Biogas production for electricity from fruit waste: a case study of Gemah Ripah biogas plant, Yogyakarta

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Abstract. Gemah ripah biogas (GRB) plant is the first biogas project in Indonesia that utilizes a 100% fruit waste as a feedstock. Now, the biogas has been operating for almost 9 years. To get objective performance study in the biogas plant existing, it important to analyze biogas production, electricity generation and energy and environmental benefits of the GRB plant. This paper presents a comprehensive analysis of the typical demonstration model in utilization of fruit waste. Regarding the observation, technically GRB has operated in appropriate function. GRB was designed for 4 T/day feed and supplies 148.5 kWh/day electricity. The further analysis exhibited that GRB project is required to be optimized for maximum energy and environmental benefits because biogas plant feed only 0.35 T/day (8% of feed design) and supplies electricity only 0.45 % of its supplies. For biogas quality, data showed that the biogas plant produces methane and carbon dioxide with average content of 59% and 37% which is already within a good standard. GRB need some of recommendation for maximum operation which is discussed in this article. Nevertheless, operating as an example of a sustainable renewable energy model, GRB can decrease of waste discharge to the landfill and utilization of waste at the source. The operation model of GRB plays an important role in reducing greenhouse, mitigating pollution and generating renewable energy.

Keywords: Biogas production, Fruit waste, Electricity, Case study, Biogas plant

1. Introduction

Waste is one of big problem in the world, especially in the developing countries. One of important component of solid waste is fruit and vegetables waste. Indonesia, one of developing country, has potential fruit waste. It was recorded that in 2016 there was about 1.75 million tons/year of waste produced [1]. Like many countries [2,14], Indonesia has committed not only decreasing of waste...
produced but also generating renewable energy from waste. Government, researcher, private sector and academics work together to implement this idea in Indonesia. Many process and technology can be used for converting waste into energy with thermal and/or bio process basic [4-7]. For example, Ariyanto [3] showed that energy can be produced by utilizing fruit waste as a raw material depending on the amount and characteristic of waste.

Anaerobic digestion is one of technology that is worth recommended for utilization of waste to energy [8-9]. This technology provides benefits not only waste management but also energy conservation and producing environmentally safe products [10]. The technology of anaerobic digestion has been applied in many countries like United State [11], Spain [11], and China [12]. However, the technology and processes cannot be applied directly in some other societies or countries due to the character of waste, local habits, social structures and other differences [3]. Therefore, experience from expert of biogas plant operation is needed to make sure a sustainability of biogas plant project on the future.

This paper presents a comprehensive study of operation of biogas plant based on fruit waste. The evaluation is needed to evaluate the performance of the existing condition and seek potential opportunities to develop the biogas plant, in the case of energy and environmental optimum benefits. The results can be used to propose a general development model of Indonesian biogas in the future. The focus is on biogas production for electricity from fruit waste in Gemah Ripah Biogas Plant, or called GRB. GRB was built in a fruit market by Waste Refinery Center UGM (WRC UGM) collaborated with private cooperative and local government [13]. As best our knowledge, GRB is the first biogas project in Indonesia that utilizes a 100% fruit waste as a feedstock [3]. The process is using wet anaerobic digestion technology. GRB was designed to digest 1400 tons of fruit waste per year to produce biogas [13], which is potential to generate 200,000 kWh of electricity. Until now, the biogas has been operating for almost 9 years. A number of studies have been conducted optimizing biogas plant [3,13] and the results of these are summarized in this paper. Biogas production and composition, electricity generation, environmental and energy benefit are described in detail. Furthermore, the operation of biogas plant combined with field experience are summarized and created as a basis to proposing maximum development of GRB especially and comprehensive development model of Indonesian biogas generally.

2. Data and methods

2.1 Gemah Ripah Biogas (GRB) Plant

Biogas plant is located inside the market of groceries market “Gemah Ripah” in Gamping, Yogyakarta, Indonesia. The plant installed in the market, with total area is 600 m². The biogas plant in Gamping was designed by research scheme both undergraduate and post graduated with the supervision by UGM and Boras University. Biogas plant was designed based on the fixed dome digester, which located in underground.

The process in the biogas plant is shown in Figure 1. Sorted fruit waste from grocery market is brought to biogas plant using small truck, the waste come to feeding unit to be weighed then ready to be crushed. Water is adding during the crushing process and waste turned to in liquid form. This liquid supply is source of energy and nutrients for anaerobic digestion process to produce biogas. The slurry is pumped to the digester and starting in anaerobic process for 25 days. The digester was design for 4 ton/day, and the overflow is setup automatically coming to the overflow pond. Biogas produced is accumulated in the digester and will come out when the valve is opened, so there is no gas storage outside digester.
2.2 Methods
The analysis through several stages as follow: Analyzing and evaluation operation of biogas plant design. This research used a tank emptying method to find out that biogas produced every day and flowmeter was used to determine the volume of biogas used. This study used sensor of methane and carbon dioxide to determine the composition of biogas. After that, verification of data and material discussion to the stakeholders were performed. Result from this study used to formulate a general development model of Indonesian biogas in the future.

3. Result and Discussion

3.1 Biogas production and composition of GRB
Biogas production in GRB was evaluated for 170 days including gas and electricity generated. The process condition was allowed to the daily operation (no treatment and no specific charge). Since the amount of waste is different day to day, we observed that the feeding was not fixed daily. Therefore, it led to unstable biogas production as shown in Figure 2A. The graph shown that there are spikes in biogas production. The lowest production is in the first day and in 105-118 days.

Influents in the form of fruit waste that has been crushed and diluted will come into contact with microorganisms and begin the anaerobic process. The moisture content of the substrate is more than 90%, causing microorganisms to quickly penetrate the influent without the need to stir the biogas reactor. After 70 hours in a biogas reactor, the biogas reactor starts producing biogas with hourly production as shown Figure 2. Cumulative biogas production in the research month is shown by cumulative graph on Figure 2.

Regarding the observation, technically GRB has operated in appropriate function. However, the quality of the crusher is needed to be increased in term of shredding. Project has produced 60 ton of fruit waste per half year to produce 650 Nm³ biogas (Fig. 1) and generate electricity 120 kWh. However, it is still under target as designed. Therefore, optimization is required hence, GRB can reach target as design.

Some activities can be carried out to optimize biogas production e.g. management supply and characterization of fruit waste to get optimum biogas production from fruit waste. Ariyanto et al. said that waste properties such as type of waste and its composition are important factors to determining biogas production [3], installation of the gas holder to prevent biogas release to the environment [13]. From the observation, GRB must upgrade quality of crusher so that all types of fruit waste can be processed. For biogas quality, data showed that the biogas plant produces methane with average content of 59% and carbon dioxide with average content of 37% which is already within a good
standard. Further purification can be carried out if the biogas is upgraded to biomethane. The techniques for transformation of biogas to biomethane is reported by Ryckebosch et al. [4].

![Figure 2](image_url)

**Figure 2.** Gas generate per day and cumulative volume of biogas for a half year

### 3.2 Electricity generated of GRB

Based on six-month observation, the generator operated for 140 hours and 53 minutes and generated electricity of around 120 kWh. The generator efficiency was only 6%. Therefore, from 1800 kWh consumed by the generator, 1600 kWh was lost to heat, kinetic energy and potential gas exhaust energy. This is only 0.45% from its potential installed. It is reported from literature (Souza et al. [15]) that an engine generator can convert 0.8 m³ of biogas to produce 1 kWh of electricity. It means that generator in GRB need to be optimized hence providing maximum biogas conversion into electricity.

Research related to this generator is very interesting to do in the future especially biogas engines with small to medium capacity. If small to medium biogas engines with high efficiency are obtained and biogas production can be optimal, it is very possible for GRB to produce electricity according to the potential installed (200000 kWh annually).

Even though electricity generated is low, but the quality electricity from GRB is not different with electricity from state electricity company in Indonesia. The generator output profile can be identified through load testing by providing a certain electrical load on the generator. The generator is connected to an artificial electrical load that requires a cumulative operating power of up to 6000 Watts. Electricity itself is a device that requires electrical energy to be operated. The value of the voltage and flow variable is measured using a multimeter, while the value of the variable Power, Power and Frequency factors is measured using Power & Harmonic Analyzer. Electricity from GRB has voltage 238-243 Volt (220-volt standard) and frequency 50 Hz (50 Hz standard), as shown in Figure 2. These results give credence to biogas activists to continue campaigning for biogas as a stable and safe electricity source.
3.3 Environmental benefits of GRB

**Decreasing emission of greenhouse gases.** It is well known that energy plays a vital role in socio-economic and human life development [14]. Since revolution industry, fossil fuel is a primary source to generate energy. The intensive use of fossil fuel provides environmental impact in the form of greenhouses and harmful gases [10]. Due to greenhouses produces the global warming effect, it is important to use renewable energy source to replace fossil fuel. Chen et al [9] report that development and utilization of waste to energy is a smart way to reduce greenhouse gas emissions. The operational of GRB on maximum capacity can reduce a total 250 ton of CO2 annually. If this technology is expanded and promoted, the annual emission reduction in Indonesia will be very significant.

**Decreasing pollution.** Around 3650 tons of fruit waste produced by Gemah Ripah Market each year would thoughtfully pollute the environment if not well treated. GRB installed in Gemah Ripah as a solution to manage their waste. If GRB operated on maximum operational, it can decrease 1460 tons of fruit waste annually and they can convert waste into energy to cover their electricity needs.

**Generating renewable energy to supply Gemah Ripah Market needs.** Gemah Ripah Market gets two benefit from GRB operation, not only their waste can remove but also it can produce the electricity. The electricity supplied kiosk on the market, besides that, the biogas channeled to food stalls around the market. This market is trying to be energy independent and zero waste market.

The analysis results obtained can be used for Indonesian biogas development., as an example, if GRB model (utilization waste at the source) is installed in a lot of a traditional market (as the source of waste) in Indonesia, it can give high impact for reducing greenhouse and mitigating pollution. Besides, it can give inspiration to proposes a general development model of Indonesian biogas in the future.

**Conclusions**

A comprehensive analysis of the typical demonstration model (GRB) in utilization of fruit waste at the source in Indonesia was carried out. From the biogas production evaluation, GRB produce 650
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Nm$^3$ of biogas for a half year with 59% methane and this biogas production is 0.65% of the total potential biogas produced because GRB only processes 60 tons of fruit waste (8% out of installed capacity) for half a year. Evaluation of electricity generation from biogas showed that 650 Nm$^3$ can produce 120 kWh of electricity (0.45% from its potential installed). Based on load test, electricity from GRB has voltage 238-243 Volt (220-volt standard) and frequency 50 Hz (50 Hz standard). From the environmental benefits assessment, the impact of GRB on the environment is decreasing emission of greenhouse gases, decreasing pollution and generating renewable energy.

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References

[1] Marendra F, Prasetya A, Cahyono R.B., Ariyanto T 2019 IOP Conf. Ser.: Mater. Sci. Eng. 543 012059
[2] Hua Y, Oliphant M, Ha E J 2016 Renew. Energy 85, 1044-105.
[3] Ariyanto T, Cahyono R B, Vente A, Mattheij S, Millati R, Sarto, Taherzadeh M J, and Syamsiah S 2017 Int J. Technol 8, 1385-1392
[4] Ryckebosch E, Drouilllin M, and Vervaeren H 2011 Biomass and Bioenergy 35, 1633-1645.
[5] Mendez M R, Aramaki T, and Hanaki K 2004 Resour. Conserv. Recycl. 41, 47-63
[6] Nasir I M, Ghazi T I M, and Omar R 2012 Appl. Microbiol. Biotechnol 95, 321-329
[7] Opatokun S A, Lopez-Sabiron A M, Ferreira G, and Strezov V 2017 Sustainability 9, 1804
[8] Bacenetti J, Sala C, Fusì A, and Fiala M 2016 Appl. Energy 179, 669-685
[9] Chen L, Cong R, Shu B and Mi Z 2017 Renew. Sustain. Energy Rev. 78, 773-779
[10] Forster-Carneiro T, Perez M, and Romero L I 2008 Bioresour. Technol. 99, 6994-7002
[11] Van Fan Y, Lee C T, Klemes J J 2017 Chem. Eng. Trans. 57, 7-12
[12] Chen T, Shen D, Jin Y, Li H, Yu Z, Feng H, Long Y, Yin J 2017 Appl. Energy 208 666–677
[13] Marendra F, Rahmada A, Prasetya A, Cahyono R B, and Ariyanto T, 2018 Jurnal Rekayasa Proses 12, 85-97
[14] Gokcol C, Dursun B, Alboyaci B, Sunan E 2009 Energy Policy 37, 424-431
[15] Souza S., Lenz A., Werncke I., Nogueira C., Antonelli J., and Souza J 2016 Eng.Agric. Jaboticabal 36 613-621