



Mitigation of pollution from abandoned metal mines

Extended summary - SC090024/S2

The Environment Agency is the leading public body protecting and improving the environment in England and Wales.

It's our job to make sure that air, land and water are looked after by everyone in today's society, so that tomorrow's generations inherit a cleaner, healthier world.

Our work includes tackling flooding and pollution incidents, reducing industry's impacts on the environment, cleaning up rivers, coastal waters and contaminated land, and improving wildlife habitats.

This report is the result of research commissioned and funded by the Environment Agency.

Published by:

Environment Agency, Horizon House, Deanery Road,
Bristol, BS1 5AH

www.environment-agency.gov.uk

ISBN: 978-1-84911-263-5

© Environment Agency – March 2012

All rights reserved. This document may be reproduced with prior permission of the Environment Agency.

The views and statements expressed in this report are those of the author alone. The views or statements expressed in this publication do not necessarily represent the views of the Environment Agency and the Environment Agency cannot accept any responsibility for such views or statements.

Further copies of this report are available from:
The Environment Agency's National Customer Contact Centre by emailing:

enquiries@environment-agency.gov.uk

or by telephoning 08708 506506.

Author(s):

Adam P Jarvis, Catherine J Gandy, Neil D Gray

Dissemination Status:

Publicly available

Keywords:

Mines, water, passive, treatment, metals, acidity, resources, recovery, England, Wales, pollution, remediation

Research Contractor:

School of Civil Engineering & Geosciences, Newcastle University, Newcastle upon Tyne, NE1 7RU. Tel: 01912464871

Environment Agency's Project Manager:

Vicky Greest, Evidence Directorate

Project Number:

SC0900024/S2

Product Code:

LIT 7343

Evidence at the Environment Agency

Evidence underpins the work of the Environment Agency. It provides an up-to-date understanding of the world about us, helps us to develop tools and techniques to monitor and manage our environment as efficiently and effectively as possible. It also helps us to understand how the environment is changing and to identify what the future pressures may be.

The work of the Environment Agency's Evidence Directorate is a key ingredient in the partnership between research, guidance and operations that enables the Environment Agency to protect and restore our environment.

This report was produced by the Research, Monitoring and Innovation team within Evidence. The team focuses on four main areas of activity:

- **Setting the agenda**, by providing the evidence for decisions;
- **Maintaining scientific credibility**, by ensuring that our programmes and projects are fit for purpose and executed according to international standards;
- **Carrying out research**, either by contracting it out to research organisations and consultancies or by doing it ourselves;
- **Delivering information, advice, tools and techniques**, by making appropriate products available.

Miranda Kavanagh

Director of Evidence

Executive summary

Reviews of passive treatment technologies for water discharged from abandoned metal mines, and metal resource recovery options, have identified a wide range of treatment systems and the potential to produce material resources or non-hazardous wastes from them by various means.

Treatment systems for metal mine drainage waters can encompass a variety of processes, but they all have as their primary goal the immobilisation of metals within the confines of the system. Technologies range from aerobic systems (such as settlement lagoons and aerobic wetlands), in which metals can be removed via precipitation as their hydroxides, to anaerobic systems which encourage bacterial sulphate reduction in organic substrates leading to precipitation of metals as sulphides. Alternative processes, such as co-precipitation, adsorption and bioaccumulation, may also result in the immobilisation of metals within treatment systems.

Both pH and redox potential (Eh) are important controls on the geochemical behaviour of metals in aqueous environments, so are important parameters to consider in treatment system design. Although the precipitation of (oxy)hydroxides is proven to successfully remove iron from coal mine drainage, the higher hydroxide solubility products of zinc and other metals necessitates a higher target pH for their precipitation, which limits the suitability of aerobic wetlands to treat metal mine water discharges. Area-adjusted removal rates of zinc in such systems are much lower than those of iron, resulting in a considerably larger system than an equivalent one for iron. In contrast, the solubility products of the sulphides of some of the key metals in metal mine discharges (such as zinc) are lower than that of iron sulphide, and so these metals should be removed preferentially over iron. As such, a more favourable approach to immobilising metals at the pH values typically achievable in passive treatment systems (up to pH 8) appears to be the use of anaerobic systems in which bacterial sulphate reduction leads to the simultaneous generation of alkalinity and precipitation of metals as sulphides. However, in most cases residence times tend to be too long for these systems to be realistically feasible in UK settings. Identification of potential carbon additives and sources of microbial inocula are essential to maintain bacterial sulphate reduction at sufficient rates to immobilise metals within a reasonable timeframe. A number of studies have investigated the periodic addition of carbon sources (such as ethanol, wine wastes) to the compost substrate but the majority have been done at laboratory scale and do not take account of scale issues or different environmental conditions observed at actual mine sites. Pilot-scale experimentation is therefore necessary to establish the performance of these systems under field conditions.

Other mechanisms, including co-precipitation, adsorption and bioaccumulation, may serve to immobilise metals within treatment systems although many are pH-dependent, with implications for the rate of metal removal. In addition, sorption media may become exhausted and it is possible, if pH/Eh conditions change, for desorption of metals to occur, potentially releasing metals into solution. Again, most experiments have been done over short time periods in laboratory columns so issues of scale would need to be investigated before the technology could be applied at full scale.

In terms of resource recovery options from passive remediation systems treating metal mine discharges, a number of technologies have been identified for the production of material resources or non-hazardous wastes. A limited number of studies have shown that metals accumulate in substrates of passive remediation systems over decadal time scales to levels ranging from approximately 10 to 10,000 mg/kg but, even at the higher end of this scale, such levels are lower than typical mineral grade cut-off values

considered for economic recovery in mine operations. Levels of metal accumulation are principally controlled by metal loading rates and the timeframes for accumulation. Studies have also shown that metal accumulation within treatment systems is often localised, with higher accumulations typically found in surface layers and in zones near to system inlets. This heterogeneous distribution of metals suggests that substrate reuse or decontamination should be spatially targeted and it may be possible, should these systems reach the limit of their metal removal capacity, to remove and replace the upper substrate layer, thus increasing the lifetime of the systems. In addition, in aerobic and anaerobic treatment systems, metals are heterogeneously distributed between oxidised or reduced mineral phases and organic bound metal complexes. These phases may have different stabilities under recovery or disposal conditions.

It seems unlikely that metals will accumulate in all mine water treatment systems to levels suitable for economic recovery. However, based on the form, volume and levels of metal accumulation, exhausted substrates may be considered as hazardous wastes which pose a toxicological risk to receiving environments. This can preclude their disposal to landfill, depending on the outcome of leachability tests. Despite this, at present, little consideration has been given to the disposal of exhausted substrates derived from mine water treatment systems.

Chemical and biological leaching (for metal recovery or decontamination) are the most cost-effective options for metal removal from low-grade treatment substrates. A wide variety of lixiviants, such as acids, chlorides, ferric iron and ammonia, are likely to be effective in removing heavy metals from oxidised and sulphidic Zn, Cu, Pb and Cd-rich materials. The choice of lixiviant will, however, depend on substrate and target metal chemistries. For very low-grade materials, bioleaching, in which acidic or ferric iron concentrations generated from microbial activities induce dissolution of oxidised or sulphidic minerals, is the most cost-effective approach. The recovery of metals from pregnant solutions can be achieved by precipitation or selective solvent extraction.

On larger scales of waste resource management, metal decontamination for reuse or safe disposal may not be feasible. This may be especially true of substrates which are complex in terms of contamination and substrate composition. An alternative solution would be to subject wastes to stabilisation or solidification in an attempt to restrict the movement of contaminants. The materials could then be reused as construction cements or backfilling materials.

Other resource options from passive mine water treatment systems include ground source heat and micro-hydroelectricity. Ground source heat recovery from mine waters has been tested in the UK (albeit with coal mine waters). With careful management of system pressures and by minimising exposure to atmospheric conditions, mine water-based heating and cooling schemes can function reliably and with minimal maintenance requirements. Although mine water discharges in the UK are not known to have been used in micro-hydroelectric schemes, discharges from abandoned metal mines are often found in upland regions where, given a suitable head and water flow rate, there may be potential for development of such schemes.

Clearly, the different types of passive remediation systems for metal mine drainage will have an impact on the resource recovery options. In particular, the predominant abiotic and biotic metal removal mechanism plays an important role in dictating the form in which metals are precipitated and retained in treatment systems. This is undoubtedly an important consideration in the application of metal recovery technologies since metals bound to organic particles are only mobile after decomposition or weathering. In contrast, precipitated minerals will be more easily dissolved and mobilised by changes in pH. On this basis, removal efficiencies are likely to be influenced by both mineral

form and the chemistry/composition of the substrate. For treatments involving inorganic absorptive materials (such as geosynthetic clays, zeolites, caustic magnesia), metals tend to precipitate in a relatively homogenous manner, typically in the form of hydroxides or oxyhydroxides. Wetland treatment systems, on the other hand, are highly heterogenous and comprise a number of minerals or metal complexes, the formation and distribution of which are heavily dependent on redox potential, pH and biological activity. Metals typically precipitate as oxyhydroxides, carbonates and sulphides in such systems.

In anaerobic compost systems designed to retain metals as sulphides, it has been shown that significant proportions of metals are retained in the organic matter within the treatment systems. However, in the presence of sulphide and given sufficient time and consistently low redox potentials, it is thought that these organically bound metals are eventually transformed to sulphides. Nevertheless, while a relatively homogenous mineral precipitate is produced in treatment systems designed to remove metals by adsorption to inorganic materials, for wetland-based treatment systems (particularly anaerobic systems) a heterogenous metal mineralogy will be the norm. This variation in mineral form within treatment systems is likely to have consequences for the designation of these materials for disposal and the application of recovery technologies.

In addition, the wide range of organic and mineral associations within the different treatment systems will have a profound effect on the outcome of leachability tests and hence the cost of landfill disposal or requirement for remedial treatment. For instance, acidic residues, such as ochres produced in aerobic systems, would require treatment with alkali (such as lime) before disposal to a landfill to prevent generation of acidic leachates. Metal removal technologies are also influenced by treatment type, with the choice of technology governed by the composition of the waste material.

An alternative technology is the selective precipitation of metals within treatment systems for their subsequent recovery. Such systems, however, tend to be active rather than passive due to the close process control required, particularly with respect to pH. The technique has been applied in different types of treatment system, including anaerobic compost reactors where selective precipitation is feasible due to the differing solubility products of metal sulphides. Similarly, selective precipitation has been shown to be possible using different inorganic chemically active adsorbents for the recovery of oxidised metals from mine water. By using an integrated adsorption process with independently operating fixed-bed adsorption systems comprising different materials, the selective removal of various metals is achievable.

A common conclusion to both reviews is the need for pilot-scale experimentation to establish the performance of different passive remediation technologies for metal mine drainage under field conditions and to determine metal recovery/decontamination efficiencies from remediation substrates. The passive treatment technologies review shows that it is feasible to immobilise metals, using various processes, at a laboratory scale but few studies have been done at pilot or full scale. Similarly, with regards to resource recovery, few studies have investigated the recovery of metals from pilot or full scale systems but technologies have been proven on other wastes. The next step, therefore, is to investigate remediation processes and resource recovery technologies at pilot scale.

We are The Environment Agency. It's our job to look after your environment and make it **a better place** – for you, and for future generations.

Your environment is the air you breathe, the water you drink and the ground you walk on. Working with business, Government and society as a whole, we are making your environment cleaner and healthier.

The Environment Agency. Out there, making your environment a better place.

**Would you like to find out more about us,
or about your environment?**

Then call us on

08708 506 506* (Mon-Fri 8-6)

email

enquiries@environment-agency.gov.uk

or visit our website

www.environment-agency.gov.uk

incident hotline 0800 80 70 60 (24hrs)

floodline 0845 988 1188

* Approximate call costs: 8p plus 6p per minute (standard landline).
Please note charges will vary across telephone providers



Environment first: This publication is printed on recycled paper.