TITLE	The ABR Concept: A holistic approach to managing wastewater from low-income communities and institutions
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Short CV for Introduction **Purposes (100 words max)**	Graduated from University of Natal with BSc Eng (Che) in 1998. Between 1999 and 2005 I have been working towards a PhD in monitoring and modelling of biological processes for the treatment of wastewater. From 2002 I have been researcher and project leader for the WRC project "The ABR for sanitation in dense peri-urban areas".
Photograph attached (jpg)	

INTRODUCTION

Municipalities in South Africa face the challenge of providing sanitation to all people by 2010: (DWAF 2003) In serviced areas, this is accomplished by connections to trunk sewers and centralised treatment works. In rural areas, conventional pit latrines, and several dry toilet options have been shown to provide adequate sanitation. However, it is acknowledged that there is a lack of technology available for the management of wastewater in dense low-income communities such as semi-formal communities on the fringes of urban developments and poorly resourced institutions e.g. rural schools and primary healthcare clinics.

Although the provision of adequate sanitation to all people is regarded as the biggest challenge facing society at present, it is part of a bigger water management challenge: the current urban lifestyle supported by large quantities of piped potable water, generating large volumes of dilute, but nutrient and pathogen laden wastewater has both a large environmental impact associated with the treatment processes and pumping of potable water and wastewater, and a limited application in a water scarce context. It is therefore essential that the rollout of sanitation is coupled with a whole new approach to water management, in which the use of potable water is limited to applications that require water of that quality, and the contamination of wastewater with nutrients and pathogens is minimised, to reduce the cost of treatment.

The domestic water cycle consists of water extraction from a water resource, treatment, pumping and reticulation to the user, consumption and wastewater generation, removal of wastewater, treatment of wastewater and release of treated effluent to the environment.

This paper presents a conceptual wastewater management system centred round an anaerobic wastewater treatment unit. The principle of this system is to minimise the volume of wastewater that requires treatment, and to use a minimum effort treatment procedure to produce a reusable wastewater with nutrient value for irrigation.

THE ABR PROJECT

The Water Research Commission of Southern Africa funded a project to investigate the applicability of an anaerobic baffled reactor (ABR) to treat wastewater generated by dense peri-urban communities.

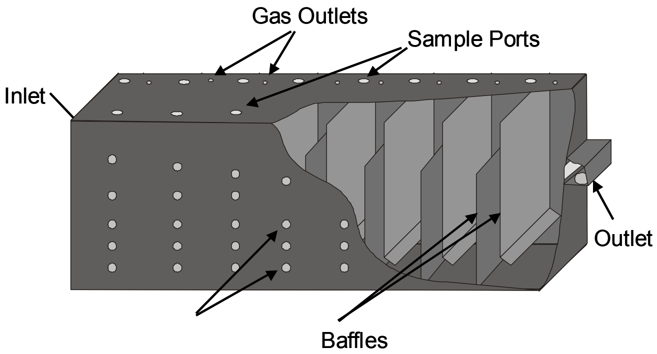

Figure 1: Schematic layout of the pilot ABR, showing hanging and standing baffles

The ABR consists of alternating hanging and standing baffles, which compartmentalise the reactor, and that force the liquid flow up and down from one compartment to the next. The overall flow rate is low, allowing solids to settle out in the upflow region of each compartment. In this way, high concentrations of biomass are retained in the process, and relatively high treatment rates can therefore be obtained, while overall sludge production is characteristically low. Figure 1 is a diagram of the construction of the pilot ABR used in this research with a cut-out to show the construction of the internal baffles. The peculiar virtue of the ABR is that specialised micro-organism populations develop and are retained in each compartment of the reactor, specifically adapted to the prevailing conditions of substrate concentrations, pH and inhibiting compounds. These populations allow an efficient treatment of the wastewater, and furthermore, have shown resilience to shock hydraulic and organic loads, and quick recovery from process upsets (Barber and Stuckey, 1999). The result is a technology that achieves good COD conversion rates with a relatively simple construction, and minimal operating and maintenance requirements.

MATERIALS AND METHODS

A 3 KL pilot reactor was built and operated on screened and degritted wastewater drawn by a submersible pump from the head of works at Umbilo Wastewater Treatment Works (WWTW) and subsequently at Kingsburgh WWTW. Kingsburgh WWTW does not treat industrial effluent and it was therefore assumed that the wastewater used in the Kingsburgh part of the study was essentially domestic in origin. The flow rate to the pilot ABR was controlled to achieve a fairly steady hydraulic retention time.

pH was measured *in situ* using an electrode. Grab samples were drawn from the feed box and outlet pipe of the reactor on a weekly basis, sealed and transported to the UKZN biochemical engineering laboratory and analysed for total COD, soluble COD (0.45 µm filtered), total solids, ammonia and phosphate according to Standard Methods. (APHA 1998). *Escherichia* coli were cultured on Chromocult Coliform Agar plates using the filtration method according to Standard Methods (APHA 1998)

Data from a 22 h retention time (Foxon et al., 2004) and a 42 to 44 h hydraulic retention time (Foxon et al, 2005) are presented in Table 1.

Table 1: Average results of ABR unit for two constant hydraulic retention time experiments

Analysis	Unit	Influent	Effluent		Discharge Standard[3]
			22 h	42 to 44 h	
pH		6.95[1] (n=5)[2]	6.5	6.50 (n=6)	5.5 – 9.5
Total COD	mg COD/L	693±240 (n=389)	192±21 (n=33)	130±64 (n=18)	75
Soluble COD	mg COD/L	127±33 (n=15)	82±25 (n=12)	63±45 (n=16)	-
Total Solids	mg/L	739±182 (n=15)	225±55 (n=14)	378±97 (n=13)	25[4]
Ammonia	mg N/L	38±11 (n=270)	33±3 (n=6)	51±23 (n=10)	3
Phosphorus	mg P/L	15±6 (n=245)	5.5±1 (n=5)	20±6 (n=7)	10
E. coli	Log(cfu/100 mL)	7.4	7.0	6.7	3

[1] Average calculated from mean [H$^+$] concentration
[2] n = number of observations
[3] General authorisation for the discharge of wastewater (DWAF 1999)
[4] Discharge standard for TSS

Table 1 shows that the ABR alone can not treat a conventional domestic wastewater to an acceptable quality for discharge to watercourses. It functions as a high rate septic tank with superior solids retention, shock resistance, and overall better treatment efficiency. It is unable to remove nutrients and has exhibited insufficient pathogen deactivation for either discharge or reuse.

If one considers the reasons for treating wastewater, they can be summarised into two requirements: (1) To minimise the negative impact on the environment and people when discharged and (2) to neutralise its offensiveness from a smell and visual perspective

A physical inspection of the pilot ABR wastewater proves that the second requirement has been achieved. In order to achieve the first, sufficient deactivation of pathogens must occur during the treatment process and nutrients nitrogen and phosphorus should be prevented from entering local waterways. Under all circumstances in which people may be exposed to the treated wastewater, pathogen loads represented by indicator organism concentrations must be reduced to statistically safe levels (WHO, 1989), although there is currently some debate over what these numbers may be. However, preventing nutrients from entering local waterways does not necessarily mean that they must be removed from the wastewater. Under appropriate conditions, they may be regarded as a resource for the enhancement of agricultural enterprises. (WHO, 1989)

With this in mind the ABR *unit* wastewater treatment concept was extended to an ABR *system* concept in which the ABR is responsible for converting the organic content of wastewater to a harnessable energy source, while leaving the potentially valuable nutrients as fertiliser in the final effluent. The remaining and significant issue relates to the microbiological quality of the treated effluent; are there process variations or additions that can reduce the pathogen load to an acceptable level for reuse?

Two potential solutions are being investigated: firstly, the possibility of including membrane filtration of the ABR effluent is being explored; secondly, the routing of the treated wastewater through a constructed wetland or reedbed has been considered.

MEMBRANE POST-TREATMENT

The advantage of membrane treatment is that it potentially allows dissolved beneficial components to pass through, while retaining virtually all particulate matter, including most pathogens. Table 1 indicates that only half of the total COD in the ABR effluent will pass through a 0.45 μm filter; less than half can be expected to pass through a properly functioning membrane filter. A preliminary study has shown that under anaerobic conditions, fluxes of up to 1.5 $L.m^{-2}h^{-1}$ can be achieved with a Kubota membrane. The disadvantage of using membranes is that the membrane units will form a significant portion of the cost of the ABR installation. Furthermore the membrane sheets will require occasional inspection and cleaning.

CONSTRUCTED WETLAND

Various studies have shown that a wetland can achieved up to 100% pathogen indicator organism removal, considerable phosphorus removal and variable amounts of nitrogen removal depending on the construction of the wetland. The wetland may be planted with a range of reeds and grasses that may have economic significance in local communities. At this stage, research into the application of wetlands for ABR effluent polishing is largely still theoretical.

The use of an ABR in conjunction with some post-treatment will probably be targeted at households with semi-pressure rooftank water supply; lower levels of water supply are not sufficient to operate a wet-core (flushable) toilet, and the higher level, full mains pressure, may result in a wastewater that is too dilute, resulting in hydraulic overloading of the ABR.

ABR CONCEPT

The proposed water management concept has 6 stages: The first stage is wastewater generation stage, which is linked to potable water supply level and toilet superstructure design. The second stage is the blackwater collection system which in a community would be a condominium-type sewer, and in an institution, an appropriately designed toilet block. An appropriate greywater collection and reuse system is also required. The pre-treatment stage (stage 3) includes a solids trap and the ABR itself, and the fourth stage, a post-treatment step in the form of a constructed wetland, or membrane unit. The reuse of the effluent generated for irrigation purposes is the fifth stage of the process. Finally, it is necessary to have an inspection system involving both the users and the appropriate municipal authority to monitor system maintenance and effluent microbiological quality.

Stage 1: Wastewater generation: In domestic use, the wastewater with the highest COD and pathogen load originates from the toilet and the kitchen sink. If greywater is reused in a domestic context, i.e. only householders are exposed to their own greywater, the risk of the spread of disease as a result of greywater reuse is minimal. It is therefore only necessary to have an active treatment process for toilet and kitchen sink water. In a wastewater treatment and reuse context, separation of urine from faeces has no real advantage since the nutrients in the urine are eventually recovered, without requiring separate storage, dilution or handling.

The ABR sanitation concept will probably be targeted at households with semi-pressure rooftank water supply; lower levels of water supply are not sufficient to operate a wet-core (flushable) toilet, and the higher level, full mains pressure, may result in a wastewater that is too dilute, resulting in hydraulic overloading of the ABR. Full-pressure water users will in general be in a higher income bracket, where full water-borne sanitation can be afforded by the consumer, and therefore will be the only sanitation level acceptable to most people in this category.

The toilet superstructure and flushing procedure will require careful design since the amount of water used for flushing will affect the ability of small bore reticulation to transport toilet contents away. From a treatment perspective, low flush volumes will produce concentrated wastewater, resulting in efficient treatment, however, the smaller the flush volume, the bigger the risk of sewer blockage. In a situation where an effective greywater (bath and basin water) separation system is in place, a conventional toilet with a flush volume of 5 to 7 L would be acceptable, with a 0.5 L pour flush arrangement for urine-only flushing. Where large amounts of greywater are likely to enter the treatment unit, it is recommended that a pour-flush toilet is installed.

Stage 2: Shallow sewer: A shallow sewer is a small bore sewer that connects a group of householders within a micro-catchment to a municipal sewer or local treatment process. Local studies (Eslick and Harrison, 2004) have shown that shallow sewer systems can work effectively, at considerably lower capital cost than conventional sewer systems, but that problems arose as a result of a difference between the level of service expected by the community, and that offered by the small bore sewer system. The system envisaged here would be on a considerably smaller scale with no more than 20 households connected to a treatment unit, but would nevertheless be subject to a wide range of difficulties at the user/technology interface.

Stage 3: Pre-treatment – Screening and ABR unit: If a community owning an ABR system has a high level of commitment to maintaining the system, it may not be necessary to have a screening unit before the ABR. This would reduce the system maintenance requirements. However, in most instances, a screening and degritting unit would be required to limit the amount of non-biodegradable material entering the ABR.

The ABR unit is expected to perform at least as well as shown by the pilot ABR results presented in Table 1. Based on the work with the pilot ABR, an altered design with fewer compartments and a shorter flow path and therefore better solids retention characteristics has been designed (Foxon et al., 2005). This design ABR should increase the extent of treatment achieved relative to the pilot ABR as well as showing slightly better resilience to peak hydraulic and organic loads. Biogas generated may be collected and piped to an energy generator.

Stage 4: Polishing step: After ABR treatment, the primary objective is to remove pathogens from the effluent so that it is safe to reuse. Both membrane filtration and the construction of a wetland would effectively remove pathogens from the effluent.

Stage 5: Effluent reuse: The effluent from the polishing step will be safe to use for irrigation, and should additionally provide a significant amount of fertilisation as a result of nutrients present in the effluent. However the release of the effluent must be to a sufficiently large area such that contamination of the water table or nearby water courses is avoided.

Stage 6: Monitoring and maintenance: As with all services, if no monitoring or maintenance of the system is undertaken, it is likely to fail as a result of mechanical failure (blockages, leaks, damage to reticulation and reactor) or user neglect or abuse. Furthermore, the implementation of a visible monitoring and maintenance programme will create an awareness of the system among users that it is susceptible to problems if not managed and cared for right from the toilet bowl to the secondary treatment process. Monitoring and maintenance must occur on three levels outlined in Table 2.

Table 2: Maintenance checklist for an on-site ABR system treating domestic wastewater

Daily Checks	Weekly Checks	Quarterly checks
Rake Screens	Remove Screenings	Check grit level in compartment 1
Collect screenings	Check inlet for blockages	Measure outlet COD concentration
	Check outlet for blockages	Inspect biogas system
	Check outlet pH	
	Check grit in screenings unit	

Individual homeowners are responsible for maintaining their own connection and reticulation on their property. Maintenance of the shallow sewer and screening unit would require a community elected or employed representative responsible for daily and weekly checks. Weekly removal of screenings, and inspections 3 or 4 times a year by the municipality will improve the chances of the system operating successfully.

ADVANTAGES OF THE PROPOSED SYSTEM

The ABR concept offers a number of advantages:

- The treatment requires no energy input and relatively little maintenance
- Maintenance of the sewer and solids trap can be limited by the cooperation of the users
- Nutrients present in the wastewater become a resource for agriculture
- Low sludge production from the anaerobic process means that it is technically possible to operate with no process residue
- Biogas production may be harnessed to provide an energy source to the community

PITFALLS OF THE PROPOSED SYSTEM

Community education and participation are essential at each of the six stages in order that the system is not upset through negligence or abuse. Within the eThekwini Municipality, there has not been any indication that the kind of participation required will be forthcoming.

A post treatment polishing step using either membrane filters or a constructed wetland will effectively eliminate pathogens. However people may be exposed to untreated wastewater through failure of the shallow sewer and at the screening unit.

The application of this system is also severely limited by the availability of land below the treatment process which is available for agriculture, or in the absence of an active land use programme, is able to absorb the nutrient load without contaminating the water table or nearby streams.

CONCLUSIONS

This paper has presented a brief overview of the potential of the ABR within a sanitation system to provide a satisfactory level of sanitation, coupled with advantages of water, energy and nutrient recycling. At present, only the performance of the ABR unit is well characterised. The ABR must now be moved into a field application so that all the other issues may be thoroughly researched.

ACKNOWLEDGEMENTS

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