Anaerobic Digestion of Municipal Wastewater (MWW) in a Periodic Anaerobic Baffled Reactor (PABR)

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Abstract

The scope of this work is to study the treatment of municipal wastewater in a Periodic Anaerobic Baffled Reactor (PABR). PABR is an innovative, high-rate bioreactor, designed to operate under high organic loadings. Apart from the Hydraulic Retention Time (HRT) an important operational parameter is the Switching Period (T). The current research work aims to study the impact of the operational parameters variation (HRT and T) in the biogas and biomethane productivity.

Six distinct experimental phases were conducted, during which the operational parameters of the PABR were consecutively modified: HRT varied from 10 to 1 day, T between 2.5 and 0.25 days while the OLR remained constant at values near 1 $g_{sCOD}/L_{bioreactor}$*d. The maximum CH_4 productivity was 26.5 LCH_4/d corresponding to the operation under HRT=1d, OLR=0.89 $g_{sCOD}/L_{bioreactor}$*d and T=0.25 days. Conclusively, the PABR is a high-rate AD system, capable of treating MWW under extreme operational conditions.

Keywords: Anaerobic Digestion; Bioreactor; High-rate; Methane; Municipal Wastewater; PABR

1. Introduction

Currently, the benchmark approach to municipal wastewater (MWW) management consists of sewer collection, treatment in a facility aiming at removal of suspended solids through primary sedimentation, biological oxidation of organic matter, biological nutrient (N and P) removal and disposal of the clarified effluent following disinfection by chlorination. The process generates a mixture of primary and excess secondary sludge which are typically mixed, stabilized by anaerobic digestion and dewatered before disposal (Chan et al., 2009). The key operating costs lie in the aeration and in sludge (biosolids) management (Mohan et al., 2008).

Alternative approaches that would reduce the energy requirements have been contemplated in the recent years. Indeed, it is possible to produce energy from the dissolved organic matter in wastewater, rather than consuming energy for aeration, followed by a partial recovery through anaerobic digestion of the biosolids. Among them, direct anaerobic digestion (AD) of the wastewater has been examined (Sosnowski et al., 2003).

The PABR was designed by Skiadas and Lyberatos (1998). It is an innovative high-rate anaerobic digestion system capable of anaerobically processing high organic-loaded feedstocks at low HRTs. As shown in Figure 1 it consists of two concentric cylinders. The space between the two cylinders is divided into four compartments, each one of which is further divided into two sections, one downflow and one upflow, thus resembling a simple ABR, only arranged in a circular structure. However, an important property of the specific bioreactor is the ability to periodically change the inflow and (outflow) compartment.

The time required for all the compartments to act as feeding compartments is the switching period T. This specific operational parameter gives the bioreactor the element of operational flexibility: when T is high, the bioreactors operation is similar to an ABR, while when it is low the operation approaches the one of an Upflow Anaerobic Sludge Blanket (UASB).

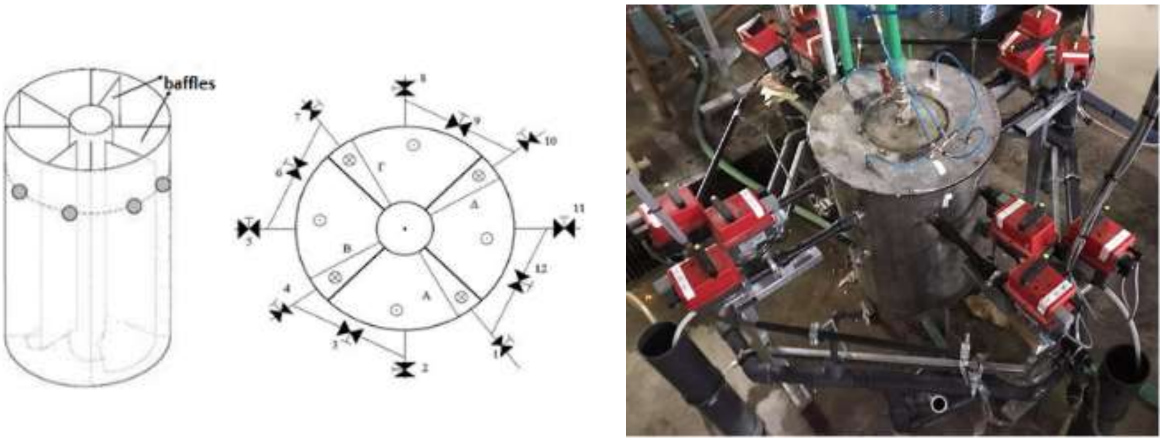

Figure 1. PABR experimental setup

2. Materials and Methods

A pilot-scale 77-L active volume PABR was utilized for the AD experiments. The system was fed with a synthetic municipal wastewater, operating under mesophilic conditions 35ºC, for 147 consecutive days.

The synthetic wastewater used for the PABR in the present study consists of: 10 to 1.0 g/L glucose, 0.306 to 0.0285 g/L NH_4Cl (regarding the experimental phase), 0.08 g/L CH_3COONa, 0.044 g/L KH_2PO_4, 0.0275 g/L $MgSO_4*7H_2O$, 0.0025 g/L $CaCl_2$, 0.004 g/L KCl, 0.125 g/L $NaHCO_3$, 1.875 mg/L $FeCL_3*6H_2O$, 0.1875 mg/L H_3BO_3, 0.225 mg/L KI, 0.15 mg/L $MnSO_4$, 0.0275 mg/L $ZnSO_4*7H_2O$, 0.0375 mg/L $CuSO_4*5H_2O$ and 12.5 mg/L EDTA (Shuli Liu et al., 2020). Every experimental phase had different concentration of glucose and ammonium chloride so that the OLR would be kept constant while reducing the HRT. The concentrations of the above mentioned substances, were chosen by calculating the C/N ratio that would occur so that it remained constant near the value of 50.

The scope of the experimental process was to evaluate the efficiency of the PABR under different conditions in terms of organic load reduction and biogas and biomethane productivity. Municipal wastewaters tend to have COD concentration lower than 1000mg/L, so by reducing the organic load of the feed mixture we tried to approach that value as much as possible.

Therefore, the bioreactor operated under various HRTs and T while the organic loading rate was kept at values near 1 g_{sCOD}/L*d (as outlined in Table 1). In all cases, the ratio of HRT/T was kept constant and equal to 1.

Table 1. Operational Parameters, 6 phases, PABR

Operational Parameters	**Experimental Phases**					
Phases	**1**	**2**	**3**	**4**	**5**	**6**
Operation Duration (days)	21	23	20	10	69	4
HRT (days)	10	6	4	3	2	1
T switching period (days)	2.5	1.5	1	0.75	0.5	0.25

Six distinct experimental phases were carried out as shown in Table 1. Throughout the experimental process pH, total alkalinity, Total Suspended Solids (TSS), Volatile Suspended Solids (VSS), total and soluble Chemical Oxygen Demand (tCOD, sCOD), Volatile Fatty Acids (VFAs) TOC, TN and TKN (data not shown), biogas production and methane content were monitored in regular intervals, to assess the efficiency of the process. TSS, VSS, tCOD, sCOD and alkalinity were measured according to Standard Methods (APHA, 1995), VFAs were measured using a gas chromatograph (SHIMADZU GC-2010 plus), while a GC-TCD (SHIMADZU GC-2014) was used for the measurement of the methane content in the generated biogas. Moreover TOC-L Shimadzu was used for the measurement of total organic carbon and total nitrogen.

3. Materials and Methods

The overall efficiency of the PABR throughout the experimental phases is presented in Table 2:

Table 2. Experimental results, 6 phases, PABR

	Experimental Phases					
Phases	**1**	**2**	**3**	**4**	**5**	**6**
OLR (gsCOD/L*d)	0.91	0.96	0.95	0.90	0.85	0.89
tCOD removal (%)	79.5	83.7	86.9	89.6	85.3	64.9
Biogas productivity (L/d)	25.6	33.8	37.0	35.6	32.3	44.3
CH4 productivity (L/d)	6.9	15.2	18.7	18.5	21.1	26.5

From table 2 it is apparent that HRT reduction from 10 to 1 days significantly affected the biogas and methane productivity, as well as the tCOD removal achieved in the PABR respectively.

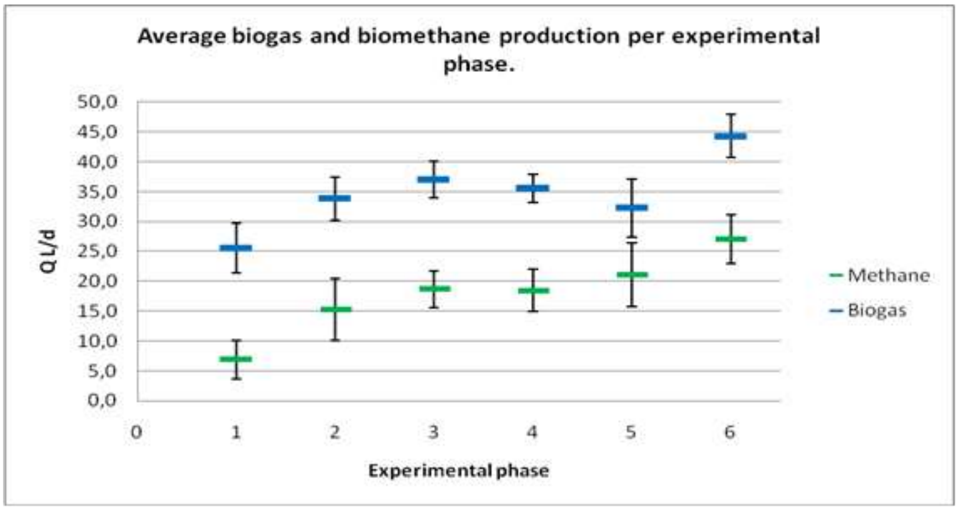

Figure 2. Biogas and biomethane average production throughout the six experimental phases.

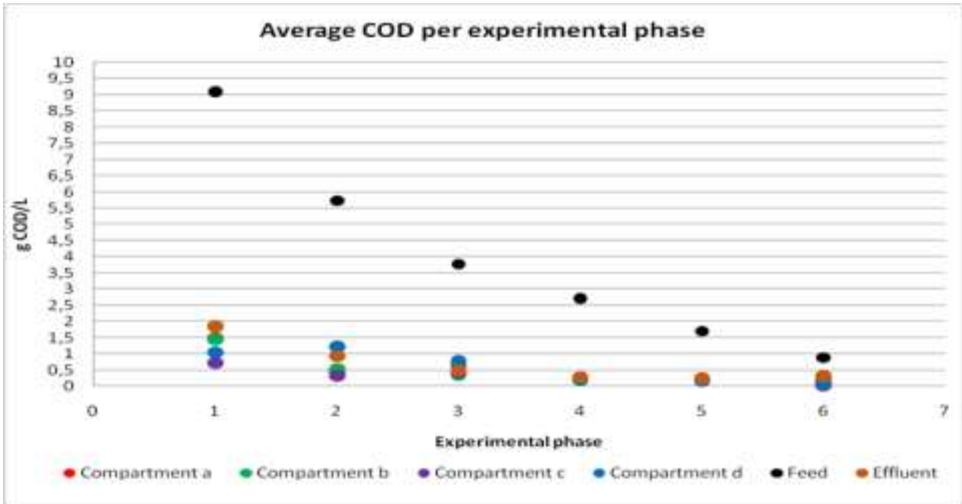

Figure 3. COD concentration in the PABR compartments, Feed and Effluent at every operational experimental phase.

As shown in Figure 2 maximum biogas production observed during the 6th experimental phase, reaching 44.29, while the biomethane production reached 26.5 L/d. As shown in Figure 3 the PABR reactor managed to reduce the effluent COD at every experimental phase that operated.

4. Conclusion

In this paper, we evaluated the efficiency of a PABR for the treatment of a synthetic municipal wastewater operating under different conditions and assessed biogas and biomethane productivity.

It was shown that the PABR can efficiently operate under HRTs as low as 1 day. Specifically, maximum biogas production was observed in the experimental phase when the basic operational parameters were HRT: 1 d and the OLR: 0.89 g_{sCOD}/L*d. In those phases biogas production reached 44.3 L/d, while the biomethane production reached 26.5 L/d. Furthermore, the reduced organic load of the PABR effluent leads to the conclusion that can replace the benchmark approach for treating similar wastes, even though the biogas production is not suitable for energy recovery. For example, at the fourth experimental phase were the COD removal was the highest, the average daily bio-methane production was 30% lower from that of experimental phase 6. This approach would be efficient with liquid wastes of high organic load (10-6 g/L) if the PABR anaerobic system was used as a pretreatment method to aerobic oxidation tanks.

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