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RESEARCH TO DEVELOP ENGINEERING GUIDELINES FOR THE IMPLEMENTATION OF CONSTRUCTED WETLANDS FOR WASTEWATER TREATMENT IN SOUTHERN AFRICA

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INTRODUCTION

In recent years, increasing production and disposal of wastewaters have caused accelerated eutrophication of many of South Africa's impoundments,(1,2,3) which has necessitated the imposition of stringent effluent nutrient discharge standards.

African conditions, however, seriously constrain the ability particularly of rural communities, to reliably achieve required discharge standards. If waste-water treatment is practised at all, it is likely to be pit latrines, septic tanks, oxidation ponds or biological trickling filters; systems designed to meet basic discharge standards rather than high level nutrient polishing and solids removal. Unfortunately, water scarcity for effluent dilution or post-treatment, means that these effluents can significantly contribute to the eutrophication of downstream impoundments.

Natural wetlands form an important barrier against non-point source discharges of most heavily industrialised areas of South Africa(4). Research is now underway at a number of locations to evaluate the potential for constructed wetlands in wastewater treatment, as simple, low cost, low technology approach to address the problems(5,6).

This paper reports current research designed to provide engineering data on the biological and physiogeo-chemical constraints of the constructed wetland concept.

EXPERIMENTAL INVESTIGATIONS

Division of Water Technology, CSIR

The Division of Water Technology (DWT) of the Council for Scientific and Industrial Research initiated a Constructed Wetland research programme in late 1985. Recognising the inherent cautious nature of design engineers to unproven technologies, a consulting engineering company, Stewart Sviridov & Oliver is working with the DWT to establish guidelines for constructed wetland design implementation.

Research is underway in a series of laboratory, bench and pilot-scale facilities, under the advice and guidance of a co-ordinating committee comprising scientific, industrial and consulting personnel interested or active in the field.

Pilot Studies 1st Stage

Studies investigating the controlling factors responsible for the efficient operation and design of wetland systems, include the substrata reponsible for most nutrient removal and hydraulic capacity of the system; the macrophyte species responsible for aeration and enhancing permeability; and the effluent characteristics, loading rates and retention times in the operational regime.

Substrate types are evaluated for permeability (K_f) and nutrient removal capacity under controlled conditions with desired effluent types. For example, seven soil types demonstrated K_f values of 0.71 to 45.4 cm/d for stabilization pond effluent, compared with 23.2-239.9 cm/d for stabilization pond effluent that had passed through a rough ash filter.

Settled sewage caused surface blockages of hydraulic cells leading to impermeability problems. In the field, microbiological activity and rhizosphere structure should degrade this layer and promote permeability. For effluents with higher organic or solids concentrations, coarser substrata, higher hydraulic heads or lower loading rates are required to achieve adequate passage through the bed.

Phosphate uptake capacity of the soils studied ranged from 4.04 x 10^{-3} ug/g to 896.5 ug/g with waste power station ash at 54.91 ug/g. This range was related to soil clay content as well as the metals Fe, Al, Ca, Mg and organic matter, and was inversely related to hydraulic permeability.

Evaluating a local soil or media type will require a balance between permeability and desired nutrient removal. Waste power-station ash is a promising substrata as it combines high permeability with a degree of phosphate removal associated with the high salt concentrations and alkalinity.

Potential plant species have been established in simple pot reactors containing waste ash as substrata and receiving oxidation pond effluent or settled sewage over a 12 month period. Table 1 indicates the effluent treatment efficiency of each system.

Each of the plant species utilized demonstrated rapid development of both above and below ground structure, and occupation of the available space in the pots. At a loading rate of stabilization pond effluent at 8.4 cm/d and settled sewage at 2.8 cm/d, effluent discharge consents were within general standards, and close to special discharge consents of 1 mg/l PO_4-P.

The low effluent concentrations masks any significant difference between species under the loading conditions, which would suggest that any of the species could be appropriate. However, in other studies it has been found that the grass Pennisetum clandestionum, frequently cultivated as a lawn material, and the Arundo donax do not readily produce subsurface rhizome proliferation, and are hence restricted in their capacity to oxygenate the wetland system. The occurrence of nitrification and denitrification is evidence of the simultaneous presence of aerobic and anoxic zones within the bed, whilst the significant removal of phosphate is a response to the salt and alkalinity associated with the waste ash, resulting in pH levels as high as pH 11 initially. The macrophytes did not appear to be detrimentally affected by the high pH and positively benefit from the presence of micronutrients.

Twelve pilot-scale reactors, each of 4 m^2 surface area have also been constructed to investigate the systems operational regimes and effects on wastewater treatment potential. These studies compare two macrophytes: P. australis and Scirpus; three effluents: stabilization pond ash filtered stabilization pond, and septic tank; and two substrata, soil or ash.

As with the pot studies, the low effluent pollutant concentrations of each system masks significant differences between species or conditions, although low ammonia and COD levels of the Scirpus tend to suggest a superior oxygenation capacity of this plant. This may, however, to some extent be a result of a more rapid establishment of this species than Phragmites, and will require long term operation to evaluate true efficiency. Again nitrification and denitrification has been accomplished, whilst phosphate levels with soil and ash substrate generally remain within special discharge consent. Relatively high suspended solids levels is a result of carryover of soil and ash particles into the effluent and is not thought to pose a serious pollutant threat to the receiving waters.

Reactors were planted in May 1987 and have established a viable macrophyte stand. Early after planting, Phragmites was almost destroyed by aphids, requiring insecticide (Malasol) treatment. Scirpus was ignored by aphids and maintained a dense, actively growing stand. However, heavy rainfalls and wind have blown over Scirpus necessitating stem cutting to allow new growth. Scirpus died back in early winter (April) while Phragmites remained green and upright indicating a .pa greater temperature tolerance. Table 2 provides effluent levels from the systems after a year of operation.

Pilot Studies - 2nd Stage

A former fish dam 5 m x 5 m x 1 m deep was lined with hyperplastic membrane (Carbofol 500 um) protected by a 50 mm sand layer prior to filling with coarse gravel (19 mm), planted with local Arundo donax receiving septic sewage at 10 cm/m²/d. Arundo fully occupied the bed within four months and the system was operated for one full season. Although suspended solids (90%) and COD (65%) were significantly reduced to 34 and 95 mg/l respectively, these did not meet the effluent discharge standards of 20 and 75 mg/l respectively, whilst only 18% ammonia and 7% phosphate removal was achieved. Local Scirpus and Phragmites were planted and the influent changed to raw sewage. Close to total occupancy of bed space was achieved within six months and effluent quality has improved with 73% COD removal to 68 mg/l and 38% ammonia reduction to 22.7 mg/l . Suspended solids and P were uneffected. The influent is now supplemented with molasses to simulate high COD loadings associated with rural communities, and effluent quality is remaining close to or below COD discharge consent as the plant community fully develops.

Two other lined dams have been converted into wetlands in upgrading studies of twelve small-scale units. One system with waste power-station ash is planted with Phragmites and loaded with raw sewage. Effluent flows over into a Phragmites bed with a local soil covered in a layer of coarse ash. The first bed is designed for primary treatment of solids and carbonaceous removal and the second bed is designed for removal of P and N from 10 cm/m²/d of raw domestic sewage. The first six months of operation have achieved consent meeting effluent qualities except for ammonia which remains higher due to the low initial oxygenation capacity of the plants.

Combined Artificial Wetland, High Rate Algal Pond Studies

The system consists of two units, each 22 m x 11 m and 40 cm deep. Septic sewage is loaded to the wetland at a rate of 13.5 cm/d. Effluent from the bed is pumped from the sump into the algal pond.

The coarse gravel bed, was planted with Arundo donax and two 2 m bands of Typha sp. A. donax resembles P. australis yet has a more vigorous growth which makes it potentially more efficient at oxygen transfer to the rhizosphere. Two bands of Typha sp. were included as denitrification zones, since they are reported to be less efficient at oxygenating the rhizophere, and anoxic conditions would prevail.(5)

Effluent COD levels over a year period were reduced 59.2%, NH_4-N 34.5%, PO_4-P 31.9% and suspended solids 78% (Table 3). Inability to achieve total organics removal and nitrification results from the high loading rate, short circuiting and inability of macrophytes to meet oxygen demands. Arundo roots extended down to 30 cm, whilst the root structure was black, indicating reducing conditions round the rhizomes. Subsequently, Typha, Phragmites and Scirpus were planted and the influent introduced along the sides. Typha has occupied much of the bed while Scirpus and Phragmites have taken longer to become established with unoccupied space present in the Phragmites zone after nine months. Present discharge quality from the wetland is 78 mg/l COD, 28 mg/l SS, 16 mg/l NH_4-N, 0.2 mg/l NO_3-N and 5.6 mg/l PO_4-P.

Mpophomeni Sewage Works

Mpophomeni, a Kwazulu town on the eastern shore of a sensitive P limited impoundment, has a biofilter sewage works with an artificial reed bed for polishing final effluent. Surface area of the reed bed is 2 500 m^2, by 1.5 m deep with a maximum design loading of 20 cm/m^2/d. Lined with a hyperplastic membrane with a bottom drainage level of crushed gravel and a geotextile filter layer, the bed consists of acidic soil (Doveton series) of high P fixing capacity and Phragmites.

Inconsistent loading rates (5 - 23.5 cm/m^2/d) have led to some inability to assess the performance although the reed bed has a marked effect on the quality of effluent (Table 5). Effluent concentrations except E. coli, comply with the General Standards requirements. Reduction in physico/ chemical constituents are between 20% (for conductivity) and 88% (for orthophosphate). Good nitrification and denitrification is performed with associated alkalinity increase.

The system was taken off line twice due to poor bed permeability. Core sample analyses have shown that 85% of total root development occurred in the 0-60 cm region, probably due to the high water table. Lack of subsurface root development has seriously reduced expected permeability improvement, whilst decay of plant biomass and effluent suspended solid appears to be sealing the surface in this vertical flow application.

On-site infitrometer studies are presently evaluating the benefits of increasing the calcium content of the soil with gypsum to enhance permeability(9).

Grootvlei Power Station, Transvaal

Trial systems at Grootvlei are also designed to remove nutrients and pathogens from a biofilter plant effluent. A horizontal flow, stone media stage is divided into a zone planted with *Scirpus* to nitrify, a zone with mulched plant material for denitrification, and stone media with *Typha* in the third zone. The second stage is a vertical flow, soil bed planted in *Scirpus* with a gravel underdrain for nutrient polishing.

At a loading rate of 7.5 cm/m^2/d, mean effluent parameters were 1.9 mg/l Total N, 0.8 mg/l PO_4P, 19 mg/l COD, 10.8 mg/l suspended solids and 2 x 10^4 Feacal coliforms/100 ml. Influent level reductions were 79% - Total N, 86% - PO_4P, 67% - COD and 99.9% - Faecal coliforms.

Olifantsvlei Sewage Works, Johannesburg

A system at Olifantsvlei sewage works near Johannesburg is intermediate between natural wetlands and wetlands constructed with gravel or soil. Three units are geotextile lined, 120 m x 20 m and 2 m deep. Two beds were filled with peat from an adjacent natural system, while the third has a woven rope net supporting the peat mass above the channel bottom. Each bed is dominated by *Phragmites* and receives approximately 50 cm/m^2/d secondary effluent.

The units have run intermittently for three years and available data indicates significant nitrification, denitrification, suspended solids and pathogen removal, though phosphate removal is limited due to the lack of suitable binding to the peat, and problems with surface rather than subsurface flow through the peat.

Additional Studies

1. Reed beds have been established in two rural areas of Gazankulu, At Giyani, population 90 000, outflow from biological seeping beds is channelled to reed beds where retention time is four days. Seven beds are alternately isolated and drained down 10 cm for one day to destroy mosquito eggs. Harvested reeds are used in basket weaving, a traditional industry of the area. A similar system has been constructed at Nknowankowa.

2. A horizontal flow pilot unit 100 m x 20 m filled with waste coarse ash and planted with Typha at the inlet, Phragmites at the effluent end is treating petrochemical effluents at a design loading of 5 cm/d. Coarse ash neutralizes acidic effluent, filters oil and petrochemical residues and provides high permeability.

3. Another pilot facility has been constructed to treat secondary effluent. Two units, one filled with waste ash and one gravel and local fine sand, are planted with Phragmites, and receive maturation pond effluent at a design loading of 20 cm/d.

4. A vertical flow pilot-scale unit to be constructed in the near future for secondary effluent treatment is likely to be a combination of waste mining slime for its high phosphate uptake, and local soils of medium phosphate uptake but improved permeability characteristics. A gravel, or coarse stone system will be designed principally for suspended solids removal and nitrification, prior to final discharge to a nature reserve ecosystem.

Construction of several full-scale wetlands are also planned as total treatment processes or integrated into pond or conventional systems and in Zimbabwe, water hyacinth (Eichornia crassipes) will be investigated.

CONCLUSION

Constructed wetlands have considerable potential in Southern Africa for treatment of raw wastewaters emanating from rural communities, for upgrading oxidation pond and secondary effluents to general and special discharge standards and for .pa
treatment of industrial effluents. The paper has been a brief synopsis of a variety of experimental work under way in Southern Africa to evaluate such systems for various applications.

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Table 1. Nutrient levels in the Effluent and Removal Efficiencies for Macrophyte Species Receiving Stabilization Pond Effluent or Settled Sewage at 8.4 cm/d and 2.8 cm/d respectively.

Pot	Species	Eff	COD		PO_4		NH_4N		NO_3N	
			mg/l	%Rem	mg/l	%Rem	mg/l	%Rem	mg/l	%Rem
1	T	SPE	16.3	54	0.77	51	0.54	61	1.3	70
2	S	SPE	17.1	51	0.77	54	0.36	74	0.7	84
3	C	SPE	17.1	51	0.71	51	0.35	74	0.3	93
4	K	SPE	13.36	62	1.06	32	0.38	72	0.25	94
5	S	SPE	23.1	34	0.4	74	0.35	74	0.5	89
6	P	SPE	16.19	54	0.84	46	0.33	76	0.77	82
7	A	SPE	23	35	0.3	81	0.45	67	0.37	92
8	T	SS_1	19.96	94	0.63	92	1.24	94	0.46	40
9	S	SS_1	21.07	93	0.99	88	0.73	97	0.35	54
10	C	SS_1	16.8	95	0.96	88	0.74	97	0.98	-27
11	K	SS_1	15.48	95	1.36	83	0.63	97	0.36	53
12	S	SS_1	16.16	95	1.48	82	0.89	96	0.43	44
13	P	SS_1	16.3	95	1.1	86	1.45	93	0.27	65
14	A	SS_1	24.9	92	0.47	94	1.25	94	0.45	41

Table 2. Effluent Results for the Pilot Reactors Receiving 20 cm/d of Influent during 12 month period

Species	Strata	Influent	COD mg/l	PO_4P mg/l	NH_4N mg/l	NO_3N mg/l	Suspended Solids mg/l
	Soil	FSPE	42	0.3	3.4	0.9	16.0
S	Soil	FSPE	35	0.4	1.9	0.9	15.2
P	Soil	FSPE	29	0.2	2.3	0.7	18.4
S	Soil	SPE	34	0.3	1.5	1.2	28.8
P	Soil	SPE	37	0.6	2.1	1.7	21.6
P	Soil	SPE	30	0.2	3.9	1.2	31.6
P	Ash	SPE	27	0.4	4.6	2.1	4.8
S	Ash	SS_2	21	0.6	9.4	0.7	14.4
	Ash	SS_2	31	0.7	27.5	0.4	4.8
P**	Ash	SS_2	29	1.7	32.5	0.4	11.2
P	Soil	SS_2	39	0.3	9.3	0.5	27.2
P*	Soil	SS_2	47	0.2	11.4	0.4	25.6

* Reactor receiving effluent from reactor marked**

Mean Influent Characteristics:
FSPE - COD-75 mg/l, PO_4P-4.4 mg/l, NH_4N-11.2 mg/l, NO_3N-3.1 mg/l
SPE - COD-116 mg/l, PO_4P-4.5 mg/l, NH_4N-120 mg/l, NO_3N-3.4 mg/l
SS - COD-166 mg/l, PO_4P-7.6 mg/l, NH_4N-42,4 mg/l, NO_3N-0.9 mg/l

Species
S - Schoenoplectus lacustris
P - Phragmites australis
K - Pennisetum clandestinum
C - Cyperus platycaulis
T - Typha capensis

Influents
FSPE - Ash Filtered Stabilisation Pond Effluent
SPE - Stabilisation Pond Effluent
SS_2 - Septic Sewage

Table 3. Pollutant Level Removal Through the Combined Systems

Parameter	Influent mg/l	After Artificial Wetland mg/l	After Artificial Wetland % Removal	After Algal Pond mg/l	After Algal Pond % Removal	Cumulative % removal
NH_4-N	40	26	34	6	47	82
PO_4-P	8	5	31	4	32	54
NO_3-N	0	2	-	13	-	-
COD	223	91	59	46	49	79
SS	186	41	77	105	-	-

Combining NH_4-N and NO_3-N Total % removal of influent NH_4-N = 49%

Table 4. Comparison of Reed Bed Influent, Effluent and General Standard Regulations. Mpophomeni.

Determinand	General Standard	Reed Bed Influent Mean	Reed Bed Influent Max	Reed Bed Influent Min	Reed Bed Effluent Mean	Reed Bed Effluent Max	Reed Bed Effluent Min	% Removal
pH (pH units)	5.5-9.5		8.5	6.1		7.9	5.3	
Alkalinity as $CaCO_3$		43.2	92.7	4.7	86.1	160.7	25.3	-99.3
Conductivity as mS/m	75 above intake	59.8	92.6	30.2	46.8	63.2	17.3	20.1
NO_3 as N		46	109.6	3.9	15.1	54.2	0.34	67.1
NH_3 as N	10	2.8	18	0.01	1.2	3.62	0.01	57.1
PO_4 as P	1	7.0	13.5	-	0.87	6.5	0.3	87.7
SS	25	39.1	220	4	13.7	54.6	4	65.0
TOC		11.6	27.6	1.9	5.4	9.8	2.2	53.4
COD	75	64.1	168	8	22.5	54.5	8	54.9
PV	13	10.5	-	-	5.0	-	-	75.9
Coliforms/100 ml		$5.6x10^5$	$18x10^5$	$1x10^4$	$5.5x10^4$	$10x10^5$	Nil	90.1
E.Coli/100 ml	Nil/100 ml	$1.6x10^5$	$6x10^5$	$1x10^3$	$3.4x10^4$	$5x10^4$	Nil	97.9
F.Strep/100 ml		$3.7x10^4$	$4x10^5$	Nil	$1.3x10^3$	$2.7x10^4$	Nil	96.5

All concentrations are in mg/l unless otherwise indicated.

REFERENCES

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1. Alexander, W V. "The Potential of Artificial Reedbeds for the Treatment of Wastewaters in Southern Africa. Paper presented at Seminar Technol Transfer Water Supply & Sanitation in Developing Areas, 12-15 February 1985.

2. Wood, A and M Rowley. "Artificial Wetlands for Wastewater Treatment". Paper presented at Symposium Ecology and Conservation of Wetlands in South Africa, 15/16 Oct 1987 CSIR South Africa.

3. Zohary, T. "Hyperscums of the Cyanobacterium <u>Microcystis aeruginosa</u> in a Hypertrophic Lake". <u>J Planton Res</u> 7, p.399-409 (1985).

4. Viljoen, F C. "An Input Output Study of Various Physical and Chemical Constituents in Water After Passage Through a Section of the Natalspruit Wetland". Paper presented IWPC Biennial Conference, Port Elizabeth, South Africa 12-15 May 1987.

5. Alexander, W V and A Wood. "Experimental Investigations into the use of Emergent Plants to Treat Sewage in South Africa". Paper presented at Symposium Macrophytes in Wastewater Treatment, IWPC, Piracicaba, Brazil, August, 1986.

6. Wood, A, J Scheepers, M Hills, and M Rowley. "Combined Artificial Wetland and High Rate Pond for Wastewater Treatment and Protein Production" (1987).

7. Furness, H D, K J Healey, D A Kerdachi, and W N Richards. "The Performance of an Artificial Wetland for the Treatment of Biological Filter Effluent". Paper presented at Symposium Ecology and Conservation of Wetlands in South Africa, 15/16 Oct 1987 CSIR 1987 South Africa.