GUIDELINES FOR THE IMPLEMENTATION OF ANAEROBIC BAFFLED REACTORS FOR ON-SITE OR DECENTRALISED SANITATION

K.M. Foxon and C.A. Buckley

Pollution Research Group, School of Chemical Engineering, University of KwaZulu-Natal, Durban 4041
e-mail: foxonk@ukzn.ac.za

ABSTRACT

Although there have been many experimental studies of anaerobic baffled reactor (ABR) technology for the treatment of various wastewaters, there is little information available to assist in the design of an ABR. A pilot-scale anaerobic baffled reactor (ABR) was constructed and operated over a five year period and characteristics of the reactor performance with respect to conditions within the compartments and effluent quality were monitored during this time. A simple conceptual model of steady-state operation of the ABR was developed and calibrated with experimental data where available. A protocol for specifying ABR design parameters for the treatment of a wastewater with specific flow and load characteristics was developed and the calibrated model used to determine values for the design parameters. This paper provides a framework within which a process engineer can design an ABR for the treatment of a specific domestic wastewater.

INTRODUCTION

A Water Research Commission project (K5/1248) entitled *The anaerobic baffled reactor for sanitation in dense peri-urban areas* studied the performance of an 8-compartment anaerobic baffled reactor (ABR) fed municipal wastewater at the Umbilo and Kingsburgh wastewater treatment plants (WWTP) near Durban over a five year period (1) The objective of this project was to determine whether and under what conditions an ABR can be used in a sanitation system, particularly in the case of low-income communities. A study was undertaken to quantify water use and wastewater generation in a low-income peri-urban community (KwaMashu-Newlands Interface Housing Development) and to characterise the wastewater generated (2). These data were used to facilitate model-based predictions of the performance of an ABR or similar on-site or decentralised technology under conditions similar to those encountered in a South African low-income peri-urban community (1).

The ABR concept

The ABR is a high rate anaerobic digester that is internally compartmentalised by a series of hanging and standing baffles (3). Figure 1 is a diagram of the 8-compartment ABR used in the pilot study reported in (1). Wastewater enters the reactor and flows under a natural head under and over the hanging and standing baffles. No oxygen or mechanical mixing is applied in the ABR; treatment is achieved by anaerobic digestion by naturally selected anaerobic microbial consortia (referred to as *sludge*). The ABR is similar in concept to a septic tank in that passive treatment of wastewater is obtained by the (relatively) unassisted development of anaerobic micro-organism consortia in a simple digester design. However, compartmentalisation results in four significant but inter-related differences to the mechanism of wastewater treatment in the ABR (1):

- Settling of particulate components of the feed, dispersed sludge, sludge granules and certain parasites occurs in the up-flow region of each compartment resulting in good solids retention characteristics and the development of a thick sludge blanket in the bottom of each compartment.
- The wastewater flow must pass through this sludge blanket, ensuring good contact between soluble components in the wastewater and micro-organisms in the sludge and therefore good treatment rates (1).
- Spatial separation of different microbial consortia treating the wastewater in each compartment results in the development of biomass specifically suited to the wastewater characteristics predominantly observed in each compartment. Theoretically, this means that the sludge in each compartment will treat wastewater in that compartment better than sludge with the average composition of sludges from each of the different compartments of an ABR.
- The pseudo-plug-flow property of liquid flow through an ABR means that the retention time of a slug of wastewater containing a toxic or inhibitory compound in each compartment is much less than in a single compartment reactor with the same total hydraulic retention time (HRT); the contact *time* between any micro-organism and the toxic or inhibitory compound is less in an ABR, as the time required to completely wash that compound out of the compartment is less. Provided the concentration of the toxic or inhibitory compound in each compartment is less than the lethal dose of that compound, the overall recovery of the ABR from the effects of the compound will be faster than in a single compartment system where the tail of the residence time curve of any soluble constituent is considerably longer than for an equivalent HRT plug-flow system.

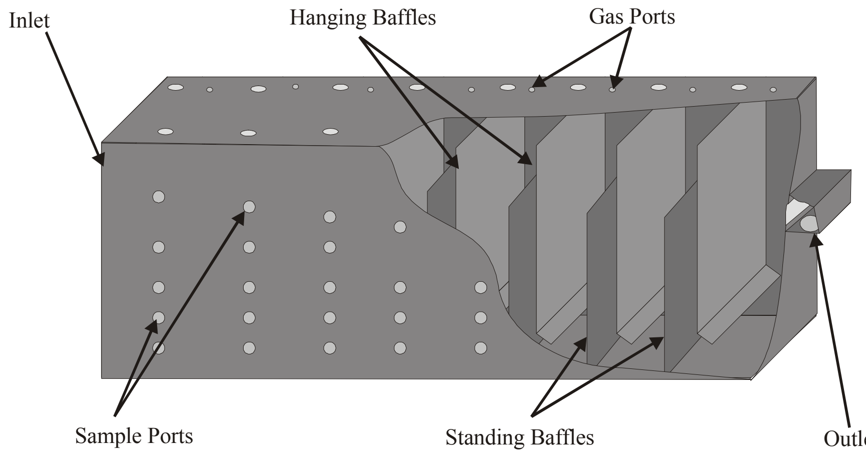

Figure 1: Diagram of 8-compartment pilot-scale ABR with cut-away showing internal baffle construction

An ABR therefore has several advantages for anaerobic treatment of wastewater over septic tanks or anaerobic ponds, principally:

- enhanced anaerobic treatment rates, therefore smaller treatment volume;
- increased resilience to slugs of toxic or inhibitory compounds in the wastewater and;
- more rapid recovery from process up-sets (1, 3).

There are also limitations to the application of an ABR for sanitation: results from the pilot study: Anaerobic treatment alone is not able to remove nutrients nitrogen and phosphorus from wastewater and therefore, further treatment, or alternatively reuse of the effluent for agricultural purposes is required (1, 4). Also, it was shown that although significant removal of pathogen indicator organisms *Escherichia coli* (E. coli), total coliforms (T. coli), coliphages and *Ascaris* sp. ova was obtained, nevertheless, the effluent pathogen quality was not sufficiently high to be considered to *not* pose a risk to human health (E. coli counts were regularly greater than 1 x 10^6 cfu/100 mℓ). This limits the potential for reuse of the wastewater, particularly in a community context (1, 5, 6).

Application of an ABR in sanitation

The pilot study (1) concluded that the ABR has application in on-site and decentralised sanitation in conjunction with an appropriate post-treatment, such as membrane filtration for disinfection, rock filters or constructed wetlands. Depending on the scale of the application and the type of post-treatment, the treated effluent should be reused for agricultural purposes or directed into a soakaway or evapo-transpiration zone. Certainly, where a septic tank is considered an acceptable sanitation system, an ABR would consistently achieve better effluent quality, which would ultimately extend the life of the soakaway/evapo-transpiration zone.

Design of an ABR

There is little literature available to assist in the design of an ABR. In most experimental studies, operating flows and loads have been determined in relation to the performance of an existing reactor design (3, 7, 8). Designs of new systems are often reported to be based on the design of some previous study (e.g. 9, 10). The only application of a critical design procedure in the sizing and layout of an ABR known to the authors is the central treatment unit in the DEWATS system (Decentralised wastewater treatment system) (11), which has been widely applied in South-East Asia.

This paper presents a rational basis for the process design of an ABR for the treatment of domestic wastewater for either an on-site application or a small scale decentralised application using a simple model to assist in the prediction of treatment performance.

ANALYSIS OF PILOT ABR PERFORMANCE

The results of the pilot-scale ABR study were used to develop a simplistic one-process model of treatment.

Materials and Methods

The design of the pilot ABR was based on an 8-compartment laboratory-scale ABR treating soluble high-strength and toxic industrial wastewaters (12). The pilot ABR had a working volume of 3 m^3 with dimensions 3 m × 1 m × 1 m and a constructed height of 1.2 m allowing a headspace height 0.2 m. The reactor body and baffles were constructed from laser-cut plates of mild steel welded into a gas-tight tank.

The pilot ABR was operated at two hydraulic retention times (22 h and approximately 42 h) at Kingsburgh WWTP over a 4 month and a 6 month period respectively. Kingsburgh WWTP treats a wastewater that has no formal industrial effluent component. It serves a community of about 350 000 population equivalents from middle-income suburbs. The average up-flow velocity in each compartment was calculated from compartment dimensions and the average HRT. These values were 0.55 m/h and 0.27 m/h respectively.

The sludge in the reactor had evolved during previous exploratory studies using the pilot ABR (1). Grab samples of influent and effluent to and from the reactor were obtained between 1 and 4 times per week during the study periods and analysed for COD (open reflux method (13)), free and saline ammonia (NH_3 + NH_4^+) (eThekwini Water Services, accredited laboratory), total Kjeldahl nitrogen (TKN) (Standard Methods (13) and pathogen indicators (E. coli and T. coli: membrane filtration technique according to Standard Methods (13); coliphages: double layer technique; *Ascaris* sp. ova: Centrifugation and enumeration according to the modified Bailenger method (14))

Results from pilot ABR study

Chemical and microbiological analyses (results not shown) indicated that sludge characteristics and load in both operating periods were continually changing, through microbial evolution and growth of the sludge and as a result of a number of washout incidents (1). It was concluded that microbial steady-state was not achieved during either operational period. Influent wastewater characteristics did not change significantly between the two operating periods (data not shown). Values for concentration of COD, (NH_3 + NH_4^+), TKN and pathogen indicators in the pilot ABR influent and effluent are presented in Table 1.

Table 1: Influent and effluent wastewater characteristics from the pilot ABR during two operating periods with HRT of 22 h and between 40 and 44 h respectively, during operation at Kingsburgh WWTP.
Data are presented as average ± standard deviation (number of observations)

	Unit	Influent	HRT = 22 h	HRT = 40 to 44 h
COD	mg COD/ℓ	721 ± 194 (n = 189)	212 ± 143 (n = 57)	130 ± 64 (n = 18)
TKN	mg N/ℓ	44 ± 5 (n = 26)	n.m.	37 ± 4 (n = 23)
NH_3 + NH_4^+	mg N/ℓ	25 ± 5 (n = 7)	34 ± 3 (n = 7)	51 ± 23 (n = 10)
E. Coli	Log[cfu/100 mℓ]	7.7 (25)	n.m.	6.8 (25)
T. Coli	Log[cfu/100 mℓ]	7.3 (25)	n.m.	6.6 (25)
Coliphage	Log[pfu/100 mℓ]	4.1 (24)	n.m.	3.6 (24)
Ascaris ova	eggs/ℓ	772 ± 341 (n = 13)	n.m.	17 ± 15 (n = 13)

n.m. = not measured

Examination of COD values in the effluent (data not shown, (1)) indicated that despite the microbial changes and increasing sludge loads, the effluent characteristics did not correlate with these changes. Average effluent COD values for the two operating periods were significantly different (Student's t-test, $p<0.05$). Insufficient data were obtained to indicate whether there was a trend in NH_3 + NH_4^+ concentration during the two operating periods. Average values for NH_3 + NH_4^+ in the effluent were not significantly different ($p>0.05$) for the two operating periods, despite the fact that greater COD removal at the longer retention should have resulted in greater solubilisation of organically bound nitrogen to NH_3 + NH_4^+ . This conclusion is a consequence of the large standard deviation in the effluent measurements for the 40 to 44 h HRT operating period.

The sludge load in the pilot ABR was characterised in terms of average solids concentration in the up-flow region of each compartment, and settled sludge bed height (data not shown). Figure 2 shows total solids concentration in compartments 4, 5 and 6 during the 40 to 44 h HRT operating period, indicating a gradual increase in total solids concentration in some of the compartments. It was concluded that the pilot ABR does not achieve steady state with respect to solids load in the compartments, but rather that solids accumulate slowly with time as a result of solids settling. Since the extent of treatment, as observed by the effluent COD value does not appear to change much with time, it is concluded that the extent of treatment is not strongly dependent on the amount of biomass present in the ABR, at the sludge loading observed during these trials. However, a significant change in effluent COD concentration is seen as a result in the change in HRT. The implication of this result is that the extent of treatment depends less on the amount of biomass available, than on the time for which the wastewater is in contact with the biomass, i.e., the HRT. Furthermore, there is an accumulation of biomass in the reactor which will ultimately have to be removed (desludged) at intervals to prevent it overflowing in the effluent.

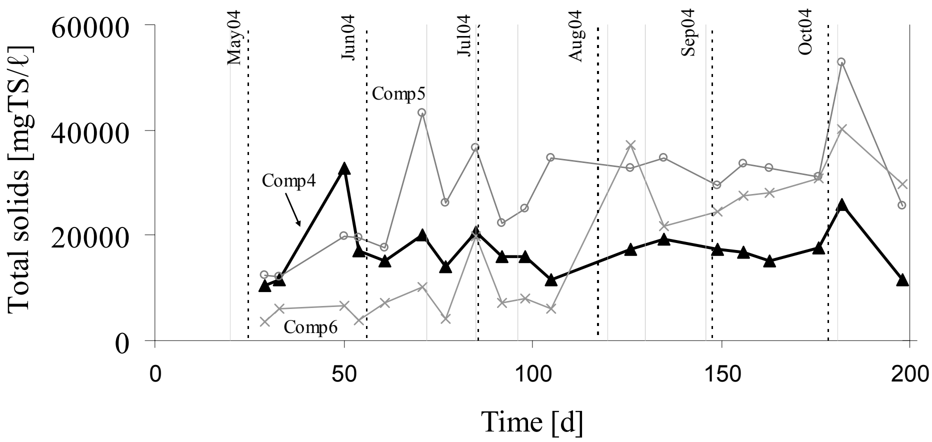

Figure 2: Total solids concentration in compartments 4, 5 and 6 during the 40 to 44 h HRT operating period, showing the overall accumulation of solids in the ABR

A SIMPLE MODEL OF TREATMENT PERFORMANCE OF AN ABR TREATING DOMESTIC WASTEWATER

A simplistic model of extent of treatment versus retention time is proposed to assist in the design of an ABR for the treatment of domestic wastewater. The extent of treatment is defined as the faction of biodegradable COD that is anaerobically removed from the wastewater stream. This model is intended to give an indication of the effluent characteristics in terms of COD and nitrogen of an ABR for specific flow and load conditions for a particular design HRT.

Model assumptions

A simple model i.e. one that can only describe a few observations in a system, is only valid when all the potentially variable conditions in the system that the model cannot describe are not expected to change significantly. This model makes the following broad assumptions:

- There is *sufficient* sludge *initially* present (including all bacterial and archeal genera required to undertake the different steps of anaerobic digestion) such that sludge load is not a limiting factor.
- The up-flow velocity is sufficiently low to allow adequate solids retention such that all functional groups of the anaerobic microbial consortia are able to *maintain* non-limiting populations in each compartment.
- Any other limiting condition (such as low pH) does not change substantially with different retention times.
- All organically bound nitrogen (TKN less (NH_3 + NH_4^+)) measured in the influent wastewater was assumed to be associated with biodegradable COD.

Model Structure

The model has a general *black box* structure in that it is only concerned with the overall performance of the ABR; i.e. it only predicts effluent quality.

The model proposed assumes that any readily biodegradable organic material, measured as readily biodegradable COD (RBCOD) present in the influent wastewater is completely consumed early in the reactor and the kinetics of RBCOD consumption may be ignored.

Slowly biodegradable COD (SBCOD) is made up of particulate and colloidal fractions of organic material in the wastewater. The mechanism of treatment of these fractions is not well known, but has been shown to be hydrolysis-limited under most conditions. This was shown to be the case from compartment 2 onwards in the pilot ABR by a combination of microbial, chemical and modelling techniques (1). Intuitively, hydrolysis depends on (i) the available surface area of the substrate, and (ii) the concentration of hydrolytic enzyme-producing micro-organisms. The pilot study indicated that the relationship between sludge concentration (indicated by total solids concentration in each compartment) and amount of COD removed was not strong for a well established sludge; therefore, the overall extent of treatment is assumed to be dependent on the available surface area of wastewater components for hydrolysis. Macro-solids (diameter > 10 mm) are not considered since these will be retained in the first compartment.

There are too many unpredictable variables in an on-site or decentralised wastewater treatment unit to be able to adequately calibrate a sophisticated mechanistic model. In particular, variable feed flows and loads will alter hydraulic, chemical and to a certain extent, microbiological conditions on an hourly basis. Therefore, although the dynamics of particle and colloidal surface area may have an important effect on treatment rate, a model that accounted for them would be unnecessarily complex; a simple empirical mode is used to describe the relationship between contact time and effluent COD characteristics.

Wastewater characterisation

The influent wastewater COD is assumed to be divided into the following fractions:

- Inert COD is defined to be that portion of the influent total COD that cannot be removed by anaerobic digestion. It is assumed that particulate inert COD will be retained in the sludge blankets in compartments, and will ultimately leave the reactor through desludging rather than in the effluent. No reliable biodegradability data were obtained in this study; the inert COD component was assumed to be the same value as the average effluent COD value measured in the effluent of the activated sludge system treating the same wastewater as the pilot ABR at Kingsburgh WWTP. Mechanistically, this fraction also includes any inert by-products generated from the digestion of biodegradable fractions.
- Readily biodegradable COD (RBCOD) was assumed to consist of organic acids in the influent wastewater. This differs from standard characterisation definitions (e.g. 15) by only considering organic acids i.e. compounds with no nitrogen component, to make up the RBCOD fraction, thereby simplifying N characterisation)
- Slowly biodegradable COD (SBCOD) was calculated as the difference between the total COD and the sum of the inert and RBCOD.
- Active biomass in the influent wastewater was assigned to the SBCOD fraction.
- The organically bound nitrogen in the influent wastewater is determined as a fixed ratio of the SBCOD fraction, $i_{N,SBCOD}$.

Conversion model

The following simple conversion rules govern the design model for the ABR:

- All inert COD in the effluent will appear unchanged in the effluent.
- All RBCOD is consumed early in the reactor and will never appear in the effluent.
- The amount of SBCOD digested is a function of time only.
- The amount of organically bound nitrogen converted to NH_3 + NH_4^+ is the total organically bound nitrogen in the SBCOD digested.

The model does not predict the accumulation of biomass in the reactor as a result of microbial growth.

The model can be described mathematically as follows:

$$COD_{t,in} = I_{in} + S_{in} + X_{S,in} \qquad \text{equation [1]}$$

$$\frac{dX_S}{dt} = -f(HRT) \qquad \text{equation [2]}$$

$$COD_{t,e} = I_{in} + X_{S,e} \qquad \text{equation [3]}$$

$$X_{S,e} = X_{S,in} + \int_0^{HRT} f(HRT)dt \qquad \text{equation [4]}$$

$$COD_{t,e} = I_{in} + X_{S,in} + \int_0^{HRT} f(HRT)dt \qquad \text{equation [5]}$$

$$N_{FSA,e} = N_{FSA,in} + i_{N,SBCOD} \cdot \left(-\int_0^{HRT} f(HRT)dt \right) \qquad \text{equation [6]}$$

Note that although some biomass is entrained in the effluent, it was not experimentally differentiated from the SBCOD in the effluent. Theoretically the amount of biomass present in the effluent will be a function of the up-flow velocity. The relationship between particulate COD in the effluent and up-flow velocity in the pilot ABR study was investigated, but no significant correlation between the two parameters was found.

Calibration of the design model for an ABR treating domestic wastewater

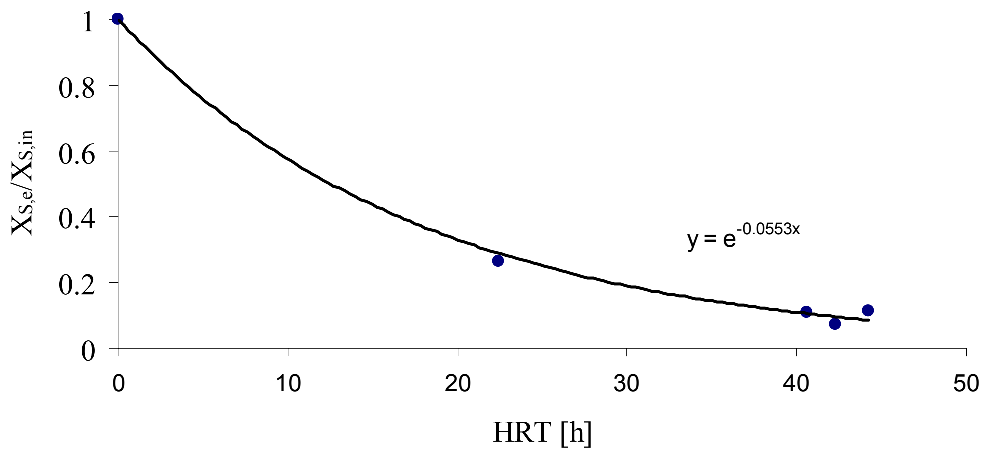

Figure 3: SBCOD remaining in the effluent as a fraction of influent SBCOD for the pilot ABR treating domestic wastewater

Data for influent and effluent COD was available for the 22 h operating period, and three constant HRT periods in the 40 to 44 h HRT period. The effluent COD concentration from the activated sludge system at Kingsburgh for the same operating periods was found to be 48 ± 7 mgCOD/ℓ. Figure 3 presents the effluent SBCOD concentration calculated according to equation [3] vs. HRT. The zero point is calculated as the influent COD concentration less the inert COD concentration for zero retention and therefore no treatment. This relationship is described by an exponential curve:

$$\frac{X_{S,e}}{X_{S,in}} = e^{-0.0553 \cdot HRT} \qquad \text{equation [7]}$$

Rearranging equation [4] and substituting into equation [7]:

$$\int_0^{HRT} f(HRT)dt = X_{S,e} - X_{S,in} = \left(e^{-0.0553 \cdot HRT} - 1\right) \cdot X_{S,in} \qquad \text{equation [8]}$$

Therefore, from equation [6]

$$N_{FSA,e} = N_{FSA,in} + i_{N,SBCOD} \cdot \left(1 - e^{-0.0553 \cdot HRT}\right) \cdot X_{S,in} \qquad \text{equation [9]}$$

Using the data in Table 1 generates a value of $i_{N,SBCOD}$ = 0.028 mgN / mgCOD, which agrees well with ranges reported in the literature of between 0.02 and 0.04 mgN / mgCOD (16), although most literature sources consider separate values of i_N for different COD fractions (inert, RBCOD, SBCOD). The pilot study (1) did not generate sufficient information to calibrate such a model, but a simple model extension could be made, if required. The general model presented here and calibrated using pilot study data has yet to be validated using independent data.

GUIDELINES FOR THE PROCESS DESIGN OF AN ABR TREATING DOMESTIC WASTEWATER

In engineering terms, an ABR functions as a series of mixed reactors, in which the biological catalyst, the biomass in the sludge of each compartment is retained in that compartment when the liquid flow passes out of the compartment. The first one or two compartments have the added function of retaining solids originating from the feed.

<u>Design objective</u>

The design objective is to maximise the amount of contact time between suspended or dissolved contaminants and the biomass and minimise the amount of sludge washout in the ABR effluent. This is achieved by maximising the hydraulic retention time (the treatment time), the number of passes through the sludge bed (i.e. number of compartments) and minimising the up-flow velocity to reduce solids carry-over., determined by solids retention, within the constraints of space and capital cost. Solids retention is achieved by minimising the velocity of liquid on the up-flow side of each compartment since solids loss is through carryover of slow-settling solid particles when the up-flow velocity exceeds the particle settling velocity. Low up-flow velocity can be achieved by either selecting a reactor geometry that has a short flow path for a specified hydraulic retention time (e.g. a low, wide reactor, or few compartments), or by reducing the flow to a specific reactor size, i.e. increasing hydraulic retention time.

In the analysis that follows, the parameters in the process design are described, indicating the effect on process performance of the choice of parameter value.

<u>Design Parameters</u>

The classic ABR process design consists of a number of equally dimensioned compartments. For a specific wastewater flow, the design is fully specified by fixing the following 6 independent parameters: (i) Design hydraulic retention time, (ii) number of compartments, (iii) peak up-flow velocity, (iv) compartment width to length ratio, (v) reactor depth and (vi) compartment up-flow to down-flow area ratio. The civil design of the reactor interior also requires values for hanging baffle clearance, headspace height, baffle construction and inlet and outlet construction. All other internal features such as length and width individual compartments dimensions are dependent on the first six parameters.

Hydraulic retention time: The mean hydraulic retention time affects the contact time in which wastewater treatment may occur, and indirectly, the up-flow velocity, that controls solids/sludge retention. It is also the parameter that dictates the size of the reactor (working volume) and therefore has a significant effect on the capital cost of the system.

Peak up-flow velocity is the maximum permitted up-flow in the reactor that does not cause an unacceptable entrainment and washout of sludge. The peak up-flow velocity is the design velocity increased by a *peak flow factor*. The latter is the ratio of the peak flow expected to the average daily flow rate from a community. Studies on simplified sewerage (small bore sewer systems) in poor communities in Brazil found a peak flow factor of 1.8 to be adequate for design purposes (17).

Number of compartments, reactor depth, and compartment up-flow to down-flow area ratio all define the *peak up-flow velocity* within the reactor. Independently either increasing the number of compartments, the reactor depth or reducing the compartment up-flow to down-flow area ratio results in an increase in peak up-flow velocity. Except in the case of the up-flow to down-flow area ratio, the change to up-flow velocity is caused by the lengthening of the overall path that wastewater has to traverse through the reactor (working height of reactor x number of compartments x 2 [m]) and therefore greater superficial velocity that wastewater must achieve. The number of compartments should be selected to equal to or greater than the number zones within the reactor that can develop microbial consortia with significantly different characteristics. Boopathy (18) showed that for 4 ABRs with 2, 3, 4 and 5 compartments respectively, and with all other dimensions identical, more compartments resulted in better solids retention and overall greater extent of treatment for a swine manure feed. This implies that repeated passes through the sludge bed has a greater beneficial effect in increasing extent of treatment than maintaining a low up-flow velocity, although Boopathy's findings (18) were for constant flow-rate conditions. Intuitively, there will be a cross-over point where increasing the number of compartments will increase the up-flow velocity to a point where washout of sludge occurs to the detriment of the biological processes, resulting in poorer COD removal performance than for a smaller number of compartments.

Reactor width to length ratio does not have a direct effect on the superficial up-flow velocity. However, a compartment that is too long will experience channelling and by-passing effects; more liquid flow will pass up through the sludge blanket near to the hanging baffle than near the following standing baffle, effectively by-passing much of the sludge bed and under-utilising reactor space.

<u>Fixing the design</u>

Table 2 presents recommended ranges for values for the design parameters for an ABR treating domestic wastewater as described above. Although the limits of operation have not been fully tested, these values have been selected based on experiences gained through 5 years of observing laboratory- and pilot-scale reactors in operation. Some justifications for the recommended values are provided in (1)

Table 2: Recommended ranges and equations for parameters in the design of an ABR for treatment of domestic wastewater

Parameter	**Symbol**	**Unit**	**Recommended parameter range or equation**
Flow rate	F	m^3/d	-
Hydraulic Retention Time	HRT	h	20 to 60 but 40 to 60 during start-up
Reactor working volume	V_W	m^3	FxHRT/24
Peak up-flow velocity	v_p	m/h	0.54
Design up-flow velocity	v_d	m/h	$v_p/1.8 = 0.30$
Number of compartments	N	-	4 to 6
Hanging baffle clearance	d_h	m	0.15 to 0.20
Compartment up-flow area	A_U	m^2	$F/(v_D x24)$
Up-flow to down-flow area ratio	$R_{U:D}$	m^2/m^2	2 to 3
Compartment width to length ratio	$C_{W:L}$	m/m	3 to 4
Total compartment area	A_C	m^2	A_U x $(1+R_{U:D})/R_{U:D}$
Reactor depth	r_D	m	1 to 3 (The reactor depth will largely be governed by the cost of excavation)
Reactor width	r_W	m	$\sqrt{\frac{V_W \cdot C_{W:L}}{N \cdot r_D}}$
Reactor length	r_L	m	N x r_W / $C_{W:L}$

Design Example

Consider a wastewater with an average flow of 10 000 ℓ/d, and a COD load of 10 kg COD/d. The RBCOD fraction of the COD is determined to be 5 % m/m, and the inert fraction is 12 % m/m. The value for $i_{N,SBCOD}$ is determined to be 0.03 mg N / mg COD and the influent $NH_3+NH_4^+$ load is 420 gN/d. The maximum working depth of the reactor is 2 m due to local geological constraints.

The effluent from the primary treatment system for this wastewater should have a COD value of 200 mg COD/ℓ.

The average influent COD characteristics are calculated as follows:

$COD_{t,in}$ = 1 000 mg COD/ℓ

S_{in} = 0.05 x 1 000 = 50 mg COD/ℓ

I_{in} = 0.12 x 1 000 = 120 mg COD/ℓ

$X_{S,in}$ =$COD_{T,in}$ – S_{in} – I_{in} = 830 mg COD/ℓ

$N_{FSA,in}$ = 42 mg N/ℓ

Using equations [3] and [7], the following relationship between effluent COD and HRT can be derived:

$$COD_{t,e} = I_{in} - e^{-0.0553 \cdot HRT} \cdot X_{S,in} \qquad \text{equation [10]}$$

For $COD_{t,e}$ = 200 mg COD/ℓ and solving for HRT, we find that HRT = 42.3 h

Values and equations used in Table 2 are used to determine design parameters for an ABR treating this wastewater.

Flow(g)	F	=	$10\ m^3/d$
Hydraulic retention time(c)	HRT	=	42.3 h
Reactor working volume(c)	V_W	=	$10 \times 42.3 / 24\ m^3 = 17.6\ m^3$
Design up-flow velocity(r)	v_d	=	0.30 m/h
Number of compartments(s)	N	=	5
Hanging baffle clearance(s)	d_h	=	0.2 m
Compartment up-flow area(s)	A_U	=	$10 / (0.3 \times 24) = 1.39\ m^2$
Compartment up-flow to down-flow area ratio(s)	$R_{U:D}$	=	3
Compartment width to length ratio(s)	$C_{W:L}$	=	4
Total compartment area(c)	A_C	=	$1.39 \times 4 / 3 = 1.85\ m^2$
Reactor depth(g)	r_D	=	2 m
Reactor width(c)	r_W	=	$((17.6 \times 4)/(5 \times 2))^{-1/2} = 2.67$ m
Reactor length(c)	r_L	=	$5 \times 0.663 / 4 = 3.32$ m

(g) given; (c) calculated; (r) recommended; (s) selected

The amount of NH_3+NH_4^+ in the effluent is calculated using equation [9]:

$$N_{FSA,e} = 42 + 0.030 \cdot \left(1 - e^{-0.0553 \cdot 42.3}\right) \cdot 830 = 64.5 \text{ mg N/ℓ}$$

DISCUSSION

The methodology presented in this paper assists in designing an ABR for the primary treatment of domestic wastewater. It is based on a number of fundamental observations and assumptions i.e. that

- The overall kinetics of wastewater treatment in the ABR are dominated by the kinetics of hydrolysis: It is believed that once a critical load of sludge has developed, the kinetics of hydrolysis become independent of the sludge concentration. Therefore, the most important factor controlling effluent quality is retention time.
- Intimate contact between sludge and wastewater ensures efficient use of treatment volume. This means that a greater number of passes through the sludge blanket, achieved by increasing the number of compartments will increase the overall COD removal. However, after approximately 5 compartments, the added benefit in each additional compartment becomes progressively less. Appropriate hydraulic design, particularly the length of each compartment (distance between successive standing baffles) is important to ensure that wastewater is not able to bypass large portions of the sludge bed.
- The peak up-flow velocity in the reactor must not exceed the washout velocity of the most susceptible micro-organisms in the sludge in each compartment. In the pilot ABR study, it was found that slow-growing methanogenic micro-organisms failed to establish themselves securely at an average up-flow velocity of 0.55 m/h, but were seen in significant numbers when the average up-flow velocity was reduced to 0.27 m/h. Careful consideration of the dimensions and number of compartments of the ABR can allow a reduced up-flow velocity without changing the overall volume of the reactor.

<u>ABR effluent quality and post-treatment requirements</u>

The ABR effluent cannot be discharged or reused without pre-treatment since it fails to meet standards for health related indicator organisms and nutrients. However, in waterscarce communities, it may have the potential to provide an effluent with reuse value, if it can be made safe to people and the environment. An ABR may be easily coupled with one of several post-treatment systems, such as membrane filtration, reed beds or anaerobic filters in order to remove pathogens to an acceptable level. The nutrient rich and pathogen free effluent may be used for agricultural purposes, provided there is no risk of nutrient contamination in ground or surface water.

CONCLUSIONS

This paper critically addresses a gap in the literature of anaerobic baffled reactors vis. an analysis of the effect of reactor dimensions on the performance of biological processes in an ABR. A methodology for a process design for an anaerobic baffled reactor for the primary treatment of domestic wastewater has been presented. The critical factors in the design of the ABR were identified as hydraulic retention time, contact between sludge and wastewater and peak up-flow velocity. Calculations of ABR effluent characteristics for a design wastewater flow and load have been presented.

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