

Short Communication

Domestic wastewater treatment with a decentralized, simple technology biomass concentrator reactor

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ABSTRACT

A new type of membrane-like aerobic reactor initially designed for the degradation of hydrocarbon-derived groundwater contaminants was tested for treating domestic wastewater. The biomass concentrator reactor (BCR) consists of an enclosed, aerated tank containing a graded filtration medium with the function of solids separation, and was previously used to treat industrial wastewaters containing refractory substances, with good results. It is a small-footprint reactor that could be operated in remote areas with no long-range sewage connections, with few appropriate controls and little monitoring instrumentation. The BCR was run for 90 days in pilot conditions with domestic wastewater feed. Results of the application are illustrated in the paper.

Key words | BCR, biomass, domestic wastewater, MBR, membranes, wastewater treatment

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INTRODUCTION

A new type of membrane-like aerobic reactor initially designed for the degradation of hydrocarbon-derived groundwater contaminants was tested for treating domestic wastewater. Following many literature-reported examples on the use of membrane systems in decentralized treatment of household (domestic) wastewater (Blstakova *et al.* 2009; Pikorova *et al.* 2009; Chong *et al.* 2013), the system herein tested (biomass concentrator reactor (BCR)) was identified as an ideal candidate for this type of application, and applied for degradation of domestic wastewater in pilot conditions.

The BCR is a small-footprint reactor that can be easily operated in remote sites, without long-range sewer system connections, with few appropriate controls and little monitoring instrumentation. Since it provides both the biological and clarification treatment steps, it is an ideal solution for small communities, and offers some advantages over traditional membrane reactors, in terms of both construction and operating costs, and lower propensity to fouling.

The filtration component dispenses the need for gravity clarification of the effluent, that could constitute a critical

treatment bottleneck in small systems under highly varying hydraulic loads and even induce process failure (Capodaglio 2002).

Limitations inherent to membrane bioreactor (MBR) processes are: the cost of membranes themselves, and the progressive loss of membrane filtration capacity due to fouling. However, their advantages with respect to traditional treatment techniques include smaller footprint, high loading rate capabilities, modularity and disinfected/highly clarified effluent suitable for reuse. Consequently, MBR technology could play a prominent role in any decentralized wastewater treatment scheme and could be an 'ideal' solution to accommodate village or urban area growth by providing location-specific sewage treatment options. These can not only outweigh most of the negative aspects associated with centralized systems, but also provide local water reuse opportunities (Capodaglio *et al.* 2016).

The paper illustrates the performance of a pilot-scale BCR system that was run on domestic sewage for about three months.

MATERIALS AND METHODS

The BCR process

The BCR initially designed by the US EPA National Risk Management Research Laboratory in Cincinnati (USA) was subsequently redesigned and enhanced at the University of Pavia to make it more compact, efficient and amenable to several diverse applications. It consists of an enclosed, aerated tank containing filtration columns with the function of solids separation. Strictly speaking, this filtration medium can be assimilated to a membrane, although the selected porosity of the columns (5–20 μm) does not fall into the traditional porosity range defining membrane systems used in wastewater treatment (usually below 1 μm). The BCR was successfully tested for methyl-ter-butyl ether (MTBE) and other compounds' removal from groundwater and wastewaters (Capodaglio *et al.* 2010).

Due to the characteristics of the filter (Table 1 and Figure 1), the effluent filtration occurs by gravity with only a total head loss in the order of 2–3 cm. Fine bubble aeration provides the scouring energy to keep the filter surfaces clean.

Chong *et al.* (2013) evaluated traditional MBR systems for use in decentralized settings, versus energy requirements and greenhouse gas (GHG) emissions of typical decentralized biofiltration systems, and concluded that, considering also methane emission from communal septic tanks, the

Table 1 | BCR system characteristics

Reactor volume (total)	0.06 m ³
HRT (calculated, average)	2–2.4 d
Volumetric loading (COD)	0.35 kg/m ³ d
Membrane surface	1.24 m ²
Air flow	40 L/min
Membrane type	Porex [®] corrugated radial cartridge
Membrane material	UHMWPE (ultra-high molecular weight polyethylene)
Pore size	20 μm
Dimensions of filter unit	15.5 cm (ext. diam.) \times 25.4 cm (length)
Specific surface area	0.62 m ² /cartridge

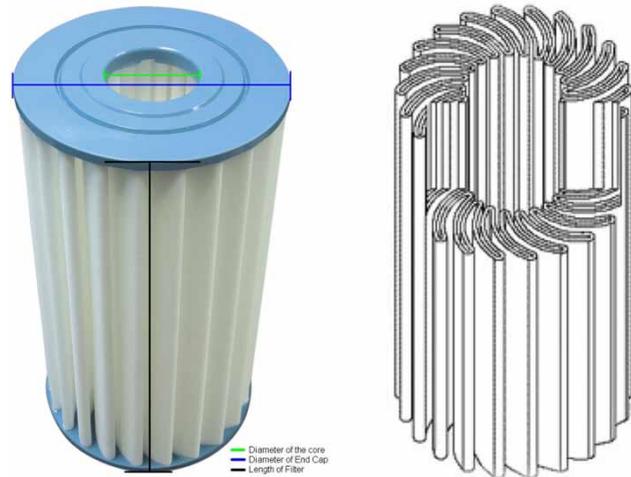


Figure 1 | The BCR filter medium (left) and section drawing (right).

overall GHG emission balance could more or less be equivalent, while the sheer energy consumption of MBR systems is about three-fold that of traditional decentralized aerobic systems. The BCR process, in this respect, working by gravity flow only, positions itself energetically much closer to a traditional system than to a MBR, while still maintaining a good degree of filtration capacity.

The BCR used for these tests was a lab-scale 60 L vessel containing two filter cartridges. A larger, field scale suitable for actual use in small communities applications is available (Capodaglio & Callegari 2009).

The laboratory settings for BCR testing are shown in Figure 2. The setup consists of a feed storage vessel, restocked every other day with fresh domestic wastewater, a feed pump, the actual reactor containing the filter units and a fine bubble diffuser, and an air pump.

The BCR was seeded and operated with sludge from the local municipal wastewater treatment plant, and pre-settled wastewater consisting of undiluted, mainly domestic sewage,

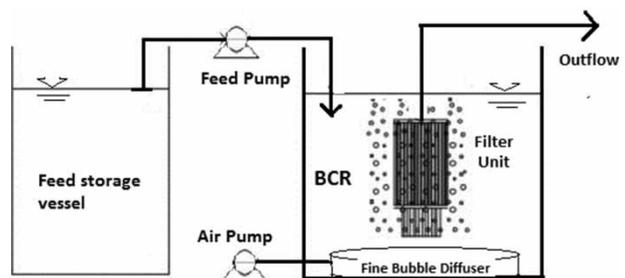


Figure 2 | BCR experimental setting.

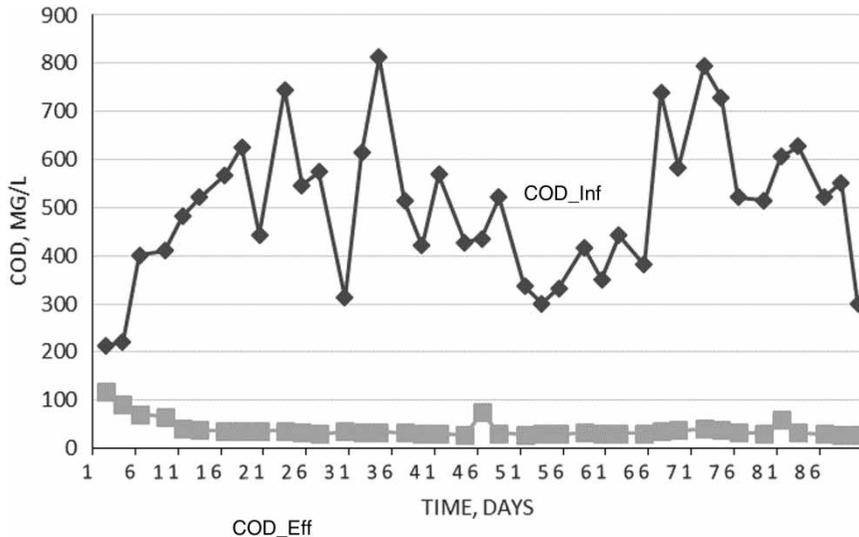


Figure 3 | Influent and effluent COD concentrations during the experimental period.

at an influent flow rate of about 27 L/d for 90 days, and laboratory temperature (approximately $20 \pm 2^\circ\text{C}$).

Samples of influent and effluent were taken three times/week; at the same time, other relevant operational parameters were also measured, such as pH and temperature, Mixed Liquor Suspended Solids (MLSS) and SVI were observed on a weekly basis, while membrane flux, was observed biweekly. The estimated specific biomass yield, Y , during the whole trial was at about 0.1–0.2 mg MLSS/mg chemical oxygen demand (COD).

Influent COD concentration ranged from 212 to 813 mg/L during the test. COD, ammonium ($\text{NH}_4\text{-N}$), total nitrogen (TN) were determined using a Hack-Lange DR3800 spectrophotometer. The minimum target dissolved oxygen concentration in the reactor vessel of 2 mg/L was always maintained; however, in order to keep the biomass in suspension, a minimum air flow was kept going at all times. After seeding, sludge MLSS concentration rapidly increased to over 4 g/L, oscillating for the entire duration of the tests in the 4–5 g/L range.

RESULTS AND DISCUSSION

Effluent COD levels ranged from 27 to 120 mg/L, with an average removal efficiency of over 93% (Figure 3). Table 2 summarizes the influent and effluent characteristics from the BCR test period. As can be seen, concentrations of

Table 2 | Influent and effluent characteristics during the test period

	COD	$\text{NH}_4\text{-N}$	TN
Infl. average (mg/L)	498	135	174
Infl. range (mg/L)	213–812	72.4–232	98–297
Effl. average (mg/L)	40.2	67.3	110.5
Effl. range (mg/L)	27.2–119	35.3–132	65.6–202
Removal efficiency (%)	93 ^a	–	37

^aCalculated on actual in/out data pairs.

COD in the influent fluctuated considerably during the study period. The COD of permeate, in turn, was a relatively constant value that stabilized around 40 mg/L after the first two weeks of operation.

The specific flux through the membrane in our experimental conditions was approximately constant at 22 L/m²d, a very low value compared to the rated filter capacity. Consequently, the filtration capacity of the membrane remained substantially constant during the tests and no backwashing became needed. This is contrary to similar trials conducted with actual membranes (pore size 0.1 μm) in similar conditions, where the medium filtration capacity decreased by 77% after just three months, requiring membrane substitution and/or regeneration (Pikorova *et al.* 2009).

The present study shows that the BCR, originally designed for the removal of complex pollutants (MTBE

and others) from contaminated groundwater, can be successfully operated for treating conventional pollutants in the discharges of small communities, with results that are comparable with those that could be obtained with traditional MBR systems, and with considerably lower energy inputs/GHG emissions and maintenance requirements.

CONCLUSIONS

A small pilot-scale BCR plant was run to investigate its overall performance when treating domestic wastewater, and more specifically the filter's behaviour in these conditions. Results demonstrate that the BCR has the capability to remove COD and nitrogen from municipal (domestic) wastewater in a manner that is comparable to traditional MBR systems.

In real conditions, where the main differential factor from the experiments herein described would consist in a varying temperature regime and variable flows, the BCR's performance should not be influenced significantly by the latter, while marked seasonal temperature variations may affect the process. Its response should nevertheless be very similar to that of an equivalent MBR system under similar conditions.

Results also showed that solids separation was achieved using minimal pressure differential between the two (permeate/retentate) sides of the membrane, while maintaining a good quality effluent with low turbidity. This (and its energy/GHGs footprint consequences) is the main advantage of such a system compared to a conventional membrane system.

The BCR is a relatively simple, compact system for biologically treating different types of liquid solutions: this application has shown that it can be used for purification of domestic wastewater. Due to its characteristics (low

cost, flexibility), its use could be ideal in decentralized facilities, where the energy for supply of the aeration equipment could be provided by renewable (e.g., solar, wind) sources.

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