LOW FOOTPRINT MINE WATER TREATMENT: FIELD DEMONSTRATION AND APPLICATION

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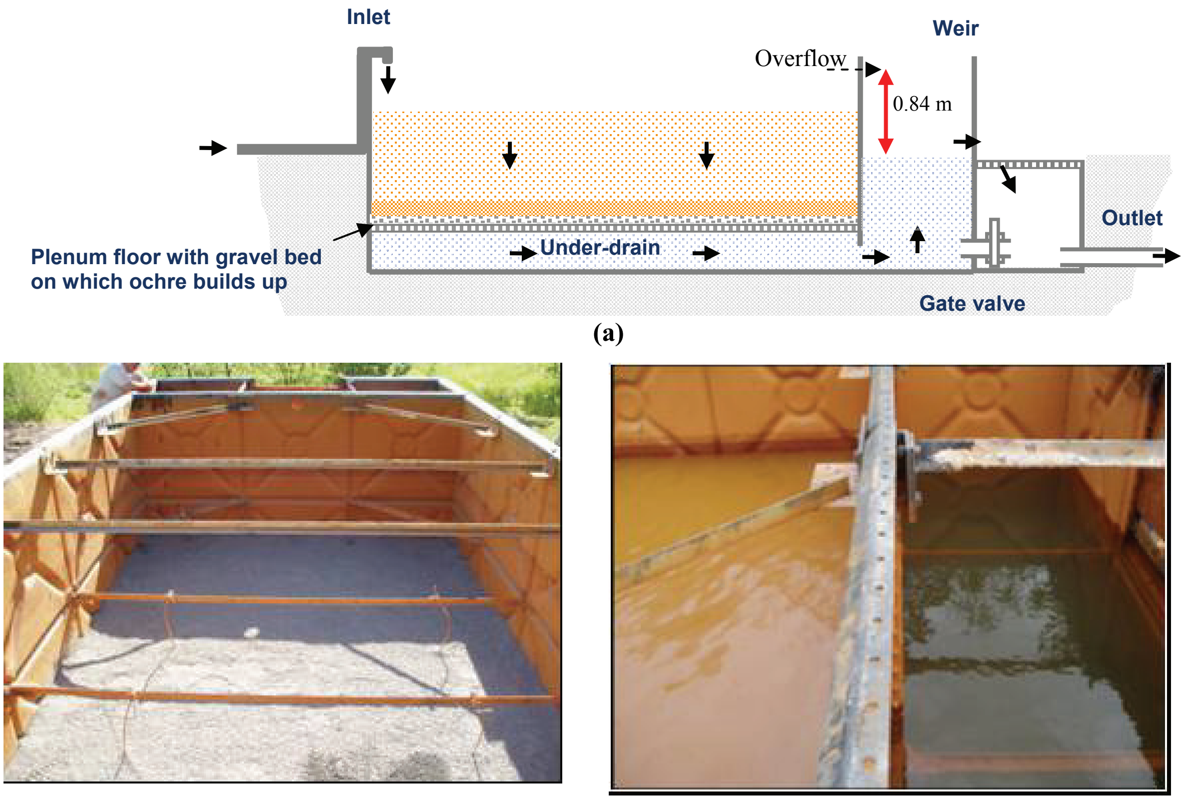
Abstract
This paper presents iron removal data from a novel low footprint mine water treatment system. The paper discusses possible design configurations and demonstrates that the system could treat 1 L/s of mine water containing 8.4 mg/L of iron to < 1 mg/L with a system footprint of 66 m^2. A conventional lagoon and aerobic wetland system would require at least 160 m^2 to achieve the same treatment. Other advantages of the system are that it produces a clean and dense sludge amenable to on-site storage and possible recycling and that heavy plant will generally not be required for construction.

Introduction
Passive mine water treatment schemes typically incorporate settling ponds/lagoons. These are included at various points in the treatment system for the removal by settling of oxidised iron solids. For waters that are net-alkaline from source and of circum-neutral pH, where abiotic Fe(II) oxidation and precipitation occurs rapidly, the water is directed through settling lagoons from source before being routed through aerobic surface flow wetlands. The treatment for net-acidic waters is similar, except that the acidity is consumed and pH raised up-front, usually by routing the water either through some form of anoxic limestone drain or anaerobic compost based (or other substrate) system. Having produced a circum-neutral, net-alkaline discharge from these units, the water is then routed through settling lagoons as for the treatment of net-alkaline water. In the UK, the current best practice for the passive treatment of net-alkaline mine waters similarly involves lagoons and aerobic wetlands. The intention is to remove 30-50 % of the iron 'up-front' in the settlement lagoons before the mine water enters the wetland. This allows for more effective sludge management and prolongs the life of the wetland. The design of lagoons is usually based on either an empirical iron removal rate derived from the performance of aerobic wetlands (Hedin and Nairn, 1992) or by defining a nominal retention time. The tendency to use guidelines that are based on observations is explained by the difficulty in accurately formulising the effect of the lumped processes of Fe(II) oxidation, oxygen transfer and settling velocities encountered for mine waters of different pH and chemistry. Settling lagoons (and aerobic wetlands) based on these guidelines are typically large. Whilst effective treatment is often achieved by such systems, the surface area requirement is often a hindrance to their application to treat mine waters wherever, for a multiplicity of different reasons, land availability is restricted. In the case of UK, in addition to land area being at a premium (a reflection of the population density) many mine water discharges occur in steep-sided valleys, making the application of convention large-area passive systems problematic.

Previous research (by the authors) on an existing Rapid Alkalinity Producing System (RAPS) unit in South Wales revealed that the system, counter to designed intent, was actually removing iron (as ochre) very effectively on top of the RAPS unit. This lead to the idea that perhaps this accidental but very effective iron removal could be engineered into a system specifically designed to achieve it. Subsequent trials at laboratory and small field scale indicated promising results (see Sapsford et al., 2005). As a result of this initial promise a large pilot scale system was constructed at the former Taff Merthyr colliery site in South Wales where net-alkaline mine water is being treated in a conventional lagoon/wetland system. The system is hereafter referred to as the Vertical Flow Reactor (VFR). The VFR comprises a commercially available bespoke steel panelled tank, 7.32 m long by 3.66 m wide and 2.30 m deep, with a baffle wall 1.22 m from the end of the tank. A cartoon schematic of the tank and photographs are shown in Figure 1(a). The mine water flows down through a bed of sandstone gravel, which sits on a plenum floor. The plenum floor is made of galvanised steel mesh sheets sitting on top of 300 mm high concrete support pillars. This means that the whole gravel bed is under-drained by a large void space, the design is for research reasons but is also intended to improve the uniformity of flow through the ochre and gravel bed. Water flows through this under-drain, under the baffle wall and up through into a rise chamber. The mine water discharges into an overflow chamber where a pipe takes the water away to discharge back into the existing wetland system. Further details of the pilot scheme and typical results are available in Sapsford et al. (2005; 2006). These results revealed that the pilot system was achieving higher iron removal rates than the conventional lagoon system that runs in parallel and generally in a shorter residence time. Intensification of iron removal in the system is attributed to 1) filtration of iron hydroxide particles by the ochre bed and 2) surface-catalysed oxidation of iron (II) and subsequent accretion of iron hydroxide around pre-existing iron hydroxide particles in the accumulating bed. However, the results were not as promising as some of the initial trials had indicated. The reason for this was found to be short-circuiting of the flow where the edge of the tank intersected the ochre/gravel bed. The coarseness of the gravel used in the first-instance (20 mm chips) is believed to have contributed to this problem. Subsequently, the ochre that had accumulated in the system was removed and a new gravel bed installed. The new gravel bed consisting of a 10 mm thickness of 6 mm sandstone gravel chips and was laid over the original 10 mm thickness of 20 mm gravel chips. Before application of the new gravel layer, a ~300 mm fillet of builder's sand was packed against the walls of the tank to curtail problems of short-circuiting flow down the tank walls. This paper presents the most recent promising results obtained from the system.



(b) (c)

Figure 1. The VFR. (a) Schematic; (b) After installation of new gravel bed; (c) Ocherous downflow (left), clean upflow (right).

Results and Discussion

Table 1 gives the typical chemistry of the mine water at Taff Merthyr. Measurements have been made over approximately 2 years. The chemistry is typical of the relatively benign mine waters associated with coal mine drainage in the UK (acknowledging this does not underestimate the environmental damage that such discharges cause).

Table 2 shows the influent and effluent iron concentrations for the VFR tank over the period June 2006 (when the new gravel bed was installed) to January 2007. Iron removal was excellent in the first few months with well over 90% Fe removal. Importantly, the system was discharging water well below the UK Fe discharge consent limit of 1 mg/L. Flow rates through the tank are variable through a combination of chance occurrences and design. The flow rates are inconsistent for many reasons including seasonal changes in flow rates exiting the mine workings, intermittent blockages in the VFR influent pipe (as happened in August 2006) and occasionally purposefully (e.g. 16/09/2006) to assess the effect of increased flow rates on iron removal efficiency.

Generally iron removal efficiency is excellent in the tank over the course of the 8 months between June 2006 and January 2007. There are some notable exceptions. The influent flow rate was increased (flow is controlled by a manually operated ball-valve) to around 2.2 L/s in September.

Table 1. Chemistry of Taff Merthyr mine water.

	Mean	Number of samples	Standard Deviation
pH	6.7	41	0.4
Redox Potential	+ 7.6 mV	39	80.7
Dissolved Oxygen	4.2 mg/L	37	1.1
Alkalinity (as $CaCO_3$)	233 mg/L	13	22
Total Iron	8.4 mg/L	42	2.7
Filtered Iron <0.45 µm	7.3 mg/L	40	0.8

Table 2. Treatment data for the Cardiff University VFR.

Date	Total Fe INFLUENT (mg/L)	Total Fe EFFLUENT (mg/L)	Flow Rate (L/s)	% Fe Removal	Comment
06/06/2006	7.84	0.11	0.34	99	
08/06/2006	9.07	0.13	0.48	99	
14/06/2006	8.65	0.06	0.46	99	
07/07/2006	7.72	0.25	0.99	97	
16/09/2006	9.32	1.47	2.2	84	Bed Damage?
22/09/2006	8.90	2.99	1.4	66	
29/09/2006	8.48	0.01	0.73	100	
16/10/2006	7.21	0.20	0.57	97	
20/10/2006	6.49	0.08	0.34	99	
15/11/2006	6.66	1.94	0.83	71	Overflowing
17/11/2006	6.86	1.97	0.97	71	Overflowing
27/11/2006	5.08	2.97	0.93	42	Overflowing
07/12/2006	4.74	1.35	1.04	72	
05/01/2007	5.35	0.51	0.56	90	

Although the system achieved high iron removal rates of 70 g/m^2/day, UK discharge consent (which is the operational target effluent concentration) was being exceeded. Also, the following week when flow rates where reduced, the iron removal efficiency was poor (66 %, see Table 2) suggesting that the increased throughputs had in some way affected the ochre bed. However, iron removal efficiencies recovered thereafter. In November the iron removal efficiencies dropped again. This was because over the course of the preceding operation the water backed up, developing the necessary driving head in the down-flow chamber to drive the water through the increased thickness of ochre and also to overcome decrease in permeability in the ochre bed caused by compression. By November the head of water developed was 0.84 m. With the current tank configuration this resulted in some water from the down-flow side of the tank draining through the over-flow into the up-flow chamber (see Fig. 1(a)). This resulted in the observed decrease in iron removal efficiency. Subsequently the gate-valve was opened slightly so that water exited the tank through it, and sufficient driving head could then develop (without overflowing) to continue tank operation.

This research project will culminate in design criteria for a treatment system based upon this concept. The criteria will be based on the results of ongoing experiments (e.g. Barnes et al., 2006) aimed at determining homogenous and heterogeneous Fe(II) oxidation rates in the laboratory and field which are essential for predicting the operation of the system for different mine water chemistries. It is the intention of this paper to outline some of the basic design concepts and operational procedures (that will be recommended in the final guidelines) and use the data gathered so far to offer a simple worked example of a comparison between the footprint of a conventional lagoon/wetland system and the VFR system.

1. Design calculation information and assumptions

1) Treating Taff Merthyr water (see Table 1) therefore the target treatment is the reduction of Fe in the mine water from the mean of 8.4 mg/L to a target of 1mg/L (UK discharge consent limit).
2) Design for the treatment of a flow of 1 L/s (86.4 m^3/day).

3) Using data from Table 2 estimate that the VFR in its current configuration could successfully treat (i.e. discharge < 1 mg/L Fe total) 0.75 L/s of Taff Merthyr water for 5 months before overtopping through the overflow (see Fig. 1).
4) Assume that by linearly increasing the VFR from the current footprint of 25 m^2 to 33 m^2, the VFR could treat 1 L/s of mine water for 5 months.
5) An iron removal rate of 5 $g/m^2/day$ for Taff Merthyr lagoons. This is based on actual observation of typical iron removal rates in the existing Taff Merthyr lagoon (see Sapsford et al., 2006).
6) Assume that two settling lagoons are required in parallel to ensure continued treatment whilst one to be taken off-line and de-sludged (this is common practice in the UK).
7) The calculation uses 10 $g/m^2/day$ as a typical iron removal rate for an aerobic wetland (e.g. Hedin and Nairn, 1992).
8) The calculation is based on following UK best practice of removing 50% of the iron up-front in a lagoon and the rest in an aerobic wetland.

Meeting the above criteria with a lagoon and wetland system would require a total area of 160 m^2. This is based on two parallel lagoons each of 64 m^2 and an aerobic wetland of 32 m^2. This calculated area should be amended to closer to 200 m^2 because the figure of 162 m^2 it does not take into account the additional footprint incurred by the bunds, embankments and other landscaping features common to these schemes.

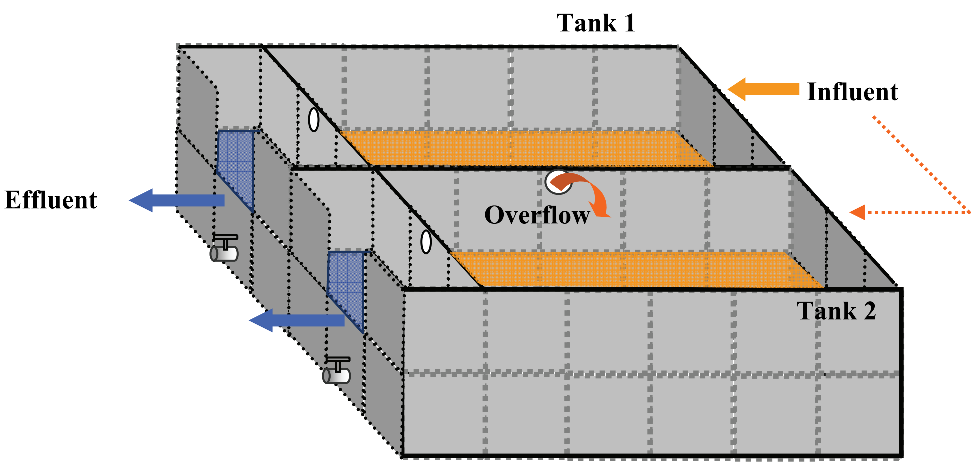


Figure 2. Schematic of two VFRs running in parallel.

The VFR system would require a minimum of two tanks in parallel (see Fig. 2), also to allow de-sludging of one tank whilst maintaining treatment capacity in the other. The operation sequence would then be as follows:

1) Mine water would be directed into the first VFR tank. With a suitable flow distribution system up-front, the second tank could act in this time as additional capacity for treatment of storm flow.
2) After 5 months the water level would rise in tank 1. This would then (with the appropriate positioning of the height of the overflow) overflow into tank 2 (see Fig. 2).
3) The mine water is then treated in two locations. A portion of the flow will still be exiting the system through the ochre bed in tank 1, whilst the untreated overflowing portion will be treated in tank 2.
4) The life-time of tank 2 (i.e. time before it overflows and the treatment system fails completely) should be at the very least 5 months (i.e. the same as the tank 1) but in reality should be longer because tank 1 is still treating a portion of the influent mine water.
5) Before the life-time of tank 2 is exceeded, maintenance is required. Influent is diverted from tank 1 to tank 2 and tank 1 is de-sludged.

By operating the parallel tanks in this way it anticipated that the VFR system would successfully treat mine water for at least 10 months without maintenance and possibly well over a year without maintenance. The development of methods of de-sludging the tank is an area for future test work. The focus will be on ways to achieve de-sludging that a maintenance team could perform easily in a few hours with portable equipment and so be suitable for remote sites. Methods to be considered include pumping the ochre out, draining the system down and scraping or jetting. Sludge could be easily stored (and further dewatered) on site by transferring it from the VFR tanks to a drying bed for dewatering and future removal. If required, it would be possible to extend the life-time before intervention was necessary by simply 'bolting' on additional VFR tanks either in series or in parallel. Each bed should have a longer and longer life-time before blockage because water will still be partially treated by vertical flow through the preceding tanks. Even if their ochre beds became completely blinded, partial treatment will be achieved by those tanks acting as settling lagoons. With four VFRs running in parallel, at the end of the first cycle of operation one of the tanks could be permanently decommissioned and used as the on-site drying bed for continued operation of the other three cells. The fact that the units can be under-drained completely by opening the gate valve (see Fig. 2) makes this an attractive option.

Depending on various considerations including the build cost and maintenance schedules, the number of VFR run in parallel would be a matter of choice. To treat the Taff Merthyr flow as outlined above, considering a minimum of two VFRs in parallel, the required footprint would be 66 m^2. This compares very favourably to the 200 m^2 required for the lagoon/wetland system. Even with four VFRs in parallel the total area is 132 m^2, less than for the lagoon/wetland system, and that includes (as outlined above) final use of one of the beds for on-site ochre storage and dewatering. There are additional advantages of the VFR system: Sludge recovered from the VFR after the initial year of operation (with the 20 mm gravel) as detailed in Sapsford et al. (2006) had a solids content of 8.3 % (m/v). This compares favourably with many ochre sludges that have solids contents typically < 5 % (m/v). Dense and easily de-waterable sludge is favourable from the perspective of on-site storage and costs of eventual removal from site. In addition to producing a dense sludge, the ochre recovered from the VFR system is 'clean' i.e. not mixed with organic or other debris and therefore more amenable to recycling if/when viable recycling options arise. Many mine water discharges are so remote that access roads for heavy plant required for the construction of conventional systems is difficult or impossible. The on-site assembly used in construction of these bolt-together (commercially-available) water tanks is potentially very useful for treating mine water discharges in such locations.

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