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Kinetics Study of Sewage Sludge Treatment by Ultrasonic Membrane Anaerobic System (UMAS)

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Abstract

Pilot scale ultrasonic membrane anaerobic system(UMAS) was studied to determine the kinetic parameters for sewage sludge treatment process. Monod, Contoise and Chen and Hashimoto are the three models which were used in this study. Seven steady states were run at mesophilic temperature and the operating pressure was maintained between 1.5 to 2 bars. The growth yield coefficient Y and the specific microorganism decay rate bwere found to be 0.391gVSS/gCOD and 0.012 day^{-1} respectively. The parameters of the three models were calculated such as for Monod equation parameters were K_s0.654mg/l and K 0.312gCOD/gVSS.day. Contoiseequation parameters were B=0.212 gCOD/gVSS and u_m=0.287. For Chen and Hashimoto model the parameters as K=0.294 and μ_{max}=0.312 day^{-1}.The three modelswere successfully fitted tothe system and have shown good prediction. The correlation coefficient was 94 for Contois, 91 for Monod model and 93 for Chen and Hashimoto model.

Keywords: Kinetic, Sewage Sludge, Ultrasonic, Membrane, Anaerobic Digestion.

Introduction

Sewage sludge is the unavoidable product from wastewater treatment plant. Many deferent processes are used in order to minimize sludge and make it safe, easy to be transferred and beneficial.Anaerobic treatment system has many advantages and more favored over the aerobic system. Its operational cost relatively low, produce less waste sludge and produce biogas which, can be used in many deferent ways. However, the conventional anaerobic system is limited to certain conditions, i.e. it is not feasible for treating low – strength wastewater in cold climate (Berube et al., 2006). In addition anaerobic process is slow, long residence time in the reactor, and large reactor's volumes are required. In case of sewage sludge digestion it was concluded byOh (2006). hydrolysis has been considered to be the rate limiting step in the overall anaerobic digestion.

Anaerobic treatment is the most suitable method for the treatment of effluents containing high concentration of organic carbon, high-rate anaerobic reactors, which also retain biomass, have a high treatment capacity and hence low site area requirement (Zinatizadeh et al., 2006).Membrane systems have been used for many years, spatially after its availability in different good specifications and lower cost. It has been entered to the anaerobic system to overcome its limitation.Sharrer et al. (2010) reported thatthe membrane shows its effectiveness when was used in anaerobic membrane bioreactor, solids could completely retain, hydraulic retention time became shorter leading to smaller volume of the reactor. Moreover, by using membrane system pollutant degradation will improve and no need to the conventional additives, i.e. coagulant which are used to enhance thickening after conventional anaerobic operationHowever, membrane fouling due to adsorption of organic matter, deposition of inorganic matter and adhesion ofmicrobial cells to the membrane surface, is major hindrance for anaerobic membrane bioreactor implementation. In order to prevent membrane fouling, incorporating ultrasound to anaerobic membrane bioreactor is expected to make good control for membrane fouling(Xu et.al.2011).It is essential to have good understanding for the kinetic of the biological process to get a better design for the anaerobic process for sewage sludge treatment. Three widely used kinetic models used in this study are shown in Table1(LiewAbdullahet al.,2005).The aims of this study are to provide some data on the kinetics and performance ofultrasonicated membrane anaerobic system.

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

Model	Eq.1	Eg.2
Monod	$U = \frac{KS}{K_S + S}$	$\frac{1}{U} = \frac{K_S}{K}\left(\frac{1}{S}\right) + \frac{1}{K}$
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 & Hashimoto	$U = \frac{\mu_{\max} \times S}{YKS_0 + (1-K)SY}$	$\frac{1}{U} = \frac{YKS_0}{\mu_{\max} S} + \frac{Y(1-K)}{\mu_{\max}}$

Materials and Methods

The Ultrasonic membrane anaerobic system (UMAS) was composed of a cross flow ultra-filtration membrane (CUF) apparatus, a centrifugal pump, an anaerobic reactor of effective volume of 50 L and 6 ultrasonic transducers were bonded to the two sided of the tank chamber and connected to one unit of 250 watts 25 KH_Z Crest's Genesis Generator. The UF have molecular weight cut-off (MWCO) of 200,000, a tube diameter of 1.25 cm and an average pore size of 0.1 μm. the length of each tube was 30 cm. The maximum operating pressure on the membrane was 55 bars at 70°C, and the pH ranged from 2 to 12. The reactor was composed of a heavy duty reactor with inner diameter of 25 cm and a total height of 250 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. The sewage sludge was taken from the anaerobic tank in Indah waste water treatment plant in Kuantan, Pahang, Malaysia. The sludge was screened through strainer before being added to the digester to avoid clogging and pump damage. After, daily samples were analyzed to determine the TSS, VSS, COD, BOD, VFAs, Color, Turbidity, Nitrogen and pH for the Raw feed permeate and from inside the reactor.

The anaerobic reactor

The reactor which made of PVC was covered with aluminum foil to prevent any direct light. The volume of the reactor was 50L with inner of 15 cm and a total height of 100cm.

Analytical Techniques

The chemical oxygen demand COD for all samples were determined by the dichromate reflux (HACH Water analysis Method).The biochemical oxygen demand (BOD) was determined by analyzing the Oxygen depletion after sample incubation at 20°C for 5 days. As described in (the standard method5210B).Digester mixed liquor (reactor content) suspended solids was determined by filtration through a glass fiber filter method. The analytical procedure was the same in the standard methods.The volatile fatty acids were measured by simple titration against 0.02N NaOH and 0.02N H_2SO_4.The color was measured using spectrophotometer.The volume of gas was measured daily using J-tube gas analyzer. It is assumed in this method that the biogas produced composed only of two gases CO_2 and CH_4. Then sodium hydroxide was absorbing the CO_2. The remaining volume is methane gas CH_4.The device consisted of a glass- tube connected by a flexible hose to a syringe. The syringe was initially filled with 0.5 M NaOH solution, the glass tube was inserted into the gas zone inside the reactor where a column of biogas drawn into the glass-tube until a certain mark. Then the end of the tube immediately immersed in water. By manipulating the syringe many times, the NaOH solution was absorb the carbon dioxide CO_2, leading to reduction in the length of the biogas column, then the biogas column was measured again.The percentage of methane in the biogas is calculated by the formula:

$$\frac{\text{The Final length of gas column}}{\text{The Initial length of the gas column}} \text{ x } 100\%$$

Results and Discussion

Table 2 shows the summary of some results as an average of the steady states.The total suspended solids and Volatile suspended solids decreased by 80% as itwas very clear in the high production of biogas. The biochemical oxygen demand showed reduction 60% and the color of sewage sludge became 88% brighter than in the feed sample indicating to high clarification and very good digestion for the sludge.

Table 2:Summary of experimental results

Parameter	**Influent**	**Effluent**
TSS mg/l	2218.518	439.816
VSSmg/l	556.291	109.943
BOD mg/l	109.844	42.945
Color units PtCo	3541.222	423.362

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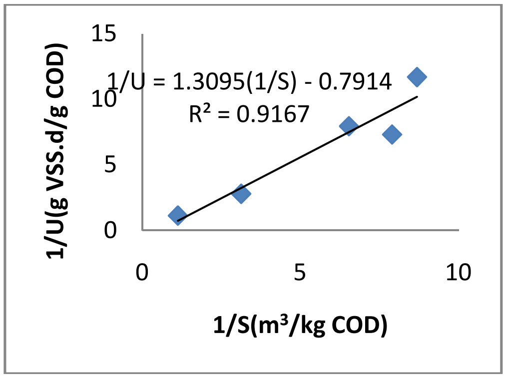


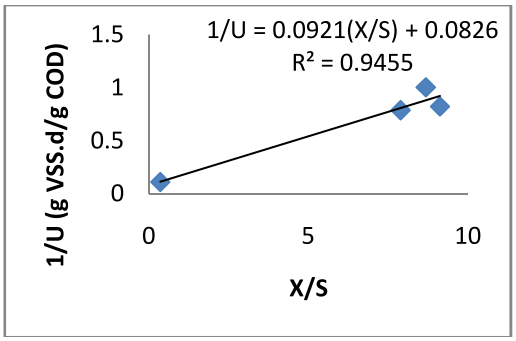
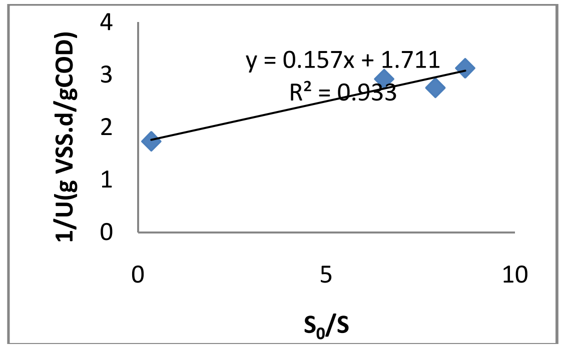


Figure 1: Monod model, Figure 2: Contois model

The kinetic coefficients of the selected models were derived from equation 2 in Table 1 by using a linear relationship. The determined coefficients values are summarized in Table 3. From the results, the three models showed very good prediction with correlation coefficients 91 to 95%, as shown in Fig. 1-3. Further more out of the three models Contois showed the best coefficients fitting, gave with the highest correlation value. This indicated that Contois model is capable of describing the performance of the ultrasonic membrane anaerobic reactortreating sewage sludge. Also this insured that Contois model is effective at predicting process performance during steady state.



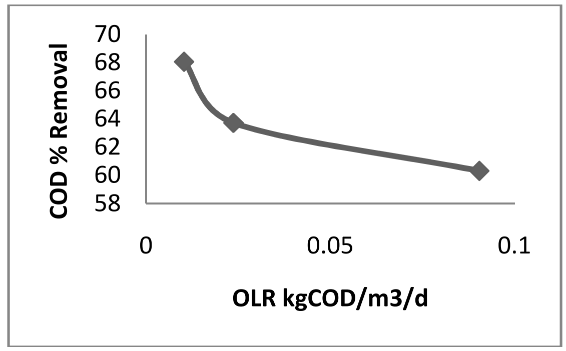
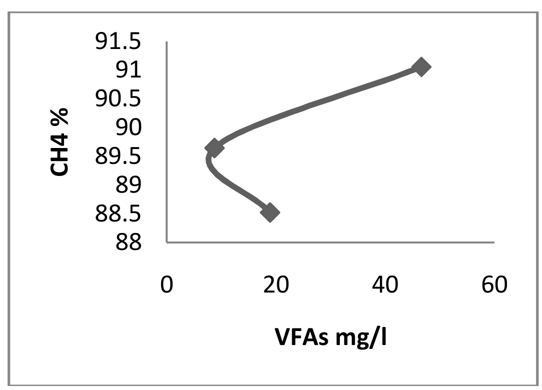


Figure 3: Chen and Hashimoto model.
Figure 4: COD removal and organic loading rate

It can be noticed that from Fig. 4 the percentage of COD removal decreased with the organic loading rate increasing. When the organic load was 0.0904 kgCOD/m^3/d the COD removal was 60.32% and they remained adversely proportional until 68.05% when the organic loading rate is 0.0103 kgCOD/m^3/d. This kind of behavior due to the fact that this period the reactor performance was more dependent on sludge acclimatization and granulation and it is predicted that the COD removal will improve after few days after this when the biomass completely acclimatized to the new environment.



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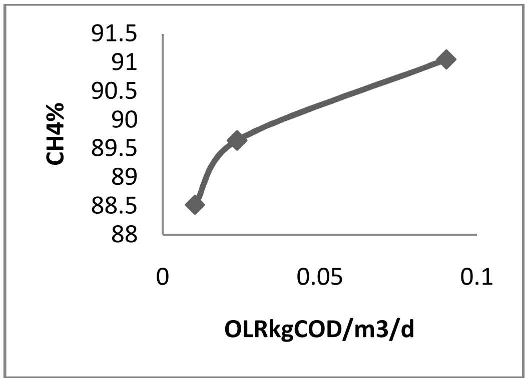

Figure 5: Effect of volatile fatty acids on methane
Figer6: Percentage of Methane gas produced and percentage produced.organic loading rate.

As shown in Fig.5, as the volatile fatty acids decreased from 18.891mg/l to 8.704 mg/l, methane gas percentage increased from 88.5% to 89.64%. But when the fatty acids increased to 46.631 mg/l methane gas also increased, although the fatty acids increasing lead to reduce the methane percentage. This may be attributed to the increasing of the VFAs not include an increasing in propionic acid concentration which is the main inhibitor to the activity of methanogenic bacteria, (Wang et al., 2009).Fig.6 shows that the methane percentage increased with organic loading rate. When the organic loading rate was 0.0103kgCOD/m^3/d, the methane percentage was 88.52% and they directly increased together up to 0.0904 kgCOD/m^3/d and 91.05% respectively. This continues proportional increasing because the organic loading rate was still low at early stage of digestion. Also this noticeable from the color of samples which is not completely changed. It is expected that there will be a decreasing for methane percentage after this due to the decreasing of volatile solids.

Table 3: Results of the application of three kinetic models.

Model	Equation	R^2(%)
Monod	$U^{-1} = 1.3095\ S^{-1} + 0.7914$ $K_s = 0.312$ $K = 0.169$ $\mu_{Max} = 0.284$	91.67
Contois	$U^{-1} = 0.0921\ X\ S^{-1} + 0.0826$ $B = 0.212$ $u_{Max} = 0.287$ $a = 0.214$ $\mu_{Max} = 0.363$ $K = 0.482$	94.55
Chen & Hashimoto	$U^{-1} = 0.1579\ S_o\ S^{-1} + 1.711$ $K = 0.048$ $a = 0.059$ $\mu_{Max} = 0.312$ $K = 0.294$	93.34

Conclusions

Monod, Contois and Chen and Hashimoto kinetic models can be used to estimate the performance of Ultrasonic membrane anaerobic system for sewage sludge treatment, and Contois model showed the best fitting. UMAS is an effective system for Sewage Sludge treatment, producing biogas rich with methane. Methane gas percentage increases with volatile fatty acids increment may be because of little increase in concentration of propionic acid. The system shows COD removal percentage of 68.05 %. At low organic load methane percentage is increasingly proportional with the organic loading rate.

Nomenclattures

VSS: Volatile suspended solid.
TSS: Total suspended solid.
BOD: Biochemical oxygen demand.
COD: Chemical oxygen demand.
OLR: Organic loading Rate.
U: Specific substrate utilization rate (SSUR)gCOD/gVSS/d
S: Effluent substrate concentration mg/l
S_0: Influent substrate concentration mg/l
X: Micro-organism concentration mg/l
μ_{max}: Maximum specific growth rate day^{-1}
K: Maximum substrate utilization rate gCOD/gVSS.d
K_s: Half velocity coefficient mgCOD/l

X: Micro-organizm concentration mg/l
b: Specific microorganism decay rate day^{-1}
Y: Growth yield coefficient gVSS/gCOD
VFA: Volatile fatty acids.

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