

A SUCCESSIVE ALKALINITY PRODUCING SYSTEM (SAPS) AS OPERATIONAL UNIT IN A HYBRID PASSIVE TREATMENT SYSTEM FOR ACID MINE DRAINAGE

Almudena Ordóñez, Jorge Loredó and Fernando Pendás.

Departamento de Explotación y Prospección de Minas. University of Oviedo.
Escuela Técnica Superior de Ingenieros de Minas
Independencia 13
33004 Oviedo. Spain
Phone: +34 985 104294, Fax: +34 985 104245
e-mail: inyaci@atenea.etsimo.uniovi.es

ABSTRACT

The use of passive systems for acid mine drainage treatment has increased dramatically over the last few years. These systems can include different operational units, whose limitations should be evaluated mainly depending on the type of effluent that has to be treated. Net acidic water with low concentration in ferric Iron, Aluminium and/or dissolved Oxygen can be successfully neutralised by means of the known Anoxic Limestone Drainage units (ALD). However, high contents of these metals, in presence of Oxygen reduce dramatically the efficiency of ALD systems, causing permeability reduction and limestone "armoring" by oxides. These type of effluents have their alternative treatment in the anaerobic substrate wetlands, but these have large area requirements.

To avoid the previous problems, the systems SAPS (Successive Alkalinity-Producing Systems) or "vertical flow anaerobic wetlands" have been developed. In them, mine water is forced to follow a vertical circulation, which has been proved to be more efficient in the treatment. Normally, these systems are constituted by a limestone layer, followed by another of an organic substrate and a final layer of ponded water. Vertical flow is achieved by means of a perforated pipe at the bottom of the system, in contact with the limestone. The objective of the limestone (which is not armoured in this position) is to generate alkalinity. The organic substrate allows reduction of dissolved Oxygen, removal acidity and Aluminium, the reduction of ferric Iron to ferrous Iron, as well as reducing the contents of other trace metals that could exist. These systems should be followed by a sedimentation and oxidation pond, and they are able to remove ten times more acidity than the conventional anaerobic wetlands.

Several experiments with a hybrid treatment system at laboratory scale were undertaken in the University of Oviedo to evaluate the efficiency of the different types of passive treatments for acid mine drainage. The water used has very high contents in Mn (200 mg/l), Fe (50 mg/l), Sulphates (10g/l) and pH = 3. In a first phase, the hybrid system was composed by an ALD, followed by four sedimentation/oxidation cells and a "lab-wetland" with about 250 m³ of organic substrate. In a first experiment, a progressive decrease in the efficiency of the system was observed, due to the failing of the unit ALD, as was expected. Finally, there was limestone armoured with ferruginous deposits.

In a second phase, the unit ALD was substituted by a SAPS unit to avoid the problems detected in the previous experiment. The lab-scale SAPS was a PVC column of 1.3 m of length and 0.25 m of diameter in which three successive layers of identical thickness (limestone + organic substrate + free standing water) were

disposed. After 30 days of experiment, reductions of about 65% in acidity, 100% in Al, 27% in Mn and 99.5% in Total Fe, had been achieved. Although Sulphate content is not removed by passing through the SAPS, it is reduced in a 32% after going through the wetland. The average pH obtained for the SAPS effluent was 7.1 units. The Redox Potential measurements show the presence of reduction environment in its interior. At the end of the experiment, ferric oxides armoring the limestone used in the SAPS could not be seen. Multielemental analysis of the organic substrates used inside the SAPS and the "lab-wetland" are going to be realised.

According to the obtained results, it can be deduced that the hybrid passive systems, which combine different types of treatment units, can become an efficient and economical alternative for acid mine drainage treatment. Particularly, SAPS systems represent an efficient solution for the treatment of effluent with high concentrations in Iron and Aluminium.

INTRODUCTION

Most of the mine waters can be successfully treated with any of the traditional passive treatment systems (aerobic and anaerobic constructed wetlands, anoxic limestone drainage, etc.). However, in some cases the chemistry of the mine water is not suitable to apply to these methods.

That is the case of water containing dissolved oxygen, ferric iron, and/or aluminium. The anoxic limestone drainage system (ALD) cannot be used then, because aluminium reduces the permeability of the system and ferric iron causes the limestone "armoring" with ferruginous oxides ("ochre") when oxygen is present. This can be problematic as long as the content in dissolved oxygen of mine water which has been exposed to atmosphere, is usually higher than the suitable standard for a correct ALD operation, and also these systems have a limited capability to produce alkalinity. On the contrary, anaerobic wetlands do not have limitations for Iron, Aluminium, or dissolved oxygen content in their influents. However, the efficiency of these systems depends directly on the weather conditions, the treatment process is very slow and it requires vast areas of treatment. A successful alternative which combines the advantages of both of these systems, and that does not have their restrictions, is the successive alkalinity producing system (SAPS).

These hybrid systems have been developed by Kepler and McCleary (1994) to reduce the problems found using wetlands and ALD systems separately. The SAPS systems consist of a layer of limestone of about 0.5 - 1 m thick and above it, a second layer of an organic substrate of similar or bigger thickness, is arranged. Over the organic substrate, there is 1 or 2 m of ponded water. The objectives of this arrangement are as follows: The organic substrate generate alkalinity (by sulphate reduction) and remove other metals dissolved in the water, but its main function is to reduce ferric to ferrous iron and eliminate the aluminium and the oxygen dissolved in the water before it enters in the limestone layer. After this, the dissolution of calcium carbonate can be maintained during many years, increasing the alkalinity of the water progressively (Waz-

laf et al., 1995). In a SAPS system, the water is forced to move down through the mentioned layers and the effluent goes out of the system by means of a drain placed at the bottom of the limestone. This vertical flow has proved to be very effective, due to the high pressures that the water suffers in a SAPS system, compared to the reduced pressures existing in a lateral flow system like ALD. Besides, the cross sections are bigger in a SAPS. These systems are normally covered with an impermeable material, such as clay (Figure 1).

These systems, like ALD, need to be followed by an aerobic pond or wetland to favour oxidation. Compared to traditional wetlands, SAPS systems yield 10 times more alkalinity (Watzlaf, 1998), and they require 40% less area for their construction (Younger et al., 1997).

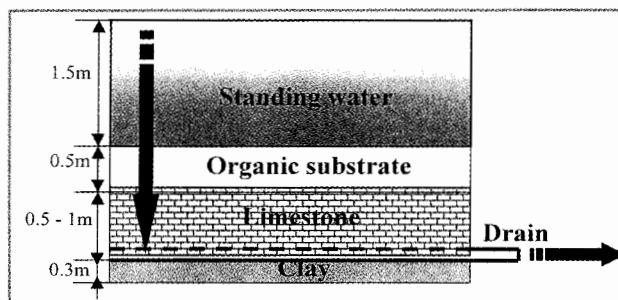


Figure 1. Scheme of a SAPS system (modified, Younger, 1998).

There is not a wide experience of using these systems as they started being utilised recently and so their long-term effects are not well known. However, the results obtained in these systems so far, show that anoxic conditions are acquired inside the limestone and so, SAPS systems are becoming an efficient and economical type of passive treatment.

MATERIALS AND METHODS

Several experiments at laboratory scale were undertaken to evaluate the efficiency of the different passive treatment systems applied to acid mine drainage. The water used was

A SUCCESSIVE ALKALINITY PRODUCING SYSTEM (SAPS) AS OPERATIONAL UNIT IN A HYBRID PASSIVE TREATMENT SYSTEM FOR ACID MINE DRAINAGE

synthetic mine water, that was prepared in the laboratory containing very high contents in Mn, Fe, sulphates and very low pH (Table 1). Synthetic water is more convenient for the experiments and the results are more uniform than when real mine water is used.

pH	Acidity Calc.	Sulphates	Mn	Fe	Al
Units	mg/l CaCO ₃	mg/l	Mg/l	mg/l	mg/l
3	503	10.000	200	50	50

Table 1. Chemical parameters stabilised for the synthetic mine water that was used in the experiment.

In the experiments, a hybrid system was used, composed by three classic units in passive treatments. In a first phase, this system was formed by an ALD, followed by four sedimentation/oxidation ponds (cells) and a substrate wetland at laboratory scale. After a period of operation, it could be observed a progressive decrease in the efficiency of the system, due to the failure of the unit ALD, as limestone was armoured with ferruginous deposits.

In a second phase, the ALD was substituted by a SAPS to exclude the limitations and difficulties found after using it to treat the synthetic water. The combined system use in this case integrate the following units connected to each other:

Lab-SAPS

It consists on a PVC cylindrical anaerobic column of 60 litres of capacity in which the distinctive characteristics of a SAPS system are reproduced. It has been filled with a 40 cm thick layer of limestone and a second layer of compost of the same thickness (both layers are separated by a geotextil). The rest of the column was completely filled with ponded water, which is fed through the system by gravity.

Oxidation cascade

The SAPS effluent enters into a unit composed of four cells that form a cascade where oxidation conditions –that allow metal oxides precipitation- are reached. Maintaining the aerobic environment in this unit, the ochre deposits on the wetland surface (next unit) are avoided. Therefore, the efficiency of the organic substrate is not eventually reduced.

Lab-wetland

From the last oxidation cell, water enters in the “lab-wetland”. This is a receptacle of 375 litres of capacity, divided in 15 sections, in which water follows a circuitous path. The bottom of this container was filled with a thin layer of bentonite, to imitate the real arrangement in a constructed wetland. Bentonite is impermeable clay and it has an important ion exchange capacity. The rest of the wetland was filled with compost as organic substrate, with some disperse limestone inside, and a superficial layer of residues of wetland vegetation (*Typha*) to imitate the natural biomass existing in the superficial part of a

real wetland. *Typha latifolia* plants collected in a natural donor site, were put of the organic substrate.

An scheme of this hybrid system is shown in Figure 2.

The flow was maintained as a constant rate of 7 ml/min during all the experiment. Considering the porosity of the limestone (50%) and the compost (30%), the estimated residence time is 3.5 days inside the SAPS, 3 days in the oxidation cascade, and 10 days inside the wetland. Therefore, the water is more than 2 weeks inside the system. This experiment started on 10th February of 1999 and it lasted 44 days.

The system monitoring was executed by sampling weekly the water before and after every stage of the treatment:

- System influent, before the SAPS
- SAPS effluent, before the oxidation cascade
- After each oxidation cell in the cascade
- Wetland influent
- System effluent

In every sample, the sulphate content was analysed and the concentration of the three metals (Mn, Al, Fe) which the water was doped with. The acidity was also calculated. More often, pH, Redox Potential and electrical conductivity were measured in every phase of the system and in the superficial

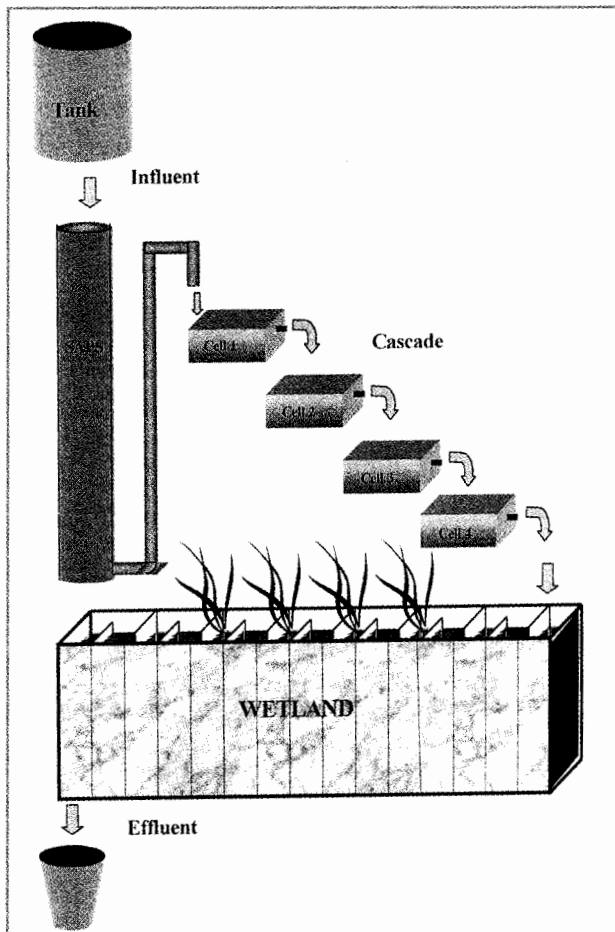


Figure 2. Scheme of the hybrid system: “SAPS-oxidation cascade-wetland” at laboratory scale.

part of the organic substrate in all the sections in which the wetland is divided. Once the experiment was finished, the content in 32 elements of the organic substrate used inside the SAPS and inside the wetland was analysed by ICP, as well as the solid deposits that the water precipitated inside the oxidation cells.

RESULTS

The results corresponding to the calculated acidity, -expressed as mg/l CaCO₃ (Hedin et al., 1993)-, and the contents in sulphates, manganese, total iron and aluminium (mg/l) in all the collected samples are shown in Table 2.

In the following graphs (Figures 3 and 4), the evolution of pH and Eh in the analysed samples is shown as a function of time and the different phases of the hybrid system.

26/02/99					
	Acidity calc.	Sulphates	Mn	Fe	Al
	mg/l CaCO ₃	mg/l	mg/l	mg/l	mg/l
Influent = in SAPS	729	10662	184	43	50
out SAPS	186	10866	102	0,1	0
out Cell 1	175	10998	96	0,1	0
out Cell 2	167	11151	92	0,1	0
out Cell 3	162	11085	89	0,1	0
out Cell 4=in wetland	162	11160	89	0,1	0
Effluent= out wetland	1	6909	0,5	0,1	0
05/03/99					
	Acidity calc.	Sulphates	Mn	Fe	Al
	mg/l CaCO ₃	mg/l	mg/l	mg/l	mg/l
Influent=in SAPS	729	10564	215	16	50
out SAPS	228	10782	125	0,2	0
out Cell 1	218	10760	120	0,1	0
out Cell 2	209	10929	115	0,1	0
out Cell 3	204	11191	112	0,1	0
out Cell 4=in wetland	200	11503	110	0,1	0
Effluent=out wetland	2	5860	1	0,1	0
12/03/99					
	Acidity calc.	Sulphates	Mn	Fe	Al
	mg/l CaCO ₃	mg/l	mg/l	mg/l	mg/l
Influent=in SAPS	708	10532	179	41	50
out SAPS	235	11004	129	0,2	0,1
out Cell 1	235	10895	129	0,1	0
out Cell 2	239	11022	131	0,1	0,1
out Cell 3	238	11088	131	0,1	0
out Cell 4=in wetland	235	11397	129	0,1	0
Effluent=out wetland	2	6688	1	0,1	0
19/03/99					
	Acidity calc.	Sulphates	Mn	Fe	Al
	mg/l CaCO ₃	mg/l	mg/l	mg/l	mg/l
Influent=in SAPS	720	10705	185	45	50
out SAPS	269	12073	148	0,1	0
out Cell 1	288	11131	158	0,2	0
out Cell 2	280	11253	154	0,1	0
out Cell 3	278	11540	153	0,1	0
out Cell 4=in wetland	271	11620	149	0,1	0
Effluent= out wetland	6	8228	3	0,2	0
26/03/99					
	Acidity calc.	Sulphates	Mn	Fe	Al
	mg/l CaCO ₃	mg/l	mg/l	mg/l	mg/l
Influent=in SAPS	727	10993	187	42	49
out SAPS	331	10206	182	0,1	0
out Cell 1	331	10469	182	0,1	0
out Cell 2	324	10613	178	0	0
out Cell 3	317	10613	174	0,1	0
out Cell 4=in wetland	313	10981	172	0,1	0
Effluent= out wetland	51	8928	28	0,1	0

Table 2. Results of calculated acidity and sulphates and metal content in the collected samples.

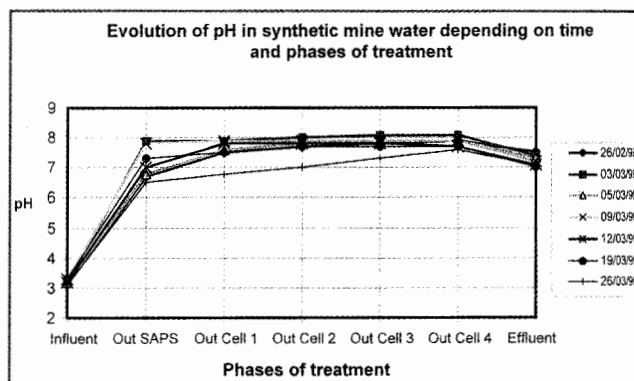


Figure 3. pH in the collected samples.

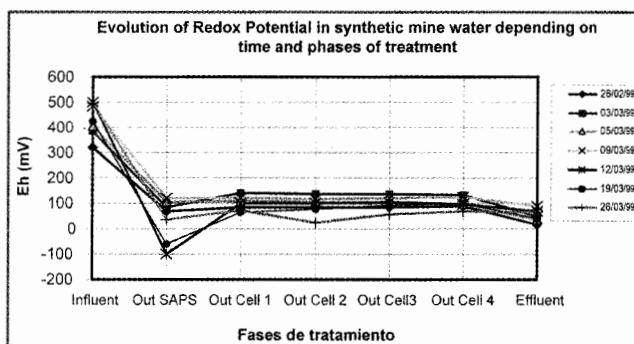


Figure 4. Eh in the collected samples.

The values of pH measured in the solids sampled in each phase of the system are compared in Figure 5. Once the experiment was finished, two samples were taken in the organic substrate inside the SAPS and several samples at different depths in different points along a cross section of the wetland were also taken. Finally, the sediment in each oxidation cell was sampled too. All these samples were analysed by ICP to know their content in 32 elements and pH was also measured in them. These results are summarised in Table 3.

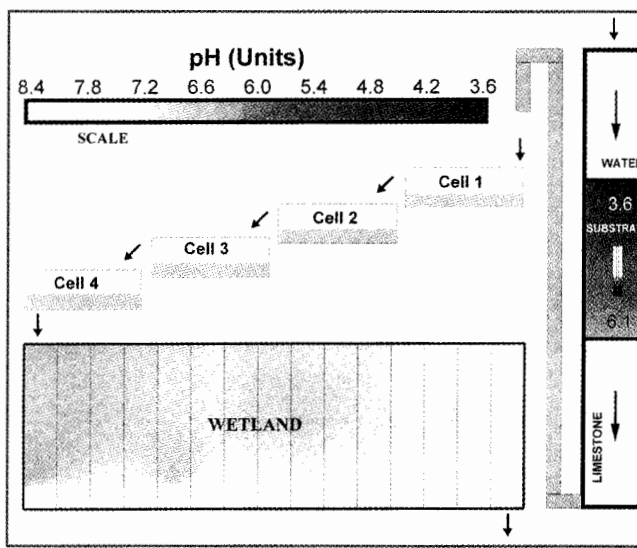


Figure 5. Evolution of pH measured in the different solids of the hybrid system "SAPS-lab wetland".

		Mn (ppm)				Fe (%)				Al (%)				
		1st	5th	9th	13th	1st	5th	9th	13th	1st	5th	9th	13th	
WETLAND	Section													
	Substrat	surface	3644	1902	603	100	0,74	0,28	0,17	0,68	0,21	0,23	0,10	0,10
		middle	2130	1595	454	74	0,92	0,28	0,14	0,55	0,18	0,11	0,09	0,09
		bottom	2997	1438	348	141	0,92	0,13	0,13	0,26	0,29	0,10	0,10	0,13
	Bentonite bed		2219	569	380	419	0,94	0,75	0,86	1,12	1,43	1,17	1,37	1,83
	primitive substrate		81				0,17				0,12			
primitive bentonite		742				0,28				0,55				
OXIDATION	CASCADE	Cell 1	24268				2,94				0,19			
		Cell 2	22307				2,26				0,11			
		Cell 3	25457				1,79				0,11			
		Cell 4	20003				1,41				0,11			
	SAPS	surface	1604				1,02				0,34			
	bottom	4460				0,35				0,46				

Table 3. Results of the ICP analysis of the solids sampled in every phase of the system.

CONCLUSIONS

The average results corresponding to the final effluent of the system "SAPS-wetland" to treat synthetic mine water are summarised as follows:

- 98% reduction of calculated acidity
- 32% reduction of sulphates content
- 92% reduction of manganese content
- 100% reduction of iron content
- 100% reduction of aluminium content
- 4 units increase of pH
- 430 mV average decrease of Redox Potential.

The average quality of the effluent is shown in Table 4.

pH	Calc. Acidity	Eh	Sulphates	Mn	Fe	Al
Units	mg/l CaCO ₃	mV	mg/l	mg/l	mg/l	mg/l
7,2	12	65	7300	7	0	0

Table 4: Average contents of the effluent of the hybrid system SAPS-wetland for synthetic mine water.

The values shown above correspond to good quality water except for the sulphate content.

The pH increases nearly 4 units inside the SAPS system, reaching neutral values at its effluent, which are maintained in next phases. It was also observed that the pH had a tendency to decrease with time. The pH measured in solids was neutral in most cases except the first part of the organic substrate used in the SAPS.

The **calculated acidity** in the water is reduced in 65% inside the SAPS and it is finally eliminated in the wetland while

it keeps constant through the oxidation cascade. The acidity reduction seems to loose efficacy with the time, too.

The **Redox Potential** reaches its minimum values (negatives) in SAPS effluent, which guarantees the presence of reducing conditions inside that system. Obviously, the Eh of the water increases in the cascade, where oxidising conditions are favoured. Although its value decreases about 40 mV inside the wetland, negative values are not reached there, so sulphate reduction will not be successful, as is explained later. On the surface of the organic substrate used in the wetland, the Eh decreases slightly and progressively through the different sections, except the last ones, where it increases. On the other hand, the Eh values tend to increase with time.

The **sulphate** concentration in the water is only partially reduced, basically because reducing conditions were not reached inside the wetland, and the sulphate-reducing bacteria need values of Eh around (-100 mV) to grow adequately. In spite of this, the high content of the influent was reduced in about 4,000 mg/l, which is encouraging. The sulphate reduction exclusively occurs inside the wetland.

Manganese concentration in water suffers a first reduction of 28% inside the SAPS and, without changing in the oxidation cascade, it is completely removed inside the wetland. It has been found that Mn precipitates when Fe has already done it. The Mn content in the influent is 100 times bigger than that of the effluent. The sediment that the water precipitated in the oxidation cells has a high content of Mn. The analysis of the organic substrate reveals that this element is mainly retained in the first sections of the wetland.

Aluminium content in the water is entirely removed after passing through the SAPS, showing a similar behaviour to the iron. The content of Al in the organic substrate is similar to

that content in the primitive compost, excepting the first sections where it is slightly higher. The percent of Al in the sediment deposited in the oxidation cells is minor and it keeps constant.

The comportment of the iron in the water is very like that of the aluminium. It is basically removed inside the SAPS. The analysis of the organic substrate used in this system showed that Fe is the only metal which is deposited mainly in the first part of the layer of compost in the SAPS. The Fe content in the water keeps constant in the oxidation cascade at about 0.11 mg/l and that causes between 1.4% and 3% of the sediment (with a decreasing tendency) in the cells corresponding to iron. As well as with the other metals, the iron remaining in the water after the oxidation facility is mostly precipitated on the surface of the organic substrate placed in the first sections of the lab-wetland.

From all exposed above, it is deduced that the successive alkalinity producing system at laboratory scale described here has achieved perfectly its aim in this experiment. This is because inside the lab-SAPS anaerobic conditions have been reached, acidity has been reduced and Al and Fe contents in water have been entirely removed, which in other cases would cause the failure of an ALD. It has been found that these reductions occur in the layer of organic substrate, to avoid the armouring of the limestone placed underneath. Therefore, the permeability of this layer of limestone is not affected and it can keep generating alkalinity successively. At the end of the experiment it could be confirmed that the limestone placed at the lower part of the SAPS column did not show "ochre" armouring as it was found in a previous experiment using an ALD.

REFERENCES

- Ackman, T.E. and R. Kleinmann, 1985. In-line aeration and treatment of acid mine drainage: performance and preliminary design criteria. Bu. Mines Inform Circ. IC-9027, p. 53-61.
- Fernández Rubio, R., S. Fernández Lorca and J. Esteban Arlegui, 1986. Abandono de minas. Impacto hidrológico. ITGE, Madrid, 267 p.
- Fernández Rubio, R., 1995. Tratamiento biológico de aguas en pantanales, Tecno-Ambiente, Seminario sobre "Depuración de aguas de tormenta, residuales, urbanas y de mina, por humedales naturales y construidos". E.T.S.I.M.O., pp. 37-44.
- Hedin, R.S. and G.R. Watzlaf, 1994. The effects of anoxic limestone drains on mine water chemistry. Proceedings of the international land reclamation and mine drainage conference and third international conference on the abatement of acidic drainage, Chelsea, Vol. 1, PA, USA, US Department of the Interior, Bureau of Mines Special Publication SP 06⁹-94, pp. 185-194.
- Hedin, R.S., R. W. Nairn, and R. L. P. Kleinmann, 1993. Passive treatment of coal mine drainage. Information Circular IC-9389, United States Department of the Interior, Bruce Babbitt, Secretary, Bureau of Mines, Pittsburgh, PA., 35 pp.
- Hedin, R.S., G. R. Watzlaf and R. W. Nairn, 1994. Passive treatment of acid mine drainage with limestone. J. Environ. Qual., Vol. 23, nº 6, USA, pp.1338-1345.
- Kepler, D.A. and E. C. McClearly, 1994. Successive alkalinity producing systems (SAPS) for the treatment of acidic mine drainage. Proceedings of the International Land Drainage and Reclamation Conference and the Third International Conference on the Abatement of Acidic Drainage, Pittsburgh, Vol. 1: Mine Drainage, US Bureau of Mines Special Publication SP 06A-94, pp 195-204.
- Loredo, J., A. Ordóñez, and F. Pendás, 1999. Tratamiento de aguas de mina mediante sistemas pasivos. Ingeniería Química, Vol. 353, Enero 99, pp. 167-178.
- Turner, D. and D. McCoy, 1990. Anoxic alkaline drain treatment system, a low cost acid mine drainage treatment alternative. in D.H. Graves (Edit.): Proc. of the National Symp. on Mining, Lexington, Univ. Kentucky, pp. 73-75.
- Watzlaf, G.R. and R. Hedin, 1993. A method for predicting the alkalinity generated by anoxic limestone drains. in West Virginia Surface Mine Drainage Task Force Symposium, Morgantown, West Virginia, April 93, pp. 27-28.
- Watzlaf, G.R. and D. M. Hyman, 1995. Limitations of passive systems for the treatment of mine drainage. 17th. Annual Conference of National Association of Abandoned Mine Land Programs, French Lick, USA.
- Watzlaf, G.R., 1996. Effects of aluminium on anoxic limestone drains. Proceedings of the West Virginia acid Mine Drainage Task Force Meeting, Morgantown.
- Watzlaf, G.R., 1997. Passive treatment of acid mine drainage in down-flow limestone systems. National Meeting of the American Society for surface Mining and Reclamation, Austin, USA.
- Watzlaf, G.R., 1998. Passive treatment systems for the treatment of mine drainage: Anoxic limestone drains. Reunión Científico-Técnica sobre "El agua en el cierre de Minas", E.T.S. Ingenieros de Minas, Oviedo.
- Watzlaf, G.R., 1998. Passive treatment systems for the treatment of mine drainage: Reducing and alkalinity producing systems. Reunión Científico-Técnica sobre "El agua en el cierre de Minas", E.T.S. Ingenieros de Minas, Oviedo.
- Wentzler, T.H. and F. F. Aplan, 1972. Kinetics of limestone dissolution by acid waste waters. in C.Rampacek (De.): Environmental control, Am. Inst. of Mining, Metallurgical and Petroleum Eng., San Francisco. USA, pp. 512-523.
- Younger, P.L., T. P. Curtis, A. P. Jarvis, and R. Penell, 1997. Effective passive treatment of aluminium-rich, acidic colliery spoil drainage using a compost wetland at Quaking Houses, County Durham. Proceedings of a CIWEM National Conference. University of Newcastle, pp. 200-208.