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KINETICS OF ANAEROBIC DIGESTION OF PALM OIL MILL EFFLUENT

*JT Nwabanne[1], AC Okoye[2] and HC Ezedinma[1]
[1]Department of Chemical Engineering
[2]Department of Environmental Management
Nnamdi Azikiwe University, PMB 5025, Awka, Nigeria

ABSTRACT

Globally, Nigeria is one of the largest producers of palm oil however the effluents generated from palm oil mills are usually discarded into the water bodies thereby causing environmental pollution. Serious efforts are made in the treatment before discharge into surface waters. This work is aimed at studying the kinetics of anaerobic digestion of palm oil mill effluent (POME) in a batch reactor at mesophilic condition. The digestion period lasted for 40 days. Maximum biogas production of 19.50% was obtained at hydraulic retention time of 10 days. Temperature has a significant effect, particularly on the performance of biogas-forming bacteria. Micro-organisms grew as temperature increased from 28 to 34^{o}C after which the growth started decreasing. The percentage total suspended solid (TSS) and the effluent substrate concentration decreased as hydraulic retention time increased. The kinetics of anaerobic digestion of palm oil mill effluent followed a first order kinetic model with a first order reaction constant of 1.306day^{-1}. The maximum rate of utilization (K), half velocity constant (K_s), endogenous decay constant (K_d), microbial growth yield (Y) and maximum specific growth rate μ_{max} were found to be 0.868day^{-1}, 97.66mg/l, 0.344day^{-1}, 0.550 and 0.477day^{-1} respectively. Values of K and K_s suggest that the digesting microbes require much retention time to regenerate and hence inoculation is needed for better performance.

Keywords: POME, anaerobic, digestion, kinetics.

INTRODUCTION

In Nigeria palm oil industry is the largest producer of palm oil mill effluent. The operation of palm oil mill requires large volume of water, which are subsequently discharged into the environment, either raw or treated. Palm oil mill effluent (POME) is a colloidal suspension of 95-96% water, 0.6-0.7% oil and 4-5% total solids including 2-4% suspended solids originating in the mixing of sterilizer condensate, separator sludge and hydrocyclone wastewater that are mostly debris from palm fruit mesocarp (Ahmad *et al*., 2003; Bek-Nielsen *et al*., 1999; Ahmad *et al*., 2005). Raw POME has a Biological Oxygen Demand value of around 25,000mg/l, making it about 100times more polluting than sewage (Mahaswaran and Singam, 1997). Due to high pollution load and environmental significance of POME, treatment of POME, is currently receiving attention in order to mitigate its effects on the environment. A number of treatment processes has been reported by several researchers for treatment of POME (Ahmad *et al*., 2003, 2005; Zinatizadeh *et al*., 2006). Biological treatment is a very common process used. A concentrated mass of micro-organism is used to break down organic material into stabilized wastes. Considering the highly organic character of POME, the anaerobic process is the most suitable approach for treatment (Perez *et al*., 2001).

Anaerobic digestion is a microbial process in which micro-organism breakdown biodegradable material in the absence of oxygen. It is widely used to treat wastewater, sludge and organic waste because it provides volume and mass reduction of the input material. The organic matter is decomposed and it generates a gas (called biogas which is highly energetic), a residual sludge, and a wastewater with less pollution (Mailleret *et al*., 2004). The process of anaerobic digestion occurs in three stages: (1) hydrolysis and acidogenesis (2) acetagenesis and (3) methanogenesis. Digestion is not complete until the substrate has undergone all three stages. Each stage has unique bacteria responsible for the process. The first group hydrolyses the organic matter into volatile fatty acids of low molecular weight and alcohol, and the second group converts them to methane and carbon dioxide. Biogas production is sensitive to digester temperature and pH (Angelidaki and Ahring, 1993; Angelidaki *et al*., 1999; Keshtkar *et al*., 2003; Yilmaz and Atalay, 2003). Methane-forming bacteria are most productive in either mesophilic conditions at 25-40^{o}C or in the thermophilic range at 50-65^{o}C.

Anaerobic digestion can be carried out either in batch or continuous process. In the batch process, the substrate is put in the reactor at the beginning of the digestion period. Retention time ranges from 30-60 days and only about 1/3 of the tank volume is used for the active digestion. Large

*Corresponding author email: joe nwabanne@yahoo.com

tank volume required for this type of operation is a problem. In the continuous process, fresh substrate is added and an equal amount of effluent is removed continuously, maintaining equilibrium. Reactions occur at a fairly consistent rate resulting in nearly constant biogas production. The purpose of the present work is to study the anaerobic digestion of POME effluent in a batch reactor in order to determine the kinetics of the process.

MATERIALS AND METHODS

Material collection and preparation

Palm oil mill effluent (POME) was collected from Mother Theresa palm oil processing mill, Awka South Local Government Area, Anambra State, Nigeria. Coarse and other particulates (solid materials) were removed from the sample using 100mm sieve prior to laboratory study.

Experimental procedure

Preliminary studies were taken immediately on delivery of the sample to the laboratory to determine such parameters as pH, Chemical Oxygen Demand (COD), microbial concentration (Bio-load) and Total Suspended Solid (TSS) according to the approved techniques by American Public Health Association (APHA, 2005). Five liter of the sample were poured into a bioreactor, stirred to ensure a homogenous mixture and subjected to anaerobic digestion. Digestion lasted for a period of 40 days. Periodic samples were collected every 5 days and analyzed for the above parameters. The biogas produced was measured after every 5 days by means of downward displacement of water by the biogas in an inverted measuring cylinder.

RESULTS AND DISCUSSION

Figure 1 shows the effect of time on biogas production during anaerobic digestion. From the figure, it can be seen that maximum biogas production of 19.50% was obtained at hydraulic retention time of 10 days, and started decreasing thereafter. This decrease in biogas production as time increase is as a result of gradual decrease in the

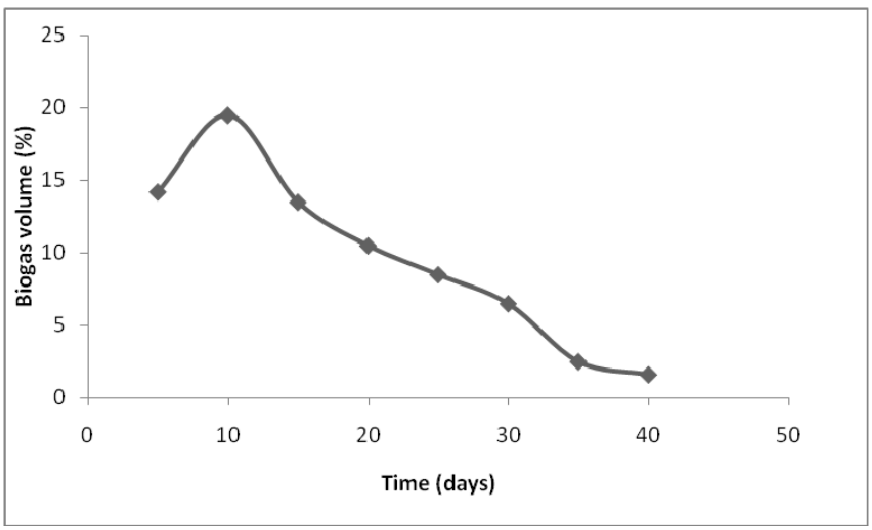

Fig. 1. A plot biogas volume against hydraulic retention time.

Table 1. Batch experimental data for determination of kinetic parameters.

t (day)	Temp (^oC)	pH	So (mg/l)	Se (mg/l)	Xo (mg/l)	Xe (mg/l)	X (mg/l)	Initial TSS (mg/l)	Effluent TSS (mg/l)
0	0	4.7	58000		1034.84			1050	
5	28.0	7.6		8437		5004.46	3019.65		960
10	34.0	7.8		5035		8322.94	4678.89		840
15	32.0	7.5		2248		4777.20	2906.02		720
20	34.5	7.2		730		3133.28	2084.06		630
25	35.0	6.9		537		2253.66	1644.25		500
30	35.5	6.8		410		1088.72	1142.59		430
35	36.4	6.7		207		934.76	834.67		300
40	37.0	6.6		109		780.59	526.34		110

X= average cell mass concentration = $\frac{X_0+X_E}{2}$ (Reynolds and Richard, 1996).

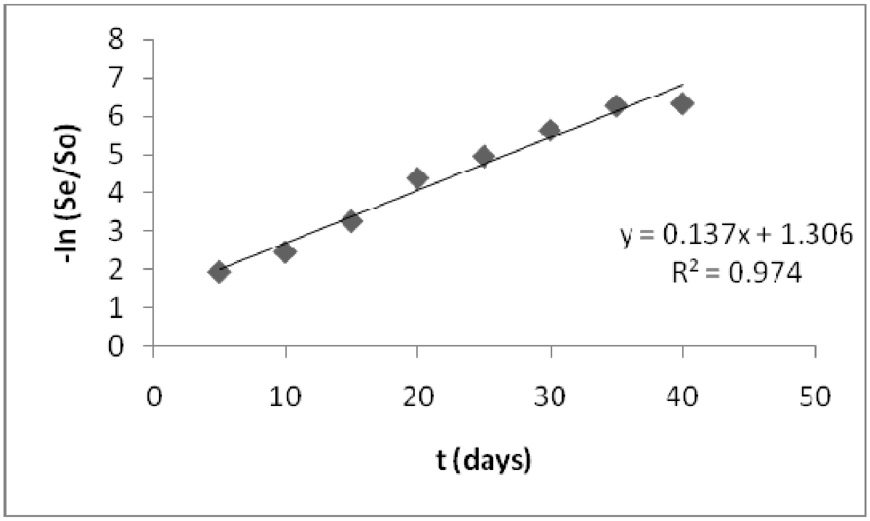

Fig. 2. First order kinetic plot for POME digestion.

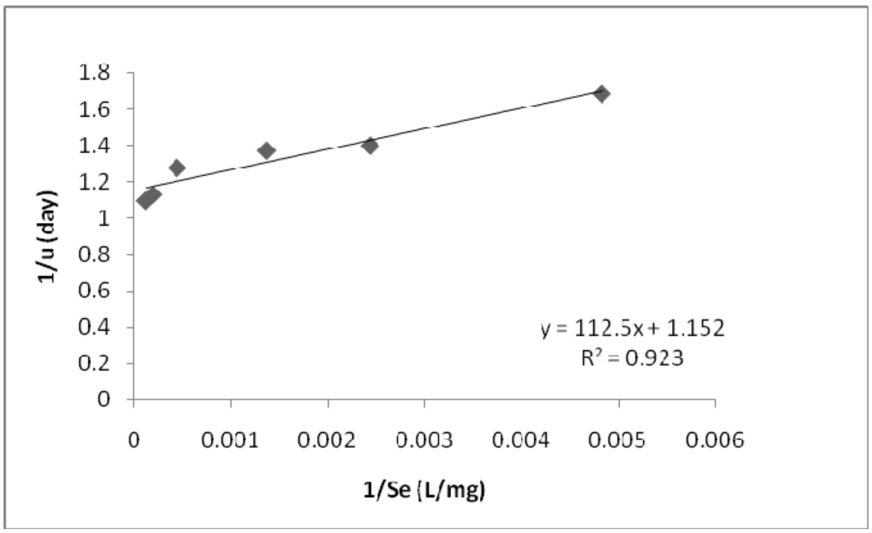

Fig. 3. Plot for determination of K and K_s

concentration of biodegradable substrate (Jose *et al*., 2009).

Temperature has a significant effect, particularly on the performance of biogas-forming bacteria. Table 1 shows the effect of temperature on microbial effluent concentration during anaerobic digestion. During the process, the temperature of the digester remained at mesophilic conditions (28 to 37^{o}C). It can be seen from the table that micro-organisms grew as temperature increased from 28 to 34^{o}C after which the growth started decreasing. This decrease in microbial effluent concentration was as a result of increase in temperature which made the condition unfavourable to the micro-organism. A mesophilic digester should be maintained between 30^{o}C and 35^{o}C for optimal functioning.

The pH of the effluent was between 6.6 and 7.8 during the digestion period, which indicates sufficient alkalinity of the reactor medium for the wastewater. A bioreactor should be operated at pH values between 6.7 and 7.4 because the methanogenic activity falls when the pH value decreases below 6.5. Another study Yadvika *et al*. (2004) reported a desired pH range of 6.8-7.2 for anaerobic digestion. Jash and Ghosh (1996) reported a favourable pH range of 6.6-7.8 for methanogenic bacteria. The percentage total suspended solid (TSS) decreased as hydraulic retention time increased.

Kinetic evaluation

The kinetics of the microbial process of anaerobic digestion may be divided into kinetics of growth and kinetics of food (or substrate) utilization. Some kinetics

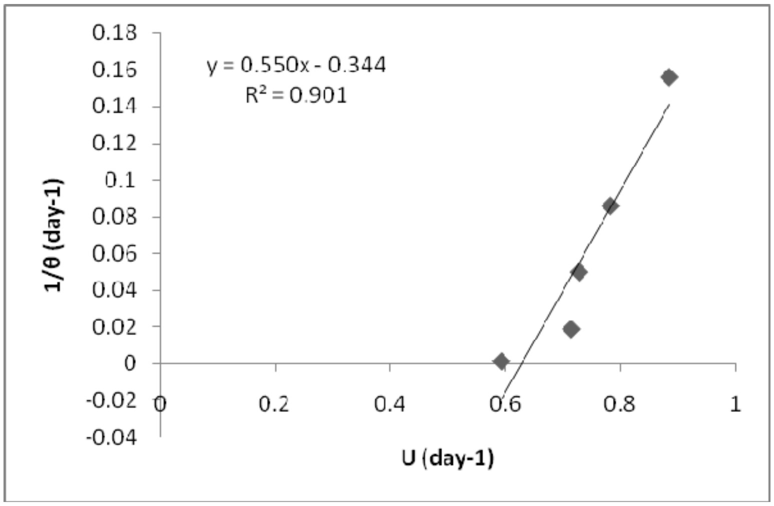

Fig. 4. Plot for determination of Y and K_d

models were investigated. A time-averaged cell mass (Reynolds and Richards, 1996) was used for COD determination.

According to Raj and Anjaneyulu (2005) limited substrate consumption is a first order reaction which can be expressed as:

$$\frac{-ds}{dt} = K'S \quad (1)$$

Where K' is the rate constant?

The above equation is characterized as exponential growth and the substrate concentration profile with respect to hydraulic retention time (HRT) as follows:

$$S = S_o \exp\left(-K_s t\right) \quad (2)$$

Where S_o is the influent substrate concentration (mg/l), S is the effluent substrate concentration (mg/l) and t is hydraulic retention time (days).

Equation (2) shows the exponential growth of the organism as the substrate is utilized. Rearranging and taking natural logarithm of both sides of Equation (2) gives equation (3)

$$In\left(\frac{S_e}{S_o}\right) = -K_s t \quad (3)$$

A plot of - $In(S_e/S_o)$ against t was linear as shown in Figure 2, with regression coefficient of 0.974. This confirmed that the kinetics of POME digestion followed a first order reaction.

The rate of substrate utilization (U) is related to effluent substrate concentration (Se) according to Equation (4) (Viessman and Hammer, 1993).

$$\frac{1}{U} = \frac{K_S}{KS_e} + \frac{1}{K} \quad (4)$$

Where K_s is half-velocity constant (mg/l), K is the maximum rate of substrate utilization (day^{-1}).

A plot of $\frac{1}{U}$ against $\frac{1}{S_e}$ was linear as shown in figure 3 with $\frac{K_S}{K}$ and $\frac{1}{K}$ as slope and intercept respectively. Values of K and K_s calculated from the intercept and slope of the graph were $0.868 day^{-1}$ and 97.66mg/l respectively, suggesting that the digesting microbes requires much retention time to regenerate and hence inoculation for better performance.

The specific rate of substrate utilization is related o mean cell residence time according to Equation (5).

$$\frac{1}{\theta} = YU - K_d \quad (5)$$

Where θ is mean cell residence time (day), K_d is the endogenous decay coefficient (day-1) and Y is the biomass yield (mg/mg).

A straight line graph was obtained by plotting 1/θ against U as shown in figure 4. From the slope and intercept of the graph, the Y and K_d value was obtained as 0.550mg/mg and $0.344 day^{-1}$ respectively.

The maximum specific rate of growth of micro-organism μ_{max} is related to biomass yield Y and maximum rate of substrate utilization K according to Equation (6).

$$K = \frac{\mu_{max}}{Y} \quad (6)$$

The maximum specific rate of growth of microorganism μ_{max} calculated from Equation (6) was $0.477 day^{-1}$. Zinatizadeh *et al*. (2006) in their study on kinetic evaluation of palm oil mill effluent digestion in a high rate up-flow anaerobic sludge fixed film bioreactor obtained μ_{max} value of $0.207 day^{-1}$. According to the authors, the small value of μ_{max} implies relatively high amount of biomass in the reactor.

CONCLUSION

The results obtained from this research study reveal that palm oil mill effluent derived from palm oil production has a high level of anaerobic biodegradability and that substantial quantity of biogas can be obtained it. The kinetics of POME was well described by first order kinetic model. Biokinetic parameters K, K_s, K_d, Y and μ_{max} were found to be 0.868day^{-1}, 97.66mg/l, 0.344day^{-1}, 0.550 and 0.477day^{-1} respectively.

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