in Germany and worldwide.

1. INTRODUCTION

At the moment a seasonal heat storage within an abandoned coal mine has not been realized in Germany. Therefore the HT-MTES (High Temperature-Mine Thermal Energy Storage) project of the International Geothermal Centre (in cooperation with RAG AG and delta h Ingenieurgesellschaft mbH) would lead the way within the sector of renewable energy storage systems. This R&D project is funded by the German Federal Ministries BMWi, BMU and the BMBF "Initiative Energy Storage" program. The aim of this project is to create a technically and economically feasible conceptual model for a HT-MTES for the energetic reuse of the coal mine Prosper-Haniel, which is situated in Bottrop, Germany. The conceptual idea is based on the storage of seasonal unutilized waste heat during the summer from solar thermal power plants, industrial production processes or CHP plant within the mine layout and to utilize the stored heat e.g. through the distribution of a district heating grid during the winter, when there is a heat high demand. For the implementation of such a HT-MTES within a former coal mine, the corresponding infrastructure measures and appropriate circulation applications have to be developed. Precondition for this development is the presence of a still active and fully open mine, which is resembled by the coal mine Proper-Haniel (accessible till the end of 2018). An investigation of the most relevant geotechnical, hydrogeological and geophysical parameters of the coal mine Prosper-Haniel is going to be performed. As a foundation for the implementation of a seasonal heat storage the undisturbed rock temperatures range between 30°C and well over 50°C within the galleries and mining faces that are going to be flooded, after the mine is fully closed down. The total mining area consists of 165 km^2 and the subsurface galleries have a total length of 141 km, at a maximum depth of more than 1200 m. A HT-MTES needs to have a large volume, in order to store vast amounts of heat. At the same time, it needs to be reliable, cost efficient and should be integrated into existing urban frameworks. The requirements for the structures within a HT-MTES are immense, as they have to withstand high temperature stresses, while maintaining their cross-sectional stability. In order to meet economical requirements, a HT-MTES needs to be operative in the range of 40 to 50 years. Depending on the utilized heat source and its application, different heat capacities, mass flows and temperature levels would be encountered within the mine thermal energy storage. All affected components need to be suitable for the intended operations and their possible resulting stresses. If the seasonal heat storage is operated by several different heat sources a careful coordination of the specific heat amounts and loading cycles of the relative source needs to be taken into consideration.

2. CURRENT STATE OF TECHNOLOGY

The idea of obtaining thermal energy from an existing and inoperative coal mine has already been pursued for a long time, although to a comparatively limited extent. Up to this point a pilot plant has not been established, in which the possibility of thermal energy storage in a former coal mine has been considered. Well-known executed projects concerning the utilization of mine water include:

- The Mijn-Water-project in Heerlen (Netherlands), whereby an already completely flooded and no longer accessible mine structure was accessed through directional drilling technology.
- The building of the School of Design at the Zeche Zollverein in Essen, which is heated by 28°C mine water from a depth of about 1.000 m (originating from the mine drainage of the RAG AG).
- The utilization of mine water of the former coal mine Robert Müser in Bochum as an energy source for the heat supply of two schools and the main fire station in Bochum. Within this pilot plant the 20°C mine water, which originates from the mine drainage of the RAG AG from a depth of 570 m, is being used.

The thermal utilization of the mine water from existing mine drainage stations, as they are realized in Essen or Bochum, show economically the highest efficiency, as there are no additional pumping costs. Due to the lack of suitable customers and a not yet existing final planning security concerning the future locations of mine drainage stations after the end of active coal mining (end of 2018) and the renaturation of the Emscher, a further expansion currently only takes place to a limited extent. The „open" utilisation plan of the Mijn-Water-projects could be realized in the Netherlands, as the mine workings are already mostly flooded after they have been closed down. In case of a mine water table of < 150 m below the surface, the proportion between the thermal energy obtained and the input energy (pump energy) is to be assessed as positive, despite the low temperature of the mine water of about 28°C. Nevertheless, the mine water must be brought to a higher temperature level through heat pumps. In contrast to the Mijn-Water-project in the Netherlands, the mine water tables in the majority of the central and northern Ruhr area, with a depth of partly > 800 m below the surface, are considerably deeper so that at water temperatures of up to 35°C, the energetic expense for the lifting is too high compared to the thermal energy obtained.

One way of increasing the efficiency is to increase the temperature of the mine water through the storage of seasonal heat in the mine workings, which has though not been realized yet. Currently merely a few medium-depth hydrothermal aquifer storages are in the planning stage or in operation, which are similar in regard of the temperature and the layer depth. Worth mentioning here are a project of the BMW Group at the plant Dingolfing (planning stage), the deep storage Neubrandenburg (in operation) and the energy concept Spreebogen (in operation). As a recent study in the area of heat storage in aquifers the publication Zeghici et al. (2015) will be discussed in more detail.

On the site of the BMW plant Dingolfing, a research project on an intermediate storage of thermal energy in a high temperature aquifer storage is carried out by the BMW Group in a depth of 500 to 700 m. Surplus thermal energy that results from power production in a CHP plant should be injected into the storage in the summer and accessed in the winter. This includes plans to pump 130°C hot water, which is heated with surplus heat into a water-bearing Malm layer during the summer months. During winter this heat can then be extracted again and specifically utilized. The potential of this storage is estimated to be 115 GWh, so that the CHP plant can be primarily driven by power demands and as a result a higher utilization ratio of the cogeneration is obtained (BMW 2013).

In Neubrandenburg the good geological conditions in combination with a geothermal heat supply, which is in operation since 1987, are used to store the summerly surplus heat of a gas and steam turbine power plant with a performance of 77 MW_{el} in a depth of 1250 m and to operate the hot water supply of the district heating grid „Rostocker Straße" in the winter. With a temperature of 80°C, heat is injected into the aquifer with a rate of 100 m^3/h and a thermal output capacity of 4 MW and during the winter produced with a temperature of 65-78°C. As a geothermal aquifer storage the Postera sandstones are used, which are situated in a depth of 1250 m. The reservoir temperature of about 50°C is increased to 78°C in the course of the storage operation. The operation of a heat pump can be dispensed (Bine 2007), (Kabus et al. 2009), (Kabus et al. 2007).

In order to act as a role model for energy saving constructions and the use of innovative technologies for building maintenance, the energy concept Spreebogen was put into operation gradually from 1997 to 2003, which contains in addition to the Reichstag building and the Federal Chancellery, the neighboring parliament building „Jakob-Kaiser-Haus", „Paul-Löbe-Haus" and „Marie-Elisabeth-Lüders-Haus". An important element of the energy concept is the heat and cold storage in aquifers: The energy supply system enables the provision of 82% of the required power and of about 90% of the annually required thermal heat through the cogeneration with a CHP plant. Through the cold storage and the combined heat and cooling production of the applied heat pumps, 60% of the summerly cooling demand of buildings are covered (Bine 2007), (Bine 2003).

The feasibility study of Zeghici et al. (2015) describes a high temperature aquifer thermal energy storage (HT-ATES) in a geothermal reservoir in the Moesian platform (Romania). The study assesses the possibility of using a deep geothermal reservoir as a storage for both heat and cold at the same time. An advantage of this technique would be the exploration through only one borehole, so that there would be a high saving potential concerning the drilling costs. As a result of the study, it can be said that such a "mono-well-system" would even be usable for a high-temperature aquifer heat storage, when no insulating layers between the heat and cold storage are present. During the study, it was moreover shown that with a sufficient thickness of the aquifer, it is possible to establish a heat and cold storage within the same geothermal reservoir and thus reduce drilling costs. The numerical calculations show that there must be at least 160 m vertical distance between the cold and heat storage, so that there would be no distortion within the two storages. A successful implementation of a high-temperature aquifer heat storage is highly dependent on the selection and analysis of the selected aquifer.

3. NUMERICAL MODELLING OF GEOTHERMAL ENERGY

For the dimensioning and optimization of an underground heat storage, a numerical simulation tool is required, which is able to realistically and practicably map the specific hydraulic, thermal and geological conditions within the mine layout and simulate the heat input and withdrawal from the subsurface storage. For this purpose, a numerical based model must be created, which depicts the fluid and heat transport within the specific mine elements (shafts, drifts and mining areas) and the thermal-hydraulic connection of the mine layout to the surrounding rock with its naturally present geological heterogeneity.

4. SEASONAL HEAT STORAGE CONCEPT FOR THE COAL MINE PROSPER-HANIEL

The fact that Prosper-Haniel is still an open and active coal mine opens up numerous advantages for the development and exploitation of a mine thermal energy storage system:

- Increased hydraulic properties are encountered, due to the presence of former mining areas and galleries within the relatively dense carboniferous rock. These substantially enhance the heat transport capability of the underground.

- Open shafts and drifts allow a comparatively easy accessibility and technical feasibility of a mine thermal energy storage.

- A positive customer structure can be anticipated, due to the high population density within the vicinity of the mine.

The seasonally stored heat can be utilized to supply the surrounding residential and commercial areas, e.g. through a coupling with the Ruhr district heating grid or with the integration into the “InnovationCity Ruhr” process. Consecutively, one conceptual model for a HT-MTES is described in further detail.

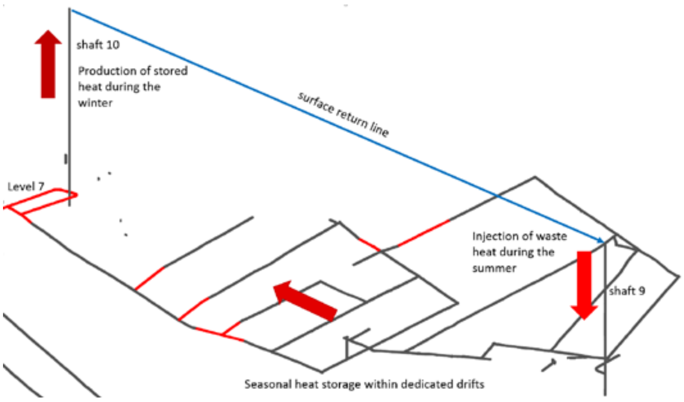

Figure 1: HT-MTES between shaft 9 and 10

The following conceptual model consists of a HT-MTES between shaft 9 and 10. Primarily the drifts on level 7 will be used as a seasonal heat storage. In this case, excess heat is injected into the storage via shaft 9 during the summer, stored within the drifts of level 7 and produced via shaft 10 during the winter. It must be ensured that the in fig.1 illustrated drifts are to the greatest possible extent hydraulically decoupled from the rest of the mine layout, in order to increase the efficiency of the overall storage capacity. An interference with the planned mine drainage on level 6 should be avoided by all means. Therefore suitable dam positions have to be localized. The dimensioning of these dams is based on a numerical modelling and sensitivity analysis. Additionally, a surface return line between shaft 10 and 9 has to be installed. Since 2002, up to four CHP plants are operated with mine gas at shaft 9, producing a thermal output of 4,6 MW. These CHP plants could act as a possible heat source for the HT-MTES, as their cooling water temperatures are in the range of 80 - 90°C. Also, a coupling with the existing district heating grid could be an option. Based on the injection with a ΔT of 50 K, the conceptual HT-MTES would have a theoretical heat transfer capacity of 3,5 MW.

5. CONCLUSION AND OUTLOOK

The development of diversified storage capacities will have a great impact on the future promotion of renewable energies. Within the Ruhr area, unused mine structures in combination with available unutilized waste heat from power plants and industrial processes, resemble a vast potential for large heat storage capacities. Out of this reason, fundamental research in the field of seasonal heat storage in abandoned mines has to be conducted, so that this technology can be developed and established in the near future. The aim of this feasibility study is to conceptualize a seasonal heat storage system for the coal mine Prosper-Haniel. Until the end of 2018 Prosper Haniel is still accessible, so that specific underground measures for a mine thermal energy storage are possible to be conducted. A pilot plant could be realized on the basis of the feasibility study, when the mine layout is fully flooded. In the case of a technical and economical implementation of a pilot plant, the results in terms of design and operation of a seasonal heat storage within an abandoned coal mine would be scalable to other locations in Germany and worldwide.

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