International Journal of Chemical, Materials and Biomolecular Sciences
ISSN: 2415-6620
Vol:3, No:6, 2009

Biogas Production from Waste using Biofilm Reactor: Factor Analysis in Two Stages System

N. Zainol, J. Salihon, and R. Abdul-Rahman

***Abstract*—**Factor analysis was applied to two stages biogas production from banana stem waste allowing a screening of the experimental variables second stage temperature (T), organic loading rates (OLR) and hydraulic retention times (HRT). Biogas production was found to be strongly influenced by all the above experimental variables. Results from factorial analysis have shown that all variables which were HRT, OLR and T have significant effect to biogas production. Increased in HRT and OLR could increased the biogas yield. The performance was tested under the conditions of various T (35°C-60°C), OLR (0.3 g TS/l.d–1.9 gTS/l.d), and HRT (3 d–15 d). Conditions for temperature, OLR and HRT in this study were based on the best range obtained from literature review.

***Keywords*—**Biogas, factor analysis, banana stem waste.

I. Introduction

ANAEROBIC digestion is among the oldest biological wastewater treatment processes, having first been used more than a century ago. The most important reasons for the choice of anaerobic digestion as a treatment method are the feasibility to treat wastewaters with a high organic load. According to international [1], the aerobic treatment of such a wastewater requires biological purification systems with high construction and operational costs (energy consumption), besides which stabilisation of the biological reactions is not assured (activated-sludge tanks), or the wastes cause clogging of installations such as aerobic biological filters and biodiscs. In the case of seasonal operation of the production units, the disadvantage of a slow start-up after the non-feeding conditions makes the aerobic treatment unacceptable for the treatment of mill wastewater. With bioreactors for anaerobic fermentation these problems are not present [2].

The treatment capacity of an anaerobic digestion system is primarily determined by the amount of active population retained within the system which in turn is influenced by wastewater composition, system configuration and operation of anaerobic reactor. Unlike the conventional biofilm systems in which the growth support media are fixed in space either by gravity or by direct attachment to the reactor wall, the anaerobic fluidised bed system retains the growth support media in suspension by drag forces exerted by upflowing wastewater. Moreover, the distribution of biomass holdup (in form of biofilm) is relatively uniform, because of the completely mixed conditions maintained and the continuous biofilm sloughing process which counterbalances the accumulation of biomass due to growth [3-5].

This paper deals with the optimisation of the biogas production process in two stages biogas production. There were three variables to be optimised namely the second stage temperature (T), hydraulic retention time (HRT) and organic loading rate (OLR). The methods of 2^3 factorial experiments and the path of steepest ascent [6] were used to find the area containing the maximum yield. Yates method [7] was used to calculate the main effects and interactive effects of the experimental variables on the yield. The method of Rotatable Composite Design [8] was then used to evaluate the experimental variables at the maximum point.

II. Theory

A. An Introduction on Factor Analysis

The method of factor analysis will be used to screen the experimental variables which are most relevant to the fermentation. This method has been shown to allow an efficient screening of the experimental variables which are most relevant to the biogas yield in a particular type of fermentation.

The method of factorial analysis enables us to describe the various experimental variables in terms of mutually orthogonal factors which are uncorrelated to each other but which have the same mean and the same variance as the standardised form of the experimental variables. Mutually orthogonal factors are important in that only such factors may be used to construct linear models, where the interactions between factors are not taken in to account. Empirical models are constructed to describe the yields in terms of these mutually orthogonal factors. The significance of each actor in its effect on the yield is then determined by removing the particular factor from the model involving all the factors and comparing the mean square difference between the actual data and the prediction of the resulting model with the mean square difference between the actual data and the predictions of the model involving all the factors using the statistical F-test. These factors can then be classified into categories according

N. Zainol is with Faculty of Chemical and Natural Resources Engineering, Universiti Malaysia Pahang, Locked Bag 12, 25000 Kuantan, Pahang, Malaysia (corresponding author to provide phone: +6095492373; fax: +6095492399; e-mail:azwina@ump.edu.my).

J. Salihon is with Faculty of Chemical and Natural Resources Engineering, Universiti Malaysia Pahang, Locked Bag 12, 25000 Kuantan, Pahang, Malaysia (e-mail:salihon@ump.edu.my).

R. Abdul-Rahman is with Department of Chemical and Process Engineering, Faculty of Engineering, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia (e-mail: rakmi@vlsi.eng.ukm.my).

to how significantly each of them affects the yield. If an experimental variable contributes only to factors which do not affect the yields significantly then it can be concluded that it is not relevant to the yield and can be dropped from subsequent experiments. If an experimental variable contributes to one or more factors which have significant effects on the yield then the experimental variable is relevant to the yield and should be retained for further investigation and optimisation

To construct the models, a new table of the experimental results consisting of the yields and the factors has to be evaluated by calculating the experimental values of each factor. A linear regression between these factors and the yields is then constructed. Other models are constructed in the same manner but employing successively less factors. The evaluation of the significance of each factor is then done by the statistical F-test.

In this work the estimation of the regression coefficients of all models were done by using Matlab programming which operates by minimising the sum of squared differences between the actual and predicted yields. The results of the regression analysis were tested for significance at three levels of confidence namely 99%, 95% and 90%. The breakdown of the significance of the results into these three confidence levels were considered sufficient for this preliminary work.

III. Materials and Method

A. Experimental set-up

All experiments were done in 20 L anaerobic sequencing batch reactor followed by 10 L fixed bed reactor with gas outlet. All the reactors were seeded with anaerobic acclimatized banana stem sludge. The process was conducted at ambient temperature for the first stage and thermophilic temperature for the second stage. The second stage temperature (T), hydraulic retention times (HRT) and organic loading rates (OLR) of the reactors were varied for different experimental runs (Table I). Daily withdrawal of an appropriate volume from the reactor corresponding to the determined HRT or OLR was done by a draw-and-fill method. Biogas evolved from the reactor was measured and collected in a gas holder by water displacement. Samples were collected and analyzed for performance evaluation.

B. Analytical Methods

Chemical oxygen demand (COD) concentration was spectrophotometrically analyzed using a spectrophotometer and methods as in Spectrophotometric Instrument Manual. Gas collection was done using water displacement daily. Substrate concentration was measured as suspended solid according to Standard Methods for The Examination of Water and Wastewater. 20 ml well-mixed sample was filtered through a weighed standard glass-fiber filter and the residue retained on the filter is dried to a constant weight at 103^{o}C to 105^{o}C. The increase in weight of the filter represents the total suspended solids [9].

C. Experimental Design

In this work the value of each experimental variable was varied over as wide a range as possible so as to gain the maximum knowledge of the behaviour of the system over wide-ranging conditions. In most cases practical difficulties prevented the use of too large variation in the values of the experimental variables. In cases of zero yields the experiment could not be treated statistically since a zero yield is not sensitive to further changes in the values of the variables which would otherwise have decreased the yield. It was assumed that the response surface did posses a maximum. If the area that has been examined did not cover the maximum, a linear model might be sufficient to represent since there would not be as much curvature as there would be if it had contained the maximum. Therefore, a linear model approach was tried first. If it did not fit the data of the orthogonal factors and yields, a non-linear model would have to be fitted instead so as to account for the curvature that is likely to occur near the maximum yield.

IV. Discussion and Conclusion

The experimental variables that characterise a factor are defined as those that have absolute values of coefficients greater than 0.4 (thus allowing for 40% error) in the equation describing that factor in terms of the experimental variables. The following conclusions can be made from Table IV.

1. Factor F1 being characterised by HRT and OLR
2. Factor F2 being characterised by T
3. Factor F3 being characterised by HRT and OLR

At 99% confidence level, the best model for biogas yield is the model involving the factors F2, F3 and constant (Table IX). Table X shows that these factors consisted of contribution from experimental variables of OLR, HRT and T.

TABLE I
Experimental Results

	HRT (d)	**OLR (gTS/l.d)**	**T (^{o}C)**	**Biogas (l/g COD)**
1	5.4	1.0	40.1	16.3
2	12.6	0.4	40.1	15.8
3	5.4	1.1	40.1	16.5
4	12.6	0.4	40.1	16
5	5.4	1.0	54.9	23.2
6	12.6	0.4	54.9	21.7
7	5.4	1.1	54.9	30.3
8	12.6	0.4	54.9	25.2
9	3.0	1.9	47.5	18.5
10	15.0	0.3	47.5	18.4
11	9.0	0.6	47.5	17.5
12	9.0	0.6	47.5	19
13	9.0	0.6	35.0	12.6
14	9.0	0.6	60.0	25
15	9.0	0.6	47.5	21.8
16	9.0	0.6	47.5	21.3
17	9.0	0.6	47.5	20.6
18	9.0	0.6	47.5	20.8
19	9.0	0.6	47.5	20.3

International Journal of Chemical, Materials and Biomolecular Sciences
ISSN: 2415-6620
Vol:3, No:6, 2009

TABLE II
CALCULATION OF W

	w1	w2	w3
1	-1.17951	0.822782	-1.17951
2	1.17951	-0.85193	-1.17951
3	-1.17951	1.020162	-1.17951
4	1.17951	-0.81443	-1.17951
5	-1.17951	0.844598	1.17951
6	1.17951	-0.86226	1.17951
7	-1.17951	1.031589	1.17951
8	1.17951	-0.82184	1.17951
9	-1.98369	3.290494	0
10	1.983691	-1.05058	0
11	1.41E-14	-0.36578	0
12	1.41E-14	-0.25041	0
13	1.41E-14	-0.25637	-1.98369
14	1.41E-14	-0.27894	1.983691
15	1.41E-14	-0.27737	0
16	1.41E-14	-0.27486	0
17	1.41E-14	-0.3128	0
18	1.41E-14	-0.30308	0
19	1.41E-14	-0.28897	0

TABLE III
THE CORRELATION MATRIX OF THE STANDARDISED VARIABLES

	HRT	OLR	T
HRT	1	-0.8921	0
OLR	-0.8921	1	-0.00139
T	0	-0.00139	1

TABLE IV
THE EIGEN VECTOR VALUES

	F1	F2	F3
HRT	0.7071	-0.0016	-0.7071
OLR	0.7071	0	0.7071
T	0.0011	1	-0.0011

TABLE V
EIGEN VALUES OF THE CORRELATION MATRIX

Eigen value		% contribution
1	0.1079	3.60
2	1.0000	36.93
3	1.8921	100.0

TABLE VI
THE VALUES OF THE FACTORS

	F1	F2	F3
1	-0.25354	-1.17762	1.417118
2	0.230335	-1.1814	-1.43513
3	-0.11397	-1.17762	1.556685
4	0.256848	-1.1814	-1.40862
5	-0.23552	1.181397	1.429949
6	0.225627	1.177622	-1.44503
7	-0.1033	1.181397	1.56217
8	0.254204	1.177622	-1.41645
9	0.92404	0.003174	3.729376
10	0.659805	-0.00317	-2.14553
11	-0.25865	-2.3E-17	-0.25865
12	-0.17706	-2.3E-17	-0.17706
13	-0.18346	-1.98369	-0.17909
14	-0.19506	1.983691	-0.19942
15	-0.19613	-2.3E-17	-0.19613
16	-0.19436	-2.3E-17	-0.19436
17	-0.22118	-2.3E-17	-0.22118
18	-0.21431	-2.3E-17	-0.21431
19	-0.20433	-2.3E-17	-0.20433

TABLE VII
THE COEFFICIENTS OF THE LINEAR MODEL

	Value
Coefficient	Biogas (l/g COD)
a0	20.0421
a1	-1.4519
a2	3.5178
a3	0.2734

TABLE VIII
THE EVALUATION OF THE LINEAR MODEL

No	Predicted yield	Actual yield	Squared error
1	16.65501	16.3	0.126035
2	15.15939	15.8	0.410376
3	16.49053	16.5	8.96E-05
4	15.12815	16	0.760125
5	24.93092	23.2	2.996068
6	23.46208	21.7	3.104928
7	24.77509	30.3	30.52461
8	23.4284	25.2	3.138555
9	19.73126	18.5	1.516007
10	18.48638	18.4	0.007461
11	20.34691	17.5	8.104922
12	20.25077	19	1.564426
13	13.28127	12.6	0.464131
14	27.24901	25	5.058034
15	20.27324	21.8	2.331
16	20.27115	21.3	1.058535
17	20.30276	20.6	0.088351
18	20.29466	20.8	0.255366
19	20.28291	20.3	0.000292
		SSE	61.50931
		MSE	3.237332
		RMSE	1.799259

TABLE IX
THE EVALUATION OF THE LINEAR MODEL

Model	MSE	MSEm/MSEfm
123	3.237332	1
12	3.378807	1.043701
1	15.75386	4.866309

TABLE X
THE COEFFICIENTS AND CONSTANTS OF THE LINEAR MODELS

Model	a0	a1	a2	a3
123	20.0421	-1.4519	3.5178	0.2734
12	20.0421	-1.4519	3.5178	
1	20.0421	-1.4522		

TABLE XI
THE COEFFICIENTS OF THE QUADRATIC MODEL

	Value
Coefficient	**Biogas (l/g COD)**
b0	27.81828
b1	29.34881
b2	3.816442
b3	5.04921
b11	-5.49296
b22	-0.5289
b33	-3.51712
b12	3.666676
b13	-0.4894
b23	0.842651

TABLE XII
THE EVALUATION OF THE QUADRATIC MODEL

No	Predicted yield	Actual yield	Squared error
1	14.75283	16.3	2.39374
2	15.14253	15.8	0.432272
3	17.54549	16.5	1.093058
4	16.12278	16	0.015075
5	24.96853	23.2	3.127695
6	22.98085	21.7	1.640583
7	28.98985	30.3	1.716493
8	24.34451	25.2	0.731861
9	18.50735	18.5	5.4E-05
10	18.44661	18.4	0.002173
11	18.28587	17.5	0.61759
12	21.4298	19	5.903935
13	13.19783	12.6	0.357405
14	24.45613	25	0.295797
15	20.7064	21.8	1.19596
16	20.77399	21.3	0.276692
17	19.74539	20.6	0.730363
18	20.01021	20.8	0.623761
19	20.39305	20.3	0.008657
		SSE	21.16316
		MSE	1.113851
		RMSE	1.055391

The performance curve of biogas yield is shown in Fig. 1 and Fig. 2. The value of HRT, OLR and biogas were in unit of day, gTS/l.d and l/g COD respectively. All variables which were HRT, OLR and T have significant effect to biogas production. Increased in HRT and OLR could increased the biogas yield (Fig. 2). Methanogens--methane-producing organisms--live in a syntrophic, relationship with certain other microorganisms that consume the feedstock and produce simple acids as part of their metabolism. The simplest acids are essential to the metabolic processes of the methanogens. As acid-producing organisms tend to choke in their own acetic by-products, methanogens cooperate by consuming these by-products in the methane-producing process.

Given sufficient time to establish the proper ratio of methane-producing organisms to acid-producing organisms, a homeostasis, or stability, will occur with a pH of about seven in a digester. The objective here is to create a stable working relationship among the microbial population in the digester. This implies the need for fairly constant operating temperatures and feedstock characteristics. Conversely, any rapid variations of these conditions will cause the microbial population to shift dramatically and possibly upset the overall system balance in the digester. HRT is an important parameter because it influences the efficiency of the biogas digester. Shorter retention times will create the risk of washout, a condition where active biogas bacteria are washed out of the digester at too young an age, making the population of bacteria unstable and potentially inactive. Daily conversion of organic material to methane will continue to increase per unit increase of weight (i.e., age) of bacteria up to a certain point. Thereafter, methane production will drop off per unit weight (or age) of bacteria.

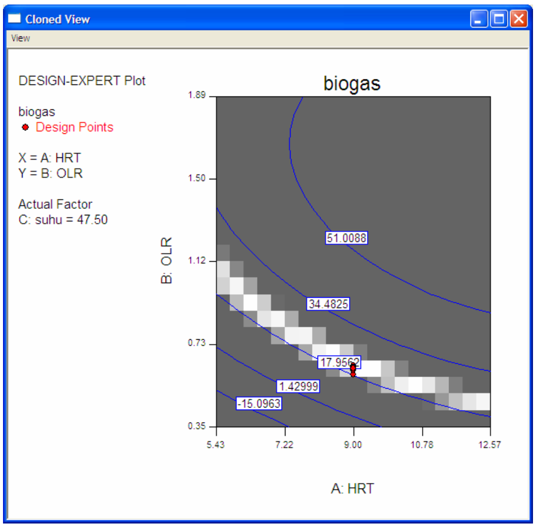

Fig. 1 Contour graph for biogas yield

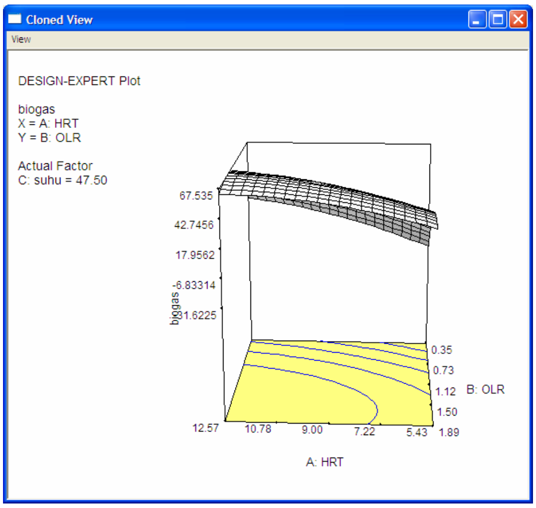

Fig. 2 3D graph for biogas yield

References

[1] L. Hartmann, “Biologische Abwassereinigung 3,” Uberarbeitete. Springer, Berlin. 1993.

[2] D. Dalis, A. K. Anagnostidis, A. A. Lopez, A. I. Letsiou, I. Hartmann, “Anaerobic digestion of total : raw olive-oil wastewater in a two-stage pilot-plant (up-flow and fixed-bed bioreactors),” Bioresource Technology. 57 (1996) 237-243.

[3] W. T. Tang, L. S. Fan, “Steady state phenol degradation in a draft-tube, gas-liquid-solid fluidized bed bioreactor,” AIChE J. 33 (1987) 239.

[4] P. Fox, M. T. Suidan, J. T. Bandy, “A comparison of media types in acetate fed expanded-bed anaerobic reactors,” Wat. Res. 24 (1990) 827-835.

[5] M.T. Suidan, J. R. V. Flora, T. K. Boyer, A. M. WueUner, B. Narayanan, “Anaerobic dechlorination using a fluidized-bed GAC reactor,” Wat. Res. 30 (1996) 160- 170.

[6] W. G. Cochran, G. M. Cox, “Experimental Design,” John Wiley and Sons, New York, 1957.

[7] F. Yates, “The design and analysis of factorial experiments,” Imperial Bureau of Soil Science, Harpenden, England, 1937.

[8] D. M. Himmelblau, “Process analysis by statistical methods,” John Wiley and Sons, New York, 1970.

[9] A. E. Greenberg, L. S. Clesceri, A. D. Eaton, “Standards methods for the examination of water and wastewater. 18th Edition,” American Public Health Association, Washington, DC, 1992.