Technical note

A cooling water system as a biofilm reactor for the treatment of municipal wastewater

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Abstract

In this study, a water cooling tower was used as a low-rate biofilm reactor for treating municipal wastewater. The performance of the system was evaluated at three different flow rates ($5\ \ell\cdot s^{-1}$, $2\ \ell\cdot s^{-1}$ and $1.6\ \ell\cdot s^{-1}$). The biofilm reactor gave the best results at a flow rate of $1.6\ \ell\cdot s^{-1}$, namely: 43.3% nitrogen removal, 42.3% chemical oxygen demand (COD) removal, 1.7% phosphorus removal and 39.8% suspended solids (SS) removal. These results were achieved with a once-through flow and low organic ($19\ g\ COD\cdot m^{-2}\cdot d^{-1}$) and hydraulic loads ($0.173\ m^3\cdot m^{-2}\cdot d^{-1}$). This type of biofilter system is being used in West Malaysia to treat municipal effluents. Our system performance, at a flow rate of $1.6\ \ell\cdot s^{-1}$ was capable of treating municipal wastewater to meet general effluent standards in South Africa (*Government Gazette*, 1984). This is sufficient for treating effluent for a population equivalent of 2 800 people.

Nomenclature

	Symbol	Description	Unit
a)	T	temperature	C
	pH	pH value	-
	TKN	total Kjeldahl nitrogen	$mg\ N\cdot\ell^{-1}$
	NH_4-N	ammonia nitrogen	$mg\cdot\ell^{-1}$
	NO_3-N	nitrate nitrogen	$mg\cdot\ell^{-1}$
	TP	total phosphorus	$mg\cdot\ell^{-1}$
	PO_4-P	orthophosphate	$mg\cdot\ell^{-1}$
	SS	suspended solids	$mg\cdot\ell^{-1}$
	-	settleable solids	$m\ell\cdot\ell^{-1}$
	HRT	hydraulic residence time	min
	-	alkalinity	$mg\ CaCO_3\cdot\ell^{-1}$
	COD	chemical oxygen demand	$mg\cdot\ell^{-1}$
b)	N	nitrogen	$mg\cdot\ell^{-1}$
	TDS	total dissolved solids	$mg\cdot\ell^{-1}$
	-	conductivity	$mS\cdot m^{-1}$

Introduction

Water is a valuable resource that needs to be conserved, especially in a country like South Africa which is in a semi-arid region (Schutte and Pretorius, 1997). Population growth and industrial development demand increasing water supplies which emphasises the importance of wastewater treatment (Tebbutt, 1977).

A suitable wastewater treatment method should be economical, effective and reliable. One such a system is the activated sludge process, used mainly for large-scale treatment of municipal effluents. This system is based on the suspended growth of bacteria (Gray, 1989). Although effective, activated sludge treatment systems have some disadvantages, such as: long sludge age, vast quantities of sludge production and high energy consumption. For smaller populations, trickling filters (fixed film reactors), are often used offering advantages such as: effective land utilisation, low initial capital outlay, low operation and maintenance costs, no specialised mechanical equipment, non-clogging configuration, efficient BOD reduction and an aesthetic advantage over conventional systems (Gray, 1989; Characklis and Marshall, 1990; Le Tallec et al., 1997).

Many different types of fixed film reactors are currently in use (Muyima et al., 1997). One such a system is a modified cooling tower biofilm reactor (P.E. Biofilter System[1]) used for the treatment of sewage of small communities (650 to 4 757 people) in Malaysia. This type of system has not yet been used in South Africa and very few data are available in the literature on the effectivity of this type of system. The objective of our study was therefore to determine the effectivity of a cooling water system used as a biofilm reactor, to treat municipal wastewater.

Materials and methods

Biofilm reactor

A conventional cooling water system (SULZER, EWK Range, Type 661/09) was used as a biofilm reactor (Fig. 1). This system provided a fill surface area of approximately 800 m^2 and a sump volume of 2.5 m^3. The fill material was corrugated at a 60° angle and assembled in a cross-corrugated pattern with adjacent sheets (Fig. 2). The system was operated with the fans in the "off" position.

Feed and inoculum

Primary settled sewage from Daspoort Water Care, Pretoria, South Africa, was used to feed the biofilm reactor. The natural bacterial community was allowed to develop and form biofilms in the reactor. A start-up period of 3 d was allowed before monitoring started.

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Type	Motor	Weight		A	B	C	D	E	F	G	Inlet H	Outlet J	Drain K	O/Flow L	Make-up M
EWK	kW	Oper kg	Nett kg	mm	mm	mm	mm	mm	mm	mm	NB	NB	NB	NB	NB
661/09	5,5	4 280	1 040	3 510	2 480	170	2 110	3 160	2 002	3 052	150	200	50	40	25
	7,5			3 600							D	D	M	M	M

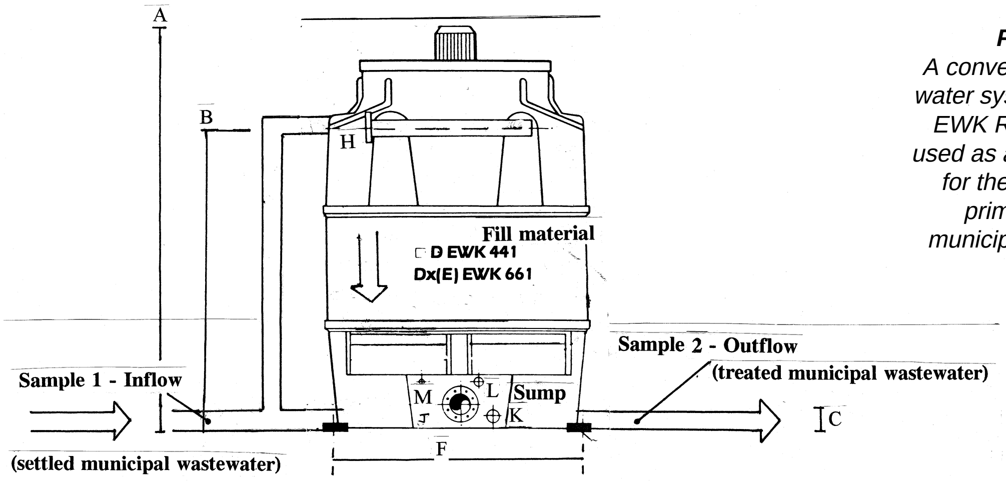

Figure 1
A conventional cooling water system (SULZER, EWK Range 661/09) used as a biofilm reactor for the treatment of primary settled municipal wastewater

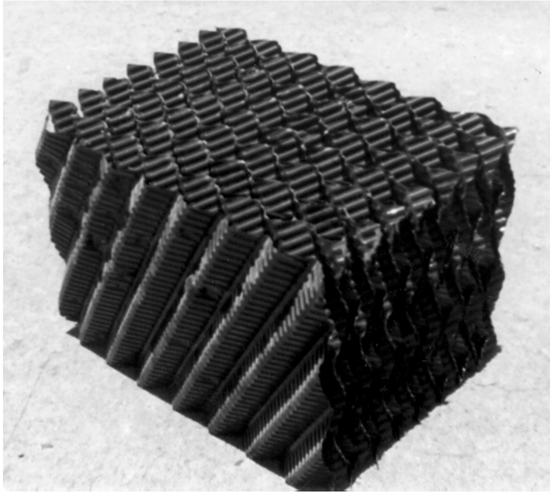

Figure 2
Fill material of the biofilter for municipal wastewater treatment

Hydraulic load, flow rate and sampling

The biofilm reactor was operated at different wastewater flow regimes which resulted in different hydraulic loads (Table 1). The system was shut down and cleaned, before changing the flow regime. Samples were taken two to three times a week for chemical and physical analysis (Fig. 1). Although recirculation took place, sampling at the inflow and bottom of the fill material (before entering into the sump) simulated a once-through mode of operation. The HRT was calculated for the total system, including the sump volume. The latter was, however, not taken into consideration when calculating the efficiency of the system due to the method of sampling (before and after the fill material).

Chemical and physical analyses

The following chemical and physical analyses were conducted according to *Standard Methods* (1976): COD, NH_4-N, NO_3-N, PO_4-P, TP, SS, settleable solids, TDS, TKN, alkalinity, conductivity and pH.

TABLE 1
AVERAGE HYDRAULIC AND ORGANIC LOADINGS IN THE BIOFILM REACTOR USED FOR THE TREATMENT OF MUNICIPAL WASTEWATER

Parameters	Operation Period I	Operation Period II	Operation Period III
Flow rate	5 $\ell \cdot s^{-1}$	2 $\ell \cdot s^{-1}$	1.6 $\ell \cdot s^{-1}$
Hydraulic loading	0.54 $m^3 \cdot m^{-2} \cdot d^{-1}$	0.216 $m^3 \cdot m^{-2} \cdot d^{-1}$	0.173 $m^3 \cdot m^{-2} \cdot d^{-1}$
Organic loading	52.9 $g \cdot m^{-2} \cdot d^{-1}$ COD	27.5 $g \cdot m^{-2} \cdot d^{-1}$ COD	19.0 $g \cdot m^{-2} \cdot d^{-1}$ COD
*HRT (hydraulic retention time)	8 min 20 s	20 min 50 s	26 min 2 s

$$\text{*HRT} = \frac{\text{sump volume}}{\text{flow rate}}$$

TABLE 2
AVERAGE IN- AND OUTFLOW CONCENTRATIONS OF CHEMICAL PARAMETERS OF THE BIOFILM REACTOR USED FOR MUNICIPAL WASTEWATER TREATMENT

Parameters (mg·ℓ^{-1})	Operation period I (5 ℓ·s^{-1})	Operation period II (2 ℓ·s^{-1})	Operation period III (1.6 ℓ·s^{-1})	General standard (mg·ℓ^{-1}) (*Government Gazette*, 1984)	Special standard (mg·ℓ^{-1}) *(Government Gazette*, 1984)
COD (filtered)					
- inflow	97.95	127.26	109.47		
- outflow	70.48	88.21	63.19	75.0	30.0
- removed	27.55	39.05	46.28		
COD (unfiltered)					
- inflow	153	224	177		
- outflow	110	171	113		
- removed	43	53	64		
TKN					
- inflow	25.75	35.89	29.74		
- outflow	24.88	31.66	16.86	NS	NS
- removed	0.87	4.23	12.88		
NH_4-N					
- inflow	18.33	27.69	21.0		
- outflow	17.57	25.15	11.61	10	1.0
- removed	0.76	2.54	9.39		
NO_3-N					
- inflow	2.41	0.92	1.6		
- outflow	2.26	0.78	13.51	NS	1.5
TP					
- inflow	3.25	4.92	4.84		
- outflow	2.98	3.84	4.76	NS	NS
- removed	0.27	1.08	0.08		
PO_4-P					
- inflow	1.34	3.47	3.9		
- outflow	2.23	2.97	3.87	1.0	1.0
- removed	-	0.5	0.03		

NS = Not specified

Results and discussion

This study focused on COD removal across the cooling tower fill material at different flow rates. Samples were therefore collected at the inlet of the tower and at the bottom of the fill material, before entering the sump (Fig. 1). This ensured that only the performance across the fill material was evaluated. This accounted for any COD contribution from the sump.

The best COD removal (42%) was achieved at a flow rate of 1.6 ℓ·s^{-1} and an organic load rate of 19 g COD·m^{-2}·d^{-1} (Table 2). This was sufficient to meet the general effluent standard (Table 2). At this rate 138 240 ℓ of water per day (population equivalent of 2 800) can be effectively treated. Other studies have indicated, that higher organic loading rates result in more efficient COD removal (Van Niekerk, 1996). The high-rate biofilters, used by Van Niekerk (1996), with constant hydraulic loads of 30 to 40 m^3·m^{-2} filter·d^{-1} and organic loads ranging between 500 and 1 500 g COD·m^{-3}·d^{-1}, removed 50 to 70% of the influent carbon at hydraulic residence times (HRT) of 1 to 5 min.

A decrease in ammonium concentrations and increase in nitrate concentrations in the outflow were observed, indicating that nitrification was taking place during the experimental period (Table 2). The best total Kjeldahl nitrogen (TKN) removal was 43.3% at a flow rate of 1.6 ℓ·s^{-1} (Table 2). The former was ascribed to the low flow rate (1.6 ℓ·s^{-1}) which resulted in a longer hydraulic residence time (HRT) (*ca.* 26 min) allowing slow-growing nitrifiers to develop (Muyima et al., 1997). This was, however, not sufficient, to meet effluent standards (Table 2). Similar results were achieved, in another study, where 5 to 40% removal of the influent nitrogen occurred and this was ascribed to biomass synthesis (Van Niekerk, 1996).

TABLE 3
AVERAGE IN- AND OUTFLOW CONCENTRATIONS OF PHYSICAL PARAMETERS OF THE BIOFILM REACTOR USED FOR MUNICIPAL WASTEWATER TREATMENT PARAMETERS

Parameters (mg·ℓ^{-1})	Operation period I (5 $\ell\cdot s^{-1}$)	Operation period II (2 $\ell\cdot s^{-1}$)	Operation period III (1.6 $\ell\cdot s^{-1}$)	General standard (mg·ℓ^{-1}) (*Government Gazette*, 1984)	Special standard (mg·ℓ^{-1}) (*Government Gazette*, 1984)
SS					
- inflow	49.6	68.7	45.5		
- outflow	38.9	56.9	27.4	25	10
- removed	10.7	11.8	18.1		
Settleable solids (m$\ell\cdot\ell^{-1}$)					
- inflow	0.15	0.27	0.12		
- outflow	0.07	0.15	0.18		
- removed	0.08	0.12	-		
TDS					
- inflow	399.1	403.6	401.7		
- outflow	395.3	378.3	399.37		
Alkalinity					
- inflow	214.3	237.6	221.4		
- outflow	213.9	233.7	175.9		
Conductivity (mS·m^{-1})					
- inflow	59.5	60.2	60.1		
- outflow	59.0	56.5	59.3	250 mS·m^{-1}, 25°C	250 mS·m^{-1}, 25°C
pH					
- inflow	7.5	7.8	7.5		
- outflow	8.0	8.1	7.8	5.5 - 9.5	5.5 - 7.5
Temperature (°C)					
- inflow	23.7	20.1	22.0		
- outflow	18.3	12.7	18.6	≤35°C	≤25°C

In this study 1.6% to 22% of the TP and 0 to 14% PO$_4$-P was removed (Table 2). This is not surprising, since it is well known that these type of systems do not remove phosphates effectively (Rovatti et al., 1995; Sorm et al., 1996).

Between 17 and 40% of the SS and 1% to 6.3% of TDS were removed (Table 3). The SS were probably removed by entrapment in the biofilm. Entrapment of SS in the biofilm, although not experienced during this study, could result in fouling and clogging of the fill material. The primary function of the bioreactor is, however, not to remove SS, which are normally removed during primary settling and final clarification and not in the bioreactor.

The conductivity (59.5 and 60.1 mS·m^{-1}) and pH (6.8 to 7.5) were within the effluent standard and the pH was also in the range suitable for most biological reactions, including nitrifation (Table 3).

Conclusions

Evaluated as a "once-through" system, 42.3% of the COD was removed at a flow rate of 1.6 $\ell\cdot s^{-1}$. This was good enough to meet the general effluent standard and sufficient for the treatment of wastewater for a population equivalent of 2 800. Recirculation may improve the efficiency of the system, and needs to be further investigated. This type of system has great potential for the treatment of wastewater produced by small communities; for example camping sites, holiday resorts, small towns and informal settlements etc. The system has many advantages over other more conventional systems. Firstly it is modular which means easy expansion if required. The operation of the system is easy and no sophisticated engineering is required for the design and installation of the system. Since higher organic loading rates have resulted in better performance of this type of system, it will be worthwhile evaluating the system for high-strength wastes, such as those produced in the food industry for example.

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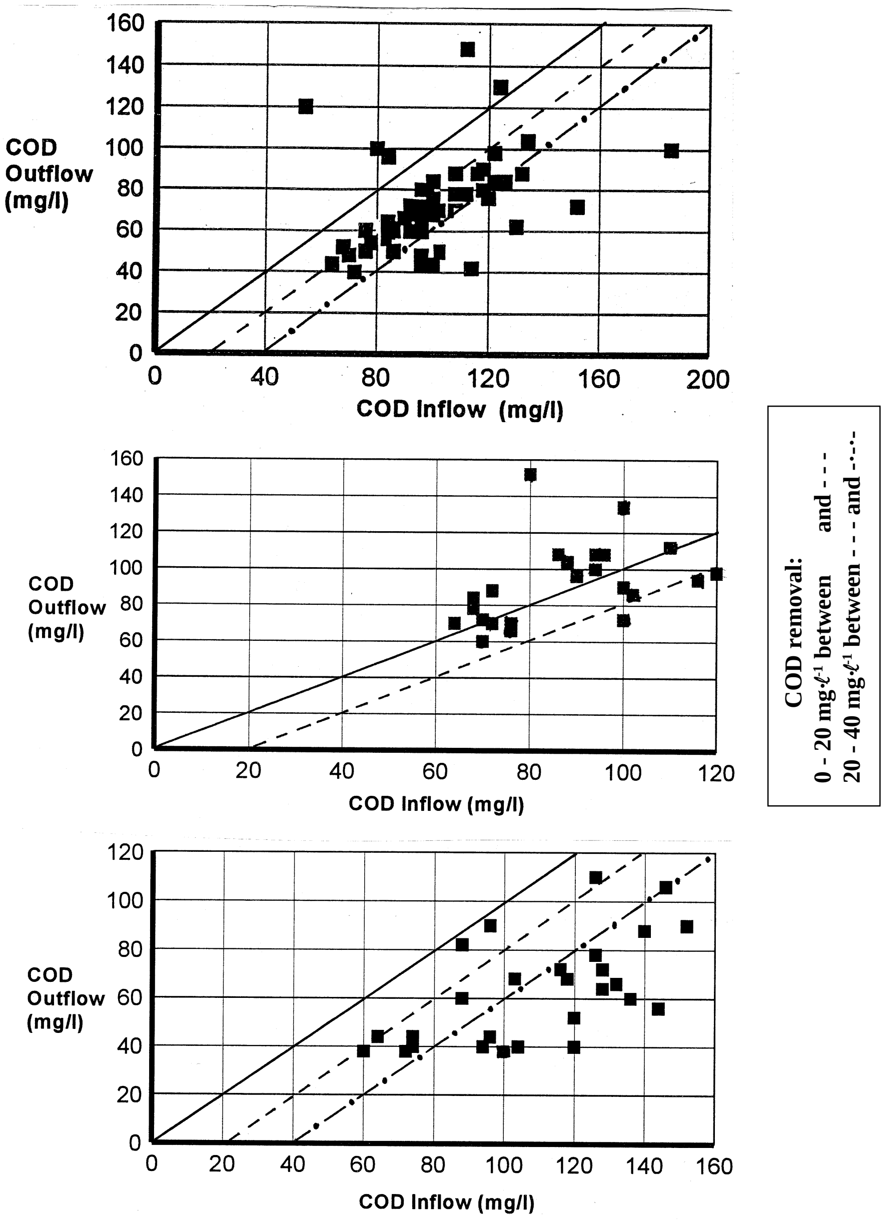

Figure 3
Correlation between COD inflow and COD outflow concentrations of primary settled municipal wastewater after treatment with the biofilm reactor. This reactor was operated at different flow rates:
(a) 5 ℓ·s^{-1},
(b) 2 ℓ·s^{-1} and
(c) 1.6 ℓ·s^{-1}

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