Biogas Production Optimization from POME by Using Anaerobic Digestion Process

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Abstract

The aim of this research is to optimize Biogas production from palm oil mill effluent (POME) with organic loading rate (OLR), carbon-to-nitrogen (C / N) ratio and pH using anaerobic processes. Information on the optimum level of factors that significantly effects on biogas production is not previously searched, and thus optimum inputs level such as pH, OLR, C/N ratio to anaerobic reactor are not available in the published paper. This study explores the potential of POME in anaerobic digestion with the perspective to develop a constructive process to treat POME and it can significantly contribute to biogas production. Design of Experiment (DoE) is used to determine the inputs (OLR, C/N, pH) for conducting research to achieve outputs (biogas production). Based on Central Composite Design (CCD), 5 levels of inputs for pH, C/N, and OLR are obtained. The findings of data analysis from Response Surface Methodology (RSM) shows that pH of 6.9, C/N of 30, and OLR of 6 VSS g/L.d have contributed to obtaining 3.8 L/day biogas production from POME. Treating POME anaerobically has proven to be successful because it is value-effective and environmentally friendly. The consequences of the research outcome in terms of environmental pollution are huge. The study suggests implementing a pilot scale study for producing required data is needed in developing economic scale POME treatment plant.

***Keywords**: Carbon-to-Nitrogen Ratio, Greenhouse Gas, Organic Loading Rate, Palm Oil Mill Effluent, Waste to Energy..*

1. Introduction

Methane that has been emitted from palm oil mill effluent(POME) is identified as one of the vital source of Potential for Worldwide Warming. It has also been stated in various researches That POME's worldwide methane potential is around 600 million m3 per annum, and this gas has a GWP which is 25 times higher than carbon dioxide. It has also been stated that methane is a source of heat and energy, which currently appearing as a GWP and contributing to increase climatic change [4]. In biogas, 60 to 70% is methane gas, which means that biogas is one of the main elements for greenhouse effect. The palm oil sector is one of Malaysia's main sectors and is rising quickly to become a major agricultural industry which contributes to the Malaysian economy. The palm oil industries in Malaysia is the world's second biggest. The total production of crude palm oil is 19,961,581 tonnes and 17,319,374 tonnes respectively in 2015 and 2016 [11].

The amount of usable resources recovered from POME in methane gas form, clean water, and organic fertilizers are plenty. During the anaerobic digestion of POME, about 28 m^3 of biogas per m^3

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of POME is produced [10]. This study's aim reflects the prospective policies for reducing POME's environmental effects while optimizing POME's biogas production. In this study, laboratory scale anaerobic digester was used for the biogas production.

POME has always been considered an extremely polluting wastewater produced during CPO manufacturing from palm oil factories. POME is a brownish liquid composed of biomass, biochemical oxygen demand (BOD), and chemical oxygen demand (COD). POME is also acknowledged as GWP's accountable source of CO2 and CH4 emissions. However, different study results showed that POME's methane potential could be a reliable source of renewable energy rather than carbon emissions [1].

The information mentioned in Table 1.0 showed that methane gas is POME's significant biogas element. This section's review concludes that methane gas potential in POME is significantly high, which shall be captured to achieve sustainability in energy supply.

Table 1. Composition of biogas produced from POME [Shahidul et al., 2018]

Element	**Formula**	**Composition (Vol.%)**
Methane	CH_4	50-75
Carbon dioxide	CO_2	25-45
Water	H_2O	2-7
Oxygen	O_2	<2
Nitrogen	N_2	<2
Hydrogen Sulphide	H_2S	<2
Ammonia	NH_3	<1
Hydrogen	H_2	<1

1.1 Source and Procedure of Palm Oil Mill Effluent Production

Three significant activities are accountable for POME generation. POME is primarily produced by new fruit bunch (FFB) sterilization, crude palm oil (CPO) clarification, hydrocyclone separation of crushed shell and kernel combination in the factories [18]. Clarification of extracted CPOs led to approximately 60% of POME, while FFB sterilization contributed approximately 36% [3]. The process of hydrocyclone contributed only 4% [20].

1.2 Impacts on the environment of Palm Oil Mill Effluent

Effluent from palm oil mills (POME) has the ability to cause air, water and soil contamination. Untreated POME releases CH_4 and CO_2 into the atmosphere lead in greenhouse gases (GHGs) being formed. The GHGs can subsidize in increasing The Earth's surface temperature. Increasing temperature will influence the Earth's biotic communities. The increased carbon dioxide (CO_2) and elevated temperature can be adapted and used by some crops [10]. Meanwhile, some plants failed and unable to survive in extreme conditions. POME is also responsible for increase biodiversity loss due to high level of BOD and COD.

Discharging POME into the river may result in water contamination. POME is acidic, of course. It will decrease the pH of the water when untreated POME is released into the river [6]. This will make the water inhabitable POME's release into the soil can lead to soil pollution. By leaching heavy metals, POME affects the soil and changes the soil's physicochemical characteristics.

1.3 Anaerobic Digestion for Biogas Production

Anaerobic digestion is one of the appropriate therapy techniques for effluents containing elevated organic carbon concentrations such as effluent from palm oil mills (POME) [1]. It is one of the convenient stabilization methods because it is cost-effective, environmentally friendly, decreases the amount of sludge and is capable of recovering and recovering electricity in the form of methane [15]. This organic process relies on anaerobic microorganisms to digest the biological substance (pollutants) and thereby decrease the effluent BOD. Hydrolytic, acetogenic, acidic and methanogenic microorganisms degrade the complicated polymers of POME [9]. Biogas, consisting of 65% CH4, 35% CO2, and some trace amounts of hydrogen sulphide, are the end products of anaerobic digestion [5].

1.4 Problem Statement

POME is treated with a variety of anaerobic techniques. Mostly biogas production by using lab scale anaerobic reactor. But the optimum level of factors that effects on optimum biogas production from POME by using anaerobic reactor not published. Due to the lack of knowledge in optimizing biogas production from POME, potential agro-based industries are suffering. During the CPO production, CH_4 and CO_2, which are known as GHG are emitted into the atmosphere. As a consequent, POME becomes a global worming potential due to the emission of CH_4 and CO_2 gas. The use of environmental-friendly Biotechnology can alter POME's status from waste to energy [WtE]. Treating POME not only emphases on the capturing of biogas but also recover clean water and produce organic fertilizer. Thus, POME can become a precious resource in the future and this study is designed to capture biogas from POME.

1.5 Research Question

How to optimize biogas production from POME under the effects of pH, organic loading rate (OLR), and carbon-to-nitrogen (C/N) in an anaerobic environment? The purpose of this study is to get this issue answered.

1.6 Objectives

This study's broad objective is to Optimize Biogas Production from POME by using Anaerobic Digestion Reactor with the aid of OLR, pH, and C/N ratio. The wide objective is split into the following particular objectives in order to achieve the objective of this research:

a) Identify the factors such as OLR of VSS, pH and C/N ratio that significantly affect the biogas production from POME.

b) Optimization of factors like OLR of VSS, pH and C/N ratio that effect to biogas Production.

2. Models to estimate optimum biogas production

This section presents the models used to estimate biogas production of POME. This model has been used for designing an anaerobic reactor to capture biogas from POME.

2.1 Central Composite Design in optimization

The axial or star point usually denoted as (α) increases the number of levels to 5 levels thereby giving the experimental design flexibility. It allows the experimental designer to determine the factors that affect on response output in experiment. In Central Composite Design (CCD) the minimum numbers of factors it can accommodate including research variables [24].

2.2 Design of Experiments (DoE) for Model Development

Design of Experiments (DoE) is used for determining the inputs (OLR, C/N, pH) for conducting research to achieve outputs (biogas production). The range of inputs (as independent variable) is the key factor to ensure the results from inputs are in line with research goal. However, in the current research DOE is used to determine the range of input such as OLR, C/N, pH in producing biogas. The range of OLR 1 -11 VSS g/L.d, pH 5.3 -8.4, C/N 20 - 40 is been determine from the DoE.
Critical Process Parameter (CPP) and Material Attributes (CMAs) mathematical relationships with Critical Quality Attributes (CQAs) are the potential factors for achieving research goal. Fractional factorial 7-level designs with three variables are used in the current research.

2.3 Experiment Set up for Conducting Experiment Run

Total five batch reactors each of 5 litter capacity have used to conduct 20 run that reported in. The outputs (biogas) of 20 runs with respect to inputs of three variables. The distribution of biogas outputs from reactors have analyzed by Design Expert software which shows that outputs are normally distributed

2.4 Input-output variables characterization of biogas production

The dependent variable is the characterization of biogas in the anaerobic reactor. The inputs used in the reactor during anaerobic digestion are the autonomous OLR, pH and C / N variables.

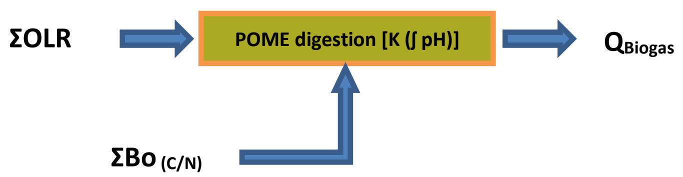

Figure 1. Input output process model POME to biogas (CH_4, CO_2, and H_2S)

Where, C/N = Adjusted by high carbon content Biomass and
K = Process conversion factor from input to output (k<1).

2.5 Method of data collection and analysis

To accomplish the study objective, quantitative information are collected. Analysis and testing are the technique used to perform information collection. Reactor water samples are gathered to adjust the pH, C/N, and OLR. Data are gathered over a period of 30 days biogas every day at the fixed time at 10.00AM. Biogas is collected and measured with use the water displacement method.

The data analysis was done by DOE which include RSM are presented into graphs to show the results of OLR, pH and C/N on biogas production.

3. Result and discussion

3.1 Determining the factors that significantly effect on biogas production

The study under this section was to be carried out identify the factors that significantly affect the biogas production from POME. Design Expert (Version – 2018) are used for data analysis. The input factors in this study are pH, C/N, and OLR. This experiment is setup to identify inputs which are significant ($p<0.05$) and contribute to biogas production. The inputs data were collected from the experiment.

Table 2. Factors that significantly contribute to produce biogas production from POME

Factors (input Variables)	**p-value of factors**	**Significance level of factors**	**The Effect Size as Contribution and biogas production statistics**
pH	$p_{pH} = 0.0012$	As $P_{pH} <.05$; significant	**R^2** =0.9994; Adjusted R^2 = 0.9951; Adequate precision= 55.1708; Coefficient of Variation (CV)= 0.6194%
C/N	$p_{C/N} =0.0001$	As $P_{C/N} <.05$; significant	
OLR	$p_{OLR}= 0.3989$	As $P_{OLR} >.05$; Not significant	

Table 2 shows the p-value with respect to Biogas production and pH is 0.0012 ($p<0.05$), which is significant at 95 percent level; it indicates that pH has a significant effect on Biogas production from POME. The p-value with respect to Biogas production and C/N is 0.0001 ($p<.05$), which is significant at 95 percent level; it indicates that C/N has a significant effect on Biogas production from POME. The p-value with respect to Biogas production and OLR is 0.3989 ($p>0.05$), which is not significant at 95 percent level; it indicates that OLR has effect but not significant to Biogas production from POME.

3.2 Optimization factors that effect to biogas production

The findings of data analysis with outputs as response (biogas) shows that the pH, C/N and OLR input variables factors have contributed to biogas production from POME. The input–output data relating to biogas production are estimated by using Design Expert (Version – 2018).

3.3 Data analysis and findings

The results of the experiment are analyzed by DoE software and results are presented as 2D and 3D plots, which are presented in Figure 2 and Figure 3. The optimum value of inputs and outputs (biogas) are depicted in Figure 2 and Figure 3.

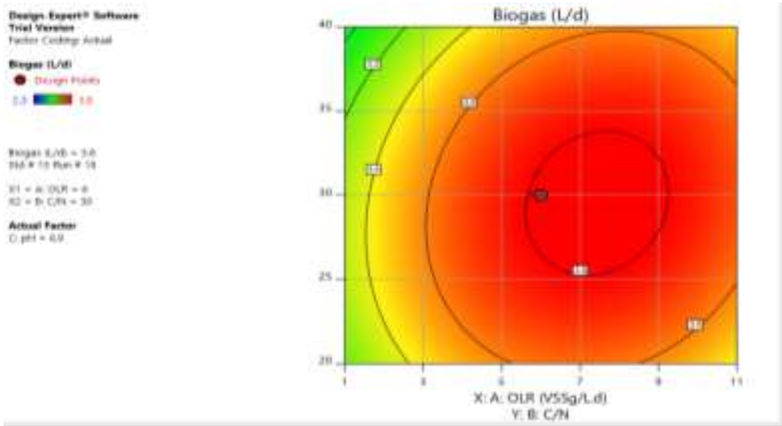

Figure 2. Contour optimization on OLR, C/N and biogas

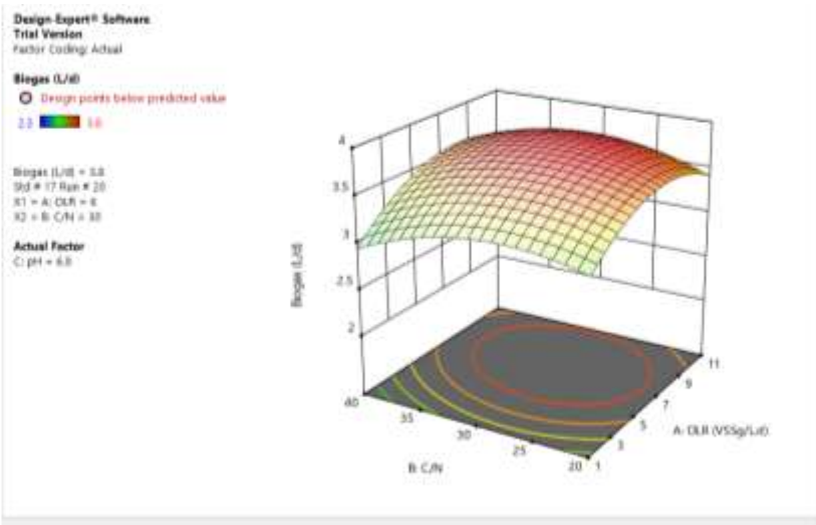

Figure 3. Surface response optimization on OLR, C/N and biogas

Table 2 shows the optimum values required to produce biogas from POME. If anaerobic bioreactor installation and operation with these optimal inputs will produce the optimal amount of biogas. Based on the findings which listed in Table 2, it can be concluded that a bioreactor run with these combinations will contribute to produce optimum level of biogas. In conclusion, it can be stated that the optimum values of factors contributed to biogas production from POME are stated in Table 3. The distribution of model prediction and actual biogas production are presented in Figure 4.

Table 3. Optimum values of variables and output

Input Factors	Optimum Value	Optimum Outputs as Biogas (L/d)
OLR (vssg/L.d)	6	
C/N	30	3.8
pH	6.9	

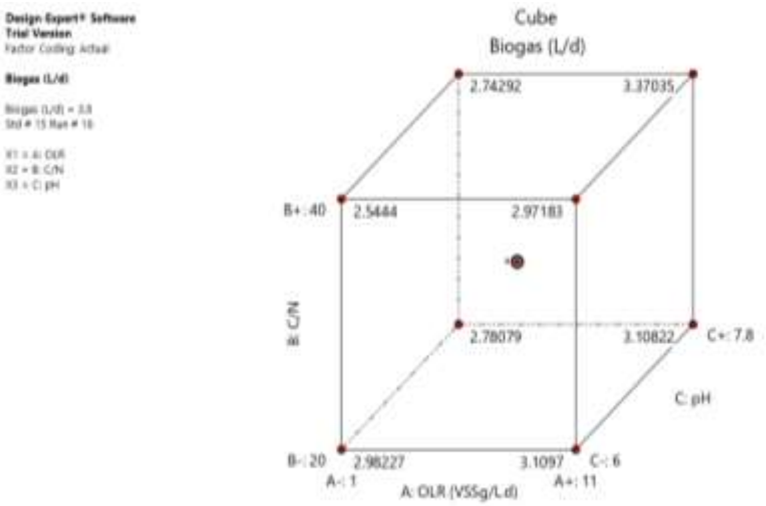

Figure 4. Surface response optimization C/N, pH, OLR and biogas

The objective of the research is achieved and the research question is replied. The model confirmation was further tested which shows that coefficient of 20 run is 3.81 and standard error is only 0.1133%.

4. Conclusion

The result findings demonstrate that anaerobic digestion process is a preferable method optimize the production of POME methane. The anaerobic reactor is configured for hydrolysis at the first stage and acidogenesis. The anaerobic reactor is configured for acetogenesis and methanogenesis in the second stage. It was found that the optimum pH of 6.9, C/N of 30, and OLR of 6 VSSg/L.d were able to obtain biogas production of 3.8 L/day. Different research has verified that biogas waste methane could be captured and used as renewable energy for heat and electricity generation using the WtE notion.

The anaerobic digestion process has the potential to become a leading technology in the recovery of biogas resources from POME. This article shows that a significant role can be played by connecting the energy potential of biogas such if palm oil mill waste reducing the dependence of fossil fuels as well as mitigating climate change. Gradually, the current case study has comprehensive consequences for the greening method of increasing palm oil mill waste worldwide, particularly in rapidly developing Asian economies.

This research is designed to conduct a study to optimize biogas production from POME. Similar studies are reported in many published journals; mostly biogas production by using lab scale anaerobic reactor. But the optimum level of factors that effects on optimum biogas production from POME by using anaerobic reactor not published; in this aspect, this research is novel. This study provide additional knowledge for researchers involved in the field of renewable energy production from hazardous POME and other wastewaters.

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