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THE USE OF EFFLUENT FROM AN ANAEROBIC BAFFLED REACTOR (ABR) FOR AGRICULTURAL USE IN PERI-URBAN COMMUNITIES

S. Pillay[1], K. Foxon[2], N. Rodda[1], M.T. Smith[1] and C. Buckley[2]

ABSTRACT

An anaerobic baffled reactor (ABR) was investigated for on-site sanitation for low-income communities. The eight-compartment reactor allows high solids retention with high treatment rates, and is stable to organic and hydraulic shock loads. The reactor was fed with raw domestic wastewater from a middle-income community connected to a wastewater treatment facility. A mean COD removal of 82% was achieved, which complied with effluent discharge regulations for irrigation. However, the high level of microbial pollutants *(E. coli*, total coliforms, coliphage and *Ascaris* spp.), ammonia and sodium constrained effluent reuse. Restricted agricultural use is possible with high nutrient concentrations, provided microbial levels are reduced. A microfiltration membrane, which will form an integral part of the ABR, was considered as a post-treatment option. Significant removals ($p < 0.001$) of *E. coli*, total coliforms and coliphage were obtained between ABR effluent and membrane filtrate, with coliform counts below irrigation guidelines. The results indicate the potential of an ABR with a membrane post treatment step to obtain effluent suitable for irrigation agriculture.

INTRODUCTION

South Africa is a water scarce country, which receives an average rainfall of 500 mm per annum; well below the world average of 860 mm. Rainfall is seasonal and unevenly distributed throughout the country, with approximately twenty-one percent receiving less than 200 mm per annum (Jacobs *et al*., 1999). The country does not have sufficient water resources to meet the future demand for water, and it is anticipated that the by the year 2050, severe water shortages will be experienced (Seckler *et al*., 1999). The lack of basic sanitation services aggravates this situation through the microbial contamination of existing water resources. Poor water quality is associated with the transmission of waterborne diseases, such as cholera, dysentery, typhoid fever and parasitic infections, and has serious implications over a wide range of public health and socio-economic issues.

Due to the historical inequalities of apartheid, the provision of potable water and sanitation services to communities is currently unevenly distributed. Within urban areas, municipalities provide potable water of the highest quality and sanitation services are available to most consumers. However, within rural communities and informal communities that surround urban areas, the necessary water supply and sanitation infrastructure is often not available. These communities belong to low-income groups and many cannot afford basic treatment options. As a result, untreated water resources are used for domestic purposes. It has estimated that forty-one percent (20 million) of the current population do not have adequate sanitation facilities (DWAF, 2003). The provision of potable water and adequate sanitation facilities to these areas has therefore become a national priority. Local municipalities are planning to provide potable water and basic sanitation to all citizens within the next 10 years. The South African government is currently implementing a programme whereby each household is entitled to 200 L/d of free potable water (DWAF, 2003). However, the provision of sanitation services and facilities is proving to be more difficult. Municipalities have little or no supervision in housing arrangements of rapidly growing, informal communities. As a consequence, settlements are often densely clustered which does not allow future implementation of waterborne sewage systems. Furthermore, the cost of developing such infrastructure can be high and beyond the financial resources that are available for a developing country. Pit latrines and septic tanks are commonly used to meet the basic sanitation needs of these communities. These methods of sanitation are not always appropriate, and in many instances contaminate groundwater and surface waters (Stenstrom, 1996). For this reason, the South African Water Research Commission (WRC) is investigating alternative domestic wastewater treatment technologies that can meet the sanitation needs of people and at the same time, limit environmental damage.

At present, the anaerobic baffled reactor (ABR) is being investigated as an interim on-site sanitation solution for low-income, informal households without adequate sanitation facilities. The reactor uses a series of hanging and standing baffles, which compartmentalise the reactor, retaining high concentrations of biomass that allow a high-rate anaerobic treatment. The design also allows for the spatial separation of microbial consortia horizontally down the reactor, which results in it being reasonably stable to hydraulic and organic shocks loads, environmental parameters, such as pH and temperature, and exposure to toxic materials (Barber and Stuckey, 1999). The ABR is being proposed as a short to medium term sanitation solution as it requires no mechanical parts and hence does not require power, can function over a wide range of flow and load conditions, requires little or no maintenance, and can meet space constraints imposed by random housing arrangements. A minimal sewage infrastructure, however, may be required to transport the waste from households to reactor.

In the past, government policies have been primarily concerned with increasing the supply of water (UNEP, 2002). However, water scarcity has challenged water managers to focus on an integrated approach to water and wastewater management with emphasis on efficient water use without affecting the safety and health of the public. Depending on the chemical and microbial quality of ABR-treated wastewater, it may be returned to the soil as a fertiliser replacement. Its utilisation in irrigation is seen as beneficial as it offers economic benefits and nutrient. Many countries are currently using products derived from the treatment wastewater, such as sludge, as an alternative to nitrogen fertilisers. In Egypt, for example, sludge has been used successfully in the growth of various fruits and crops without any harmful effects (UNCSD, 1999). This study tested the suitability of ABR-treated effluent for discharge into the environment according to the World Health Organisation (WHO, 1989) and the South African Department of Water Affairs and Forestry (DWAF, 1996) guidelines.

METHODS AND MATERIALS

Pilot reactor

A pilot-scale reactor (3000L) was constructed and installed at Kingsburgh wastewater treatment plant which treats domestic wastewater from a middle-income community. The eight-compartment reactor was constructed of mild steel, and has sampling ports on the side and top of the reactor. A submersible pump was used to supply raw wastewater to a feed box, controlled by a programmable logic controller (PLC). The reactor was operated at a hydraulic retention time of 42 h from April to October 2004. Conventional digested sludge was used as the seed material, however, consecutive periods of operation on municipal wastewater feed had resulted in the evolution of a sludge with different physical and microbial characteristics.

Membrane Filter

A preliminary laboratory trial was conducted with a single flat Kubota membrane from Copa. Effluent from the ABR was filtered through the membrane in a specially constructed unit for 4 days, for 4 – 4.5 h each day, and microbial quality was monitored.

Sample collection and handling

Grab samples were obtained during the study period from reactor feed box, sampling ports, and at the outlet pipe. A specially designed sampling column was used to obtain sludge samples from the upflow region of each compartment, placed in a bucket, mixed, and sampled for analysis. Samples for ammonia and phosphate were filtered and acidified to limit biological activity during transit. All samples were transported and stored at 4^0C, and analysed within 30 h.

Microbial Indicators

(i) Coliforms. Coliforms were measured using the membrane filtration technique (APHA, 1989). Enumerated coliforms included total coliforms and *Escherichia coli* (*E.*

coli). Grab samples were serially diluted and filtered through a gridded 0.45 μm membrane filter. Filters were aseptically placed on Chromocult Coliform Agar (Merck), and incubated at 35°C for 18 to 24 h. *E. coli* colonies and total coliforms were identified by colour.

(ii) Coliphages. Coliphages was enumerated according to the double layer technique (eThekwini Waste Water Laboratory Test Method No. MM023) using the host culture *E. coli* (ATCC 13706). Bacteriophages caused lysis on a lawn of *E. coli* host cells, forming clear plaques and were enumerated as plaque forming units (PFU) per 100 mL.

(iii) Parasite Detection

This was limited to a single helminth genus, namely *Ascaris* spp. Grab samples of raw wastewater (1 L) and effluent (10 L) was collected on a weekly basis and allowed to sediment for 18 h. The supernatants of samples were discarded and the remaining sediments were centrifuged at 1000 g for 15 minutes. The centrifuged supernatant was discarded and the enumeration of parasite eggs in the sediment was conducted according to the modified Bailenger method (Ayres and Mara, 1996). Eggs were enumerated as total eggs per litre. Viability of the eggs was not assessed before and after the anaerobic treatment periodt.

Analytical Methods

Measurements of COD, total suspended solids (TSS), free and saline ammonia, and phosphate were obtained using Standard Methods (APHA, 1989).

Statistical Analysis

All data were analysed utilising the Statistical Package for the Social Sciences (SPSS) statistical software. Differences between means were determined by t-test.

RESULTS AND DISCUSSION

REACTOR PERFORMANCE

Chemical oxygen demand

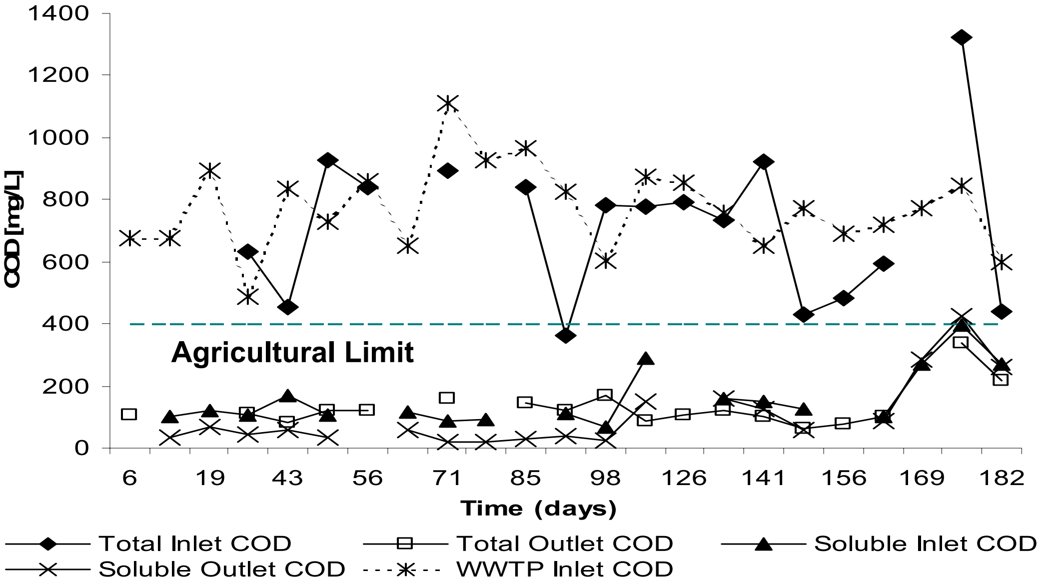

Figure 1: Comparison of COD profiles for whole and soluble inlet and outlet measurements of the ABR, and wastewater treatment plant samples.

The inlet and outlet chemical oxygen demand (COD) measurements for the pilot-scale ABR over 6 month period are presented in **Figure 1**. Two influent and effluent values are presented: whole and soluble (filtered) measurements. For comparison, influent COD measured by the Kingsburgh wastewater treatment plant laboratory has been included. For the campaign, the average influent COD measured was 719 ± 200 mg/L whilst average effluent COD were 130 ± 64 mg/L, resulting in an average COD removal of 82% through the reactor. Effluent COD measurements were consistently below the guidelines set by DWAF for agricultural use. (DWAF, 1996). Near the end of the study period, a COD spike in the influent sample was observed at day 181 (**Figure 1**). Nevertheless, the COD removal remained consistent with that for the entire study.

Nutrient concentrations

values for influent and effluent values for ammonia were above 50 mgN/L, although in the operating period reported here, insufficient data were obtained to find statistically significant mean values. In general, the ammonia concentration will increase during anaerobic digestion as organically bound nitrogen is released as reduced nitrogen.(Speece, 1996).

Average phosphate concentrations were 28 ± 3 and 20 ± 6 mg/L in, and average potassium concentrations were 21 ± 4 and 25 ± 5 mg/L for influent and effluent samples respectively. Sodium levels were highly variable with a mean concentration of 131 ± 140 mg/L being detected. Effluent sodium, potassium and phosphate values will usually be determined entirely by influent characteristics as these components are largely unaffected by anaerobic digestion.

Health-related microbial indicators

Influent and effluent samples were analysed weekly for *E. coli*, total coliforms and coliphage from April to October 2004. A subset of grab samples (13) were analysed for the presence of *Ascaris* eggs.

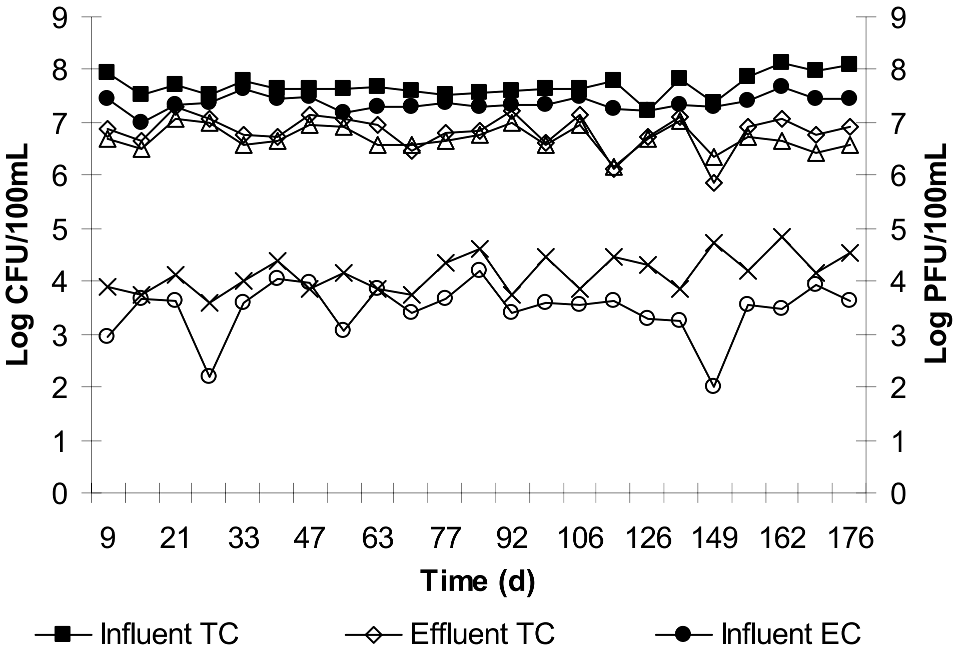

Figure 2: Deactivation of coliforms and coliphages through the pilot-scale ABR.

The number of *E. coli* fed into the reactor ranged between 1x10^7 and 5x10^7 CFU/100 mL. Average effluent measurements ranged from 7x10^5 to 1x10^7 CFU/100 mL with an average reduction of 76% or approximately 2 log. The reduction of *E. coli* from inlet to outlet was significant ($p < 0.05$) but variable throughout the study period (**Figure 2**).

A similar trend was found with respect to total coliforms (**Figure 2**). Total coliforms fed into the ABR from the inlet pipe ranged between 2x10^7 and 1x10^8 CFU/100 mL. A statistically significant removal of total coliforms was observed ($p < 0.05$) with a mean removal of 83% or approximately 2 log. However, average total coliform measurements in the effluent were consistently higher than *E. coli* and ranged between 1x10^6 and 2x10^7 CFU/100 mL.

By contrast, coliphage reduction through the digester was not as high as those of the observed for coliform groups (**Figure 2**), with a mean removal efficiency of 64% or 1.8-log achieved for the study period ($p < 0.05$). This was in accordance with the findings of Moce′-Llivina *et al*. (2003) and Skraber *et al*. (2004) who found that coliphages were less sensitive than coliform and other bacterial groups to environmental parameters

The number of *Ascaris* eggs in the influent was high and varied between 347 to 1 253 eggs/L, with an average concentration of 772 eggs/L. A mean removal of 98%, corresponding to a 2-log removal, was observed after anaerobic digestion.

IMPLICATIONS FOR AGRICULTURAL USE

Table 1: A summary of wastewater characteristics in comparison to discharge guidelines for agricultural use.

Parameter	Influent	Effluent	Filtered Effluent	Target Quality[a]
COD_{tot} (mg/L)	719 ± 0.2 (18)	130 ± 64 (18)	326 ± 11 (9)	400[b]
pH	6.7 – 7.4	6.2 – 7.4	nd	6 – 9
Ammonia (mg/L)	55 ± 24 (10)	51 ± 23 (10)	nd	30
Phosphate (mg/L)	28 ± 3 (7)	20 ± 6 (7)	nd	Na
Sodium (mg/L)	150 ± 118 (5)	131 ± 140 (5)	nd	70[c]
Potassium (mg/L)	21 ± 4 (6)	25 ± 5 (6)	nd	na
Total Suspended Solids	416 (1)	135 (1)	0 (4)	50
E. coli (CFU/100mL)	2 x 10^7 (23)	5 x 10^6 (23)	8.8 x 10^2 (12)	1 x 10^3 [d]
Total Coliforms (CFU/100mL)	5 x 10^7 (23)	8 x 10^6 (23)	4.5 x 10^3 (12)	1 x 10^4
Coliphage (PFU/100mL)	1.9 x 10^4 (23)	4.4 x 10^3 (23)	2.5 x 10^2 (6)	20[e]
Ascaris spp. (Total eggs/L)	772 (13)	16 (13)	nd	≤ 0.1[f]

Abbreviations: (n), number of samples; na, not applicable (guidelines currently not available); nd, not determined

a: agricultural use guidelines established by DWAF (1996), unless otherwise stated.

b: for 500 kL/d discharge.

c: tentative guideline, maximum to prevent toxicity to the most sodium-sensitive plants.
d: geometric mean, limit for unrestricted irrigation (WHO, 1989).
e: guideline for full and intermediate contact (Venter *et al*., 1996)
f: revised WHO guideline based on the findings of Blumenthal *et al*. (2000).

The WHO (1989) guidelines are commonly used as the standard for wastewater reuse in many countries. In South Africa, DWAF has established its own guideline based on guidelines from the WHO and various environmental agencies. The results presented above are summarised and compared to discharge guidelines from these two sources (**Table 1**). However, in certain instances, tentative recommendations have been included based on the irrigation method used and human exposure to effluent (Blumenthal *et al.*, 2000).

Flood or furrow irrigation are expected to be the most common method of irrigation implemented in this case, as they are the simplest options available. Wastewater irrigation by these techniques are associated with higher risks of infection by Human Norwalk-like Virus, diarrhoeal disease and parasitic infections, when compared to spray irrigation (Blumenthal *et al.*, 2000). Children are particularly at high risk as increased nematode infestation and diarrhoeal disease have been observed at exposure to effluent that met WHO guidelines (Blumenthal *et al.*, 2000). For this reason, the current WHO (1989) guideline for nematode eggs (1 egg/litre) has been revised to 0.1 eggs/litre for communities where nematode infestation and exposure is high (Blumenthal *et al.*, 2000). A guideline of 10^3 *E.coli* (100mL) has been used as the target quality based on the findings of Blumenthal *et al.* (2000). Currently, no limit exists for this parameter, or for coliphages (virus indicator organisms), in WHO or DWAF agricultural guidelines.

As can be seen in **Table 1,** the effluent contains high levels of plant nutrients, implicating it as a possible fertiliser replacement. However, both ammonia and sodium levels were above the target limit (30 mg N/L and 70 mg Na/L respectively) for irrigation. Ammonia levels above 30 mg/L can lead to prolonged vegetative stages with reduced fruit production and yields (DWAF, 1996). For grain crops, excessive ammonia supplementations result in weak stalks that are unable to hold grain (DWAF, 1996). Furthermore, the likelihood of groundwater contamination and resultant eutrophication is much greater. The guideline for sodium is tentative with no strict limitations imposed. Irrigation can occur above this limit depending on the sensitivity of crop to be used. Crops that can be irrigated at this level include pepper, tomato, potato and maize (DWAF, 1996). A small-scale field study was conducted to assess the effects of effluent irrigation on plant growth. The results of the experiment revealed that irrigation with ABR effluent was comparable with that of a commercial plant nutrient treatment, and gave slightly better growths than irrigation with tap water only (Singh and Badat, 2004).

The main constraining parameter regarding effluent reuse, therefore, was the level of microbial pollutants. The health risks associated with using ABR effluent are high, as none of the microbial indicators achieved discharged limits (**Table 1**). In order for the effluent to be used as an agricultural resource, a polishing treatment was necessary. A membrane filter was considered as a post-treatment option, which will form an integral part of the technology in the future. The microbial quality produced from the membrane is shown in **Table 1**. The filter was able to significantly remove both *E.coli* ($p < 0.05$) and total coliforms ($p < 0.05$), with log removals of 2.9 and 2.7 observed for *E. coli* and total coliforms respectively. The reduction of coliphages was also significant ($p < 0.05$), but was above guidelines recommended by Venter *et al*. (1996) for full and intermediate contact. The results indicate that the fouling layer had not developed sufficiently to restrict the passage of viruses through the membrane.

CONCLUSION

The objectives of this study were to evaluate the performance of a pilot-scale ABR as a primary sanitation option for low-income communities, and examine possible water re-use strategies of ABR effluent. A consistent COD removal of 82 % was achieved, which complied with effluent quality regulations for irrigation agriculture. However, the removal of indicator organisms and nutrient concentrations was inadequate. Despite the high-pathogen load, a field-scale study was conducted to evaluate the effect of plants irrigated with ABR effluent. The results indicated that the effluent has no detrimental effects on plant growth, and is comparable to a hydroponic treatment (Singh and Badat, 2004). In order for re-use to occur, the pathogen load must be further reduced. An ultrafiltration membrane was envisaged as a suitable pot-treatment option for the ABR. The preliminary results indicate that coliforms and TSS are reduced to a level that is appropriate for agricultural use. Although there is no restriction for the level of coliphages in agricultural use, communities may be at high risk to viral infections at levels greater than 20 PFU/100 mL. Further investigations are required to test the full capability of the membrane to removal microbial contaminants.

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