ANAEROBIC TREATMENT OF WASTEWATER FROM SUGAR CANE INDUSTRY

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Abstraksi
Sebuah reaktor *upflow anaerobic sludge blanket* (UASB) digunakan untuk mengetahui kemampuan proses anaerobik untuk menguraikan zat pencemar organik dari air limbah indusri gula. Dengan menggunakan lumpur granular dari reaktor UASB yang mengolah limbah industri buah dan sayur, reaktor dalam penelitian ini mampu mengurangi kandungan COD air limbah sampai 80 % dalam waktu 5 minggu sejak pertama kali dioperasikan. Selama waktu penelitian, reaktor dapat dioperasikan pada beban organik sebesar 2.7 g COD / l· d dengan efisiensi pengurangan COD rerata sebesar 86 %.
Kata kunci: UASB, proses anaerobik, limbah industri gula

INTRODUCTION

In many developing countries, especially in Asia and South America, sugar cane industry is one of the most important agricultural industries. As a consequence, sugar cane industry has significant wastewater production. Unfortunately, due to the lack of know-how and financial support, most of sugar cane industries in developing countries discharge their wastewater without adequate treatment. Similar with other wastewater generated by food processing plants, wastewater from sugar cane industry generally contains organic materials such as carbohydrates and proteins.

Current mainstream technologies for wastewater treatment, such as aerobic activated sludge and tertiary nutrient removal processes seem to be based on rather high capital costs, which consume more energy, more skilled labour requirement, produce more sludge, and do not allow recovery of valuable energy and nutrients. In some extends, those technologies are not economically and technologically affordable, especially for developing countries where the availability of high skilled personal and permanent energy supply are not guaranteed.

Although anaerobic reactors for wastewater treatment have been used since more than 2000 years ago in the form of Indian and Chinese animal manure digesters (Veenstra, 2000), the anaerobic process had been ignored for a long time as an option for wastewater treatment since it was considered to be inefficient and too slow to serve the needs of quickly expanding wastewater volumes especially in industrialized and dense populated area (Polprasert *et al.*, 2001). Pushed by the world energy crisis, anaerobic digestion for wastewater treatment has been "rediscovered" in the late of 1960s. Since the work of Young and McCarty (1969, cited in Hickey *et al.*, 1991), the application of anaerobic process for industrial and municipal wastewater treatment has been considered as a practical and an economical alternative to aerobic wastewater treatment.

Considering the kinetics, microbiology and modelling aspects, Iza *et al.* (1991) suggested that the concept of high-rate anaerobic reactors is based on three fundamental aspects:

(i). Accumulation of biomass within the reactor. Since the growth of microorganisms is very slow, the efficient operation of high rate anaerobic treatment is determined by the ability of to retain biomass concentration within the reactor by effective separation of the biomass from the liquid. This aspect can be reached by means of settling, attachment to support media or by recirculation.

(ii). Improving contact between wastewater and biomass. This aspect overcomes the problems of substrates and products from the bulk liquid to the biomass (biofilms or granules). It can be reached by proper mixing within the reactor (e.g.: contact process reactor), evenly distributing the effluent and avoiding short-circuit (e.g.: anaerobic filter reactor, UASB, and fixed bed reactor) or providing sufficient reactor height in order to achieve proper distribution of effluent (e.g.: downflow stationary fixed film reactor).

(iii). Enhancing the activity of the biomass, due to adaptation and growth. Since anaerobic process is performed by a number of bacterial trophic groups, it is

necessary to characterize the population dynamics and activity of these different groups.

The purpose of this study is to examine the biodegradability of organic components of wastewater from sugar cane industry wastewater and to examine the possibility of using upflow anaerobic sludge blanket reactor to treat wastewater from sugar cane industry by evaluating the start-up process and the operation performance.

MATERIALS AND METHODS

An upflow anaerobic sludge blanket (UASB) reactor with an operational volume of 2.3 L (including recirculation flow) was employed in this study. The reactor was water jacketed and operated at constant temperature of 37 $^{\circ}$C. Schematic diagram of the reactor used in this study is shown in Figure 1.
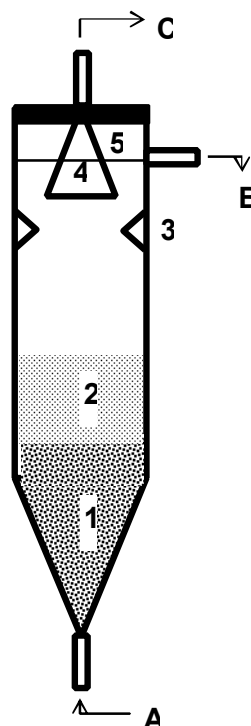
Figure 1. Typical cross section of a UASB reactor:

(1). granular sludge bed   A: influent
(2). sludge blanket zone   B: effluent
(3). gas bubbles deflector   C: gas outlet
(4). gas collector
(5). settling compartment

The inoculum for this reactor was granular sludge obtained from full scale UASB reactor treating wastewater from fruit and vegetables industry and was stored in 8 ^{o}C cooling room for 20 months. The initial weight of the seeding sludge was approximately 43 g VSS (volatile suspended solids).

This study used artificial sugar cane industry wastewater, which was slightly modified from OECD synthetic wastewater for domestic wastewater (European Commision, 1967). This composition gave an average chemical oxygen demand (COD) value of 5700 mg/l.

Table 1. Composition of the synthetic sugar cane industry wastewater

Constituents	Chemical Form	Amount (g/100 ltr)
Pepton	-	16
Meat extract	-	11
Urea	CH_4N_2O	3
Sodium chloride	NaCl	0.7
Calcium chloride-dihydrate	$CaCl_2.2H_2O$	0.4
Magnesium sulfate-heptahydrate	$MgSO_4.7H_2O$	0.2
Dipotassium hydrogen-phospate	K_2HPO_4	2.8
Sucrose	$C_{12}H_{22}O_{11}$	500

In the start-up period, the reactor was continuously fed with wastewater was started with a hydraulic retention time (HRT) of 10 days. After stable performance was achieved, the organic loading rate (OLR) was increased by lowering the HRT to 5 days, 2 days and 1 day.

To observe the performance of the reactor, residual fatty acids and COD value of both effluent and influent were measured 3-5 times per week. The determination of the COD was done using the method of Wolf and Nordmann as has been employed by other researchers (Phoolphund, 1997; and Koydon, 2004).

The residual volatile fatty acid composition of the effluent was determined using a method that was described by Gallert and Winter (1997). The measurement was done with a gas chromatograph from PACKARD, model 437 A. The gas chromatograph equipped with a flame ionisation detector (FID) with hydrogen (30 ml/min.) and syntethic air (300 ml/min.) as burning gas.

RESULTS AND DISCUSSION

Loading Regimes

As soon as the inoculum sludge was transferred, the reactor was filled with tap water and then continuously fed with sugar cane wastewater at hydraulic retention time (HRT) of approximately 10 days. This HRT gave the reactor an organic loading rate (OLR) of approximately 0.5 g COD/ l· d. After COD removal efficiency of the reactor reached over 80%, the OLR was increased step wisely by lowering the HRT. During the operation of the reactor in this experiment, the HRT was lowered from 10 d to 5 d and 2 d. This made the OLR increased from 0.5 g COD/ l· d to 1.0 g COD/ l· d, 2.7 g COD/ l· d and 5.2 g COD/ l· d respectively (see Fig. 2).
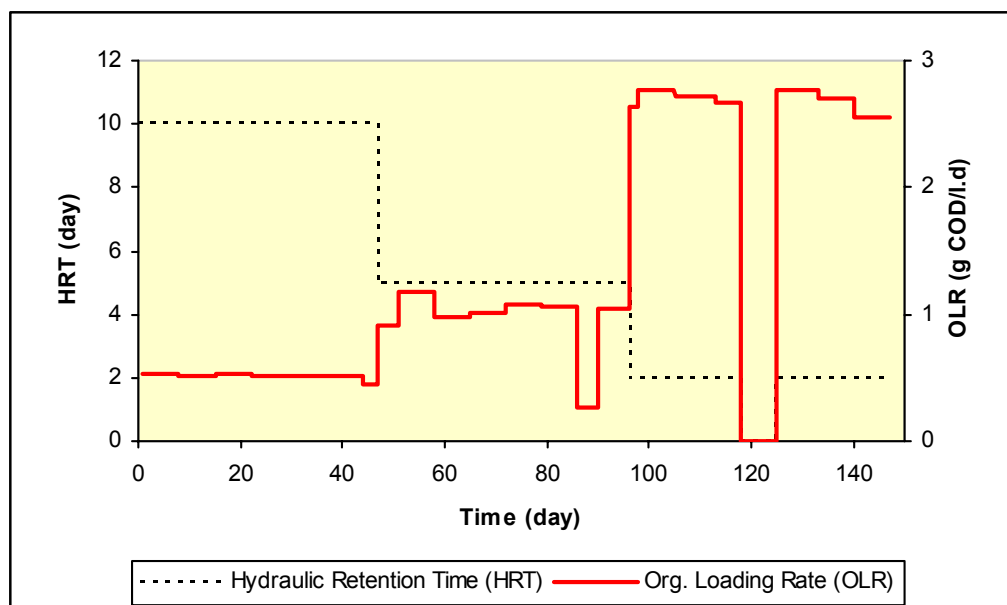

Figure 2. Loading regimes in terms of HRT and OLR. The variations of OLR value within the same HRT were due to the COD value variations of the synthetic wastewater.

In the 18th week of operation, reactor R2 experienced a failure of thermostat due to twisting of warm water jacket tube. This failure caused a temperature drop from 32 °C to about 24 °C. Since there was a symptom of operation failure, the inlet was stopped for 7 days to allow reparation and degradation of residual fatty acids. After the reactor operated in normal temperature condition and most of the accumulated volatile fatty acids were removed, the reactor was reloaded with an OLR of 2.7 g COD / l· d.

**COD Removal Efficiencies and COD Removal Activities**

After initial loading with an OLR of 0.5 g COD / l· d, the reactor had a COD removal efficiency of approximately 60 %. However, it took about 5 weeks to reach 80 % of COD removal efficiency. The COD removal efficiency of the reactor reached an average value of 84 % when the reactor was loaded with an OLR of 0.5 g COD / l· d (only in the stable operation phase). After increasing the OLR of the reactor to 1.1 g COD / l· d and 2.7 g COD / l· d, the average COD removal efficiency was 85 % and 86 %, respectively (see Fig. 3).
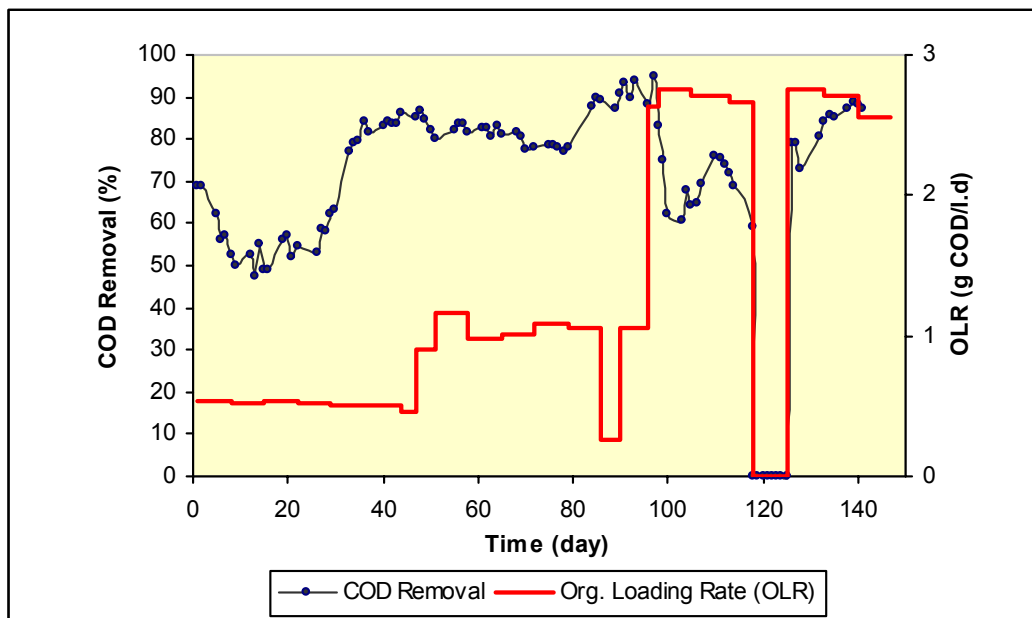
Figure 3 COD removal efficiency and its relationship to the OLR.

A decrease of COD removal efficiency was observed when the organic loading rate was increased from 1.1 g COD / l· d to 2.7 g COD / l· d. The removal

efficiency decreased from 88 % to 64 %. However, this OLR increment did not lead to an organic overload symptom. The COD removal efficiency was also hindered when the temperature was suddenly dropped. In the 18th week, the reactor experienced a failure of the thermostat caused by a twisted tube. The failure caused the temperature of the reactor system drop from about 32 ^{o}C to ambient temperature of approximately 20 ^{o}C to 24 ^{o}C. This temperature decrease occurred when the operation of the reactor was considered as not yet stable after increment of its organic loading rate (COD removal efficiency has not yet reached 80 % and residual fatty acids concentration in the effluent were more than 10 mM). The combination of both conditions caused the COD removal efficiency of the reactor dropped from 73 % to 59 %.
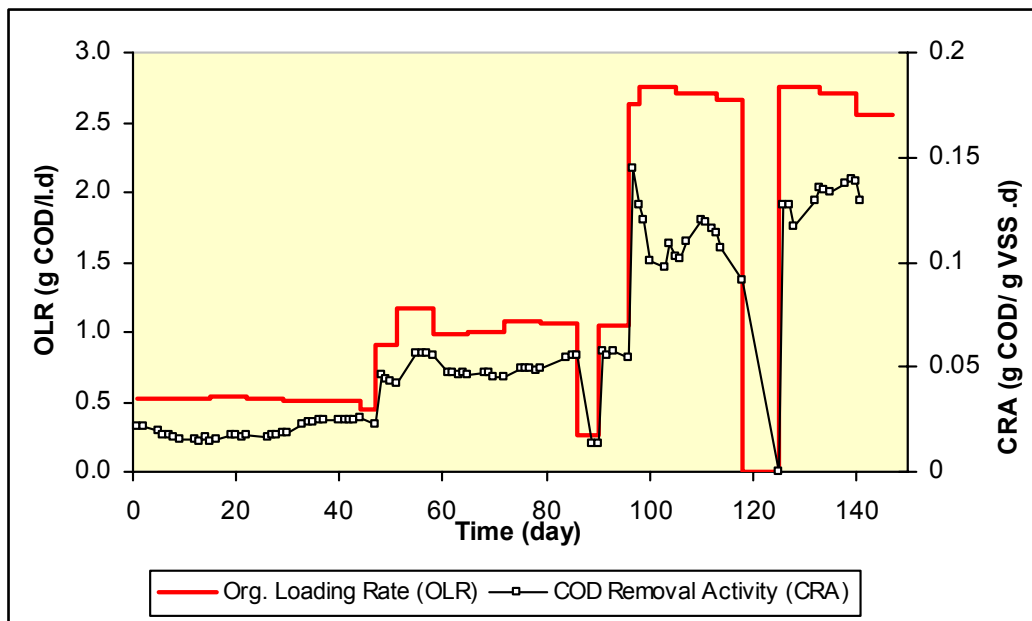

Figure 4 COD removal activity of reactor R1 and its relationship with the OLR.

The COD removal activity of the reactor corresponded with the OLR value. When the OLR was increased, the value of COD removal activity also increased. Under an OLR of 0.5 g COD / l· d, the COD removal activity reached 0.024 g COD/ g VSS· d. When the OLR was increased to 1.1 g COD/ l· d and 2.7 g COD/ l· d, the COD removal activity of the reactor reached 0.049 g COD/ g VSS· d and 0.135 g COD/ g VSS· d, respectively (see Fig. 4).

Residual Volatile Fatty Acids

The predominant residual volatile fatty acids found in the reactor were acetate and propionate (see Fig. 5). Under stable operation, the concentration of acetate was much higher than the concentration of propionate. It can be concluded that acetate degradation was more rate-limiting compared to the other fatty acids degradation.
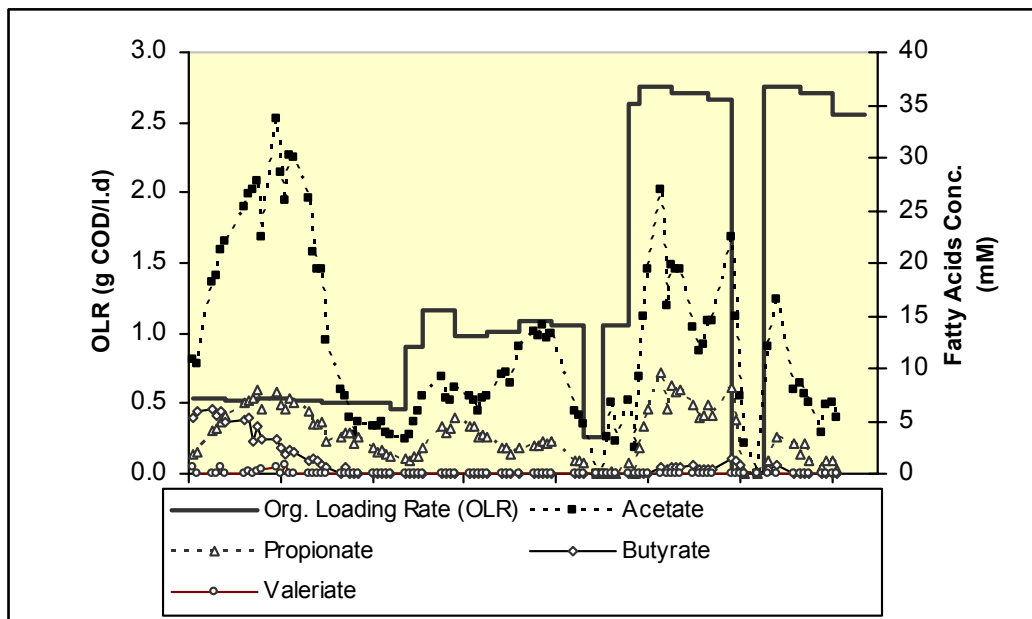
Figure 5   Residual fatty acids in the effluent and the relationship with the OLR.

The increase of fatty acids concentration was related with the increase of organic loading rate. When the organic loading rate was increased, residual fatty acids in the effluent would also increase. This condition occurred since the aceticlastic methanogenic bacteria consortia needed time of acclimatization to degrade more acetate. The same condition applied to acetogenic and acidogenic bacteria. The consequence of accumulated fatty acids in the effluent was the decrease of COD removal efficiency. When fatty acids concentration in the effluent increased, it caused the decrease of the COD removal efficiency (see also Fig. 6).
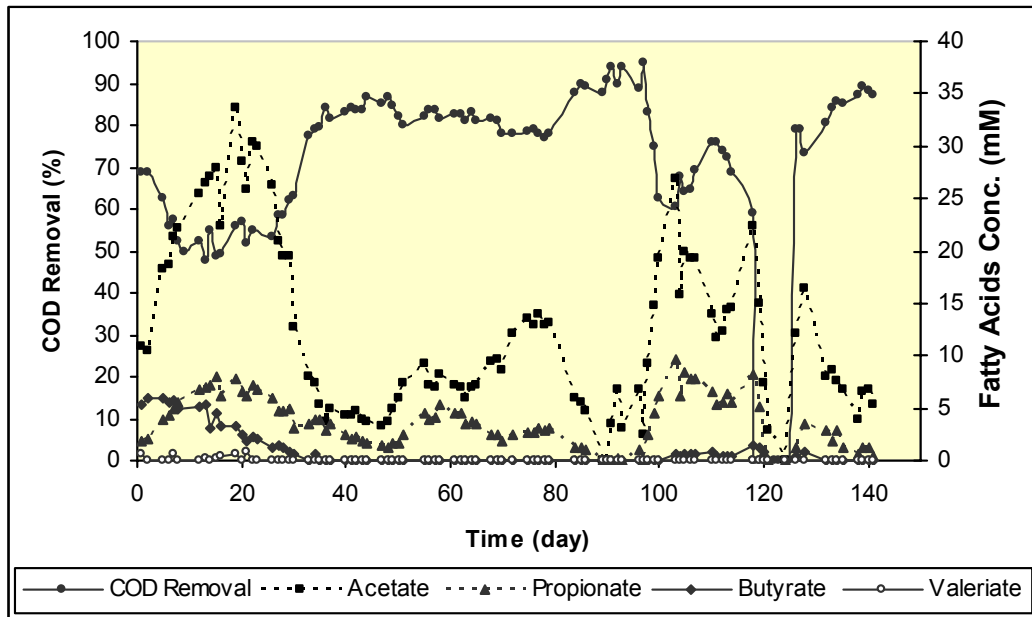
Figure 6   Residual fatty acids in the effluent and the relationship with the COD removal efficiency

When the reactor reached stable operation, valeriate and butyrate concentrations in the effluent were zero or nearly zero. It could be concluded that valeriate and butyrate were easily degraded to acetate or propionate by acetogenic bacteria in the reactors, presumably *Syntrophomonas wolfei*.

If it is compared to the total COD value of the effluent, the COD value in the form of volatile fatty acids in the effluent had relatively high percentage. The COD value in the form of fatty acids reached a range of 50% to nearly 100% compared to the total COD value of the effluent. This high value indicates that sugar cane industry wastewater was relatively easy to degrade.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

From the results of this study, it can be concluded that there is the possibility to use granular sludge from one UASB reactor as an inoculum for another UASB reactor, although the sludge can be categorized as relatively inactive and due to a long storage period without feeding. It supports the report that granular sludge can be stored for many months without loosing its activity

(Lettinga *et al.*, 1980 in Polprasert et al. 2001). Granular sludge has the ability to increase its activity by applying a proper organic loading rate, considering the "readiness" of methanogenic bacteria to utilize the products of fermentive and/or acetogenic bacteria.

Lower temperature hindered the ability of UASB reactor to degrade organic materials. Failure of the thermostat caused the temperature of the reactor system to drop from about 32 ^{o}C to ambient temperature of about 20 ^{o}C to 24 ^{o}C. In combination with a not yet stable operation after increment of its organic loading rate (COD removal efficiency have not yet reached 80 % and residual fatty acids in the effluent were more than 10 mM), the COD removal efficiency of the reactor dropped from 73 % to 59 %. The accumulation of fatty acids was also observed, indicating that there were unbalanced activities of acetogenic bacteria and methanogenic bacteria.

In general, it can be concluded that anaerobic processes can be used as an option for sugar cane industry wastewater treatment. Anaerobic technology offers high organic matter removal and possibility of energy recovery in the form of biogas.

Recommendations

Some recommendations are proposed based on the experiences of this study:

1. Fang and Chui (1993 cited in Fang *et al.*, 1995) reported that the COD removal efficiency of an UASB reactor is mainly dependent on organic loading rate and was not sensitive to either COD level of wastewater or hydraulic retention time, thus the effort towards maximum operation of UASB reactor is suggested to be done by stepped-loading process. This method can be proceeded by considering the amount of organic loading rate and also hydraulic retention time, e.g. increasing the OLR from 1 kg COD /m^{3}· d to 2 kg COD /m^{3}· d to 3 kg COD /m^{3}· d and so on (by means of increasing the COD concentration and not by lowering the HRT). This

stepped-loading process is necessary to enhance the growth and activity of methanogenic bacteria and continue reactor efficiency.

2. Adjusting effluent recycle ratio is also necessary in order to enhance the mixing of wastewater and granular sludge bed and to avoid washout. In UASB reactors with a low flowrate and low organic concentration, natural mixing is not reliable since the force from effluent is very limited and only a few gas bubbles are produced. Thus, an effluent recycle is necessary.

3. To have higher COD removal efficiency, especially for carbohydrate-rich wastewater, that must be hydrolysed, it is suggested to have two stages of UASB process. The first reactor is used for hydrolysis and acidification process, and then the products of the first reactor (fatty acids) are fed as substrates to the second reactor. The second reactor functions as methanogenesis reactor.

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