# Integration of Heat Recovery and Renewables within a Mine Water Treatment Scheme: A UK Case Study

Christopher J. Satterley[1], Sinead Chamberlain[1], Philip Broughton[1]

[1]*The Coal Authority, Mansfield, United Kingdom, christophersatterley@coal.gov.uk*

**Abstract** The Coal Authority has installed both mine water heat recovery and a solar array at its mine water treatment scheme at Dawdon, UK. Monitoring of these schemes indicates that savings in electricity costs could be around 30% (approximately 78,000 kWh) and CO2 savings of 54.7 tonnes per year combined. Pay back periods within 10 years are achieved, demonstrating that even small scale renewables have the potential to reduce energy costs and CO2 emission associated with mine water treatment. These installations are part of the Coal Authority's ongoing programme to reduce costs associated with mine water treatment in the UK.

**Key words** Valorisation, Mine Water, Renewables, Heat Recovery, Low Carbon

## Introduction

The Coal Authority operates over 75 mine water schemes across the UK with a new build programme of up to three new schemes per year. The Authority is funded by the United Kingdom Government to manage the legacy of historic coal mining in Britain. The Authority seeks to implement novel technologies and new ways of working that will deliver significant community and environment benefits and lead to the delivery of a treatment scheme programme without the need for continued Government funding.

To achieve this, the Authority is undertaking an extensive innovation, commercialisation, research and development programme. It seeks to create value from its assets and adopt a circular economy model, at a national and local level, that maximises its potential and realises sustainable benefits for the country.

Reducing the energy consumption and carbon intensity of mine water treatment are key requirements in order to ensure that such treatment is sustainable and cost effective in the long term. The Authority's Innovation Programme includes investing in renewable generation, heat recovery from mine water and seeking alternative uses for ochre produced from mine water treatment.

Recent developments at our Dawdon active treatment site in the North East of England to seek alternative energy sources to reduce costs and carbon emissions are an exemplar of the Authority's overall approach. This paper will give details of the renewable energy generation technologies deployed at Dawdon, as well as how we have assessed their performance since deployment, lessons learned and our the future potential for these technologies within the Authority's mine water treatment operations.

## Site Description

Rising mine waters following widespread coal mine closures in the coastal mining area of County Durham, UK, were identified as at risk of flowing into the regionally important overlying Permian Magnesian Limestone Aquifer. Due to the hypersaline and sulphate rich nature of the mine water, considerable deterioration of water quality of the aquifer would result from relatively small flows. Consequently, a long-term abstraction strategy was considered necessary to control mine water levels at a lesser head than water levels within the Aquifer, and active mine water treatment facilities were installed first at Horden (2004, temporary plant), and Dawdon (2008). In 2011, the active Horden facility was replaced with a lower energy passive system. At Dawdon in County Durham, a High Density Sludge (HDS) active treatment system is employed, housed within an industrial steel framed and clad building in order to comply with local planning requirements. Submersible pumps positioned -69.6 m Above Ordnance Datum (AOD) (well head level: 33.3 mAOD) within the Dawdon Colliery Theresa Shaft control the shaft water level at -47 mAOD (optimum) and deliver mine water to the HDS plant (located 850 m away from the pumping station) at up to 150 L/s via a rising main. Influent mine water is treated with the addition of lime and a polymer flocculent, in order to reduce in-stream iron concentrations before final discharge to the North Sea. The iron is recovered as an ochreous high density sludge which is disposed of off-site and has potential for reuse in a range of applications. Total iron levels in the raw mine water are typically observed to be approximately 70 mg/L with the plant reducing this to <1 mg/L prior to discharge. The Electrical Conductivity of the raw mine water is typically observed to be approximately, 60 mS/cm @25°C with pH in the circum-neutral range around pH 7 with temperatures at surface after pumping typically above 19 °C.

In 2011 a 14 $kW_{th}$ DanfossTM DHP-H OPTI PRO heat pump unit was installed at Dawdon in order to demonstrate the potential for heat recovery from pumped mine water. The system has a design annual heating load of 39,800 kWh to maintain an indoor temperature of 20 °C from a raw mine water flow of 1 L/s. The system was connected to 18 domestic-type radiators (60 $m^2$) for space-heating of offices, workshops and crew rooms on the plant. In addition, the heat pump system provided domestic hot water via a 210 L buffer tank with an immersion heater. Auxiliary heaters are installed to provide heating when the heat pump system is under maintenance or otherwise out of service. A schematic of the system is shown in Figure 1. The system is a three loop system where mine water transfers heat to a heat transfer fluid via a tube and shell heat exchanger, the heat transfer fluid then feeds the heat pump which uses a standard Rankine Cycle (expansion and compression with a phase change). This configuration ensures that fouling in the heat pump is minimised.

In early 2016 an array of 192 photovoltaic solar panels (Axitec 260 W solar modules) was installed on the South East facing roof (inclination 15°) of the treatment plant building covering an area of 312 $m^2$. The system has a total installed capacity of 49.92 kW with an expected annual yield of 43,098 kWh, saving an estimated 21.28 tonnes of $CO_2$ per year (approx. 0.5 kg $CO_2$/kWh). The panels are a polycrystalline tier 1 type with a rated efficiency of 15.98% (under standard test conditions). Figure 2 shows a photograph of the installation in place at the treatment plant.

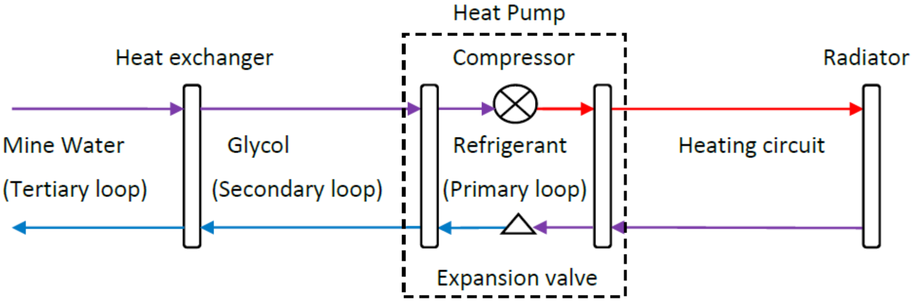


***Figure 1*** *Schematic diagram of heat pump system installed at Dawdon*

***Figure 2*** *Photograph of the installed solar PV array at the Dawdon mine water treatment plant.*

## Methods

During installation of the heat pump system a series of meters and a telemetry system was installed. Table 1 shows the metering used in the performance assessment of the system.

The total heat extracted from the mine water (W) can be calculated based on Equation 1:

$$W = ¿\ C_v.\Delta T.Q \qquad \textbf{\textit{Eq. 1}}$$

Where; $C_v$ = specific volumetric heat capacity (4200 J/L/°C for water), ΔT = temperature difference between mine water feed and return from heat exchanger (°C), Q = flow of mine water feed to heat exchanger (L/s)

The maximum potential heat extraction for the system installed at Dawdon is 16.8 kW based on a design temperature difference of 4 °C across the mine water side of the heat exchanger and a flow rate of 1 L/s.

*Table 1* *List of metering installed on the heat pump system at the Dawdon mine water treatment plant*

| Temperature / °C | Energy / kWh | Flow / L/s |
|---|---|---|
| Heat transfer fluid to heat pump | Electrical power to heat pump | Mine water feed to heat exchanger |
| Heat transfer fluid return from heat pump | Heat energy from heat pump (to buffer tank) | |
| Heat supply from heat pump to buffer tank | Heat energy from buffer tank | |
| Heat supply from buffer tank to radiators | Heat transfer fluid to heat pump | |
| Outside air temperature | | |
| Mine water feed and return from heat exchanger | | |
| Heat transfer fluid feed and return from heat exchanger | | |

The coefficient of performance (COP) of a heat pump system is considered a useful metric in assessing the system and is defined in Equation 2:

$$COP = \frac{Heat\ energy\ supplied\ by\ system}{Electrical\ energy\ required\ by\ system} \qquad \textbf{Eq. 2}$$

For heat pump systems similar to Dawdon a COP of around 5.0 is considered to be indicative of a high performing system (Natural Resources Canada 2009).

Initially, the heat pump was installed with a heat exchanger to extract heat from the treated mine water prior to discharge, however despite the low Fe levels in the treated water (<1 mg/l, total Fe) significant ochre accretion on system filters and pipework (Figure 3) was observed that resulted in reduced flow, impaired performance (Bailey, Moorhouse and Watson 2013) and increased maintenance requirements.

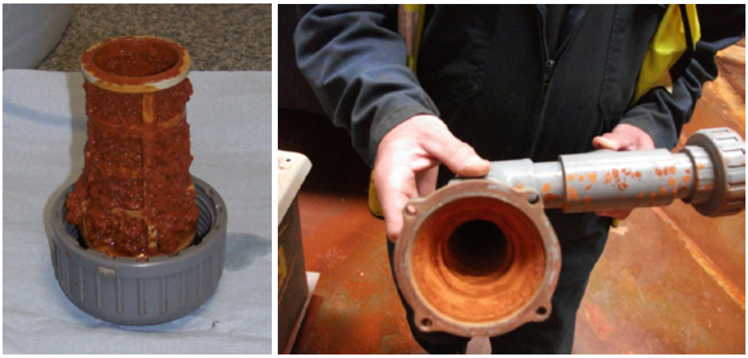

***Figure 3*** *Blocked strainer filter on mine water feed to heat exchanger (left) and ochreous deposits on the heat exchanger inlet (right).*

In 2012, the system was reconfigured to extract heat from the raw ferruginous mine water, which is of relatively poor quality (>70 mg/l, total Fe). The reconfigured system showed significantly reduced fouling and negligible impact on performance. Following further remedial work in 2013 to calibrate all meters and correct heat transfer fluid leaks, a monitoring study was conducted between January and May 2014 to determine the performance of the system.

For the solar installation at Dawdon, all power generated by the array is monitored using a standard electricity meter (Landis+Gyr E230 residential/light commercial meter). The meter is telemetered directly into a web-based energy management tool allowing remote real-time monitoring of the solar panel performance, which is judged both in terms of energy generated compared to expected output and contribution to the overall site energy consumption. Results presented are for the first full year of operation from April 2016 to March 2017.

## Results & Discussion

During the heat pump test period between 17 January 2014 and 30 May 2014, the plant heating system was operational for a total of 679 hours. During this period a total of 18 periodic readings of the operational hours, heat produced and electricity consumed were taken to enable an estimation of COP for the heat pump. During this time, the pump went out of service on 3 occasions between readings, accounting for 134 hours of operation during which there were periods where auxiliary heat was the sole source of heating and calculating a COP value for the heat pump would therefore be meaningless. As it is not possible to ascertain exactly when the heat pump was out of operation between these reading periods, the full 134 hours is excluded for the purposes of energy totals and COP calculation, leaving a test period of 545 hours. Table 2 shows the overall performance values for the test period.

***Table 2** Overall performance values for the mine water heat pump at Dawdon during test period between January and May 2014.*

| Operational hours[1] | Total heat produced / kWh | Total electricity consumed / kWh | COP[1] | Average mine water flow rate / L/s | Average indoor temperature / °C | Average outdoor temperature / °C |
|---|---|---|---|---|---|---|
| 545 | 9,246 | 1,924 | 4.81 | 0.95 | 19.9 | 6.8 |

[1] see text for further description

Over the test period considered, the heat pump was found to be operating very well with an average COP of 4.81, close to the high performance value of 5.00. Throughout the test period, the temperature of the indoor heated space was maintained at an average of 19.9 °C in compliance with the system design, even during winter months. Performance at this COP for the annual design heating load of 39,800 kWh creates and annual saving of approx. £2,670 (assuming £0.085 /kWh) and $CO_2$ reduction of 15.7 tonnes $CO_2$/year when compared with an electrical heating system supplying the same heat load. This annual saving results in a payback period of 9.2 years.

It should also be noted that for a period of 237 hours during the test period the average COP was maintained above 5.00, this was largely confined to the early period of the test in January and early February (during the UK winter) with an average outdoor temperature of 6.8 °C. The observed slight decline in COP in the later part of the test period could be related to a reduction in mine water flow rate to the heat exchanger observed in the second half of the test compared to the first. This flow rate reduction could have been due to minor fouling on heat exchanger surfaces although this appeared to stabilise above 0.9 L/s during the latter stages of the test period implying that any fouling layer may have stopped growing in thickness.

The actual heat extraction of the system was found to be 13.7 kW during the test period (approximately 84% of the maximum design potential heat extraction). This is due to an achieved average temperature difference on the mine water side of the heat exchanger of 3.43 °C (average mine water inlet temperature of 22.7 °C) and an average flow rate of 0.95 L/s, both slightly below design values, but consistent with the minor fouling of heat exchange surfaces expected in real world operation and in agreement with the manufacturer's rated capacity of the system (14 kW).

The solar installation at Dawdon has generated a total of 46,378.6 kWh of electricity in the period April 2016 – March 2017, its first full year of operation. This is 107.6% of the expected annual output according to design. This over performance can be explained by the average amount of sunshine in England being approximately 109% higher than the overall average (1961-1990) that is used for general design calculations (UK Met Office 2017). Therefore it is reasonable to assume that the installation is performing broadly in line with the design. This has generated a total saving of £5,997 in the first full year of operation (this assumes an average cost avoided for electricity of £0.085 /kWh with an average solar feed-in tariff of 4.4 p/kWh (Ofgem, 2017)) and a $CO_2$ saving of 23.2 tonne/year. At this rate of return the system payback period will be 9.9 years.

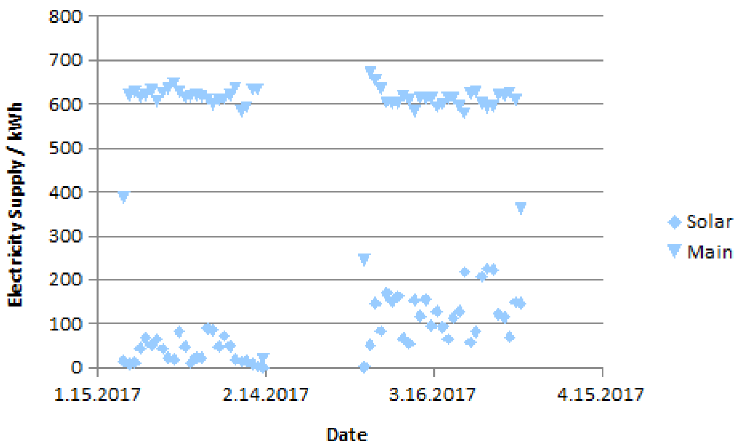


***Figure 4*** *Solar (blue diamonds) and main (red squares) daily electricity supply at Dawdon MWTS during early 2017 follow installation of main supply meter telemetry. See text for further explanation.*

In January 2017 telemetry and data collection was also initialised on the main electricity supply meter, allowing regular comparative data to be collected for the overall electrical demand of the site as well as the solar PV production. The daily generation figures for the period between 19 January 2017 and 31 March 2017 where data is available is shown in Figure 4. It should be noted that the gap in data between 13 February and 3 March 2017 is due to a power fault on site that tripped the telemetry system requiring a manual reset, and therefore data is not available for that period.

The data collected in early 2017 show an average daily solar PV electricity supply of 81.5 kWh which is 13.8% of the overall average daily electrical demand of the site of 589.8 kWh, representing a significant contribution to the overall electrical demand of the site. Figure 4 also shows that as solar irradiance increases throughout March due to seasonal variation, which has a significant impact on the contribution of the system to the overall electrical demand. In the period before the loss of data in mid-February the average contribution of the solar PV system to the overall electrical demand was 5.7%, whereas after that period until the end of March the contribution rose significantly to 17.1%. Therefore to obtain a better representation of the overall performance of the system a full season of data is required.

## Conclusion

Overall, the above results demonstrate that the deployment of renewable energy generation for both heating and electricity can achieve significant cost (potentially around 30%, 78,000 kWh) and $CO_2$ savings (54.7 tonnes per year) on mine water treatment schemes, even at smaller scales. Both installations were able to retrieve pay back periods of approximately 10 years, in line with industry expectations. This study also highlights the benefits and challenges of implementing these technologies, include ensuring that for heat extraction, mine water is extracted before oxidation and for both technologies the need for accurate and available metering data in order to rapidly assess the performance and added value of renewables.

## Future Work

The Coal Authority is actively pursuing an innovative programme of renewable generation deployment, mine water heat recovery and reuse of mine water treatment products such as ochre across their mine water treatment sites.

For reuse of ochre, options are currently being considered for the reuse of ochre which include within the land restoration sector (for immobilisation of contaminants such as arsenic), phosphate reduction and industrial pigments.

Solar PV capacity also has further potential to be increased at the Dawdon site, utilising additional existing footprint on the site and solar PV capacity is already being installed at a number of other Coal Authority treatment sites.

In the future it will be important to monitor the performance of these continual improvements to assess the value gained against expectations and look for further opportunities for improvement.

**Acknowledgements**

The Coal Authority would like to thank the UK Department for Business, Energy and Industrial Strategy for supporting their work.

**References**

Bailey, MT, Moorhouse, AML and Watson, IA (2013). Heat extraction from hypersaline mine water at the Dawdon mine water treatment site. Mine closure 2013: proceedings of the eighth international conference on mine closure. Australian Centre for Geomechanics, Perth, Tibbett, M., Fourie, A. B. and Digby, C., eds. ISBN 9780987093745.

Natural Resources Canada (2009). Commercial earth energy systems: A buyer's guide, Her Majesty the Queen in Right of Canada, ISBN 0-662-32808-6.

Ofgem (2017). Feed-in Tariff (FIT): Generation & Export Payment Rate, available at: https://www.ofgem.gov.uk/publications-and-updates/feed-tariff-fit-generation-export-payment-rate-table-1-january-31-march-2017 [accessed 31 March 2017].

UK Met Office (2017). UK temperature, rainfall and sunshine anomaly graphs, available at: http://www.metoffice.gov.uk/climate/uk/summaries/anomalygraphs [accessed 31 March 2017].