LONG-TERM PERFORMANCE OF VERTICAL FLOW PONDS – AN UPDATE[1]

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Abstract. Some vertical flow ponds (VFP's, SAPS) are performing less well than expected. This paper compiles quantitative data on performance and problems to extend previous evaluations in 2002 and 2004.

Of 40 sites, about half are performing entirely satisfactorily. Six sites have essentially ceased to treat. Most of the remainder are treating at a moderate level, but not up to original expectations, which in some cases were unrealistic. Problems include overflow because of plugging by Fe precipitate on top of compost or by Al precipitate in limestone, leakage, decreased treatment because of short-circuiting or Al coating, or inadequate size for the acidity loading. Low-cost rebuilding has restored several systems. Some problems result from inadequate preconstruction flow and chemical data.

The evaluation shows that vertical flow ponds are an effective method for treatment of most net-acid discharges if the ponds are properly designed and constructed. Improved designs such as bioreactors or automatic flushers may be needed for systems with influent Al exceeding about 20 mg/L.

Additional key words: Passive treatment, acid mine drainage, coal mine drainage, SAPS, economics.

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Introduction

Passive systems for treating acid mine drainage from coal mines are now in widespread use. For net acid discharge waters, vertical flow ponds (VFP's), also known as Successive Alkalinity Producing Systems (SAPS), are the most common passive method. Over the period since 1990, total costs of passive systems exceed $65 million, of which VFP's are a major fraction (Brent Means, personal comm., 2005). In view of the environmental and financial importance of these systems, an evaluation of their performance is desirable. Because some systems have "failed," some workers view these systems as unreliable. In view of controversy that may affect future funding of these systems, it is important that accurate information be available to evaluate the extent of problems and any limits on the chemical quality and flow rates that may be treated by these systems.

Previous evaluations were made by Rose and Dietz (2002) and Rose (2004). Skousen and Ziemkiewicz (2005) and Ziemkiewicz et al. (2002) have also published evaluations. These showed that most VFP's were performing satisfactorily, but that some were doing less well than expected. In view of the limited information on the life of VFP's, the current paper is intended to extend the previous information to a longer time period, and to elucidate additional information on the nature of problems with these systems. This information should then focus attention on any problems, and lead to improvements in design and construction that will avoid such problems in the future.

The general approach of this paper has been to collect quantitative data on the chemical and physical characteristics of the VFP's and on the inflow and outflow, and to examine changes over time in chemical performance. Specific problems in design, construction and maintenance have been noted. The systems evaluated in the previous compilations (Rose and Dietz, 2002; Rose, 2004) have been the main focus of attention, in order to extend the performance history of this relatively representative set of systems, but some additional systems for which data has become available are added to the compilation.

Chemical performance has been evaluated mainly using acidity, because hot peroxide acidity (if measured by the most recent methods) summarizes the effects of pH, Fe, Al, Mn and alkalinity in a single parameter (American Public Health Association, 1998; US EPA, 1979; Cravotta and Kirby, 2004). However, the individual acidity components are compiled to identify problems caused by extreme concentrations of individual constituents.

Methods

The general approach of this evaluation has been to use the data on dimensions, flow, chemistry and problems at VFP's compiled in previous publications and to seek updated chemical information from local individuals and groups monitoring these sites. The data are then examined for trends and performance.

The chemical data are generally by standard methods used in acid mine drainage studies, but several aspects deserve comment. Most of the metal determinations are "total" values on non-filtered samples, as conventionally used for regulatory purposes. These determinations can include suspended Fe, Al and Mn precipitates. If appreciable metal occurs as suspended solids, then the problem may not be with the VFP but with the settling ponds and related facilities. However, in most cases, the effect of suspended solids is small, because the samples are relatively clear and low in suspended solids. Determinations of total suspended solids are available in many cases to evaluate the extent of this uncertainty. Also, acidity determinations are not affected by suspended particulates.

Acidities used in the compilation are all hot peroxide acidities, so far as known, but some variance in method and reporting is recognized. As discussed in Rose (2004), acidity determinations by American Public Health Association (1998) or USEPA (1979) are actually net acidities if done properly with an initial titration to pH 4 with H_2SO_4. Since essentially all analyses are by certified labs, this procedure has generally been used. However, many earlier determinations were reported as zero if the value was actually negative. In Rose (2004), acidity values of zero have been recalculated using the Fe, Mn, Al, pH and alkalinity values. That version of acidity for older values is retained in the present database, but it is observed that most labs are now reporting negative acidities as instructed in standard methods.

Most flow values are derived from weirs or by bucket and stopwatch methods. However, at a few sites (Oven Run E, Rock Run), good flow measurements are lacking and only estimates are available.

Recent data were solicited from and furnished by PA Bureau of Abandoned Mine Reclamation, Mill Creek Coalition, Stream Restoration Inc., Ohio Dept of Natural Resources, Natural Resources Conservation Service (Somerset Co.), Office of Surface Mining and others. In addition, many sites were visited in the past year to observe performance. During these visits, water samples were collected of the inflow and outflow at these sites, and the samples were analyzed for hot peroxide acidity and other constituents at the Materials Characterization Lab at Penn State University.

Recent chemical and flow data, mostly for the period 2002-05, are compiled in Table 1. More complete data on the sites and for earlier inflow and outflow are available in Rose and Dietz (2002) and Rose (2004). Data for the Joller site was supplied by Brent Means of OSM, based on data from PADEP.

Methods of Comparison

In order to evaluate any decreases in performance with time, several acidity parameters have been calculated and compared for the pre-2002 period vs. the 2002-2005 period.

Acidity removal in mg/L has been calculated by the difference in acidity of the influent water and the effluent water:

$$\text{Acidity Removal (mg/L)} = A_{in} - A_{out} \qquad (1)$$

where A indicates acidity in mg/L as $CaCO_3$. As indicated above, the acidity as presented here is a net acidity that includes effects of alkalinity. This parameter tests the chemical effectiveness of the VFP on water actually flowing through the VFP.

If the acidity of influent water or its flow rate changes markedly, then the change in acidity concentration may be misleading. As an alternative, percent acidity removal is calculated as

$$\text{Percent acidity removal} = 100\,(A_{in} - A_{out})/A_{in} \qquad (2)$$

Note that this parameter can exceed 100% if the effluent is net alkaline (negative acidity).

Table 1. Compilation of data for recent period (2002-2005) vs earlier period.

	Period	N	pH		Acidity(mg/L)		Alkalinity		Fe		Mn		Al		SO4		Flow	Acid Rem.(mg/L)		% Rem.		Rate (kg/yr)		Rate(g/m2/d)	
			in	out	in	out	in	out	in	out	in	out	in	out	in	out	L/min	02-05	pre-02	02-05	pre 05	02-05	pre-02	02-05	pre-02
Pot Ridge TEST	02-05	3	2.97	5.89	515	59	0		126	19	31	20	26	4.8	1191	766	34	456	362	89	91	8197	14460	16.9	29.8
	95-00	28	3.05	6.39	396	34	0	67	72	28	23	20	19	1.6	811	898	76								
Pot Ridge C6	02-05	3	3	3	570	366			118	30	28	25	25	21	1046	942	247	204	176	36	44	26484	20037	65.4	49.5
	97-00	14	3.07	3.41	399	223	0	0	84	35	24	23	16	12	921	875	217								
Coldstream B	02-05	20	2.57	3.81	376	109	0	9	39	14	2.2	1.6	20	8	380	292	80	267	839	71	122	11199	21784	47.2	91.8
	99-02	20	2.5	7.2	685	-154	0	154	115	7	1	0.5	35	0.2	485	506	49								
Coldstream A		21	2.66	7.1	329	-20	0	87	39	3.7	1	0.5	18	0.6	309	291	680	349	817	106	140	124772	88116	142.4	100.6
	99-02	23	2.6	7	582	-235	0	260	105	4.4	2	1	48	0.8	401	436	205								
McKinley	02-05	14	3.6	6.8	95	4	5	68									53	91	97	96	96	2545	2906	11.6	13.3
	96-97	10	3.9	6.53	101	4	3	65	5	0.4	36	17	2	0.3	717	619	57								
Howe Bridge	02-05	9	5.5	5.8	317	69	38	12	145	24	30	24	<0.1	0.03	939	708	148	248	217	78	67	19318	16470	47.0	40.1
	92-00	41	5.8	5.9	323	106	31	57	193	74	38	36	0	0	1214	1102	144								
Jennings	02-05	6	4.4	6.8	212	-53	0	110	17	4	11	10	6.7	0.5	605	600	110	265	437	125	161	15349	15711	42.1	43.0
	97-00?	8	3.1	6.8	272	-165	0	212	69	10	18	16	23	0	772	729	68								
Oven Run E1	02-05	3	3.5	5.3	120	26	0	21	6.2	2.1	8.4	8.9	11	7.2	807	839	498	94	133	78	61	24595	34799	19.2	27.2
	98-99	15	3	4.3	217	84	0	13	16	11	11	11	15	10	900	944	498								
Oven Run E2	02-05	2	5.3	6.65	26	-5	21	45	2.1	0.6	8.9	9.3	7.2	0.14	839	841	494	31	20	119	28	8049	5233	6.3	4.1
	98-99	14	4.3	5.5	72	52	6	23	3	4	11	11	8	4.5	941	926	498								
Oven Run D1	02-05	4	4.9	5.9	185	80	9	27	32	2.9	25	24	1.3	1.1	1347	1391	353	105	104	57	91	19503	20149	44.5	46.0
	95-00	14	4	5.6	114	10	0	28	38	3	29	28	1.8	0.9	1372	1358	369								
Oven Run D2	02-05	3	6.1	6.8	36	-1	22	36	1.3	0.4	23	18	1.2	0	1278	1153	353	37	5	103	50	6873	879	16.3	2.1
	95-00	14	5.5	6.7	10	5		42	1.4	0.4	28	24	1.6	0.4	1640	1323	334								
Oven Run B1	02-05	22	2.8	3.6	493	285	0	0.1	53	41	18	17	37	27	955	982	893	208	317	42	62	97627	98136	33.4	33.6
	99-01	29	2.87	4.51	515	198	0	31	68	40	20	18	41	22	939	1114	589								
Oven Run B2	02-05	22	3.6	4.3	285	167	0	4.5	41	17	17	17	27	20	982	970	893	118	161	41	81	55385	49842	19.5	17.6
	99-01	29	4.5	6.28	198	37	31	101	40	12	18	18	22	6.4	1114	1188	589								
Rock Run 1	02-05	6	3.7	5.5	104	78	0	54	13	11	4	4	9.5	7				26	51	25	40		2654	0.0	
	99-01	10	3.6	6.1	129	78	0	152	26	8	4.5	4.5	11	1.5	1013	986	99								
Rock Run 2	02-05	6	5.5	6.5	78	13	54	43	11	0.4	4	1.8	7	1.6				65	-2	83	-17		-118	0.0	
	99-01	10	6.8	6.9	12	14	104	123	0.8	0.1	2.4	1.3	0.5	0.6	929	924	112								
Hortert	05	1	x	x	103	-25												128	91	124	86	256	1483	0.0	
	99-01	26	4.9	6.7	106	15	3.5	47	0.2	0.4	57	32	2.8	0.6	818	591	31								
Joller	02-05	8	2.98	3.9	149	76	0	4.2	13	8.5	1.5	2.1	11.4	16.2	204	228	118	73	180	49	87	4520	54286		
	00-01	7	3.08	6.31	207	27	0	35	29	14	2.1	3.1	15.5	0.7	177	207	570								

If the flow rate changes appreciably, then the above parameters do not meaningfully express the behavior. Therefore, acidity removed in mass per year is also calculated:

$$\text{Acidity Removal Rate (kg/yr)} = 0.5256\ Q(A_{in} - A_{out}) \qquad (3)$$

where Q is the flow rate from the system in L/min.

In order to compare the economic performance of the VFP's with other methods of treatment, a simple economic evaluation has been made of the cost for removal of a given mass of acidity. This general approach has previously been used by Ziemkiewicz et al (2002) and Skousen and Ziemkiewicz (2005). The cost of constructing the systems has been estimated using the AMDTreat computer program (Version 3.2) of the US Office of Surface Mining (Means et al., 2004). The length and width of the water surface as listed in Rose and Dietz (2002) and Rose (2004) have been increased by 12 feet to attain the dimensions at the top of the berm, assuming 3 feet of freeboard at a 2:1 slope. These dimensions were then entered into the option for calculating VFP cost from dimensions in AMDTreat. The observed thickness of the limestone and compost was entered from the previous compilations. Clearing and grubbing cost was included. The design flow rate was set at twice the average flow rate. Other inputs were the default values, including \$4.50/yd^3 excavation cost, \$2.50/yd^3 for compost purchase and spreading, and \$12.00/T for limestone. The cost of two 24-hour secondary ponds has been added, as has the default engineering cost of 10% of the capital cost. The total of these items is taken as a standardized estimate of the capital cost of the system.

Systems are assumed to have a life of 20 years. The average rate of acidity removal (metric tons/yr as $CaCO_3$) was calculated from the available data in Rose and Dietz (2002), Rose (2004) and the recent data (Table 1), to the extent that data were available. The cost per metric ton (1000 kg) of acidity removal is then calculated:

$$\text{Cost (\$/T)} = (C_1+C_2)/(t_1*R_1 + (20-t_1)*R_2/1000) \qquad (4)$$

where C_1 (\$) is the construction cost estimated by AMDTreat, C_2 (\$) is a renovation or repair cost estimated by the writer for several systems such as Howe Bridge, t_1 (years) is length of the first period during which removal rate R_1 (kg/yr) was observed, and R_2 is a removal rate either observed in recent years or estimated by the writer and applied to the remaining part of 20 years. Although many refinements can be envisioned, this value is considered to be a useful approximation of the cost of systems.

Results

Data on acidity removal are summarized in Table 1 and illustrated in Fig. 1, 2, and 3. Sixteen sites have adequate data for comparison of the pre-2002 acidity removal rate vs. the 2002-2005 rate in mg/L of acidity. As indicated on Fig. 1 and 2, most of the sites show approximately the same removal in the later period as in the original period, indicating little decrease in effectiveness. Note also that VFP systems do not remove Mn, and that some effluent acidity is due to Mn. In particular, Mn acidity is a major component of effluent acidity at Pot Ridge Test, Howe Bridge, Jennings, and the Oven Run sites.

Five systems of the 15 show marked decrease in acidity removal. The history and characteristics of these less satisfactory systems are now discussed.

The Coldstream A and B systems with influent of 20 to 50 mg/L Al have decreased in acidity removal from about 800 mg/L down to 260 and 350 mg/L. The final effluent at Coldstream A is still net alkaline, but is net acidic at Coldstream B. Despite the large decrease in removal, the current values for removal are still very high, so the systems cannot be considered to have failed. The systems are not overflowing, so they have not plugged. The writer infers that coating of limestone fragments by Al precipitate, as observed at other sites, may be decreasing their effectiveness. This decrease is occurring despite regular flushing. At Coldstream A, the VFP is followed by a wetland and a large limestone bed. The effluent acidity cited in Table 1 is the final effluent from the limestone bed. Limited data shows that the effluent from the VFP unit itself is net acidic, although it was formerly net alkaline. These data indicate that the VFP has definitely lost effectiveness and that appreciable treatment is now transferred to the limestone bed. At Coldstream B, the system consists of two VFP's in series, and the final effluent is now acidic. The long-term trend for the Coldstream systems is not encouraging, but they have been treating well for the past 7 years.

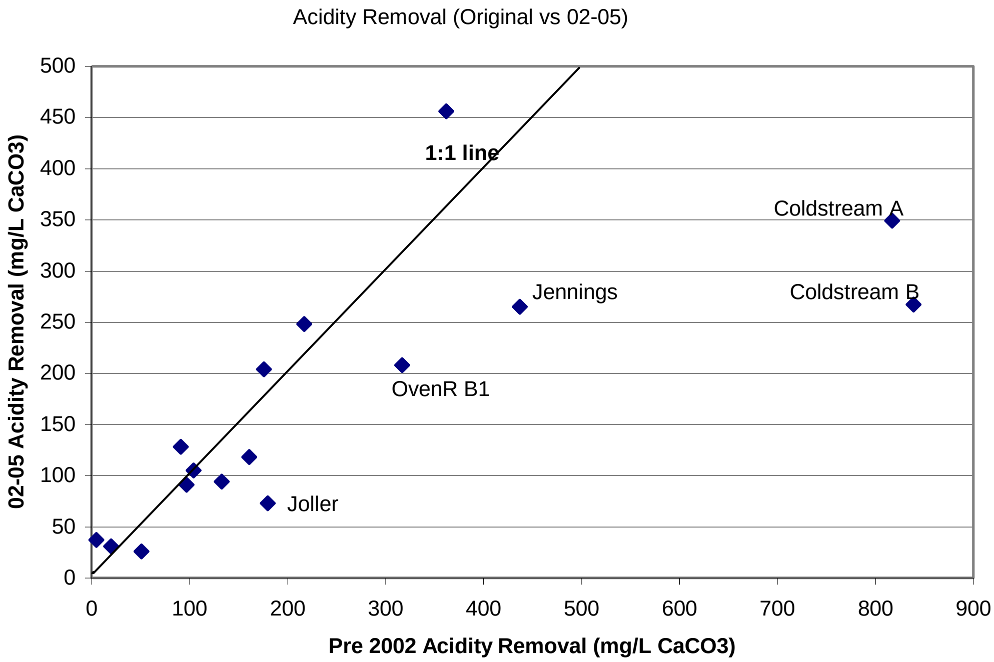

Figure 1. Changes in acidity removal in mg/L at VFP's. Most systems show little change in removal rate between pre-2002 and 2002-2005 periods. The line indicates equality of pre-2002 and more recent performance. Data from Table 1.

The Jennings system, receiving 23 mg/L Al, is constructed with a mix of compost and fine limestone overlying a layer of river gravel containing the underdrain. It can be considered as an early version of a sulfate-reducing bioreactor, though more than 90% of the acidity removal is by limestone dissolution (Watzlaf et al., 2000). By 2004, after 7 years of service, the VFP was extensively overflowing, suggesting plugging. Draining and excavation in summer 2004 showed accumulation of Fe and Al precipitate in the upper compost, and FeS precipitate and

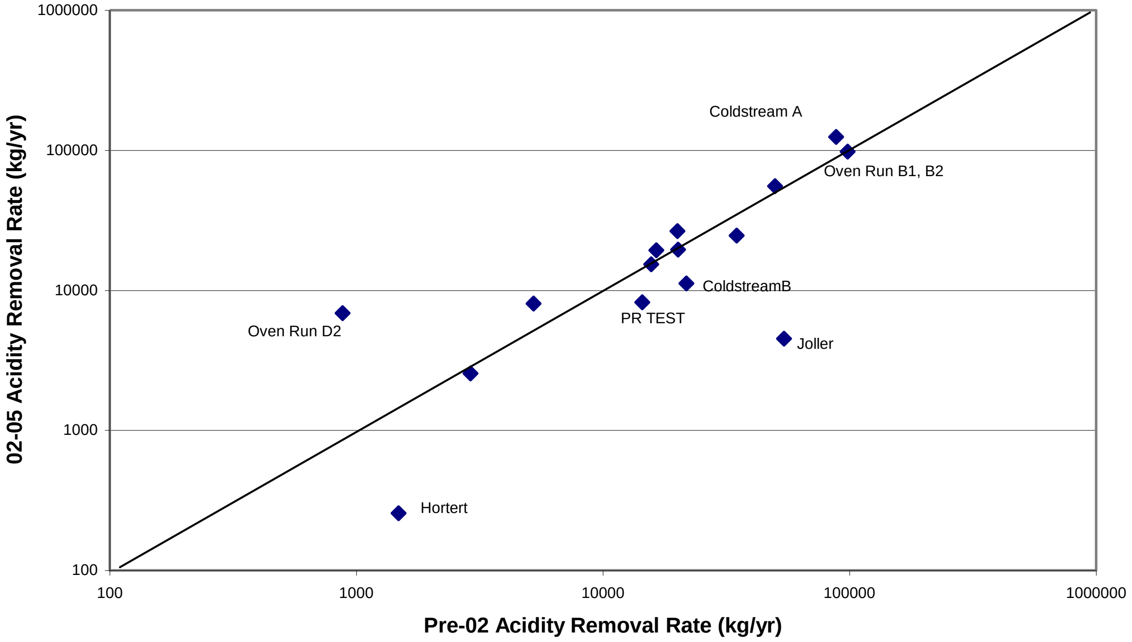

Figure 2. Changes in acidity removal in kg/yr at VFP's. Most systems show little change in removal rate between the pre-2002 and 2002-2005 periods. The line indicates equality of pre-2002 and recent performance. Data from Table 1.

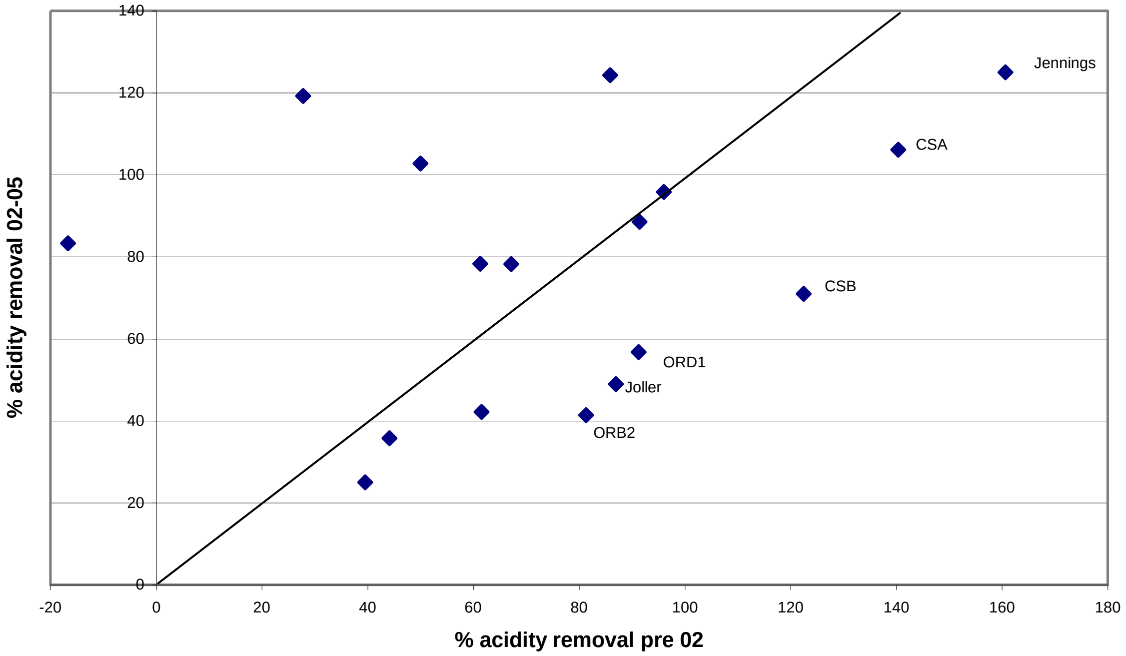

Figure 3. Changes in percent acidity removal from pre-2002 to 2002-2005. The line indicates equality of pre-2002 with recent performance. Data from Table 1.

considerable compaction in the lower compost. After the autopsy, the compost-limestone mixture was thoroughly mixed to restore permeability and the effluent is now alkaline with no overflow. If this performance continues, it suggests a method for restoring bioreactor systems treating elevated Al.

The Oven Run B systems receiving 39 mg/L Al are also experiencing problems, apparently caused by plugging with Al and Fe precipitate, despite flushing. Although Oven Run B1 is still removing reasonable amounts of acidity, it is overflowing considerable water, so the rate of acidity removal in kg/yr has markedly decreased. Because of the deterioration of Oven Run B1, Oven Run B2 receives considerable additional acidity, Fe and Al, and is showing signs of decreasing effectiveness.

Little additional information is currently available on the Joller system.

Figure 2 compares removal rates in kg/yr. This plot indicates that only Oven Run B has markedly declined in mass of acidity removed per year, though a small decrease is observed for Coldstream B, and the recent Coldstream A flow is strongly affected by two measurements more than 10 times the median flow rate. However, the overall pattern is that most systems have not markedly declined in effectiveness. At Oven Run D2, the improved removal apparently results from an increased acidity influent to Oven Run D1, leading to an increased influent acidity to Oven Run D2 and essentially complete removal in this unit.

Figure 3 shows a third comparison, of percent removal of acidity. This parameter can be affected by changes in the inflow acidity and the flow rate, as well as concentration or mass of acidity removed. This diagram shows large decreases in percent removal for the systems discussed above (Coldstream A and B, Jennings, and Oven Run B1). Oven Run D1 also shows a decrease in percent removal. This change appears to reflect a very large increase in influent acidity concentration, which is based on only 4 samples and may be misleading. Most other systems show reasonable consistency in percent removal. Note that many systems operate at much less than 100% removal.

Economic Evaluation

The intent of this economic evaluation is to determine whether VFP's are an efficient use of funds compared to other treatment methods. Ziemkiewicz et al. (2002) and Skousen and Ziemkiewicz (2005) have provided this information for many sites in West Virginia. They suggested comparison with a cost of $500/T for removing acid by active NaOH treatment. This cost was only for the reagent, and included no costs for equipment, ponds and labor. They suggested a cost of 2 or 3 times this when all costs are included. Several calculations by the writer using NaOH in AMDTreat give costs per metric ton of $1000 to $1200 for acidity removal with NaOH. These calculations include the capital cost, a secondary pond, engineering, chemicals, and labor, but not sludge disposal.

The costs per metric ton of acid removed for the sites of this study are listed in Table 2. Costs range from $49 to $3400/T, with a median of about $300/T. Three systems (Somerville, Hortert and Lambert) show costs exceeding $1000/T. Somerville was showing short circuiting when studied by Demchak et al. (2000), and on a recent inspection appeared to be almost completely plugged. Information on Hortert and Lambert is incomplete, but Lambert was apparently not treating, possibly due to lack of maintenance, when visited several years ago. Hortert is still treating, but the influent load is small and is largely Mn.

Several of the systems with costs exceeding $500/T have high influent loads (Oven Run B, Glasgow) and have known problems, indicating that high loads are more challenging to treat. However, Coldstream A has one of the lowest costs despite a high load.

Based on this data, it is concluded that most well designed and maintained VFP systems can treat acid at an effective cost.

Table 2. Cost Evaluation of VFP's. Costs based on AMDTreat program, as described in text, using eq. 4.

System	Const Date	Flow L/min	Acidity in ng/L CaCO3	Period 1	Yrs	Rate 1 kg/yr	% Eff. Per. 2	Rate 2 kg/yr	Cost 1 $	Cost 2 $	Cost/T
Howe Bridge	91	114	323	91-01	11	16470	02-05	19318	38055	12685	143
Pot Ridge TEST	95	76	396	95-00	6	14460	02-05	8197	80935	0	402
Pot Ridge C6	97	217	399	97-00	5	20037	02-05	26484	52704	0	106
Oven Run D1+D2	95	323	114	95-00	7	21028	02-05	26376	116350	0	237
Oven Run E1+E2	97	494	217	98-01	4	40032		32624	339324	0	497
Oven Run B1+B2	99	817	506	00-01	2	2E+05	02-05	45994	776064	77606	660
Jennings	97	68	272	97-01	4	15711	02-05	15349	41717	8343	162
McKinley	96	384	101	96-01	6	2906	02-05	2545	27864	0	525
Sommerville	95	95	390	96-97	2	7540	0	0	42457	0	2815
Hortert	99	30	106	99-01	3	1483	50	741.5	29596	0	1735
Maust 1+2	97	179	154	97-02	6	31645	75	23734	110302	0	211
Rock Run 1+2	99	99	129	99-01	3	2636	75	1977	39081	0	941
Lambert	97?	38	66	00-01	2	3131	0	0	21314	0	3404
Harbison(Ohiopyle) 1	99		205	99-01	3	4416	75	3312	18329	0	264
Coldstream A	98	205	582	99-02	4	88116	02-05	124772	115530	0	49
Coldstream B	98	49	685	99-02	4	21784	02-05	11199	30248	0	114
Glenwhite SQF	99	201	198	99-02	4	12703	20	2540.6	18641	4660	255
Glenwhite SPH	01	399	106	38354	2	64173	50	32087	91199	0	129
Glasgow 1	99	76	1113	99-05	7	14620	20	2924	104834	26209	934
Power	99	380	200	99-05	6	36594	50	18297	207203	0	436
DeSale 1RL	00	103	439	00-05	6	10893	75	8169.8	55510	0	309
DeSale 2RL	00	277	269	00-05	5	47094	75	35321	119068	0	156

Problems at Vertical Flow Ponds

As indicated in the previous discussions and in compilations of data, some VFP systems have “failed” to the extent that they are almost ineffective, and others are treating at a lower rate than intended. Table 3 presents information on the treatment characteristics and problems at 39 VFP’s for which data are available to the writer. Of these, 20 are treating without significant problems. Two (Howe Bridge, Jennings) had problems with overflow and plugging, but have been rebuilt at low cost and are treating satisfactorily. Six are accomplishing little or no treatment (Filson 1, Pot Ridge A, Lambert, Tangascootack 1, Minersville and Sommerville). At several (Oven Run B1, Pot Ridge C6 and C10, Coldstream A and B, Glenwhite SQF, Glasgow 2, Middle Branch), treatment is markedly decreased, as noted in the previous discussions, but considerable treatment is still occurring (or could occur at Middle Branch if it was re-assembled after an autopsy).

Table 3. Problems at vertical flow ponds as evaluated for this paper.

Name	Built	County	Source of data	Problems
Howe Bridge	91	Clarion	Dm,W,M,R	Fe plugging, rebuilt 2002
Filson 1	94	Clarion	Dm, M	Overflow, Fe plugging
McKinley	96	Clarion	Dm, M	OK
Sommerville	95	Clearfield	Dm,R	Short circuiting, plugging
Pot Ridge Test	95	Cambria	R	Inflow decrease, but treatment OK
Pot Ridge C6	97	Cambria	R	Overflow (Al plugging?)
Pot Ridge C10	97	Cambria	R	Overflow (Al plugging?)
Pot Ridge A	97	Cambria	R	Overflow (Fe and Al plugging)
Oven Run B1	99	Somerset	B	Overflow (Fe plugging?)
Oven Run B2	99	Somerset	B	OK?
Oven Run D1	95	Somerset	B, Se,R	OK
Oven Run D2	95	Somerset	B, Se,R	OK
Oven Run E1	97	Somerset	B, W,Se,R	OK
Oven Run E2	97	Somerset	B, W,Se,R	OK
Jennings	97	Butler	S, W	Overflow (compaction), Rebuilt
DeSale 1	00	Butler	S, R	OK
DeSale 2	01	Butler	S, R	OK
Ohiopyle	99	Fayette	S	OK
Hortert	99	Butler	B, R	Oversized?
Maust 1	97	Somerset	DE,Me	OK
Maust 2	97	Somerset	DE,Me	OK
Lambert	97?	Somerset	DE,Me	Abandoned?
Rock Run 1	99	OH	O	OK
Rock Run 2	99	OH	O	OK
Coldstream A	98	Centre	B, R	Decreased performance (Al coating?)
Coldstream B	98	Centre	B, R	Decreased performance (Al coating?)
Tangascootack 1	98	Clinton	DE, R	Inadequate size and relief
Tangascootack 2	99	Clinton	DE	OK
Tangascootack 3	00	Clinton	DE	OK
Glenwhite SQF	99	Blair	B	Fe plugging (no compost)
Glenwhite SPH	01	Blair	B	OK
Glasgow 1	99	Cambria	R	OK
Glasgow 2	99	Cambria	R	Al plugging?
Dysart	01?	Cambria	R	OK
Power	99?	Clearfield	R	OK
Minersville	02	Huntingdon	DE, Me	Short circuiting
Northpoint	98	Bedford	N, R	Leakage
Middle Branch	01	Clinton	DE, T	Inadequate size, short circuiting
Bellwood	01	Blair	B	OK

B= PA Bur Aband. Mine Recl., DE= PA Dept. of Envir. Prot., Dm=Demchak, M=Mill Cr. Coalition,
Me= Brent Means (OSM), N= Northpoint, O= OH Det. Nat. Res., R= Rose,
S= Stream Restoration (Dunn), Se=Seibert (NRCS), T= Trout Unlimited, W= Watzlaf

Major problems recognized by the writer are as follows:

1. Plugging by Fe oxide precipitate on top of the compost. This problem occurs with high-Fe inflows, and was the major problem at Howe Bridge and Pot Ridge A. For some sites, additional oxidation-settling ponds preceding the VFP can minimize this problem. At others, it may be necessary to remove the Fe precipitate periodically, as has been done at Howe Bridge.
2. Plugging of the limestone layer with Al precipitate, and/or decreased neutralization because of coating of limestone with Al precipitate. This problem appears to be major at Glasgow 2, Pot Ridge C6 and C10, and is decreasing the effectiveness of Coldstream A and B. The latter sites have been flushed regularly but still show decreasing performance, suggesting that flushing does not necessarily solve this problem. Rose (2002) showed data suggesting that significant Al problems occur only at influent Al concentrations exceeding about 20 mg/L.

Possible solutions for discharges with higher Al are bioreactors or automatic flushing systems (Gusek, 2004; Weaver et al., 2004).

3. Short circuiting through the compost and limestone into the underdrain. This problem was observed at Middle Branch, where compost had shrunk away from cleanout pipes connected to the underdrain, allowing rapid flow from open water into the underdrain. The same problem appears to occur at Minersville. Sommerville was observed to have zones of more rapid flow through the compost layer (Demchak et al., 2000). This problem can be avoided by proper design and construction of systems.
4. Inadequate size. Most existing systems were sized based on 15 hour retention time in the limestone, but at some localities this is inadequate based on an apparent limit for acidity treatment of 35 to 40 $g/m^2/d$ (Rose, 2004). Tangascootack 1 and Middle Branch were overloaded by this criterion, and only part of the acidity was being treated. Similar conclusions apply to the Pot Ridge and other systems. At some sites, such as Middle Branch, the undersizing resulted from inadequate preconstruction flow and chemical data.

Conclusions

Information on 40 representative vertical flow ponds has been compiled. About half the systems studied are more than 7 years old, with a maximum of 14 years at Howe Bridge. For 15 systems, recent chemical and flow data supplement earlier information and allow examination of trends in performance with time.

The data indicate that about half of VFP's are performing entirely satisfactorily, and another 30% are performing usefully, though several are declining in performance. Six systems (15%) have essentially ceased to treat, but most of these systems exhibit problems in design or construction that would not be expected in a currently constructed system. The main group of systems shows no obvious decline in acidity removal with time. Several systems that encountered problems have been modified or rebuilt for relatively low cost and are restored to satisfactory treatment.

An economic evaluation of 23 systems shows that 3 systems (13%) have estimated costs for acidity removal exceeding the approximately $1000/T cost of an active treatment system using NaOH. The median removal cost of the 23 VFP's is $300/T of acid (as $CaCO_3$). Several systems have costs less than $200/T. The economic evaluation shows that vertical flow ponds can be economic for treating most net acid discharges.

Major problems identified include (1) plugging by accumulation of Fe precipitate on top of compost, (2) plugging and declining performance owing to Al precipitation in the limestone layer, (3) short circuiting due to design features or inadequate compost, and (4) inadequate size to treat the acidity load. Except for problems from Al precipitation, these difficulties can be largely surmounted with proper design and construction, or by relatively low-cost maintenance or renovation. Bioreactors or automatic flushing systems may provide a solution for elevated Al.

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