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Low enthalpy heat recovery potential from coal mine discharges in the South Wales Coalfield

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ABSTRACT

Fossil fuels generate the majority of space heating and hot water demand in the UK, contributing to greenhouse gas emissions and energy security issues. Concerns about the long term availability of traditional fossil fuels are recognised by the UK government and sustainable, low carbon supplies are being actively investigated. One such option in the renewable energy mix is the use of low enthalpy heat, using open loop ground source technology to recover heat from abandoned flooded coal mines. To assess this potential in the South Wales Coalfield we measured annual temperatures and chemistry at sixteen mine water sites. Mean monthly temperatures ranged from 10.3 to 18.6 °C with an overall mean of 13.3 °C, proving their suitability for low enthalpy heat recovery. Collated data shows the geothermal gradient can vary within the South Wales Coalfield. Exothermic chemical reactions within abandoned mine workings can also contribute to the overall temperature of mine waters. Using discharge and temperature data we estimate that 42 MW of potential heating energy could be generated from currently monitored mine water discharges, however historic dewatering data from operational mines suggests that 72 MW could be generated, enough to heat about 6500 homes. The true potential, if new pumping wells were drilled to exploit flooded workings is likely to be much greater. The use of low enthalpy mine water for space heating and hot water indicate a total emission reduction of around 59% and 76% compare to main gas and electricity heating respectively.

1. Introduction

1.1. The space and hot water heating problem

The consumption of energy for domestic and commercial heating and hot water requirements contributes to almost half of the UK's energy usage (DECC, 2013), costing the UK economy nearly £33 billion per year (DECC, 2012). The principal source of energy for heating and hot water in the UK is natural gas, a fossil fuel, which supplies 70–80% of the heating demand (DECC, 2013) but also contributes around a third to the UK's greenhouse gas emissions (DECC, 2012). The UK Government is targeting renewables to provide the equivalent of 12% of the heating demand by 2020 (DECC, 2009) whilst also reducing greenhouse gas emissions.

Currently renewable heat systems only account for around 1% of the heat generated in the UK, falling short of the government's target of 12% (Connor et al., 2015). The UK Government recognises that the current use of fossil fuels is not sustainable, and that there is a growing need for both energy security and a reduction in carbon emissions (DECC, 2009). One option for generating sustainable low carbon heating and hot water is the use of heat exchangers to exploit mine water associated with flooded workings. Mine waters could provide a sustainable, low enthalpy heating source to supplement the renewable energy mix in the UK, whilst also improving energy security. Abandoned and flooded mines also have the potential to be used for the storage of energy, including compressed air energy systems or the direct use of mine water to regulate the temperature of microalgae to obtain on-site biodiesel production (Scott et al., 2009; Shang et al., 2010). Compressed air energy storage is commonly used where there are large voids, such as salt mines and limestone caverns (Evans, 2009). Other potential heat uses include agricultural glasshouse heating, produce drying and fish farm heating.

There is a substantial, unused resource of mine water in the UK. The Coal Authority estimates that it pumps in excess of 3000 L of mine water every second from abandoned mine workings across the UK, estimating that there is 100 MW of potential heat energy (Coal Authority, 2010); despite this the UK has been slow to adapt to this technology (Bailey et al., 2013). To better characterise the low enthalpy heat recovery potential of flooded workings in South Wales, and to help support the development of this low enthalpy heat extraction, we collated information on mine water temperatures, discharge rates and measured geothermal gradients within the South Wales Coalfield. Rafferty (2000) and Banks et al. (2009) reported the importance of geochemistry in the context of mine water based heat pump system. In order to run the heat pump

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system smoothly and avoid aquifer contamination, mine water chemical composition baseline studies, monitoring and study of mineral stability are necessary.

The data was used to;

1. characterise annual temperature variation of mine water discharges
2. estimate the possible contribution of exothermic chemical reactions to mine water temperature and geochemical facies of mine water in South Wales Coalfield.
3. describe measured geothermal gradients
4. estimate the heat potential from mine water discharges in the South Wales Coalfield

1.2. Existing mine water heating systems

Abandoned flooded mine workings can provide heating and cooling for a single household or for district heating. Low enthalpy energy contained within mine water is exploited using heat pumps. Different types, designs, and configurations of heat pumps are available, enabling them to meet either the total heating requirement of a building, part of the load, or to cover the basic requirement while a conventional system supplies the peaks. There are two basic types of heat pump systems:

1.2.1. Open-loop systems

Groundwater is pumped from a borehole (or mine shaft) and circulated directly through the heat pump, which extracts heat directly from the water. This method is appropriate where a significant water yield of suitable quality, can be sustainably abstracted.

1.2.2. Closed-loop systems

Groundwater is not abstracted however a liquid coolant is pumped to depth via a pipe network in a borehole to capture the heat from the mine water. The coolant is never in contact with the mine water and thus the closed-loop configuration can be used where contamination is an issue or where flooded workings cannot be intercepted. The limiting factor of these closed-loop systems is the surface area of the heat exchanger, which is dependent on the cross sectional area of the linear component of the heat exchanger and its length.

The use of mine water for heat recovery has been successfully demonstrated (Banks et al., 2003; Banks et al., 2009; Jessop and Macdonald, 1995, Watzlaf and Ackman, 2006; Wieber and Pohl, 2008; Verhoeven et al., 2014). Mine water heating systems have been in operation since the early 1980s in mining areas in the USA and Europe (Table 1) illustrate the potential for low enthalpy heat recovery from abandoned mine workings. The installations vary in size, from single buildings (Hall et al., 2011) to larger district heating and cooling systems (e.g. Verhoeven et al., 2013). The municipality of Czeladz, Poland is located in the Central European Coalfield where there is considered to be a large potential for the utilization of geothermal energy from mine waters (Malolepszy and Ostaficzuk, 1999). It is estimated that the potential thermal output from abandoned mine water is 2.5 MWt and a small scale pilot project in Czeladź is in operation generating 117 kW (REMINING-Lowex, 2012). The potential value of mine water associated with the flooded Barredo and Figaredo mine workings, near Mieres in Central Asturias in Spain, implies there is potentially 40 million m^3 per year of available mine water that could provide 260,000 thermal MWh per year (Jardón et al., 2013). Currently a heat pump of 117 kW capacity provides heating to a research building using mine water from the Barredo Shaft and there are plans to heat other buildings using same source. One of the most successful mine water schemes is in the municipality of Heerlen, Netherlands, where a low-temperature district heating system has been in operation since October 2008, funded by the European Interreg IIIB NWE program and the 6th Framework Program project EC-REMINING-lowex. The mine water project has been upgraded from a straight forward pilot system to a full-scale hybrid sustainable energy structure called Minewater 2.0 (Verhoeven et al., 2014).

In the UK this technology was first introduced in Scotland when a temporary pilot site was constructed at Mossend in 1992 followed by two permanent sites commissioned in 1999–2000 at Shettleston and Cowdenbeath (Banks et al., 2009). Recently the Coal Authority has installed a demonstration system in Dawdon, County Durham, UK generating an estimated 12 kW heat output (Bailey et al., 2013). Despite having a long mining history and extensive abandoned flooded mine workings, there has been very little use of mine water for ground source heating in South Wales. The National Assembly for Wales commissioned a desk based feasibility study for potential heat extraction from the South Wales Coalfield (Green, 2007) concluding there was a viable source for heating whilst also converting an '*environmental liability in to an environmental asset*'. A feasibility study near the Taff Merthyr mine water treatment works (Manju et al., 2011) suggested that 220 kW could be produced to heat a nearby sports centre, however, funding for this project did not materialise. To date, there is only one operational mine water heat pump system in Wales, located in Crynant in the Dulais Valley, South Wales, UK National Grid Reference SN 79338 04293. Installed in 2014 as a proof of concept during the European Regional Development Fund supported 'Seren Project' the open loop scheme abstracts mine water at ~11.5 °C from flooded workings from the Carboniferous Coal Measures strata, Rhondda No 2 seam at a depth of 65 m producing 35 kW of heat and hot water demand for a large farmhouse, workshops and adjoining physiotherapy centre.

1.3. Social, environmental and regulatory issues associated with mine water heating systems

The use of mine water as a renewable heating source could contribute to the sustainable regeneration of former mining areas, providing both jobs and secure, low carbon heating energy. Flooded mine workings are attractive as they have increased permeability's and storage, stable year round temperatures at depth, lack of competition from other groundwater users and are often located near urban areas (Younger, 2014). Other

Table 1
Summary of existing mine water open loop heating schemes.

Location	Depth (m)	Installation year	Mine type	System capacity (kW)	Use	Reference/source
Henderson Colorado, USA	Unknown	Early 1980	Metal	Unknown	Air heating	Jensen (1983)
Heinrich Mine, Essen–Heisingen Germany	Unknown	1984	Coal	350	Heating	Hall et al. (2011)
Springhill, Nova Scotia Canada	140	1986	Coal	111 heating/159 kW cooling	Heating/cooling	Jessop and Macdonald (1995)
Park Hills, Missouri, USA	133	1995	Coal	112	Heating	Hall et al. (2011)
Folldal, Norway	600	1998	Metal	18	Heating	Banks et al. (2004)
Shettleston Scotland, UK	100	1999	Coal	65	Heating	Banks et al. (2009)
Quebec, Canada	Flooded open pit	2006	Coal	36 apartments	Heating	Jessop and Macdonald (1995)
Czeladź, Poland	200 m	2012	Coal	117 kW	Heating	REMINING-Lowex (2012)
Heerlen, Netherlands	700	2007	Coal	700	Heating/cooling	Verhoeven et al. (2014)
Mieres, Spain	70	2009	coal	117	Heating/cooling	Younger, 2014
Dawdon, England, UK	66.7	2011	Coal	12	Heating	Bailey et al., 2013
Markham, England, UK	235	2012	Coal	20	Heating	Anthresh et al. (2015)
Crynant, Wales, UK	65	2014	Coal	35	Heating	Seren Project (data unpublished)

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