Full scale pilot test of a novel technology to remediate alkaline coal mine water using high-surface media at Acomb Mine Water Treatment Scheme, UK

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Abstract Acomb scheme is an existing coal mine water treatment scheme, which recently has been struggling to treat the iron-rich water. This scheme, like the majority in the UK, uses conventional methods of aeration cascades, settlement lagoons and aerobic wetlands. At Acomb, a full-scale pilot test of a Deferum treatment unit was installed, which uses high-surface media to remove the iron. This unit at Acomb successfully removed an average of 74 % of the iron from the mine water. Going forward, this type of treatment is likely to be useful where there are difficulties due to restrictions on land and costs.

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

Introduction

The mine at Acomb was abandoned by the National Coal Board in 1952, with mining dating back to at least the 19th Centaury using pillar and stall workings combined with the more recent total extraction of the Little Limestone Coal seam. The discharge at Acomb originates from the former mine adit, which commenced soon after the mine was abandoned, resulting in over 30 years of contamination entering the Red Burn. As part of an ongoing mine water remediation programme of existing discharges (agreed between the Environment Agency and the Coal Authority), the mine water treatment scheme at Acomb was constructed in 2002 to treat the mine water discharging from the abandoned adit. The scheme was designed to remove iron from a net-alkaline mine water and comprises of an aeration chamber, hydrogen peroxide dosing system, two parallel settlement lagoons, two aerobic reed bed wetlands and a sludge drying bed (Fig. 1). The discharge effluent, although not in breach of any consent, is higher than expected and desired by the Coal Authority for a treated effluent. Monitoring of the flow rates and mine water chemistry shows mean flow rates of 17 L/s varying between c. 10 L/s and c. 40 L/s; mean iron concentrations for the raw water of 33 mg/L; and mean iron concentrations for the treated water of 8 mg/L.

Subsequent to the construction of the scheme at Acomb, there have been some changes to the environmental regulations. Therefore at this site, and other treatment schemes operated by the Authority, mechanisms are being investigated to aid with improving the treated discharge quality in order to meet the revised regulations. In conjunction, the Authority also have the challenge of treating mine water discharges in locations

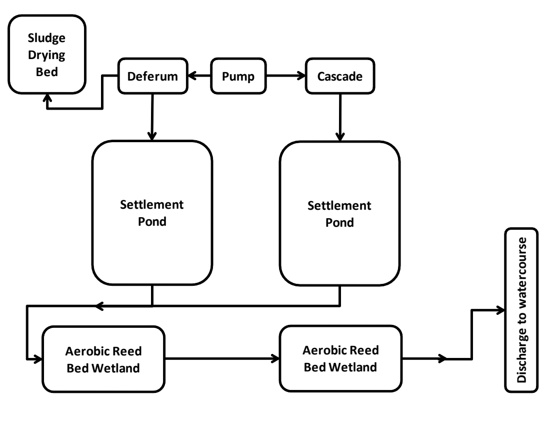

Fig. 1 *Generalised layout of Acomb Mine Water*

where the area of suitable land is limited, in addition to complying with the stringent requirements of cost-benefit analyses. The availability of land influences several factors relating to a mine water treatment scheme including the costs of constructing and maintaining a scheme, the type of treatment (*i.e.* active or passive) methodology applied and the size or efficiency of a scheme. In order to meet these criteria, the Authority manages a research and development programme to test the viability of novel methods and technologies. One such method is the utilisation of the Deferum high surface media unit to remove the iron. The Acomb site was selected for this trial for a number of reasons. Firstly, the scheme had the necessary infrastructure and security required for this type of technology already in-situ, combined with sufficient space for the installation of a full-scale Deferum system. Finally, the mean iron concentration in the treated discharge is higher than the concentrations preferred by the Authority (c. 1 mg/L), therefore some additional mechanism was required to improve the quality of the treated discharge.

Methodology – The Deferum Unit

The treatment unit (Fig. 2) was installed at Acomb where the trial began in November 2011 and concluded in September 2012. The trial unit was designed to treat 6 L/s, however, throughout the test one line of the unit was not in use, therefore a maximum flow rate of c. 3.5 L/s was achieved (c. 20 % of the mean flow rate). The raw mine water is pumped in to the Deferum unit under pressure (0.4 MPa) and enters the aerator to remove dissolved gasses and oxidise the water. From the aerator the water is passed through the distributor at the bottom of the unit, before moving upwards towards the filter media to remove the iron. After filtration the water passes through a final filter before being discharged to mix with the mine water in one of the settlement lagoons. As the filter media becomes 'clogged' the water level rises until the system switches in to a backwash mode; the slurry from which is discharged out of the unit and, for the trial at Acomb, was transferred to a sludge drying bed.

Results and Discussion

Throughout the trial, regular on site and laboratory measurements were taken of the raw mine water and the outlet water from the unit (treated). A summary of the key results are summarised below and shown in Figs. 3 and 4 and tables 1 and 2.

Total iron: During the trial the on site total iron had a mean concentration of 31 mg/L (22

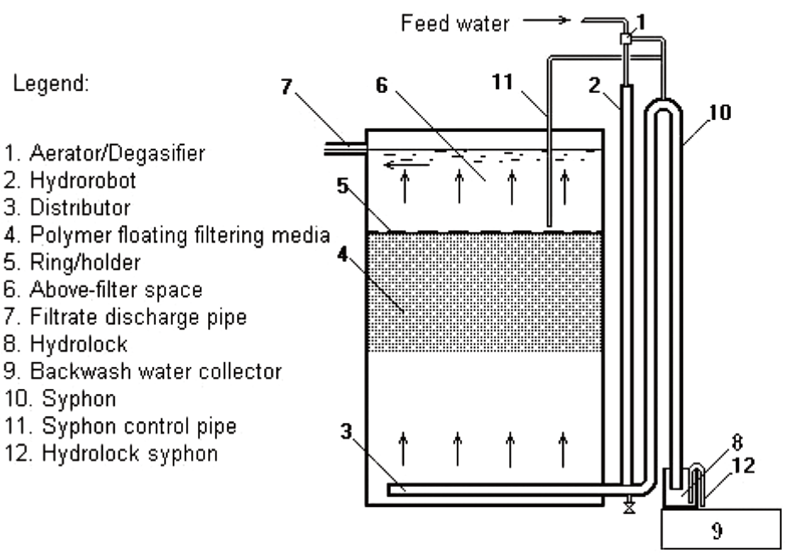

Fig. 2 *Schematic of a Deferum unit (from www.deferum.com).*

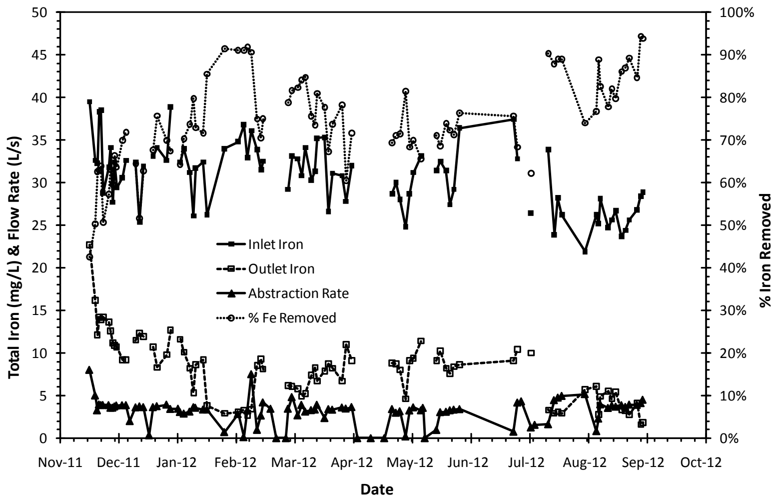

Fig. 3 *On site iron measurements against flow rate and removal percentage.*

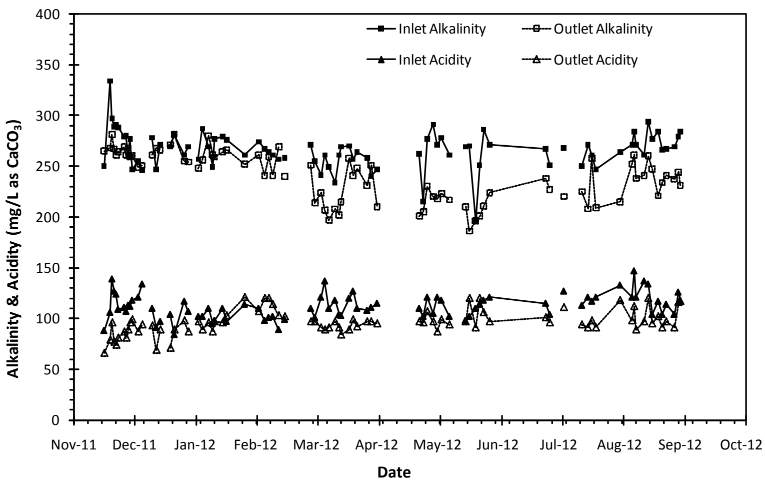

Fig. 4 *On site alkalinity and acidity measurements.*

to 40mg/L). Treated total iron from the unit varied between 2 mg/L and 23 mg/L with a mean concentration of 8 mg/L. In terms of iron removal, the Deferum unit removed a mean value of 74 % (43 % to 94 %); with a mean flow rate of 3.1L/s and a mean removal of 23 mg/L, which equates to a removal loading of 6.6 kg/d. Assuming a footprint area of c. 25 m^2 for the unit, this converts to a mean area adjusted removal rate of 265 $g/m^2/d$ (14 to 847 $g/m^2/d$). The above data uses the more frequently measured on site data, however routine laboratory samples were also taken and tested. The laboratory data includes measurements of total, ferrous and dissolved iron, the results of which are summarised in table 1. The laboratory data shows a mean ferrous iron concentration of 27 mg/L and a total iron concentration of 31 mg/L (this does not include 3 erroneous values of <5 mg/L). The ferrous concentrations are marginally below the total iron concentrations, thus part of the raw iron is in the ferric form and probably implies the water is at least in part oxygenated before being pumped from the sump – this is evident by the dissolved oxygen concentrations (3.2 mg/L) of the raw mine water. The treated water leaving the unit has a total iron value of 12 mg/L and a ferrous iron concentration of 11 mg/L. The speciation of the iron in the treated water is therefore predominantly in the dissolved ferrous form, rather than the particulate as well as ferric form, suggesting the water has not been sufficiently oxygenated as well as de-gassed

Sample Point	Total Iron	Alkalinity (as $CaCO_3$)	Acidity (as $CaCO_3$)	pH	Dissolved Oxygen	Temp. °C	EC µs/cm at 25 °C	T.D.S.
Inlet	31	266	112	6.6	3.2	12.3	1706	1178
Outlet	7	241	96	6.6	3.5	12.1	1600	1109

All values are means as mg/L unless otherwise stated

Table 1 *Summary of on site results for the Deferum unit.*

Sample Point	Fe (Tot)	Fe^{2+}	Fe (Dis)	Alk	Acy	SO_4	Cl	Ca	Na	Mg	K	Zn	Mn	Al
Inlet	31	27	31	252	49	511	29	212	43	50	13	0.05	0.6	0.02
Outlet	12	11	11	251	20	508	30	211	42	50	13	0.01	0.6	0.02

All values are means as mg/L. Alk = Alkalinity as $CaCO_3$; Acy = calculated metal acidity as $CaCO_3$

Table 2 *Summary of laboratory results (as total unless stated otherwise) for the Deferum unit.*

(*i.e.* dissolved CO_2 may be present in the water) – this is illustrated by the dissolved oxygen concentrations (3.6 mg/L) of the treated water.

Acidity (expressed as mg/L $CaCO_3$): Acidity was measured both on site and in the laboratory, in addition to calculated metal acidity (Hedin *et al.* 1994) based on Fe, Mn, Al, Zn and pH. Due to changes in acidity concentrations over time and in transit to the laboratory (*i.e.* as a result of CO_2 degassing; McAllan *et al.* 2009), comparisons and analysis have been made using on site acidity and calculated metal acidity. The mean concentration for the raw mine water and the Deferum outlet (treated) are shown in Fig. 4 and tables 1 and 2. On site acidity measurements show a reduction through the Deferum of approximately 16 mg/L, whereas the calculated metal acidity values show a reduction of 29 mg/L. These reductions in acidity by the Deferum unit are predominantly the result of the reduction in iron concentrations through the unit. The differences between on site acidity and calculated metal acidity suggest that the raw mine water contains a significant amount of temporary acidity, probably caused by dissolved CO_2.

Alkalinity (expressed as mg/L $CaCO_3$): This was measured on site and in the laboratory (Fig. 4 and tables 1 and 2). The laboratory results show limited differences between the raw mine water and Deferum outlet; these are comparable to, and generally correspond with the on site alkalinity concentration. However, the on site alkalinity values do show a minor difference between the raw and treated alkalinity. This 25 mg/L reduction closely matches the 29 mg/L reduction in calculated metal acidity. This is to be expected since the removal of iron affects the alkalinity and metal acidity equally (McAllan *et al.* 2009).

Other parameters: In addition to the parameters discussed above, a series of other chemistry analyses were undertaken. These results, summarised in tables 1 and 2, indicate that the Deferum does not significantly remove or change these parameters; an exception to this is zinc, where a reduction in the mean concentrations of 50 µg/L to 10 µg/L was observed. This reduction can most plausibly be attributed to the co-precipitation of zinc with ferric hydroxide.

The trial of the Deferum Unit at Acomb lasted for 290 days between November 2011 and September 2012, during this time the unit was non-operational on 8 occasions of approximately 1 to 5 days duration for each shut down. During the trial, the Deferum successfully removed a mean of 74 % of the total iron; thus resulting in a reduction in the total iron concentration from 31 mg/L to 8 mg/L. This mean value of 74 % (24 mg/L) equates to a mean area adjusted removal rate of 265 g/m²/d. The maximum removal percentage (94 %) was achieved at the end of the trial, when flow rates were approximately 4.3 L/s; with total iron concentrations reduced from 29 mg/L to <2 mg/L. The highest recorded quantity of iron removed during the trial however, was 34 mg/L (reducing concentrations down from 37 mg/L to 3 mg/L), when flow rates were approximately 3 L/s.

If standard settlement lagoons were to be utilised to treat this mine water, then dependent upon the various sizing criteria which could be applied, the lagoon area required is estimated to range between approximately 310 m² (based on PIRAMID 2003); 427 m² (based on Tarutis *et al.* 1999) and 610 m² (based on Hedin *et al.* 1994) in size. These areas are significantly larger than the estimated footprint area of 25 m² provided by the Deferum Unit installed at Acomb.

Conclusions

The Deferum unit was designed to remove all of the iron at a flow rate of 6 L/s, and although it failed to achieve this high removal rate, it successfully removed a significant amount of the total iron from the raw mine water. The footprint area (c. 25 m²) required to do this was significantly less than a standard settlement lagoon area between 310 m² and 610 m². In areas where there is restricted land available, the Deferum unit becomes a viable future option to discharge mine water at a lower (although still elevated) concentration, thus reducing environmental impacts. Alternatively, this technique provides an additional option to use in conjunction with a more 'typical' mine water treatment scheme, with the Deferum replacing the settlement lagoons, followed by an aerobic wetland. Both of these options (and other potential scenarios) would still require the need for a sludge drying bed, or other location, to dispose of the backwash slurry. Due to issues associated with non operational time periods and assuming treatment is required to comply with environmental quality standards, additional units as well as the need for water storage may also be required.

Acknowledgements

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