Journal of Tropical Resources and Sustainable Science

journal homepage: jtrss.org

Performance of Modified Anaerobic Hybrid Baffled (MAHB) bioreactor treating recycled paper mill effluent: Effects of organic loading rates

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Received 31 October 2017
Accepted 24 November 2017
Online 10 June 2018

Keywords:
organic loading rate, anaerobic digestion, recycled paper mill effluent, modified anaerobic hybrid baffled bioreactor

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Abstract

The performance of modified anaerobic hybrid baffled (MAHB) bioreactor treating recycled paper mill effluent (RPME) was investigated at various organic loading rates (OLR) of 1, 2, 3 and 4 g COD/ L.day. The bioreactor was operated continuously at constant hydraulic retention time (HRT) of a day without effluent recycled and chemicals adjustment/addition. Throughout 70 days of operation, a maximum removal efficiency up to 97% of chemical oxygen demand (COD) and 98% of volatile fatty acid, biogas production of 12.51 L/day equivalent to methane (CH_4) yield of 0.108L CH_4/ g COD and a stable pH system between 6.6 to 7.2 were achieved. Additionally, alkalinity of the bioreactor system shows a stable profile that indicates the whole system was well buffered with a quit high degradation of volatile solid (VS) up to 18%. These results indicated that MAHB bioreactor has been successfully treated RPME at various OLR.

1. INTRODUCTION

Paper industry poses significant environmental effect to receiving waters due to high contents of biodegradable organic matter in their effluent. In Malaysia, total capacity of pulp and paper produced achieved over 1 million tonne per year (Roda and Rathi 2006). According to the statistics, the high production of pulp and paper still does not fulfil the high domestic consumption. Rapid demand in this industry leads to overexploitation of available sources, which caused severe affect to land, water and air environments. This pulp and paper industry generated diverges pollutants depends on the pulping process applied. The use of anaerobic digestion for degradation of biodegradable organic matter from pulp and paper mill effluent (PUPME) provides excellent energy recovery and waste stabilization. The performance of anaerobic digestion in wastewater treatment systems can be improved by sustaining high concentration of biomass due to its proportionality between total biomass and treatment capacity.

Take into account of high organic characteristics of PUPME, anaerobic digestion process was the most suitable approach to solve this problem. Anaerobic baffled reactor (ABR) is suggested as a promising technology for anaerobic treatment. ABR has been used in biological treatment of wastewater using anaerobic digestion process and shows a good recovery of methane and also well sludge handling. A variety of different organic loading rates (OLR) has been reported in literature for ABR, which depending on quality and quantity of microbial community as well as the substrate used. The unique configuration of ABR able to support partial separation of both acidogenesis and methanogenesis process (Zwain, Aziz et al. 2017). Furthermore, ABR do not rely on development of granulated sludge and its modification can result in high capacity and efficiency of organic matter removal without required post treatments process (Zwain, Aziz et al. 2016).

Apart from the advantages offered, some weaknesses of this conventional ABR system are highlighted which are requirement of shallow reactor to maintain acceptable gas and liquid up-flow velocities, which can cause biomass washout and longer start up period (Liu, Tian et al. 2009). Possibilities of nutrients limitations in final compartments, phase separation eliminations and excess of substrate concentration in the front compartment that leads to low pH (accumulation of fatty acids), which exposed the bacteria to toxic conditions are also drawbacks of conventional ABR. In order to eliminate disadvantages of conventional ABR, some modifications are needed and crucial in the design of ABR. The aim of this study was to evaluate the effect of different organic loading rate on the performance of anaerobic digestion using a modified anaerobic hybrid

eISSN Number: 2462-2389

baffled (MAHB) bioreactor in treating recycled paper mill effluent (RPME).

2. MATERIALS AND METHODS

2.1. Bioreactor

A rectangular laboratory scale, MAHB reactor (Figure 1) with a working volume of 58 L which contains 5 compartments separated by modified baffled has been used in this study.

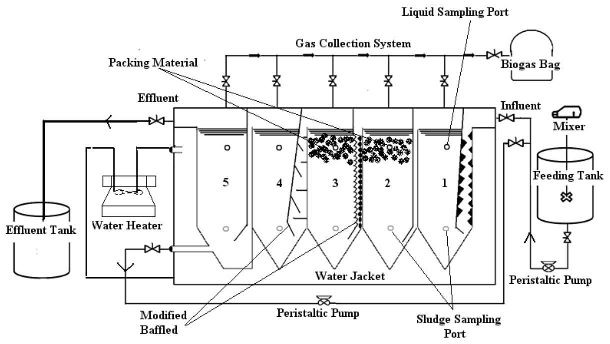

Figure 1: Modified Anaerobic Hybrid Baffled (MAHB) Reactor

MAHB reactor were equipped with polypropylene as ring packing located under surface in compartment 2 and 3 act as supporting media for formation of biofilm. Two sampling ports, (i.e top and bottom) were present for each compartment makes the sampling process more viable. The MAHB reactor was maintain under mesophilic conditions (~38°C) by circulating hot water through bioreactor jacket.

2.2. Bioreactor operation

The reactor was inoculated with methanogenically active biomass from anaerobic sludge (10% v/v) taken from anaerobic pond of Malpom Industries Berhad that were mixed with 750 mg/L COD of recycled paper mill effluent (RPME) taken from Muda Paper Mills Sdn Bhd. The physico-chemical characteristics of the substrate, RPME were investigated. Different influent COD concentration was prepared by diluting RPME using tap water at concentrations of 1000, 2000, 3000 and 4000 mg/L. for each different COD feeding, the steady state performance was evaluated and variation of ±5% in effluent COD concentration at each condition was considered as the criterion for steady state conditions. Reactor digestion method (Jirka and Carter 1975) using Spectrophotometer DR-2800 was employed to measure COD value while biogas composition was analysis using Shimadzu GC-FID with propack N coloum. Helium is flowing at 50 ml/min act as carrier gas, with detector temperature of 38°C, column temperature of 28°C and injector temperature of 128°C. Volatile fatty acid (VFA) was measured using esterification method while the following parameters (i.e. alkalinity, pH, volatile suspended solids (VSS), total suspended solids (TSS) and biological oxygen demand (BOD_5) were analyzed according to Standard Methods (Clescerl, Greenberg et al. 1998). Throughout all analysis, triplicate samples was analysed to increase the result precision and only the average values are reported in this study. It was found that relative error between repeated runs was less than ±5 which shows the repeatability is satisfactory.

3. RESULTS AND DISCUSSION

3.1. Effect of different organic loading rates on biogas and methane production

Biogas productions in terms of days at various OLRs are shown in Figure 2. The plotted line shows increasing values of biogas production at OLR of 2 g COD/L/day from 7.21 L/day to highest production of 12.51 L/day then decreasing to 6.8 L/day of biogas production as the OLRs further increases to 4 L/day.

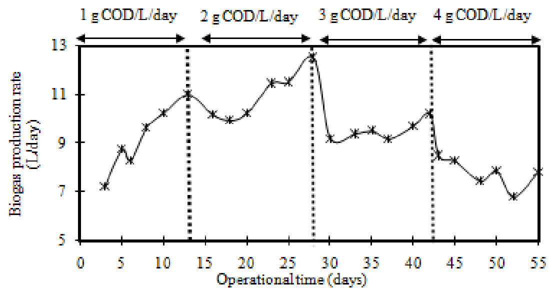

Figure 2: Biogas production rate profile with increasing organic loading rates (OLR) in MAHB reactor during experimental operation period.

This indicates that with the increased in OLR, biogas production is also increased to reach maximum value before started to decrease at the remaining increased OLRs. Kennedy et al. (2006) and Zwain et al. (2017) also obtained similar result where further increment in OLR did not show any improvement in biogas production once the maximum OLR was achieved. This phenomenon might be due to high concentration of toxic materials presence (high loads of RPME at high OLR) that affects the efficiency of anaerobic microorganism (Buzzini and Pires 2002). Furthermore, an increase in OLR led to decreases in conversion of organic matter in wastewater to VFA as well as conversion of VFA to methane. This phenomenon can be explained attributed to a relatively similar population of methanogens subjected to higher substrate concentration. Chaisri et al. (2006) also reported similar trends where high OLRs (10 g COD/L/day) can cause a decrease in biogas production due to not enough microorganisms to deals with the excess substrate. For better understanding, the production rate of biogas and methane at different OLRs are as shown in Figure 3.

As can be seen, both biogas and methane production shows an increment from 10.99 L/day to 12.51 L/day and 6.45 L/day to 7.92 L/day for biogas and methane, respectively as the OLR increases from 1 g COD/L/day to 2 g COD/L/day. However, as the OLR

eISSN Number: 2462-2389

were further increased to 3 g COD/L/day, both biogas and methane production started to decrease. Further increased in OLR to 4 g COD/L/day resulted in slightly constant values of biogas of methane productions. Similar behaviour was also reported by Kennedy et al. (2006) and Torkian et al. (2003). Both researchers suggested that the decrease in methane production at high OLR might be due to inhibition of methanogens. This phenomena might be due to apparent instability that affected by gas bubbles attachment at high OLR condition which then leads to biomass suspension and cell washout.

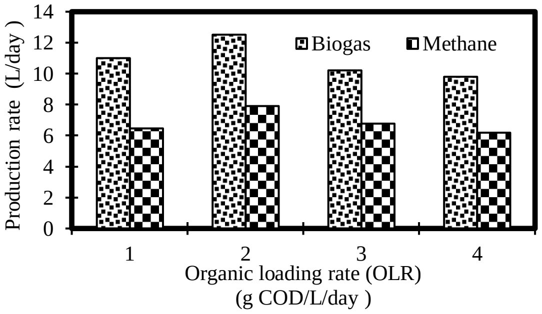

Figure 3: Biogas and methane yield for various organic loading rates (OLR) in MAHB reactor.

Rincon et al. (2007) reported that the reduction in methane production at high OLR can be explained by activity of methanogenic microorganisms that might not impaired up to high OLR because of the inadequate buffering capacities and inappropriate stability provided in the experimental system. From the result obtained, the optimum loading rate is 2 g COD/L/day. Nevertheless, it is cautioned here that this optimal OLR is not universal as the optimal rate depends on operating condition and reactor configurations.

3.2. Effect of different organic loading rates on volatile solid (VS) and COD degradation

Performance of MAHB reactor at different organic loading rates (OLR) can be assessed by VS degradation and COD removal as presented in Figure 4.

As the OLRs were increased from 1 g COD/L/day to 2 g COD/L/day, COD removal efficiency also increased from 86.5% to 97.9%. VS degradation also shows similar increments as organic loading increased. As the OLRs are further increased to 4 g COD/L/day, a slightly decreased in COD removal and VS degradation was noted. Similar trend were also reported by Leitao (2004) which indicates that an increase in OLRs leads to a decrease in solid removal efficiency. As the OLRs were increased, the reduction in VS degradation occurred as a result of sludge washout (caused by turbulence due to gas production) and shorter contact between the sludge biomass and substrate which leads to interruption of biological and physical process that took place inside the MAHB reactor. In contrast, Miron (1997) reported that an increased in solid removal efficiency were noted as the OLRs increased associated to high solid of influent. These variances between previous researchers might be due to primary sludge used to increase OLRs. The primary sludge consisted of settleable suspended solids that increased the suspended solids removal efficiencies due to easier hydrolyzed matter (Rizvi 2010).

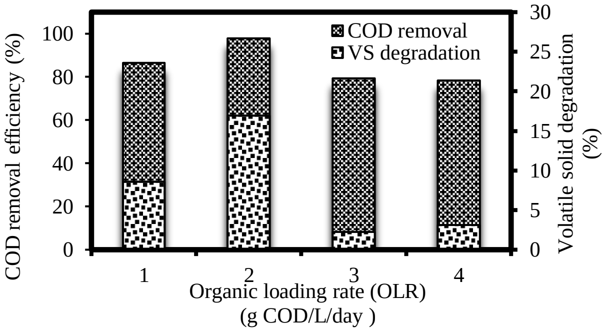

Figure 4: VS and COD removal for various organic loading rates (OLRs) in MAHB reactor.

3.3. Volatile fatty acid (VFA) accumulation

The effluent concentration and removal efficiency of volatile fatty acids (VFA) at different organic loading rates (OLR) are shown in Figure 5. It was observed that as the OLR increased up to 2 g COD/L/day, an increase in VFA concentration to 35 mg/L and a decrease in VFA removal efficiency to 86% (7% reduction) was observed at effluent concentration.

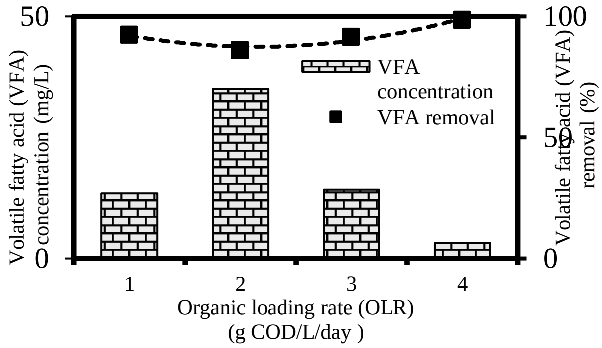

Figure 5: Effluent concentration and removal efficiency of volatile fatty acids (VFA) at different organic loading rates (OLR)

This particular condition might be due to the fact that insufficient amount of acetoclastics methanogens bacteria were presented in the MAHB reactor that can convert the volatile fatty acids to hydrogen, acetate and carbon dioxide or maybe due to VFA inhibition (Wijekoon, Visvanathan et al. 2011). A further increment in OLR to 4 g COD/L/day gave a fast decreased of VFA concentration (3.25 mg/L) which indicates an increased in VFA removal efficiency up to 98.7%. This high removal efficiency indicates that high active methanogenic activities in the MAHB reactor at high OLR since enough substrate presence for better growth of the methanogenic microorganism. This results shows that VFA removal are high for all different OLRs with more than 86% VFA removal efficiency. Furthermore, stable and high pH (6.4-7.3) supports the methanogenic activity.

eISSN Number: 2462-2389

Throughout the whole process, it shows that pH and alkalinity were remained stable in a range of 6.4 - 7.3 and 250 mg/L - 370 mg/L, respectively during the process study. This indicates that the whole system was well buffered and still under the range of methanogenic condition which were proved by high methane content of more than 50% throughout this study.

4. CONCLUSION

In this present study, MAHB reactor shows an excellent performance in terms of COD removal and methane production with increased organic loading rates. However, further increased of OLRs to 4 g COD/L/day favours a process failure with decreasing pH and also COD removal efficiency.

ACKNOWLEDGEMENT

The authors wish to acknowledge the financial support from the Universiti Sains Malaysia (RU-I A/C.1001/PJKIMIA/814148).

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