INTERNATIONAL JOURNAL OF
ENERGY AND ENVIRONMENT

Volume 4, Issue 3, 2013 pp.449-458

Journal homepage: www.IJEE.IEEFoundation.org

Studies on biomethanation of water hyacinth (eichhornia crassipes) using biocatalyst

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Abstract
Water hyacinth is a huge source of biomass in tropical countries. That can be used for biogas production. The aim of this conversion process is to improve the quality, specific energy content, transportability, etc. of the raw biomass source or to capture gases which are naturally produced as biomass is micro biologically degraded. An experimental study on catalytic biomethanation of Water Hyacinth has been carried out in a semi batch digester at different substrate concentration using cow urine as an organic catalyst under controlled pH with in the range of 6.9 to 7.2. The rate of bio gas production varies with different conditions and parameters like temperature, stirring speed, feed concentration, catalyst concentration, etc. It has been found that the catalyst mainly increases the production rate of biogas from water hyacinth. Mathematical analysis of the experimental data on catalytic biomethanation has been done in the present study. Mathematical equations relating maximum specific growth rate and kinetic parameter at different substrate and catalyst concentration have been developed.

Keywords: Anaerobic digestion; Water hyacinth; Catalyst; Biodegradation; Biogas; Bioreactors; Modeling.

1. Introduction

Anaerobic digestion is a biological process where organic material is decomposed by anaerobes in absence of air to yield methane rich biogas. The general technology of biomethanation of complex organic matter is well known and has been applied for over 60 years as part of domestic sewage treatment to stabilize organic wastes [1]. Anaerobic process is more advantageous than aerobic process in solid waste treatment because of high degree of waste stabilization, low production of excess biological sludge, low nutrient requirement and high production of methane gas as a useful by-product. Various studies have been conducted for evaluating different process parameters and model equations on biomethanation process [2-16] but only few are reported on catalytic bionethanation process [17-21].
In the microbiological analysis of methanogenic process four different bacterial groups are identified [22, 23] as being responsible for carrying out the anaerobic digestion of complex organic matter. These are (i) the hydrolytic (hydrolysis of carbohydrates), (ii) acetogenic & homo acetogenic (monomer compounds to organic acid) (iii) acidogenic (organic acids to acetic acid) (iv) methanogenic bacteria (acetic acid to methane and carbon dioxide). However, the bio gas production is mainly depends on different parameters such as substrate concentration, pH of the substrate, temperature, stirring speed C/N ratio etc. It has been reported that the presence of some organic material may enhance the biogas

production as the enzymatic part of the concern bacteria is activated [24, 31]. It has been further observed that some metal as well as some organic compound including green biomass may enhance the bio-methanation process. It has been reported that different biomass used as catalyst such as powdered leaves of some plant like Gulmohar, *Leucacena leucocephala, Acacia auriculiformis, Dalbergia Sisco* and *Ecalyptus tereticonius* [25], alkali treated plant residue [26], partially decomposed ageratum [27], tomato plant waste [28], partially digested cattle dung [29], onion storage waste [30] etc. can enhance the biogas production by 14%-80%.

2. Materials

To produce WH powder, fresh WH has been collected and dried in sunlight for a minimum period of 3 days. To get bone dry product it has been then dried in an oven for two hrs at 70^0C. After that it has been grinded in a ball mill and passed through 1.4 mm screen. The under size has been used as feed stock (Table 1).

Table 1. Characteristics of water hyacinth

Parameters	Results
Proximate Analysis	
Moisture	86.1
Ash (Dry basis)	2.24
Volatile Matter (Dry basis)	7.59
Fixed carbon	4.07
CHN analysis (by weight)	
Total carbon	22.7
Hydrogen	6.28
Nitrogen	1.14

3. Experimental details

A semi batch digester has been used to carry out the experimental work. A closed conical flask having capacity 500 ml with a provision of feed inlet and gas outlet nozzle has been used as digester. The gas generated inside the digester has been transferred to the gas burette and is collected by downward displacement of water through an aspiratory bottle connected with the gas burette. A schematic diagram of experimental set up is given in Figure 1.

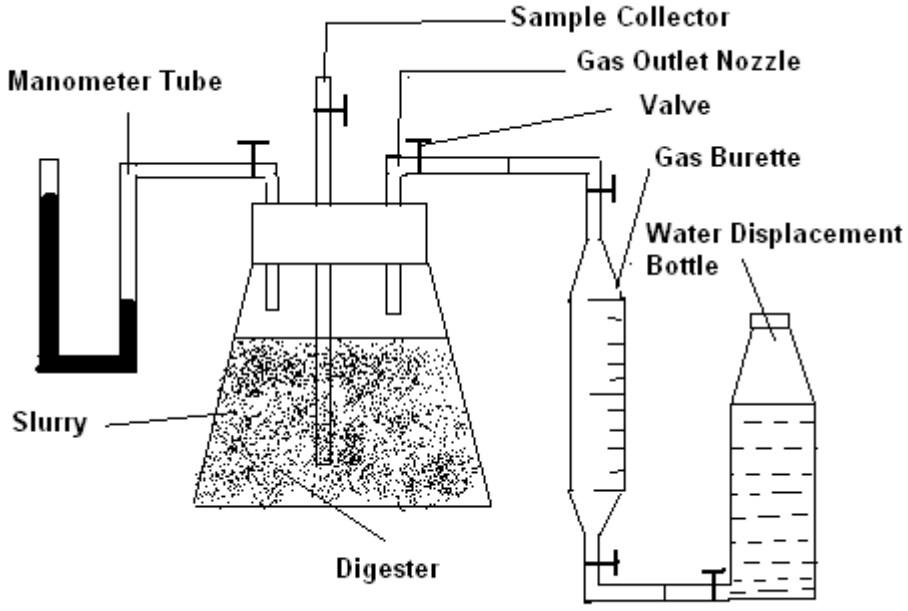


Figure 1. Schematic diagram of experimental setup

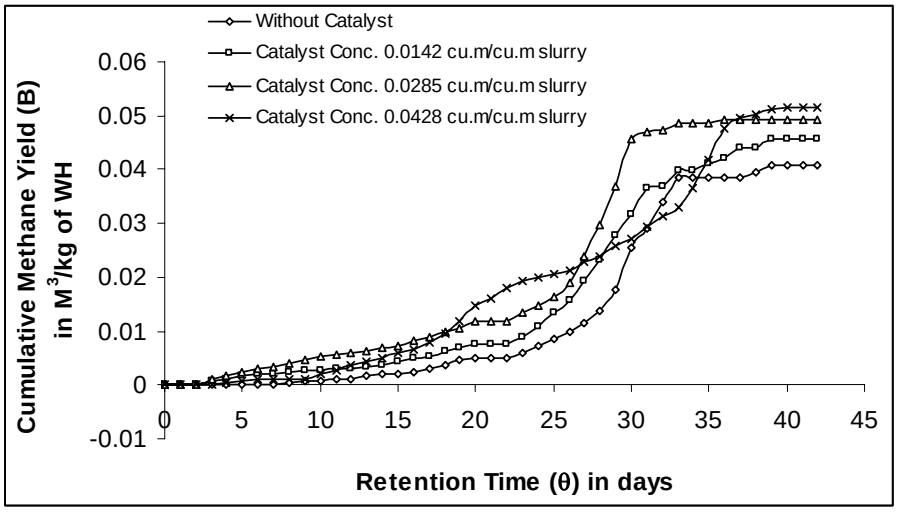
In order to carry out the biomethanation process 350 ml slurry of known substrate and catalyst concentration have been fed into the digester in which 1% mixed culture as inoculums has been added which has been prepared using cow dung dissolved in distilled water maintaining pH within the range of 6.8 to 7.2 being incubated at 35^0C for 7 days under anaerobic condition and preserved in the incubator at 0^0C.

Experiments have been carried out at varying substrate concentration as well as at varying catalyst concentration. Gas generated has been measured in a gas analyzer. A constant temperature 32^0C is maintained throughout the experiment.

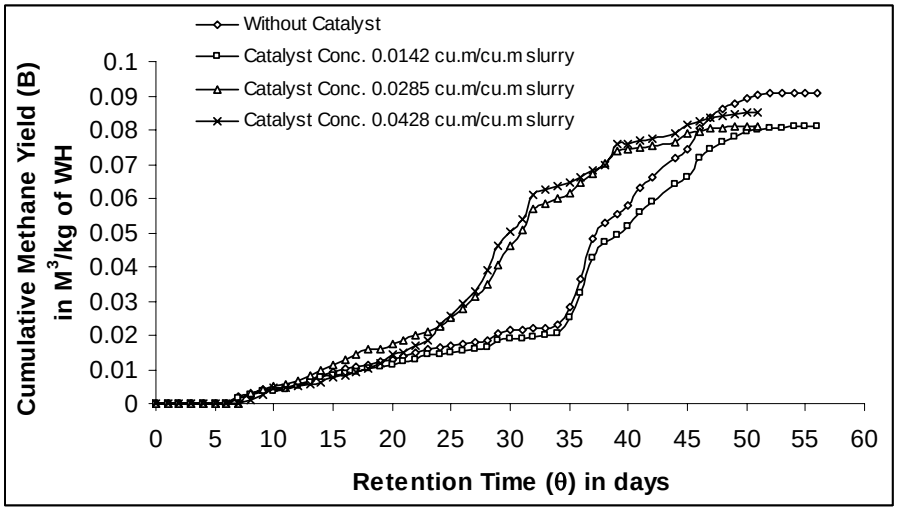
In order to carry out the biomethanation process different setups were charged varying the catalyst concentration and different feed stock concentrations and 350ml fresh water and 7 ml inoculums are added to each set up. Inoculum was prepared by anaerobic digestion of cow dung for seven days. Inoculum was used as source of microbes. pH of the substrate was maintained at 7 and temperature of the system was 32^0C. Proper anaerobic condition should be maintained during the experimental process.

4. Result and discussion

The results of the experimentation have been represented graphically in Figures 2a, 2b, 3a, 3b, 4a, 4b, 5, and 6, and the results based on data analysis have been tabulated in Tables 2 and 3 at substrate concentration 29.43 kg/m^3 and 20.00 kg/m^3 respectively.



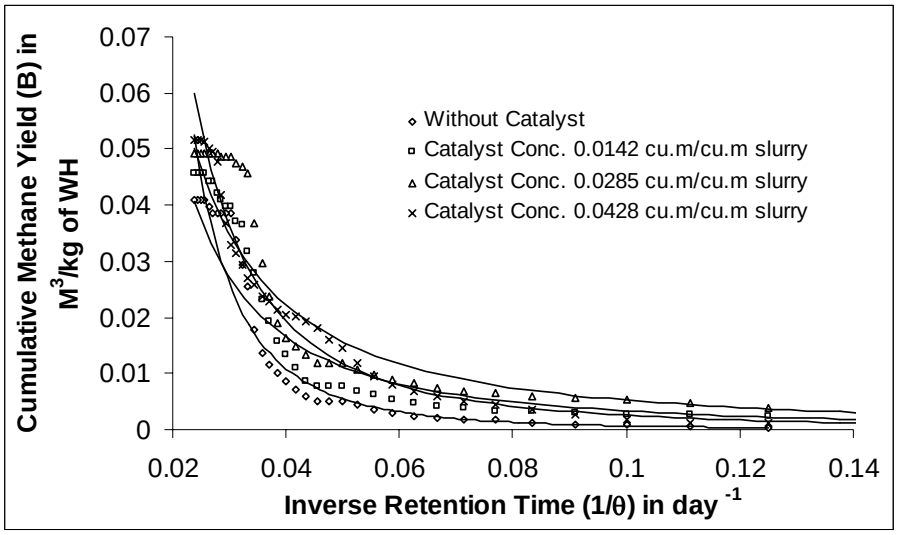
(a)



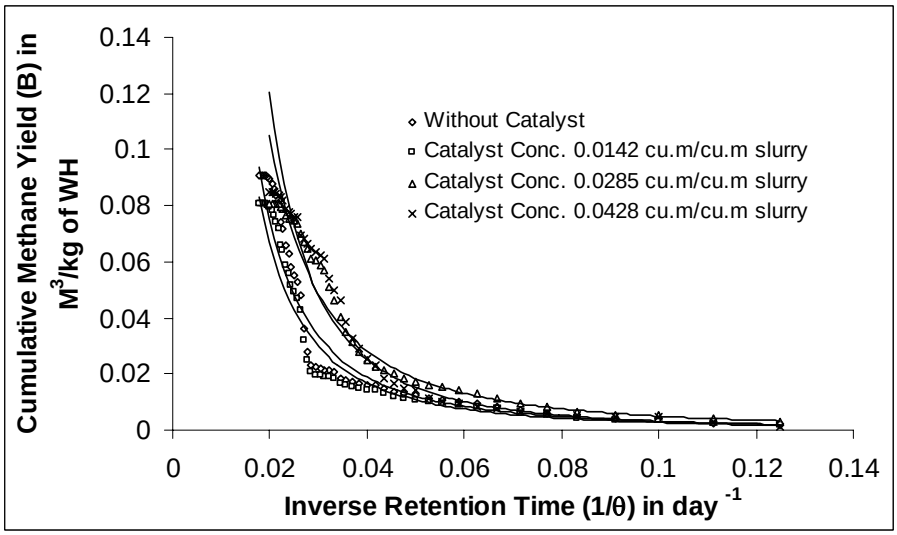
(b)

Figure 2. (a) Plot of cumulative methane yield (B) in m3/kg of W.H. against retention time (θ) in days at 29.43 kg/m^3 W. H. concentration; (b) Plot of cumulative methane yield (B) in m3/kg of W.H. against retention time (θ) in days at 20.00 kg/m^3 W. H. concentration

Figure 2a and 2b show the plots of Cumulative Methane yield (B) in m^3/kg of W.H. against Retention Time (θ) in days at substrate concentration 29.43 kg/m^3 and 20.00 kg/m^3 respectively at digestion temperature 32^0C. From Figures 2a and 2b it has been observed that the production of biogas has been increased with increase in catalyst concentration. Moreover, the use of cow urine has been reduce the initial hydraulic retention time of biogas production as methanogenic bacteria has been activated by this biocatalyst sufficiently lead to biogas production.



(a)



(b)

Figure 3. (a) Plot of cumulative methane yield (B) in m3/kg of W.H. against Inverse of retention time (θ) in day^{-1} at 29.43 kg/m^3 W. H. concentration; (b) Plot of cumulative methane yield (B) in m3/kg of W.H. against Inverse of retention time (θ) in day^{-1} at 20.00 kg/m^3 W. H. concentration

Figures 3a and 3b show the Plot of cumulative methane yield (B) in m3/kg of WH against inverse retention time (1/θ) in day^{-1}. It appears from the Figure 3a and 3b that cumulative methane yield in m^3/kg of W.H shows non–linear exponential relationship with inverse retention time in day^{-1} within the range of parameters experimented with, from which the ultimate methane yield (B_o) at inverse retention time, 1/θ =0 and values has been tabulated Tables 2 and 3.

The equations which fit such curves are generalized by the correlation (1) where coefficient C and exponent m depend on the substrate concentration, digestion temperature, catalyst concentration and process kinetics.

$$B = C.e^{-m/\theta} \tag{1}$$

The values *C* and *m* in equation (1) are tabulated in Table 4.

Table 2. Different parameters are obtained when water hyacinth concentration is 29.43 kg/m^3

SI. No.	Catalyst concentration in m^3/ m^3 slurry	Theoretical Ultimate Methane Yield (B_0) (m^3/kg W.H.)	Actual Maximum Methane Yield (m^3/kg W.H.)	Maximum specific growth rate (μ_m) in day^{-1}	Kinetic parameter (k)
1	Without	0.108	0.040822	0.604595	0.17231
2	5	0.081	0.045631	0.637755	0.210459
3	10	0.083	0.049212	0.656599	0.235719
4	15	0.121	0.051636	0.606796	0.220874

Table 3. Different parameters are obtained when water hyacinth concentration is 20.00 kg/m^3

SI. No.	Catalyst concentration in m^3/ m^3 slurry	Theoretical Maximum Methane Yield (B_0) (m^3/kg W.H.)	Actual Maximum Methane Yield (m^3/kg W.H.)	Maximum specific growth rate (μ_m) in day^{-1}	Kinetic parameter (k)
1	Without	0.103	0.073214	0.607165	0.19915
2	5	0.089	0.079464	0.616903	0.211598
3	10	0.149	0.080962	0.613874	0.249847
4	15	0.185	0.085045	0.598444	0.219031

Table 4. Values of *C* and *m* of equation (1) for different substrate and catalyst concentration

	Catalyst concentration in cu.m / cu.m slurry			
	Without	0.0142	0.0285	0.0428
Substrate conc. 29.43 kg/m3				
C	0.108	0.081	0.083	0.121
m	-52.4	-36.8	-30.5	-42.0
Substrate conc. 20.00 kg/m3				
C	0.103	0.083	0.149	0.185
m	-44.7	-38.2	-36.0	-43.2

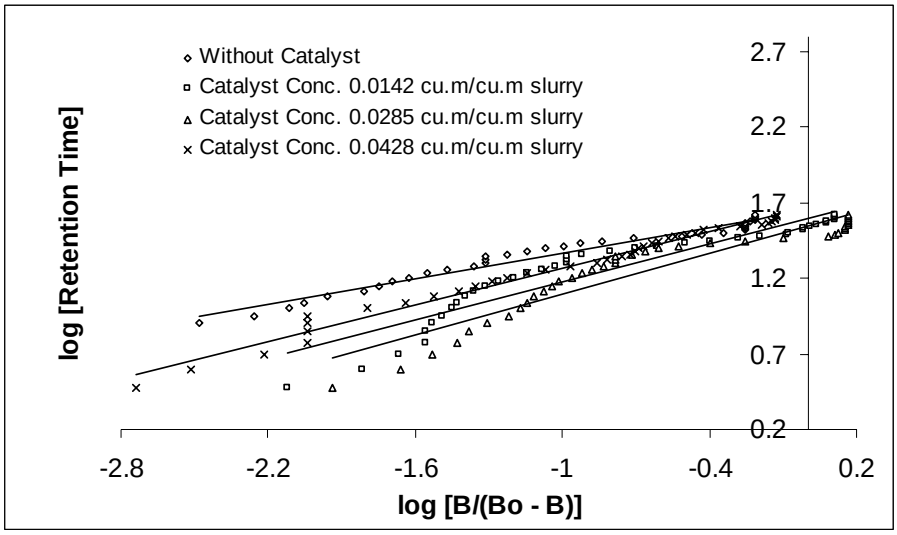
It has been found that the graphical analysis is more significant to reduce the approximation error as made by Chen and Hashimoto [32, 33], who assumed a linear relationship between cumulative methane yield in m^3 /kg of W.H. and inverse retention time in day-1. Figure 4a and 4b show the plot of log (retention time) against log [B/ (Bo - B)] at substrate concentration 29.43 kg/m^3 and 20.00 kg/m^3 respectively for different catalyst concentration and at digestion temperature 32^{0}C. It has been observed from Figure 4a and 4b that log [B/ (Bo - B)] shows the linear relationship with log (retention time) within the range of the parameter experimented with. The equations, which fit such curves, maybe represented by a generalized correlation as given by equation (2) where coefficient A and exponent n depend on the cell mass concentration, substrate concentration, digestion temperature, catalyst concentration and process kinetics. The values of A and n for equation (2) are tabulated in Table 5.

$$\theta = A.\left(\frac{B}{Bo - B}\right)^n \tag{2}$$

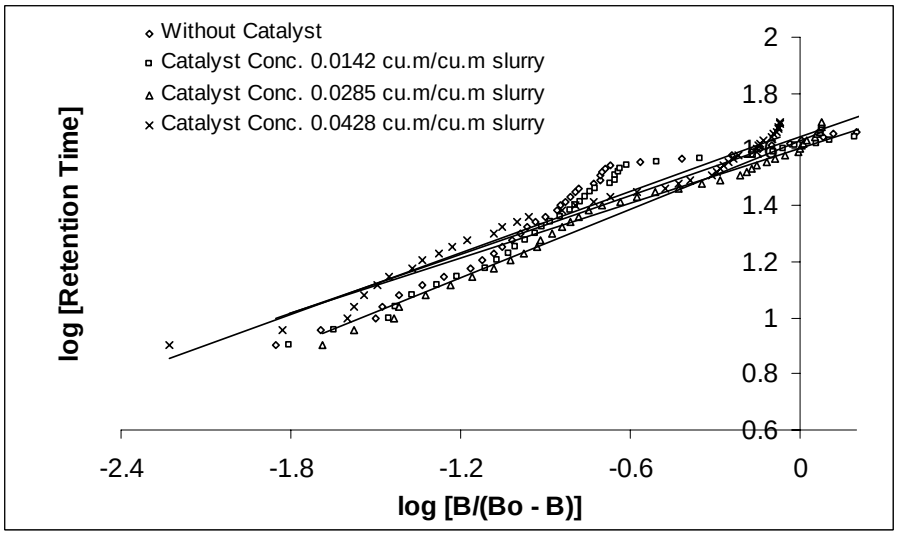
It has been further observed that Chen and Hashimoto kinetic model equation [32 & 33] given as equation (3) is not valid for semi batch digestion of WH.

$$\theta = \frac{1}{\mu m} + \frac{k}{\mu m}.\left(\frac{B}{Bo - B}\right) \tag{3}$$

However, comparing with the model equation of the Chen and Hashimoto intercept and slope of the graphs of Figure 4a and 4b represent the term $1/\mu_m$ and k/μ_m respectively, from which maximum specific growth rate (μ_m) and kinetic parameter (k) have been determined and tabulated in Table 2 and 3.



(a)



(b)

Figure 4. (a) Plot of log (Retention time) against log [B / (Bo - B)] at 29.43 kg/m^3 W. H. concentration; (b) Plot of log (Retention time) against log [B / (Bo - B)] at 20.00 kg/m^3 W. H. concentration

Table 5. Values of A and n of equation (2) for different substrate and catalyst concentration

	Catalyst concentration in cu.m / cu.m slurry			
	Without	0.0142	0.0285	0.0428
Substrate conc. 29.43 kg/m3				
A	45.08	41.78	42.55	44.46
n	0.285	0.33	0.359	0.364
Substrate conc. 20.00 kg/m3				
A	44.36	0.083	0.149	46.88
n	0.328	0.343	0.407	0.366

Figure 5 shows the variation of ultimate methane yield (Bo) in m^3/kg of W.H. with the catalyst concentration in m3/m3 slurry at different water hyacinth concentrations. It has been found that ultimate

methane yield initially decreases with increase in catalyst concentration then increases with increase in catalyst concentration. The equations (4) and (5) fit the curves well of Figure 5 for substrate concentration 29.43 kg/m^3 and 20.00 kg/m^3 respectively

$$B_o = 79.858C^2 - 3.1298C + 0.1083 \quad (4)$$

$$B_o = 61.059C^2 - 0.4679C + 0.0981 \quad (5)$$

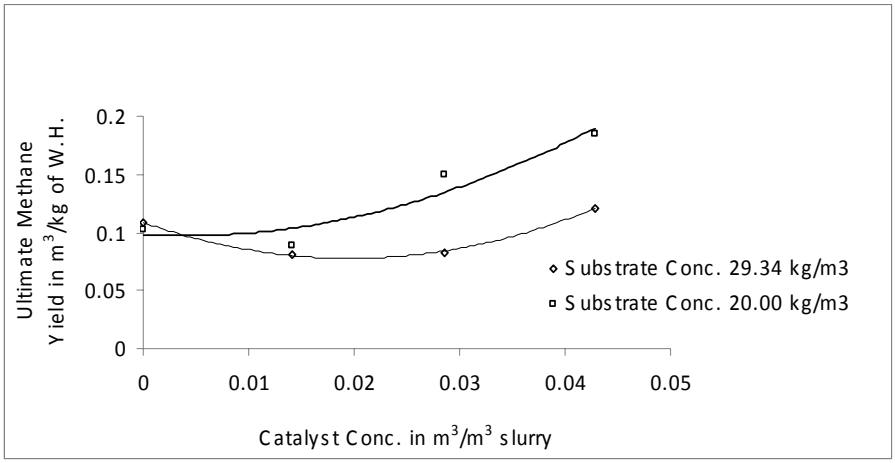


Figure 5. Plot of ultimate methane yield (Bo) in m3/kg of W.H. against volume of catalyst used in ml at different water hyacinth concentrations

Figures 6 and 7 represent the non-liner relationship between maximum specific growth rate (μ_m) in Day $^{-1}$ and kinetic parameter (k) against catalyst concentration in m^3/m^3 slurry at different water hyacinth concentrations.

It has been found from Figure 6 that the maximum specific growth rate (μ_m) depends on catalyst concentration and increases initially with increase in catalyst concentration in m^3/m^3 slurry for different WH concentrations but after a attaining a maximum value it decreases gradually. It also reveals that catalyst concentration, for which μ_m is maximum, is 0.0221 m^3/m^3 slurry at 29.43 kg/m^3 WH concentration. The equations which fit such curves are,

$$\mu_m = -102.5C^2 + 4.5454C + 0.6019 \quad (6)$$

$$\mu_m = -30.906C^2 + 1.1179C + 0.6072 \quad (7)$$

It has been further observed from Figure 7 that the kinetic parameter (k) which is a measurement of the overall digester performance, depends on the catalyst concentration and increases initially with increase in catalyst concentration for different WH concentrations but after a attaining a maximum value it decreases gradually. It also reveals that catalyst concentration, for which k is maximum, is 0.02274 m^3/m^3 slurry at 20.00 kg/m^3 WH concentration. The equations which fit such curves are,

$$k = -65.312C^2 + 3.9928C + 0.171 \quad (8)$$

$$k = -53.378C^2 + 2.9705C + 0.9144 \quad (9)$$

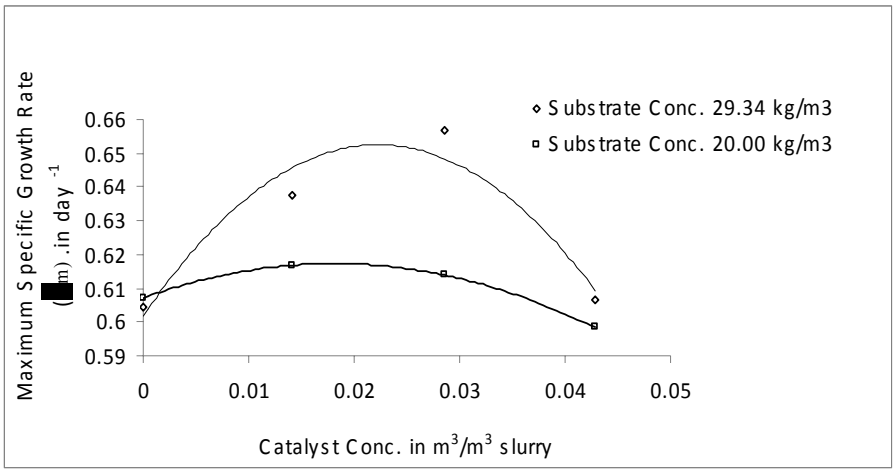


Figure 6. Plot of maximum specific growth rate (μ_m) in day $^{-1}$ against volume of catalyst used in ml at different water hyacinth concentration

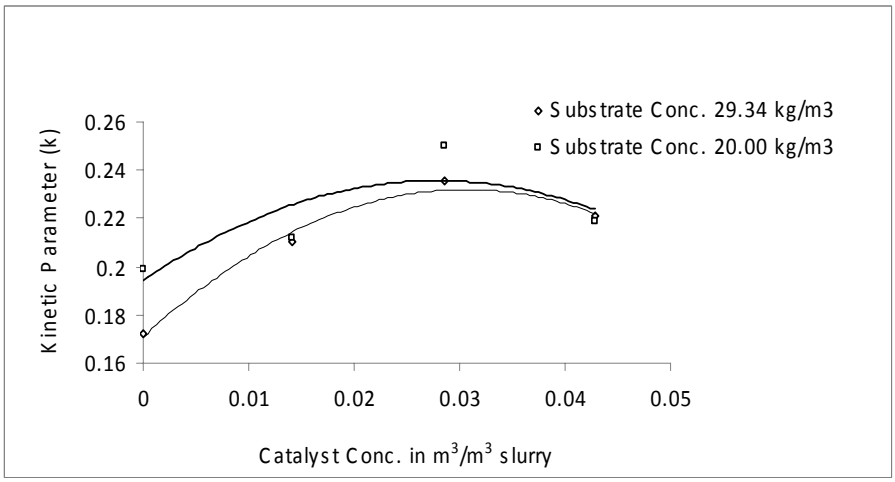


Figure 7. Plot of kinetic parameter (k) against volume of catalyst used in ml at different water hyacinth concentrations

5. Conclusion

The present experimental study is a systematic investigation on the effect of organic material used as biocatalyst on biomethanation of water hyacinth. It has been observed that the organic catalyst can enhance the rate of production of biogas from water hyacinth and the biogas production start earlier when catalyst has been used. The experimentation shows that the rate of production also increased with increase in catalyst concentration. A kinetic model has been developed which describe the biomethanation process successfully. By fitting the experimental data the maximum specific growth rate (μ_m) and kinetic parameter (k) has been obtained. It has been found that variation of maximum specific growth rate (μ_m) and kinetic parameter (k) follow a non-linear relationship with catalyst concentration within the range of the parameters experimented with.

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