Proceedings World Geothermal Congress 2015
Melbourne, Australia, 19-25 April 2015

Geothermal Re-use of Coal Mining Infrastructures and Mine Water in Hard Coal Mining in the Ruhr Area/Germany

Leonhard Thien

EnergieAgentur.NRW, Netzwerk Geothermie NRW, Lennershofstraße 140, 44801 Bochum, Germany

thien@energieagentur.nrw.de

Keywords: Coal Mining, Energiewende, heat mining, Mining Infrastructures, Mine Water.

ABSTRACT

In the implementation of the German Energiewende the generation of power from renewables is not the only important element. Heat generation from renewables is also of major significance if the Energiewende is to be accomplished. Consequently the ambitious goals of the Energiewende also include the expansion and greater utilisation of geothermal energy.

In addition to the exploitation of heat from near-surface and deep geothermal sources, the re-use of coal mining infrastructures is a further source of geothermal heat. When it comes to using geothermal heat obtained from mining installations the heat is recovered using equipment whose original purpose had nothing to do with tapping geothermal heat. The geothermal re-use of mining facilities is an exciting regional approach which contributes to the implementation of the Energiewende.

For example, former mines can be equipped with closed loop heat exchangers and former supply lines can be converted into geothermal probes. A further variant is the direct and indirect utilisation of mine water. Warm mine water in abandoned mines is available in the temperature range of approximately 20°C to 40°C. In the Ruhr region about 80 million m³ of mine water is lifted annually. This enormous potential should be exploited using innovative technologies and creative projects. This lecture gives in addition an overview over Best Practice Examples to re-use of Coal Mining Infrastructures.

If location and user fit together it will be possible to forge ahead with the expansion and use of the mine infrastructure in relation to the specific locations and hence to make a regional contribution to the accomplishment of the Energiewende.

1. INTRODUCTION

In the implementation of the German Energiewende the generation of power from renewables is not the only important element. Heat generation from renewables is also of major significance if the Energiewende is to be accomplished. A major portion of final energy needed in Germany is accounted for by the heating of buildings (approx. 70% of the final energy for the households sector BMWi (2010)). Consequently the ambitious goals of the Energiewende also include the expansion and greater utilisation of geothermal energy. The base-load capability of geothermal energy is a big advantage here.

In addition to the exploitation of heat from near-surface and deep geothermal sources, the re-use of coal mining infrastructures is a further source of geothermal heat. When it comes to using geothermal heat obtained from mining installations the heat is recovered using equipment whose original purpose had nothing to do with tapping geothermal heat. The geothermal re-use of mining facilities is an exciting regional approach which contributes to the implementation of the Energiewende.

The long tradition of mining in the federal state of North Rhine-Westphalia, as well as the extensive expertise in the fields of mining, drilling technology, heat distribution and power plant engineering can also be used for geothermal purposes. For example, former mines can be equipped with closed loop heat exchangers and former supply lines can be converted into geothermal probes. A further variant is the direct and indirect utilisation of mine water. Warm mine water in abandoned mines is available in the temperature range of approximately 20°C to 40°C. In the Ruhr region about 80 million m³ of mine water is lifted annually Eilert (2010). This enormous potential should be exploited using innovative technologies and creative projects.

The following remarks will give an overview of the potential for the geothermal use of former mining installations. In conclusion best-practice projects highlight the various possible uses.

2. FRAMEWORK CONDITIONS

2.1 Germany and NRW

The Federal Republic of Germany is a country in Central Europe and it comprises 16 states. Germany shares borders with nine neighbouring countries and it has natural borders in the north in the form of the North Sea and the Baltic Sea and in the south in the form of the Alps. Germany has a population of approximately 80 million. It is one of the most densely populated countries and internationally it is reckoned to have the third highest number of immigrants, UN (2006).

North Rhine-Westphalia is in the west of the Federal Republic of Germany and with its approximately 18 million inhabitants it is the most populous of the German federal states. The Rhine-Ruhr conurbation in the centre of the state has around 10 million inhabitants and is one of the 30 largest metropolitan regions in the world and a central component of the European conurbation.

The Ruhr region forms the northern part of the Rhine-Ruhr conurbation. Its economic rise was based on industrialisation and the coal and steel industry, and specifically coal mining. Since the decline of these industries from the 1960s on a structural transformation has taken place and it is still in progress today. Even now North Rhine-Westphalia is dominated by various key industries and is one of Germany's economic centres. Accounting as it does for around 22 per cent of the German gross domestic product North Rhine-Westphalia is the federal state with the highest economic output.

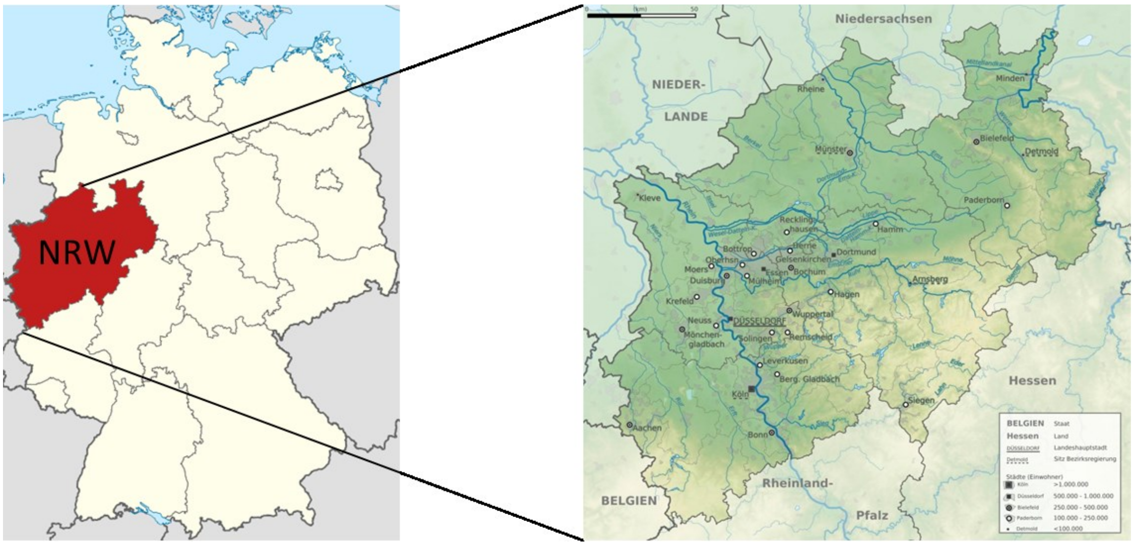

Figure 1: General map of Germany and of the State North Rhine-Westphalia, Wikipedia (2014)

2.2 Mining in NRW

Coal was being mined in the Ruhr region as long ago as the Middle Ages. In the mid-20th century mining reached a high point. In the early 1950s alone 50 new surface shafts were sunk in Ruhr mining. In 1957 more than 600,000 mineworkers were employed in the Ruhr region. In addition a considerable number of people were employed in the supply industry.

As from 1958 the process of mine closures began in Germany and the Ruhr. Nationwide 78 mines were closed in period of only ten years. The workforce declined sharply; in 1960 it was only about 500,000 and it was halved by 1970 to only around 250,000. At the end of 2012 there were only three mines producing hard coal and the workforce declined to about 15,000 RAG (2012).

In 2007 the federal government the individual states and Ruhrkohle AG (RAG) agreed to definitively run down hard coal mining in Germany completely by 2018. That means that all coal mines in Germany will be closed and no hard coal will be extracted any longer.

Figures 2: The path of traditional (old) energy supply towards of the Energiewende

Parallel to the abandonment of hard coal, the RAG group was restructured. At the end of 2007 two independent companies were formed from the former RAG group, namely RAG Aktiengesellschaft and Evonik Industries AG. The RAG foundation has since been the owner of both companies. The successful and profitable "white corporate segments" such as real estate, power plants (STEAG) and chemicals (Degussa) were amalgamated under Evonik (also Evonik New Energies) and the "black segment" of mining became RAG Aktiengesellschaft. The RAG foundation is responsible among other things for the socially compatible withdrawal from subsidised hard coal mining. It utilises its assets to secure the funding of mining's long-term responsibilities as from 2019 RAG (2014). Figure 2 illustrates the conversion of the energy supply industry in the Ruhr area and demonstrates how energy technology can continually develop. Compared to other regions this development can be built upon an existing tradition.

2.3 Mine water management

By mine water we mean the quantity of water which arises in a mine and is brought to the surface by the drainage system.

To safeguard mining in the still operative mines the active mine workings must be kept dry by means of water management. Water management is necessary both during hard coal mining and subsequently through to the permanent and effective refilling of shafts. Shaft refilling describes the permanent and effective measure to seal off old mine shafts. This measure could endure for several hundred years (long-term responsibilities), Meier and Jost (2009).

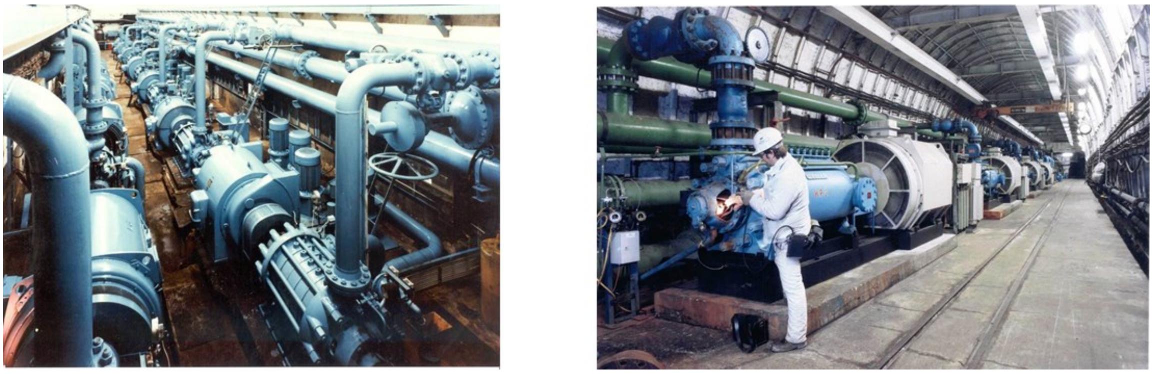

Figure 3: Pump chamber and pump station of the mine “Heinrich” and the mine “Zollverein”, RAG (2008)

In the Ruhr region water management has been and still is implemented using pumping stations. Figure 3 (left) shows the pump station of the mine “Heinrich “, and the left figure shows the pump station of the mine “Zollverein”. The pumps are located on different floors (horizontal levels) in the mine workings and they pump the mine water arising there to the surface via pressurised lines. During coal mining operations water management is essential to prevent the mines from flooding. After completion of the coal mining water management is still necessary to prevent the rock strata from sagging uncontrollably.

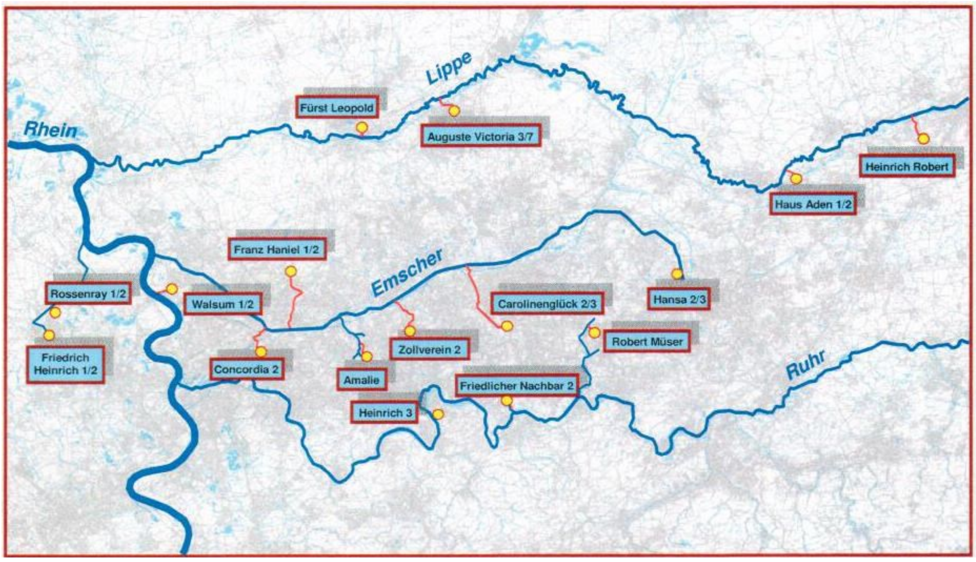

Figure 4: Overview of the mine water management sites, Niemann (2013)

Many older shaft structures are no longer used today to produce coal. The shafts serve primarily to transport material, for water management or for ventilation. Figure 4 shows the mine water management sites in the Ruhr region.

Figure 5: Mine water discharge in to the “Harpener Teiche” and then in to the river Ruhr, Bücker (2013)

The mine water is discharged into the rivers Ruhr, Emscher, Lippe and Rhine. Every year approximately 80 million m³ of mine water are pumped from a depth of as much as 1,000 meters and discharged above ground. This mine water has a temperature of approximately 20° – 30°C, RAG (2013). It thus represents a considerable geothermal heat potential.

2.4 Mine water and its constituents

Owing to numerous mineral substances present in the Earth's interior, the mine water mostly exhibits its own chemistry. When mine water is being transported various chemical reactions can occur in pumps, pipes and in all the operating installations. These reactions are influenced by the temperature, pressure, redox potential/oxygen content and pH, Schetelig et al. (2013).

Iron and sulphur compounds occur in almost all mine water. Sulphur occurs in the coal and the surrounding rock as pyrite (FeS2). In sulphate-bearing water gypsum may precipitate (arise) in combination with calcium ions. Iron and iron hydroxide lead to rust and sedimentation of iron ochre.

Sodium chloride (NaCl) can be found in all mine water, although in varying concentrations. High salt concentrations may alter the value for the solubility product and, for example, hold antisoluble substances in solution.

Carbonic acid can occur as free gas or in bound form. In all cases attention must be paid to the carbonic acid equilibrium on account of the corrosion capability. This applies in particular with respect to iron and its various valences Schetelig et al. (2013).

2.5 Sump water

The water arising from the open-cast mining of brown coal is called sump water. Sump water often contains portions of calcium, iron(II) oxide, zinc, magnesium, sodium, ammonium and manganese Wanke et al (2008)

3.0 POTENTIAL USES

The simplest way technically to extract geothermal heat from existing water management and to make it available to directly a consumer is via a heat exchanger. The mine water should have a minimum temperature of 25°C for direct use. Downstream of the heat exchanger the secondary circuit is used directly to heat the buildings (see the example of Zeche Zollverein).

In addition the mine water can be heated up to a higher temperature using a heat exchanger and heat pump. This technology can be used anywhere where mine water is available and there are appropriate heat purchasers/consumers above ground. Using heat pump technology the mine water is brought up to a temperature level of 50°C to 60°C. In this way it is possible to ensure that mine water is widely used.

A further possibility is to use old mine shafts, supply lines and the whole mine workings. Before the mine is definitively closed the installations present are normally removed except for gas extraction lines. Then a platform is fixed at a certain depth from which the shaft is filled upwards (partial filling). In the course of time the lower part of the shaft fills up with mine water. After the closure of the shaft there is therefore also the possibility of using geothermal mine water from the shaft or even the enormous volume of the mine workings as a whole. In addition to the direct utilisation of the mine water it is possible, for example, to use "closed systems" such as bundles of hoses, probes etc. as a heat source.

4.0 BEST-PRACTICE EXAMPLES

In the following remarks a description is given of the various potential uses with reference to actual examples. The last example is not from hard coal mining but from open-cast brown coal mining.

4.1. Heat from mine water at the Zeche Zollverein site, Essen

On the World Cultural Heritage site Zeche Zollverein the "SANAA Cube" was erected as an architecturally innovative university building. The following figure 6 on the left shows the building. The cube structure can be clearly seen. Today the building is part of the Folkwang Museum. Because RAG operates one of the central water management installations for mine water at Zollverein, the mine water from this installation has been used to heat the building since 2006. This is done using a so-called "active heat insulation". This term describes the thermal building component activation which is implemented by installing plastic pipes in the walls and ceilings. In the walls, which are only twenty-five centimetres thick, a 3000-metre hose system has been embedded in concrete. Warm water with a temperature of approximately 28 degrees lows through this piping system, Zollverein (2014).

Figure 6: SANAA Cube and the heat Exchanger, Willemsen (2014) (left side), Kissing (2008) (right side)

The building otherwise has no other insulation in the exterior walls. The heat transfer unit used in this project to utilise the heat from the mine water is a plate-type heat exchanger. Figure 6 on the right shows the heat exchanger. This is supplied with a part-stream of the mine water pumped locally and is designed for a transfer capacity of 790 kW. After flowing through the plate-type heat exchanger the cooled mine water is returned to the main stream. The installation has operated in a stable fashion for a number of years and this provides a reliable heat supply for the Folkwang Museum. The plate-type heat exchanger is of stainless steel and is backwashed at regular intervals to wash out any particles that may have been entrained. At the present time RAG is developing further designs to utilise the residual mine water. It may thus be possible to heat parts of the World Cultural Heritage site Zeche Zollverein or also the adjacent buildings.

4.2 Heat from mine water at the Robert Müser site, Bochum

At the former Robert Müser mine site in Bochum RAG operates an installation to lift the mine water. The water management system at the Arnold mine pumps about 10 million m³ mine water per year with a temperature of approximately 20 °C. Until 2012 this mine water was discharged unused into the nearby Ruhr River, Bücker (2014). Near the Arnold mine there are two schools and the main fire station of the town of Bochum. This means that there are excellent heat purchasers for the energy-related utilisation of the mine water lifted. With two heat exchangers the heat of the mine water, which is pumped form a depth of 570 metres, is transferred to a separate circuit, the so-called "cold local heating network". The heat contained in this water then serves as a source of energy for the individual heat pumps in the respective technical facility centres of the buildings. It was necessary to solve technical problems, especially with regard to the heat exchangers. Here high-grade materials had to be used to preclude any corrosion problems from the salt in the mine water.

Using heat pump systems the mine water extracted is raised to a higher temperature level. This ensures a base-load supply for the existing buildings. Figure 7 (right) shows the installed heat pumps inside the school's utility room. A newly erected unit-type combine heat and power (CHP) plant in a heating centre of a school building produces the electrical energy used to operate the heat pumps. Similarly the heat generated by the CHP plant is used. Existing gas boilers serve to supply the peak load. With this technology it is possible to provide a temperature of between 50 and 80 degrees as required. In addition the CHP plant supplies the heat pumps with electrical energy.

Figure 7: Warm-Water- deflector and heat pumps in the plant room of the school, Bücker (2013)

By means of a hydraulic separator, as it is shown in figure 7 (left), the individual heat generators are hydraulically integrated in the existing hot water system.

The installation was opened in October 2012 and commissioned by the operator, Stadtwerke Bochum (public utilities).

Thanks to the energy supply concept described the fuel requirement can be reduced by about 1,200 MWh/a. This is the equivalent of a reduction in CO_2 emissions of 245 t/a. In addition it is intended to exploit the experience accumulated to initiate an extensive utilisation of mine water heat.

A further goal is to gather experience in the installation of heat pumps in existing building stock. Normally the buildings heated with heat pumps are primarily new buildings. In this project it is intended to heat existing building stock using heat pump technology. One particular challenge here is the selection of the heat exchangers. Here consideration is to be given to the possible uses for electric heat pumps, gas absorption heat pumps and gas engine heat pumps, Bücker (2014). Given the diverse circumstances and heat purchase quantities in the existing building stock, it is also appropriate to use different kinds of heat pumps.

5.3 "Shaft heat" at the Auguste Victoria site, Marl

A further possibility for extracting geothermal heat is the use of old mine shafts. At the mining site in Marl this idea has also been put into practice. When building four new multi-family houses the geothermal heat is recovered in an innovative way from an old, abandoned shaft of the neighbouring Auguste Victoria mine. In the preparatory phase Evonik Wohnen GmbH engaged a specialist firm of planning engineers to examine the feasibility of geothermal post-re-use of the shaft. The results of the study were positive and so it was possible to initiate the project's implementation.

It is particularly important here to analyse the local situation before backfilling the haulage shafts and to examine, and where relevant adapt, the existing riser pipes with respect to the requirements of geothermal energy. A former shaft riser pipe of steel with a nominal diameter of 350 mm was selected to tap the heat potential and hence to recover geothermal heat in future. This riser pipe was converted for geothermal use into a 700 metre deep geothermal heat probe. The original idea was to use the existing riser pipe as a casing and a centric ascending pipe as a so-called coaxial probe. In the annular chamber of the riser pipe the cold liquid heat transfer medium flows downwards, heats up at the same time and then rises upwards again in the probe inner pipe suspended in the casing. A remote inspection by camera, however, revealed corrosion and areas of peeling on the riser pipe, which meant that it was not possible to guarantee trouble-free operation of the geothermal probe. It was therefore decided to use a double-U probe. The company contracted to carry out the work developed for this purpose a special probe foot with appropriate weights in order to insert the probe to a depth of 700 metres. A special heat conductive bentonite-cement suspension was then pressed in via the injection pipes.

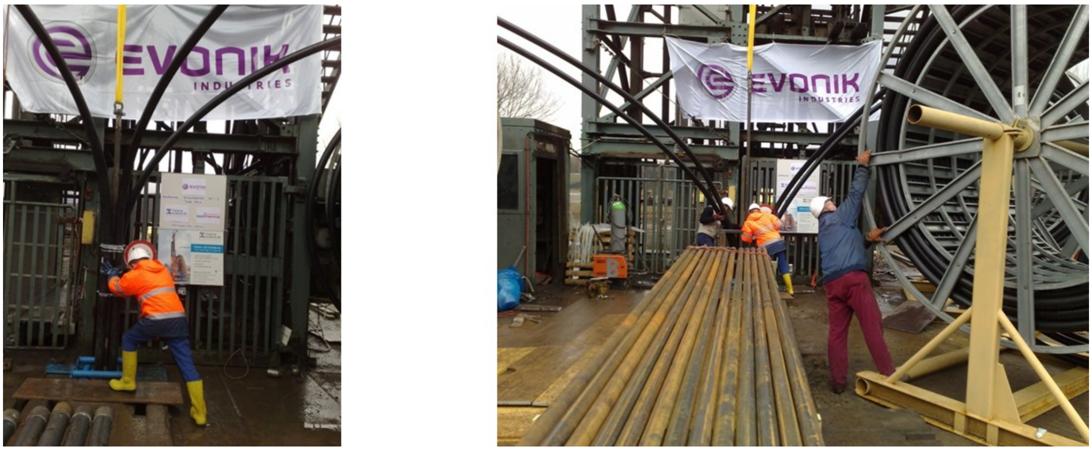

Figure 8: Insertion of the 700 metre long probe, Gahlen (2010)

The distance between the geothermal probe system in the shaft and the new residential houses in the Ziegelstraße is approximately 300 metres. Two of the four buildings can be heated with geothermal heat from the former mine. The heat needed for the other two buildings is extracted from additional, near-surface geothermal probes on the site and these each go to a depth of around 170 metres. The financial costs are low compared to other deep-geothermal projects and this mean that economical operation of the system is possible Farwick et al. (2010).

5.4 Alternative combined heat and power generation from "sump water" (brown coal open-cast mining)

In NRW it is not only hard coal that is mined. There are also very extensive brown coal mining areas where open-cast mining is practised. The operator of the open-cast mining areas is RWE Tower GmbH.

In the immediate vicinity of the "Hambach" open-cast mining area the Erftverband association has erected a new operational, office and storage building. The new facilities have been supplied since April 2014 with heat recovered from sump water. The sump water is pumped and taken off by RWE Power GmbH, as the operator of the brown coal mining facilities, from a great depth to keep the Hambach open-cast mine dry. In view of the great pumping depth the water has a high and constant temperature between 22 and 26°C. One of the sump water pipes runs in the direct vicinity of the Erftverband building complex mentioned.

Figure 9: Tube bank heat exchanger and a heat pump at the Erftverband site in Erftstadt.

Utilisation of heat from sump water has to date repeatedly failed in the Rhineland open-case mining area due to the high operational effort required, e.g. dealing with iron sedimentations of iron ochre/iron deposits in the heat exchanger, (service life approx. 2 weeks and great performance reduction in the heat exchangers). The heat exchangers traditionally used soon come up against their functional performance limits with slightly contaminated media such as sump water with iron ochre sedimentation Erftverband (2013). In this project special heat exchangers are now used. In a tube bank heat exchanger innovative "special pigs" and a special control system are used. With this innovative technology the heat exchanger is self-cleaning and the efficiency is maintained.

The sump water pumped, at approximately 35m³ per hour, supplies the heat exchanger in the primary circuit with a flow temperature of approximately 22°C. The return temperature is about 18°C. Using heat pumps the system temperature in the heating circuit is brought up to 65°C to heat the buildings mentioned. For the installed heat pump system a power of 620 kW is provided. The necessary electrical energy to operate the heat pumps is to be provided in future by a new photovoltaic installation yet to be erected. The small local heating network is regulated centrally and is equipped with a flow temperature regulation system which is dependent on the outside temperature. The Erftverband intends to extend this system, comprising heat generation using sump water supported by photovoltaics, to other locations if its functionality is verified Erftverband (2014).

5.0 SUMMARY

The long tradition of mining in North Rhine-Westphalia and the extensive expertise in the areas of mining, drilling technology, heat distribution and power plant construction can also be exploited for geothermal purposes. The application of this knowledge helps to keep energy costs down, to open up new markets, to improve the export opportunities for the technology companies and to create jobs.

The examples described show that the use of mine water to heat buildings can be of interest and meaningful both in terms of energy generation and of economy. The quality of the mine water plays a major role in its utilisation. The operators of installations have been able to accumulate a lot of experience in the first few years of operation with the extraction of the mine water and also in dealing with the constituents of the mine water. Many problems with heat exchangers and filter systems have been solved by adjusting the backwashing times or the filter permeability. The selection of appropriate materials for heat exchangers, piping etc. also plays a major role. There are many innovative approaches to dealing with the water constituents.

On the part of RAG much thought is being given and many concepts considered concerning the possible use of mine infrastructure and mine water. A lot depends of course on the uses structure of the energy consumers on the surface. If both fit together it will be possible to forge ahead with the expansion and use of the mine infrastructure in relation to the specific locations and hence to make a regional contribution to the accomplishment of the Energiewende.

REFERENCES

BMWi: “Energie in Deutschland – Trends und Hintergründe der Energieversorgung“, Bundesministerium für Wirtschaft und Energie, August (2010)

Bücker, C.: Innovative Grubenwassernutzung in Bochum. Workshop 5 Geothermische Energieerzeugung im regionalen Markt. DGK 2013. Essen (2013)

Bücker, C., Willmes, J.: Nutzung von Grubenwasser zur Wärmegewinnung – Ein Beispielprojekt. bbr-Sonderheft Geothermie 2014, Bonn (2014)

Eilert, W.: Nachnutzung von Bergbauinfrastruktur. 6. NRW – Geothermiekonferenz, 26.10.2010. Gelsenkirchen (2010)

Erftverband: Alternative Kraftwärmekopplung aus Sümpfungswasser. Projektskizze, Erftverband, Erftstadt (2013)

Erftverband: Erftverband beschreitet gemeinsam mit RWE Power neue Wege bei der Wärmeversorgung, Press Release, 23.04.2014, Erftstadt (2014)

Farwick, U.; Walter-Hertkorn, S.; Müller, J.: Wärme aus altem Bergwerksschacht – Möglichkeiten der Tiefen Geothermie im Wohnungsbau. bbr Sonderheft Geothermie 2010. Bonn, (2010)

Gahlen, K.: Installation of the heat probe in Marl. Private Photo (2010)

Kissing, H.: Private Photo, (2008)

Meier, G., and Jost, G: Geotechnical and mine surveyor risk evaluations of water galleries in the copper slate mining industry. 9. Altbergbau – Kolloquium, Leoben (2009)

Niemann, A.: Chancen und Risiken untertägier Pumpspeicherkonzepte in Anlagen des Bergbaus. IWASA – Veranstaltung, Aachen (2013)

RAG: Wasserhaltung bei der RAG. 2. Sitzung des AK „Bergbauinfrastruktur-Geothermische Fragen“. Essen (2008)

RAG: Unternehmensporträt „Den Wandel gestalten“, RAG Aktiengesellschaft, Herne (2012)

RAG: RAG Aktiengesellschaft, Servicebereich BG E, September 2013, Herne (2013)

RAG: www.rag-stiftung.de, Herne (2014)

Schetelig, K., Heitfeld, M., Mainz, M., Hofmann, T., Eßers, M.: Geothermie aus Grubenwässer – regenerative Energie aus stillgelegten Steinkohlenbergwerken. IWASA – Veranstaltung, Aachen (2013)

UN: International Migration 2006, United Nations - Department of Economic and Social Affairs – Population Division. USA (2006)

Wanke, C.; Ritzel, S.; Sachse, R., Michel, R.: Radiologische Bewertung der Grubenwassereinleitungen des Steinkohlenbergbaus im Bereich Fossa Eugeniana. Hannover (2008)

Wikipedia: www.wikipedia.org/wiki/Nordrhein-Westfalen (2014)

Willemsen, Th.: Stiftung Zollverein. www.zollverein.de/welterbe/architektur/sanaa-gebaeude. Essen (2014)

Zollverein: www.zollverein.de/welterbe/architektur/sanaa-gebaeude. Essen (2014)