# Biogas Production from POME by Optimum Level of Inputs

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## Abstract

The purpose of this research is to optimize biogas production from POME by using anaerobic reactor with various Organic Loading Rate, Carbon-Nitrogen ratio and Hydraulic Retention Time. For conducting this research, a two-stage fermentation anaerobic bioreactor has used at OLR rate1, 2.6, 5, 9 and 11 g/L·d; at C/N ratio 14.54, 20, 28, 36, 41.454; at HRT 2.295, 4, 6.5, 9, 10.70 days. The anaerobic bioreactor is operated for 30 days. The finding of this research demonstrates the optimum input values are OLR is 5 (g/L·d), C/N is 28, HRT is 6.5 days and output of Biogas is 3.8 L/d from POME. This finding will bring benefits to palm oil industries in achieving economic and environmental sustainability. This research concludes that in-depth research into this matter is important to implement this technology in the palm oil industry.

## Keywords

POME-Palm Oil Mill Effluent, OLR-Organic Loading Rate, C/N-Carbon Nitrogen Ratio, HRT-Hydraulic Retention Time, BOD-Biochemical Oxygen Demand, COD-Chemical Oxygen Demand, GHG-Greenhouse Gas

## 1. Introduction

Palm oil industry plays a vital role in Malaysian economy. The number of palm oil industries increasing rapidly. The total production of CPO in 2017 and 2018 was 19,919,331 and 19,516,411 tons respectively [1]. Indeed, about 21% of FFB convert to CPO and another 79% are Waste biomass. A part of this waste when getting mix with water becomes palm oil mill effluent to be known as POME. The POME is a hazardous effluent due to its containing of COD, VSS and nutrients. Biomass of palm oil effluent is the main sources of methane [2]. Indeed, decomposing of POME in environment is a key element to pollute the environment including the water, air and soil. The discharging of POME is unwanted to the atmosphere and the majority of palm oil factories are either discharge it to water bodies without treatment or they do treatment in Open tank. On the other hand, utilization of potential of biogas of POME, will give two benefits. Firstly, harvest renewable energy. Secondly, reduce greenhouse gas (GHG) emission to atmosphere. Indeed, to produce of biogas from POME would reduce the impact on environment. Renewable energy Biogas can help to reduce the use of conventional fossil fuel at the same time and contribute to keeping environment safe. However, the use of environmentally Friendly biotechnology can alter POME's status from waste to resource [WtR]. Treating POME is not just about capturing of biogas but also would produce water and as well as can contribute to producing organic fertilizer [3]-[7].

However, biomass of palm oil mill effluent has many uses, and biogas production would be most potential by using anerobic reactor.

The methane potential of POME could be a dependable renewable energy source instead of its present status as carbon emission sources for GWP [8]. It has been reported that about 28 $m^3$ of biogas could be produced from 1.0 $m^3$ of POME with methane potential of about 15 $m^3$ [9]. However, the typical composition of biogas produced from POME is listed in **Table 1**.

The data listed in **Table 1** demonstrated that the methane gas is the major component in biogas produced from POME [10]; which indicates that $CH_4$ gas potential in POME is significantly high.

The Hydrolysis, Acidogenesis, Acetogenesis, and Methanogenesis are the main steps of POME digestion which ultimately produce biogas. The research findings are on potential factors for biogas production.

## 2. Literature Review

It has been reported that during POME treatment in open tank, COD and volatile suspended solids (VSS) of POME convert to methane gas ($CH_4$) and emits to the air as Greenhouse gas (GHG) [3]. It has also been demonstrated that methane must be captured from POME for use as energy generation and to protect the environment as well [4].

Methane emission from POME has been identified as one of the vital source

**Table 1.** Composition of Biogas produced from POME [10].

| Element | Formula | Composition (Vol. Percent) |
|---|---|---|
| Methane | $CH_4$ | 50 - 75 |
| Carbon Dioxide | $CO_2$ | 25 - 45 |
| Nitrogen | $N_2$ | <2 |
| Hydrogen Sulphide | $H_2S$ | <2 |
| Ammonia | $NH_3$ | <1 |
| Hydrogen | $H_2$ | <1 |

[5]. It has been also stipulated that the global $CH_4$ potential of POME is about 600 million $m^3$ per year; and this gas is emitted to air as GHG which is 25 times higher in the scale of GWP than carbon dioxide [6]. It has been also stated that biogas is a favourable heat and energy sources [7]. With such background, the booklet has been structured to disseminate information on biogas production process from POME with the aim to contribute to achieve sustainable energy supply and to reduce carbon emission to the atmosphere.

### 2.1. Problem Statement

The POME is the source of methane and carbon dioxide gas also known as biogas. When POME is processed in an open tank, biogas is approximately 65% $CH_4$, 32% $CO_2$, 2.5% $H_2S$ and some minor quantity of other gas. The $CH_4$ and $CO_2$ regarded as GHG, which emits to air; and thus, POME becomes global warming potential. Even this method Required longer retention time and a large area of land. Although fresh techniques and techniques have been established to discover approachable alternatives for POME management, Malaysia's Department of Environment (DOE) is still struggling to fulfill more stringent effluent discharge boundaries. Besides, Information on the optimum level of factors that significantly effects on biogas production is not preciously searched, and thus optimum inputs level such as Organic Loading Rate (OLR), Carbon-Nitrogen Ratio (C/N) and Hydraulic Retention Time (HRT) to anaerobic bioreactor is not available in the published paper. This study aims to capture biogas from POME.

Biogas production has shown in **Figure 1**. The objective of digestion anaerobic condition is to breakdown irresolvable long-chain polymers in short-chain

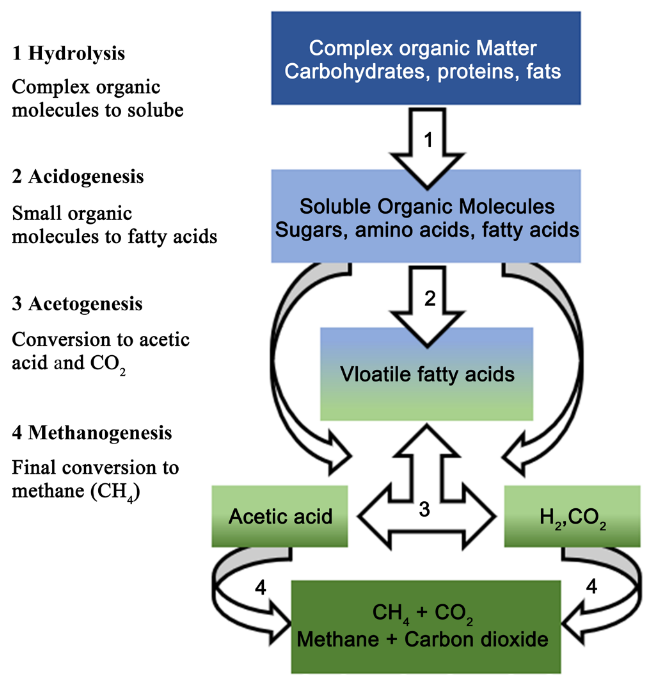


**Figure 1.** Biogas production process from POME [8] [12].

polymers of fats, proteins and carbohydrates [11]. The various steps of biogas production from POME are depicted in **Figure 1**.

The fourth stage is the methanogenesis by which $CH_4$ is produced [9]. The production of $CH_4$ is presented by the following steps:

$$C_6H_{12}O_6 \leftrightarrow 2CH_3CH_2H + 2CO_2 \quad (1)$$

$$C_6H_{12}O_6 + 2H_2 \leftrightarrow 2CH_3CH_2COOH + 2H_2O \quad (2)$$

$$C_6H_{12}O_6 \rightarrow 3CH_3COOH \quad (3)$$

After the fermentation of acetic acid, acetoclastic methanogens would use acetic acid to produce biogas and carbon dioxide is presented by Equation (4) and Equation (5) [13] [14] [15]:

$$CH_3COOH \rightarrow CH_4 + CO_2 \quad (4)$$

$$2CH_3CH_2OH + CO_2 \rightarrow CH_4 + 2CH_3COOH \quad (5)$$

The POME is the source of methane and carbon dioxide gas also known as biogas. The $CH_4$ and $CO_2$ regarded as GHG, which emits to air; and thus, POME becomes global warming potential. Even this method Required longer retention time and a large area of land [16]. Although fresh techniques and techniques have been established to discover approachable alternatives for POME management, Malaysia's Department of Environment (DOE) is still struggling to fulfill more stringent effluent discharge boundaries [17]. Besides, Information on the optimum level of factors that significantly effects on biogas production is not preciously searched, and thus optimum inputs level such as Organic Loading Rate (OLR), Carbon-Nitrogen Ratio (C/N) and Hydraulic Retention Time (HRT) to anaerobic bioreactor is not available in the published paper. This study aims to capture biogas from POME.

## 2.2. Research Gap

Few researches have been done on the recovery of usable biogas as energy from POME by using a two-stage fermentation and an anaerobic reactor. Concerning this, the research gap is on recovery of usable resources from POME by using a two-stage fermentation and an anaerobic reactor.

## 2.3. Research Question

How to optimize biogas production from POME under the effects of Organic Loading Time (OLR) of Volatile suspended solid (VSS), hydraulic retention time (HRT) and carbon-to-nitrogen (C/N) ratio in an anaerobic environment?

## 2.4. Objective of Research

This study abroad objective is to optimize Biogas production from POME by using a two-stage fermentation and an anaerobic reactor. The broad objective is split into the following particular goals in order to achieve the objective of this research:

a) Identify the level of significance of factors such as Organic Loading Rate (OLR) of VSS, hydraulic retention time (HRT) and carbon-to-nitrogen (C/N) ratio that significantly affect the biogas production from POME.

b) Optimization level of inputs of Factors like Organic Loading Rate (OLR) of VSS, hydraulic retention time (HRT) and carbon-to-nitrogen (C/N) ratio that Effect to Biogas Production.

## 3. Research Methodology

This section discusses the research methodology for achieving the research objectives. The section 3.3 is developed to achieve research objective 1.0 which stated in sub-section 2.4.a. The section 3.2 is developed to achieve research objective 2 which stated in sub-section 2.4.b. The experiment set up is described in Figure 2. For analysing data; MiniTab (Version 18.1) and Design Experts (Version 2018) have used (Shahidul *et al.* 2018c).

### 3.1. Research Design for Achieving Specific Objective One

The objective of this section is to determine the factors that significantly ($p \leq 0.05$) effect on biogas production from POME. To achieve this goal, an experiment has set up presents by Figure 2. The feedstock has prepared with POME and inoculum to maintain C/N, pH, HRT, SRT and OLR limits suggested by Shahidul *et al.* (2018c).The significant level of contribution of manipulating variables (C/N, pH, HRT, SRT and OLR) in biogas production was measured with the scale of p-value at 95% confidence level. If the p-value is less than 0.05, it indicates outputs are significant. However, the optimum experimental range of variables has been estimated by using Design of Experiment (DOE, 2018); the output of the software is listed in Table 2.

The information listed in Table 2 will be used for achieving objective number one.

### 3.2. Research Design for Achieving Specific Objective Two

This section describes research method to achieve objective two that stated in Section 2.4.2). The objective of this section is to determine the optimum value of (OLR, pH, C/N, HRT, and SRT) responsible for biogas production from POME. To achieve this goal, experiment setup and feedstock preparation present in Figure 2. The experimental data was analysed by Minitab (Version 18.1) to

**Table 2.** Experimental range and independent variables levels.

| | Range and Levels | | | | |
|---|---|---|---|---|---|
| Variables | $-\alpha$ (1.681) | Low (−1) | Central (0) | High (1) | $+\alpha$ (1.681) |
| $X_1$ (OLR) | 1 | 2.6 | 6 | 11 | 14.409 |
| $X_2$ (C/N) | 13.182 | 20 | 30 | 40 | 46.817 |
| $X_3$ (HRT) | 1.954 | 4 | 7 | 10 | 12.045 |

estimate the optimum amount of biogas production. Water displacement method is used to collect biogas. The optimum level of biogas production is evaluated from 3D graph which prepared from experimental data and by using design of expert's software.

### 3.3. Feedstock Preparation

The substrate is a mixture of POME and inoculum. Banana skin was used to prepare the inoculum. The mesh size of the skin was converted to less than 1.0 mm and was kept 30 days at atmospheric temperature [18] before it is added into the feedstock. In order to maintain the C/N from 20 to 40, the weight of inoculum added with POME for each run of experiment. **Table 3** shows the characterization of the feedstock.

### 3.4. Sample and Data Collection Procedure

Fresh POME sample is collected from FELCRA Jaya Samarahan SDN BHD, using 25 L high-density polyethylene containers, before being transported to the Operation Research laboratory of University Malaysia Sarawak. The bioreactor

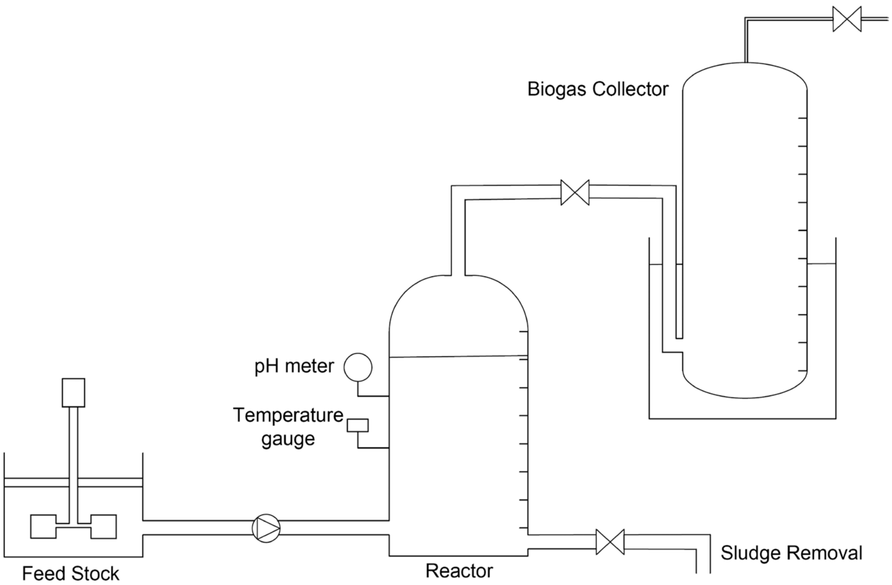


**Figure 2.** Experimental setup.

**Table 3.** Characterization of feedstock (Shahidul *et al.*, 2018c).

| Item (g/L) | Value | | |
|---|---|---|---|
| | POME | Inoculum | Substrate* |
| COD g/L | 96 | 0.0 | 75 |
| VSS g/L | 30 | 80 | 35 |
| pH** | 4.5 | 5.5 | 7.5 |
| TSS g/l | 75 | 11 | 50 |
| C/N | 7 | 83 | 30 |

operates continuously for 30 days. Data is collected by obtaining the volume produced by using water displacement method. The data is obtained and tabulated every day for 30 days. Data is taken every 12 hours.

## 4. Result and Discussion

This section has two subsections; 4.1 discus about objective number one. Section 4.2 discusses objective No.2.

### 4.1. Determining the Factors that Significantly Effect on Biogas Production

To get the answer to question and to achieve the research objective 01, The experimental run and data range are listed in Table 2 have used in software Mini Tab (Version 18.1) and Design Expert (Version 2018) to estimate significance level of contribution to biogas production. The outputs of software run have listed in Table 4.

Table 4 Mini Tab (Version-18.1) and Design Expert (Version 2018) were used for data analysis. Factors that significantly contribute to producing biogas production are from POME.

Table 4 shows the p-value with respect to Biogas production and OLR is 0.0388 ($p < 0.05$), which is significant at 95 percent level; it indicates that OLR has a significant effect on Biogas production. The p-value with respect to Biogas production and C/N is 0.1367 ($p > 0.05$), which indicates that C/N has effect but not significant to Biogas production. The p-value with respect to Biogas production and HRT is 0.7121 ($p > 0.05$), which is not significant at 95 percent level; it indicates that HRT has effect but not significant to Biogas production from POME.

### 4.2. Optimization Factors that Effect to Biogas Production

The results of the experiment were analysed by Design Expert (Version 2018) software and results are presented by 3D plot, which are presented in Figure 3 and Figure 4.

These optimum values of all factors including independent and dependent variables are listed in Table 5.

Table 5 demonstrates that optimum output is 3.8 Litre at optimum input Biogas.

Table 4. Significance level of factors.

| Factors | p-Value | Significance Level of Factors |
|---|---|---|
| OLR | $p_{OLR} = 0.0388$ | $p_{OLR} < 0.05$; Significant |
| C/N | $p_{C/N} = 0.1367$ | $p_{C/N} > 0.05$; Not significant |
| HRT | $p_{HRT} = 0.7121$ | $p_{HRT} > 0.05$; Not significant |

$R^2$ =0.8487; Adjusted $R^2$ = 0.7126; Adequate precision= 7.615; Coefficient of Variation (CV) = 8.96%.

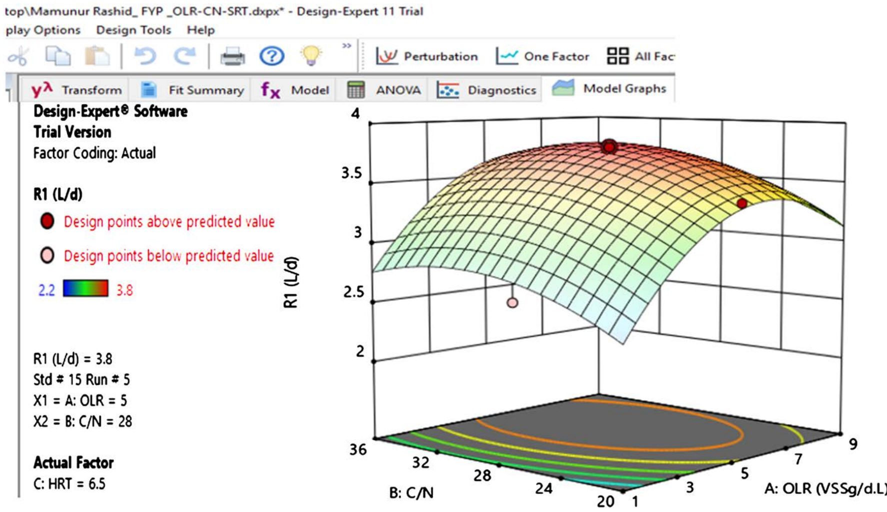


**Figure 3.** Surface response optimization on OLR, C/N and Biogas.

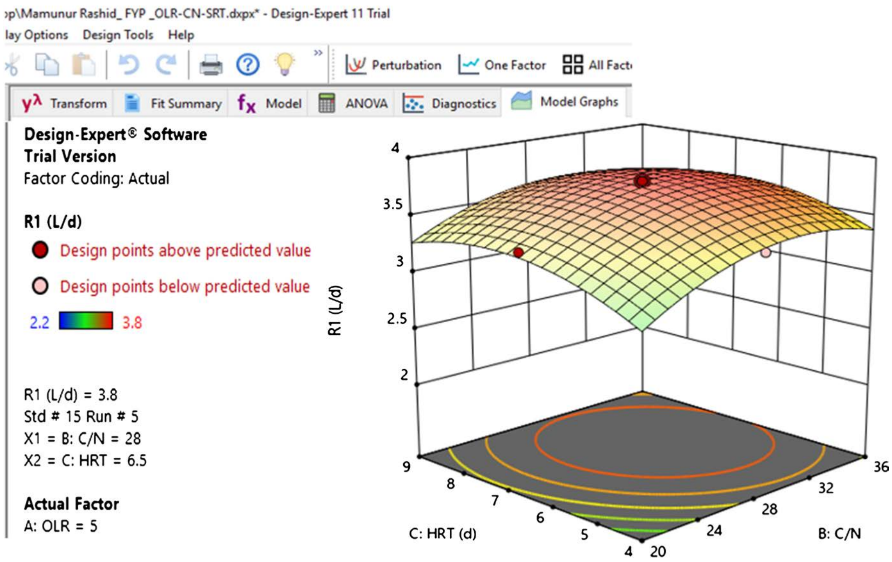


**Figure 4.** Surface response optimization OLR, HRT and Biogas.

**Table 5.** Optimum values of inputs output.

| Figure No. | Input Factors | Optimum Value | Optimum Output (Biogas) |
|---|---|---|---|
| 4.1 and 4.2 | OLR | 5 g/L·d | 3.8 L/d |
| | C/N | 28 | |
| | HRT | 6.5 d | |

## 5. Conclusion and Implementation

The result of this study is the achievement of the research goal. The research was carried out in order to optimize Biogas production from POME by using a two-stage fermentation and an anaerobic reactor. In this study three independent variables and one dependent variable have used; which shows the OLR input factors have significantly ($p < 0.05$) contribute to produce biogas. One the other hand C/N and HRT also contributed to produce biogas as well, but the effect was not significant. The optimum level of biogas production was 3.8 Litre/day at the rate of OLR used which equivalent to about 350 Litre of biogas per kilogram of COD. The findings of this research will bring benefits to palm oil industries in achieving economic and environmental sustainability. This research concludes that in-depth research into this matter is important to implement this technology in the palm oil industry.

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## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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