Iranica Journal of Energy & Environment

Journal Homepage: www.ijee.net

IJEE an official peer review journal of Babol Noshirvani University of Technology, ISSN:2079-2115

Effect of Substrate and Granules/Inocula Sizes on Biochemical Methane Potential and Methane Kinetics

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P A P E R   I N F O

Paper history:
Received 28 February 2015
Accepted in revised form 7 December 2015

Keywords:
Biogas production
Anaerobic digestion
Modified Gompertz
Agro-industry

A B S T R A C T

This study aimed to evaluate the Biochemical Methane Potential (BMP) of different types of wastewaters and sizes of granules. The granules (CS: from a cassava, SS: a seafood, and PS: a palm oil factory) and wastewaters initial Chemical Oxygen Demand (COD) were 18,800, 4,200 and 100,000 mg/l respectively). Modified Gompertz equation was used to compare the data from the experiments. Wastewater from a cassava factory gave the highest BMP when used with only granules from its own source (CS). Wastewater from seafood factory had the highest nitrogen content thus, represented the most imbalance nutrient source. In this case, mix-granules (SS+CS) gave highest BMP. Palm oil mill effluent did not match COD: N ratio criterion and had too high COD level which caused substrate inhibition. Here the mix-granules (PS+CS) gave highest BMP. In general, the larger granule size and the nutrient balance could improve the efficiency and hence increase the biogas production rate. The initial COD or different substrate has a strong effect on BMP and the maximum specific methane rates whereas the different sizes of granule have an effect on the length of lag phase period. In most cases, it was sufficient to represent the experimental data with traditional modified Gompertz equation and Monod models.

***doi**: 10.5829/idosi.ijee.2016.07.02.02*

INTRODUCTION

Industrially, the anaerobic digestion of organic waste material is widely used not only to reduce organic matter in wastewater, but also to generate biogas, a clean and renewable energy which can partly substitute energy from fossil sources. A wide range of organic wastes, including agricultural waste, agro-industrial waste, wastewater, sewage sludge, can be used to produce biogas through anaerobic digestion of biodegradable materials [1]. In the digestion processes, organic waste is converted into biogas and other products by bacteria through four major phases: hydrolysis, acidogenesis, acitogenesis and methanogenesis [2]. The biogas from anaerobic digestion comprises of methane (CH_4), carbon dioxide (CO_2), and some trace of gases in a variable amount [3]. In Thailand, a ‘Strategic Plan for Renewable Energy development’ has been established since 2003. It aims to increase the share of renewable energy from 6.4% or 4,237 kilotons of crude oil equivalent (ktoe) per year in 2008 to 20.3% of the commercial primary energy or 19,700 ktoe per year by the year 2022 [4]. Although Thailand is an agricultural country with the large volume of potential biogas feed stocks, such as waste from agro-industry, solid waste from municipals, animal waste, industrial wastewater, etc., but only two major sources, namely wastewater from cassava starch factories and pig farms [4] are currently utilized for biogas production [5-11]. Thus, the production of biogas from agro-industrial wastewater is one option to increase significantly the share of renewable energy. The long term objective is not only to reduce water pollution, but also to gain economic value from wastewater. In doing so, one of the important parameter in the design and start-up biogas plant is the bio-methane potential (BMP) which is widely used to determine the anaerobic biodegradability of organic waste or wastewater [12, 13].The scope of this research

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Please cite this article as: S. Jijai, G. Srisuwan, S. O-Thong, I. Norli and C. Siripatana, 2016. Effect of Substrate and Granules/Inocula Sizes on Biochemical Methane Potential and Methane Kinetics, Iranica Journal of Energy and Environment 7 (2): 94-101.

is to study the bio-methane potential of three different types of agro-industrial wastewater which represent the different substrate characteristics in terms of compositions, COD/N ratio, digestibility and physico-chemical properties. Then we compared the bio-methane potential from different substrate sources and different sizes of granules using the modified Gompertz equation. In addition, other more elaborated kinetic models, including Schnute, Gompertz power law, Grau n-order and traditional Monod models were exploited to characterize mechanistic aspects of the batch anaerobic digestion. The preliminary results in this work could be valuable for planning and making decisions in the start-up of the continuous biogas generating systems which is a normal mode of operating biogas plant in medium and large scales.

MATERIALS AND METHODS

Wastewater and Inocula

The wastewater samples were collected from a cassava starch factory, a seafood factory and a palm oil mill. Characteristics of wastewater from three sources are shown in Table 1. The wastewater samples were kept at 0-4 °C until used in the experiment. The granular sludge/inocula were collected from the methanogenic fermentation stage of the up-flow anaerobic sludge blanket (UASB) reactors from the respective factories. The characteristics of granules/inocula from three sources are shown in Table 2. The granule size was measured using Olympus stereo microscope model DP 12 SZCTV.

TABLE 1. Characteristics of wastewater

Parameter	Cassava factory	Seafood factory	Palm oil mill
pH	5.0	6.3	4.2
COD (g/l)	18.8	4.2	100
TKN (mg/l)	320	343	1,089
TP (mg/l)	70	42	249
TS (g/l)	16.3	3.54	81
VS (g/l)	11.5	2.62	62.6
SS (mg/l)	1,900	256.7	47,000
VSS (mg/l)	250	172	41,000
Alkalinity (mg/l as $CaCO_3$)	162.5	1,400	687.5
VFA (mg/l as $CaCO_3$)	562.5	740	4,018.8

TABLE 2. Characteristics of granules/inocula

Sources	Sizes (mm)	SMA (gCOD/gVSS.d)
Cassava factory	1.5-1.7	0.28
Seafood factory	0.7-1.0	0.26
Palm oil mill	0.1-0.2	0.16

Experimental set-up

The anaerobic digesters having a total volume of 250 ml and a working volume of 200 ml were used in all experiments. The BMP test was conducted using the method of Owen et al. [13] with at least three replications. Initial pH for all reactors was adjusted to 6.8-7.2 by the addition of NaOH 1 N. The digesters were flushed withnitrogen gas before sealing. It was sealed with rubber plug and cover with aluminium cap. The experiments were conducted at the room temperature (28-30 °C). Biogas production was measured daily by the water displacement method as used by other authors [3-4, 10, 14]. The methane content was measured using Gas Chromatograph (GC-8A Shimadzu). The experimental setup is shown in Figure 1.

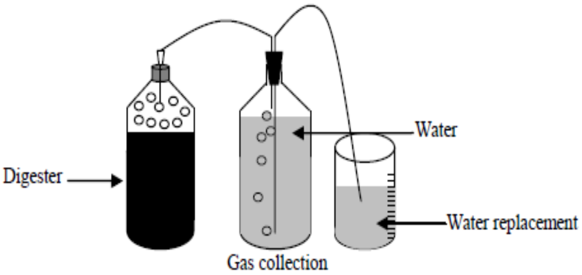

Figure 1. Schematic view of the experimental set-up

Experimental design

All experiments were operated in batch mode. Three different sizes of granules/inocula were used for all three sources of wastewater. Granules, 15% by volume, were used as inocula of methanogenic bacteria. The variables designed in this study were shown in Table 3.

The granules from different sources had different sizes and thus their mixtures were used to study the effect of granule sizes on the biogas production and performance of the treatment system. In addition, different types of agro-industrial wastewater represented the different substrate characteristics in terms of compositions (protein, carbohydrate and fat).

TABLE 3. Experimental design of this study

Wastewater/sources	Granules/Inocula		
	100%	50:50	50:50
Cassava factory (CW)	CS	CS+SS	CS+PS
Seafood factory (SW)	SS	SS+CS	SS+PS
Palm oil mill (PW)	PS	PS+CS	PS+SS

where CS = Granule from a cassava factory, SS = Granule from a seafood factory, PS = Inoculun from a palm oil mill

Chemical analysis

In all experiments, we analyzed pH, chemical oxygen demand (COD), total Khejdhal nitrogen (TKN), total phosphorus (TP), total solids (TS), volatile solids (VS), suspended solids (SS), volatile suspended solids (VSS), alkalinity and volatile fatty acids (VFA). All analytical procedures are performed in accordance with standard methods for examination of water and wastewater [15].

Kinetic model of biogas production

One of the most widely-used semi-empirical model for kinetic study of methane production is the modified Gompertz equation as shown in Eq. (1) [1-2, 4, 16-21].

$$M = P \cdot \exp\left\{-\exp\left[\frac{R_m \cdot e}{P}(\lambda - t) + 1\right]\right\} \qquad (1)$$

where; M is Cumulative methane production (ml), P is Methane production potential (ml), R_m is the maximum specific methane production rates (ml/d), λ is lag phase period or minimum time to produce biogas (days) and e is a mathematical constant (2.7182).

Another, more generalized time-derivative Gompertz extension, the Schnute model which have the following time derivative of the specific growth rate (μ) and the solution.

$$\frac{d\mu}{dt} = -\mu(\alpha + \beta r) \qquad (2)$$

$$P = P_\infty \exp\left(\frac{-\alpha t}{\beta}\right)\left(\exp(\alpha t) - \frac{\beta\mu_0}{\alpha + \beta\mu_0}\right)^{1/\beta} \qquad (3)$$

where P, μ, β, α are biogas generated, the specific biogas production rate, and the Schnute parameters respectively. We also exploited a power-law extension of Gompert which have the following time derivative of the specific growth rate (μ) and the solution.

$$\frac{d\mu}{dt} = -\alpha\mu^{1+n} \qquad (4)$$

$$P = P_\infty \exp\left(-\frac{\mu_0^{1-n}}{\alpha}\left(\frac{1}{1-n}\right)\left(\alpha n \mu_0^n t + 1\right)^{1-\frac{1}{n}}\right) \qquad (5)$$

And the substrate-concentration dependent models, traditional Monod Kinetics and Grau n-order models, which have the following solutions for constant biomass concentration. The solution of Monod kinetics is,

$$S = K_s W\left(\frac{S_0}{K_s}\exp\left(\frac{K_1 S_0 - t}{K_1 K_s}\right)\right), P' = P - P_0 = P'_\infty - K_s Y_{ps} W\left(\frac{P'_\infty}{K_s Y_{ps}}\exp\left(\frac{K_1 P'_\infty - Y_{ps} t}{K_1 K_s Y_{ps}}\right)\right) \qquad (6)$$

where P', P_0 and P_∞ are the observed, initial (non-observable) and final methane accumulation, Y_{ps} is methane yield coefficient, K_1 and K_s are Monod parameters, and W(z) is Lambert W function and of the Grau n-order modeling.

$$P = P_\infty^{\frac{n}{n-1}}\left(P_\infty + (n-1)Y_{ps}k_{ns}t\right)^{\frac{1}{1-n}} \qquad (7)$$

where k_{ns} and n are parameters Grau n-order model Matching Gompertz parameters to Monod parameters.

RESULTS AND DISCUSSION

The result of this study in term of organic removal is shown in Figure 2 which compares the COD in influent, effluent and COD reduction in three types of wastewater having different sizes of granules/inocula. Wastewater from seafood factory gave the highest COD reduction of all three different sources of inocula because it contained lower organic substrates than other sources. On the other hand, when the same inocula were used (SS+CS or CS+SS) for wastewater from palm oil mill which had the highest COD (100,000 mg/l) among these three sources, the COD reduction for all three types of inocula was lowest. For all three types of wastewater, it was found that the mix-inocula with granules from cassava factory (SS+CS, CS+SS and PS+CS) gave the highest COD removal percentage.Table 3 summarizes our experimental design for studying the effect of granules/inocula from different sources and sizes on the biogas production from the three wastewaters. Biogas production was monitored for 45 days when gas generation essentially stopped. At the end of experiment period, the cumulative biogas production from 3 sources of substrates reached the value of 156-1,013 ml and methane content was in the range of 39.94-56.91%. It was observed that mix-inocula (PS+CS), when used with palm oil mill effluent, gave the highest methane production potential of 409.12 ml which was higher than that produced by using single inocula. However, in the experiment with the wastewater from cassava factory, largest amount of methane was produced (385.15 ml) when inoculated with the granules from cassava factory alone. Mix-granules/inocula in this case was inferior to the granules from its own source. Among three wastewaters, the one from seafood factory gave lowest methane production potential. In this case, the methane production for the inocula (control (SS), mix-granules (SS+CS and SS+PS) were 84.95, 119.69 and 68.40 ml respectively. The methane yield in term of BMP was shown in Table 4

Wastewater from cassava factory, seafood factory and palm oil mill gave the BMP in the ranges of 150.95-161.12 ml CH_4/gCOD removed,113.07-120.13 ml CH_4/gCOD removed and 90.54-107.95 ml CH_4/gCOD removed respectively. Thus, the wastewater from cassava factory gave the highest BMP value. Low BMP value in the case of the wastewater from palm oil mill

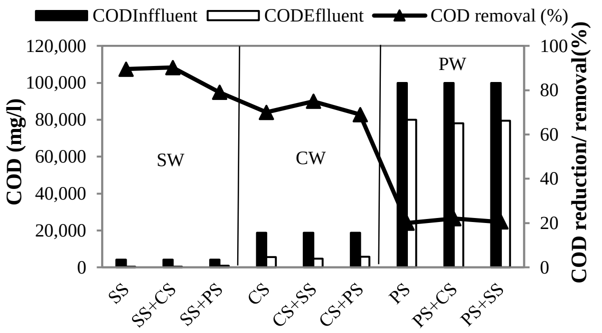

Figure 2. Comparison of COD influent, COD effluent and COD reduction

(100,000 mg COD/l) posted some questions whether it was a result of nutrient imbalance alone or substrate/product inhibition got involved. So we did a supplementary experiment where the original wastewater was diluted with pure water, making it one-fourth of the original concentration (25,000 mg COD/l). It was found that the diluted wastewater gave a better result than that from cassava factory, thus clearly indicated that substrate or/and product inhibition occurred considerably when wastewater from palm oil mill was used in its original form.

TABLE 4. The results of proximate analyses of raw materials, Gompertz parameters, and methane yield

Substrate	COD (g/l)	Digester	Modified Gompertz				Methane yield (ml CH_4/g CODremoved)
			P (ml)	R_m (ml/d)	λ (d)	R^2	
CW	18.8	CS	385	21.8	-1.24	0.994	161.12
		CS+SS	413	22.9	-1.16	0.997	152.48
		CS+PS	365	24.4	1.00	0.998	150.95
SW	4.2	SS	85	10.3	1.61	0.998	119.44
		SS+CS	120	18.1	-0.38	0.997	120.13
		SS+PS	68	10.6	1.81	0.998	113.07
PW	100	PS	364	70.4	-0.04	0.987	104.76
		PS+CS	409	67.6	-1.43	0.998	107.95
		PS+SS	331	53.3	-1.40	0.998	90.54
PW	25	PS	621	29.3	1.32	0.991	154.46
		PS+CS	765	50.0	-2.51	0.988	177.59
		PS+SS	578	26.2	-1.52	0.983	145.54

Where CW = Wastewater from a cassava factory, SW = Wastewater from a seafood factory, PW = Wastewater from a palm oil mill

The results suggest that the initial COD has a strong effect on BMP, P, R_m and λ and must be taken seriously. The parameters obtained using Eq. (1) to describe the methane production is shown in Table 4. It was found that most experiments showed essentially very short time lag before the microorganisms started to function fully. This implies that the microorganism in the system is viable and the substrates were readily biodegradable, thus causing biogas production to occur immediately after inoculation. In other words, the microorganisms did not need to adapt themselves to a new environment, because the granules or inocula in this study were collected from the methanogenic fermentation stage of the up flow anaerobic sludge blanket (UASB). These results are similar to that of Rincon et al. [6]. It should be also noted that most batches exhibited negative time-lag (λ). This indicates that the lag-phase of methanogens′ growth occurred faster than predicted by Gompertz model. In other words, the favorable substrate condition in most batches accelerated its growth in the initial anaerobic process, shorten the time to reach exponential phase considerably.

For cassava wastewater, the performance of the anaerobic digestion was similar regardless the type of granules. In term of the maximum specific methane production rate (R_m), the control digesters (CS) which used only granules from its own source, the digesters with CS+SS, and digesters with CS+PS gave the methane production rates of 24.5, 23.4 and 25.7 ml/d respectively. In contrary, for seafood and palm oil mill wastewater the best performance occurred when mixed granules containing CS and the granules from its own sources was used together.

These results showed that the granules from the cassavafactory was the most active among three sources and the size of granules is directly related to how active the involved microbes and gave lower of lag phase period or minimum time to produce biogas (λ). The bigger size of granules means that the microbes were more active so that they achieved high saturated population density thus forming bigger granules. Among three wastewater sources, as shown in Figure. 3, palm oil mill wastewater took shortest time to accumulate the methane gas and reached the final values within approximately 13 days. The highest R_m in palm oil mill wastewater was attributed to the high substrate concentration. However, the very high initial COD of palm oil mill wastewater with relatively low methane yield coefficient (Y_{ps}), suggested the presence of toxic products or excessive acid accumulation (as shown by low final pH) which brought about the cessation of methanogenesis. This was verified by the supplementary experiments using diluted palm oil mill wastewater (25,000 mg COD/l), as shown in Figure 4.

At this level of COD the acidogenesis and acitogenesis were not too high, thus these two steps could synchronize with methanogenesis, maintaining pH to within methanogen's active limited (6.8 – 7.2 pH) which in turn suppressed the nagative effect two previous steps. Our results for palm oil mill wastewater were in agreement with the study of Paepatung et al. [4]. Similarly, albeit with smaller R_m it took approximately

15 days for the digesters containing seafood wastewater to release methane completely, reaching their saturated values. However, although this wastewater has relatively low initial COD (4,200 ml/l), but because of its imbalance COD/N ratio (12.3 g COD/g N), the specific rate of methane production was the lowest among the three substrate sources.

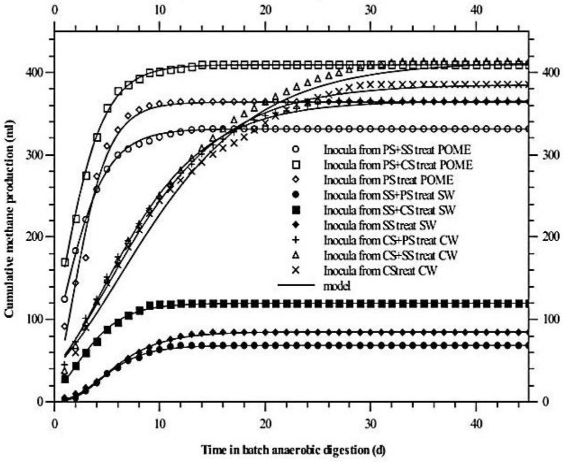

Figure 3. Comparison of experimental data and modified Gompertz model

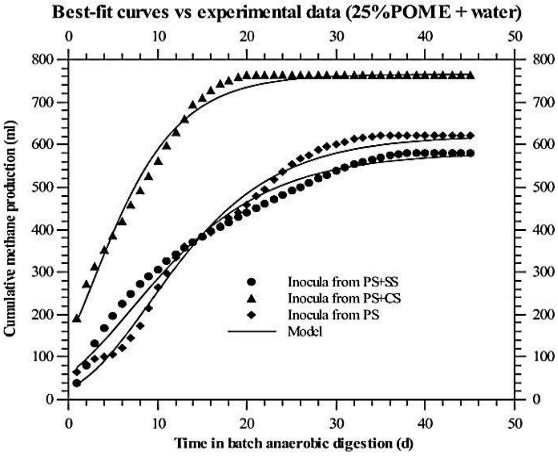

Figure 4. Comparison of experimental data and modified Gompertz model (Palm oil mill effluent)

It is interesting to note that it took 30 days for the cassava wastewater to release all potential methane and reached the saturated amount although its methane potential was among the highest one. Furthermore, the sources and sizes of granule have only a small effect on its performance in term of BMP. Cassava wastewater showed much as maller R_m as compared to the original palm oil mill wastewater.

This implies that the composition of cassava wastewater (mainly polysaccharides and proteins) and its low initial COD helped to maintaina good supply of acetate for methanogens without excessive amount of organic acids accumulated which could stop the microbes to function.

In this case the acid formation was slowed down by a relatively slow hydrolysis of polysaccharides to monosaccharide which in turn slowed down the acid formation and acetate.

Regarding the effect of the COD/N ratio, Sumardiono et al. [22] reported that the biogas production showed a satisfactory performance in the COD/N range of 71.4 to 85.7. Based on this criterion, the COD/N ratio of seafood, cassava and palm oil mill were 12.2, 58.8 and 91.8 respectively, thus none of them fell within the optimal range. Nevertheless, we can state that seafood wastewater fell into the lower extreme whereas palm oil mill wastewater fell into another side but almost within an optimal range. Cassava wastewater fell in the middle close to the lower end of the optimal range but not within it.

Hence, the performance of the reactors containing cassava and dilute of 25% palm-mill wastewater from original (with suitable initial COD) were good and comparable. Therefore, the lower performance occurred with seafood wastewater was largely caused by extremely low COD/N ratio. Here a larger portion of carbon source was used for microbial growth instead of for methane production and may bring about a more toxic environment due to the accumulation of dissolved ammonia which reduced cell activities and methane production.

The resulte from models fitting for our experimental data set, higher order Gompertz-type models (Schnute and power law models) did not indicate any advantage over the original (or modified) Gompertz model. However, this is only a specific conclusion and certainly Schnute and power law models provide much more flexibility which should be used in general. Monod-type model is more interpretive, giving better insight on the mechanistic explanation of the biogas data. However, the results reflected that single-substrate Monod formulation may not adequate if a considerable fraction of slowly degradable substrate is present, thus two-substrate formulation should be developed for better insight of these processes.

We also illustrated the four-points matching (P_0, P_∞, P_1 and P_2) for Gompertz-type to Monod-type models and, in similar manner, for Gompertz-type to Grau n-order models. Since we assumed that $P_0 \approx 0$, the discrepancy between the matching approach and the best-fit curve of the Monod model was still high. The result from matching are shown in the Figure 5 and summarized description of the models in Table 5. In conclusion, the results has successfully explored some popular models used in interpreting biogas data from batch experiments

TABLE 5. Summarized description of the models, parameters and the best-fit parameter (R^2)

Models	**Parameter**	**CS**	**SS**	**PS (100%)**	**PS (25%)**
General parameters	Initial COD($g\ l^{-1}$)	18.8	4.2	100.0	25.0
	S_0 (mg/l)	12,084	3,526	14,946	20,825
	Y_{ps}	0.03187	0.02409	0.0243	0.02983
	P'_∞(ml)	385.2	85.0	363.8	621.3
Gompertz equation	μ_0(d^{-1})	0.3454	1.529	1.3851	0.4120
$P = P_\infty \exp\left(-\frac{\mu_0}{\alpha}\exp(-\alpha t)\right)$	α(d^{-1})	0.1537	0.3302	0.5225	0.1280
	R^2	0.9943	0.9977	0.9877	0.9906
Modified Gompertz equation	R_m(ml d^{-1})	21.78	10.32	70.089	29.27
$P = P_\infty \exp\left(-\exp\left(\frac{R_m \times e}{P_\infty}(\lambda - t) + 1\right)\right)$	λ(d)	-1.239	1.613	-0.0482	1.317
	R^2	0.9943	0.9977	0.9877	0.9906
Corrected Gompertz equation	μ_0(d^{-1})	0.4127	1.433	1.0313	0.2439
$P' = P_\infty\left[\exp\left(-\frac{\mu_0}{\alpha}\exp(-\alpha t)\right) - \exp\left(-\frac{\mu_0}{\alpha}\right)\right]$	α(d^{-1})	0.1781	0.3238	0.5032	0.1065
	P_0(ml)	43.37	1.030	53.900	73.31
	Fitted P_∞ (ml)	430.00	86.44	418.53	724.80
	R^2	0.9850	0.9975	0.9845	0.9916
Schnute model	μ_0(d^{-1})	4.359	1.618	0.4533	0.2056
$P = P_\infty \exp\left(\frac{-\alpha t}{\beta}\right)\left(\exp(\alpha t) - \frac{\beta\mu_0}{\alpha + \beta\mu_0}\right)^{1/\beta}$	α(d^{-1})	0.1181	0.3255	0.8616	0.1539
	β	0.7816	0.0247	-1.8356	-0.5754
	R^2	0.9954	0.9973	0.9937	0.9928
Modified Schnute equation	α(d^{-1})	0.1089	0.4061	0.7045	0.1278
$P = \left(R_m \frac{1-\beta}{\alpha}\right)\left[\frac{1 - \beta\exp(a\lambda + 1 - \beta - \alpha t)}{1-\beta}\right]^{1/\beta}$	β	0.7991	-0.6099	-1.00	-0.2397
	λ(d)	-0.1547	1.635	-0.1375	0.8061
	R_m(ml d^{-1})	28.74	9.839	64.101	26.94
	R^2	0.9980	0.9994	0.9931	0.9941
Corrected Schnute equations	μ_0(d^{-1})	36.054	1.519	0.4483	0.5728
$P' = P_\infty\left[\exp\left(\frac{-\alpha t}{\beta}\right)\left(\exp(\alpha t) - \frac{\beta\mu_0}{\alpha + \beta\mu_0}\right)^{1/\beta} - \left(1 - \frac{\beta\mu_0}{\alpha + \beta\mu_0}\right)^{1/\beta}\right]$	α(d^{-1})	0.1182	0.3189	0.8600	0.1049
	β	0.78	0.0247	-1.800	0.2629
	P_0(ml)	0.3484	0.9571	96.43	22.68
	Fitted P_∞ (ml)	391.0	86.44	461.03	671.4
	R^2	0.9969	0.9975	0.9802	0.9905
Gompertz power law extension	μ_0(d^{-1})	0.4074	1.183	1.4298	0.2433
$P = P_\infty \exp\left(-\frac{\mu_0^{1-n}}{\alpha}\left(\frac{1}{1-n}\right)(\alpha n\mu_0^n t + 1)^{1-\frac{1}{n}}\right)$	α(d^{-1})	0.1903	0.3120	0.5019	0.0540
	n	0.05696	0.01000	-0.0420	-0.2433
	R^2	0.9946	0.995	0.9882	0.9890
Grau n-order model	K_{ns}($mgl^{-1}d^{-1}$)	1011	450.0	3386.4	1000
$P = P_\infty^{\frac{n}{n-1}}\left(P_\infty + (n-1)Y_{ps}k_{ns}t\right)^{\frac{1}{1-n}}$	n	0.7654	0.6000	0.89	0.4000
	R^2	0.9985	0.9700	0.9712	0.9887
Grau n-order model: estimated from Gompertz-Grau matching (assuming P_0=0)	K_{ns}($mgl^{-1}d^{-1}$)	785.6	287.6	3577.4	1029
	n	0.8665	0.7437	0.8442	0.8139
Monod kinetics	K_1($mgl^{-1}d^{-1}$)	0.00072	0.02974	0.0001773	0.00104
$= K_1\left(\frac{P'}{Y_{ps}} - K_s \ln\left(\frac{P'_\infty - P'}{P'_\infty}\right)\right)$	K_s(mgl^{-1})	1659.5	601.24	9453.7	5569.4
	R^2	0.9900	0.9860	0.9864	0.9924
Monod kinetics: estimated from Gompertz-Monod matching	K_1($mgL^{-1}d^{-1}$)	0.00055	0.00238	0.0001828	0.00071
	K_s(mgl^{-1})	11169	930.6	9452.7	9249
Corrected Gompertz power law	μ_0(d^{-1})	0.8113	1.496	1.4762	0.3430
$P' = P_\infty \exp\left(-\frac{\mu_0^{1-n}}{\alpha}\left(\frac{1}{1-n}\right)(\alpha n\mu_0^n t + 1)^{1-\frac{1}{n}}\right) - P_\infty \exp\left(-\frac{\mu_0^{1-n}}{\alpha}\left(\frac{1}{1-n}\right)\right)$	α(d^{-1})	0.4157	0.3328	0.5520	0.1155
	n	0.2925	0.010	-0.00535	-0.0187
	P_0(ml)	22.90	1.026	26.40	38.4
	Fitted P_∞ (ml)	430.0	86.37	391.0	670.0
	R^2	0.9955	0.9975	0.9828	0.9900

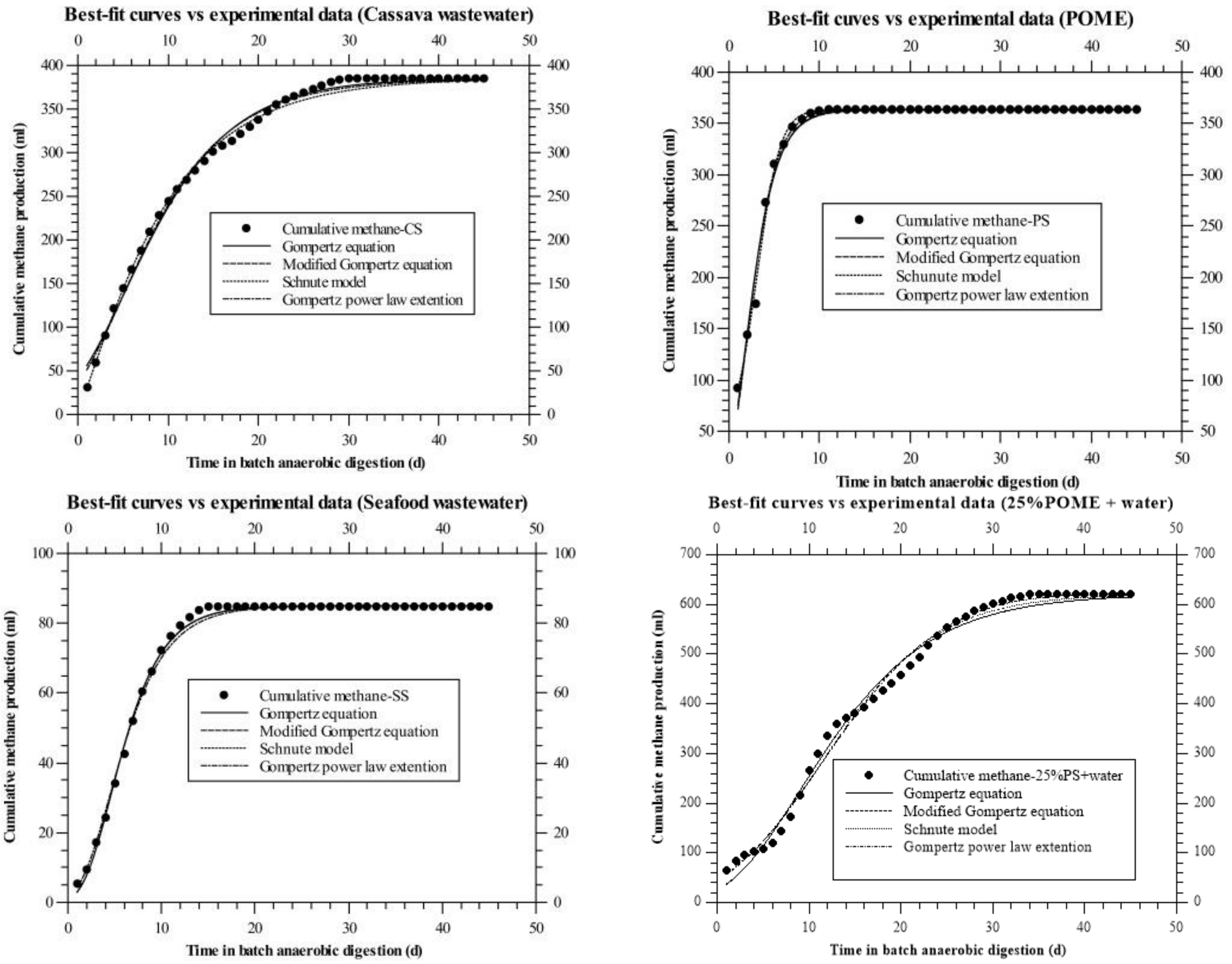

Figure 5. Methane accumulation vs time for different kinetic model

CONCLUSIONS

The Modified Gompertz model (equation 1) fitted the experimental data well and its parameters (P, R_m and λ) are very useful in performance comparison for all substrate sources in anaerobic batch digesters. In its original form, among three wastewater sources cassava wastewater were the best performing substrate, giving the best BMP and Methane production potential (P). Although the seafood wastewater has a nitrogen-rich imbalance COD/N ratio which enhanced cell growth, giving the highest % COD removal, its performance in term of methane production is low. Although, the original wastewater from palm oil mill wastewater was the most readily degradable substrate sources, too high initial COD created conversion imbalance, thus brought about lowering pH and stop methanogens growth. This can be mitigated by sufficient dilution. In addition, all models considered seem to fit the data well. For the purposes of design, operation and optimization, it is an advantage to resort more mechanistic models such as Monod kinetics. Since Gompertz-type model fitted most of data so-well. This approach has the following advantages. Firstly, we can obtain more accurate parameters from fitting accumulated biogas data to Gompertz-type model and secondly convert them to design parameters in Monod-type models. This will help us to reduce the frequency to collect less accurate experimental data (such as COD, VFA, TS, etc.) and thus save and cost.

ACKNOWLEDGEMENT

The authors would like to thanks Walailak University and Ministry of Science and Technology of Thailand grant for financial support.

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Persian Abstract

DOI: 10.5829/idosi.ijee.2016.07.02.02

چکیده

هدف از این کار ارزیابی پتانسیل متان بیوشیمی (BMP) انواع مختلفی از فاضلاب¬ها و اندازه گرانول¬ها می باشد. گرانول¬ها (CS:از یک نشاسته کاساو, SS: یک غذا¬ دریایی و PS: یک کارخانه روغن پالم) و اکسیژن شیمیایی مورد نیاز(COD) اولیه فاضلاب¬ها (به ترتیب هجده هزار و هشتصد، چهار هزار و دویست و یک صد هزارمیلی گرم برلیتر) بودند. معادله اصلاح¬یافته گومپرتز برای مقایسه داده¬های بدست¬ آمده از تجربی استفاده شد. فاضلاب کارخانه نشاسته کاساو بالاترین BMP را زمانی که تنها از گرانول¬های منبع خودش یعنی CS استفاده کرد, نشان داد. فاضلاب کارخانه غذای دریایی بالاترین مقدار نیتروژن را داشته است بنابراین بیشترین عدم توازن در منبع مواد مغذی را نشان داد. در این مورد گرانول¬های چند¬تایی (SS+CS) بالاترین BMP را دادند. خروجی کارخانه روغن پالم معیار نسبت COD به نیتروژن مناسبی نداد و COD بالایی داشته که باعث بازدارندگی سوبسترا شد. دراینجا گرانول¬های چندتایی (PS+CS) بالاترین BMP را داد. در حالت کلی اندازه گرانول بزرگتر و توازن مواد مغذی توانست کارایی را بهبود بخشد و از اینرو نرخ تولید بایوگاز افزایش یابد. COD اولیه یا سوبسترا مختلف اثر قوی¬ای بر¬روی BMP و نرخ¬های ویژه ماکسیمم دارد. در¬حالی که اندازه¬های مختلف گرانول بر طول دوره فاز ساکن تاثیر دارند. در بسیاری از موارد, ارائه کردن داده¬های تجربی با مدل¬های مونود و معادله اصلاح¬یافته گومپرتز سنتی کافی بود.