A sustainable approach to managing the treatment of mine waters associated with historic mining

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Abstract

The Coal Authority operates over 70 mine water treatment schemes across the UK and treats around 100 billion litres of mine water per annum to protect the water environment. Funded by the United Kingdom Department of Energy and Climate Change to manage the legacy of historic coal mining in Britain, the Authority is challenged to build new mine water treatment schemes within a flat line budget.

In 2015, the Coal Authority commenced an innovation work stream to accelerate efficiencies and generate income to off-set costs. This programme ambitiously aims to deliver the UK coal mine water treatment programme without government funding and with improved environmental benefits. These aims will be achieved through efficiencies, income generation, adopting transferable technologies, using renewable energy and introducing step-change innovation.

To achieve this aim step changes are needed in terms of design and operation of schemes, but also in terms to how the water and by products are considered. Step-change designs include the adoption of small footprint schemes with minimal chemical dosing requirements and below ground schemes. Aeration and degassing technologies are being progressed to accelerate iron deposition rates.

By products for reuse include mine water for non-drinking purposes; over 63 MW of low carbon recoverable heat and over 4,000 dry tonnes of ferrous hydroxide ochre produced each year. A Ferrous Hydroxide Product Project is underway aiming to cease disposal to landfill and deliver commercial uses for this material. Options for re-use include phosphate management in rivers, agriculture and wastewater treatment, and conversion into pigments and coagulants. Commercially viability requires innovation throughout the product development process including in desludging, dewatering and processing.

Approaching mine water as an asset and understanding the value of benefits delivered by mine water treatment is helping the Coal Authority ensure the long-term sustainability of mine water treatment in the UK.

Key words: mine water, sustainability, innovation, energy, efficiency

Introduction

The Coal Authority builds and maintains mine water treatments schemes to resolve the environmental impact of rising mine water within coal mines and, more increasingly, metal mines. It is funded by the UK Government and its coal mine operation and maintenance programme operates under a flat line budget of circa £10million per annum. With a programme to build between one and three new mine water treatment schemes per annum there is a need to find efficiencies or generate incomes to absorb the cost of managing these additional schemes.

In 2015 the Coal Authority undertook a comprehensive innovation exercise to reimagine all aspects of how it delivers its mine water treatment scheme programme with the aim of dramatically reducing its need for Government funding and delivering a more sustainable delivery model. This work was successful in identifying new ways of working and the implementation of the innovation programme delivery phase commenced in late 2015.

The innovation programme seeks to deliver whole life cost savings, generate incomes, provide more sustainable sources of energy and minimize energy use. To achieve these it requires motivated capable partners, introducing step change designs, adoption of transferable or novel technologies, commercial agility and to maximise value from its assets. This in itself is a cultural change for the Coal Authority and requiring a new vision and new delivery structure.

Although having only been launched in late 2015, the innovation programme has already been successful in initiating partnership working with water companies, local authorities and developers. It has let a design and construct and operate and maintaining contract for its portfolio of mine water treatment schemes with contractual requirements to deliver innovation and efficiencies. It has started trialling new technologies and focussing a substantial part of the Authority's research and development programme to deliver small footprint, low cost schemes. There is an active renewable energy programme and income contracts secured from managing energy demand.

Sustainable use of treated mine water

The Coal Authority treats approximately 100 billion litres of water a year, which is then discharged to watercourses. At present all of the treated water is discharged to receiving watercourses. This water has potential financial value and has a sustainability value in managing water scarcity issues. An analysis of water quality indicates there is high potential for its use in industry, agriculture and a grey water market. Changes in legislation introduced in the UK Water Bill opens up commercial opportunities as a water supplier and the Coal Authority has commenced discussions with how to sell water into this market. Separately it has engaged with talks as a private supplier to large water users.

An analysis of this water indicates that a high percentage has commercial value. Water Conductivity of untreated mine water in schemes is shown in table 1.

Table 1. *Water conductivity at UK coal mine water treatments schemes 2016*

Water quality	Conductivity ($uScm^{-1}$ at $25^{O}C$	Mine water treatments schemes	Aggregated flow (Ls^{-1})	Flow percentage (%)
Low salinity	< 1500	39	1000	34
Medium salinity	1500 – 3000	21	1100	38
High salinity	> 3000	11	850	28

Water recycling opportunities becomes more favourable with large industries due to water scarceness, droughts, quality of raw water and new technologies being able to optimise / upgrade existing process waters. Where water quality does not meet user requirements, options are being investigated to raise the water quality using membrane bio-reactors, ultra-filtration, reverse osmosis and electro deionisation. The financial model for such treatment is based on the partially treated mine water costs having been absorbed by the existing costs of managing the scheme for environmental benefit. Therefore, the profit made from such schemes goes directly to offsetting the costs of the environmental benefit schemes.

The use of this supply of water complements the Water Recycling Model of: Water Conservation, Water Re-use, Water Recycling, Process and Product Integrity and Environmental Impact. Incomes from the sale of water and sustainability of supply are being well received by water companies, industries and regulators in the early discussions.

Sustainable use of mine water heat at surface

Geothermal energy represents a major source of carbon free energy (P.Younger Geothermal Energy: Delivering on the Global potential, 2015). The Coal Authority extracts approximately 100billion litres of water per annum typically ranging from 11 to 20 ^{o}C. A trial of heat exchangers at the Dawdon Mine Water Treatment Scheme (Bailey et al.,2013) has been successful in producing space heat without maintenance issues for ochre build up or adverse reactions to the hypersaline mine water. By

extracting water from the direct feed prior to aeration there have been no issues of ochre deposition within the heat exchanger.

By removing five degrees centigrade as an efficient extraction rate (Dawdon Heat Pump Report Ecolinx 2013), from the portfolio of MWTS's, at the point of water coming to surface, a potential 63 MW of heat can be harvested. This heat asset has a significant value in financial terms and in the supply of a low carbon sustainable energy source to reduce the UK's reliance on fossil fuels.

The Authority has a commercial advantage over alternative means of using ground source heat, and mine water heat extraction, in that the many of the costs are covered by the schemes operational costs. These costs include; access to mine water through boreholes, shafts and adits; pumping costs; and disposal of cooled water.

The Coal Authority has two heat schemes progressing with a combined 3.6 MW of heat potential and another nine schemes at early discussion stage.

Sustainable uses for ochre

Mine water treatment schemes in the UK produce approximately 4,500 tonnes dry solids of Ferric Hydroxide per annum. Historically, this has been disposed of to landfill. Costs of desludging and disposal of sludges has increased as schemes have matured. In 2015/2016 the desludging and disposal costs were $1.75million.

To offset these costs and provide commercial incomes the Coal Authority is engaged in a programme to find commercial markets for this material and is in discussions with foundries, coagulant manufactures and pigment manufactures (S.Bearden, 2002). Discussions with regulators are ongoing on end of waste but also the potential use of this material for sustainable environmental improvement.

In addition to the work on ferric products, areas of innovation to be explored in 2016/2017 include desludging, sludge handling, sludge drying and sludge preparation efficiencies. This work is to increase potential for economically viable products to be created or for the ochre to go in as feedstock to industry.

With many of UK water courses having high phosphate levels and with increased phosphate targets under the Water Framework Directive, the Coal Authority is working with water companies on a number of opportunities to reduce phosphate levels in watercourses and water bodies using iron rich mine water, ferric sludges and ferric products.

In 2005 the Coal Authority entered into a joint venture with a water company combining the treatment of a raw coal mine water discharge and secondary treated sewerage effluent. Data collected over the past decade indicates that there are no seasonal trends between the interactions of iron and phosphate; this is likely due to the consistent temperature of the mine water. Presence of HFO and iron flocs is key to phosphate and ferrous iron removal, with the initial interactions between iron and phosphate being essential. Using co-treatment mechanisms can help realise the new Water Framework Directive targets for phosphate without the need for the addition of chemical dosing. Further work with Water Companies is ongoing to develop niche products that target upstream or point of origin issues of phosphate, such as from agricultural sources, as well as from waste water treatment works.

Sustainable energy use

During 2015 the Coal Authority undertook a review of its mine water treatment schemes and land holdings for the use of renewable energy. This has identified a large number of schemes that will benefit from the use of renewable energy sources when this power is used on site. Changes in Government subsidies in late 2015 have reduced the profitability of feeding surplus capacity into the electrical grid such that currently electricity generation is only viable to the Authority for use rather than export. However, as technologies change and cost of infrastructure changes this might change in the future.

A rolling programme of introducing renewable energy schemes onto sites started in March 2016. Typically these will be 50kW solar schemes, such as that recently installed at Dawdon (Figure 1). Use of wind turbines, wind pumps, mini hydro, hydro and energy storage are being progressed based on an assessments of cost benefit and sustainability targets. A number of existing schemes have been identified with the opportunity for direct feed from wind turbines, existing hydro schemes and biomass power stations. Discussion with these energy providers are ongoing.

Figure 1 *Dawdon active scheme 49.92Kw scheme installed in 2016 consisting of 192 260 W panels.*

As water treated by mine water schemes has a typical flow of less than 200 L/s there is little opportunity to generate significant hydro power to offset the cost of pumping. A review of existing schemes is to be carried out to identify opportunities to source power from watercourses. The location of new schemes will consider locations sufficiently close to water bodies with a high flow as a means to provide sustainable power sources and reduce operating costs.

Realising value from mine water treatment schemes

Existing mine water treatment assets offer a number of opportunities to provide savings and generate incomes. These include leasing of land to energy generators, incomes from power use variation and letting of land for commercial incomes.

The UK's electrical network and system frequency is a continuously changing variable. When demand is greater than generation, the frequency falls, and when generation is greater than demand, the frequency rises. National Grid controls and monitors system frequency in real time using second by second metering to balance demand and generation.

The Coal Authority has recently enrolled in a contract with a Frequency Response aggregator, committing an initial 325 kW into a firm frequency response programme. Additional opportunities are being progressed. The result of this, coupled with power management will be altering pumping regimes such that existing and future pumped schemes are managed at a water level that can allow some downtime of pumps. This enables pumping to occur at times of cheaper energy tariffs and for pumps to be shut down during peak demand times to balance the power network. Careful consideration is needed to ensure that any additional drawdown or treatment capacity needed does not

remove savings from energy management. This is considered under careful cost benefit analysis and whole life costs for each scheme.

Another opportunity being progressed is the siting of power generators on mine water treatment schemes to feed into the electrical grid at times of high income. The grid is coming under increasing stress as a result of decreased electricity generation capacity, with the last coal fired power station due to be out of commission by 2023,. The Government is seeking companies to provide extra STOR (Short Term Operating Reserve) capacity, in small power plants that can come on-line quickly. These are supplied under 10 or 15 year contracts. With some Coal Authority sites having land availability and access to the grid, there is an opportunity to create extra value by leasing out suitable sites to operators and generating a substantial extra annual income.

Whole life cost savings through contract management

In 2015 the Coal Authority let two NEC3 framework contracts; one for the design and construction; and the other for operational maintenance of mine water treatment schemes. Contractors were selected who would bring efficiencies and innovation to provide whole life costs savings and who would work effectively in a tripartite manner with the Coal Authority and each other. The contract manages efficiencies through a pain/gain mechanism which provides financial incentives to deliver savings.

To promote innovation, contractors can receive funding from an innovation fund set up by the Coal Authority. This fund operates independently of the pain/gain mechanism so allows risks to be taken in the trialling of new technologies or initiatives. Where innovation is successful the contractors receive financial benefit from the savings provided.

To assist the innovation process the Coal Authority is establishing an innovation hub and innovation log. The log has been populated initially with over 360 innovation and efficiency opportunities ranging from small incremental improvements to step change novel technologies. This log is under regular review to provide a dynamic tool to provide focus to innovation and for taking the most effective opportunities forward.

Catchment management approach

Mine water treatment schemes have been developed historically based solely on capturing and treating the mine water at the point of discharge or point of greatest access to provide the cheapest possible outcome. The business case for each scheme has been built on a cost benefit assessment, with the benefits appraisal identifying the benefits of cleaning the water and some benefits of the scheme itself. However, in future, schemes will be developed using a catchment management approach with a wider view of benefits.

The catchment management approach does not just look at the benefits of removing or preventing the pollution, but also on the wider benefits to stakeholders within the catchment. Where potential users of water, heat or other mine water related products or services exist then these factors will be taken into account when considering mine water treatment location and design.

A theoretical example might be that the cheapest location and treatment for a mine water discharge is near the point of discharge with easy capture and minimal pumping to a passive treatment area. This would have historically been the preferred option. However, taking a catchment management approach, the new preferred solution might mean that the level is controlled by pumping a former mine entry. This additional pumping is off-set by:

- a wind turbine that can be sited adjacent to the mine water control point;
- a treatment location adjacent to a waste water treatment works, which takes raw mine water to help coagulate raw effluent and improve sludge settlement without the need for processed chemical coagulants; and

- final mine water effluent treatment polishing provides a habitat island for migratory birds and local ecological amenity for community use.

This is but one example of multiple permutations that can be explored by involving various catchment stakeholders such as developers, water companies, wildlife trusts and community groups.

Such an approach is being delivered at one of our sites, where the scheme is adjacent to a derelict industrial site in an area of economic deprivation. By working with the developer, the local authority and interest groups, an energy efficient development is planned, using both heat and water from the pumped mine water, and energy from local wind and biomass to directly power the pumps. This is a multiple win situation:

- the Coal Authority gets power at a reduced rate and off-sets the cost of mine water treatment through sale of heat and water;
- the developer gets a unique selling point for their site to encourage sustainably focused industries to their sites;
- the local authority gets regeneration of the area with new jobs to replace the ones from old industries; and
- the planet gains from energy and water efficiency from reuse of heat and water, and low carbon energy generation.

Many more such projects are being planned, with implementation over the next few years.

Small footprint design

Mine water treatment schemes in the UK typically follow two design routes:

- Small footprint, high chemical and energy use active schemes; or
- Large footprint low chemical use passive schemes.

Designs have previously been based on PIRAMID Consortium guidelines (PIRAMID Consortium, 2003 Engineering guidelines for the passive remediation of acidic and/or metalliferous mine drainage and similar wastewaters). The Coal Authority is now investigating transferable technologies and potential novel technologies of its own design, which have the potential to deliver small footprint, low cost, low chemical use passive schemes. To achieve this aim the scheme components have been split into three key functions:

- Energy use;
- Rapid deposition; and
- Polishing.

A number of technologies have been identified in all of these areas, each of which has been prioritised and trials in 2016/2017 will identify if the priority technologies will deliver significant benefits.

The controlled deposition of iron is seen an important component in improving performance and reducing costs at existing mine water treatment schemes, and in the delivery of future small footprint schemes. Rapid deposition could provide savings in chemical costs, desludging, reed bed maintenance and retention lagoon sizing. It has a high likelihood of improving performance of existing schemes and replace/improve the use of cascades. It is of interest in the Ochre Product Project in delivering continuity of supply for Ferric Hydroxide products.

A number of technologies from other industries have been assessed that will accelerate rapid deposition of iron, with trials currently being carried out on self-aspirating aerators used in the shale gas industry.

Additional novel technologies within the Research and Development programme in 2016/2017 include small footprint solutions to replace reed beds, minimise lagoon size and resist ochre build up on surfaces. These technologies will help drive down capital, maintenance and energy costs, with potential additional benefits such as ability to free up land or provide consistent materials for commercial use.

Conclusions

The Coal Authority is carrying out an ambitious programme of efficiencies and innovation based on its 2015 innovation exercise. Many of these opportunities have contributed to the creation of a cohesive vision of partnership working involving a wide number of stakeholders including water companies, regulators, land developers, industry, communities, local authorities and government agencies. Discussion with these groups under its Catchment Management Initiative have been well received, with all parties seeing substantial benefits that exceed the sum of their individual interest or contribution.

A number of technologies and initiatives are being trialled to deliver the small footprint, low whole life cost, low carbon footprint, income generation schemes which are the ultimate ambition of the innovation programme. A large number of water company opportunities have been identified which have commercial and sustainability opportunities, Engagement on these opportunities is in early stages but promising. The success of the innovation programme will be reviewed at the end of 2016/2017 to identify which areas show greatest promise and which are of lesser priority.

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