18th International Conference on Sustainable Energy Technologies

20-22 August 2019 - Kuala Lumpur - Malaysia

Sustainable Energy Towards the New Revolution

Conference Proceedings
Volume 2

Proceedings of the

18th International Conference on Sustainable Energy Technologies

SET 2019

20-22 August 2019
Kuala Lumpur, Malaysia

Volume 2

Edited by

Professor Saffa Riffat, Dr Yuehong Su,
Professor Norli Ismail and Dr Mardiana Idayu Ahmad

SET 2019 Admin Support
Department of Architecture and the Built Environment
Faculty of Engineering, University of Nottingham

Reference to a conference paper:

To cite a paper published in these conference proceedings, please substitute the highlighted sections of the reference below with the details of the article you are referring to:

Author(s) Surname, Author(s) Initial(s), 2019. 'Title of paper'. In Riffat, Su, Ismail, Ahmad. ed., **Sustainable Energy Towards the New Revolution**: Proceedings of the 18th International Conference on Sustainable Energy Technologies, 20-22 August 2019, Kuala Lumpur, Malaysia. University of Nottingham: Buildings, Energy & Environment Research Group. Volume X, pp XX-XX. Available from: nottingham-repository.worktribe.com/ [Last access date].

ISBN-13: 9780853583318

Version: 10.02.2020

Foreword

The 18th International Conference on Sustainable Energy Technologies was a significant international academic event in the domain of world sustainable energy technologies with a theme of '*Sustainable Energy Towards the New Revolution'*. The conference aimed to provide a forum for the exchange of latest technical information, the dissemination of up-to-date research results, and the presentation of major topics including sustainable energy, low carbon technologies, eco-cities, energy security and environmental policy.

Held from August 20th – 22nd 2019 in Kuala Lumpur, Malaysia, the conference was a collaboration between the World Society of Sustainable Energy Technologies (WSSET), the Universiti Sains Malaysia and University of Nottingham. World-renowned experts and scholars in the area, representatives of prominent enterprises and universities attended to discuss new developments and achievements in the field, as well as promoting academic exchange, application of scientific results, university-industry collaboration and government-industry collaboration.

The papers contained in these proceedings focus on topics such as Energy Storage for the Age of Renewables; Research, Innovation and Commercialisation in Sustainable Energy Technologies; Integrating Planning & Policy, Architecture, Engineering & Economics; Energy and Environment; Engineering Thermo-physics; and Systemic Change for Cities.

About 230 delegates from 30 countries attended SET2019; nearly 400 abstracts were received and 190 papers have been published in the conference proceedings. The proceedings have therefore been divided into three volumes. I hope you enjoy as much as I did the breadth of work you will find in these proceedings.

We would like to thank all participating authors for their contributions to both the conference and to the publishing of this book. We are also indebted to our international scientific committee for their advice and seemingly endless review of papers. We would also like to thank unreservedly Celia Berry, Zeny Amante-Roberts, Dr Mardiana Idayu Ahmad and Professor Dr Norli Ismail for their tireless efforts in making SET2019 one of the most successful conferences we have held. Also a huge thanks to our sponsors First Solar, PCM Products Ltd and Professor Terry Payne.

Professor Saffa Riffat
Chair in Sustainable Energy Technologies
President of the World Society of Sustainable Energy Technologies
Fellow of the European Academy of Sciences
SET 2019 Chairman

CONTENTS

Paper Number **Title** **Page**

#228: Effect of pretreatment of rice husk with $KMnO_4$ on biogas production from the co-digestion of Thai rice noodle wastewater, animal manures and rice husk

Tammathat BOONKAMNERD[1], Chairat SIRIPATANA[2], Laddawan NOYNOO[3], Nirattisai RAKMAK[4], Norli ISMAIL[5], Sunwanee JIJAI[6]

[1] School of Engineering and Resources, Walailak University, Nakhon Si Thammarat, Thailand 80160 Thailand. tammathat9@gmail.com.
[2] Biomass and Oil-Palm Excellence Center and School of Engineering and Resources, Walailak University, Nakhon Si Thammarat, Thailand 80160, schairat61@gmail.com.
[3] School of Engineering and Resources, Walailak University, Nakhon Si Thammarat, Thailand 80160, ladda1995.ln@gmail.com.
[4] Biomass and Oil-Palm Excellence Center and School of Engineering and Resources, Walailak University, Nakhon Si Thammarat, Thailand 80160, nirattisai.ra@wu.ac.th.
[5] School of Industrial Technology, Universiti Sains Malaysia 11800, Pulau Pinang, Malaysia, norlii@usm.my.
[6] Faculty of Science Technology and Agriculture, Yala Rajabhat University, Yala, Thailand 95000, sunwanee.j@yru.ac.th.

The objectives of this research were two-folds: firstly, to study the biogas production from anaerobic co-digestion of Thai rice noodle wastewater (TRW) with rice husk and different types of animal manure (cow manure, quail manure, and chicken manure); secondly, to obtain kinetic parameters for the purpose of designing continuous systems. The main focus of the research was to study the effect of pretreatment of rice husk with potassium permanganate (KMnO4) solution for 24 hours on the biochemical methane potential (BMP). The experiments were divided into 6 digesters including: the digesters 1-3 in which rice husk was pre-treated with potassium permanganate, adjusting the pH to 10 and then being soaked in the solution for the retention time of 24 hr. The digesters 4-5 which used untreated rice husk as a co-substrate. In each digester, 10 g of manure, 10 g of rice husk and 200 mL of TRW were used as co-substrates. The results show that the digester 1 which used pre-treated rice husk co-digested with cow manure and TRW gave the highest cumulative biogas (average value of 1,375 mL, 426.0 mL biogas/gCODadded) as well as the biochemical methane potential (215 mL CH_4 /$gCOD_{added}$) , followed by digester 2 which used pre-treated rice husk co-digested with quail manure and TRW (1,144 mL biogas, 221.7 mL biogas/gCODadded and 112 mL CH_4 /$gCOD_{added}$), and digester number 3 (pre-treated rice husk co-digested with chicken manure and TRW, 862 mL biogas, 186.3 mL biogas/gCODadded and 94.1 mL CH_4 /$gCOD_{added}$). The results show that pretreatment of rice husk with KMnO4 increased the co-substrate biodigestibility greatly (almost double for digest 2 and 3) which could be a result of the destruction of lignin and hemicellulose structures, helping the microorganisms to digest more substrate and thus produce more biogas. Furthermore, due to the complexity of substrate and accumulative biogas evolution (ABE) curves, the conventional the Gompertz model did not represent the ABE data very well. We also showed how Gompertz-type models and parameters can be converted to Monod-type (in this case Contois model) parameters and become more valuable not only for representing the results in batch AD specifically but also for being used directly in AD process design.

Keywords: Thai rice noodle wastewater; animal manure; pretreatment of rice husk; anaerobic co-digestion; matching model

1. INTRODUCTION

Demand for energy is increasing enormously due to a steady increase in world population and our quality of life. In Thailand, fossil fuel is the number one imported commodity in the country. Thus Ministry of Energy is seeking ways for renewable alternatives to reduce imported-energy consumption. Currently, biogas is the most frequently used renewable energy source. In the quest for new (and renewable) raw materials for biogas production, it is found that animal waste, agricultural waste and wastewater have become valuable assets and are mostly used as substrates for biogas production by anaerobic co-digestion. Thailand is the largest producer of rice in the world, and rice husks is one of the most abundant by-products to be used. Thai rice noodle is a popular product produced by many local factories across the country. The factories use large amounts of water which is finally released into the environment as wastewater. Without being properly treated, it will cause considerable environmental problems. Aerobic treatment is energy intensive thus the anaerobic co-digestion of wastewater with animal waste and rice husk have recently been considered as a promising alternative due to its low cost, energy generation and being less odorous.

Rice husk is yellow, light yellow or light brown in colour depending on the variety of rice. The chemical composition of raw rice husk has been reported to contain both organic (74%) and inorganic constituents (26%) (Xiaofei Zhao, 2018). The major organic component is cellulose 43.3 wt% and lignin 22 wt% and the major inorganic component is SiO2 (80%). Ligno-cellulosic structure of rice husk is very difficult for microbes to digest. Thus, suitable pretreatment of raw rice husk is required to destroy its ligno-cellulosic structure so that it can be further degraded by microorganisms and finally consumed in AD process to produce biogas.

The animal manures are normally used as fertilizer. Farms use water to spray over this manure in order to clean the animals' stalls. When this waste enters the river without pre-treatment, it may create severe problems due to its high chemical oxygen demand (COD). So, AD not only has a potential to produce biogas but also to decrease environmental pollution.

Thai noodle wastewater (TRW) is translucent and white opaque in colour. If exposed in an ambient environment for seven days, it will turn into more acidic pH (lower pH) and have a spoiled odour, mostly as a result of a hydrolysis process which converts long-chain carbohydrate (Dahunsi, 2018) into sugar and finally be consumed by acidogenes to produce VFA. Thus, the anaerobic co-digestion of Thai noodle wastewater would balance nutrients and increase the buffer capacity. Numerous studies confirm that TRW has a biochemical oxygen demand (BOD) range of 3,060-28,300 mg/L and a chemical oxygen demand (COD) range of 5,568-33,969 mg/L. It is suitable for being used to produce biogas by AD.

The first objective of this research was to study the biogas production from co-digestion of TRW with rice husk and different types of manure (cow manure, quail manure, and chicken manure) as well as the effect of rice husk pretreatment with potassium permanganate. Secondly, the authors wanted to obtain kinetic parameters for the purpose of designing continuous systems. Traditionally, many authors represented concisely their accumulative biogas evolution data (ABE data) in the forms of parameters of Gompertz-type equations which many times resulted in poor representations particularly when the substrate composition was complex. However, these representations are very useful for BMP estimation but not for digester design and scale-up. In this work we illustrate the necessity for developing or extending these Gompertz-type models such that they can represent or describe the ABE curves adequately when dealing with complex substrates such as in many AD co-digestion practices. Then we try to make use of their concise representation by attempting to deduce the Monod parameters (design parameters) from Gompertz parameters. We do this by proposing what we call "Gompertz-Contois parameter matching".

2. THE GOMPERTZ-TYPE MODELS

In this paper, the Gompertz-type models are referred are to those parameterised sigmoid-shape models original pioneered by Gompertz (Syaichurrozi, 2013), then extended or generalised/unified by many authors. Tsoularis and Wallace (Van, 2018) reviewed and compared many growth models and proposed a generalised form of Gompertz-type model with its several properties. The unified model covers many sigmoid models including exponential, generalised von Bertalanffy, Richards, Smith, Blumberg, hyperbolic and Gompertz growth models. Richards' model is one of a unified Gompertz-type models which has received special interest by many researchers (Van, 2018). It covers the negative exponential, logistic, Bertalanffy and Gompertz models. Recently, Tjørve and Tjørve have developed a family of Unified growth models (called U-models) (Jha and Schmidt, 2017). They claimed that the unified models use the same set of three parameters, making comparison between the sub-models directly possible and easy. In addition, they presented the model in two forms: the first where one parameter describes the time of inflection and the second where one parameter indicates the starting point of the curves.

In the remaining sections of this paper, we will refer to different types of ABE curves (Noynoo et al., 2018) which are type I refers to the ABE curves obtained from AD with only one substrate entity. Type II, III refers to those obtained from AD with two substrate entities where they are consumed in parallel and sequential manners respectively. Type IV represents those obtained by the consumption of complex substrates by the microbial consortium.

3. GOMPERTZ MODEL IN RECENTLY DEVELOPED UNIFIED FORMS

The U-family models are other ways to look at the traditional sigmoidal models. Most of traditional sigmoidal models have been re-parameterised into different forms. However, many of these re-parameterizations are not very useful because their parameters affect more than one shape characteristics, resulting in the difficulty to compare the same parameters in different models. Moreover, each parameter cannot be interpreted explicitly because of its coupling nature (Tjørve and Tjørve, 2017). Richards (1959) proposed a model which is a generalisation of a family of models which was later called "Richards model". The model has the following form:

$$W(t) = A/(1 + exp(-(b + kt)/d))^{d} \tag{1}$$

where W(t) and t are dependent variable representing growth, or accumulative product ($P'=P+P'_0$) and independent variable, specific digestion time respectively. A, b, k and d are the model parameters to be determined by curve-fitting. However, this form of Richards model is not very useful because of several parameters affect one shape characteristics of the curve. This parameter-shape multiple dependency makes all these parameters difficult to interpret.

Many researches realised this problem and they tried to solve it by re-parameterization. Recently, Tjørve and Tjørve (2017). Proposed an efficient re-parameterization of Richards model called Unified-Richards (U-Richards) model which is written as

$$W = A\left(1 + (d-1)exp\left(-k_U(t - T_i)/d^{d/(1-d)}\right)\right)^{1/(1-d)} \tag{2}$$

Where:

- k_u = relative maximum growth rate
- Ti = time of inflection (t at which the reflection point occurs). It is a location parameter.
- A = Upper asymptote of W value,
- W = P'_∞ in the context of anaerobic digestion

When t=0, W=W_0, W_0 is starting value of W (initial condition). In the context of AD, W_0 = P'_0. From the unified-Richards model (Eq. (1)), where d is exponent of part of exponent which control the inflection value, setting d→1, d≠1, the resulting in the unified-Gompertz model. That is,

$$P' = P + P'_0 = P'_\infty\, exp(-exp(-e\,k_U(t - T_i))) \tag{3}$$

Similarly, we can write P'_0 in terms of P_∞, k_u and T_i or T_i in terms of P_∞, k_u and P'_0 as follow.

$$\theta = P'_0/P_\infty = 1/\left[exp(exp(e.k_U T_i)) - 1\right] and\ T_i = \left[ln\left(ln\left((1+\theta)/\theta\right)\right)\right]/e.k_U \tag{4}$$

Or writing in term of P_∞ instead of P'_∞ and P'_0 that is

$$P = P_\infty[(1+\theta)exp(-exp(-e.k_U(t - T_i))) - \theta] \tag{5}$$

Similarly, comparing a corrected modified Gompertz form (Siripatana et al., 2016) to Eq. (3), the following relations are obtained.

$$k_U = R_m/P'_\infty = R_m/(1+\theta)P_\infty,\ T_i = \lambda + \left(1/e.k_U\right),\ R_m = k_U(1-\theta)P_\infty\ \ and\ \ \lambda = T_i - \left(1/e.k_U\right)$$

In the context of fitting ABE curves, Eq. (3) is most useful because it is a corrected form and P'_0 does not appear in the model.

4. CONTOIS MODEL

Monod kinetics does not take into account the hindrance for substrate consumption due to high cell biomass concentration which suffers from mass transfer limitation. There are a few of models were proposed to address this problem and Contois models has been in a special attention.

Firstly, we will describe the Contois model for batch AD. In doing so, we impose the following assumptions:

1. The specific growth rate of the microorganisms involved in the AD process follows Contois kinetics without any (explicit) inhibition.
2. The biogas (biomethane and biohydrogen) production is growth associated.
3. The cell yield and product (biogas) yield are constant

The Contois model is based on the following kinetic function.

$$\mu = \mu_m S / \left[K_C\left(P+P'_0\right)+S\right] = \mu_m\left(P_\infty - P\right) / \left[K_C Y_{PS}\left(P+P'_0\right)+P_\infty - P\right] \quad (6)$$

$$dP/dt = \mu_m\left(P_\infty - P\right)\left(P+P'_0\right) / \left[K_C Y_{PS}\left(P+P'_0\right)+P_\infty - P\right] = \mu_m / \left[\left(K_C Y_{PS} / \left(P_\infty - P\right)\right)+\left(1/\left(P+P'_0\right)\right)\right] \quad (7)$$

Upon integration

$$K_C Y_{PS}\int_0^P dP / \left(P_\infty - P\right) + \int_0^P dP / \left(P+P'_0\right) = \mu_m t \quad (8)$$

We obtain, after arrangement.

$$\left(K_C Y_{PS} / \mu_m\right)\ln\left(P_\infty / \left(P_\infty - P\right)\right) + \ln\left(\left(P+P'_0\right) / P'_0\right) / \mu_m = t \quad (9)$$

or

$$t = K \cdot ln\left(P_\infty / \left(P_\infty - P\right)\right) + ln\left(\left(P+P'_0\right)/P'_0\right)/\mu_m,\ K = \left(K_C Y_{PS} / \mu_m\right) \quad (10)$$

The prime notation in X is the concentration of active microbes (cell biomass) at a specific time. μ_m, μ are the maximum and the specific growth rate at a particular substrate concentration, K_c is the Contois saturation constant. If we assume that all yield coefficients are constant and using the following definitions,

$$Y_{PS} = \Delta P / \Delta S, Y_{X'S} = \Delta X' / \Delta S, Y_{PX'} = \Delta P / \Delta X' = Y_{PS} / Y_{X'S} \text{ and } P'_0 / Y_{PS} = X'_0 / Y_{X'S} \quad (11)$$

5. MATERIALS AND METHODS

5.1. Analytical characteristics of wastewater and substrates

1. The rice husk samples were collected from rice mills. The samples were kept at room temperature until used in the experiment.

2. Animal manures (Chicken, cow and quail) were freshly collected from the farm of Yala Rajabhat University, Mae Lan Campus. Prior to use in the experiment, the animal manures were dried by sunlight at ambient temperature.

3. The Thai rice noodle wastewater sample was collected from the community in Yala province. It was kept at 0-4°C until used in the experiments.

The physical and chemical characteristics of rice husk, animal manures and wastewater were analysed before starting the experiments. The parameters were measured according to the standard methods.

5.2. Experimental set-up

The BMP test was conducted using the method of Owen et al. (1979). The experiments were conducted at room temperature (28-30ºC) until batch completion. The 325-ml-volume serum bottles were used as reactors and a working volume of 20 ml was used in all experiments. The serum bottles were covered with the rubber stoppers and sealed with aluminum caps. The volume of biogas was measured daily by using water displacement method. The experiment setup is shown in Figure 1.

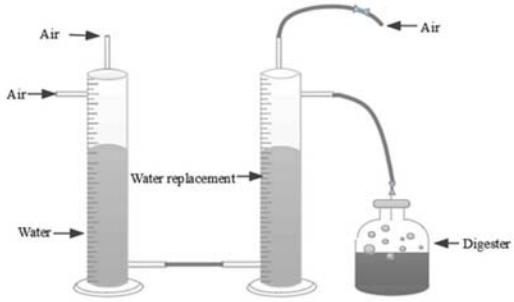

Figure 1: Schematic diagram of water displacement method system for biogas volume quantification during anaerobic digestion tests.

5.3. Experimental design

All experiments were operated in batch mode. Each reactor contains different type of manure and rice husk (non-pretreatment and pretreatment with potassium permanganate ($KMnO_4$). The anaerobic co-digester having a total working volume of 200 ml. The rice husk was pretreatment by soaking in the potassium permanganate solution prepared by adjusting the pH to alkaline of 10. After 24 hours of soaking, they were dried at 105°C and kept at desiccator for use as the co-digestion of anaerobic co-digestion (AcoD) test. The AcoD experiment of this study was divided in 6 designs with digesters 1-3 using TRW with pretreatment of rice husk and different types of animal manure and digesters 4-6 using TRW with non-pretreatment of rice husk and different types of animal manure. Each of digester used 10g of manure, added 10g of rice husk and 200 mL of TRW. Six different types of animal manure were used: digesters 1 and 4 used cow manure (CM), digesters 2 and 5 used quail manure (QM) and digesters 3 and 6 used chicken manure (ChM). Initial pH for all digesters was adjusted to 6.8-7.2 by addition of NaOH (1 N) solution. The experiments were duplicated in all digesters.

5.4. Analytical procedures

In all experiments, pH, Chemical Oxygen Demand (COD), Volatile Solids (VS), Alkalinity and Volatile Fatty Acids (VFA) were evaluated according to standard methods for the examination of water and wastewater (APHA, 2017). Daily biogas production was settled by a water displacement method. The potential of biogas production can be calculated by maximum accumulative biogas divided by gCODadded or maximum accumulative biogas divided by gVS_{added} .

6. RESULTS AND DISCUSSION

6.1. Properties of wastewater and substrates

Table 1: The results of experiment

Digester	pH		Alkalinity (mg/L as$CaCO_3$)		VFA (mg/L asCH_3COOH)		VFA/ALK		COD (mg/L)	VS (mg/L)
	before	after	before	after	before	after	before	after		
1	7.05±0.07	4.40±0.88	680	1635	720	4358	1.06	2.67	39394.14	24,933
2	7.05±0.07	5.71±0.10	1490	2470	2595	4778	1.74	1.93	19432.42	12,299
3	7.20±0.28	5.15±0.21	1670	1870	1530	5010	0.92	2.68	16138.12	10,214
4	7.00±0.00	6.16±0.48	1050	910	1335	5663	1.27	6.22	21032.96	13,312
5	7.10±0.14	5.49±0.50	780	875	1020	5850	1.31	6.69	34170.66	21,627
6	7.05±0.07	5.73±0.12	1600	1885	2340	7083	1.46	3.76	45856.34	29,023

Note: Calculate COD by factor of VS

Digester 1: Cow manure of Rice husk by pretreatment with $KMnO_4$
Digester 2: Quail manure of Rice husk by pretreatment with $KMnO_4$
Digester 3: Chicken manure of Rice husk by pretreatment with $KMnO_4$
Digester 4: Cow manure of Rice husk by non-pretreatment
Digester 5: Quail manure of Rice husk by non-pretreatment
Digester 6: Chicken manure of Rice husk by non-pretreatment

The characterisation of substrates before and after the AcoD test are shown in Table 1. The pH and VFA are important indicators of anaerobic digestion because their dynamics reflect the changing conditions. As shown in Table 1, the pH of all fermentation that co-digested with pretreated and non-pretreated of rice husk at the end of the digestion period (30 days) remained <7. The decrease of pH may have been associated with the variation in VFA concentration because the VFAs produced during AcoD reduce the pH. The highly concentrated acids in the manure led to a noticeable drop in pH. The pH decreased dramatically during the initial stage of the co-digestion of TRW, manure and rice husk (with pre-treated and non-pre-treated) likely due to the production of various organic acids from the degradation of cellulose, hemicellulose, and lignin after pretreatment (Guo and Mochidzuki, 2011). Methanogens are active at pH between 6.2 and 8, with an optimal range of 7.0 – 7.2 (Poliafico, 2007). Anaerobic digestion mainly includes 3 steps including hydrolysis, acidogenesis and methanogenesis. During the first two stages the production of a large amount of VFA leads to the decrease of solution pH. Non-methanogenic microorganisms can act to lower pH while, in this condition, methanogenic activities will be significantly inhibited. Since the pH trend is tightly linked to the variation of VFA concentration in the reactor, it was assumed to be an indicator of the process stress (L.Björnsson, 2000).

VFAs are intermediate organic acid products and the total VFA concentration is an important indicator of metabolic status (aside from influencing the pH) during anaerobic digestion (AD) (Fernández 2005). Table 2 shows that VFA/ALK after the experiment was higher than before the experiment. Therefore, when high VFA occurred, the pH in the system was rapidly reduced. Digester 2 showed the highest alkalinity at 2,470 mg/L as CaCO3 followed by digesters 6, 3, 1, 4 and 5 (1,885-875 mg/L as CaCO3). The high alkalinity was good for this system because it made a high buffer and stable biogas production. Digester 6 showed the highest COD.at 45856.34 mg/L followed by digesters 1, 2, 3, 4 and 5 with 39394.14, 19432.42, 16138.12, 21032.96 and 34170.66 mg/L respectively. Biodegradability improvement means that not only is more substrate used but also more biogas produced (Pang, Y, 2008)

7. BIOGAS PRODUCTION

The accumulative and biogas production of all experiments is shown in Table 2 whilst Figure 5 shows the total accumulated biogas volume for all experiments. The results show that digesters 1-3 that used pre-treated rice husk in the AcoD test showed more accumulated biogas than digesters 4-6 that used non-pre-treated rice husk after more than 20 days of experiment. Digester 1 (pre-treated rice husk co-digested with cow manure and TRW) gave the highest cumulative biogas (average value of 1,375 mL, 426.0 mL biogas/gCODadded) as well as the most biochemical methane potential (215 mL CH_4 /$gCOD_{added}$) , followed by digester 2 (pre-treated rice husk co-digested with quail manure and TRW) (1,144 mL biogas, 221.7 mL biogas/gCODadded and 112 mL CH_4

/gCODadded), and digester number 3 (pre-treated rice husk co-digested with chicken manure and TRW, 862 mL biogas,186.3 mL biogas/gCODadded and 94.1 mL CH_4 /$gCOD_{added}$). From these results, the pretreatment of rice husk with KMnO4 increased the co-substrate biodigestibility greatly (almost double for digest 2 and 3) which could be a result of the destruction of lignin and hemicellulose structures, helping the microorganisms to digest more substrate and thus produce more biogas.

Table 2: Accumulative and biogas production of all experiment

Digester	Substrate	Maximum accumulative of biogas production (mL)	Potential of biogas production ($mL/gCOD_{added}$)	BMP based on 50.5 * %CH_4 ($mL\ CH_4/gCOD_{added}$)
1	CM + RP	1,375	426.0	215.2
2	QM + RP	861.5	221.7	112.0
3	ChM + RP	783.5	186.3	94.1
4	CM + R	649.5	95.0	48.0
5	QM + R	1144	145.2	73.3
6	ChM + R	334	36.4	18.4

Note: CM = Cow manure, QM = Quail manure, ChM = Chicken manure
TRW = Thai rice noodle wastewater
R = Rice husk by non-pretreatment
RP = Rice husk by pretreatment with KMnO4
*Based on average value obtained from similar sets of experiments (Jijai *et al.* 2017)

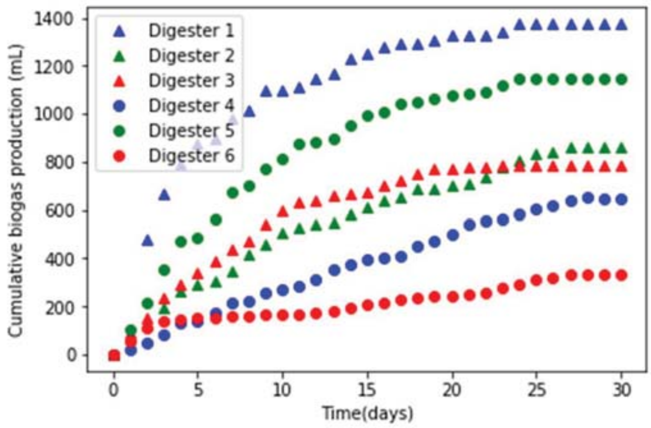

Figure 2: The total accumulated biogas volume for all experiments.

8. THE EFFECT OF RICE HUSK BY PRETREATMENT ON BIOGAS PRODUCTION

The effect of rice husk pre-treated with potassium permanganate ($KMnO_4$) had an adjusted pH of 10 and the retention time of 24 hours added to the potential of biogas production, with anaerobic co-digestion of Thai rice noodle wastewater and different type of manure (cow manure, quail manure, and chicken manure). The results depicts the comparison that the digesters used pretreatment of rice husk with potassium permanganate and adjusted the pH to alkaline of 10 at same type of manure gave a higher potential of biogas production than the digesters using non-pretreatment of rice husk. Schmidt (2017) reported that the substrates pretreatment with alkaline hydrolysis such as Sodium hydroxide (NaOH) can break down biomass in pretreatment and facilitates hydrolysis by disrupting cell wall structures, driving modification of the lignin structure and reducing cellulose crystallinity and chain length. Therefore, bacteria in the digester transformed these organic materials easily into biogas. GuangyinChen (2015) studied the effect of using concentrated NaOH as a pretreatment for substrate. The results showed that as the concentration of NaOH increased, the cellulose was higher. When the quantity of hemicellulose and lignin decreased, the efficiency of the biomass digestion was higher.

The environment of the anaerobic co-digestion process of Thai rice noodle wastewater with rice husk and different types of manure (cow manure, quail manure, and chicken manure) gave an average pH in the range of 4.40 – 6.16. It was observed that, at the end of experiment, the pH was higher than at the start of the experiment. The resulting pH is summarised in Table. 2. The initial anaerobic digestion was consumed by acidogenes to produce VFA and then was consumed by methanogenes to produce methane. Thus, as VFA increased, the efficiency of the biomass digestion is higher while the pH is decreased and can lower the methanogenic bacteria activity. Schmidt (2017) reported that Methanogenic bacteria having an average pH7 affects the highest production of biogas. Thus, the activity of biogas production depends on various parameters like pH, alkalinity (ALK), VFA which are summarised in Table 2. The presence of volatile fatty acids (VFAs) tends to decrease the pH and can lower the methanogenic bacteria activity and hence the biogas production in agreement with Patil & Deshmukh (2015) and Jijai et al. (2017) who studied the effect of biogas production from wastewater and residue wastes.

9. FITTING THE DATA SET TO U-GOMPERTZ MODEL

The results of curve-fitting for U-Gompertz model are presented in Figure 2. The best estimated parameters including those of the corresponding original models are summarised in Table 3. This is as expected because usually Gompertz can fit well when the biomass density is high. Since this is the BMP test (Yingthavorn N, 2019). where high biomass density was intended, thus U-Gompertz (or its original form) fits the data well.

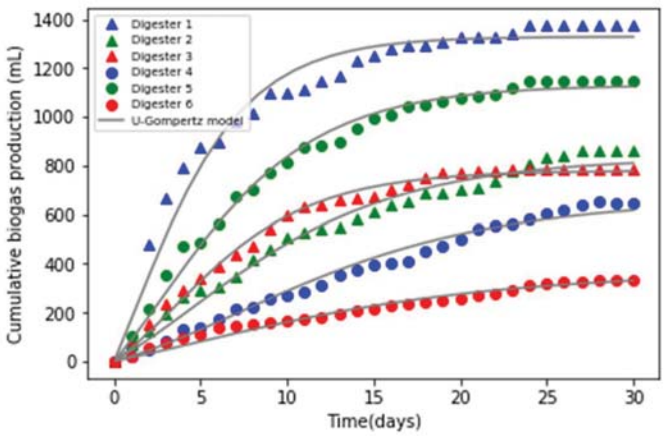

Figure 3: Biogas accumulation for Unified Gompertz model

Table 3: Parameters and the best-fit parameter (R^2) of cumulative biogas production for Unified Gompertz model

Digester	Parameter						
	P_∞(mL)	T_i(d^{-1})	k_u(d^{-1})	R^2	α(d^{-1})	λ(d)	R_m(mL/d)
1	1328.91	1.27	0.1006	0.967	0.2734	-2.3872	90.80
2	833.97	4.45	0.0536	0.9776	0.1734	-2.4141	36.95
3	779.6	3.51	0.0816	0.9918	0.1277	-0.9988	55.49
4	665.28	7.24	0.0437	0.9832	0.1039	-1.1792	26.05
5	1130.7	2.87	0.073	0.9911	0.2059	-2.1699	65.534
6	368.89	4.58	0.0359	0.9671	0.0976	-5.6684	9.7353

10. MATCHING U-GOMPERTZ MODEL TO THE CONTOIS MODEL

First, we must make sure that the U-Gompertz model does fit the ABE data well. If so, this is how the matching process proceeds.

1. Substituting Eq. (5) for θ to write θ in term of k_u and T_i. Then, the set of ABE data is fitted with U-Gompertz model and the best-fit parameters (P_∞, k_u, T_i) of the model are obtained.
2. Calculate θ from Eq. (4), and P_0' is then calculated from P_0' =θP_∞.
3. Calculate Y_{PS} from P_∞ and $\Delta S_\infty = S_0 - S_\infty$ where S_0 and S_∞ are initial and final substrate concentration based on COD or VS. ($Y_{PS} = P_\infty/\Delta S_\infty$)
4. Choose a proper range of P for matching (eg. $0.5P_\infty < P < 0.95P_\infty$) and calculate time step (t_i) corresponding to the P-range.
5. Rewrite Eq. (10) in the following form and solve for K_i

$$t_i = K_i A_i + B_i / \mu_m \quad (12)$$

$$For\ i = 1\ to\ i = n;\ K_i = \left(t_i - B_i / \mu_m\right) / A_i \quad (13)$$

Where: $A_i = ln\left(P_\infty / \left(P_\infty - P\right)\right), B_i = ln\left[\left(P_0' + P_i\right) / P_0'\right]\ and\ K_i = K_{C_i} Y_{PS} / \mu_m$

6. Searching for μ_m which satisfies the following criterion.

$$Relative\ difference\ (\%) = \left|2\left(100\right)\left[\left(K_n - K_1\right) / \left(K_n + K_1\right)\right]\right| < 1 \quad (14)$$

A good estimate of K_i is $K_{i(est)} = (K_n + K_1)/2$ and K_C is then calculated from $K_C = K_{i(est)}\mu_m/Y_{PS}$

Substituting μ_m and K_C into Equation (9) and plotting P versus t using both U-Gompertz model and the corresponding matched Contois model on the same graph. The comparison used to be satisfactory before the matched Contois model to be used for the design propose.

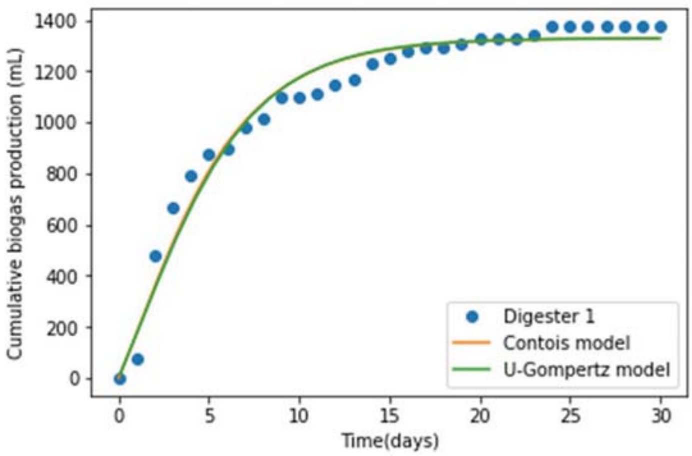

Figure 4: The best example for fitting of Gompertz-Contois Matching

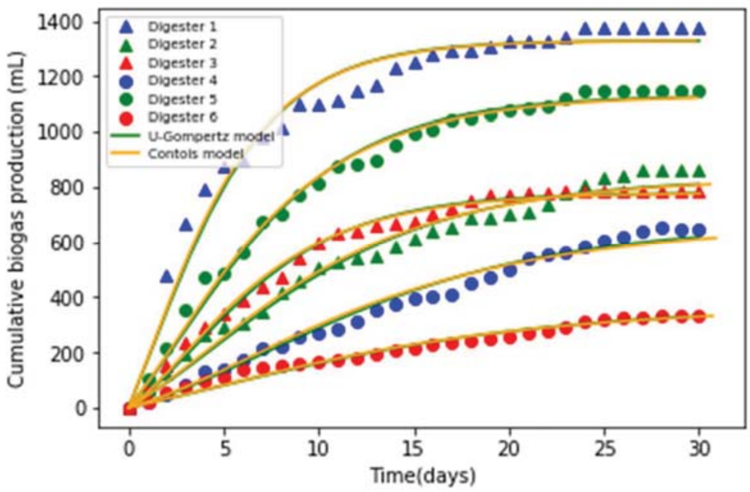

Figure 5: U-Gompertz-Contois Matching

Table 4: Parameters and the best-fit parameter (R^2) of cumulative biogas production for U-Gompertz-Contois and Monod matching model

Digester	**Parameter**					
	θ	**μ_0 (d)**	**P'_0 (mL)**	**Y_{PS} (mL/ (mgCOD/L))**	**μ_{mc} (d^{-1})**	**K_C (mg/L)**
1	0.3207	0.387	426.31	0.0426	0.76	68.47
2	0.1734	0.2786	144.57	0.0222	0.44	146.81
3	0.1277	0.4831	99.57	0.0186	0.72	194.57
4	0.1039	0.2807	69.13	0.0095	0.4	409.88
5	0.2059	0.3537	232.89	0.0145	0.61	233.78
6	0.2649	0.1526	97.71	0.0036	0.28	858.76

We have chosen the cases of single and co-digestion to illustrate the necessity for developing or extending these Gompertz-type models such that they can represent or describe the ABE curves adequately when dealing with complex substrates such as in many AD co-digestion practices. Large amounts of ABE data has accumulated in the literature and has been represented concisely by Gompertz-type models and their best estimated parameters. We try to make use of their concise representation by attempting to deduce the Monod parameters (design parameters) from Gompertz parameters. The result that as the matching techniques can be used effectively to convert the Gompertz-type parameters into their corresponding Monod-type parameters and we attempted to bridge the gap between this data and their practical uses effective in design and operation of biogas systems rather than going back to look for the original data.

11. CONCLUSIONS

The matching techniques can be used effectively to convert the Gompertz-type parameters into their corresponding Monod-type parameters. The matched Monod-type parameters (using Contois model) can be used to design a completely-mixed continuous AD process using simulation. Thus, a large amount of BMP, BHP and SMA data which was condensed in the form of Gompertz-type models and parameters, become more valuable not only for representing the results in batch AD specifically but also for being used directly in AD process design. However, these illustrations are over-simplified and in practice we must take into account other significant factors in AD-system design and operation.

12. ACKNOWLEDGEMENT

The arthor would like to thank Yala Rjabhat University and Walailak University grants for the financial support.

13. REFERENCES

Angelidaki I., Alves M., Bolzonella D., Borzacconi L., Campos J. L., Guwy A. J., Kalyuzhnyi S., Jenicek P. and van Lier JB. Defining the biomethane potential (BMP) of solid organic wastes and energy crops: a proposed protocol for batch assays. Water science and technology.2009, 59(5):927-34.

Anthony Njuguna Matheri. (2016). Modelling the Kinetic of Biogas Productionfrom Co-digestion of Pig Waste and Grass Clippings sewage sludge.Bioresour.Technol. 244, 996–1005

APHA, AWWA, & WPCF. (2017). Standard Methods for Examination of Water and Wastewater (19 ed.). New York: American Public Health Association, Washington D.C.

Cerrillo, M., Viñas, M., Bonmatí, A., 2018. Anaerobic digestion and electromethanogenic microbial electrolysis cell integrated system: Increased stability and recovery of ammonia and methane. Renew. Energy 120, 178–189.

Cook, S.M., Skerlos, S.J., Raskin, L., Love, N.G., 2017. A stability assessment tool for anaerobic codigestion. Water Res. 112, 19–28.

Dahunsi (2018). Mechanical pretreatment of lignocelluloses for enhanced biogas production: Methane yield prediction from biomass structural components.

Deepanraj B. (2015). Kinetic study on the effect of temperature on biogas production using a lab scale batch reactor

Fernández, A., Sanchez, A., Font, X., 2005. Anaerobic co-digestion of a simulated organic fraction of municipal solid wastes and fats of animal and vegetable origin. Biochem. Eng. J. 26, 22–28.

Gompertz, B. (1825). On the Nature of the Function Expressive of the Law of Human Mortality, and on a New Mode of Determining the Value of Life Contingencies, 115(0), 513–583.

Guo, P., Mochidzuki, K., Cheng, W., Zhou, M., Gao, H., Zheng, D., Wang, X.F., Cui, Z.J., 2011. Effects of different pretreatment strategies on corn stalk acidogenic fermentation using a microbial consortium. Bioresour. Technol. 102, 7526– 7531.

Iqbal Syaichurrozi. (2013). Predicting kinetic model of biogas production and biodegradability organic materials: Biogas production from vinasse at variation of COD/N ratio.

Björnsson, L., Murto, M., Mattiasson, B. Evaluation of parameters for monitoring an anaerobic co-digestion process, Appl. Microbiol. Biotechnol. 54(2000) 844–849.

Pang, Y., Liu, Y., Li, X., Wang, K., Yuan, H., 2008. Improving biodegradability and biogas production of corn stover through sodium hydroxide solid state pretreatment. Energy Fuel 22 (4), 2761–2766.

Pham Van. (2018). A new kinetic model for biogas production from co-digestion by batch mode

Poliafico, M., 2007. Anaerobic digestion: Decision support software. Masters Thesis, Department of Civil, Structural and Environmental Engineering, Cork Institute of Technology, Cork, Ireland.

TingLiu. (2018) Effects of liquid digestate pretreatment on biogas production for anaerobic digestion of wheat straw

Tjørve, E., & Tjørve, K. (2010). A unified approach to the Richards-model family for use in growth analyses: Why we need only two model forms. Journal of Theoretical Biology, 267, 417–425.

Tjørve, K., & Tjørve, E. (2017). A proposed family of Unified models for sigmoidal growth. Ecological Modelling, 359, 117– 127

Tsoularis, A., & Wallace, J. (2002). Analysis of Logistic Growth Models. Mathematical Biosciences, 179, 21–55.

Hagos, K., Zong, J., Li, D., Liu, C., Lu, X., 2017. Anaerobic co-digestion process for biogas production: Progress, challenges and perspectives. Renew. Sustain. Energy Rev. 76, 1485–1496.

Jha, P., Schmidt, S., 2017. Reappraisal of chemical interference in anaerobic digestion processes. Renew. Sustain. Energy Rev. 75, 954–971

Noynoo L., Siripatana C., Jijai S., Rakmak N. and Phayunphan K., “Gompertz-Type Two-Substrate Models for Batch Anaerobic Co-Digestion,” submitted for publication.

Ma, J., Amjad Bashir, M., Pan, J., Qiu, L., Liu, H., Zhai, L., Rehim, A., 2018. Enhancing performance and stability of anaerobic digestion of chicken manure using thermally modified bentonite. J. Clean. Prod. 183, 11–19.

Ma, J., Bashir, M., Pan, J., Qiu, L., Liu, H., Zhai, L., & Rehim, A. (2018). Enhancing performance and stability of anaerobic digestion of chicken manure using thermally modified bentonite. Journal of Cleaner Production, 183.

Ghatak, M.D. (2017). Kinetic Model Development for Biogas Production from Lignocellulosic Biomass

Uddin, M.K. (2017). A study on the potential applications of rice husk derivatives as useful adsorptive material.

Sharma, R. (2014). Effect of Pretreatment of Rice Husk for the Production of Biogas

Richards, F. J. (1959). A Flexible Growth Model for Empirical Use. Journal of Experimental Botany - J EXP BOT, 10, 290–301.

Salimi M N & Yusoff A H M. (2017). Conversion of rice husk into fermentable sugar by two stage Hydrolysis

Schnute, J. (2011). A Versatile Growth Model with Statistically Stable Parameters. Canadian Journal of Fisheries and Aquatic Sciences, 38, 1128–1140.

Siripatana, C., Jijai, S., & Kongjan, P. (2016). Analysis and extension of Gompertz-type and Monod-type equations for estimation of design parameters from batch anaerobic digestion experiments. In AIP Conference Proceedings (Vol. 1775, p. 030079).

Shitophyta and Maryudi. (2018). Comparison of kinetic model for biogas production fromcorn cob

Jijai, S., and Siripatana, C. “Kinetic Model of Biogas Production from Co-digestion of Thai Rice Noodle Wastewater (Khanomjeen) with Chicken Manure,” Energy Procedia, vol. 138, pp. 386–392, 2017.

Xiaofei Zhao, LeiLi DiWu, Taihui Xiao, Yao Ma., 2018. Modified Anaerobic Digestion Model No. 1 for modeling methane production from food waste in batch and semi-continuous anaerobic digestions

Yingthavorn N., Noynoo L., Boonkamnerd T., Rakmak N. and Siripatana C., “Biochemical Methane Potential of Palm Oil Mill Effluent (POME) Co-Digested with Rubber Latex Effluent (LTE): Effect of POME/LTE Ratio and Temperature,” submitted for publication