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The effect of transient loading on the performance of a mesophilic anaerobic contact reactor at constant feed strength

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ABSTRACT

Anaerobic contact reactor is a high rate anaerobic process consisting of an agitated reactor and a solids settling tank for recycling. It was proved earlier that this type of reactor design offers highly efficient performance in the conversion of organic matter to biogas. In this study, the effect of transient loading on reactor performance in terms of a number of key intermediates and parameters such as, COD removal, pH and alkalinity change, VFAs, effluent MLSS concentration and biogas efficiency over time was examined. For this purpose, a step increase of organic loading rate from 3.35 kg COD/m^3 day to 15.61 kg COD/m^3 day was employed. The hydraulic retention time decreased to a value of 8.42 h by an increase in the influent flow-rate during the transient loading. It was observed that the mesophilic anaerobic contact reactor (MACR) was quite resistant to large transient shocks. The reactor recovered back to its baseline performance only in 15 h after the shock loading was stopped. Hence, it can be concluded that this type of reactor design has a high potential in treating food processing wastewaters with varying flow characteristics.

1. Introduction

The main difference between anaerobic wastewater treatment and aerobic treatment is that no aeration is required in the former treatment method. The absence of oxygen allows anaerobic conversion of organic pollutants to biogas which consists mainly of methane and carbon dioxide. The two main advantages of anaerobic treatment can be listed as (i) high organic loading rates (10–20 times as high as in conventional activated sludge treatment) and (ii) low operating costs (Karellas et al., 2010; Hatamoto et al., 2011; Lin et al., 2011a). Anaerobic treatment can often be quite cost-effective in reducing the organic matter combined with the production of reusable energy in the form of biogas, which can be used for electricity production or for heating purposes (Luste and Luostarinen, 2010; Monteiro et al., 2011; Zamalloa et al., 2011).

Anaerobic treatment is quite suitable for industries discharging highly concentrated wastewaters with low nitrogen content such as food processing industry (He et al., 2005; Gohil and Nakhla, 2006; Fang et al., 2011), beer breweries (Parawira et al., 2005; Zupančič et al., 2007; Simate et al., 2011), soft drink producers (Peixoto et al., 2011) or paper processing factories (Buzzini and Pires, 2007; Lin et al., 2011b; Seckin et al., 2011).

Of anaerobic reactors, the contact reactor is a suitable high rate anaerobic process for decomposition of organic matter. Anaerobic contact process consists of an agitated reactor and a solids settling tank for recycling of microorganisms. This process can be considered as a counterpart of activated sludge system in which sludge is recycled from a clarifier to the main reactor. The performance of anaerobic reactors is primarily affected by both the substrate retention time and the degree of contact between influent substrate and microorganism population. Both of these parameters are a function of the mixing conditions ensured in the reactor. Mixing provides a suitable medium so that the biomass remains in suspension and the produced gas can be released from the contents of the reactor (Gerardi, 2003; Karim et al., 2005; Şentürk et al., 2010). Additionally, mixing ensures a homogeneous substrate distribution preventing stratification and formation of surface crust, and transfers heat (Kaparaju et al., 2008; Şentürk et al., 2010). Considering mass transfer rate, the anaerobic contact reactor is more advantageous than conventional anaerobic systems such as upflow anaerobic sludge blanket (UASB) reactors due to the fact that they possess the properties mentioned above. The main advantages of contact process are that it reaches steady-state rapidly, due to mixing, short hydraulic retention times are usually sufficient and relatively high effluent quality is obtained (Şentürk et al., 2010). The system can tolerate organic loading rates up to 8 kg COD/m^3 day and can obtain COD removal efficiencies of around 85–95%. These types of reactors can also operate with high levels of total suspended solids and lipid levels (Ward et al., 2008; Şentürk et al., 2010).

It is known that during a possible organic or hydraulic shock loading, methanogenic precursors such as formate, H_2, CO_2 and

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volatile fatty acids (VFAs) accumulate in anaerobic reactors as a result of an imbalance between input and output parameters (Voolapalli and Stuckey, 2001). However, one of the main disadvantages of anaerobic processes is that these systems are sensitive to shock loadings (Boardman et al., 1995; Borja et al., 1995). Shock loadings often result in process souring and failure due to VFA accumulation (Chua and Chen, 1995). From time to time, wastewater treatment processes could be subjected to variations in operational parameters, such as influent concentration and flow rate, which affect the reactor performance directly. Although these variations can be easily controlled via modern control techniques, the performance of the reactor could still be deteriorated due to extreme disturbances (Jing et al., 2009). It is well known that under sub-optimal conditions, VFA accumulation is an inevitable result in an anaerobic reactor and under such conditions, VFAs contribute mostly to a decrease in pH and to residual soluble COD in the effluent (Aquino and Stuckey, 2008).

There are some studies in the literature investigating the effect of shock loading rate on different anaerobic systems. Chua et al. (1996) investigated the responses of anaerobic fixed-film reactor to hydraulic shock loading, while the COD loading was maintained constant. Nachaiyasit and Stuckey (1997a) used a 10-L anaerobic baffled reactor (ABR) to examine the effect of organic shock loading, at constant hydraulic retention time (HRT) on reactor performance in terms of COD removal, and microbial responses during these shocks. In their other study, they used two ABRs to investigate the effect of transient and step hydraulic shock loading on reactor performance. The reactors were operated at 20-h HRT and 35 °C as a base-line condition (Nachaiyasit and Stuckey, 1997b). In an other study, anaerobic migrating blanket reactor (AMBR) was used to examine the effect of an organic shock loading on the performance and stability of the anaerobic reactor. To accomplish an organic shock load, sucrose solution was almost doubled in concentration at a constant HRT (Angenent et al., 2002). Mathiot et al. (1992) also investigated control parameter variations in an anaerobic fluidised bed reactor subjected to organic shock loading.

However, it should be noted that no study could be found anaerobic contact reactors investigating shock loading. The aim of this study was, therefore, to investigate the effect of a shock loading on the performance and stability of a mesophilic anaerobic contact reactor (MACR).

2. Materials and methods

2.1. Wastewater characterisation

The wastewater used in this study was obtained from a factory producing potato chips, maize chips and other snacks. The wastewater produced after peeling and cutting processes was used during the course of this study and the characterisation of the wastewater is given in Table 1. The wastewater has a COD/N/P ratio of about 275/10/1.

2.2. Mesophilic anaerobic contact reactor configuration and operation conditions

The mesophilic anaerobic contact reactor (MACR) used in this study can be seen in Fig. 1. The reactor and all the other tanks were made of stainless steel. The rector was constructed a completely closed jacketed vessel. It was leak-proof and resistant to pressures up to 2 bars. The piping was installed using Teflon and stainless steel pipes resistant to pressure and acidic/basic conditions. The feed tank was mixed continuously at a rate of 80 rpm to avoid precipitation of the particulate matter such as starch present in wastewater. The reactor was also mixed continuously at a rate of 100 rpm. Additionally, the anaerobic waste sludge was recycled continuously from the settling tank to the reactor. The control volume of the contact reactor was 33 L. Working with such a high volume reactor, compared to other anaerobic reactors studied in the literature, would allow possible scaling up from laboratory scale to full scale easily. The reactor was inoculated with anaerobic granular sludge taken from an anaerobic treatment plant in a potato-processing factory. A 10 L heater tank was attached to the system in order to keep the reactor temperature at 35 ± 2 °C. For this purpose, PT100 temperature sensors were used. The pH of the system was monitored and controlled continuously with a pH probe (Milton roy) and the pH value was adjusted by NaOH when necessary. The water used in gas washing was acidified to pH 3 by the addition of HCl and NaCl in order to prevent biogas dissolution. A heat-insulated separation tank was attached to the system for the prevention of microorganism loss. For the control of the system a programmable logic controller (PLC/Siemens S7 300) was used, and data acquisition and visualisation was carried out using WinCC SCADA (Siemens).

Table 1
Wastewater characteristics (after peeling and cutting processes).

Parameter	Unit	Average
TCOD	g/L	5.5
SCOD	g/L	2.75
BOD_5	g/L	4.5
Alkalinity	g $CaCO_3$/L	2.25
pH	–	7.5
Temperature	°C	17.5
Total Kjeldahl nitrogen	g/L	0.225
Ammonia	g/L	0.055
Sulphate	g/L	0.45
Total solid matter	g/L	4.90
Total suspended solids	g/L	2.05
Total volatile solid matter	g/L	4.45

In order to study the effects of different operational parameters, the MACR was continuously operated for more than 1 year, before the organic shock loading study was performed (Şentürk et al., 2010). During this operation time, it was observed that the reactor performance started to deteriorate when higher OLR values than 5 kg COD/m^3 day were applied. Therefore, considering the results obtained in the study (Şentürk et al., 2010), OLR was increased from 3.35 kg COD/m^3 day to 15.61 kg COD/m^3 day by increasing wastewater flow rate, to examine the effects of shock loading on the performance and stability of the MACR.

2.3. Analytical methods

All the chemicals used were of analytical reagent grade and water used during the experiments was laboratory distilled water. The COD and BOD_5 analyses were carried out according to the STM 5220C and STM 5210 B methods, respectively (APHA, 2005). The TKN and NH_3 analyses were also performed using the STM 4500-Norg B Macro-Kjeldahl and STM 4500-NH_3 C methods, respectively (APHA, 2005). The sulphate analyses were carried out using the STM 4500-SO_4^{2-} method. The alkalinity and total volatile fatty acid concentrations were determined according to STM 2320 B and STM 5560C methods, respectively (APHA, 2005). Separate volatile fatty acid concentrations were also conducted by a Gas Chromatography (Agilent) equipped with FID detector and a Zebran ZB-Wax capillary column, 30 m × 250 μm × 0.50 μm. Helium was used as the carrier gas. The oven temperature was initially set at 100 °C for 1 min increasing 20 °C/min to 120 °C and then increasing 6.13 °C/min to 205 °C. The total duration was 15.87 min. The detector temperature was 240 °C. The samples taken from the reactor were centrifuged for 15 min at 10,000 rpm at room temperature and the supernatant of the sample was analysed accordingly. Additionally, the total solid