Operational and treatment performance of an unique Reducing and Alkalinity Producing System (RAPS) for acidic leachate remediation in Lancashire, UK.

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Abstract. A Reducing and Alkalinity Producing System (RAPS) has been constructed to treat the acidic tip leachate from a former coal mine at Deerplay, Lancashire, UK. The tip leachate has a mean pH of 3.5, and is strongly net-acidic (up to 380 mg/L as $CaCO_3$). In addition it contains elevated concentrations of iron (≤ 60 mg/L) and aluminium (≤ 30 mg/L). The flow-rate varies with weather conditions, but has been as high as 6.5 L/second.

The RAPS has been engineered such that the leachate flows down through the compost, but then upwards through the limestone (and then into an aerobic wetland). The system has been operating since September 2001. The net-acidic water is converted to a net-alkaline water during its passage through the RAPS. pH increases from 3.5 to approximately 7.0. Whilst initially high, the ammonia content of the RAPS effluent decreased to baseline levels over the course of 6 weeks.

By assessing the weathering rate of limestone, from the effluent water quality, it is calculated that the system should operate for 20 years without the need for media replacement. Other operational issues associated with the RAPS are discussed, and plans for future monitoring and research are outlined.

Introduction

The Deerplay mine water treatment scheme is one of over a dozen such projects now completed by the UK Coal Authority. The Coal Authority commissioned IMC Consulting Engineers to undertake the design and construction of the scheme. The treatment system is located approximately 400 m above sea level on a steep, south-facing slope. There were in fact two discharges to be addressed at the site:

1. A ferruginous, and net-alkaline discharge with a flow-rate of approximately 20 L/second, arising from deep coal mine workings and
2. An acidic, iron and aluminium-rich discharge of tip leachate, with a flow-rate in the range 1 – 3 L/second.

Originally the net-alkaline mine water discharged into the River Calder catchment, to the north, but the water is now intercepted by pumping, and the treated water is discharged to the River Irwell, which drains south. The treatment of the net-alkaline discharge comprises aeration, settlement, and tertiary treatment using an aerobic wetland. This system is discussed in detail by Barnes (2000).

The net-acidic tip leachate has always drained to the River Irwell, but is now mixed with the treated net-alkaline mine water (though not for the purposes of treatment), prior to discharge to the river. It is the treatment of this acidic water that is the focus of this paper.

The acidic waters arise from the spoil heap of the former mine at the site. The discharge emanates from a buried pipe, which is thought to be fractured at one or more points along its length, allowing the ingress of waters percolating through the pyritic tip material. The objective of treatment was to neutralise acidity and remove metal contaminants (predominantly iron and aluminium). However, the steep nature of the site precluded the use of a compost wetland for neutralisation. Anoxic limestone drains (ALDs) were inappropriate due to the elevated iron and aluminium concentrations (see below), and active chemical treatment was to be avoided, due to cost and the isolated situation of the treatment scheme. Kepler and McCleary (1994) first proposed the use of RAPS (albeit under a slightly different name – Successive Alkalinity and Reducing Systems) for exactly the type of situation encountered at Deerplay. Such a system was therefore designed, and this paper reports the operational and treatment performance of this unique system since its commissioning in September 2001. This is only the third RAPS to be built in the UK, the others being at Pelenna, south Wales, and Bowden Close, County Durham (see Younger et al., 2002 for details). However, the system at Deerplay is unique due to its configuration (see below).

Discharge water quality

Table 1 illustrates the quality of the tip leachate at Deerplay. All analyses were undertaken by a nationally approved laboratory. The validity of measurements such as pH and alkalinity, which may change during transit and storage, has been confirmed with on-site determinations.

The data illustrate that the discharge is strongly net-acidic, with mean pH and acidity concentration of 3.3 and 165 mg/L as $CaCO_3$ respectively. Mean total iron and aluminium concentrations are 21.5 mg/L and 13.6 mg/L respectively.

Table 1. Water quality of the Deerplay tip leachate discharge, for the period September 2001 to April 2002.

Determinand	Mean	Range	n[a]
Flow-rate (L/s)	1.30	0.18 – 6.45	30
pH	3.3	2.9 – 4.0	82
Conductivity (μS/cm)	1588	62 – 2280	39
Alkalinity (mg/L as $CaCO_3$)	0	0	82
Acidity (mg/L as $CaCO_3$)	165	0 – 384	82
Chloride (mg/L)	8	0 – 53	39
Sulphate (mg/L)	863	325 – 1360	39
Iron (total) (mg/L)	21.5	1.5 – 61.0	81
Iron (ferrous) (mg/L)	8.4	1.2 – 57.5	82
Aluminium (mg/L)	13.6	3.6 – 31.5	81
Manganese (mg/L)	4.25	2.02 – 6.70	81
Ammoniacal nitrogen (mg/L)	0.9	0.2 – 3.8	39

[a]total number of measurements made

System configuration

To date RAPS have been configured such that the compost overlies the limestone (e.g. Demchak et al., 2001; Kepler and McCleary, 1994). However, engineering constraints meant that this was not possible at Deerplay. Therefore at Deerplay water flows downwards through the compost, and then upwards through the limestone bed i.e. the compost bed and limestone bed are laid out side by side. This has the advantage of ensuring that there is no possible opportunity for short-circuiting through the limestone. Water exits the compost bed via dendritic network of pipes (overlain by a 300 mm layer of limestone to prevent blockage), and then flows up through the limestone bed. Effluent water level (and therefore water level over the compost) is controlled by an adjustable section of pipe at the exit of the limestone bed.

The key objective of a RAPS is to generate alkalinity, and thus neutralise acidity. For this to happen there must be sufficient alkalinity generation potential within the system, and sufficient residence time to allow the relevant chemical and microbiological reactions to occur. Hedin et al. (1994a) established that 14 hours was the optimum time for alkalinity generation within a limestone bed. Therefore the limestone bed for the Deerplay RAPS contains 220 m^3 of carboniferous limestone. On the basis that the limestone has a porosity of 50%, and at a design flow-rate of 2 L/s, the calculated residence time is therefore 15.3 hours.

In terms of compost content and configuration, design criteria are less specific. Demchak et al. (2001) suggest a minimum compost depth of 500 – 600 mm to induce the reducing conditions necessary to prevent subsequent armouring of the limestone by aluminium and ferric iron. Younger et al. (2002) reiterate this recommendation. The compost at Deerplay is in fact approximately 2 m deep, to ensure effective reduction. This may in fact prove to be a problem in the future, if permeability begins to decrease (as is likely), and therefore hydraulic head through the compost increases. However, removal of a layer of compost would be a simple enough task if this transpires to be the case.

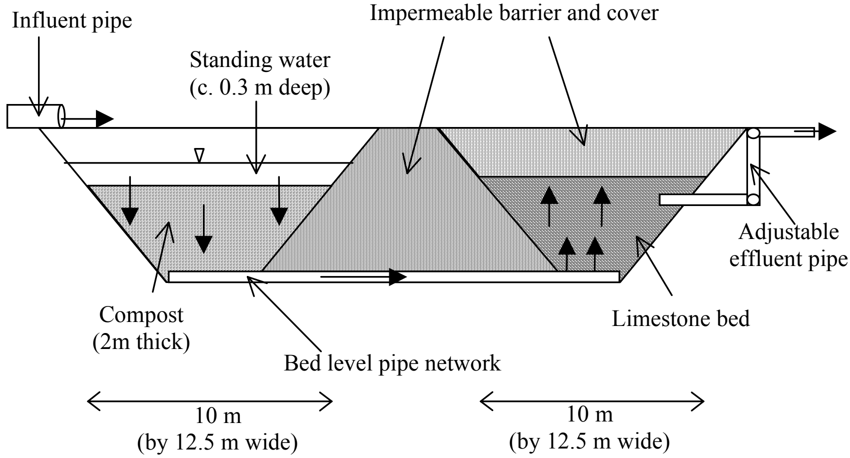

Fig. 1. Conceptual cross-section of the Deerplay RAPS (not to scale)

There is a depth of at least 300 mm of water overlying the compost, and a total freeboard of approximately 1 m. An overflow pipe is built into the compost bed in case water levels exceed the maximum water level. In addition sampling ports were installed at 3 depths during construction, in both the compost and limestone layers. The overall layout and dimensions of the system are illustrated in Fig. 1.

Treatment and operational performance

The Deerplay RAPS has been operating since September 2001. Samples have been collected from the influent and effluent channels on at least a weekly basis. For some key variables such as pH and acidity samples were collected on a daily basis for the first 3 months of operation.

Mean pH increases from 3.3 to 6.7 across the system. Alkalinity, which is consistently zero in the influent waters, is at least 100 mg/L as $CaCO_3$ in the effluent waters, as illustrated in Fig. 2.

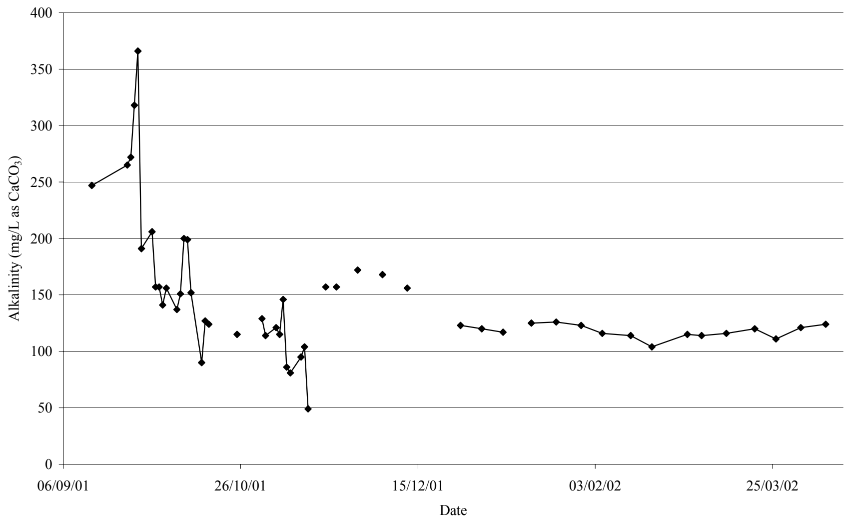

Fig. 2. Deerplay RAPS effluent alkalinity for the period September 2001 to April 2002 (Influent alkalinity is always zero)

Fig. 2. demonstrates that there is something of a 'honeymoon' period in terms of alkalinity generation, which lasts for approximately 1 month. This pattern has been observed in other passive treatment systems, and is probably due here to initially rapid dissolution of limestone dust. However, since the end of December 2001 alkalinity generation has levelled off, and is now consistently in the region of 120 mg/L as $CaCO_3$. Since the mean influent acidity is 165 mg/L as $CaCO_3$, the net generation of alkalinity is 285 mg/L as $CaCO_3$. This is at the top end of the range of alkalinity production considered capable by passive limestone systems (Younger et al., 2002).

Influent iron, aluminium and sulphate concentrations are highly variable, as indicated by the ranges of values shown in Table 1. Increases in concentrations of these variables are correlated with increases in acidity concentration, as shown in Fig. 3. This is the pattern that would be expected. However, these trends are not reflected in effluent concentrations i.e. high influent acidity concentrations are not necessarily reflected by high effluent concentrations of Fe, Al and SO_4. This suggests that the system effectively buffers the effects of changing contaminant concentrations. However, fluctuating flow-rates may have an influence in this regard. It is difficult to assess what influence such variation has at this stage, because influent and effluent measurements of flow-rate have only been sporadic.

Mean effluent iron (total) concentration is 15.5 mg/L (cf. influent concentration of 21.5 mg/L). Thus, over the operating period of the system there is not much reduction. A closer inspection of the data reveals that the RAPS goes through phases of being both a net sink for, and a net source of, iron. The reason for this is not clear at present.

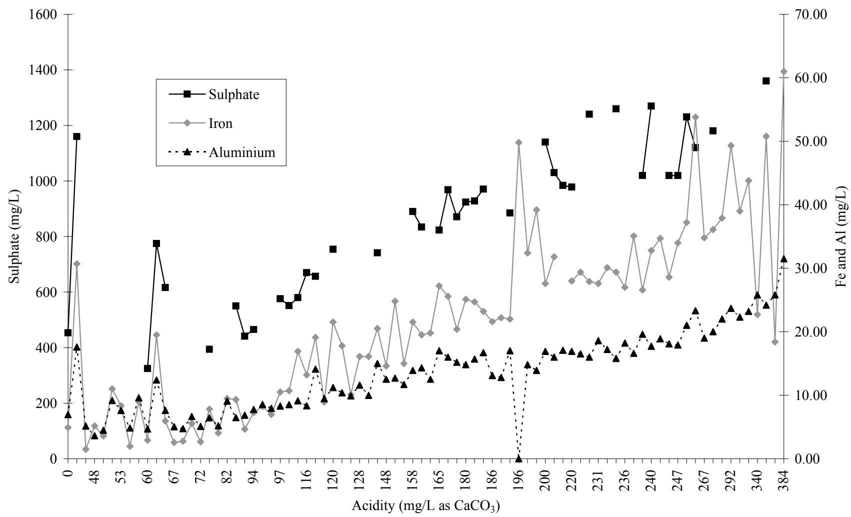

Fig. 3. Relationship between increasing acidity concentration and increases in concentration of Fe, Al and SO_4, for tip leachate at Deerplay.

In contrast aluminium is consistently removed by the RAPS. Mean effluent concentration is 0.51 mg/L (range 0.01 – 3.16 mg/L), significantly lower than influent concentration (see Table 1). It is not clear at this stage where the aluminium is removed. It seems most likely that it is removed as a hydroxide floc on the surface of the compost. However, it is also conceivable that it is armouring the limestone. This seems unlikely given the depth of compost available to induce reducing conditions, but will be a cause for concern if it proves to be the case. Newcastle University (UK) has recently begun collecting water from the sampling ports installed through the system. The results of this work should reveal the fate of metal contaminants in the RAPS.

Reductions in sulphate concentrations in compost based systems are indicative of the activity of Sulphate Reducing Bacteria (SRBs), which in turn is a sign that reducing conditions pertain in the compost. For the first 3 months of operation of the RAPS at Deerplay there was no indication that sulphate concentrations were decreasing. However, the absolute change in sulphate concentration would not need to be great to remove all of the iron as ferrous monosulphide, since sulphate concentrations are typically an order of magnitude higher than iron concentrations. Nevertheless, in recent months there has been a measurable decrease in sulphate concentration, perhaps suggesting that sulphate reduction is becoming a significant process. Again, continuing sampling will reveal whether this is the case.

Understandable concerns have often been expressed by regulatory agencies about the potential increase in organic matter arising from compost based systems. Measurements of NH_3-N at the Deerplay RAPS demonstrate that such increases are short-lived, confirming findings at other compost-based passive treatment systems (e.g. Jarvis, 2000). Fig. 4. illustrates this point, showing that NH_3-N levels returned to almost baseline levels within a month of commissioning.

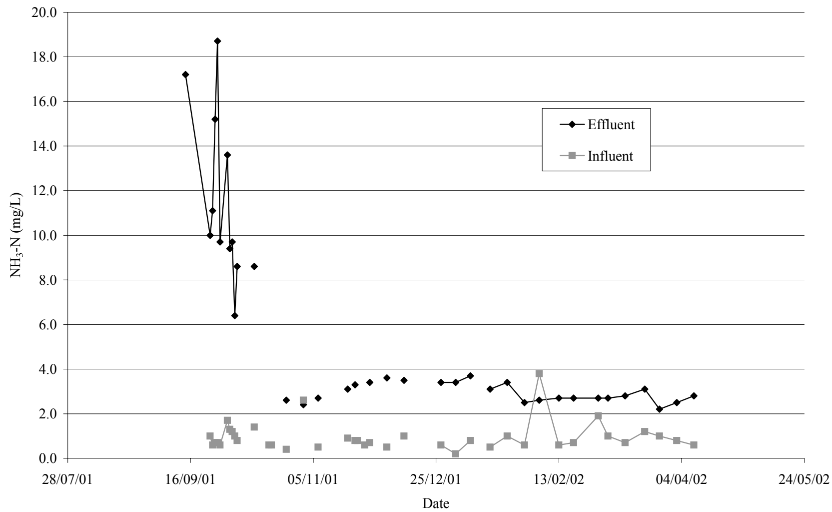

Fig. 4. Reductions in NH_3-N concentration in effluent from the Deerplay RAPS over time.

Longevity of treatment system

The details above illustrate that the RAPS at Deerplay is highly effective at generating alkalinity, as it was designed to do. The RAPS occupies a footprint of some 250 m^2. This is a fraction of the size of a compost wetland that would be required: using the design formula of Hedin et al. (1994b) an area of approximately 4000 m^2 would be needed.

The most significant issue relating to RAPS is perhaps the longevity of such systems, and in particular how quickly the compost and limestone media will become exhausted or clogged.

Younger et al. (2002) (pp. 104-112) outline a method for assessing weathering rates in mined systems that can equally be applied to the dissolution of limestone in a RAPS. Using these methods, and knowing the rate of alkalinity generation in the RAPS at Deerplay, it has been possible to calculate that the limestone (assumed to be 80% calcite) in the RAPS at Deerplay will be completely exhausted in 21 years. Of course the limestone is likely to require replacement prior to complete exhaustion, but this time period is nevertheless encouraging.

It is far more difficult to make such predictions about the longevity of the compost substrate, both in terms of the physical reduction in permeability that will inevitably occur, and the exhaustion of carbon substrates, essential for the survival of the SRB populations that create reducing conditions.

More intensive sampling of the system by Newcastle University will certainly help to answer some of these questions. In addition, IMC is an industrial partner in a recently awarded research programme led by Bangor and Newcastle Universities. This research project will investigate the very issues of changes in carbon and sulphur cycling in compost based systems, and will hopefully answer some of the key questions relating to the longevity of RAPS.

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References

Barnes, T.M. (2000) Treatment of the gravity minewater discharge at Deerplay Mine, Burnley, UK. Prceedings of the 7th International Mine Water Association Congress, Ustron, Poland, 11-15 september 2000. pp. 344-351.

Demchak, J., Morrow, T., Skousen, J. (2001) Treatment of acid mine drainage by four vertical flow wetlands in Pennsylvania. Geochemistry: Exploration, Environment, Analysis 1:1

Hedin, R.S., Watzlaf, G.R., Nairn, R.W. (1994a) Passive treatment of acid mine drainage with limestone. Journal of Environmental Quality 23:1338-1345.

Hedin, R.S., Nairn, R.W., Kleinmann, R.L.P. (1994b) Passive treatment of polluted coal mine drainage. Bureau of Mines Information Circular 9389. United States Department of Interior, Washington DC. 35 pp.

Jarvis, A.P. (2000) Design, construction and performance of passive systems for the treatment of mine and spoil heap drainage. Unpublished PhD thesis, Department of Civil Engineering, University of Newcastle, UK, 231 pp.

Kepler, D.A. and McCleary, E.C. (1994) Successive Alkalinity Producing Systems (SAPS) for the treatment of acidic mine drainage. Proceedings of the International land reclamation and Mine drainage Conference and the 3rd International Conference on the Abatement of Acidic Drainage. (Pittsburgh, PA; April 1994). Volume 1: Mine Drainage, pp. 195-204.

Younger, P.L., Banwart, S.A., Hedin, R.S. (2002) Mine Water: Hydrology, Pollution, Remediation. Kluwer academic Publishers, Dordrecht. 442 pp.