A high surface area media treatment trial of a circum-neutral, net alkaline coal mine discharge in the South Derbyshire Coal Field (UK) using hydrous ferric oxide

Arabella M. L. Moorhouse, Lee M. Wyatt, Ian A. Watson, Steve Hill

The Coal Authority, 200 Lichfield Lane, Mansfield, Nottinghamshire NG18 4RG, UK; abbymoorhouse@coal.gov.uk

Abstract In 2010, a trial using high surface area media, in the form of a SCOOFI (Surface Catalysed Oxidation of Ferrous Iron) system was undertaken for 12 months to assess the effectiveness of the medium for removing iron from a net-alkaline, circum-neutral mine water in Leicestershire. Three different configurations were investigated, which achieved mean iron area-adjusted removal rates up to 139 g/m²/d; higher than the 10 g/m²/d quoted in the literature for conventional schemes. Although the media successfully removed some iron, the ochre quickly clogged the system and the unstable nature of the precipitate resulted in problems when maintaining the scheme.

Keywords Coal mine water, net-alkaline, high surface area media, iron removal

Introduction

The South Derbyshire Coalfield (covers areas in the English-Midland counties of Derbyshire and Leicestershire) has been subject to rising mine water over the past twenty years, since mining ceased c. 1990, with the situation being monitored by the Coal Authority in a series of boreholes across the region. The Authority, a non-departmental government body responsible for the abandoned coal mine legacy within the UK, has a long term strategy to control these rising waters from Cadley Hill (c. 7 km to the NW), the lowest point of the coalfield. However, recent evidence obtained by the Authority suggests that the risks of contamination to the regional groundwater aquifer by the rising mine water are lower than previously considered. Hence, this dewatering strategy is currently in abeyance whilst further options are currently under review.

Saltersford Valley Picnic Area is a nature reserve located in the southern region of the South Derbyshire Coalfield, approximately 1 km NW of Measham, Leicestershire. Subsidence associated with sub-surface coal mining resulted in the Saltersford Brook flooding farmland producing a series of small permanent lakes, known locally as 'flashes', which form the nucleus of the nature reserve. The site was purchased by Leicestershire County Council in 1990 and was transformed into a recreational area, suitable for use by the local population in addition to enhancing conditions for wildlife. The site was designated as a Local Nature Reserve by Natural England in 2004, and includes woodland, grassland, wetland and freshwater lake habitats.

Mine water breached the surface at Saltersford from the abandoned Nether Leys Pit shaft in early 2010. The discharge quickly discoloured the lake, concerning both local residents and politicians, and was reported by the local press; prompt action was therefore required to minimise the visual impact of the discharging mine water to the area. The discharge is currently not included on the Environment Agency (EA) priority list, as the principal local water course of the Saltersford Brook, is presently not impacted by the discharge. However, as the Saltersford Brook flows directly into the River Mease, which is designated as a Special Area of Conservation

(SAC) site, future protection of the water course may be required. The discharge may transiently dry up as a result of de-watering associated with a proposed nearby opencast site, and ultimately, if a pump and treat scheme is implemented near Cadley Hill. In these rather unusual circumstances, the Authority considered that a temporary mine water treatment method would be more appropriate for this location in preference to schemes (*i.e.* aeration cascades, settling lagoons and aerobic wetlands), typically constructed and operated by the Authority. The limited amount of land available for any treatment scheme combined with the need for a prompt, yet temporary response, made this site a prime location for trialling an alternative mine water treatment technique such as the use of high surface area media or a SCOOFI (Surface Catalysed Oxidation of Ferrous Iron) system.

SCOOFI Mine Water Treatment Schemes

The number of SCOOFI mine water treatment schemes in the UK have essentially been limited to small-scale field trials, (*e.g.* Younger 2000; Jarvis and Younger 2001) with an exception being a full scale trial installed at an ironstone mine at Skinningrove, Cleveland, c. 2000, which is no longer operational. SCOOFI media are suitable for net-alkaline waters with iron concentrations less than 50 mg/L, in locations where space is limited (PIRAMID Guidelines 2003), therefore the initial water chemistry of the mine water discharge at Saltersford was considered suitable for treatment with a SCOOFI reactor. A number of texts describe SCOOFI reactors in detail (*e.g.* Younger *et al.* 2002; PIRAMID Guidelines 2003); however, in essence a SCOOFI reactor is a porous plastic media with a very high surface area ratio. They work on the principal that as oxygenated water flows through the media, iron will gradually precipitate onto the surface of the media, steadily resulting in a thin layer of ferric hydroxide (ochre). Once the ochre has coated the porous material, the rate at which iron is removed from the water increases, as the rate of ochre catalysed iron oxidation is faster than iron oxidation in open water (Younger *et al.* 2002). As this process is continuous, iron will continue to be removed from the water until such quantities of ochre have accumulated that the water flow becomes restricted and the SCOOFI media become blocked. Once this occurs the plastic media must be extracted and the ochre removed. The occasional cleaning requirements of SCOOFI reactors mean that the plastic media need to be contained in such a way that they can be easily removed from the water channel. Two different techniques have been applied at Saltersford to date; a) by inserting the SCOOFI media into meshed bags and b) by stringing individual media along a cord to form a chain.

Results and Discussion

Flow and Chemistry of Mine Water

The flow and chemistry of the mine water discharge at Saltersford was relatively stable for the first six months of the trial, which coincided with the drought of Spring 2012. However, the iron and flow rate of the discharge has changed considerably since June 2012 as a result of the very wet summer (Table 1); the mine water monitoring boreholes in the South Derbyshire Coalfield demonstrated a rapid water level rise in June 2012, with an increase of 1.8 m recorded over a period of 8 weeks within 1 km of site. The mine water is net-alkaline, with a mean alkalinity of 457 mg/L expressed as $CaCO_3$ (laboratory results), a typical pH of 6.4 (on site), and mean sulphate and chloride concentrations of ≈ 2060 mg/L and 64 mg/L respectively; these parameters have remained comparatively constant throughout the trial period. The infrastructure installed at Saltersford was designed to accommodate a flow of 4 L/s with a maximum iron concentration of 35 mg/L; the increase in flow, and corresponding deterioration in the chemistry of the untreated discharge have therefore had a negative impact on the trial. In the first six months of the trial (December 2011 – May 2012), the average flow was 1.5 L/s and the

Period	Sample	Flow (L/s)	pH	Ferrous Iron (mg/L)	Total Iron (mg/L)
21/12/11 - 28/05/12	**Raw Water** *(n=64)*	1.53	6.38	26.5	26.7
08/06/12 - 01/08/12	*(n=9)*	3.75	6.38	35	35.5
09/08/12 – 05/01/13	*(n=24)*	4.44	6.36	42.7	42.3
21/12/11 - 28/05/12	**SCOOFI Inlet** *(n=64)*	1.53	6.55	25	25.2
08/06/12 - 01/08/12	*(n=9)*	3.75	6.51	33.2	33.9
09/08/12 – 05/01/13	*(n=24)*	4.44	6.58	40.5	40.3
21/12/11 - 28/05/12	**Treated Water** *(n=60)*	1.53	6.55	18.6	19.5
08/06/12 - 01/08/12	*(n=9)*	3.75	6.51	30.2	30.5
09/08/12 – 05/01/13	*(n=24)*	4.44	6.62	38.2	37.8

***Table 1**. Summary of the mean flow rates and water chemistry of the Nether Leys Pit Discharge (on site results).*

mean raw total iron concentration was 26 mg/L (Table 1). For the last five months of the trial (September 2012 – January 2013) however, the system has been routinely dealing with flows of 4.4 L/s, which exceed the original design capacity and raw total iron concentrations of 42 mg/L that are in the upper region of the suggested acceptable SCOOFI treatment levels (PIRAMID Guidelines 2003).

Design of Treatment System

The scheme constructed at Saltersford (Fig. 1) consists of an aeration cascade comprised of a series of four steps, a small settling pond area and two parallel channels (0.5 m × 0.4 m × 12 m; volume 2.5 m^3) which house the Veolia Cascade Filterpak YTH1170 high surface area (200 m^2/m^3) units. Within the channels a series of baffle plates are installed to alternate the flow of water both up and down through the SCOOFI media. Two different configurations of SCOOFI media have been used in this trial to facilitate easy handling and maintenance of the scheme; nylon mesh bags and SCOOFI chains. The results of the trial discussed here are divided into three sections, a) Bagged Media, b) Bags *vs.* Chains and c) Media Chains. For one week in March 2012 (20/03/12 – 27/03/12), the system was emptied of media to ascertain the effectiveness of the scheme infrastructure to remove iron. During this period it was established that the small cascade and settling pond removes on average 2 mg/L of iron with a small amount of ochre also precipitating in the channels. The following discussion will therefore focus on the water chemistry of the inlet and outlet of the SCOOFI media channels.

***Fig. 1.** The Saltersford SCOOFI Reactor System showing the aeration cascade and settling pond to the left and media channels to the right; several SCOOFI media chains are visible in the bottom right hand corner of the settling pond.*

Bagged Media Trial

In this first trial, the SCOOFI media were contained within nylon mesh (2 mm × 2 mm) bags 500 mm × 380 mm in size. Over the first two weeks of the trial, the amount of iron removed by the media gradually increased as ochre steadily precipitated in the system (Fig. 2). During the period of peak performance, the system removed a mean of 7 mg/L of iron reducing the average total iron concentration from 25 mg/L to 18 mg/L. A similar pattern was observed for the ferrous iron, with a mean of 7 mg/L of ferrous iron also being removed by the media; based on a mean flow during this period of 1.4 L/s, this equates to an average area-adjusted iron removal rate of 119 $g/m^2/d$ for the media contained within the meshed bags.

During this short trial it was discovered that the iron quickly and preferentially precipitated on the mesh bags, congesting the system and unbalancing the flow of water; after only two months, the system blocked up, overflowed and had to be cleaned out. From a maintenance perspective, this rapid clogging of the system is impractical; furthermore, data were required to assess the performance of the media alone. Therefore, an alternative method of grouping the media together was necessary.

Bags vs. Chains

In order to investigate the performance of the media, it was decided to string a number of individual SCOOFI units together in a chain thereby making the mesh bags redundant. This second trial lasted for three months (April 2012 – June 2012) and compared the bagged media with the media chains to ascertain the impact of the mesh bags on the iron removal observed in the first trial.

The results shown in Figs. 2 and 3 ostensibly suggest that the bagged media were more successful at removing iron compared to the media chains, as on average the bagged media removed a mean 4.6 mg/L of iron whereas the media chains removed 3.4 mg/L of iron. However, these results are affected by an uneven distribution in the flow between the two channels during this trial. In a repeat from the first trial, ochre rapidly precipitated on the meshed bags, obstructing the channel and directing the majority of the flow through the media chains channel. Unfortunately flow data was not recorded from the two discharge channels during the trial, however, the channel containing the media chains was typically observed to have higher flows in contrast to the bagged media channel. Consequently the media chains were treating a higher loading compared to the bagged

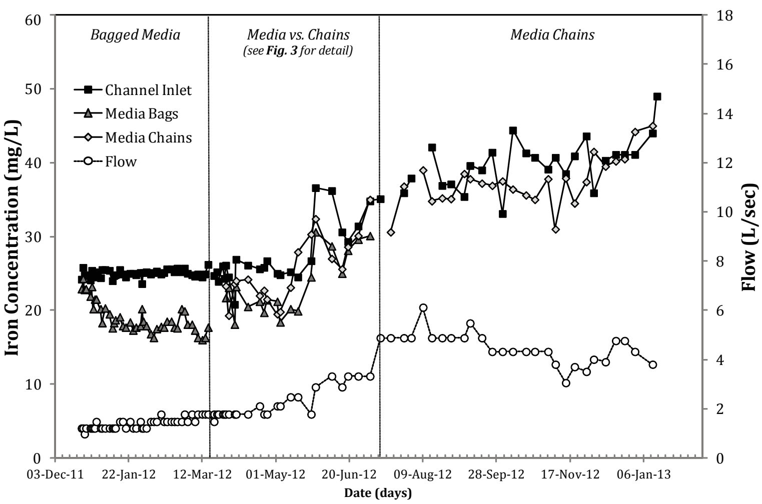

Fig. 2. *Total iron concentrations of the SCOOFI channel inlet and outlet waters for the three media configurations tested at Saltersford from December 2011 to January 2013.*

Note: the total iron concentrations of the SCOOFI channel inlet and outlet waters during the Media Chains trial show that the media removed ≈ 3 mg/L of iron (e.g. October and November 2012), however as the system becomes clogged with ochre (due to being overwhelmed) iron is discharged from the scheme (e.g. December 2012).

media, and therefore removing a greater amount of iron. The overall mean flow rate during this period was 2.4 L/s, and the raw iron concentration increased to 29.5 mg/L. Based on a limited number of direct observations, it is estimated that the channel containing the media chains typically contained 60 – 70 % of the flow, whereas the bagged media channel had a maximum of 30 – 40 %. Based on these figures it is estimated that the area-adjusted removal rate for the media chains was, on average, in the range of 111 – 129 g/m^2/d, whereas the removal rate for the bagged media was in the range of 50 – 99 g/m^2/d. These results demonstrate that the media chains are more effective at removing iron compared to the meshed bags, probably due to the even flow distribution through the media chains, which, in contrast to the mesh bags, remained unimpeded by ochre.

The lower removal rate calculated for the bagged media in this second trial may be due to a number of reasons. Firstly, the flow rate being treated by the bagged media was lower compared to the first trial (<1 L/s) and secondly, the bagged media partially blocking the channel have a negative impact on the hydraulic efficiency of the channel resulting in shortcutting in the system. The meshed bags were removed at the end this trial and replaced with chains of SCOOFI media.

Media Chains

The flow rates and raw iron concentrations have varied throughout this third trial with peak flows (6.1 L/s) occurring in July – September (the average flow during this trial was 4.4 L/s) and a mean raw total iron concentration of 42 mg/L (Fig. 2); the scheme has therefore been subject to flows and iron concentrations that exceed the original design parameters. Throughout this final trial the scheme has removed a mean iron concentration of 2.4 mg/L; however, there have been periods when the channels have become overfull of ochre, resulting in iron being released from the system as ochre particulates. If the periods of iron release are discounted then the amount of iron removed by the media when they are not blocked, increases to 3.2 mg/L, with a maximum amount of 9.2 mg/L removed; typically the total iron concentration discharging from the scheme is 38 mg/L. Despite this trial being adversely affected by periods of very high flow rates which have occasionally swamped the scheme combined with periods of iron release when then scheme has become clogged with ochre, a mean area-adjusted iron removal rate of 139 g/m^2/d has been calculated for the SCOOFI Media chains. This result indicates that the media chains are an effective form of treatment for the removal of iron.

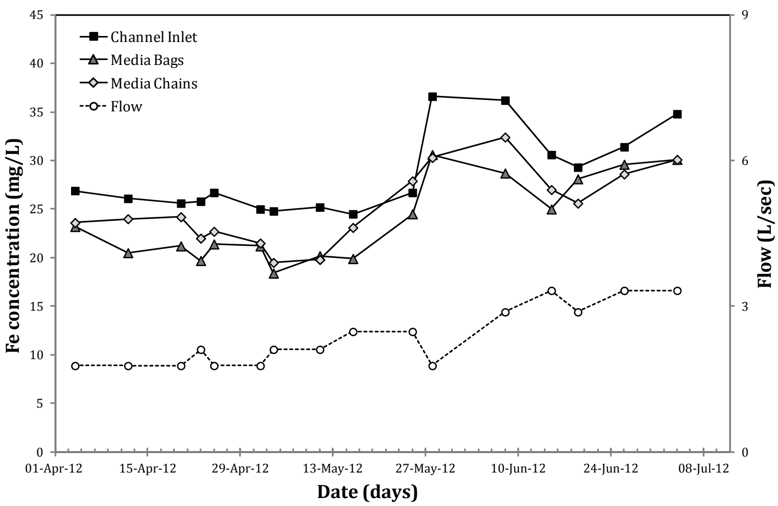

Fig. 3. *Total iron concentrations of the SCOOFI channel inlet and outlet waters during the Bags vs. Chain Media trial. Although the graph suggests that the bagged media were more efficient at removing iron, the media chains were treating a greater loading of iron during this period due to higher flow rates.*

Note: for clarity, the axes differ from those used in Fig. 2 to illustrate the detail.

Conclusions and Recommendations

The scheme at Saltersford has been adversely affected by the increase in water flow rates and raw iron concentrations, which has resulted in the scheme being overwhelmed and unable to prevent the lake at Saltersford from being discoloured by the iron. However, the SCOOFI trial at Saltersford has provided some relevant results in the use of high surface area media. The media chain trial has produced some indicative area-adjusted removal rates (139 g/m²/d) that far exceed those typically quoted by Hedin *et al.* (1994; *i.e.* 10 g/m²/d), which suggest that high surface area media could potentially be used in areas where there is insufficient space for settlement ponds. However the trial has also raised some important maintenance issues which need to be addressed before the system can be used elsewhere. Firstly, the ochre which precipitates onto the media at Saltersford is very unstable. Although the flow of water in the scheme is not sufficient to flush out the ochre, as soon as the media are disturbed, the ochre readily detaches from the units and flows out of the channels. Therefore, although a thin layer of ochre initially forms on the media, the majority of the precipitate is present as an unstable amorphous mass which is very difficult to remove and contain in a controlled manner, especially during maintenance. Secondly, the channels at Saltersford become congested with ochre very rapidly, and have been found to be difficult to maintain and clear out. This has been exacerbated by the very high flow rates and increasing raw iron concentrations observed during the trial, which has necessitated in the requirement for regular monitoring and maintenance to endeavour to prevent the system from overflowing and flooding the public footpath. These two maintenance issues need to be addressed to make this type of technology more efficient and cost effective for future deployment.

The nature of the ochre which collects on the media would necessitate the need for an aerobic reed bed or possibly a Vertical Flow Reactor (VFR) to follow a SCOOFI system. This would facilitate the collection of any ochre disturbed during maintenance of the system in addition to ‘polishing’ (Batty and Younger 2002) the water; this trial has not provided any information to suggest that the media alone could treat iron down to the current Environmental Quality Standard (EQS) concentration of 1 mg/L. This technology, therefore, would not be suitable for very small areas. However, the use of SCOOFI media could reduce the size of settling ponds and the Authority plan to undertake further trials to investigate this possibility further.

Acknowledgements

The authors thank those people at Integrated Water Services for all of their efforts maintaining the trial at Saltersford and for their patience stringing the SCOOFI media together.

References

Batty LC, Younger PL (2002) Critical role of Macrophytes in achieving low iron concentrations in mine water treatment wetlands. Environmental Science and Technology 36:3997–4002

Hedin RS, Nairn RW, Kleinmann RLP (1994) Passive treatment of coal mine drainage. USBM IC 9389, US Dept of the Interior, Washington DC, 35 pp

Jarvis AP, Younger PL (2001) Passive treatment of ferruginous mine waters using high surface area media. Water Research 35:3643–3648

PIRAMID Consortium. (2003) Engineering Guidelines for the Passive Remediation of Acidic and/or Metalliferous Mine Drainage and Similar Wastewaters. European Commission 5th Framework RTD Project no. EVK1-CT-1999-000021 “Passive in-situ remediation of acidic mine/industrial drainage (PIRAMID). University of Newcastle Upon Tyne, UK, 166 pp.

Younger PL (2000) The adoption and adaptation of passive treatment technologies for mine waters in the United Kingdom. Mine Water and the Environment 19:84–97.

Younger PL, Banwart SA, Hedin RS (2002) Mine Water Hydrology, Pollution, Remediation – Vol 5 Environmental Pollution. Kluwer Academic Press, Dordrecht, 442 pp