Low Carbon After-Life – overview and first results of project LoCAL

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Abstract

The LoCAL Project "Sustainable Use of Flooded Coal Mine Voids as a Thermal Energy Source - a Baseline Activity for Minimising Post-Closure Environmental Risks" aims at providing bespoke tools for investigating flow and heat transfer in flooded mine workings. New tools for quantifying and modelling heat transfer in networks of flooded mine workings are under development Another aim of the LoCAL project is to overcome the hydrochemical barriers to effective heat transfer from raw and treated mine waters. Ochre clogging is a well-known phenomenon which affects a lot of mine water heating and cooling systems. The LoCAL project not only covers technical and engineering issues, but also provides economic and management models for efficient energy extraction and distribution. Technical, legal, managerial and cost-benefit analyses of various types of decentralised and centralised heat pump systems are being carried out. Project activities are being simultaneously undertaken in mining areas of the UK by research organizations in partnership with industrial enterprises (University of Glasgow in partnership with Alkane Energy Ltd.), Spain (University of Oviedo, with HUNOSA as the industrial partner) as well as in Poland (Central Mining Institute, in partnership with Armada Development). The current paper describes first project outcomes of the three areas mentioned above.

Key words: Mine water, heat recovery

Introduction

It has long been recognised that mine water can be used as a source of both heating and cooling. A flooded underground mine represents a huge thermal resource and store, with a temperature at (or somewhat above, in deep mines) the annual average air/soil temperature.

The concept of using mines as sources of heating and cooling is widely recognised and reviewed (Banks et al. 2003, 2004; Watzlaf & Ackman 2006; Banks et al. 2009, Hall et al. 2011; Preene & Younger 2014; Ramos et al. 2015 and Bracke & Bussmann, 2015, Banks 2016). MW scale mine water heating and cooling systems are operating at at Heerlen, Netherlands (Minewater Project, 2008; Ferket et al., 2011; Verhoeven et al., 2014) and in Mieres, northern Spain (Loredo et al., 2011; Ordóñez et al., 2012; Jardón et al., 2013).

Nevertheless, developers often appear reluctant to invest in mine water sourced heating and cooling. It is these barriers to concept uptake that the LoCAL project seeks to address. Five main barriers can be enumerated (Banks 2016):

1. Risk of ochre (ferric oxyhydroxide) clogging of heat exchangers. Many mine waters from coal and metal sulphide mines contain high concentrations of dissolved iron, manganese and other metals, which can form mineral scales under adverse hydrochemical conditions. This risk can potentially be mitigated by (a) maintaining reducing conditions in the mine water - heat exchange circuit, (b) managing pipeline pressures and dissolved gases and (c) utilising environmentally benign reducing agents (sodium bisulphite, sodium dithionite).
2. Risk of thermal breakthrough of thermally spent (e.g. cool) reinjected water, via open mine pathways, to the (e.g. warm) production well(s). This risk can be managed by conscientious mapping of underground workings, together with analytical modelling (Lauwerier 1955,

Pruess & Bodvarsson 1983, Rodríguez & Díaz 2009, Loredo et al. in press), possibly coupled to pipe network models such as EPANET (Ferket et al. 2011), or by numerical modelling.

3. Legal and licensing uncertainty. Can an abstraction licence be obtained and for how long can it be guaranteed? Does the operator accrue any liability for current or future discharge of contaminated mine water? Can a discharge consent be obtained? Will the water need to be treated prior to discharge? Will the water need to be reinjected to the mine via one or more costly reinjection boreholes?
4. Does a proven long term demand for heating and cooling exist in the local vicinity of the mine (given that heating and cooling can typically only be transferred over modest distances). Is there any new development planned - and, if so, is it still at an early enough planning stage that conventional heating and cooling solutions are not "locked in"? If existing demand is present, will new low-temperature heating systems need to be retrofitted?
5. What is the density of heating and cooling demand? If a dense heating / cooling demand is not present in the immediate vicinity of the mine, how extensive a district heating and cooling network will be required and what capital investment does this represent? Will there be a centralised heating / cooling plant room, or will distributed heat pump / heat exchange solutions be used?

The above-mentioned barriers were the inspiration to start an international project under the EU Research Fund For Coal and Steel, named: "*Low Carbon Afterlife: Sustainable Use of Flooded Coal Mine Voids as a Thermal Energy Source - a Baseline Activity for Minimising Post-Closure Environmental Risks*" (Acronym: LoCAL). One of the LoCAL Project's aims is the provision of bespoke tools for investigating flow and heat transfer in flooded mine workings. For this purpose a new tool for heat transfer modelling in flooded mine workings is under development within the LoCAL project. The tool combines flow modelling in the underground mine workings with an updated version of the heat transfer model proposed by Rodriguez and Diaz (Rodriguez R, Diaz MB, 2009). For the purpose of providing evidence required for calibration of this tool, monitoring of specific sites is being undertaken as part of the project, which provide evidence of important mixing processes at the system scale. Once the tools is fully developed and calibrated, the LoCAL project will demonstrate its use on a system in development.

Another aim of the LoCAL project is to overcome the hydrochemical barriers to effective heat transfer from raw and treated mine waters. Ochre clogging is a well-known phenomenon which affects a lot of mine water pipelines. It is particularly important in case of heat transfer from mine water, because ochre can not only affect flow, but also the heat transfer process itself, at least where the mine water used for heat transfer is rich in dissolved iron. Therefore, within LoCAL two types of strategies are being explored. The first comprises preventative methods for ochre clogging of subsurface pumps and pipework during open-loop heat-pump exploitation of mine waters. The second type comprises approaches suited to closed-loop strategies for oxidised, ochre-precipitating mine waters in treatment ponds.

The LoCAL project does not only cover technical and engineering issues, but also provides models for efficiency of energy extraction and distribution. For this purpose technical, legal, managerial and cost-benefit analyses of various types of decentralised heat pump system (as well as centralised plant room systems) is ongoing. Ownership, management and financial models are studied in order to assess the accessibility to subsidies with different ownership models. Responsibility for contamination and licensing aspects with different ownership models is being taken into consideration. Pathways to market uptake of mine water-sourced heat pump systems are also being investigated. As the mine water can potentially serve not only as a source for heating but also as a sink for cooling, models for incorporating cooling into delivery systems are in progress as well. Ultimately, the project is designed to provide a 'toolbox', to ensure application of the project results, comprising all models and tools developed by the LoCAL project.

LoCAL project pilot sites

UK sites

Two UK heat extraction operations are currently incorporated within the project- Caphouse Colliery in Overton, near Wakefield, Yorkshire, at 53.6416°N 1.6251°W, and Markham Colliery just north of Bolsover, Derbyshire, at (53.2424°N 1.3285°W). These sites, within 50km of one another, form part of the East Pennine Coal Field and during their lifetime worked numerous coal seams from Pennine Lower and Middle Coal Measures of the Westphalian (Pennsylvanian) Coal Measures Supergroup of the English East Midlands (Sheppard, 2005). Differing hydrological and hydrochemical scenarios have influenced the thermal extraction techniques utilised at each site.

Caphouse

Caphouse Colliery was in operation from the 1780's through to 1985. The site was converted and reopened as the Yorkshire Mining Museum in 1988 and eventually became the National Coal Mining Museum of England (NCMME) in 1995. Iron-rich waters were continually pumped from the Hope Shaft, sunk in 1827 to 197m bgl, until 1993 when it was intended for regional mine waters to be pumped and treated at the hydrologically connected Woolley Colliery (53.5961°N 1.5338°W). In 1996 a hydrological blockage between Caphouse and Woolley lead to locally rising water levels and so pumping at the Hope Shaft had to recommence in order to prevent uncontrolled break-outs of ferruginous mine water via the numerous other abandoned mine openings in the region.

The Hope Shaft is now pumped on a daily basis by a submersible pump at c. 170 m bgl to maintain mine water levels at 148-153 m bgl. Water is pumped at around 76 L/s for 12-16 hr/day, typically from 10-11 pm onwards, to take advantage of cheaper night-time electricity. A 10 kW heat pump was installed at Hope in April 2015 to provide space heating to a small building housing a museum exhibit. The heat pump can be coupled to either one of two heat exchangers; an 'open loop' shell-and-tube heat exchange system which can only be used when the Hope Shaft is being actively pumped (i.e. night-time and early morning) and a 'closed loop' heat exchange unit submerged in the first aeration pond of the treatment system that can be used throughout the day. Initial analytical results show little isotopic variation in the raw minewater and a recent rapid rise in salinity, suggesting possible breakthrough of deeper sourced waters to the pump interface (Figure 1; Burnside et al. In Press).

Markham

Markham Colliery operated from 1904 to 1993. Markham's Shafts 1, 2 and 4 were backfilled on abandonment, while Shaft No 3 was left largely open, in order to vent mine gas accumulation, with a hydraulically open plug set in the shaft at the level of the Ell seam (428.8 m bgl). The No. 3 shaft and the land surrounding it was acquired by Alkane Energy in 1998 in order to extract coal bed methane. As water levels continued to rise c. 2m/month following abandonment of the coalfield, methane-rich horizons were eventually submerged and methane extraction became uneconomic by 2006.

By May 2011, the water level in Shaft No. 3 was 239.5 m bgl. In 2012 a "standing column" heat pump arrangement was installed, complete with pump at 235 m bgl (extracting water at c. 15°C and 2-3 L/s), sealed shell-and-tube heat exchanger thermally coupled to a 20 kW heat pump, and return diffuser at 250 m bgl for the return of thermally spent (at 12°C) water (Athresh et al., 2015). On 28th January 2015, mine water levels had risen sufficiently to allow the entire standing column arrangement to be raised in the shaft, with the pump being positioned at 170 m bgl, below the reinjection diffuser at 153 m bgl. Initial analyses show little isotopic variation, suggest strong stratification in the water column and indicate a gradual increase in salinity of waters at the pump interface as the water table continues to rise (Figure 1; Burnside et al. In Prep).

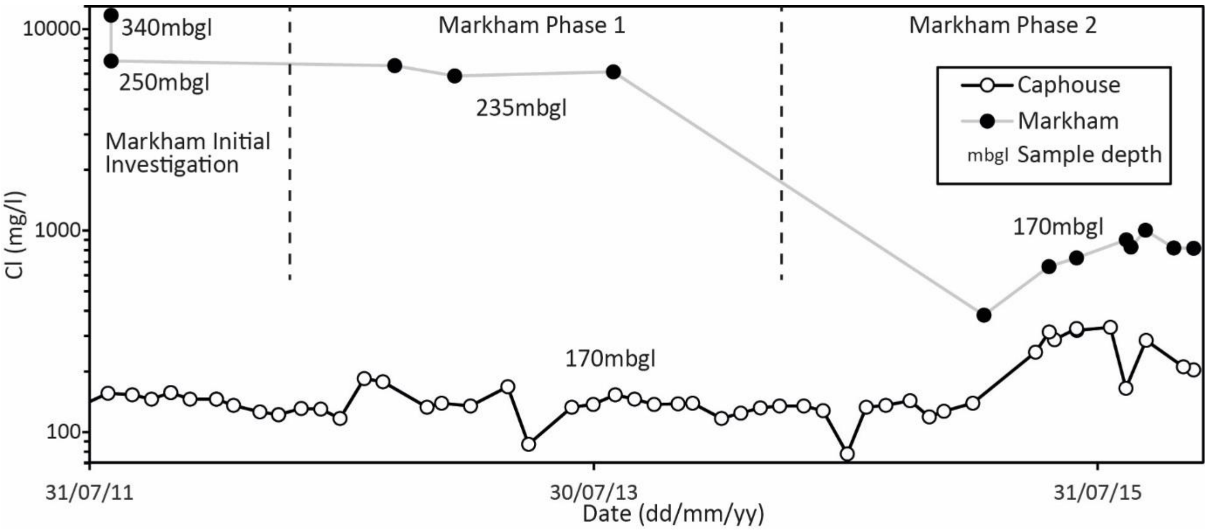

***Figure 1**: Chloride plot for Caphouse and Markham sites (Burnside et al. In Press; In Prep).*

Spain site

HUNOSA has developed two geothermal projects in order to take advantage of the minewater supplying heating and cooling to the surrounding population and industrial districts by use of heat pump technologies. This activity aims at making pumping sustainable in economics and environmental terms. Barredo is a closed mine with an average discharge of 4Mm^3/year.

Both geothermal projects share the mine water pumping system. Installed in Barredo Shaft, the infrastructure uses a best quality self-supporting pipe, made of rubber and polyster. Four pumps Grundfos SP 215-4-AA (75 kW), with a nominal flow of 215m^3/h and a nominal height of 60 meters provide the necessary water flow for geothermal supply.

For the University buildings, that are sited around 300 meters far for the shaft, minewater is distributed directly the by gravity into the buildings with two pre-isolated pipes made of polypropylene (Ø 6" for the Research Centre and Ø 4" for the Hall of Residence). The exchanger of the energy to the secondary circuit of clean water and the heat pumps are placed directly on the buildings.

For the Hall of Residence, the generation scheme is simple because cooling is not required. A heat pump RTWB 207 produces hot water at 35 °C with a runback temperature of 30 °C.

At the Research Centre building, a compensated generation system, consisting of two chillers RTWB 210 (heating power of 362 kW each unit), was built. This design allows us to produce simultaneous heating and cooling. Both chillers produce hot water at 50 °C that returns at 45 °C after being used on the heat circuit and simultaneous cold water on the cold focus at 7 °C. When the water comes back from the cold circuit of the building it returns at 12 °C. Thus the heat pump can work steadily with a thermal gap of 5 °C on each focus. Should the thermal loads become unbalanced, mine water acts as a balancing fluid. When cold requirement exceeds the heat requirements the mine water decreases the temperature of the return water of the heating circuit through a plate heat exchanger (UFP 102/55). Furthermore, in winter time the minewater is used to dissipate the excess cold produced by the chillers ensuring that they can operate with an appropriate thermal gap. (Klinger et al., 2012).

In the case of the hospital, that is located 2 km far from the shaft, the minewater goes directly to heat exchanger placed on the mine installations. It is a tubular heat exchanger with a thermal exchanging power of 3500 kW. After the exchange, the minewater is discharged into a river. The heat is given to a secondary circuit that is a secondary close loop of clean water of 4 km made with polyethylene pipes, Ø 400 mm. Three Grundfos HS -150-125-381 320 5/1 FA pumps (3*55 Kw) are used to pump this clean water to the heat pumps in the hospital.

Hospital Vital Álvarez Buylla thermal installation includes two Carrier 30XWH-1.152 chillers, which can provide heat (1509 kW each one) or cold (1141,4 kW each one) to the building, depending on the climate conditions and the specific needs of the clima system. Another chiller, a CARRIER 30XWH-652, produce simultaneous heating and cooling in a compensated generation system, similar to the one of Research Center.

First data of the geothermal systems allow us to establish that use of minewater energy in these buildings has reduce emissions more than a 60%, comparing actual systems with conventional natural gas boilers and air chillers. Furthermore, even considering the pumping costs, geothermal mine water energy is truly competitive and can provide substantial savings to the final consumers.

Polish site

The Upper Silesian Coal Basin (USCB, southern Poland) is a heavy industrialized region and mining has formed the basis of its industrial development for several centuries (Janson et al. 2009). In 1990 there were 63 active coal mines; although subsequently, around half of them have been closed. In most cases, the abandoned mines are only partially flooded. Mine water levels are being kept down by permanent dewatering from several pumping stations in order to protect the remaining active mines from flooding.Polish pilot site for LoCAL project is located close to Ewa shaft from former Szombierki mine, in the city of Bytom. The amount of the water pumped from Szombierki mine is around 5 m^3/min (83 L/s), while the temperature varies from 24 to 28 degrees (Fig. 2). The team of Central Mining Institute is currently conducting monitoring of mine water from abandoned and active mines in Bytom (Janson et al. In Press). Szombierki mine has been closed for several years, but the Armada Development company (industrial partner in LoCAL project) is conducting land reclamation works at the site. Reclamation included the construction of a sports area (golf course) and housing development. The proximity of the minewater discharge from the former Szombierki is an argument for using renewable energy as the main source for heating and cooling at the planned residential area. First step of implementation of this assumption is an pilot installation that is being constructed within LoCAL project. Company has prepared an technical project for pilot installation, and its main assumption is to use water directly from Ewa shaft discharge pipeline.

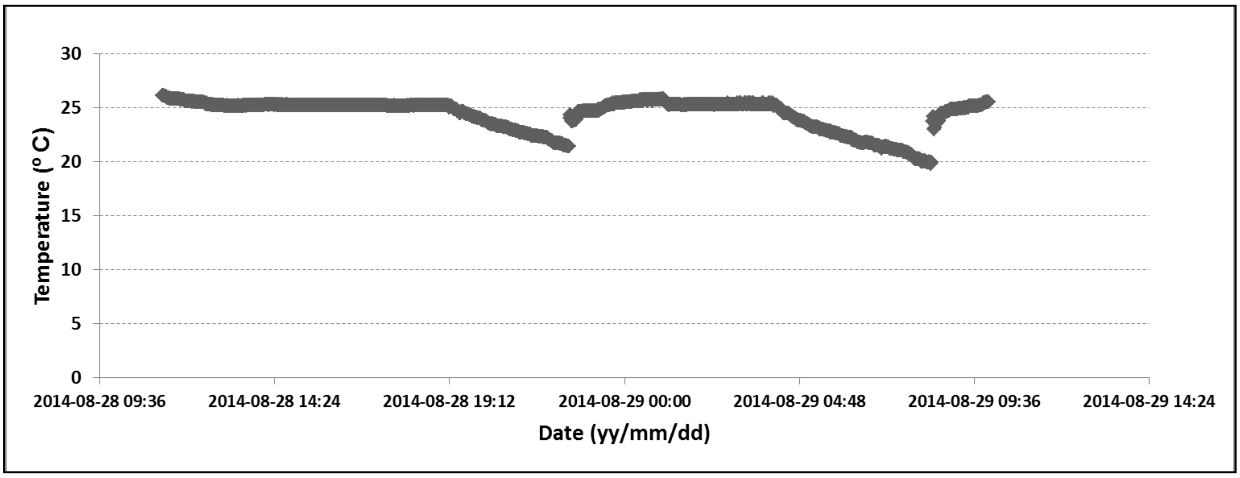

***Figure 2**: Temperature plot for mine water discharge from Szombierki Ewa shaft*

At the Armada pilot site mine water will be used for heating administrative buildings via 6 kW heat pump. It is planned to implement two circuits, mine water will flow through heat exchanger and than the 20% solution of plopylene glycol will support heat pump. The main problem at Polish site remains the proper ownership model, as Armada, being the party interested in the use of mine water for heating purposes, is not the owner of pumped mine water, although the pipeline crosses their lands.

Conclusions

The current paper describes the motivation, aims, concepts and some first project outcomes of the pilot project areas from UK, Spain and Poland included in joint international project LoCAL - "Sustainable Use of Flooded Coal Mine Voids as a Thermal Energy Source - a Baseline Activity for Minimising Post-Closure Environmental Risks". The project is ongoing, therefore no conclusive statements can be drawn yet, however the conditions seem to be appropriate for heat extraction at all LoCAL pilot sites. At UK test sites both closed and open loop systems are under tests and methods for prevention of ochre clogging are tested as well. In Spain the efficiency of heating system based on mine water seems to be proven as more effective compared to traditional gas boiler systems. In Poland the temperature, quantity and proximity of pumped mine water is very promising for the installation of mine water based heating system; the main problem there remains the proper ownership model.

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