Performance of a Successive Alkalinity Producing System (SAPS)

Ben Rees[1], Rob Bowell[1], Matt Dey[2] and Keith Williams[2]

[1]SRK Consulting, Windsor Court, 1-3 Windsor Place Cardiff, UK. CF10 3BX. Email:brees@srk.co.uk Tel: + 44 (0) 29 203 48150 Fax: + 203 48199
[2]Cardiff University, Division of Materials and Minerals, Cardiff. UK.

Abstract
Unlike net alkaline minewater that can in certain cases be readily treated in aerobic wetlands, net acid minewater requires distinct treatment. Treatment can potentially be achieved using a Successive Alkalinity Producing System (SAPS) which comprises passing the minewater vertically through a layer of substrate overlying a limestone bed. Assessment of such a system used to treat a minewater discharge in South Wales, UK indicates that iron removal is aerobic resulting in accumulation of surface ochre precipitates. As a result, this leads to a reduction in vertical bed permeability. Without on-going management, this can cause over-spill of the SAPS. Successful long-term treatment using systems such as a SAPS requires on-going management and they should not be considered a walk-away option.

Introduction
During active mining and post closure, the control of water requires prudent site management to firstly minimise the generation of minewater and secondly to treat where necessary. In order to reduce associated treatment costs in the long term, artificial wetlands have gained acceptance, particularly for treating coal mine drainage.

In such circumstances, where iron is often the predominant contaminant of concern, removal utilises the natural oxidation of iron II (Fe^{2+}) to iron III (Fe^{3+}) followed by hydrolysis of the iron III as shown (Hedin et al., 1994 and Ferris et al., 1989):

$$\text{OXIDATION} \quad Fe^{2+} + \frac{1}{4}O_2 + H^+ \Rightarrow Fe^{3+} + \frac{1}{2}H_2O \qquad (1)$$

$$\text{HYDROLYSIS} \quad Fe^{3+} + 3H_2O \Rightarrow Fe(OH)_3 + 3H^+ \qquad (2)$$
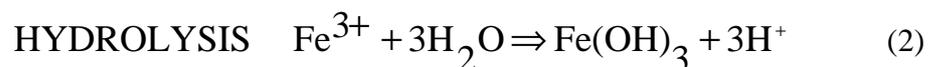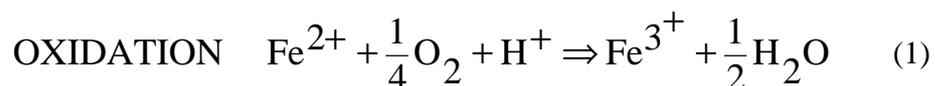
As the hydrolysis process generates proton acidity (H^+), the water being treated must contain sufficient alkalinity to buffer this reaction if it is to remain 'net alkaline'

(Hedin et al., 1994). For this reason, waters with insufficient buffering capacity are termed 'net acidic' and require distinctly different treatment requirements.

Net Acid Water Treatment

In order to facilitate efficient Fe removal and pH control, successful treatment of net acid water requires alkalinity supplementation. This can be achieved using a number of alkali dosing methods such as lime dosing, magnesium hydroxide or ammonia (Kuyucak, 2001) or as has been recently implemented at Pelenna, South Wales, using a Successive Alkalinity Production System (SAPS) (Younger, 1995). The minewater being treated has an average total Fe content of 70mg/l and flow rate of 8l/s.

The SAPS works by adding alkalinity to the minewater as it vertically passes through a limestone bed beneath a layer of organic substrate, such as bark mulch or mushroom compost. The substrate is aimed at stimulating bacterial processes under reducing conditions and as a result SAPS have also become known as RAPS or Reducing and Alkalinity Producing Systems. For example, if bacterial sulphate reduction (BSR) occurs then it serves to generate alkalinity and also dissolved sulphide (Postgate, 1979). This sulphide can then potentially react with dissolved metals such as Fe to form Acid Volatile Sulphide (AVS) salts.
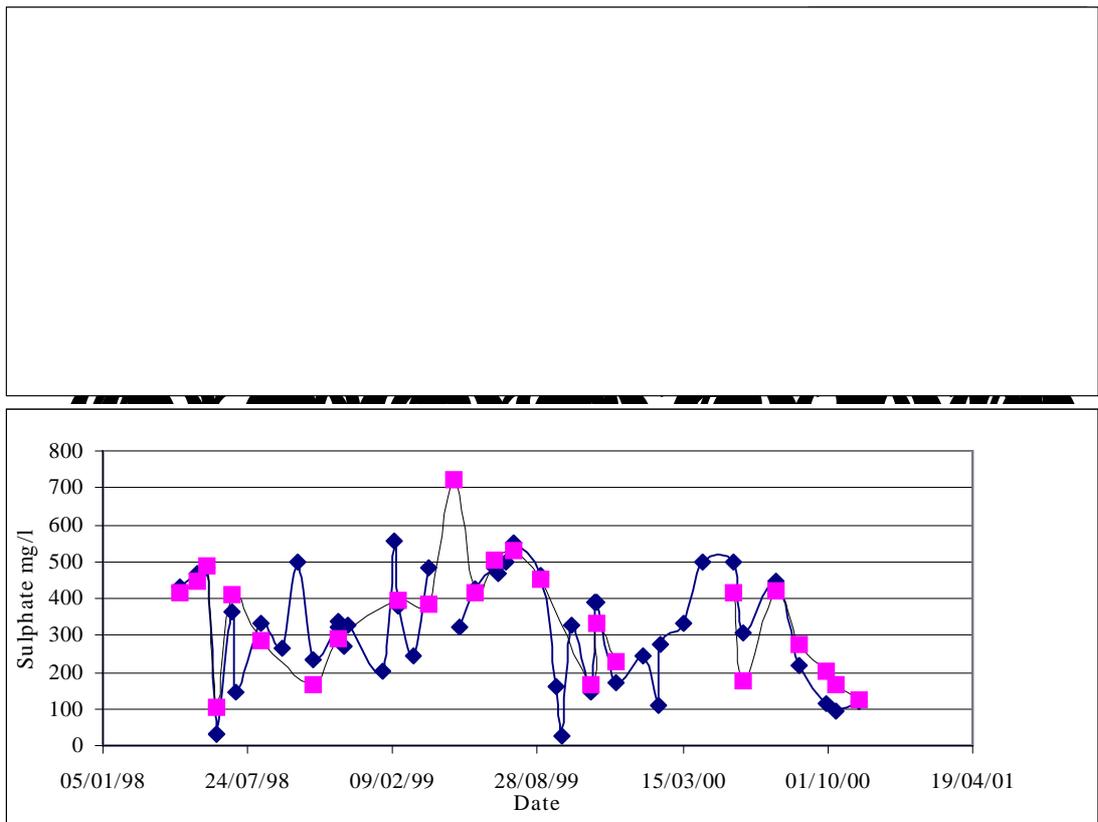

Figure 1. Variation of total Fe and SO_4 through SAPS

Monitoring of the influent and effluent chemistry at the Pelenna SAPS reveals Fe removal is occurring but poor sulphate removal (Figure 1). This suggests sulphate
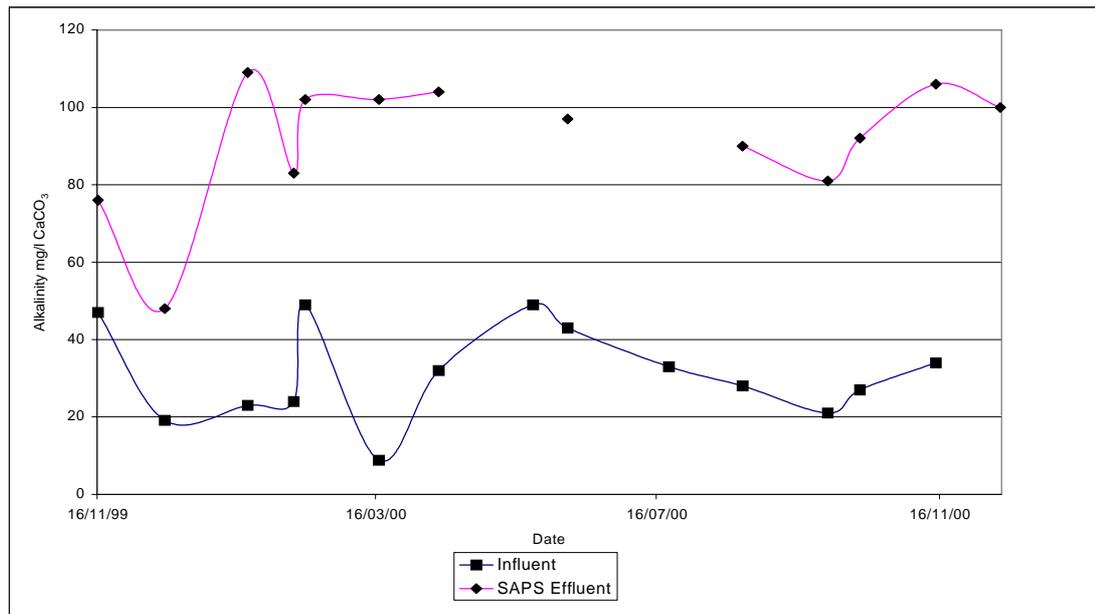
Figure 2. Increase in alkalinity through SAPS

reduction and iron sulphide formation are negligible in the system and it is more of a SAPS than a RAPS. Alkalinity however, increases through the SAPS, suggesting limestone dissolution is occurring (Figure 2). So what processes are responsible for Fe removal?

Iron Removal

As sulphide formation can not account for observed Fe removal, there must be other processes occurring. Visual observation of the SAPS indicates Fe oxidation via equations 1 and 2 would account for most Fe removal as ~0.2m of surface ochre precipitate were found.

However, other processes may also be occurring that enhance Fe removal. One such process could be the well documented process of autocatalytic Fe oxidation, where Fe^{2+} can be removed from solution by oxidation at the surface of previously formed ferric hydroxides (Stumm, 1996). In order to preliminary assess the occurrence of this process, Fe concentrations over time were recorded in two beakers of iron (II) sulphate solution, one of which also contained fresh ochre from the SAPS. The beaker containing ochre resulted in significantly lower Fe concentrations over a relatively short time period suggesting that autocatalytic iron oxidation is feasible as a method to enhance Fe removal. As this initial experiment was conducted using distilled water, further research is currently being undertaken to assess the significance of this process using real minewater.

3

SAPS Longevity

The continuous accumulation of ochre on the surface of the SAPS could have significant implications for long term SAPS performance. In order to assess this effect, a full-scale cross section of the SAPS was reconstructed in the laboratories of the Division of Materials and Minerals at Cardiff University. The reconstruction used a transparent Perspex tube 2m long and 0.15m wide filled with the same material as found at the SAPS, including the surface ochre precipitates. Falling head permeability tests were then conducted to assess vertical permeability (Craig, 1987).

Using Darcy's equation (Craig, 1987), the minimum permeability required to permit flow was calculated. The effect of ochre accumulation was then simulated using fresh ochre collected form the SAPS. As summarised in Figure 3, as ochre thickness
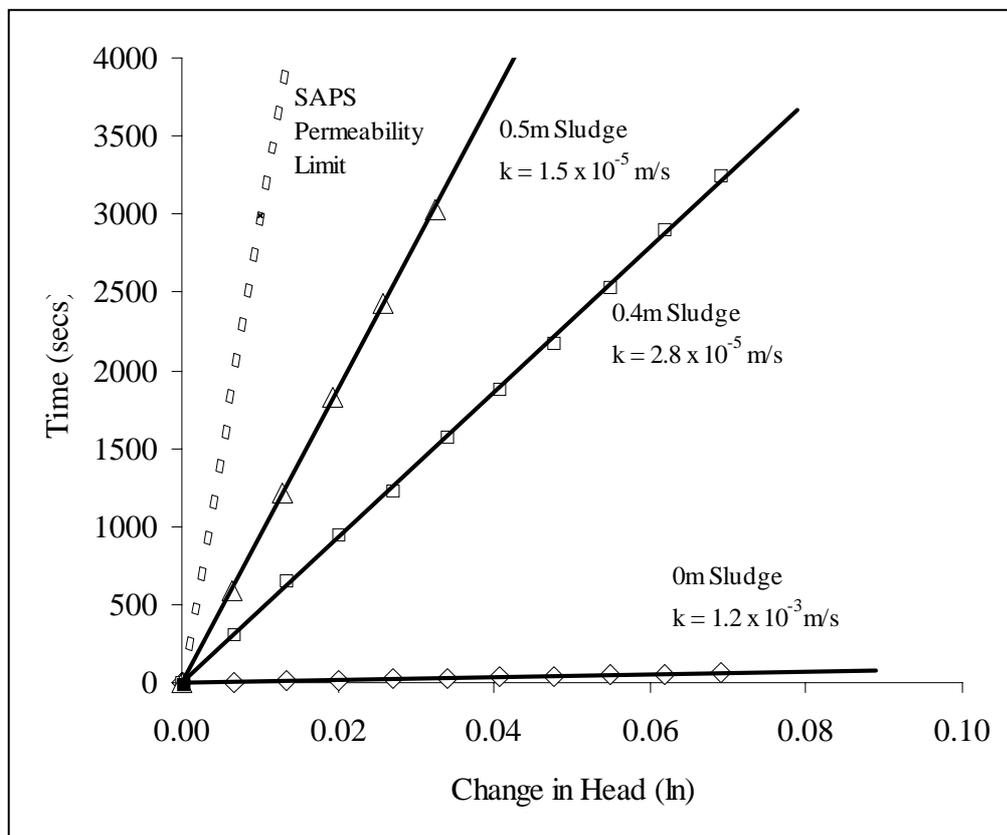

Figure 3. Variation of vertical permeability with ochre depth

increased vertical permeability decreased. This suggests that the bed permeability will decrease overtime and the SAPS will become impermeable leading to over-spill unless maintenance is made. Since operation in early 1998, 0.2m of surface ochre has accumulated in approximately 1.5m. If this accumulation rate continues, then problems with vertical permeability are anticipated to occur ~5 years after commissioning, although no account of ochre ageing is included in this prediction

A further complication at Pelenna is that during the period February 2000 - May 2000, minewater did not enter the system due to blockage of the minewater distribution network. Therefore, previously deposited ochre may have compacted, thereby potentially creating different sub-surface conditions that may affect long term permeability.

In the short term, the saving grace of the Pelenna system may be the ~1m of freeboard available and the wet Welsh weather. Combined, these factors may provide sufficient head to allow flow to continue, albeit at a reduced rate for a longer period of time before remediation engineering is required or the system over-spills.

Summary

Successful treatment of net acidic minewater requires separation of the alkalinity supplementation and Fe removal stages. The alkalinity should be added in an anaerobic environment and then the water exposed to oxygen to enable efficient Fe oxidation. Long term treatment of net acidic minewater is possible, provided the water chemistry is first fully characterised, the treatment design is based on this geochemical understanding and it is recognised that the system requires on-going maintenance which will incur operational costs. Successful long-term treatment using systems such as a SAPS requires on-going management and they should not be considered a walk-away option.

Acknowledgements

References

Craig, RF. 1987. Soil Mechanics, 4th Edition. Wokingham UK, Van Nostrand Reinhold.

Ferris, F.G., 1989. Tazake, K. and Fyfe, W.S. Iron Oxides in Acid mine Drainage Environments and their Association with Bacteria. Chemical Geology, 74 321 – 330.

Hedin, R.S., Nairn, R.W. and Kleinmann, R.L.P. 1994. Passive Treatment of Coal Mine Drainage. U.S. Bureau of Mines Information Circular No. 9389,

Kuyucak, N. March 2001. Treatment Options for Mining Effluents. Mining Environmental Management, pp12-15.

Postgate, J.R. 1979.The Sulphate Reducing Bacteria. Cambridge University press.

Younger, P.L. 1995. Design, construction and initial operation of full-scale compost-based passive systems for treatment of coal mine drainage and spoil leachate in the UK. Proceedings of the International Mine Water Association Symposium, Johannesburg, S. Africa. (Vol II), pp. 413 –424.

Stumm, W. and Morgan, J.J. 1996. Aquatic Chemistry. Third Edition. Wiley Interscience.