Journal of Applied Sciences

ISSN 1812-5654

science alert

ANSInet
an open access publisher
http://ansinet.com

Journal of Applied Sciences 10 (3): 226-230, 2010
ISSN 1812-5654
© 2010 Asian Network for Scientific Information

Kinetics Study of Sewage Sludge Treatment by an Aerobic Digestion

[1]Abdurahman H. Nour, [1]Azhary H. Nour, [1]A.P.S. Vissaliny and [2]A.P.V. Rajaletchumy
[1]Faculty of Chemical and Natural Resources Engineering,
[2]Faculty of Industrial Sciences and Technology, University Malaysia Pahang, UMP, Lebuhraya,
Tun Razak, 26300, Kuantan-Pahang, Malaysia

Abstract: In this study, a 50 L laboratory scaled Membrane Anaerobic System (MAS) combining ultrafiltration (UF) membrane with anaerobic reactor was used to treat raw sewage sludge. Six steady states were attained as a part of a kinetic study. The three kinetic models (Monod, Contois and Chen and Hashimoto) were successfully fitted. The results of all six steady states were successfully fitted above 98% by Monod, Contois and Chen and Hashimoto. Contois model appeared to be the best at 99.7%. The microbial kinetic constants were Y = 0.74 g VSS g^{-1} COD and b = 0.20 day^{-1}. The minimum solids retention time, θ_c^{min} obtained from the three kinetic models ranged from 5-16.9 days. The k values were in the range of 0.350-0.519 g COD g^{-1} VSS day and μ_{max} values were between 0.259 and 0.384 day^{-1}. The Solids Retention Time (SRT) decreased from 1250 days to 16.1 days. The methane gas yield was between 0.19 to 0.54 L g^{-1} COD day^{-1} when the organic loading rate increased from 0.1 kg COD/m^3/day to 10 kg COD/m^3/day. The COD removal efficiency was 96.5-99% with HRT of 7.8 days. And the rage of mixed liquor suspended solids was from 12760 to 21800 mg L^{-1}.

Key words: Anaerobic, ultrafiltration, sewage sludge, kinetics, steady state, treatment

INTRODUCTION

An aerobic digestion is a naturally occurring microbiological process in the environment; best observed in swamps and deep reaches of sediments in water and soil. The 1970s energy crisis revealed another role of anaerobic digestion-that of providing methane gas as alternative fuel. An early 1980s survey of biogas plants in Europe found that most of the plants were used in fact full-scale operating plants. An aerobic biological processes have received high interest in wastewater treatment owing to attractive advantages of energy saving, biogas recovery and lower sludge production. With the advancement of membrane technology, application of membrane filtration in the treatment of wastewater can contribute to developing an efficient wastewater treatment process that is capable of retaining biomass concentration within the reactor and producing high quality effluent. Membrane technology was also applied by Ahmad *et al*. (2003). Ultra-Filtration (UF) and Reverse Osmosis (RO) processes were used after two pretreatment stages consisting of chemical treatment and adsorption. It is a high cost approach in terms of construction and operation. Ponding systems commonly used for POME treatment need long retention times of 45-60 days (Chin *et al*., 1996). Also, it is difficult to maintain the distribution of liquor to ensure smooth performance over a huge area. Some researchers reported that, aerobic degradation of POME by a tropical marine yeast (*Yarrowia lipolytica*) NCIM3589 in a lagoon was studied. Ninety-five percent of COD removal was achieved with a retention time of 2 days. Treatability of POME was also examined in an aerobic Rotating Biological Contactor (RBC), which eighty-eight percentage of COD removal was obtained at an Hydraulic Retention Time (HRT) of 55 h when the influent COD concentration was 16,000 mg L^{-1}. An aerobic treatment is the most suitable method for the treatment of effluents containing high concentration of organic carbon (Perez *et al*., 2001). As compared with the conventional treatment methods, it can offer among others, clear final effluent, less usage of chemicals, low energy consumption, small foot-print and low maintenance cost. Membrane separation techniques have proven to be an effective method is separating biomass solids from digester suspensions and recycle them to the digester (Thamer *et al*., 2007). Several studies on membrane anaerobic processes for the treatment of various wastewater have been done (Pillay *et al*., 1994; Fakhru'l-Razi, 1994; Sui *et al*., 2007). These studies have showed that the Membrane Anaerobic System (MAS) processes had retained all particulate matters and consequently liquefied and decomposed them due to long solids retention time. For the accurate and precise design

Corresponding Author: Abdurahman H. Nour, Faculty of Chemical and Natural Resources Engineering,
University Malaysia Pahang, UMP, Lebuhraya, Tun Razak, 26300, Kuantan-Pahang, Malaysia

Table 1: Mathematical expressions of specifics substrate utilization rates for known kinetic models

Kinetic model	Eq. 1	Eq. 2
Monod	$U = \frac{k\,S}{k_s + S}$	$\frac{1}{U} = \frac{K_s}{K}(\frac{1}{S}) + \frac{1}{k}$
Contois	$U = \frac{U_{max} \times S}{Y(B \times X + S)}$	$\frac{1}{U} = \frac{a \times X}{\mu_{max} \times S} + \frac{Y(1+a)}{\mu_{max}}$
Chen and hashimoto	$U = \frac{\mu_{max} \times S}{Y\,K\,S_o + (1-K)\,S\,Y}$	$\frac{1}{U} = \frac{Y\,K\,S_o}{\mu_{max}\,S} + \frac{Y(1-K)}{\mu_{max}}$

of the bioreactor, it is very important to have values of kinetic parameters involved in the bioreactor. These parameters depend on type of substrate, microorganisms and temperature. Domestic sewage, on the other hand, is a complex substrate and kinetic data on its biodegradation in anaerobic systems are limited. Three widely used kinetic models used in this study were shown in Table 1. The objective of this study is to evaluate the applicability of three kinetic models (Monod, Contois and Chen and Hashimoto), overall microbial kinetics, as well as the influence of the organic loading rates and retention times on kinetic models.

MATERIALS AND METHODS

This research was conducted in 2008 at University Malaysia Pahang-UMP research laboratory. A laboratory digester of Membrane Anaerobic System (MAS) with an effective 50 L volume was used to treat the raw sewage sludge. A schematic representation of laboratory of Membrane Anaerobic System (MAS) which consists of cross flow ultrafiltration membrane (CUF) apparatus, (Fakhru'l Razi, 1994) a centrifugal pump and an anaerobic reactor is shown in Fig. 1. The UF membrane module has molecular weight cut-off (MWCO) of 200,000 and a tube diameter of 1.25 cm and an average pore size of 0.1 μm. The length of each tube is 30 cm. The total effective area of the two membranes is 0.024 m^2. The maximum operating pressure on the membrane is 55 bars at 70 °C and it can be used in pH range from 2 to 12. The reactor was made up of clear PVC with an inner 15 cm and a total height of 100 cm. The operating pressure in this study was maintained between 1.5-2 bars by manipulating the gate valve at the retentate line after the CUF unit. For the gas measurement, the gas volume was measure daily, using a 20 L displacement bottle. The gas method used to perform this analysis was J-Tube gas analyzer, which shown in Fig. 2. The method assuming that the biogas produced only of two gases CO_2 and CH_4 then sodium hydroxide solution (NaOH) was added to the composition. Sodium hydroxide was absorbing the CO_2. The remaining volume is methane gas CH_4. The device was consists of a glass-tube connected by a flexible hose to a syringe. Initially, the device was filled with 0.5 M NaOH solution, the glass tube was inserted into the gas line, where a column of biogas is drawn into the glass-tube until a certain mark and the end of the glass-tube then immersed in water. By manipulating the syringe many times, the NaOH solution was absorbing the carbon dioxide CO_2, as evidenced from

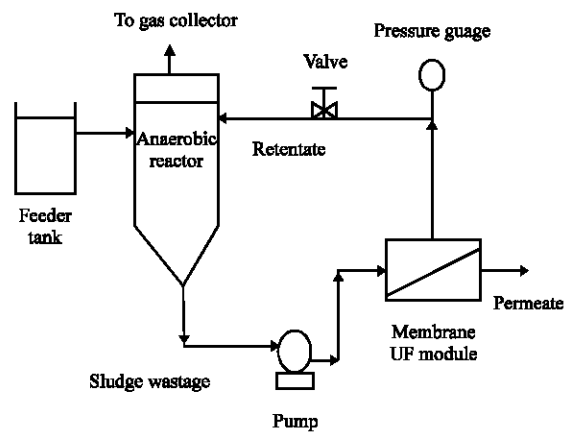

Fig. 1: Experimental set-up

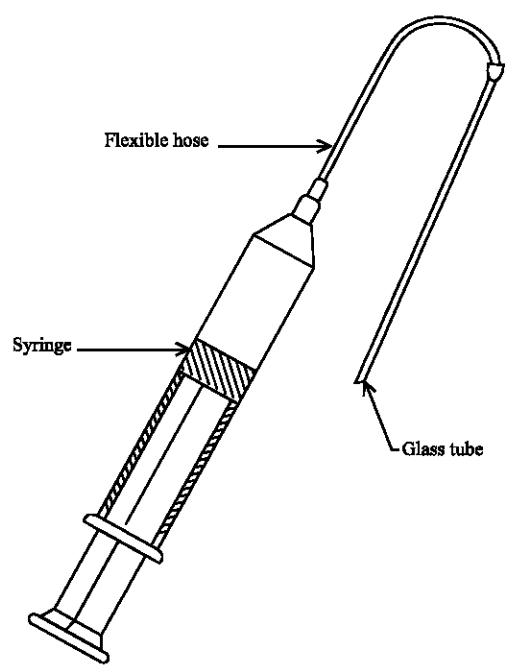

Fig. 2: J-Tube gas analyzer

reduction in the length of the biogas column and then measured the biogas column again. The percentage of methane in the biogas is:

$$\frac{\text{Final length of gas column}}{\text{Initial length of gas column}} \times 100\%$$

A 20 L water displacement bottle was used in this study to measure the daily gas volume. Since the biogas produced composed only of two gases CO_2 and CH_4, sodium hydroxide solution (NaOH) was added to the composition to absorb CO_2, the remaining volume is methane gas CH_4. In this study, the system was said to achieve steady state when the operating and controlling parameters were within ±10 of the average value.

RESULTS AND DISCUSSION

Table 2 shows the experimental results obtained from this research. The kinetic coefficients of the selected three models were derived from Eq. 2 in Table 1 by using a linear relationship. The coefficients are summarized in Table 3. Results obtained from this study showed that, the three models shown a good relationship with R^2> 99% for the Membrane Anaerobic System (MAS) treating raw sewage sludge as shown in Fig. 3-5. The better performance of both models (Contois and Chen and Hashimoto) implied that organic loadings should be taken into consideration for digester performance. In fact, these two models suggested that the predicted permeate COD concentration (S) is a function of influence COD concentration (S_o). However, in Monod model, the permeate COD concentration, S is independent of S_o. The excellent fitting of these three models (R^2>99%) in this study suggests that, the membrane an aerobic system process is able to sustain loadings between 0.1 and 10.0 kg/COD/m^3/day.

At the first steady state, the MLSS concentration was 12760 mg L^{-1} while the MLVSS concentration was 9540 mg L^{-1} which was 74.8% of the MLSS. This was somewhat low and can be attributed to the high content of suspended solids in the sewage sludge. However, the Volatile Suspended Solids (VSS) fraction was increased from 74.8 to 78% of the MLSS at the sixth steady state. This indicated that the long SRT of the MAS had allowed for the decomposition of the suspended solids and subsequent conversion to methane and this observation was also reported by Yildiz *et al.* (2004). The HRT's for

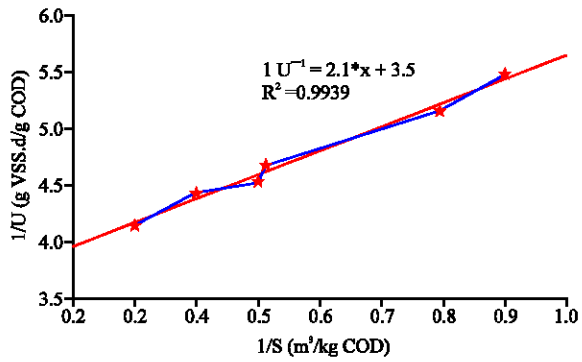

Fig. 3: Monod model

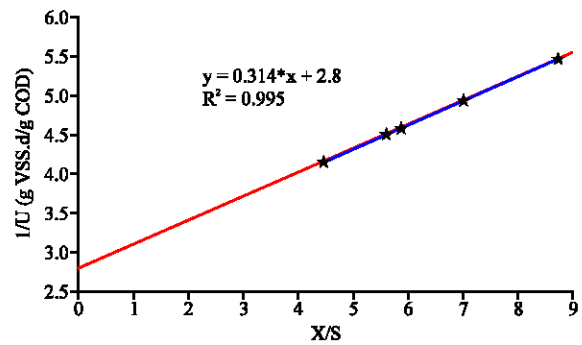

Fig. 4: Contois model

Table 2: Summary of experimental results Steady State (SS)

Experimental results	1	2	3	4	5	6
Feed (L day^{-1})	0.053	0.58	1.875	4.0	4.52	6.41
COD feed (mg L^{-1})	94000	86500	80000	80000	77500	78000
COD permeate (mg L^{-1})	1090	1480	1900	2200	2500	3800
Total gas yield (L g^{-1} COD day^{-1})	0.28	0.34	0.60	0.74	0.70	0.81
Methane (%)	69	76.3	74.4	71.8	69.1	66.3
CH_4 yield	0.19	0.26	0.45	0.53	0.48	0.54
MLSS (mg L^{-1})	12760	13870	15400	16300	18200	21800
MLVSS (mg L^{-1})	9540	10400	11200	12400	14000	17000
HRT (day)	943.4	86.2	26.7	12.5	11.06	7.80
SRT (day)	1250	625	200	55.6	21.7	16.1
OLR (kg COD/m^3 day^{-1})	0.1	1	3	6	7	10
BLR (kg COD kg^{-1} VSS day^{-1})	0.01	0.10	0.27	0.48	0.50	0.59
SSUR (kg COD kg^{-1} VSS day^{-1})	0.183	0.201	0.218	0.222	0.226	0.241
SUR (kg COD/m^{3}day^{-1})	0.0249	0.9174	2.9008	5.8759	6.8676	9.8427

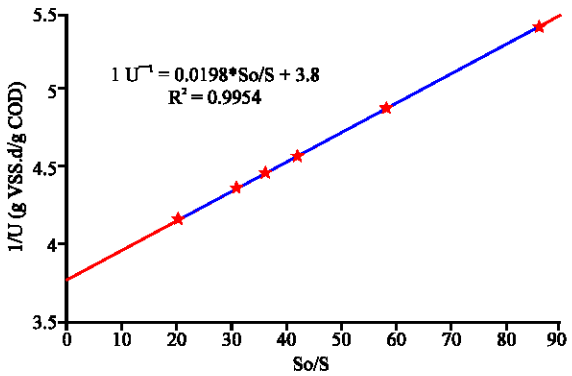

Fig. 5: Chen and Hashimoto model

Table 3: Results of the application of three known substrate utilization models

Model	Equation	R^2 (%)
Monod	$U^{-1} = 2025\ S^{-1}+3.61$	99.4
	$K_s = 498$	
	$K = 0.350$	
	$\mu_{Max} = 0.259$	
Contois	$U^{-1} = 0.306\times S^{-1}+2.78$	99.7
	$B = 0.111$	
	$\mu_{Max} = 0.344$	
	$a = 0.115$	
	$\mu_{Max} = 0.384$	
	$K_s = 0.519$	
Chen and Hashimoto	$U^{-1} = 0.0190\ S_oS^{-1}+3.77$	99.5
	$K = 0.006$	
	$a = 0.006$	
	$\mu_{Max} = 0.277$	
	$K_s = 0.374$	

the six steady states were between 843.4 to 7.8 days. The HRT's were mainly influenced by the UF membrane flux-rates which directly determined the volume of influent sludge that can be fed to the reactor.

Methane gas production and its composition: Many factors govern the performance of anaerobic digesters where adequate control is required to prevent reactor failure. The few major factors that greatly influence digester performances in sewage sludge treatment are pH, mixing, operating temperature, nutrients for bacteria and organic loading rates into the digester. In this regards, the microbial community in anaerobic digester is sensitive to pH changes, in this study, the pH maintained to the optimum (6.8-7) to avoid methanogens affect which cause reduction of biogas production. The methanogenesis is strongly affected by pH. As such methanogenic activity will decrease when pH in the digester deviates from the optimum value. Mixing also provides good contact between microbes and substrates, reduces resistance to mass transfer, minimizes build-up of inhibitory intermediates and stabilizes environmental conditions. In this study, the mechanical mixing and recirculation of

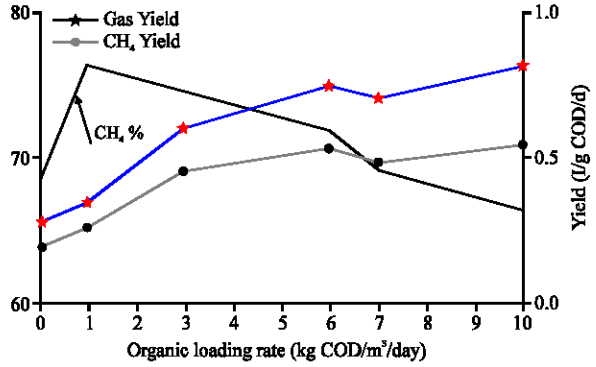

Fig. 6: Gas production and methane content

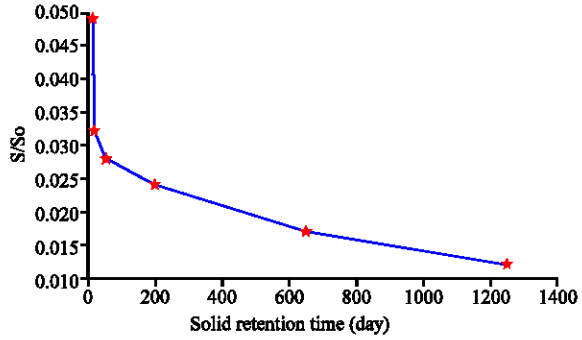

Fig. 7: Normalized COD concentration as a function of solid retention time

biogas adopted. Results have shown that mixing improved the performance of anaerobic digester. Figure 6 shows the gas production rate and methane content of the biogas produced by Membrane Anaerobic System (MAS). The biogas production of methane content registered a general decline with increasing organic loading rates. Various studies have proven that higher Organic Loading Rate (OLR) will reduce COD removal efficiency in wastewater treatment systems. However, gas production will increase with OLR until a stage when methanogens could not work quick enough to convert acetic acid to methane. In this regards, the gas yield increased with increasing OLR. It increased from 0.28 L g^{-1} COD day^{-1} at 0.1 kg COD/m^3/day to 0.81 L g^{-1} COD day^{-1} at 10.0 kg COD/m^3/day. The methane content ranged from 66.3 to 76.3%. The declining methane content can be attributed due to the higher OLRs which favors a higher growth rate of the acidogenic bacteria over the methanogenic bacteria. This had led to the higher rate of carbon dioxide formation thus reducing the methane content of the biogas. Figure 7 shows the relationship between normalized effluent COD and SRT at different HRT with influent COD concentration of 94000 mg L^{-1}. The normalized effluent COD decreases with increasing

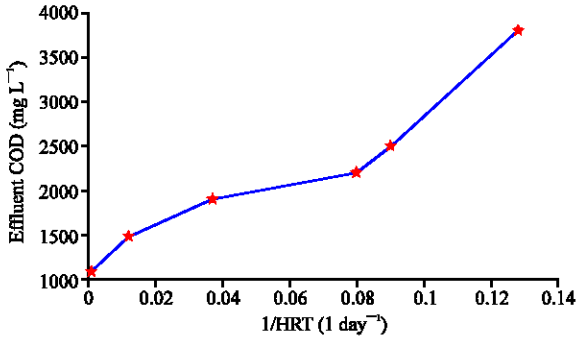

Fig. 8: Effluent COD vs. 1/HRT

SRT. While Fig. 8 depicts effluent COD versus inverse of HRT. Organic loading rates OLR is related to substrate concentration and HRT, thus a good balance between these two parameters has to be obtained for good digester operation. Short HRT will reduce the time of contact between substrate and biomass. The affect of temperature on the performance of anaerobic digester was investigated. The operating temperature was 60°C and found that the substrate degradation rate and biogas production was higher than operating at 37°C.

CONCLUSION

The MAS was found to be a successful biological treatment system to achieve a high COD removal efficiency in a short period of time. The proposed kinetic equations are applicable to anaerobic treatment of sewage sludge wastewater. The MAS was able to operate at very high SRT making it quite tolerant to variations in influent COD loadings. Thus, it makes MAS a good alternative for treating high strength wastewater and for recovery of energy as methane would be a value added product for the process.

NOMENCLATURES

COD = Chemical oxygen demand (mg L^{-1})
OLR = Organic Loading rate (kg/m^3/day)
CUF = Cross flow ultrafiltration membrane
SS = Steady state
SUR = Substrate utilization rate (kg/m^3/day)
TSS = Total suspended solid (mg L^{-1})
MLSS = Mixed liquid suspended solid (mg L^{-1})
HRT = Hydraulic retention time (day)
SRT = Soild retention time (day)
SSUR = Specific substrate utilization rate (kg COD/kg VSS/day)
MAS = Membrane an aerobic system
MLVSS = Mixed liquid volatile suspended solid (mg L^{-1})
VSS = Volatile suspended solids (mg L^{-1})
MWCO = Molecular weight Cut-Off
BLR = Biological loading rate
U = Specific substrate utilization rate (SSUR) (g COD/G VSS/day)
S = Effluent substrate concentration (mg L^{-1})
S_o = Influent substrate concentration (mg L^{-1})
X = Micro-organism concentration (mg L^{-1})
μ_{max} = Maximum specific growth rate (day^{-1})
K = Maximum substrate Utilization rate (COD/g/VSS.day)
K_s = Half velocity coefficient (mg COD L^{-1})
X = Micro-organism concentration (mg L^{-1})
b = Specific microorganism decay rate (day^{-1})
Y = Growth yield coefficient (g VSS/g COD)
T = Time
MLSS = Mixed liquid suspended solids (mg L^{-1})

REFERENCES

Ahmad, A.L., S. Ismail and S. Bhatia, 2003. Water recycling from palm oil mill effluent (POME) using membrane technology. Desalination, 157: 87-95.

Chin, K.K., S.W. Lee and H.H. Mohammad, 1996. A study of palm oil mill effluent treatment using a pond system. Water Sci. Tech., 34: 119-123.

Fakhru'l-Razi, A., 1994. Ultrafiltration membrane separation for anaerobic wastewater treatment. Water Sci. Technol., 30: 321-327.

Perez, M., L.I. Romero and D. Sales, 2001. Organic matter degradation kinetics in an aerobic thermophilic fluidized bed bioreactor. Anaerobe, 7: 25-35.

Pillay, V.L., B. Townsend and C.A. Buckley, 1994. Improving the performance of anaerobic digesters at wastewater treatment works: The coupled cross-flow microfiltration/digester process. Water Sci. Technol., 30: 329-337.

Sui, P., X. Wen and X. Huang, 2007. Membrane fouling control by ultrasound in anaerobic membrane bioreactor. Front. Environ. Sci. Eng. China, 1: 362-367.

Thamer, A.M., A.H. Birima, M.J. Noor, S.A. Muyibi and A. Adris, 2007. Evaluation of using membrane bioreactor for treating municipal wastewater at different operating conditions. Desalination, 221: 502-510.

Yildiz, E., B. Keskinler, T. Pekdemir, G. Akay and A. Nuhog, 2004. High strength wastewater treatment in a jet loop membrane bioreactor: Kinetics and performance evaluation. Chem. Eng. Sci., 60: 1103-1116.