sinta S2 Sinta Score
e-ISSN 2503-5010
p-ISSN 2087-0965

Accredited by Ristekdikti: Nomor 158/E/KPT/2021

JURNAL RISET TEKNOLOGI PENCEGAHAN PENCEMARAN INDUSTRI

Research Journal of Industrial Pollution Prevention Technology

Vol. 13, No. 1, June 2022

JURNAL RISET Teknologi Pencegahan Pencemaran Industri	Vol.13	No. 1	Page 1 - 52	Semarang, June 2022	ISSN No. 2087-0965

Kementerian Perindustrian REPUBLIK INDONESIA

Published by :
BADAN STANDARDISASI DAN KEBIJAKAN JASA INDUSTRI
BALAI BESAR STANDARDISASI DAN PELAYANAN JASA PENCEGAHAN PENCEMARAN INDUSTRI

Jurnal Riset

Teknologi Pencegahan Pencemaran Industri

Volume 13 No. 1, Juni 2022

FOCUS AND SCOPE

Jurnal Riset Teknologi Pencegahan Pencemaran Industri (Research Journal of Industrial Pollution Prevention Technology) seeks to promote and disseminate original research as well as review, related to following area:

Environmental Technology : within the area of air pollution technology, wastewater treatment technology, and management of solid waste and harzardous toxic substance.

Process Technology and Simulation : technology and/or simulation in industrial production process aims to minimize waste and environmental degradation.

Design Engineering : device engineering to improve process efficiency, measurement accuracy and to detect pollutant.

Material Fabrication : environmental friendly material fabrication as subtitution material for industry.

Energy Conservation : process engineering/ technology/ conservation of resources for energy generation.

Jurnal Riset
Teknologi Pencegahan Pencemaran Industri
Volume 13 No. 1, Juni 2022

IMPRINT

JRTPPI published by Center for Standardization and Industrial Pollution Prevention Services (BBSPJPPI) – Agency for Standardization and Industrial Services (BSKJI), Ministry of Industry. JRTPPI is published online twice in every year.
ISSN print edition : 2087-0965
ISSN electronic edition : 2503-5010
Electronic edition available on :
ejournal.kemenperin.go.id/jrtppi

INDEXING

JRTPPI has been covered by these following indexing services :
Crossref, Indonesian Scientific Journal Database (ISJD), Mendeley, Infobase Index, Indonesian Publication Index (IPI), Bielefeld Academic Search Engine (BASE), Google Scholar, Directory of Research Journals Indexing (DRJI).

MAILING ADDRESS

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07.30 – 16.00 GMT+7

Jurnal Riset

Teknologi Pencegahan Pencemaran Industri

Volume 13 No. 1, Juni 2022

PREFACE

Thanks to Allahu Robbie 'Alamin, Journal of Industrial Pollution Prevention Technology (JRTPPI) again will publish scientific articles, especially in the field of environmental technology for volume 13 no 1. Our high appreciation is directed to the authors and editorial board who have actively participated so as to maintain consistency of quality and punctuality of our periodic publications. We would like to acknowledge our high appreciation to the head of Center for Standardization and Industrial Pollution Prevention Services, Ministry of Industry.

This edition of the issue is five series published that in full-text English. This continous policy is an attempt of the editorial board to improve the author's performance in delivering the results of their researches. Articles in full-text English are more likely to be read by broader audience so that it will increase the number of citations. This policy is also applied in order to actualize our hope of being a globally indexed international journal.

The articles contained in this edition consist of kinetic studies of biogas, analytical hierarchy process for tofu wastewater, solar energy and solar panel as renewable energy, and utilization of peroxide bleached sugar palm in cellulose. The five manuscripts accepted and published in this edition are from researcher and lecturer in Indonesia. The duration of submission, review, and editing of the manuscripts ranged from 1-6 months.

Hopefully, these scientific articles may be new source of knowledge and experience for readers from academic, researcher, industry, and society at large. We realize that nothing is perfect until the improvement of all parties involved is continuously done.

Semarang, Juni 2022

Chief Editor

Jurnal Riset

Teknologi Pencegahan Pencemaran Industri

Volume 13 No. 1, June 2022

TABLE OF CONTENT

Jurnal Riset

Teknologi Pencegahan Pencemaran Industri

Volume 13 No. 1, June 2022

ABSTRACT

Published on 27 June 2022

Iqbal Syaichurrozi[1*], M. Fakhri Basyir[1], Rafi Muhammad Farraz[1], Putri Kurnia Villta[1], Nabilah Nabilah[1], Rusdi Rusdi[1], Sutaryo Sutaryo[2]
([1]Department of Chemical Engineering, Faculty of Engineering, University of Sultan Ageng Tirtayasa, Jl. Jendral Soedirman Km 3, Cilegon 42435, Indonesia, [2] Department of Animal Science, Faculty of Animal and Agricultural Sciences, University of Diponegoro, Semarang 50239, Indonesia)

The Effect of Inoculum to Substrate and Carbon to Nitrogen Ratios on the Biogas Quantity and Quality from Anaerobic Digestion of Salvinia molesta: Experimental and Kinetic Studies

Jurnal Riset Teknologi Pencegahan Pencemaran Industri, June 2022, Vol. 13, No. 1, p. 1-11, 6 ill, 7 tab, 14 ref

This experiment was conducted to study the effect of inoculum to substrate (I/S) and carbon to nitrogen (C/N) ratios on the biogas quantity and quality from anaerobic digestion of Salvinia molesta (SM). The I/S was adjusted to become 1.5, 2, 2.5 and the C/N was to become 21.5, 25, 30. Anaerobic digestion (AD) was operated during 30 days under the room pressure and temperature. The results showed that increase in I/S from 1.5 to 2.5 increased the biogas yield from 19.01 to 33.84 mL/g VS. Besides that, it increased the methane content from 52.54 to 69.01%. Furthermore, increase in C/N to 21.5 to 30 decreased the biogas yield from 33.84 to 30.85 mL/g VS and then decreased the methane content from 69.01 to 6.99%. Hence, the best condition was in the substrate with I/S of 2.5 and C/N of 21.5. The measured data was successfully predicted through the modified Gompertz with R2 of 0.9905, while through the first order kinetic models with R2 of 0.9476. Hence, the former gave a better prediction than the latter.

(Author)

Keywords: Anaerobic digestion, Biogas, C/N, I/S, *Salvinia molesta*

Sujarwanto Dwiatmoko1, Archibald Nagel 1,2*, Jaka Windarta 2,3
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Soaking Up The Sun: Designing Small Scale Photovoltaic (PV) Rooftop for Micro, Small, and Medium Enterprises (Msme): Study Case at Rattan Crafts Center in Trangsan Village, Sukoharjo, Central Java

Jurnal Riset Teknologi Pencegahan Pencemaran Industri, June 2022, Vol. 13, No. 1, p. 12-19, 5 ill, 5 tab, 13 ref

The National Energy General Plan has set a target of achieving a Renewable Energy (RE) mix of 23% by 2030, to achieve this the transition of non-renewable energy to RE must be done immediately. Solar energy is one of the renewable energy that is very abundant in Indonesia. Along with the issuance of the Minister of Energy and Mineral Resources Regulation number 49 of 2018 regarding the Use of Rooftop Solar Power System by Consumers of PT Perusahaan Listrik Negara (Persero) which provides opportunities for the utilization of PV Rooftop for household and commercial sector. Given this, the Central Java Government plans to install Rooftop Power Plant in the Micro, Small, and Medium Enterprises (MSME) Sector to develop the utilization of RE in the productive sector while improving the economic recovery from the Covid-19 pandemic. This study analyzes the potential development of PV Rooftop in Rattan MSME Center in the village of Trangsan, Sukoharjo Regency. The use of renewable energy (EBT) is expected to save electricity costs in MSMEs. The results of planning using Helioscope software showed that the three MSMEs with different PLTS capacities, namely 1 Kwp, 2.04 KWp, and 4 KWp can produce annual energy production of 1,191 MWh, 2,433 MWh, and 5,352 MWh respectively. After the installation of the PLTS, it was proven that in the first two months after installation, energy consumption can decrease to minimum usage.

(Author)

Keywords: Solar Energy, PV Rooftop, MSME, Helioscope

Naomi Aurora Margareth Br Simanjuntak[1], Nurulbaiti Listyendah Zahra[1*], I Wayan Koko Suryawan[1]
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Decision Making for Biological Tofu Wastewater Treatment to Improve Quality Wastewater Treatment Plant (WWTP) Using Analytical Hierarcy Process (AHP)

Jurnal Riset Teknologi Pencegahan Pencemaran Industri, June 2022, Vol. 13, No. 1, p. 20-34, 5 ill, 11 tab, 34 ref

This research aims to build a support system for tofu wastewater treatment using the Analytical Hierarchy Process (AHP) method. This research was conducted in one of the household tofu industries in Jakarta. AHP method was used to choose/decide the most effective combination of technologies to treat tofu wastewater. Based on the literature study and inlet characterization, Three alternatives were proposed. Alternative 1 consists of a Collecting tank, Neutralization Tank, Preliminary Sedimentation, Anaerobic Digester, Aeration Tank, and Final Settlement Body. While alternative 2 consists of a Collecting tank, Neutralization Tank, Preliminary Sedimentation, Anaerobic Biofilter, Aeration Tank, and Final Settlement Tank. Alternative 3 consists of a Collecting tank, Neutralization Tank, ABR, Aeration Tank, and Final Sedimentation Tank. The decision criteria used for AHP were effluent quality, land requirement, construction cost, and maintenance convenience. The primary data used were wastewater flow and outlet concentration. While data on area use, maintenance cost, and construction cost were extracted from literature study. The result shows that alternative 3 was the most effective sequence of technology. Eigen Vector Analysis Recapitulation showed that alternative 1 has an overall value of 0.31, alternative 2 has a value of 0.2 and alternative 3 has a value of 0.5. Using alternative 3, BOD5 can be removed up to 95%, COD can be removed by a maximum of 95% by ABR, and TSS can be removed by 80% which met the quality standard.

(Author)

Keywords: Tofu, Wastewater, WWTP, AHP

Dwi Joko Prasetyo[1], Nur Evita Fitriana[2], Wahyu Anggo Rizal[1], Hernawan[1], Tri Hadi Jatmiko[1], Diah Pratiwi[1], Anggita Sari Praharasti[1], Roni Maryana[3], Muslih Anwar[1], Ria Suryani[1], Andri Suwanto[1], Satriyo Krido Wahono[1] and Crescentiana Dewi Poeloengasih[1]
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Utilization of Peroxide Bleached Sugar Palm (Arenga pinnata) Fibre Waste into Cellulose Nano Crystal

Jurnal Riset Teknologi Pencegahan Pencemaran Industri, June 2022, Vol. 13, No. 1, p. 35-42, 3 ill, 2 tab, 44 ref

Sugar palm (Arenga pinnata) fibre (SPF) waste is a side product of sugar palm starch production and needs to be processed to avoid environmental pollution. Since the SPF has high cellulose content, it can be beneficial if it is valorized into high-value products such as cellulose nanocrystal (CNC). The CNC production from SPF was initiated by cellulose production by using an environmentally friendly peroxide bleaching as elementary chlorine free bleaching method. The CNC production was conducted via sulfuric acid hydrolysis at a temperature of 40°C, solid/liquid ratio of 1:10, and hydrolysis time of 45, 60, 75, and 90 minutes. The same functional groups were observed in all CNC samples, including the appearance of the ester sulfate group. The decrease in yield and crystallinity index (CrI) as the hydrolysis time was observed. These phenomena were caused by the degradation of the crystalline structure of cellulose and the formation of the ester sulfate group. The measurement of CNC diameter size was carried out by using the scanning electron microscopy (SEM) technique. The CNC diameter was below 100 nm which indicated the nanoparticle formation was observed at CNC produced at hydrolysis times of 75 and 90 minutes. In conclusion, CNC production was successfully produced from peroxide bleached SPF which is more environmentally friendly than the conventional method using chlorite bleached cellulose. Furthermore, it is needed to optimize the production of SPF CNC in further research.

(Author)

Keywords: Cellulose nanocrystal, Peroxide bleached, Sugar palm fibre

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Rooftop PV Plant Development Planning at the Central Java Provincial DPRD Secretariat Office

Jurnal Riset Teknologi Pencegahan Pencemaran Industri, June 2022, Vol. 13, No. 1, p. 43-52, 12 ill, 6 tab, 15 ref

Central Java Province targets the achievement of the new and renewable energy (EBT) portion in the energy mix by 2030 at 22.55%. In order to achieve this target, the Central Java Provincial Government has consistently developed the use of EBT, one of which is through the construction of rooftop solar power plants (Rooftop PV Plant) in government buildings. In addition to requiring a fairly high initial investment cost, the construction of a Rooftop PV plant connected to the PT. PLN (Persero) requires a fairly complicated process, so proper planning must obtain optimal results. This paper will discuss an example of a Rooftop PV Plant development plan at the Secretariat Office of the Central Java Provincial DPRD, including the use of electrical energy prior to the installation of a Rooftop PV Plant; an analysis of the condition and availability of the location; the design and system of a Rooftop PV Plant; an estimate of the total potential energy that can generate; the investment costs of a Rooftop PV Plant; as well as evaluating the results of using Rooftop PV Plant. The electricity bill at the Central Java Provincial DPRD Secretariat Office prior to installing Rooftop PV Plant is Rp. 91.308.323,- per month. The recommended PV design, built on an area of 197 m2, is a rooftop on-grid PV Plant system with 6 PV arrays, each of which

PV arrays are installed with as many as 20 solar modules arranged in series. The total number of solar modules installed is 120 solar modules with a total capacity equivalent to 30 kWp. Based on the simulation results using the PVSyst 6.4.3 software, the Rooftop PV Plant system can generate electrical energy of up to 43,420kWh per year or equivalent to 118.9kWh per day with a performance ratio of 79.4%. The potential for saving electricity costs from the simulation results can reach Rp. 4,034,441.- per month. The results of the evaluation of the utilization of the Rooftop PV Plant through the recording of the inverter monitoring system within 1 (one) year after installation shows the amount of electrical energy produced is 40,558 kWh, so that the manager of the Secretariat of the DPRD Central Java Province office can save a budget of Rp. 3,768,514.- per month from the use of the Rooftop PV Plant. This figure is not much different from the simulation results at planning. There is a difference in the cost savings of electricity payments at the Central Java Provincial DPRD Secretariat Office during 2020 of Rp. 4,493,300,- excluding savings due to the use of Rooftop PV Plant due to implementing the work from home (WFH) system during the COVID-19 pandemic, which resulted in a significant reduction in the use of electrical energy.

(Author)

Keywords: PV Plant, Rooftop, Solar Module, Government Building, Central Java

Vol. 13 No. 1 (2022) 1-11

Jurnal Riset
Teknologi Pencegahan Pencemaran Industri

Journal homepage : http://www.jrtppi.id

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The Effect of Inoculum to Substrate and Carbon to Nitrogen Ratios on the Biogas Quantity and Quality from Anaerobic Digestion of Salvinia molesta: Experimental and Kinetic Studies

Iqbal Syaichurrozi[1*], M. Fakhri Basyir[1], Rafi Muhammad Farraz[1], Putri Kurnia Villta[1], Nabilah Nabilah[1], Rusdi Rusdi[1], Sutaryo Sutaryo[2]

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ARTICLE INFO

Article history:
Received 28 December 2021
Received in revised form 08 March 2022
Accepted 08 March 2022
Available online 27 June 2022

Keywords :
Anaerobic digestion
Biogas
C/N
I/S
Salvinia molesta

ABSTRACT

This experiment was conducted to study the effect of inoculum to substrate (I/S) and carbon to nitrogen (C/N) ratios on the biogas quantity and quality from anaerobic digestion of *Salvinia molesta* (SM). The I/S was adjusted to become 1.5, 2, 2.5 and the C/N was to become 21.5, 25, 30. Anaerobic digestion (AD) was operated during 30 days under the room pressure and temperature. The results showed that increase in I/S from 1.5 to 2.5 increased the biogas yield from 19.01 to 33.84 mL/g VS. Besides that, it increased the methane content from 52.54 to 69.01%. Furthermore, increase in C/N to 21.5 to 30 decreased the biogas yield from 33.84 to 30.85 mL/g VS and then decreased the methane content from 69.01 to 6.99%. Hence, the best condition was in the substrate with I/S of 2.5 and C/N of 21.5. The measured data was successfully predicted through the modified Gompertz with R^2 of 0.9905, while through the first order kinetic models with R^2 of 0.9476. Hence, the former gave a better prediction than the latter.

Nomenclatures:

ym	= the biogas yield potential (mL/g VS)
y(t) (mL/g VS)	= the cumulative biogas yield at t days
λ	= lag phase period (days)
μ	= the maximum biogas yield rate (mL/g VS.day)
k	= the biogas production rate constant (/day)
e	= a constant (2.718282)
t	= cumulative time for AD process (days)

1. INTRODUCTION

The application of anaerobic digestion (AD) in treating various wastes is carried out conducted by many countries in the world (Kougias & Angelidaki, 2018). This method is very powerful to treat many kinds of wastes and then produces the biogas that can be used as an alternative energy source (Iqbal Syaichurrozi, Basyir, Farraz, & Rusdi, 2020). Therefore, the AD is to be one of main research topics in Indonesia, since the country want to substitute the 33% of fossil fuel energy need with renewable energies at year of 2050 (I. Syaichurrozi, Villta, Nabilah, & Rusdi, 2019). As a tropical country, Indonesia has a variety of plants that thrive in it (Sarto, Hildayati, & Syaichurrozi, 2019). Many of them are lignocellulosic plants which are

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doi : https://10.21771/jrtppi.2022.v13.no.1.p1-11
2503-5010/2087-0965
Accreditation number : (Ristekdikti) 158/E/KPT/2021

included in weeds. One kind of weeds growing well in the country is *Salvinia molesta* (SM) (Syaichurrozi et al., 2018). It can grow floating in rivers, lakes, and rice fields with a very fast growth rate. Disadvantages arising from the presence of SM in the rivers and lakes are: (1) reducing the water volume via evapotranspiration, (2) reducing the aquatic organism movements, (3) reducing the dissolved oxygen, (4) blocking the river surface, (5) disturbing the ship track; meanwhile, in the rice fields, it can (1) reduce the fertilizer effectiveness and (2) reduce the irrigation system efficiency (Syaichurrozi, 2018; Syaichurrozi et al., 2018, 2019, 2020).

Because of its huge amount and fast growth rate, the SM can be used as a potential biogas feedstock. However, big part organic materials composing the SM are lignocellulosic compounds which are not good for AD process because it is difficult to be degraded. Acid pretreatment prior AD successfully increases the biogas yield from SM (I. Syaichurrozi et al., 2019). Furthermore, Syaichurrozi et al. (Iqbal Syaichurrozi et al., 2020) investigated the effect of initial pH (5, 6, 7, 8) and biological agent addition (*Saccharomyces cerevisiae*) on biogas yield from the SM, which was previously treated through sulfuric acid pretreatment. They found that the best condition is at initial pH of 7.0 and the yeast addition. The other affecting factors that have been not investigated yet in previous studies are inoculum to substrate (I/S) and carbon to nitrogen (C/N) ratios. Fagbohungbe et al. (Fagbohungbe, Herbert, Li, Ricketts, & Semple, 2015) reported that at I/S of 1-2 resulted a higher methane yield than I/S of 0.25-0.5 on biogas production from human faecal material. Xue et al. (Xue et al., 2020) reported that C/N ratio affected the methane yield from food wastes, in which the C/N of 25-30 resulted a higher methane yield from 20. The two ratios are important factors which are considered in AD process, but them have been investigated yet in AD of SM. Therefore, they were investigated in this current work.

Modeling of biogas evolution during AD is attractive to be conducted. The popular models such as the modified Gompertz and first-order kinetic models are usually used to simulate the evolution of biogas yield as function of time. Previous studies have used the models to simulate biogas production from sheep paunch manure at variation of I/S (Lawal, Dzivama, & Wasinda, 2016) and from food wastes at variation of C/N (Xue et al., 2020). Therefore, in this work, the two models will be utilized to describe the effect of I/S and C/N ratios on biogas from the SM quantitatively. The aim of this work is to investigate the effect of I/S and C/N ratio on biogas production from the SM and simulate the biogas evolution using the two popular models.

2. METHODS

2.1. Materials

The SM and inoculum (cow rumen fluid), which were used in the current study were the same materials used by Syaichurrozi et al. (I. Syaichurrozi et al., 2019; Iqbal Syaichurrozi et al., 2020). The SM thrives on bodies of water in Pandeglang Regency, one of regencies in Banten Province (Indonesia). Before used as a biogas feedstock, it was pretreated using sulfuric acid with a procedure used by Syaichurrozi et al. (Iqbal Syaichurrozi et al., 2020).

2.2. Experimental Design

2.2.1. Scenario 1

The SM as much as 10 g (with C/N of 21.5) was diluted using the tap water with ratio of SM/water of 1/13 (w/v, g/mL) (based on Syaichurrozi et al. (Iqbal Syaichurrozi et al., 2020)). The initial pH level of the substrates was increased until neutral level (7.0±0.2) with addition of NaOH 1 M solution. Furthermore, the cow rumen fluid (inoculum) was added with ratio of inoculum per substrate (I/S) of 1.5, 2, 2.5 (v/w, mL/g).

2.2.2. Scenario 2

In this scenario, the SM/water ratio and initial pH values were similar to Scenario 1 but the inoculum/substrate ratio was adjusted based on the best ratio obtained in Scenario 1. Furthermore, the C/N ratio was varied to be 21.5, 25, 30 by glucose addition.

The characteristics of the substrates in this study are shown in Table 1.

Table 1. The characteristics of the substrates in this study

Scenario 1							
I/S	C/N	Initial NH_3-N (mg/L)	Initial NH_4^+-N (mg/L)	Initial TAN (mg/L)	Initial VFAs (mg/L)	Initial TS (g/L)	Initial VS (mg/L)
1.5	21.5	0.095	10.81	10.91	12.85	59.23	38.02
2	21.5	0.098	13.92	14.02	17.21	58.63	37.71
2.5	21.5	0.133	16.88	17.01	20.46	58.07	37.43
Scenario 2							
I/S	C/N	Initial NH_3-N (mg/L)	Initial NH_4^+-N (mg/L)	Initial TAN (mg/L)	Initial VFAs (mg/L)	Initial TS (mg/L)	Initial VS (mg/L)
2.5	21.5	0.133	16.88	17.01	20.46	58.07	37.43
2.5	25	0.133	16.88	17.01	20.46	58.07	37.43
2.5	30	0.133	16.88	17.01	20.46	58.07	37.43

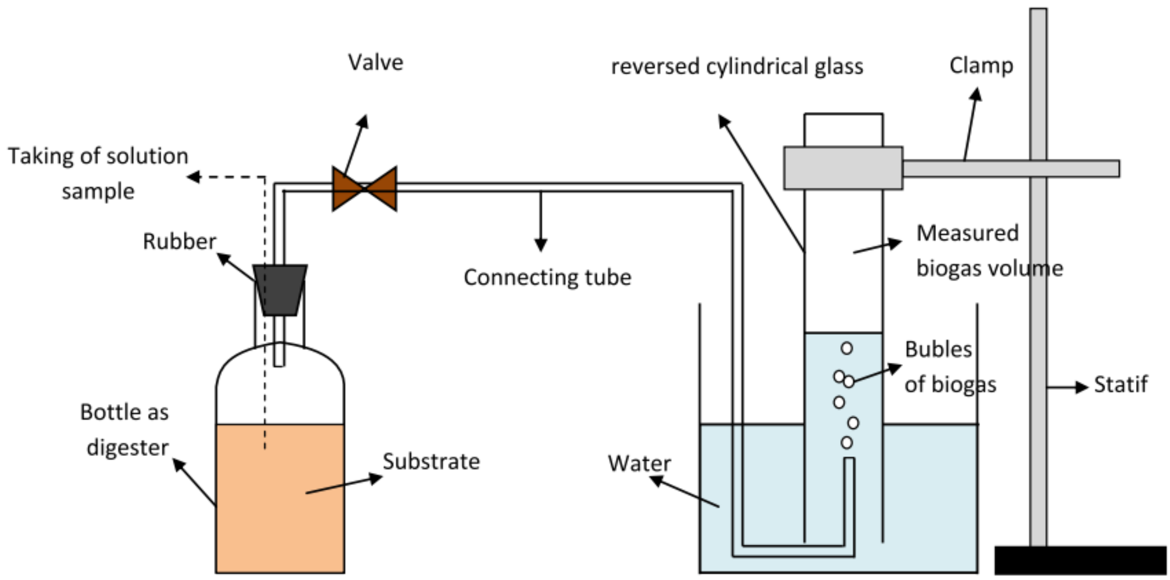

Figure 1. The laboratory anaerobic digester (Iqbal Syaichurrozi et al., 2020)

2.3. Experimental Set Up and Procedure

This study used the laboratory anaerobic digesters which were proposed by a previous study (Iqbal Syaichurrozi et al., 2020). The laboratory anaerobic digester is shown in Figure 1. The AD process was operated during 30 days with room condition (28-30 °C, 1 atm). Each digester was mixed manually one per two days. The water displacement method was applied to measure the daily biogas volume (I. Syaichurrozi, 2018). The measured biogas volume (mL) was divided by initial volatile solid mass (g VS) of substrates to get a biogas yield (mL/g VS).

2.4. Analysis

2.4.1. Liquid sample

The 10 mL of liquid sample was taken from the digesters. The pH of substrates was recorded by using a digital pH meter (model of Hanna-Digital-PHEP-98107-1) (I. Syaichurrozi et al., 2019). The ammonium (NH_4^+-N) concentration in the substrates was measured by using the Standard Method (APHA, 2012). The total solid (TS) before and after anaerobic digestion process was analyzed measured by using the Standard Method (APHA, 2012). The TS removal value was calculated by using the equation (1). The ammonia (NH_3-N) concentration was determined through the equation (2) (El-Mashad, Zeeman, Van Loon, Bot, & Lettinga, 2004). Furthermore, the total ammonia nitrogen (TAN) concentration was determined through the equation (3). The volatile fatty acids (VFAs) concentration was determined via equation (4) (Paul & Beauchamp, 1989).

2.4.2. Gas sample

The biogas volume produced during AD was collected in a gas collector. Furthermore, sample of gas was taken using a syringe for methane analysis. The methane percentage contained in the biogas was analyzed by using the GC-TCD that was same used by other authors (Iqbal Syaichurrozi et al., 2020).

$$\text{TS Removal (\%)} = \frac{\text{initial TS} - \text{final TS}}{\text{initial TS}} \times 100\% \quad (1)$$

$$(NH_3 - N) = (NH_4^+ - N)\left[1 + \frac{10^{-pH}}{10^{-\left(0.1075 + \frac{2725}{T}\right)}}\right]^{-1}, \text{ T = absolute temperature, K} \quad (2)$$

$$TAN = (NH_3 - N) + (NH_4^+ - N) = (NH_4^+ - N)\left(\left[1 + \frac{10^{-pH}}{10^{-\left(0.1075 + \frac{2725}{T}\right)}}\right]^{-1} + 1\right) \quad (3)$$

$$pH = 9.43 - 2.02\,\frac{VFAs}{TAN} \quad (4)$$

2.5. Modelling

The measured biogas yield evolution was simulated via the two popular kinetic models which were the modified Gompertz model (I. Syaichurrozi, Budiyono, & Sumardiono, 2013) and the first-order kinetic model (I. Syaichurrozi, 2018). The equations of the two models were presented in equations (5) and (6) respectively. The adjustable kinetic constants of ym, λ, μ, k in the kinetic models was determined by using a non-linear regression method through Ms. Excel.

$$y(t) = ym.\exp\left\{-\exp\left[\frac{\mu.e}{ym}(\lambda - t) + 1\right]\right\}, t \geq 0 \quad (5)$$

$$y(t) = ym\left(1 - \exp(-k.t)\right), t \geq 0 \quad (6)$$

Optimization was conducted to determine the kinetic constant values by minimizing the value of Mean Absolute Percentage Error (MAPE). The formula of MAPE was shown in the equation (7).

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{|\text{Measured biogas} - \text{Predicted biogas}|}{|\text{Measured biogas}|}\right) \times 100\% \quad (7)$$

3. RESULT AND DISCUSSION

The experiments were successfully conducted with variation of I/S with values of 1.5, 2, 2.5. The experimental data obtained during experiments were biogas yield, methane percentage, TS content, substrate pH, ammonia concentration, ammonium concentration, and VFAs concentration. The kinetic models were successfully applied to simulate the experimental data. Detail results and discussions were presented below.

3.1. Effect of I/S ratio (Scenario 1)

Variation of I/S ratio affected the daily and cumulative biogas yields and then it was shown in Figure 2(A) and (B). The peak of daily biogas yield was obtained on days 12, 14, 18 with values of 1.70, 3.56, 4.70 mL/g VS for I/S of 1.5, 2, 2.5 respectively (Figure 2(A)). Increase in I/S from 1.5 to 2.5 successfully increased the total biogas yield from 19.01 to 33.84 mL/g VS (Figure 2(B) and Table 2). Also, ratio of I/S of 2.5 resulted biogas with high methane content which was 69.01% (Table 2).

The substrate pH profiles were same for all I/S ratios (Figure 2(C)). The different I/S ratios resulted no significant effect on the changes of substrate pH. It was still stable in neutral range until the end of process. Hence, the pH level did not disturb the microbial activity. Based on Table 3, the TAN/VFAs ratio and substrate pH had a good correlation. The bigger the TAN/VFAs ratio value in the substrates, the higher the substrate pH level in the system.

The TS removal value at I/S ratio of 2.5 was higher than the others. It showed that acidogenic bacteria grew well in the substrate, so they consumed more organic compounds (expressed as TS) to become VFAs and TAN. Furthermore, the VFAs was converted to methane by methanogenic bacteria. Meanwhile, the TAN is consumed as nitrogen source for building the cell structures. The final TAN and VFAs concentrations in the substrates were presented in Table 3. The I/S ratio of 2.5 had a lower final VFAs and TAN concentrations than the others (Table 3), however it resulted a higher TS removal than the others. It proved that methanogenic bacteria thrived and converted much of VFAs to biogas successfully at I/S of 2.5.

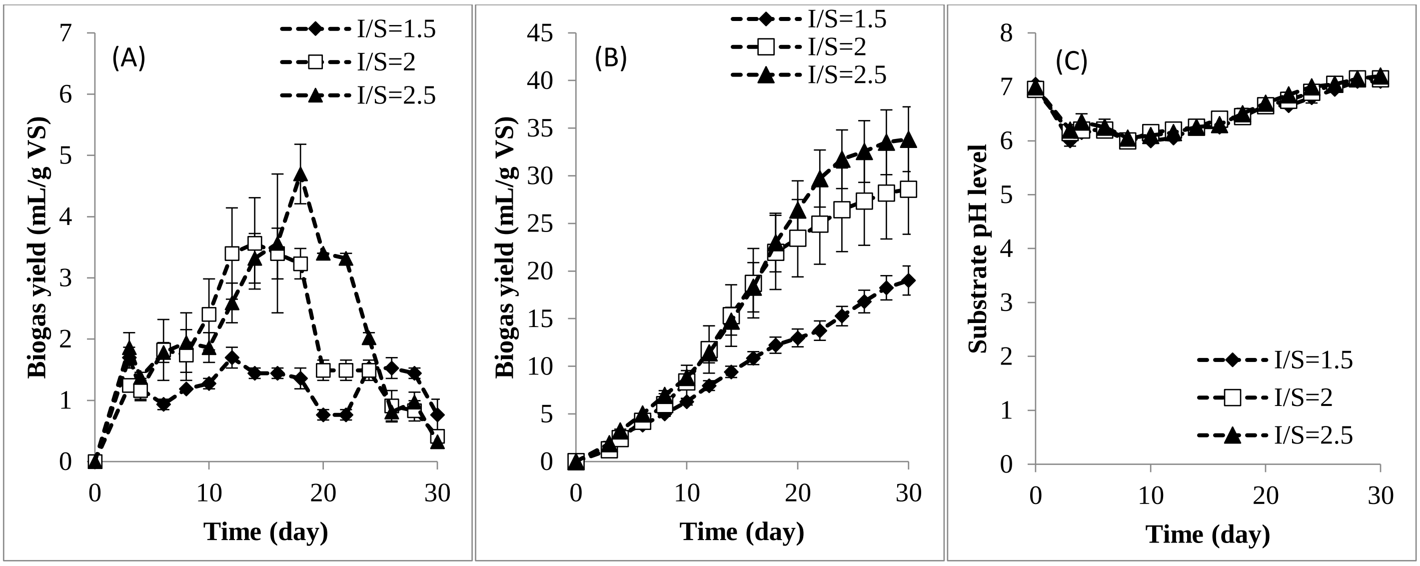

Figure 2. Profiles of (A) yield of daily biogas, (B) yield of cumulative biogas, (C) substrate pH during AD with variation of I/S ratio

Table 2. Effect of I/S ratio on total biogas yield and methane content

I/S ratio (v/w, mL/g)	C/N ratio	Initial pH	Final pH	Total biogas yield (mL/g VS)	Biogas Content		TS removal (%)
					CH_4 (%)	Others (%)	
1.5	21.5	7.0±0.1	7.1±0.1	19.01±1.53	52.54	47.46	70.01±3.41
2	21.5	7.0±0.1	7.15±0.05	28.59±4.72	71.96	28.04	70.61±2.86
2.5	21.5	7.0±0.1	7.2±0.0	33.84±3.40	69.01	30.99	76.08±8.03

Table 3. Effect of I/S ratio on ammonia, ammonium, TAN, and VFAs concentrations

I/S ratio (v/w, mL/g)	C/N ratio	Final NH_3-N (mg/L)	Final NH_4^+-N (mg/L)	Final TAN (mg/L)	Final VFAs (mg/L)	Final TAN/VFAs
1.5	21.5	0.206	20.85	21.06	24.29	0.87
2	21.5	0.183	16.56	16.74	18.90	0.89
2.5	21.5	0.179	14.41	14.59	16.11	0.91

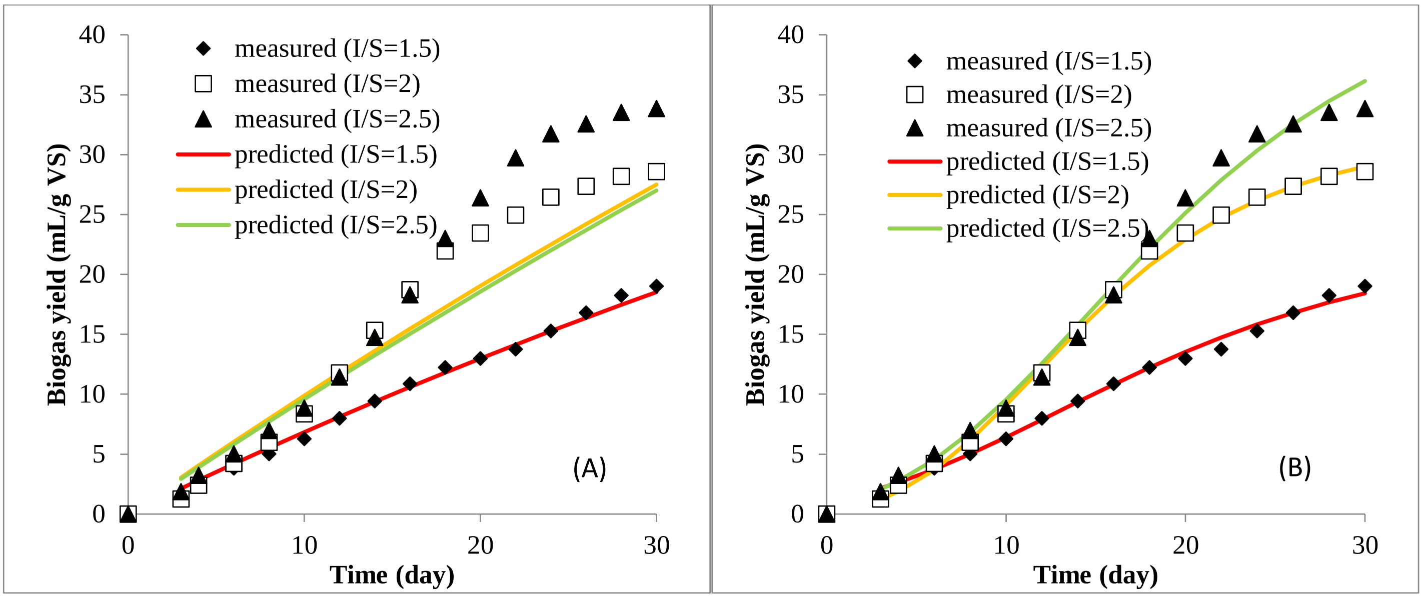

Figure 3. Plotting measured and predicted data obtained through (A) first-order kinetic model and (B) modified Gompertz model

Table 4. The kinetic constant values for Scenario 1

	I/S ratio		
	1.5	2	2.5
Modified Gompertz Model			
λ (days)	1.40	4.26	4.27
μ (mL/g VS.d)	0.74	1.58	1.62
ym (mL/g VS)	22.92	31.43	44.95
R^2	0.995	0.998	0.992
MAPE (%)	4.24	4.32	6.37
First-Order Kinetic Model			
k (/day)	0.010	0.008	0.006
ym (mL/g VS)	69.07	133.60	157.49
R^2	0.996	0.929	0.791
MAPE (%)	5.09	28.74	22.12

The measured data in scenario 1 were modeled through the two proposed models. The fitting between the measured and predicted data was shown in Figure 3. Based on kinetic constants in the modified Gompertz model, the increase in I/S increased the all kinetic constant values (λ, μ, ym). The λ showed the lag time needed by bacteria before producing biogas. The lower the I/S ratio, the lower the inoculum concentration compared to substrate concentration. In other word, the decrease in I/S from 2.5 to 1.5 will increase the substrate concentration compared to inoculum concentration. Therefore, the higher the substrate concentration (the lower I/S ratio), the lower the λ value. It means that the higher the substrate concentration, the bacteria needed the shorter lag time. This phenomena was in line with study of Budiyono et al. (Budiyono et al., 2014) where the higher the substrate concentration, the lower the λ value in biogas production from vinasse. The kinetic constant of μ showed the maximum biogas yield rate. It has good correlation with the ym value (biogas yield potential) where increase in μ will increase the ym value. Based on Table 4, ratio of I/S of 2.5 resulted the higher these values than the two others. At ratio of I/S below 2.5, which was 1.5-2, the activity of anaerobic bacteria was disturbed by the high substrate concentration in the system. The high substrate concentration will increase the osmotic pressure so that microbial cell will be broken. Therefore, although the I/S of 1.5-2 had the lower lag time (λ), these ratios resulted lower μ and ym values because the bacteria could not grow well during the AD process. According to Syaichurrozi (I. Syaichurrozi, 2018), the value of k from the first order kinetic model has negative linier correlation with the value of λ from the modified Gompertz model. It means that the higher the k value, the lower the λ value. This study also reported the same correlation (Table 4). Biologically, when the anaerobic bacteria need a short lag time (λ), they will produce biogas with high rate (k). The value of ym in the first kinetic model also increased with increase in I/S from 1.5 to 2.5.

3.2. Effect of C/N ratio (Scenario 2)

The effect of C/N ratio on AD of SM was discussed in this section. The SM contained C/N value of 21.5. Glucose was added to increase the C/N to become 25 and 30. The daily and cumulative biogas yields are shown in Figure 4(A) and (B). Furthermore, the substrate pH profiles are presented in Figure 4(C). The C/N of 25-30 resulted the higher daily biogas yields than the C/N of 21.5 in the first ten day. However, after day ten, daily biogas yields at C/N of 21.5 was more than those at C/N of 25-30. At C/N of 25-30 (glucose addition), biogas was easier produced at the first digestion time than that at C/N of 21.5 (without glucose addition). Glucose is simple carbon-organic compound that is easily converted to be VFAs. Furthermore, the methanogenic bacteria consumed the VFAs and then produced biogas. However, the higher VFAs concentration at C/N of 25-30 than at C/N of 21.5 caused the substrate pH more drop at the former C/N. Based on Figure 4(C), clearly, C/N ratio of 25-30 resulted VFAs in high concentration in the first digestion time which that is shown by the pH profiles.

The increase of C/N from 21.5 to 25 could increase the total biogas yield from 33.84 to 41.70 mL/g VS (Table 5). Further increasing the C/N decreased the total biogas yield from 41.70 to 30.85 mL/g VS (Table 5). Although the C/N of 25 resulted the higher total biogas yield than C/N of 21.5, the biogas quality from the latter was better than the former. Methane content from C/N of 21.5 and 25 was 69.01 and 34.08 % respectively. That was caused by the low pH level during AD at C/N of 25 in which the substrate pH was drop from day two to the end of AD process. The methanogenic bacteria activity was not good in pH below 5. Therefore, the biogas quality at C/N of 25 was not good. In the other side, the substrate pH at C/N of 21.5 was stable enough during AD. Table 6 showed that the VFA concentration at C/N of 25-30 was much higher than that at C/N of 21.5. TS removal values at C/N of 21.5, 25, 30 was 76.08, 48.70, 55.72% respectively (Table 6). It showed that C/N of 21.5 was good condition not only for methanogenic bacteria but also the acidogenic bacteria.

Table 5. Effect of C/N on total biogas yield and methane content

I/S ratio (v/w, mL/g)	C/N ratio	Initial pH	Final pH	Total biogas yield (mL/g VS)	Biogas Content		TS removal (%)
					CH_4 (%)	Others (%)	
2.5	21.5	7.0±0.1	7.2±0.0	33.84±3.40	69.01	30.99	76.08±8.03
2.5	25	7.0±0.1	3.8±0.1	41.70±20.32	34.08	65.92	48.70
2.5	30	7.0±0.1	3.9±0.0	30.85±14.82	6.99	93.01	55.72

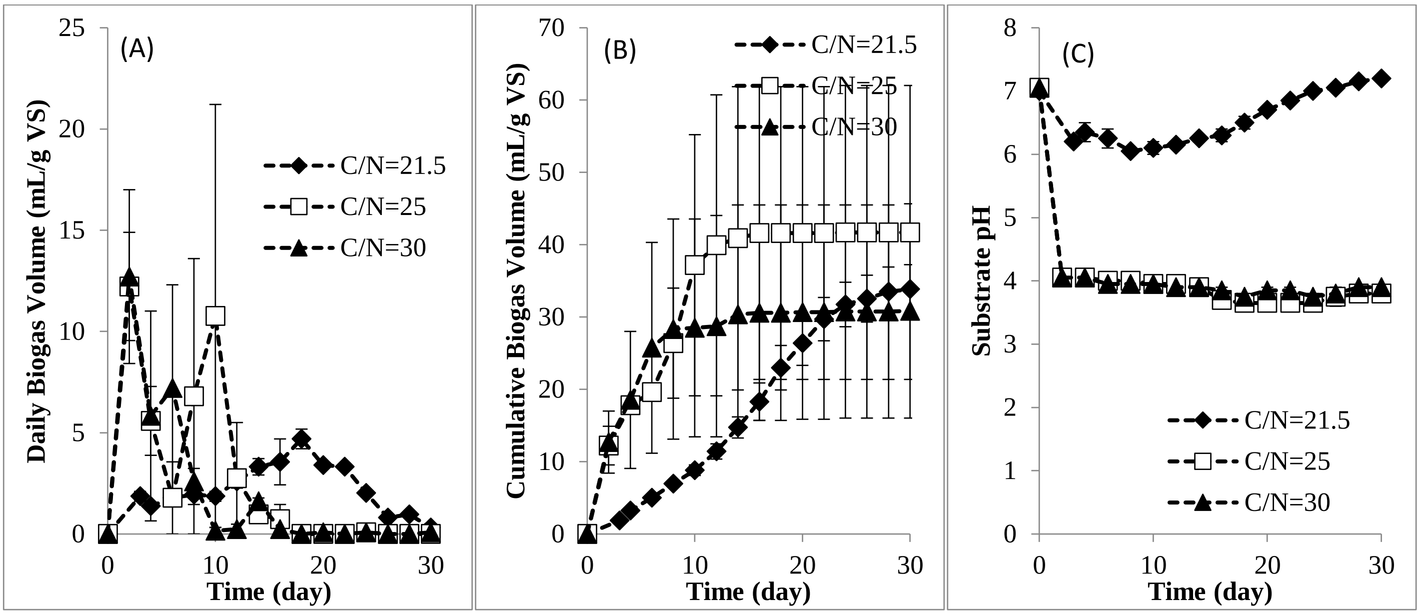

Figure 4. Profiles of (A) yield of daily biogas, (B) yield of cumulative biogas, (C) substrate pH during AD with variation of C/N ratio

Table 6. Effect of C/N on ammonia, ammonium, TAN and VFAs concentrations

I/S ratio (v/w, mL/g)	C/N ratio	Final $NH_3 - N$ (mg/L)	Final $NH_4^+ - N$ (mg/L)	Final TAN (mg/L)	Final VFAs (mg/L)	Final TAN/VFAs
2.5	21.50	0.179	14.41	14.59	16.11	0.91
2.5	25	0.0005	85.68	85.68	234.56	0.37
2.5	30	0.0003	54.26	54.26	148.54	0.37

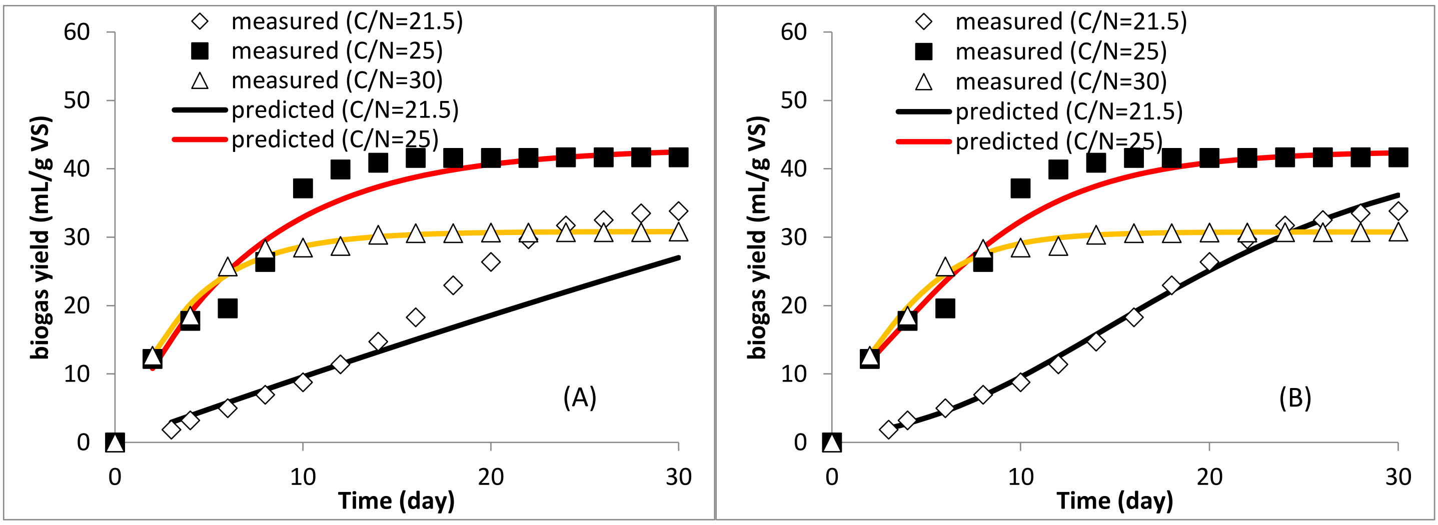

Figure 5. Plotting measured and predicted data obtained through (A) first order kinetic model and (B) modified Gompertz model

Table 7. The kinetic constant values for Scenario 2

	C/N ratio		
	21.5	25	30
Modified Gompertz Model			
λ (days)	4.27	-1.92	-1.27
μ (mL/g VS.d)	1.62	3.01	3.89
ym (mL/g VS)	44.95	42.59	30.77
R^2	0.992	0.987	0.951
MAPE (%)	6.37	5.30	1.37
First-Order Kinetic Model			
k (/day)	0.006	0.145	0.266
ym (mL/g VS)	157.49	43.03	30.82
R^2	0.791	0.984	0.937
MAPE (%)	22.12	7.10	1.56

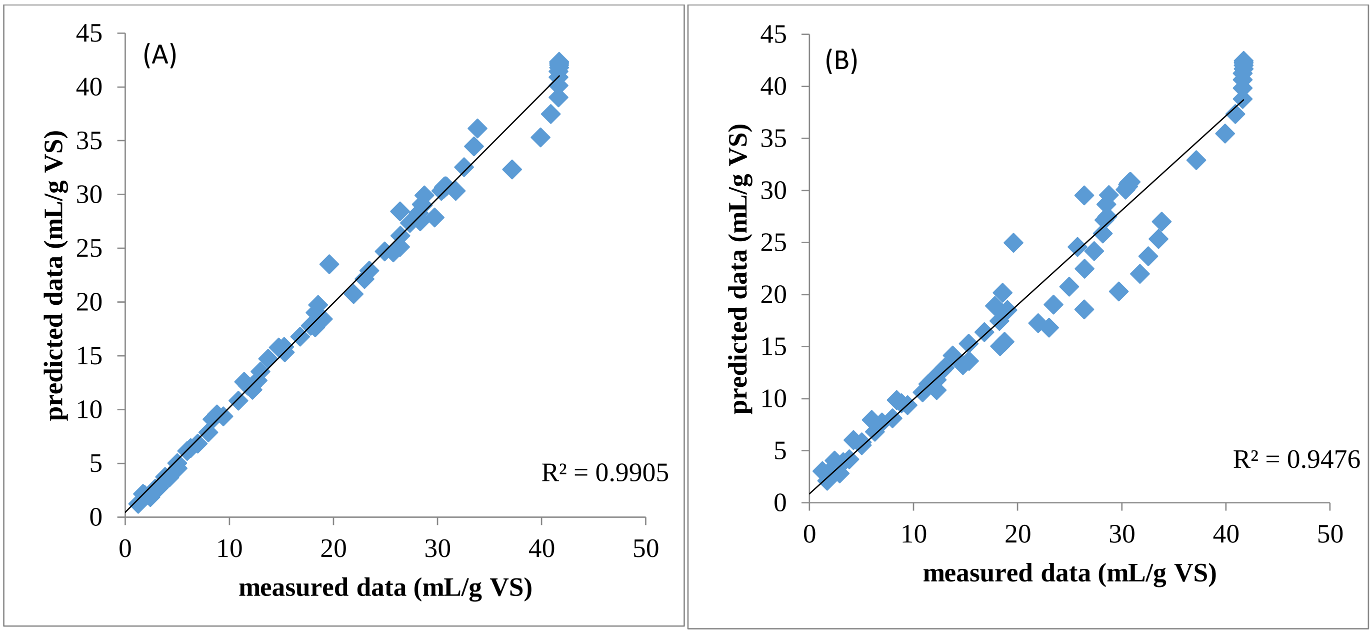

Figure 6. Plotting between all measured biogas yield data and all predicted biogas yield data from (A) modified Gompertz model and (B) first order kinetic model

The measured data in scenario 2 were also modeled through the kinetic models. The fitting between the predicted and measured data was presented in the Figure 5. The obtained kinetic constants are presented in Table 7. The increase in the C/N from 21.5 to 30 decreased the λ value. Substrates with high carbon (glucose) were converted to be VFAs easily. Furthermore, the abundant VFAs were converted to biogas easily. Therefore, the lag time (λ) decreased with increased the C/N ratio. However, further the digestion process, the abundant VFAs decreased the pH value (below 5). It hampered the methanogenic bacteria activity, so that the μ and ym decreased with increase in C/N from 21.5 to 30. In this section, commonly, the value of k from the first order kinetic model has negative linier correlation with the value of λ from the modified Gompertz model.

3.3. Comparison the modified Gompertz and first order kinetic models

The kinetic models were successfully applied to simulate the measured data of biogas yield as function of time. Based on Table 4 and Table 7, the former resulted the MAPE value of 1.37-6.37% and the latter resulted the MAPE value of 1.56-28.74%. Furthermore, the Figure 6 proved that the modified Gompertz resulted the higher R^2 value than the first order kinetic with value of 0,9905 for the former and 0.9476 for the latter. Hence, the modified Gompertz model gave better prediction than the other.

4. CONCLUSION

The experiment of AD process with variation of I/S and C/N ratios during 30 days. In scenario 1, the increase in I/S from 1.5 to 2.5 increased the biogas yield from 19.01 to 33.84 mL/g VS and the methane content from 52.54 to 69.01%. The I/S ratio of 2.5 resulted the higher the TS removal but the lower the final VFAs. It proved that the acidogenic and methanogenic bacteria were in good condition. TS was consumed by acidogenic bacteria and resulted the VFAs. Furthermore, the VFAs was converted to biogas by methanogenic bacteria easily. In scenario 2, increase in C/N to 21.5 to 30 decreased the biogas yield from 33.84 to 30.85 mL/g VS and decreased the methane content from 69.01 to 6.99%. The higher C/N (25-30) was not good for AD because VFAs was produced in high amount so that the pH level was drop (below 5). The biogas yield evolutions as function of time were simulated with R^2 of 0.9905 and 0.9476 through the modified Gompertz model and the first-order kinetic model respectively. Hence, the former was better than the latter.

ACKNOWLEDGEMENT

All authors thanks profusely to the Lembaga Penelitian dan Pengabdian Masyarakat in University of Sultan Ageng Tirtayasa due to the Grant Research of Penelitian Dosen Madya with contract number of 324/UN43.9/PP/KT/2017 (Nomor SP DIPA-042.01.2.401017/2017).

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Vol. 13 No. 1 (2022) 12-19

Jurnal Riset
Teknologi Pencegahan Pencemaran Industri

Journal homepage : http://www.jrtppi.id

Kementerian Perindustrian
REPUBLIK INDONESIA

Soaking Up The Sun: Designing Small Scale Photovoltaic (PV) Rooftop for Micro, Small, and Medium Enterprises (MSME): Study Case at Rattan Crafts Center in Trangsan Village, Sukoharjo, Central Java

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ARTICLE INFO

Article history:
Received 29 March 2022
Received in revised form 17 May 2022
Accepted 22 May 2022
Available online 27 June 2022

Keywords :
Solar Energy
PV Rooftop
MSME
Helioscope

ABSTRACT

The National Energy General Plan has set a target of achieving a Renewable Energy (RE) mix of 23% by 2030, to achieve this the transition of non-renewable energy to RE must be done immediately. Solar energy is one of the renewable energy that is very abundant in Indonesia. Along with the issuance of the Minister of Energy and Mineral Resources Regulation number 49 of 2018 regarding the Use of Rooftop Solar Power System by Consumers of PT Perusahaan Listrik Negara (Persero) which provides opportunities for the utilization of PV Rooftop for household and commercial sector. Given this, the Central Java Government plans to install Rooftop Power Plant in the Micro, Small, and Medium Enterprises (MSME) Sector to develop the utilization of RE in the productive sector while improving the economic recovery from the Covid-19 pandemic. This study analyzes the potential development of PV Rooftop in Rattan MSME Center in the village of Trangsan, Sukoharjo Regency. The use of renewable energy (EBT) is expected to save electricity costs in MSMEs. The results of planning using Helioscope software showed that the three MSMEs with different PLTS capacities, namely 1 Kwp, 2.04 KWp, and 4 KWp can produce annual energy production of 1,191 MWh, 2,433 MWh, and 5,352 MWh respectively. After the installation of the PLTS, it was proven that in the first two months after installation, energy consumption can decrease to minimum usage.

1. INTRODUCTION

Indonesia has known to be blessed with abundant solar energy potency. Located on the equator, nearly all areas in Indonesia have the potential to develop solar energy plants with an average output reaching about 4 kWh/m2 according to the National Handbook of Energy 2020. As stated in National Energy Policy (Government Regulations No. 79, 2014), the government targeted a minimum share of 23% usage of renewable energy in the 2025 national energy mix. As the current achievement of renewable energy shares in the national energy mix reaches about 9,15% in 2019 there is a 12 % gap that needs to be filled in six years. In line with central government policy, Central Java recently declared itself to be the first solar energy province in Indonesia (IESR 2020). Based on the province's abundance of solar energy potency, the Local Government has planned and worked out things such as installing numerous Photovoltaic (PV) rooftops in government buildings, schools, and pesantrens, as well as the emergence of solar energy usages in industries and other economic sectors such as MSME to boost the Renewable Energy, particularly solar energy portion in provincial's energy mix.

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doi : https://10.21771/jrtppi.2022.v13.no.1.p12-19

Accreditation number : (Ristekdikti) 158/E/KPT/2021

Based on the data, Central Java has solar energy potential more than Indonesia's average, with the approximate solar energy potential in Central Java is 4.05 kWh/kWp per day, while the average solar energy potential in Indonesia is 3.75 kWh/kWp per day (Gandabhaskara Saputra, 2020) the Local Government has proclaimed themselves to be the first solar energy province in 2019 (Directorate General of New Renewable Energy and Energy Conservation, 2020). Since then, through multiple resources and funding, Central Java has successfully built 127 PV Installation units with a total capacity of no less than 5.199 kWp (by October 2020) (Directorate General of New Renewable Energy and Energy Conservation, 2020) Nevertheless, when the COVID-19 pandemic broke out in early 2020, solar energy development through private sector funding was somewhat stalled. Economic growth in the first quarter of 2020 was a mere 2.60 percent, down from 5.34 percent in 2019 (Central Bureau of Statistics, 2020) Pandemic conditions are precisely seen at the right time for the leap of energy transition to renewable energy (RE) by the Central Java Provincial Government, with one of its activities is to develop rooftop solar panels for productive sectors that are among the most affected by the pandemic, namely MSME (Simanjutak, 2021). The transition of conventional energy to RE could be one of the Government's options in restoring the economy because for the first time during the pandemic conventional fuel sources such as oil have fallen in price to negative for the first time in history (Sumarno, Bachtiar, & Jati, 2020). Development of renewable energy, including PV Rooftop, can also reduce unemployment growth as a result of the COVID-19 pandemic, and improve energy independence and reliability (Sumarno, Bachtiar, & Jati, 2020).

The issuance of regulation of the Minister of Energy and Mineral Resources Regulation number 49 the year of 2018 concerning the Use of Rooftop Solar Power System by Consumers of PT Perusahaan Listrik Negara (State Owned Electricity Corporation) and its changes have provided opportunities for the public to utilize solar energy through the plots system on grid widely (Setyawati, 2020). The growing number of PV rooftops installed in Indonesia indicates that most PV rooftops are installed in residential areas, but the substantial load comes from the industrial category (Tambunan et al, 2020). The MSME sector, which is one of the economic supporters in Indonesia, has not used much PV Rooftop. In general, the regulation has not made a specific difference in the MSME sector, although it has been given a grouping of users between the industrial and commercial sectors who are obliged to bear additional operating costs such as emergency charges (Tarigan, 2020). The development of regulations for the use of solar energy from an on-grid system can be reviewed in Regulations of the Minister of Energy and Mineral Resources No. 49 The year 2018 were stated that only 65% of the electricity exported from PV Rooftop can be "compensated" (Modjo, 2020). Based on those regulations, designing the PV rooftop precisely will help determine the best output from the PV rooftop. Unlike the PV rooftop design in major industries which usually provides greater area and complicated roof segmentation due to the building's uneven roof construction (Rega, Sinaga, & Windarta, 2021), the roof at Trangsan Rattan Centre is commonly narrow and the construction is identical. Different from the studies conducted in MSMEs that are mobile and only use electricity for production purposes only that ideally use off-grid systems (Windarta, Handoko, et al, 2021), MSMEs in the Trangsan Rattan center have the characteristics of production and residence into one and have become electricity customers of PT. PLN so that the design will use the base of the on-grid system.

Some barriers might emerge from developing PV rooftops in MSME. Lesson learned from a similar study conducted in India, five barriers that currently halt the usage of PV Rooftops for the MSME sector, which are breakdown as operational, technical, financial, commercial, and awareness barriers (Deloitte, 2019). Those technical barriers among others are some MSMEs have inadequate roof space, MSMEs are mainly located in a highly popullated industrial areas so the shadow will affect the proper roof area and their roof are often being replaced at routine intervals.

This study is conducted to see whether is the technical barriers in India and Indonesia with the study case of Rattan MSME in Trangsan Village, Sukoharjo is quite identical, based on three sample buildings with a various electricity meter and PV rooftop.

Based on those issues mentioned above, the designing and the planning of PV rooftop installation in MSME will be very important to maximize the output and provide renewable energy introduction to the sector.

2. METHODS

This research aims to calculate the potential generation capability of the PV Rooftop Power Plant system in the MSME sector in Central Java, by taking place in the Rattan Handicraft Center, Trangsan Village, Gatak District, Sukoharjo Regency. The Rattan Crafts Center commonly uses one single electrictiy source, which is electricity powered by the state-owned electricity firm (PT. PLN). The average installed capacity is around 1.300 VA to 4.400 VA. This study will use a method to calculate the potential output PV power based on the width of the rooftop area in three MSMEs with different electricity installed capacities using Helioscope. Helioscope is a web-based PV plant designing software that is developed by Folsom Labs.

Data collection is conducted based on field observation for measurement of roof area, roof tilt, shading potential, and daily power load for three sample buildings. The Helioscope version that will be used is the non-beta version that was released in 2019.

Helioscope analysis is based on many aspects, one of them is geographical location and the surrounding potential shading. It is also consider choosing the proper type of panels and inverters, the complete layout of the plant is automatically generated with all the relevant data like power output, system loss, energy to the grid, number of modules and inverters, grouping of panels and other parameters (Md.Shahin Ali, Nazmun Nahar Rima, 2018).

The yield result of annual energy production from the design will be compared with the real energy load based on one year load before the PV is installed. The comparison will be analyzed with Microsoft Excel Office 2019 to determine whether the PV rooftop system will be able to provide energy for the MSME load needs significantly.

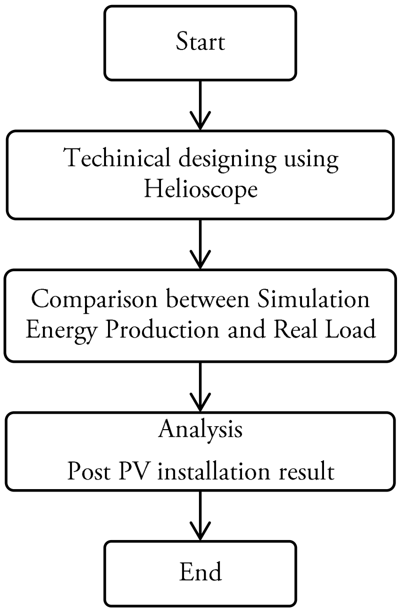


Figure 1. The Flowchart of The Study

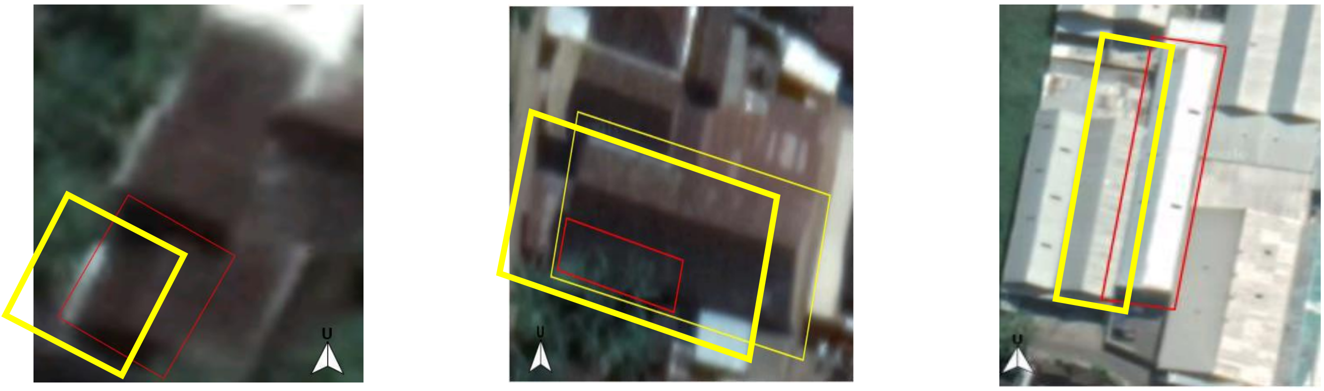
Based on observations in the field, data related to three MSME buildings, covering the width, length, and slope of the roof as well as general load data use. The calculation of the available area in the MSME which is used as samples is using the image provided by Helioscope. The calculation of the available area is shown in figure 2 below.

The image of the roof area shows that there are different characteristics of each MSME, such as coordinates, tilt, material, azimuth, and the surrounding buildings as shown in Table 1. These features were used to determine which area is proper for installing the PV panel.

The data shown in table 1 is used to create a simulation 3D design to analyze which part of the roof that proper to put the PV panel as shown in figure 3 below.

The calculation of the area of the roof to be installed PV Rooftop needs to address the area of the roof that is not affected by shadows, and the strength of the roof is assumed to be able to receive the load of solar panels. As a parameter of the area of PV modules, will be used PV module with a capacity of 340 Wp which is a maximum area of 2 m2, Thus, based on the parameters mentioned above the results could be used as boundary to of the analysis made through Helioscope that shown by Figure 4. Based on the calculations and according to the Regulation of the Minister of Energy and Mineral Resources No. 49 of 2018

Article 5 mentioned that "The capacity of PV rooftop is limited to at least 100% of the connected power of consumers of PT PLN (Persero)". Therefore, the maximum PV Rooftop capacity that can be installed in Asri Rotan is limited to 1.3 Kwp, Putra Jaya is 2.2 Kwp and Surya Rotan is 4.4 Kwp.

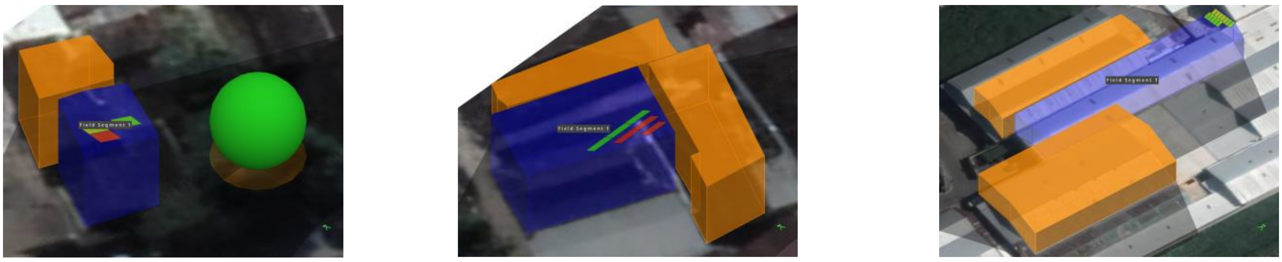


(a) (b) (c)

Figure 2. The available roof area of (a) Asri Rotan, (b) Putra Jaya Rotan and (c) Surya Rotan

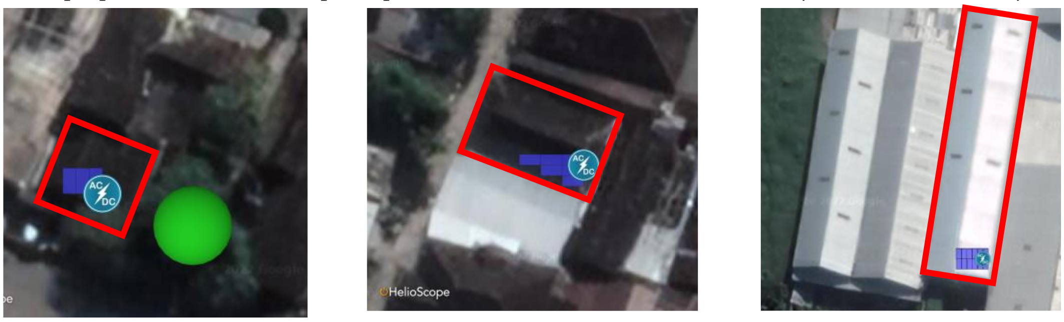
Table 1. MSME Data Samples

No	MSME	Roof Structure Material	Coordinates		Width (m)	Length (m)	Tilt (degree)	Azimuth (degree)	Surrounding Object(s)
			x	y					
1.	Asri Rotan	Wood Block	472.372	9.161.527	6	15	27	90	Buildings
2.	Putra Jaya	Wood Block	471.616	9.161.761	8	24.2	32	0	Trees & Buildings
3.	Surya Rotan	Canal C Steel	471.662	9.161.825	12.2	57	18	180	Buildings



(a) (b) (c)

Figure 3. The proper roof area and PV panel placement of (a) Asri Rotan, (b) Putra Jaya Rotan and (c) Surya Rotan



(a) (b) (c)

Figure 4. The PV placement from Helioscope for PV rooftop installation of (a) Asri Rotan, (b) Putra Jaya Rotan and (c) Surya Rotan

The other parameters that were used in terms to complete the design are the PV rooftop components. The components were divided into two main components which are the PV panel and the inverter. Based on the different PV rooftop capacities, the component is also distinguished for each MSME as shown in table 2 below.

Table 2. MSME Component Data

No	MSME	PV Panel	Inverter
1.	Asri Rotan	AE Solar 340MM6-72	Solis Mini 4G - 1000
2.	Putra Jaya	AE Solar 340MM6-72	Solis Mini 4G - 2000
3.	Surya Rotan	AE Solar 340MM6-72	Solis Mini 4G - 4000

The result of the simulation shows that there is a peak performance between July to October before declining acts in November and December.

3. RESULT AND DISCUSSION

The analysis result from Helioscope shows that the PV rooftop's peak energy production at Asri Rotan is obtained in October with 114.6 KWp, meanwhile at Putra Jaya is obtained in August with 246.3 KWp and Surya Rotan's in September with 524.7 KWp. PV rooftop's lowest energy production at all three MSMEs is obtained in February, with the energy production at Asri Rotan, Putra Jaya and Surya Rotan is 82.8 KWp, 157.5 KWp and 372.4 KWp respectively. The PV rooftop simulation energy yield from Helioscope is also compared to the actual annual load used by the three MSMEs in 2021 to give the depiction how the PV rooftop energy will affect the energy consumption of the MSME. The comparison is shown in table 3.

Based on calculations and analysis, data from the three MSMEs showed different results. Asri Rotan which has a Rooftop PV capacity of 1 KWp able to make savings of about 40 % annually, while Putra Jaya Rotan where the energy load is lower yet has a larger rooftop PV capacity of 2 KWp shows that the energy generated from rooftop PV has been able to supply overall energy needs. The results shown by rooftop PV in Surya Rotan show that with a capacity of 4 KWp and a greater load than the previous two MSMEs, it is still able to reduce energy loads above 50% annually.

Meanwhile, after the PV rooftop installation is completed at the end of January 2022, the measurements of the energy produced by the system are conducted through the display on the inverter screen and the data collected from the calculation of energy exports in the PLN Mobile application. It was found that in February 2022 when rooftop PV had been working for a full month, rooftop PV energy production in Asri Rotan, Putra Jaya, and Surya Rotan had exported 68 kWh, 109 KWh, and 226 KWh of energy respectively. The data on electricity cost also show that all three MSMEs is having a significant decrease in electricity bill.

The data collected from the PLN mobile application also shows that Asri Rotan's electricity bills have dropped from an average of Rp.366.667 to Rp.198.415 in February and continuing dropping to Rp.176.369, while Putra Jaya's bill dropped from the average Rp.308.645 to Rp.138.576 in February and March, whereas Surya Rotan's bill dropped from average Rp.988.376 to Rp.416.053 in February but significantly rising into Rp.863.280 in March as shown in table 5.

The comparison shown in table 5, ndicates that the PV rooftop installation is working properly and reducing the energy cost of all three MSMEs, where there is an interesting result is in Putra Jaya because the rooftop PV system has been able to supply almost all the energy needed. The results also showed that even though it has been able to supply all energy needs, Putra Jaya still has to pay the minimum payment bill per the January-March 2022 tariff adjustment on the letter issued by PT. PLN that based on the Minister of Energy and Mineral Resources Regulation Number 28 of 2016 where the provision for R1 customers is the subscription capacity multiplied by 40 hours of usage multiplied by electricity tariffs. The amount of electricity tariff for the R1 customer type is Rp.1,444.70 per Kwh so the bill value of Rp.138,576 obtained by Putra Jaya in February 2022 is the minimum bill obtained from the equation (1) below plus the street lighting tax.

The imposition of this minimum payment does not apply to prepaid customers, but with the provision that rooftop PV users must migrate to post-payment, the imposition of this minimum bill can cause new cost factors that halt MSME players' interest in participating in using rooftop PV.

$$\textit{\textbf{Minimum payment}} = (\textbf{40}\ \textit{\textbf{hours}} \times \textit{\textbf{electricty capacity meter}} \times \textit{\textbf{tariff}})\ (1)$$

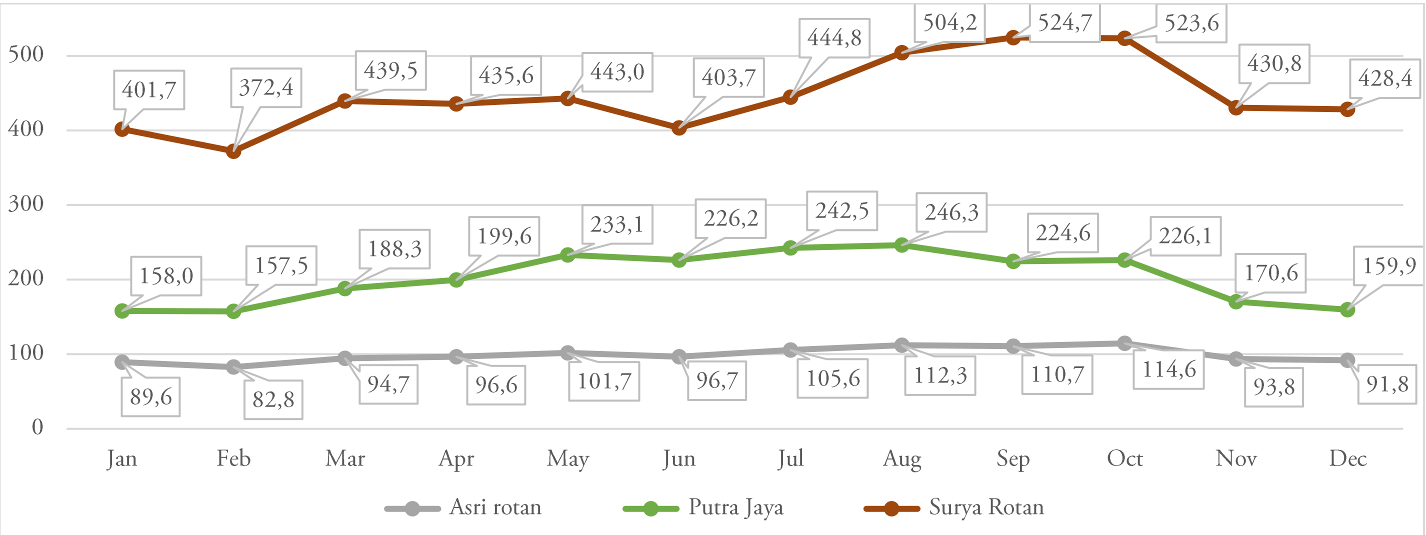


Figure 5. The monthly energy production result from Helioscope for PV rooftop installation of Asri Rotan, Putra Jaya Rotan, and Surya Rotan

Table 3. Comparison between annual energy production and the annual load

No.	MSME	Annual Energy Used* (KWh)	Annual PV Rooftop Energy Yield** (KWh)	Annual Energy Gap (KWh)	Monthly Energy Gap*** (KWh/Month)
1.	Asri rotan	2,796	1,191	1.605	133,75
2.	Putra Jaya	2,292	2,433	-141	-11,75
3.	Surya Rotan	9,338	5,352	3.986	332,17

* = The annual load is based on the actual energy used from January to December 2021 for Surya Rotan and Putra Jaya. The annual load for Asri Rotan is based on average prepaid credit for the last three months in 2021

** = The annual energy yield from PV rooftop is based on Helioscope simulation

*** = The monthly energy gap is calculated from the difference between the annual load and the annual energy divided by 12 months

Table 4. The Pre and Post PV Rooftop Instalation Energy Load Comparison

NO	MSME	Subscription TYPE	Pre PV (Kwh)			Post PV Import (Kwh)		Post PV Export (KWh)	
			Oct	Nov	Dec	Jan	Feb	Jan	Feb
1.	Asri rotan	R1	233,2	233,2	233,2	51	170	23	68
2.	Putra Jaya	R1	180	226	256	212	149	25	109
3.	Surya Rotan	B1	767	910	796	765	494	69	226

Table 5. The Pre and Post PV Rooftop Instalation Energy Cost Comparison

NO	MSME	Electricity Meter (VA)	Pre PV (Rp)				Post PV (Rp)		
			Oct	Nov	Dec	Average	Jan**	Feb	Mar
1.	Asri rotan*	1300	366.667	366.667	366.667	366.667	56.690	198.415	176.369
2.	Putra Jaya	2200	283.450	355.887	403.129	347.489	308.645	138.576	138.576
3.	Surya Rotan	4400	919.633	1.091.090	954.404	988.376	863.280	416.053	863.280

* = Asri Rotan Pre PV subscription type was prepaid so the average bills were counted on the total token bought around October to December 2021

** = The PV Installation was completed at the end of January so the migration system is not considered done by the date the January bill issued

4. CONCLUSION

According to the results of the analysis and simulation, several conclusions can be drawn, such as the results of the analysis show that the research site is potential for the development PV Rooftop among MSMEs especially small-scale PV rooftops. While the study in India shows that there are technical barriers such as inadequate rooftop space and most MSME is located in congested industrial areas where a useable roof area is greatly reduced because of shadows and congested of nearby objects were not found in Trangsan, there might be the same operational barriers such as some of the MSME is using a tin shed roof that might have to replaced regularly. Meanwhile, there is another barrier caused by monthly minimum payment regulation. Even if PV rooftop able fully supply the energy load in the MSME, the new regulation of minimum payment make the MSME still have to pay some amount of money.

There must be clear regulations to categorize whether the MSME sector belongs to the commercial sector or not. This is because there will be differences in economic costs if this sector bears other mandatory costs such as monthly minimum payment. As a follow-up step, the Government needs to prepare a financing scenario that is not necessarily through grants, but can be through a credit scheme with competitive interest for the MSME sector to develop PV Rooftop. As the basis of the previous point, it is necessary to analyze the technology related to the utilization of Rooftop Power Plant for the MSME sector including, installation price, maintenance costs to the willingness to pay from the MSME sector.

ACKNOWLEDGMENT

The author would like to thank Energy and Mineral Resources Services of Central Java and Colleagues in the Section of Renewable Energy for the support that has been provided during the writing. The author also expressed his gratitude for the willingness of the Trangsan Rattan Industry Forum Cluster in providing data and information related to the study.

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Vol. 13 No. 1 (2022) 20-34

Jurnal Riset
Teknologi Pencegahan Pencemaran Industri

Journal homepage : http://www.jrtppi.id

Decision Making for Biological Tofu Wastewater Treatment to Improve Quality Wastewater Treatment Plant (WWTP) Using Analytical Hierarcy Process (AHP)

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ARTICLE INFO

Article history:
Received 12 March 2022
Received in revised form 6 June 2022
Accepted 14 June 2022
Available online 27 June 2022

Keywords :
Tofu
Wastewater
WWTP
AHP

ABSTRACT

This research aims to build a support system for tofu wastewater treatment using the Analytical Hierarchy Process (AHP) method. This research was conducted in one of the household tofu industries in Jakarta. AHP method was used to choose/decide the most effective combination of technologies to treat tofu wastewater. Based on the literature study and inlet characterization, Three alternatives were proposed. Alternative 1 consists of a Collecting tank, Neutralization Tank, Preliminary Sedimentation, Anaerobic Digester, Aeration Tank, and Final Settlement Body. While alternative 2 consists of a Collecting tank, Neutralization Tank, Preliminary Sedimentation, Anaerobic Biofilter, Aeration Tank, and Final Settlement Tank. Alternative 3 consists of a Collecting tank, Neutralization Tank, ABR, Aeration Tank, and Final Sedimentation Tank. The decision criteria used for AHP were effluent quality, land requirement, construction cost, and maintenance convenience. The primary data used were wastewater flow and outlet concentration. While data on area use, maintenance cost, and construction cost were extracted from literature study. The result shows that alternative 3 was the most effective sequence of technology. Eigen Vector Analysis Recapitulation showed that alternative 1 has an overall value of 0.31, alternative 2 has a value of 0.2 and alternative 3 has a value of 0.5. Using alternative 3, BOD5 can be removed up to 95%, COD can be removed by a maximum of 95% by ABR, and TSS can be removed by 80% which met the quality standard.

1. INTRODUCTION

The production of tofu consists of washing soybeans, soaking, washing soaked soybeans, grinding, boiling, filtering, compacting, molding, and cutting tofu (Guo, Hu, Wang, & Liu, 2018; Yanti, Setyaningsih, Triwitono, Yuniansyah, & Admi, 2021). The process starts with washing soybeans with running water to remove impurities from soybeans (Yanti et al., 2021). Next, the soybeans are soaked for 6 – 12 hours. The remaining water from the soaking process that is not absorbed by the soybeans will be discarded. Soybeans that have been soaked are then rewashed. After that, the soybeans are put into the grinder. Finally, soybeans are ground into porridge. Soybean porridge will be boiled until boiling ± 15 - 40 minutes. Then, the soybean pulp is filtered using a cloth to obtain soybean juice (Ahmad et al., 2017).

Tofu wastewater quality parameters were indicated by concentrations of BOD5, COD, TSS, and pH (Aras, 2020; Hajar, Fadarina, Zamhari, & Yuliati, 2021). Acidic water contains high protein levels, so the content of organic matter in tofu wastewater is also high (Vidyawati & Fitrihidajati, 2019). This is because the use of vinegar is quite a lot in the process. If this wastewater is disposed of

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doi : https://10.21771/jrtppi.2022.v13.no.1.p20-34

Accreditation number : (Ristekdikti) 158/E/KPT/2021

without prior treatment, it can pollute the environment. BOD and COD parameters are indicators of the amount of organic waste that pollutes river water in industrial areas, the amount of these organic compounds can be associated with ongoing community activities.

Biological wastewater treatment reduces dissolved components, especially organic compounds, to a safe limit for the environment by utilizing microbes or plants. To get rid of dissolved organic matter, existing microorganisms will use organic matter as nutrients for their growth into new cells and carbon dioxide. The biotransformation process occurs in various ways according to the microorganisms that play a role in it, such as autotrophs or heterotrophs. Conventionally, wastewater treatment has successfully reduced BOD and COD, although the removal of nutrient compounds (nitrogen and phosphorus) is still being sought for efficient models and methods. In general, biofilter media can significantly increase the efficiency of the tofu and tempeh waste treatment process compared to processing without using a biofilter (Herlambang, 2001). For example, the efficiency of reducing the BOD5 value in the reactor using biofilter media ranged from 53.33 to 91.36%, and the COD value ranged from 61.15 to 85.83% with a residence time of 1-7 days (Herlambang, 2001). For application on a large scale, the decision to use which technology can rely not only on one but also on several important criteria. The cheapest and most accurate way to decide which technology can treat tofu wastewater effectively is using decision support system tools.

One of the relevant decision support systems that have a consistent value calculation in determining the priority level of criteria and alternatives is the Analytical Hierarchy Process (AHP) method (Sari et al., 2022). The concept of AHP is to convert qualitative values into quantitative values. This method also combines the strengths of the feelings and logic involved in various problems. It then synthesizes different considerations into results that match intuitive estimates as presented in the concerns that have been made. This study aims to build a support system for tofu wastewater treatment using the AHP method. The results of the decisions given can provide recommendations for tofu wastewater treatment with various criteria considered by the stakeholders of the tofu industry.

2. METHODS

The data were collected in two ways, primary and secondary. Primary data were collected directly in the field. The primary data included measurement of flow and wastewater concentration such as BOD, COD, and TSS. While secondary data used to analyze the decision criteria of land requirement, maintenance convenience, and low construction cost were extracted from literature studies. Volumetric measurements obtained wastewater discharge data in the field. In the WWTP design (Sakinah, 2018), the wastewater discharge is measured by collecting the wastewater generated in a Tank or bucket. The volume of wastewater accommodated in a Tank or bucket is then recorded, and data on the volume of wastewater produced per day will be obtained. Based on the design that has been done, the measurement of wastewater flowrate discharge in this design will be carried out in the same way but using two 60 L buckets with a measuring line every 5 L. It is enough to collect this data in 1 day because based on interviews with the owners of the tofu-making industry, the activities and the amount of tofu production in this industry are the same every day. Therefore, the resulting discharge is relatively the same.

The method used for sampling refers to SNI 6989.59:2008 concerning Wastewater Collection Methods. The container used to store the sample is adjusted to the parameters to be measured, namely BOD5, COD, TSS, and pH. According to SNI 6989.59:2008, the containers used for these parameters are plastic (polyethylene and the like) or glass. The laboratory testing results in the form of data on the concentration of tofu wastewater quality parameters were compared with the Regulation of the Governor of the Special Capital Region of Jakarta Number 69 of 2013.

If the concentration of each tofu wastewater quality parameter meets the quality standard, the design stage is complete. Suppose it does not meet the quality standards. In that case, planning is carried out for the design of the Waste Water Treatment Plant (WWTP), starting with determining alternative solutions for designing the WWTP to treat the tofu wastewater. A comparison is made for each alternative tofu wastewater treatment technology. Comparisons were made by calculating mass balance and preliminary sizing for each alternative. Next, the best and most suitable WWTP design solution will be chosen to be applied to the tofu-making industry in South Sukabumi Village using the analytical hierarchy process (AHP) method. This method is already used in the environmental engineering field for technology development (Hilmi et al., 2022; Sari et al., 2022). The framework steps in research using AHP can be seen in Figure 1.

Table 1. Characteristics of RS and SM

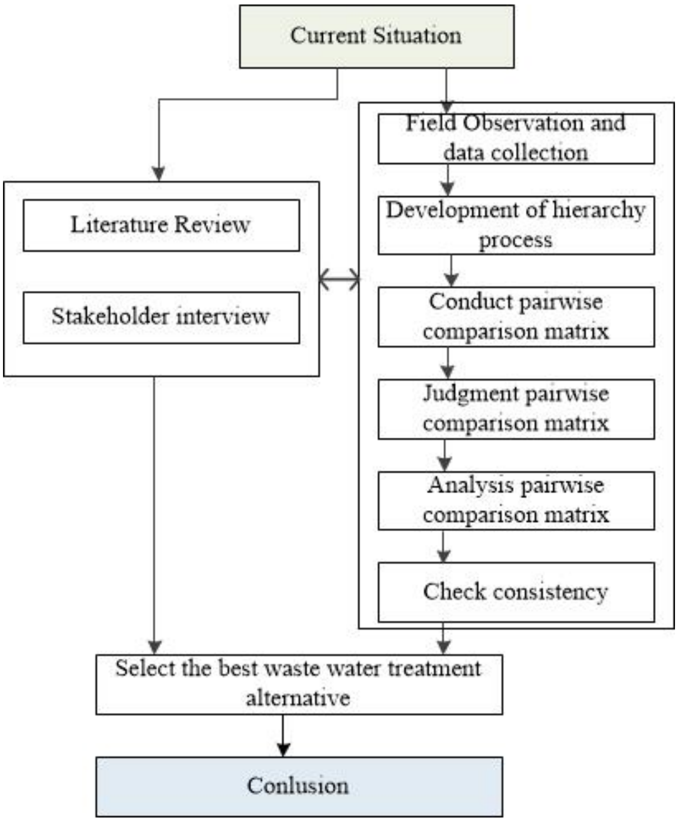

Figure 1. AHP Framework for WWTP Unit Decision Analysis

The tofu wastewater quality test results were compared with the quality standards of tofu wastewater quality parameters based on the Governor of the Special Capital Region of Jakarta Province Regulation Number 69 of 2013. The comparison results will show the parameters that have met or did not meet the quality standards. This comparison purpose is to determine which processing units can process parameters that exceed the quality standard. The unit designed must meet the design criteria to treat wastewater optimally. These processing units will form three alternative series of WWTPs.

Units in the WWTP series will treat tofu wastewater. Therefore, it is necessary to get the data from literature studies to find out alternative series of WWTPs capable of treating wastewater. One of these alternatives must then be chosen as the most effective WWTP design solution. Determination of the selected alternative is based on the fulfillment of the desired criteria effluent meets the quality standard, does not require large land, has easy operation and maintenance, and has low construction cost.

3. RESULT AND DISCUSSION

3.1. Identify problems and determine alternative solutions

Tofu wastewater is produced from soaking, washing, and compaction. The problem related to the tofu industry is untreated wastewater. Untreated wastewater occurs because the industry does not have a WWTP. An effective WWTP requires proper technology that suits the waste characteristic, sufficient land to build, and low cost of construction and maintenance. The land for the tofu-making industry in South Sukabumi Village has a length of 12 m and a width of 13 m with 156 m2. On this land, the land used for tofu production activities is 114.28 m2.

Tofu wastewater quality data was obtained from laboratory test results. Previously, a wastewater sample from the tofu production process had to be taken. Sampling is done by collecting tofu wastewater in a bucket first. The tofu wastewater is homogenized and then taken as much as 2 L from the bucket with 2 plastic jerry can measuring 1 L. In the table below, it can be seen the results of the two samples testing for each parameter. After being compared to the quality standard, none of the tofu wastewater quality parameters met the quality standard. The data shows that as the day progresses, the quality of tofu wastewater gets worse. This is because the containers used for the tofu production process are not rinsed every time. Therefore, tofu solids from the previous wastewater are still left behind and increase the TSS concentration.

The concentration of wastewater quality parameters is needed as a design reference in designing the WWTP. The mean and standard deviation were then calculated from the two samples of tofu wastewater quality in Table 1 to see the variation in the data. A high standard deviation indicates the data is too varied because individual information is far from the average (Hidayat, Sabri, & Awaluddin, 2019). Therefore, tofu wastewater quality data for designing WWTPs cannot be represented by the tofu wastewater quality data standard. However, the design can be done using the highest parameter concentration data so that the WWTP can work optimally in the worst conditions.

Based on the results of laboratory tests, it can be seen that the concentrations of BOD, COD, TSS, and pH in tofu wastewater in South Sukabumi Village do not meet the applicable quality standards. Therefore, these parameters are used to determine alternative wastewater treatment units that can treat them. The units needed to treat tofu wastewater, in general, are equalization tanks, pre-settling tanks, anaerobic biological units 1, aerobic biological units 2, and purification tanks or settling tanks (Simanjuntak, Zahra, & Suryawan, 2021). In this design, the equalization tank is replaced with a collecting tank as both have the same function and also added a neutralization tank to enhance the pH. The collecting tank accommodates the tofu wastewater produced until the production process is completed at 17.00. During the collection of wastewater, it is assumed that no treatment will occur at this well. After that, the tofu wastewater can be pumped to the first treatment unit, namely the neutralization tank.

The wastewater of the tofu manufacturing industry in Sukabumi Selatan Village has a pH of 4. This indicates that the wastewater is acidic and does not meet quality standards. Therefore, a neutralization process is needed to raise the pH to become neutral, namely pH = 7. The suitable biological unit to overcome the problem of tofu wastewater is a combination of anaerobic and aerobic treatment (Astuti & Ayu, 2019). Therefore, neutralization is essential because the wastewater will be treated in biological unit 1 anaerobically. Anaerobic processes can occur at pH 6-8, and bacteria can live and reproduce optimally at pH 6.5-7.5 (Metcalf & Eddy, 1991).

Table 1. Results of Tofu Wastewater Quality Testing

Parameters	Mean	Stdev	Standard
BOD_5 (mg/L)	2.843,5	317,1	75
COD (mg/L)	7.743,5	493,9	100
TSS (mg/L)	827	359,2	100
pH	4	0	6 – 9

The initial settling tank is needed to settle suspended solids in wastewater, especially tofu solids that are wasted from the tofu production process. Then, the biological unit removes dissolved organic substances that can be decomposed (biodegradable). Wastewater containing biodegradable organic substances can be seen from the BOD5/COD ratio. Tofu-making industrial wastewater in South Sukabumi Village has a BOD5/COD value of 0.39. Wastewater that has a BOD5/COD value of 0.3 can be treated biologically (Suryawan et al., 2021). This means that the tofu-making industrial wastewater in the South Sukabumi Village can still be treated biologically.

Biological unit 1 uses anaerobic treatment because this treatment can treat wastewater that has a high organic content (Said, 2000)v. Anaerobic biological treatment is suitable for treating wastewater with a BOD5 concentration of 3,000 – 80,000 mg/L (Said & Rahardiyan, 2015). In previous studies, anaerobic biological units that can be used to treat tofu wastewater include an anaerobic digester (S. S. Hidayati, 2017), an anaerobic biofilter with honeycomb media (Marhadi, 2016), and an anaerobic baffled reactor or ABR (Sani, 2006). The high organic content in tofu wastewater is treated in the biological unit (Budiastuti, Amanah, Pratiwi, Muhari, & Isna, 2021).

Figure 2 shows the treatment units used in the WWTP circuit. Before being treated, the tofu wastewater is collected in the collecting tank. Then, the wastewater is pumped into a neutralization tank to be stirred with a CaCO3 solution. The wastewater in a neutral state then flows into the initial settling basin. After that, enter biological unit 1. In alternative 1, the biological unit 1 used is the anaerobic digester. In the anaerobic digester, microorganisms will degrade wastewater without oxygen. A methanogenesis phase occurs in the processing process, which converts volatile organic acids into methane gas and carbon dioxide (Kementerian Pekerjaan Umum dan Perumahan Rakyat, 2017). Methane gas mixed with carbon dioxide gas will form biogas (S. S. Hidayati, 2017). Biogas will be collected in an anaerobic digester dome and can be used as fuel (Rathod et al., 2018). After that, the water will flow into the aeration tank to be treated using activated sludge. The final processing takes place in the final settling basin. The activated sludge that settles in the final settling basin will be recirculated to the aeration tank for reuse.

Figure 3 shows the treatment units used in the WWTP circuit. Before being treated, the tofu wastewater is collected in a collecting tank. Then, the wastewater is pumped into a neutralization tank to be stirred with a CaCO3 solution. The wastewater in a neutral state then flows into the initial settling basin and enter biological unit 1. In alternative 2, the biological unit 1 used is an anaerobic biofilter. In an anaerobic biofilter, microorganisms will be cultured on a honeycomb-type buffer media to form a biofilm. Microorganisms in biofilm decompose organic compounds such as BOD5 and COD (Said & Rahardiyan, 2015). After that, the water flows into the aeration tank to be treated using activated sludge. The final processing takes place in the final settling basin and activated sludge that settles in the final settling tank will be recirculated to the aeration tank for reuse so that the aeration tank and the final settling tank are one system.

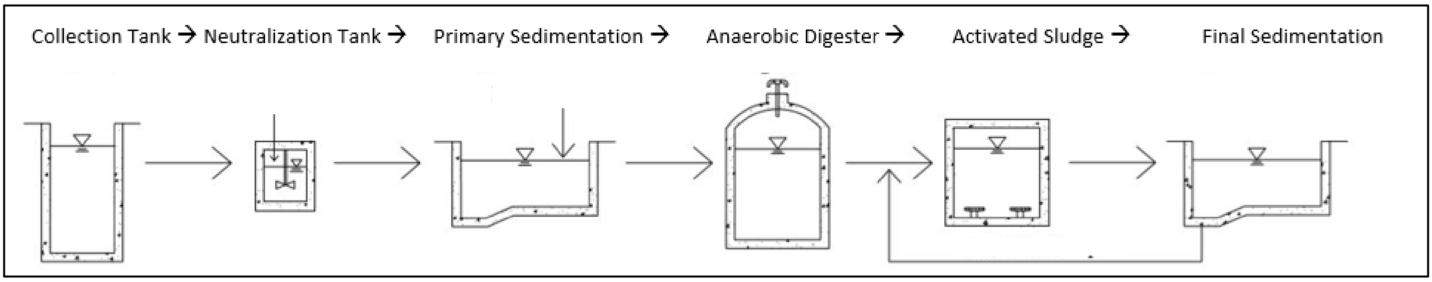

Figure 2. Units WWTP for Tofu Wastewater in Alternative 1

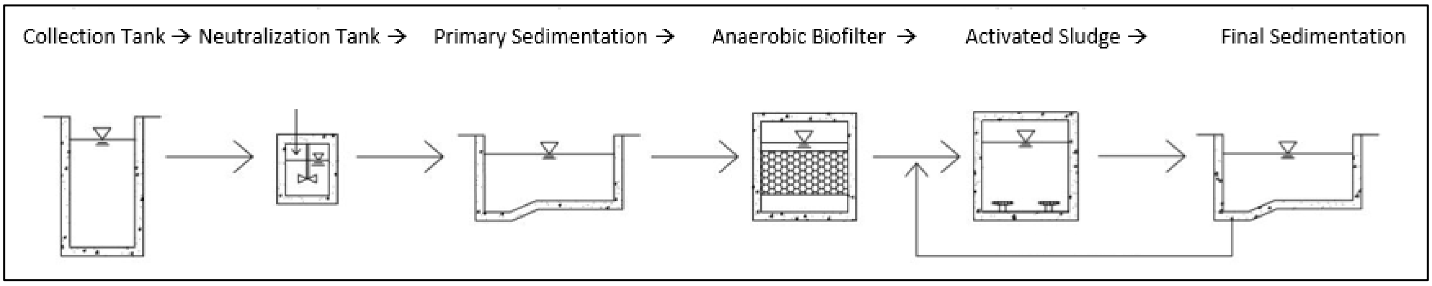

Figure 3. Units WWTP for Tofu Wastewater in Alternative 2

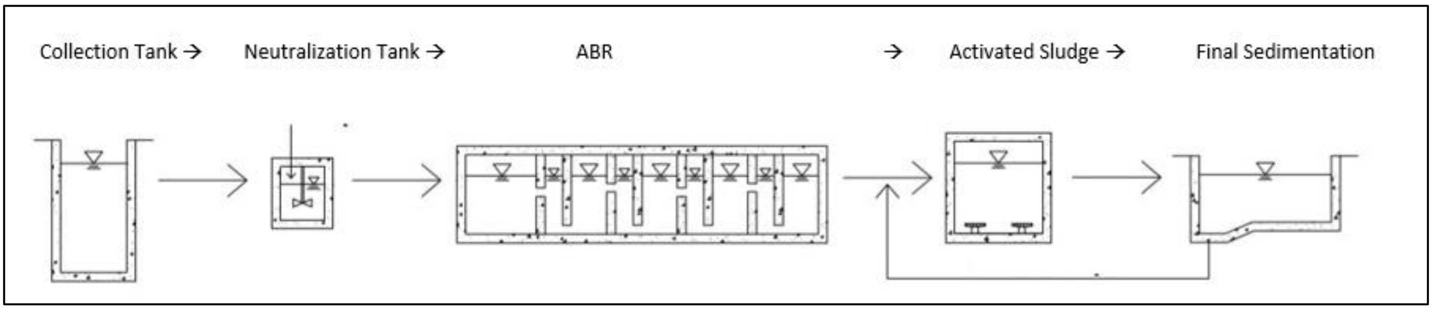

Figure 4. Units WWTP for Tofu Wastewater in Alternative 3

Table 2. Effluent Prediction Calculation Results for Tofu WWTP for Each Alternative

Alternative 1

Parameter	Influent (mg/L)	Collection Tank		Neutralization Tank		Preliminary Sedimentation		Anaerobic Digester		Aeration Tank and Final Sedimentation		**Standard (mg/L)**
		Efficiency	Efluent (mg/L)	Efficiency	Efluent (mg/L)	Efficiency	Efluent (mg/L)	Efficiency	Efluent (mg/L)	Efficiency	Efluent (mg/L)	
BOD_5 (mg/L)	3.292	0%[1]	3.292	0%	3.292	25%[2]	2.469	75%[3]	617.25	85%[6]	92.59	75
COD (mg/L)	8.442	0%[1]	8.442	0%	8.442	25%2	6.331.5	72%[3]	1.772.82	85%[6]	265.92	100
TSS (mg/L)	1.335	0%	1.335	0%	1.335	40%2	801	66%[4]	352.4	90%[6]	35.5	100

Alternative 2

Parameter	Influent (mg/L)	Collection Tank		Neutralization Tank		Preliminary Sedimentation		Anaerobic Biofilter		Aeration Tank and Final Sedimentation		**Standard (mg/L)**
		Efficiency	Efluent (mg/L)	Efficiency	Efluent (mg/L)	Efficiency	Efluent (mg/L)	Efficiency	Efluent (mg/L)	Efficiency	Efluent (mg/L)	
BOD_5 (mg/L)	3.292	0%[1]	3.292	0%	3.292	25%[2]	2.469	84%[5]	395.04	85%[6]	59.26	75
COD (mg/L)	8.442	0%[1]	8.442	0%	8.442	25%[2]	6.331.5	81%[5]	1.202.985	85%[6]	180.45	100
TSS (mg/L)	1.335	0%[1]	1.335	0%	1.335	40%[2]	801	90%[5]	80.1	90%[6]	8.01	100

Alternative 3

Parameter	Influent (mg/L)	Collection Tank		Neutralization Tank		ABR		Aeration Tank and Final Sedimentation				**Standard (mg/L)**
		Efficiency	Efluent (mg/L)	Efficiency	Efluent (mg/L)	Efficiency	Efluent (mg/L)	Efficiency	Efluent (mg/L)			
BOD_5 (mg/L)	3.292	0%[1]	3.292	0%	3.292	95%[2]	164.6	85%[6]	24.69			75
COD (mg/L)	8.442	0%[1]	8.442	0%	8.442	95%[2]	422.1	85%[6]	63.32			100
TSS (mg/L)	1.335	0%[1]	1.335	0%	1.335	80%[2]	267	90%[6]	26.7			100

1: (Hasnaningrum, Ridhosari, & Suryawan, 2021; Khansa, Sofiyah, & Suryawan, 2021); 2(Metcalf & Eddy, 1991); 3(Fdz-Polanco, Pérez-Elvira, & Fdz-Polanco, 2009); 4(Salsabil, Laurent, Casellas, & Dagot, 2010); 5(Said & Firly, 2018); 6(Qasim & Zhu, 2018)

Figure 4 shows the units that will be used in the WWTP circuit. Before being treated, the tofu wastewater is collected in a collecting tank. Then, the wastewater is pumped into a neutralization tank to be stirred with a CaCO3 solution. The wastewater in a neutral state then flows into the initial settling basin. Then, the wastewater flows directly to biological unit 1, namely ABR. Alternative 3 does not have a separate initial settling tank like alternatives 1 and 2 because the ABR unit already has a settling basin. In ABR, a bulkhead causes water to flow upflow and downflow. Both types of flow will increase the contact between wastewater and microorganisms so that organic material can be decomposed efficiently (Kementerian Pekerjaan Umum dan Perumahan Rakyat, 2017). After that, the water will flow into the aeration tank to be treated using activated sludge. The final processing takes place in the final settling basin. The activated sludge that settles in the final settling tank will be recirculated to the aeration tank for reuse so that the aeration tank and the final settling tank are one system.

Mass balance calculations were carried out on three alternative series of WWTPs with 1 different biological unit: anaerobic digester, anaerobic biofilter, and ABR. The purpose of calculating the mass balance is to determine the effluent concentration after the wastewater is treated in the WWTP series. The effluent concentration is then compared with the quality standard of tofu wastewater according to the Regulation of the Governor of the Special Capital Region of Jakarta Number 69 of 2013 to determine whether the theoretical effluent concentration has met the quality standard or not. This will show a series of WWTPs capable of treating wastewater to meet quality standards. Following are the results of the calculation of the elimination capacity of the three alternative series of WWTPs.

The series of WWTPs starts from the wastewater reservoir in the collecting tank. No processing occurs in this unit so that the removal efficiency is 0% and the concentration of all parameters remains. Likewise, in the neutralization tank. A neutralization tank serves to neutralize pH but does not exclude BOD5, COD, and TSS parameters so that the removal efficiency for all parameters is 0%. In alternative 1, the treatment unit is the initial settling basin after the neutralization tank. The wastewater is then treated in an aeration tank. The aeration tank and the final settling tank are combined in one system because the sludge in the final settling tank will be recirculated to the aeration tank by as much as 30%. Therefore, the processing in both units will set aside 85% BOD5, 85% COD, and 90% TSS. Then, the final effluent concentration coming out of the aeration tank and the final settling tank is compared with the quality standard. In Table 2, it can be seen that the concentration of TSS in the effluent has met the quality standard. However, the concentrations of BOD5 and COD did not meet the quality standards.

In alternative 2. after the neutralization tank. The treatment unit is the initial settling basin. This unit can remove 25% BOD5, 25% COD, and 40% TSS so that the parameter concentration decreases. The water flows into the anaerobic biofilter. The wastewater is then treated in an aeration tank that combined with final settling tank in one system because the sludge in the final settling tank will be recirculated to the aeration tank by as much as 30%. Therefore. the processing in both units will set aside 85% BOD5, 85% COD, and 90% TSS. Then, the final effluent concentration coming out of the aeration tank and the final settling tank is compared with the quality standard. In Table 2. it can be seen that the concentrations of BOD5 and TSS in the effluent have met the quality standard. However, the COD concentration did not meet the quality standard.

In alternative 3, the treatment unit after the neutralization tank is ABR. The settling tank is inside the ABR. The wastewater is then treated in an aeration tank. The aeration tank and the final settling tank are combined in one system because the sludge in the final settling tank will be recirculated to the aeration tank as much as 30%. Therefore, the processing in both units will set aside 85% BOD5, 85% COD, and 90% TSS. Then. the final effluent concentration coming out of the aeration tank and the final settling tank is compared with the quality standard. It can be seen in Table 2. that the concentrations of BOD5, COD, and TSS in the effluent have met the quality standard.

3.2. Arrange a hierarchical structure

In preliminary sizing used calculations are carried out to determine the size of the WWTP unit. This is related to the limited land available. considering that the tofu-making industry in South Sukabumi Village is a small-scale industry. The land available for the construction of the WWTP is 41.72 m2. The initial calculations for each alternative series of WWTPs are shown in Table 4. The planned series of WWTPs has three alternatives with different biological unit which consists of an anaerobic digester, an anaerobic biofilter, and an ABR. Therefore, it is necessary to select alternatives to choose the best biologic unit 1 to be used in the WWTP series. The selection stage begins by determining the criteria made in the hierarchical structure as follows in Figure 5.

It can be seen that there are four desired criteria. The first criterion is that the effluent meets the quality standard, second criterion is that it does not require a large land area, third criterion is easy to operate and maintain, and the fourth criterion is low construction costs. In criterion one, biological unit 1 can assist the treatment process in the WWTP series so that the tofu wastewater that is disposed of can meet the quality standards. Criterion three avoiding the use of biologic unit 1 is challenging to operate and maintain because the tofu makers are accustomed to working in a conventional simple, and easy process in South Sukabumi. Finally, criterion four bio unit logical 1 is built at the lowest possible cost because in general, The purpose of designing is to find the best and cheapest solution. Comparison matrix for the four criteria which are presented in the following Table 4.

The criteria assessment is carried out by comparing the importance of each criterion with one another. For example, the effluent criterion that meets the quality standard is slightly more critical than the criterion of not requiring a large area of land. so it is given a value of 3. This is because a series of tofu WWTPs meet the quality standard and cannot be built on insufficient land, regarding the tofu-making industry in South Sukabumi Village has limited land. Therefore, the size of biological unit 1 is also essential to consider. Based on the assessment of criteria one against two, the comparison of measures two against criteria one has the opposite value, namely 1/3.

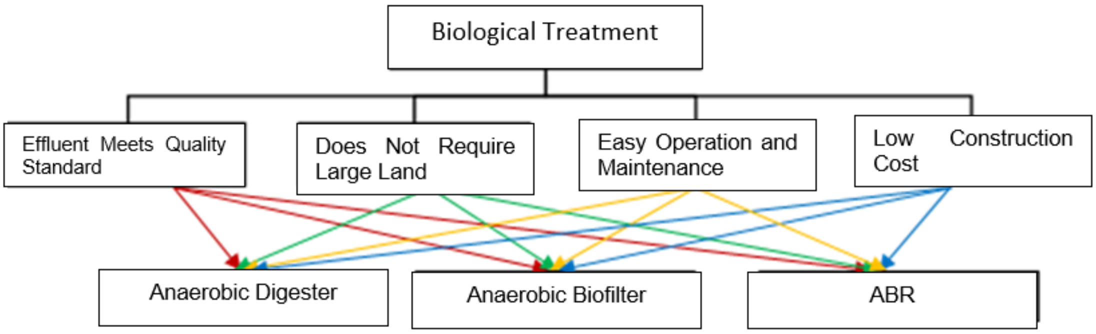

Figure 5. Hierarchical Structure of Determination of Biological Units 1

Table 3. Preliminary Sizing Results

Unit Alternative 1	Results	Unit Alternative 2	Results	Unit Alternative 3	Results
Collecting tank		Collecting tank		Collecting tank	
Long	1.35 m	Long	1.35 m	Long	1.35 m
Wide	1.35 m	Wide	1.35 m	Wide	1.35 m
Area	1.82 m^2	Area	1.82 m^2	Area	1.82 m^2
Neutralization tank		Neutralization tank		Neutralization tank	
Diameter	0.25 m	Diameter	0.25 m	Diameter	0.3 m
Wide	0.05 m^2	Wide	0.05 m2	Area	0.05 m^2
Initial Precipitation Tank		Initial Precipitation Tank			
Long	1.35 m	Long	1.35 m		
Wide	0.7 m	Wide	0.7 m		
Wide	0.95 m^2	Wide	0.95 m^2		
Anaerobic digester		Anaerobic Biofilter		ABR	
Diameter	1 m	Long	1.7 m	Long	6.45
Area	0.8 m^2	Wide	1.7 m	Wide	0.7 m
		Area	2.89 m^2	Area	4.52 m
Aeration tank		Aeration tank		Aeration tank	
Long	1.1 m	Long	1.1 m	Long	1.1 m
Wide	1.1 m	Wide	1.1 m	Wide	1.1 m
Area	1.21 m^2	Area	1.21 m^2	Area	1.21 m^2
Final settling tank		Final settling tank		Final settling tank	
Long	1.1 m	Long	1.1 m	Long	1.1 m
Wide	0.6m	Wide	0.6m	Wide	0.6m
Area	0.66 m^2	Area	0.66 m^2	Area	0.66 m^2
Total land requirement	**5.49 m^2**	**Total land requirement**	**7.58 m^2**	**Total land requirement**	**8.26 m^2**

Table 4. Criteria Assessment

Criteria	Effluent Meets Quality Standard	Does Not Require Large Land	Easy Operation and Maintenance	Low Construction Cost
Effluent Meets Quality Standard	1	3	5	7
Does not require large land	1/3	1	5	5
Easy Operation and Maintenance	1/5	1/5	1	3
Low Construction Cost	1/7	1/5	1/4	1

The criteria of "meet quality standards" are more important than the criteria of " easy of operational and maintenance" measures and easy maintenance. Suppose the operation and maintenance that can treat wastewater to meet quality standards are complex, how to operate and maintain the treatment unit can still be learned, or you can also hire an operator to control the WWTP during operation. Based on the assessment of criterion one against three, the comparison value of criterion three against criterion one is 1/5. Likewise, Operational and maintenance problems can still be overcome compared to the criteria of not requiring a large land area. Therefore, the comparison of criterion two to criterion three is given a value of 5. Based on this assessment. The comparison of standard three to criterion two has a value of 1/5.

The effluent criterion that meets the quality standard is more essential than the low construction cost criterion. so it is given a value of 7. The owner of the tofu industry in the South Sukabumi Village stated that "the order of tofu is constant every day so that the income of this industry is quite stable". Therefore, the large construction costs of the processing unit can still be tolerated. The priority is for this industry to have a unit that can treat tofu wastewater until the effluent meets the quality standard. Based on the assessment of criterion one against criterion four, the comparison value of criterion four against criterion one is 1/7.

The criterion of not requiring a large land area is more important than criterion four. The area is affected by the length and width of the unit. To get the minimum area, the length and width are designed to get the minimum size by adjusting the height or depth of the unit. The larger the unit depth measurement, then the higher the soil's cost. Therefore, the value of criterion two against criterion four is 5. Based on this assessment, the comparison of criterion four to criterion two becomes 1/5.

Operational and easy maintenance criteria are slightly more important than criterion four. This is because the tofu-making industry in South Sukabumi Village is more concerned with the ease of operation and maintenance of the unit. Even if the construction cost of the unit becomes a little more expensive. Therefore, the value of criterion three against criterion four is 3. Based on this assessment. The comparison value of criteria four to three is 1/3. After evaluating each criterion. The next thing to do is to calculate the eigenvectors. The results of which can be seen in the following Table 5.

Table 5. Eigen Vector Value of Each criterion

Criteria	Eigen Vector
Effluent Meets Quality Standard	0.54
Does not require large land	0.29
Easy Operation and Maintenance	0.11
Low Construction Cost	0.06

The eigenvector values indicate the priority level. The higher the eigenvector value, the higher the priority level. Based on the calculations and explanations above. It is found that the priority criterion is criterion one: "The effluent meets the quality standard ". The second priority is criterion two: "it does not require a large land area". The third priority is the third criteria: Easy operation and maintenance. The fourth priority is criterion four: "low construction costs". Then, three alternatives of biological unit 1 were assessed, namely anaerobic digester, anaerobic biofilter, and ABR against each criterion.

The first assessment was to compare the anaerobic digester, anaerobic biofilter, and ABR against the first criterion, namely the effluent meets the quality standard. The effluent concentration of each parameter treated in a series of WWTPs with different biological unit 1 can be seen in Table 2.

In alternative 1 a series of WWTPs that use anaerobic digester as biological unit 1, the concentration of TSS in the effluent has met the quality standard. However, the concentrations of BOD5 and COD did not meet the quality standards. In alternative 2 series of WWTPs using anaerobic biofilters, the concentrations of TSS and BOD5 have met the quality standards. Meanwhile, the COD concentration did not meet the quality standard. Finally, in alternative 3 series of WWTPs using ABR. The TSS, BOD5, and COD concentrations have met the quality standards. After calculating the mass balance, The three alternatives can be assessed compared to criterion one. Here are the results of the assessment:

Table 6. Alternative Assessment against Criterion Effluent Meets Quality Standard

Effluent Meets Quality Standard	Anaerobic Digester	Anaerobic Biofilter	ABR
Anaerobic Digester	1	1/3	1/7
Anaerobic Biofilter	3	1	1/5
ABR	7	5	1

In the flowing criteria that meet the quality standards, the ABR compared to the anaerobic digester is given a value of 7 whereas, the anaerobic biofilter is given a value of 5. This figure is given based on the results of the mass balance calculation. The WWTP series with 1 ABR biological unit can treat tofu wastewater to meet quality standards. The WWTP series with biological unit 1 anaerobic biofilter can treat tofu wastewater whose effluent meets two quality standards. Meanwhile, the effluent from the WWTP series with biological unit 1 anaerobic digester can only meet one quality standard. Therefore, the ABR meets the criteria of one more than the anaerobic digester. Compared with anaerobic biofilters, ABR is more able to meet criteria one.

Meanwhile, the anaerobic digester is slightly more able to meet criteria one than the anaerobic digester, so the value is 3. Based on the above assessment, the ratio of the anaerobic digester to the ABR is 1/7, and the anaerobic digester is 1/5. Meanwhile, The ratio of anaerobic biofilter to ABR is 1/5.

The next step is to calculate the eigenvector of alternative assessments against criterion one. The eigenvector value of the anaerobic digester is 0.08, the anaerobic biofilter is 0.19, and the ABR is 0.72. This figure shows that the alternative that best fulfills criteria one is ABR, then the second is the anaerobic biofilter, and the third is the anaerobic digester.

The second assessment compares the anaerobic digester, anaerobic biofilter, and ABR against the second criterion, which does not require a large land area. Finally, a comparison of alternatives to these two criteria is assessed based on preliminary sizing calculations. In Table 3, the land area required by a series of WWTPs from three alternatives has been calculated. The following is the area of land needed for the three alternative series of WWTPs:

The calculation results in the table above show that the alternative one with a biological unit 1 anaerobic digester requires the smallest land area. At the same time, the largest land area is needed by alternative 2 with 1 ABR biological unit. Finally, alternative 3 with biological unit 1 anaerobic biofilter has a large land area between the anaerobic digester and the ABR. Subsequently, three alternatives were assessed against the second criteria, as Table 7.

The anaerobic digester compared to the anaerobic biofilter was given a value of 5 because the WWTP series with the anaerobic digester was more able to meet the two criteria than the anaerobic biofilter. Based on this assessment, the value of the anaerobic biofilter against the anaerobic digester is 1/5. Meanwhile, The anaerobic digester, compared to the ABR was given a value of 7 because the anaerobic digester was able to meet the criteria compared to the ABR, which required the largest land. Based on this assessment, the ABR value for the anaerobic digester is 1/7. Then, the anaerobic biofilter compared to the ABR was given a value of 3 because the land area was slightly more able to meet the two criteria. Based on this assessment, the ABR value of the anaerobic biofilter is 1/3.

Table 7. Alternative Assessment against Criterion Does Not Require Large Land

Does Not Require Large Land	Anaerobic Digester	Anaerobic Biofilter	ABR
Anaerobic Digester	1	5	7
Anaerobic Biofilter	1/5	1	3
ABR	1/7	1/3	1

The next step is to calculate the eigenvector of alternative assessments against criterion two. The eigenvector values of the anaerobic digester are 0.72, anaerobic biofilter 0.19, and ABR 0.08. This figure shows that the best alternative that meets criteria one is a series of WWTPs with 1 biological unit anaerobic digester, then the second is the anaerobic biofilter, and the third is ABR.

The third assessment compares the anaerobic digester, anaerobic biofilter, and ABR against easy operation and maintenance criteria. The unit's ease of operation and maintenance can be seen in the risks when the unit operates. In alternative 1, the anaerobic digester that produces biogas is at risk of exploding. This can happen because one of the constituents of biogas is methane gas which is explosive if the concentration is 5-15% in the air, especially at high temperatures (BPSDM Ministry of PUPR. 2018). In alternative 2, the anaerobic biofilter treats the wastewater with the formed biofilm. Biofilm on the surface of the media is easily detached so that the process often becomes unstable and can cause blockages to occur (Ministry of Health. 2011). In alternative 3, it can be washed out, which causes the microbes in the mud to come out with the treated water from the ABR so that the decomposition process is less efficient. Then, an assessment of the alternatives is carried out compared to the three criteria. The results of the evaluation are as follows Table 8.

Table 8. Alternative Assessment of Criterion Easy Operation and Maintenance

Easy Operation and Maintenance	Anaerobic Digester	Anaerobic Biofilter	ABR
Anaerobic Digester	1	1/6	1/7
Anaerobic Biofilter	6	1	1/3
ABR	7	3	1

The assessment is given based on explaining the risks that may occur when the unit operates. The anaerobic digester has the highest risk. Therefore, the ABR compared to the anaerobic digester was given a value of 7 because it could very well meet the three criteria, anaerobic biofilter for the anaerobic digester was given a value of 6 because it could meet the three criteria. At the same time, the ABR for anaerobic biofilters is assigned a value of 3. ABR is slightly easier to operate and maintain because it does not use a buffer medium for the growth of microorganisms so that it is not easily clogged (Willistania, Poetranto, Kaavessina, & Margono, 2016). Based on the above assessment, the ratio of the anaerobic digester to the ABR is 1/7 and the anaerobic digester is 1/6. Meanwhile, the percentage of anaerobic biofilter to ABR is 1/3.

The next step is to calculate the eigenvector of alternative assessments against criterion two. The eigenvector value of the anaerobic digester is 0.07, the anaerobic biofilter is 0.30, and the ABR is 0.63. This figure shows that the alternative that best fulfills criteria one is ABR, then the second is the anaerobic biofilter, and the third is the anaerobic digester.

The fourth assessment compares the anaerobic digester, anaerobic biofilter, and ABR against the low construction costs. A comparison of alternatives to these four criteria is assessed based on the estimated initial construction cost of the biological unit 1. Initial construction costs include excavating soil, removing excavated soil, installing foundations, concrete, brick walls, plastering, concrete plastering, installing floor tiles, and waterproofing work. Table 9 shows the results of the initial construction cost calculation for each alternative.

Table 9. Biological Unit Initial Construction Cost

No.	Unit	Cost
1	Anaerobic Digester	Rp 8.651.696.466 (S. Hidayati, Utomo, Suroso, & Maktub, 2019)
2	Anaerobic Biofilter	Rp 24.286.193 (Santoso, 2015)
3	ABR	Rp 9.647.000 (Simanjuntak et al., 2021)

Based on the results of the calculation of construction costs in the table above, it can be seen that the anaerobic digester construction cost is the lowest. On the other hand, the construction cost of ABR is higher than that of an anaerobic digester. Meanwhile, the anaerobic biofilter has the most increased construction cost. Then, an alternative assessment is carried out, which is compared to the four criteria as follows:

Table 10. Alternative Comparison Value against Construction Cost

Construction Cost	Anaerobic Digester	Anaerobic Biofilter	ABR
Anaerobic Digester	1	7	5
Anaerobic Biofilter	1/7	1	1/3
ABR	1/5	3	1

Compared to an anaerobic biofilter, an Anaerobic digester is given a value of 7 because the cost of the biofilter has the highest construction cost and the anaerobic digester has the lowest construction cost. Based on this assessment, the ratio of the value of the anaerobic biofilter to the anaerobic digester is 1/7. Meanwhile, when compared to ABR, the construction costs of the anaerobic digester can meet the four criteria. Therefore, the anaerobic digester to the ABR is given a value of 5. Therefore, the ABR ratio to the anaerobic digester is 1/5. The ABR compared to the anaerobic biofilter was assigned a score of 3 because the construction cost of the ABR was slightly lower than that of the anaerobic biofilter. Based on this assessment, the ratio of the anaerobic biofilter value to the ABR is 1/3.

The next step is to calculate the eigenvector of alternative assessments against criterion two. The eigenvector values of the anaerobic digester are 0.72, anaerobic biofilter 0.08, and ABR 0.19. After each alternative is assessed against all the criteria, a calculation is carried out to get one main priority. All eigenvectors resulting from the comparison of alternatives and criteria are multiplied by the eigenvectors of the criteria. The following are the results obtained from the calculations performed:

The multiplication results in the table above are then compared between each alternative. The higher the product, the higher the priority level. It can be seen from the table above that ABR has the highest product yield. Therefore, the alternative chosen as the solution is ABR. The ABR unit will be used as biological unit 1 in a series of WWTPs designed for the tofu manufacturing industry. ABR is an anaerobic reactor consisting of several compartments separated by baffles (Adi, Razif, & Moesriati, 2016; Afifah, Apritama, Adicita, Septiariva, & Suryawan, 2021). Bulkheads or baffles are installed alternately to flow up and down in the compartment

Tabel 11. Eigen Vector Recapitulation of All Alternatives and Criteria

	Effluent Meets Quality Standard	Does Not Require Large Land	Easy Operation and Maintenance	Low Construction Cost	Criteria	Result
Anaerobic Digester	0.08	0.72	0.07	0.72	0.54	0.31
Anaerobic Biofilter	0.19	0.19	0.30	0.08	0.29	0.20
ABR	0.72	0.08	0.63	0.19	0.11 0.06	0.50

4. CONCLUSION

Tofu wastewater in the tofu-making industry in South Sukabumi Village has poor quality. The results of testing the quality of tofu wastewater against BOD5, COD, TSS, and pH indicate that all parameters do not meet the quality standards of tofu wastewater quality according to the Regulation of the Governor of the Special Capital Region of Jakarta Number 69 of 2013. Therefore, WWTP is designed to treat wastewater to set these parameters aside. The WWTP circuit consists of five units.

The series of WWTPs that have been designed shows there is no removal of BOD5, COD, and TSS in the collecting tank and neutralization tank. However, the pH of the wastewater rose to 7 after being treated in a neutralization tank. BOD5 can be removed by 95% by ABR and 85% by aeration tanks (activated sludge) and pre-settling tanks. COD can be removed by 95% by ABR and 85% by an aeration tank (activated sludge) and initial settling basin. TSS can be removed by 80% by ABR and 90% by aeration tanks (activated sludge) and pre-settling tanks. Based on the mass balance calculation, The wastewater effluent has a BOD5 concentration of 24.69 mg/L, COD 63.32 mg/L, TSS 26.7 mg/L, and a neutral pH. Therefore, the wastewater quality data has met the applicable quality standards. This shows that theoretically, the series of designed WWTPs can treat tofu wastewater and reduce pollution to water bodies.

ACKNOWLEDGEMENT

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Vol. 13 No. 1 (2022) 35-42

Jurnal Riset
Teknologi Pencegahan Pencemaran Industri

Journal homepage : http://www.jrtppi.id

Kementerian Perindustrian
REPUBLIK INDONESIA

Utilization of Peroxide Bleached Sugar Palm (Arenga pinnata) Fibre Waste into Cellulose Nano Crystal

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INFOARTIKEL

Article history:

Received : 07 April 2022

Received in revised form : 11 May 2022

Accepted : 13 May 2022

Available online : 27 June 2022

Keywords :

Cellulose nanocrystal

Peroxide bleached

Sugar palm fibre

ABSTRACT

Sugar palm (Arenga pinnata) fibre (SPF) waste is a side product of sugar palm starch production and needs to be processed to avoid environmental pollution. Since the SPF has high cellulose content, it can be beneficial if it is valorized into high-value products such as cellulose nanocrystal (CNC). The CNC production from SPF was initiated by cellulose production by using an environmentally friendly peroxide bleaching as elementary chlorine free bleaching method. The CNC production was conducted via sulfuric acid hydrolysis at a temperature of 40°C, solid/liquid ratio of 1:10, and hydrolysis time of 45, 60, 75, and 90 minutes. The same functional groups were observed in all CNC samples, including the appearance of the ester sulfate group. The decrease in yield and crystallinity index (CrI) as the hydrolysis time was observed. These phenomena were caused by the degradation of the crystalline structure of cellulose and the formation of the ester sulfate group. The measurement of CNC diameter size was carried out by using the scanning electron microscopy (SEM) technique. The CNC diameter was below 100 nm which indicated the nanoparticle formation was observed at CNC produced at hydrolysis times of 75 and 90 minutes. In conclusion, CNC production was successfully produced from peroxide bleached SPF which is more environmentally friendly than the conventional method using chlorite bleached cellulose. Furthermore, it is needed to optimize the production of SPF CNC in further research.

1. INTRODUCTION

Sugar palm (*Arenga pinnata*) is a multipurpose plant whose products mainly consist of fruit, sugar, and starch (Lempang, 2012). Various types of waste are generated during the production of sugar palm, *e.g.*, dregs and fibre (Firdayati & Handajani, 2005). These wastes can be utilized rather than released into the environment. By recycling its large by-product, a great source of highly valued material for other sectors was provided. This avoids the loss of a large quantity of untapped biomass as well as environmental concerns in the long term (Padam *et. al.*, 2014).

The sugar palm dregs can be utilized as raw material for bioethanol production (Dayatmo & HS, 2015), while the fibre waste can be used to produce various composite products (Huzaifah et al., 2017; Musa et al., 2021). The utilization of sugar palm fibre (SPF) waste was already conducted by many researchers. Direct utilization or simple pretreatment (e.g., alkaline pretreatment) brought out SPF as filler for composites material such as lightweight brick, concrete, and biodegradable

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doi : https://10.21771/jrtppi.2022.v13.no.1.p35-42

Accreditation number : (Ristekdikti) 158/E/KPT/2021

polymer (Huzaifah et al., 2017; Musa et al., 2021). Converting SPF to cellulose was a choice because cellulose was known to be a versatile material that can be used in bioplastics, composites, membranes, and fibres (Wang et al., 2016). Thus, the production of cellulose is a promising way to utilize SPF.

The next attractive option is converting cellulose into its micro or nano form. Microcrystalline cellulose (MCC) is commonly used in pharmaceutical, food, and beverage industries due to its chemical activity, non-toxicity, and hygroscopicity (Trache et al., 2016). The nanoform of cellulose consists of cellulose nanocrystal (CNC) and cellulose nanofibre (CNF). CNF was mainly produced through mechanical disintegration, while CNC was produced via acid hydrolysis reaction (Shak et al., 2018). Both types of nanocellulose (NC) have a high surface area, low density, good mechanical strength, and low coefficient of thermal expansion which make them very useful for various applications (Xie et al., 2018).

Market demand for NC is expected to increase with the potential largest utilization in packaging and paper applications (de Assis et al., 2017; Shatkin et al., 2014). Cowie et al. (2014) also predicted the market competition between CNC and CNF utilization in several sectors. Between these two types of NC, CNC is relatively easier to produce. Common inorganic acids, *e.g.*, sulfuric and hydrochloric acid can be used as hydrolysis agents in the CNC production process (Perumal et al., 2022). Furthermore, the latest techno-economic analysis conducted by Rosales-Calderon et al., (2021) showed that CNC fabrication via acid hydrolysis is competitive technically and economically.

Sulfuric acid is widely used to produce CNC since its product has good suspension stability due to the negative charge formed on the CNC surface (Xie et al., 2018). Through the sulfuric acid hydrolysis method, CNC has been produced from some biomass, such as rice straw, rice husk, and garlic straw (Johar et al., 2012; Kallel et al., 2016; Xu et al., 2018). CNC also has been fabricated from SPF waste through the sulfuric hydrolysis process (Ilyas et al., 2018). The process involved cellulose extraction from SPF biomass via alkaline pretreatment and bleaching process. Unfortunately, this process still comprised a chlorine-based bleaching method which is harmful to the environment. In contrast to acid or alkaline pretreatment, alkaline peroxide pre-treatment was performed at a more moderate setting (concentration, temperature) and atmospheric pressure, while still successfully removing lignin from a variety of agricultural leftovers (Ho et al., 2019).

Studies of peroxide-base bleaching treatment on SPF prior to cellulose microcrystal production were carried out by Saputro et al. (2017) and Lubis et al. (2018). To the best of our knowledge, the application of peroxide treatments on SPF followed by CNC production has not been conducted. Therefore, according to our previous study on cellulose extraction from SPF using peroxide-based bleaching treatment (Fitriana et al., 2020), in this study we intend to develop CNC production from SPF using more efficient operating condition, *e.g.*, lower temperature and higher solid/liquid ratio than a study carried out by Ilyas et al. (2021). Moreover, the effect of hydrolysis time on the production and characterization of CNC was also studied.

2. METHODS

2.1. *Materials*

Cellulose extracted from sugar palm fibre waste (C-SPF) was obtained from our previous work through alkaline and peroxide treatments with a hydrogen peroxide concentration of 15% (Fitriana et al., 2020). Sulfuric acid (95-97%, Merck) and distilled water were used as received.

2.2. *Cellulose Nano Crystal Fabrication*

The production of cellulose nanocrystal (CNC) was referred to previous work by Ilyas et al. (2018) with modification. Sulfuric acid at a concentration of 60% was used as a hydrolyzing agent and was pre-cooled prior to use. Sugar palm fibre cellulose(C-SPF) was mixed with a cold sulfuric acid solution at a solid/liquid ratio of 1:10 followed by stirring with a magnetic stirrer at 200 rpm. The temperature was then gradually increased to 40°C. Different hydrolysis times (45, 60, 75, and 90 minutes) were chosen to evaluate the effect of reaction time.

The hydrolysis process was stopped by adding distilled water to the mixture. The centrifugation procedure was conducted to separate CNC from sulfuric acid (5000 rpm, 10 minutes, 5°C). The suspension was then separated from the supernatant. The procedure was repeated five times followed by freezing the suspension overnight at a temperature of -20°C. Freeze drying of the frozen CNC suspension was then conducted at a temperature of -55°C for 20 hours. Each sample was given an NC-hydrolysis time code (NC-45, NC-60, NC-75, NC-90) and weighted to calculate the yield of each process.

$$\%Yield = \frac{m_{C-SPF} - m_{CNC}}{m_{C-SPF}} \; x\; 100 \qquad (1)$$

where $m_{C\text{-}SPF}$ was the mass of SPC cellulose and m_{CNC} was the mass of freeze-dried CNC. Furthermore, all samples were then stored in a sealed plastic bag until next used.

2.3. Characterization

The functional group analysis was conducted with Fourier Transform Infrared (FTIR) method (F. Jiang & Hsieh, 2013). FTIR spectra of cellulose from sugar palm fibre (C-SPF) and CNC of SPF (NC-45, NC-60, NC-75, NC-90) were recorded with Shimadzu IR Prestige-21 FTIR spectrophotometer. The sample was mixed with KBr powder to form a transparent pellet. Spectra analysis was conducted at a wavenumber of 4000-400 cm^{-1}.

X-ray diffraction (XRD) spectra were collected using PANalytical X'pert3 Powder with Cu Kα radiation (λ = 1.5406 Å). Diffractograms were scanned on 2θ value from 10° to 80° at step size 0.02°. The crystallinity index (CrI) was calculated based on the equation proposed by Segal, Creely, Martin, & Conrad (1959).

$$CrI = \frac{I_{002} - I_{am}}{I_{002}} \; x\; 100 \qquad (2)$$

This equation shows the relative value of CrI as a function of crystalline region maximum intensity (I_{002}) and amorphous peak intensity (I_{am}). The value of I_{002} is 2θ at around 22.6° (Ilyas et al., 2018) and I_{am} at around 18° (Segal et al., 1959).

The surface morphology of CNCs was observed with the scanning electron microscopy (SEM) method using Hitachi SU3500 at 5 kV acceleration voltage. A diluted CNC suspension was prepared and then the suspension was dripped into a carbon tape that stuck on a copper grid. The suspension was allowed to dry at room temperature for several days (Chen et al., 2017). Samples were coated with gold prior to analysis. Magnification was set at 500-25000 based on each sample condition to measure the diameter of the CNC particle.

3. RESULT AND DISCUSSION

3.1. Yield of Sugar Palm Cellulose Nano Crystal

The yield of sugar palm cellulose nanocrystal (CNC) at various hydrolysis times was presented in Table 1.

Table 1. The yield of sugar palm cellulose nanocrystal as a function of time

Time (min)	Yield (%)	
	This research	A study by Ilyas et al. (2021)
30	-	33.51
45	34.80	29.01
60	11.47	13.12
75	1.94	-
90	1.76	-

The other operating conditions were temperature of 40°C, solid/liquid ratio of 1:10 and sulfuric acid concentration of 60% with the raw material was peroxide-bleached sugar palm fibre (SPF). Meanwhile, Ilyas et al. (2021) conducted resemblant research but used sugar palm cellulose (SPC) obtained by chlorite bleached SPF with slightly different operating conditions at the temperature of 45°C and solid/liquid ratio of 1:20. Both results showed that the yield was inversely correlated with hydrolysis time.

Isolation of CNC from biomass generally consists of several steps, e.g., delignification, bleaching, and acid hydrolysis processes (Phanthong et al., 2018). Since cellulose consists of the crystalline and amorphous region, the removal of the amorphous region has occurred during the acid hydrolysis (Kim et al., 2015). However, the degradation of the crystalline region might happen during extended hydrolysis time, resulting in a decrease in CNC yield (Ilyas et al., 2021) as observed in this study.

The effect of hydrolysis time also revealed a drastic decrease in CNC yield to 1% at 75 and 90 minutes. This result was in agreement with previous research conducted by Ditzel et al. (2017) at a hydrolysis time of 90 minutes on the raw material of peroxide bleached pine wood and corn cobs, which yielded 2.3 and 6.0% CNC, respectively. Another study on CNC production of chlorite bleached rice straw also resulted in a CNC yields of 4.83 and 6.43% (Lu & Hsieh, 2012). There is no difference in CNC yield between chlorite and peroxide bleached biomass as raw material. Thus, the utilization of the peroxide bleaching method was preferred to the chlorite-based process because it is more environmentally friendly (Qasim et al., 2020), and this method can be utilized to produce cellulose from biomass as a raw material for CNC.

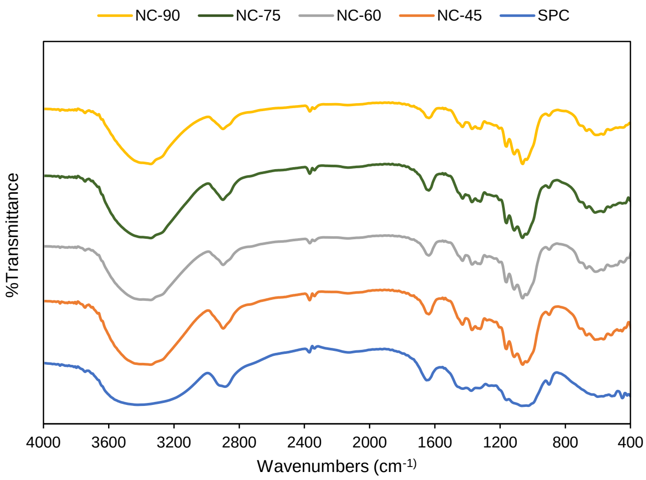

Figure 1. FTIR spectra of sugar palm cellulose (SPC) and sugar palm cellulose nanocrystal at various hydrolysis times (NC-45, -60, -75, -90)

3.2. Functional Group Analysis

The FT-IR spectra were carried out to characterize the chemical structure by identifying the functional group on the sample. Figure 1 shows the FTIR of the nanocellulose from the sugar palm (*Arenga pinnata*) fibres (NC) with various hydrolysis times. The bands near 3348 and peaks at 2900 were assigned to stretching vibration of OH, and aliphatic saturated C-H (Wang et al., 2017). The peaks at 1427 and 1319 cm^{-1} were assigned to the deformation vibrations bending and wagging of CH_2 (Zhao et al., 2019), respectively. The absorption peaks of 894 cm^{-1} were associated with the β-glycosidic linkage of cellulose (Zhao et al., 2018). There was an increase in intensity at an absorbance peak of 897 cm^{-1} in sugar palm cellulose (SPC) compared to NCs indicating enhancement purity of cellulose. The peak at 1635 cm^{-1} was attributed to the hydroxyl bending of absorbed water (Jiang et al., 2011).

It is noted that nanocellulose from the sugar palm fibres (NC) showed stronger and lower bands in OH stretching absorption than that of SPC. In addition, the nanocellulose had a stronger peak in OH stretching absorption than SPC. This result indicated that free hydroxyl groups were exposed on the surface of the nanocellulose due to the sulfuric acid hydrolysis. Furthermore, the absorption peaks that appeared at 1157 cm^{-1} and 609 cm^{-1} in NC-45, NC-60, NC-75, and NC-90 were assigned to the COS and S=O stretching vibrations, respectively. This finding reveals that the interaction between

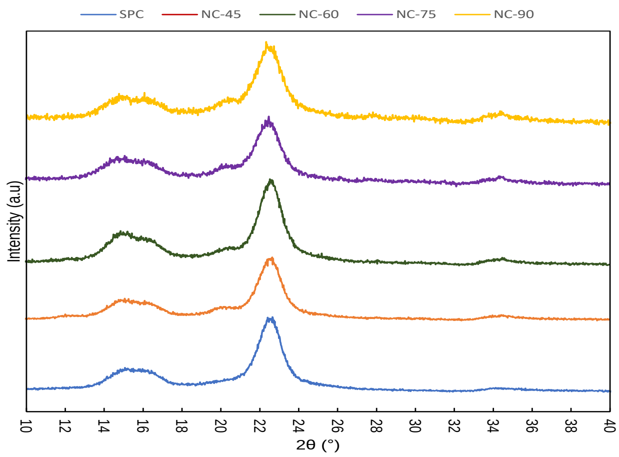

Figure 2. XRD diffractogram of sugar palm cellulose (SPC) and sugar palm cellulose nanocrystal at various hydrolysis times (NC-45, -60, -75, -90)

sulfuric acids and hydroxyl groups of nanocellulose generates acidic ester sulfate groups that are exposed on the surface of NCs (Meng et al., 2017).

3.3. Crystallinity Analysis

The crystallinity of sugar palm nanocellulose (NC) was observed by the X-ray diffraction (XRD) method. The XRD diffractogram was presented in Figure 2. All samples had similar cellulose type I plane patterns of (010) and (002) which were indicated by a peak at around 15° and 22.6°, respectively. These results are in line with the study of Ilyas et al. (2021). The results also showed the appearance of the lattice plane (021) at around 20° and this result is in accordance with the study of Park et al. (2010) after the conversion SPC to NC by sulfuric acid hydrolysis. Another lattice plane of (040) was also observed in all SPC cellulose nanocrystal diffractograms. This phenomenon was also observed in a previous study with the raw material of chlorite-bleached SPC and garlic straw (Ilyas et al., 2018; Kallel et al., 2016).

Meanwhile, the decrease of CrI during acid hydrolysis was also found in some previous studies with pine wood, corn cobs, and oil palm biomass as the raw material (Ditzel et al., 2017; Haafiz et al., 2014). This circumstance was caused by the degradation of the cellulose crystal phase (Teixeira et al., 2011). This was also probably due to the production of cellulose sulfate ester by the esterification reaction during sulfuric acid hydrolysis (Lu & Hsieh, 2010) which caused the decrease of CNC CrI (Haafiz et al., 2014; Tang et al., 2013).

Table 2. The crystallinity index of sugar palm cellulose nanocrystal as a function of hydrolysis time

Time (min)	Crystallinity Index (%)	
	This research	Previous study by Ilyas et al. (2021)
0	87.9	76.0
30	-	81.0
45	86.1	85.9
60	85.8	83.5
75	81.8	-
90	78.0	-

3.4. Morphological Analysis

The scanning electron microscopy (SEM) image size of NC is shown in Figure 3. The results of morphological observations showed that an increase in the hydrolysis time leads to a decrease in the nanocellulose diameter. Diameter measurements revealed that there would be some variation in fibre diameter for different treatments. A decrease in diameter was observed with increasing hydrolysis time. This phenomenon could be due to a longer reaction time during the hydrolysis treatment of the fibres, which removed amorphous regions from the nanofibres. Moreover, a longer hydrolysis duration may aggravate the nanocellulose structure (length and diameter). This is in line with the research of Ilyas et al. (2021) that the longer the hydrolysis time will produce smaller and shorter nanocellulose.

Unfortunately, the length of the nanocellulose cannot be determined because the fibres are stacked and overlap. This is most likely caused by the formation of interfibrillar hydrogen bonds (Deepa et al., 2015). SEM images also showed that after treatment, the diameter of sugar palm CNC was less than 100 nm at hydrolysis times of 75 and 90 minutes. The diameter size of NC-75 and NC-90 ranged from 22-66 nm. This result was in agreement with another study by Ilyas et al. (2021) which had CNC with an average diameter size of 25-37 nm based on a Field Emission Scanning Electron Microscopy (FESEM) image. According to Xie et al. (2018), CNC diameter size should be below 100 nm. Thus, based on SEM images NC-45 and NC-60 were not in the CNC size range but still in the size range of the cellulose microcrystals.

Meanwhile, a study by Ilyas et al. (2021) also showed the difference between diameter size measured by FESEM and Transmission Electron Microscopy (TEM). Their result showed an average diameter between 8-13 nm measured by TEM, which meant half to one-third compared to FESEM

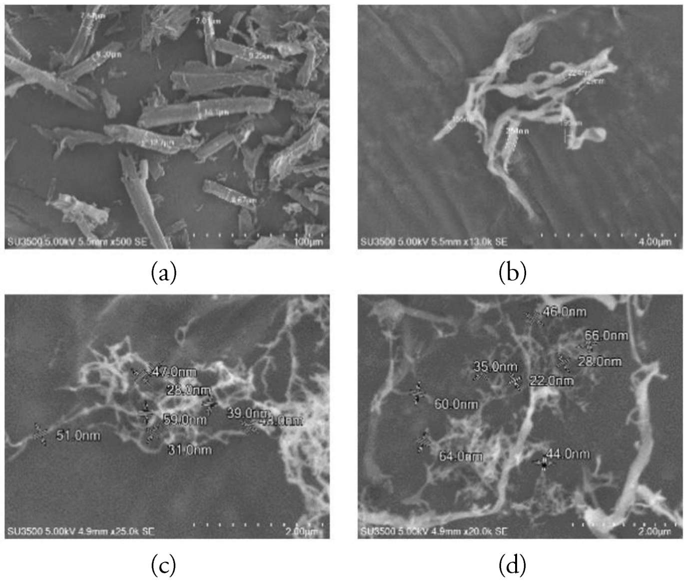

Figure 3. SEM image of sugar palm cellulose nano crystal at various hydrolysis time (a) 45; (b) 60; (c) 75; (d) 90 minutes.

measurement. Since the diameter of NC-60 was in a range of 129-254 nm according to SEM, it is suggested to measure by TEM in further studies

CONCLUSION

The production of cellulose nanocrystal (CNC) from peroxide bleached sugar palm fibre (SPF) waste was accomplished. All CNC produced by hydrolysis times of 45, 60, 75, and 90 minutes had similar functional groups and a high crystallinity index. The CNC yield decreased with increasing hydrolysis time. CNC with a diameter below 100 nm was obtained at hydrolysis times of 75 and 90 minutes. These results showed that the preparation of SPF cellulose by peroxide bleaching method followed by sulfuric acid hydrolysis could be an environmentally friendly alternative method to produce CNC. Furthermore, by involving the yield and crystallinity index results, further study on the hydrolysis time between 45 and 75 minutes can be performed to optimize not only the diameter size of CNC but also the yield and crystallinity index.

ACKNOWLEDGEMENT

This work was facilitated by Badan Riset dan Inovasi Nasional (BRIN).

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https://doi.org/10.32734/jtk.v1i2.1416

Vol. 13 No. 1 (2022) 43-52

Jurnal Riset
Teknologi Pencegahan Pencemaran Industri

Journal homepage : http://www.jrtppi.id

Kementerian Perindustrian
REPUBLIK INDONESIA

Rooftop PV Plant Development Planning at the Central Java Provincial DPRD Secretariat Office

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ARTICLE INFO

Article history:

Received 31 March 2022

Received in revised form 20 May 2022

Accepted 6 June 2022

Available online 27 June 2022

Keywords :

PV Plant

Rooftop

Solar Module

Government Building

Central Java

ABSTRACT

Central Java Province targets the achievement of the new and renewable energy (EBT) portion in the energy mix by 2030 at 22.55%. In order to achieve this target, the Central Java Provincial Government has consistently developed the use of EBT, one of which is through the construction of rooftop solar power plants (Rooftop PV Plant) in government buildings. In addition to requiring a fairly high initial investment cost, the construction of a Rooftop PV plant connected to the PT. PLN (Persero) requires a fairly complicated process, so proper planning must obtain optimal results. This paper will discuss an example of a Rooftop PV Plant development plan at the Secretariat Office of the Central Java Provincial DPRD, including the use of electrical energy prior to the installation of a Rooftop PV Plant; an analysis of the condition and availability of the location; the design and system of a Rooftop PV Plant; an estimate of the total potential energy that can generate; the investment costs of a Rooftop PV Plant; as well as evaluating the results of using Rooftop PV Plant. The electricity bill at the Central Java Provincial DPRD Secretariat Office prior to installing Rooftop PV Plant is Rp. 91.308.323,- per month. The recommended PV design, built on an area of 197 m2, is a rooftop on-grid PV Plant system with 6 PV arrays, each of which PV arrays are installed with as many as 20 solar modules arranged in series. The total number of solar modules installed is 120 solar modules with a total capacity equivalent to 30 kWp. Based on the simulation results using the PVSyst 6.4.3 software, the Rooftop PV Plant system can generate electrical energy of up to 43,420kWh per year or equivalent to 118.9kWh per day with a performance ratio of 79.4%. The potential for saving electricity costs from the simulation results can reach Rp. 4,034,441.- per month. The results of the evaluation of the utilization of the Rooftop PV Plant through the recording of the inverter monitoring system within 1 (one) year after installation shows the amount of electrical energy produced is 40,558 kWh, so that the manager of the Secretariat of the DPRD Central Java Province office can save a budget of Rp. 3,768,514.- per month from the use of the Rooftop PV Plant. This figure is not much different from the simulation results at planning. There is a difference in the cost savings of electricity payments at the Central Java Provincial DPRD Secretariat Office during 2020 of Rp. 4,493,300,- excluding savings due to the use of Rooftop PV Plant due to implementing the work from home (WFH) system during the COVID-19 pandemic, which resulted in a significant reduction in the use of electrical energy.

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doi : https://10.21771/jrtppi.2022.v13.no.1.p43-52

Accreditation number : (Ristekdikti) 158/E/KPT/2021

1. INTRODUCTION

Central Java Provincial Government's target access portion of new and renewable energy (EBT) in the energy mix (energy mix) in 2030 amounted to 22.55% (Pemerintah Provinsi Jawa Tengah, 2018). In order to achieve these targets, the Central Java Provincial Government has consistently developed the use of EBT, one of which is through the construction of rooftop solar power plants (PV Plant) in Government buildings. Also, in line with the mandate of the Peraturan Presiden Nomor 22 Tahun 2017 tentang Rencana Umum Energi Nasional in the form of the obligation to utilize solar energy at least 30% of the total roof area of Government buildings (Pemerintah Republik Indonesia, 2017). The construction of the Rooftop PV Plant in Government buildings can also be a means of socializing the general public to use renewable energy in daily life. People must realize the importance of saving fossil fuels and turn to alternative renewable energy to conserve natural resources, one of which is solar energy (Amalia, 2019).

As a form of seriousness in increasing the utilization of the Rooftop PV Plant, Central Java Province is committed to being a pioneer solar province (Central Java Solar Province) in collaboration with the Institute of Essential Services Reform (IESR), Asosiasi Energi Surya Indonesia (AESI) and the Ministry of Energy and Mineral Resources (Tumiwa & Simanjuntak, 2020). According to the data released by the Ministry of Energy and Mineral Resources, with a total solar energy potential of 8,753 MW (Direktorat Jenderal EBTKE, 2020), Central Java Province has at least a technical potential PV Plant on the roof of government buildings of 2.4 MWp, which comes from the Central Java Provincial Government office building and the Mayor's Office in Central Java (Institute for Essential Services Reform, 2021).

According to Peraturan Menteri Energi dan Sumber Daya Mineral Nomor 49 Tahun 2018 tentang Penggunaan Sistem Pembangkit Listrik Tenaga Surya Atap oleh Konsumen PT. Perusahaan Listrik Negara (Persero), Rooftop PV Plant System generates electrical energy using photovoltaic modules installed and placed on the roof, wall, or other parts of a building and channelled through the consumer electrical connection system PT. PLN (Persero) (Pemerintah Republik Indonesia, 2018). In addition to requiring a relatively high initial investment cost (Diantari, Erlina, & Widyastuti, 2018), distribution to the network of PT. PLN (Persero) requires a fairly complex process, so proper planning must be done to obtain optimal and reliable results (Hani, Santoso, Subandi, & Arifin, 2020). One of the essential things in planning the Rooftop PV Plant is to estimate the sun's potential on the roof surface of the building to know the amount of energy produced (Redweik, Catita, & Brito, 2013).

This paper will discuss an example of planning the construction of a Rooftop PV Plant in a Government building, namely the Central Java Provincial DPRD Secretariat Office. This building, also known as Gedung Setwan Jateng, is one of the Government's assets which is the identity and symbol of the development of the people of Central Java. Through good planning, it is hoped that the construction of one of the pilot projects Rooftop PV Plant, in the Central Java Provincial Government building can be successful. Some of the things that will discuss in this paper are related to the use of electrical energy in the building prior to the installation of the Rooftop PV Plant, analysis of the condition and availability of the location, design, and system of the Rooftop PV Plant, estimation of the total potential energy that can generate, Rooftop PV Plant investment costs, and evaluation of the results of Rooftop PV Plant utilization at the Central Java Provincial DPRD Secretariat Office.

2. METHODS

2.1. Library Studies

This method is used to know in-depth about the object of study through observation and review of technical documents, records, reports, and other documented data. Secondary data used in this study include regulations and policies related to Rooftop PV Plant, contract documents for Rooftop PV Plant construction, final reports on the implementation of Rooftop PV Plant construction, basic electricity tariffs, and data obtained through literature and journals related to the utilization of Rooftop PV Plant.

2.2. Field Observation

This method is used to collect data and information in the field through direct observation and measurement. Measurement activities in the field include measuring light intensity, measuring area, recording coordinates, and recording the production of electrical energy generated through an inverter. The work tools needed in field observations are listed in Table 1.

Table 1. Work tools

Tool	Function	Capacity
Lux Meter	Measures light intensity	0 to 999 lux
Measuring Tape	Measures an area	0 to 999 meters
Handheld GPS	Pick up location coordination point	-
Camera	Documenting field conditions	wide-angle, autofocus

2.3. Data analysis

This paper, a computer simulation to determine the estimated total potential energy generated carried out using the PVSyst 6.4.3 software. PVSyst is a software package developed by Swiss physicist Andre Mermoud and electrical engineer Michel Villoz which is used for the complete learning, sizing, and data analysis of a solar cell or photovoltaic (PV) technology systems. This method analyzes the measurement data to calculate the PV plant's potential energy through computer-based simulations to assess the Rooftop PV Plant system (Tarigan, Djuwari, & Kartikasari, 2015). Computer simulations were carried out to find PV Plant components and installation (Kumar, Kumar, Rejoice, & Mathew, 2017). Meanwhile, using the Rooftop PV Plant was evaluated using Microsoft Excel software.

2.3.1. Calculation of the potential capacity of the solar module

To determine the number of solar modules that can be installed and the maximum potential capacity of the PV Plant generator in each rooftop area, it can be calculated using equations (1) and (2) below:

$$\text{N modules} = \frac{\text{p area}}{\text{p module}} \text{ x } \frac{\text{l area}}{\text{l module}} \quad (1)$$

Where:

N modules = Number of solar modules
p area = Length of available rooftop area
p module = Length of solar module
l area = Width of the available rooftop area
l module = Width of solar module

$$\text{Peak Power} = \text{N modules} \times \text{P max modules} \quad (2)$$

Where:

Peak Power = Max. power capacity of Rooftop PV Plant
N modules = Number of solar modules
P max module = Max. power of a solar module used

2.3.2. Calculation of generating capacity

To calculate the peak power of the installed Rooftop PV Plant by the design that has been made, equation (2) can be used so that the following results are obtained.

2.3.3. Calculation of estimated potential energy yield per day

The calculation of the potential energy yield per day was carried out using the following equation (3):

$$E = \text{Peak Power x Peak Sun Hour} \quad (3)$$

Where:

E = Potential energy yield per day
Peak Power = Maximum power capacity of Rooftop PV Plant
Peak Sun Hour = Average adequate solar irradiation time

3. RESULT AND DISCUSSION

3.1. Use of Electrical Energy in Buildings Before Installing Rooftop PV Plant

Based on the identification and data collection results of electricity bill payment PT. PLN (Persero) every month at the Central Java Provincial DPRD Secretariat Office building for the last 1 (one) year shows the amount of electrical energy used in the building before the Rooftop PV Plant installation is 1,021,480kWh with the bill to be paid is Rp. 1,095,699,874,- in 1 (one) year or equivalent to Rp. 91.308.323,- per month, as can be seen in Table 2.

Table 2. The use of electrical energy before installing the Rooftop PV Plant

No.	Code	Payment Date	Rate	Power (Va)	Usage (kWh)	Total Bill (Rp.)
1	201901	16 Jan 2019	P2	865000	80.130	86.042.245
2	201902	13 Feb 2019	P2	865000	79.390	84.892.529
3	201903	13 Mar 2019	P2	865000	68.860	73.669.852
4	201904	11 Apr 2019	P2	865000	77.280	82.417.015
5	201905	13 May 2019	P2	865000	72.500	77.486.701
6	201906	17 Jun 2019	P2	865000	76.900	82.655.244
7	201907	9 Jul 2019	P2	865000	70.540	76.052.147
8	201908	12 Aug 2019	P2	865000	86.990	92.961.255
9	201909	11 Sept 2019	P2	865000	103.120	111.341.172
10	201910	10 Oct 2019	P2	865000	104.880	112.361.414
11	201911	12 Nov 2019	P2	865000	104.910	112.288.910
12	201912	10 Dec 2019	P2	865000	95.980	103.531.390
		Total			1.021.480	1.095.699.874

3.2. Analysis of Conditions and Availability of Rooftop PV Plant Construction Sites

The Central Java Provincial DPRD Secretariat Office is located on Jl. Pahlawan No. 7, Mugassari Village, South Semarang District, Semarang City, Central Java Province, precisely located at coordinates 6.993296 South Latitude and 110.420595 East Longitude.

3.2.1. Available area measurement

The total roof area of the building is 1,600 m2, but not the entire roof area can be used because there is an elevator control building and other objects, namely the outdoor unit from the air conditioning machine. It is necessary to measure the area used to install a Rooftop PV Plant using shop drawings from buildings, satellite imaging, and direct measurements in the field.

The results of direct measurements in the field of potential solar power areas based on overlays from shop drawings of buildings and satellite imaging are presented in Table 3 below:

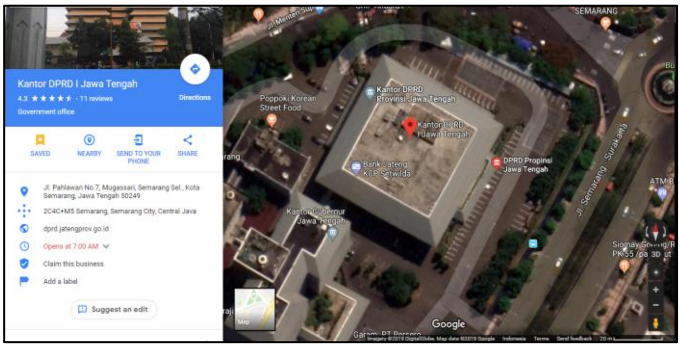


Figure 1. Location of the Central Java Provincial DPRD Secretariat Office based on Google Maps

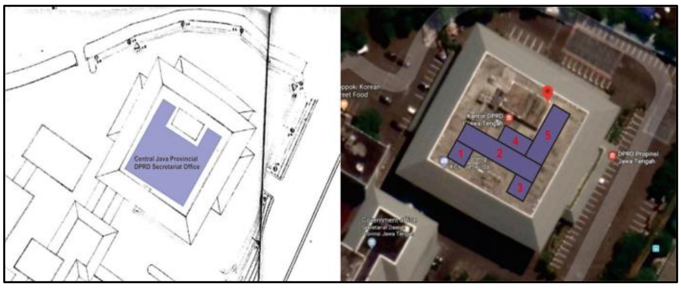


Figure 2. Solar potential area based on shop drawings and satellite imaging

Table 3. The results of the measurement of the rooftop area of the Central Java Provincial DPRD Secretariat Office

Zone	Length (m)	Width (m)	Area (m2)
1	9	9	81
2	32	6	192
3	9	9	81
4	12	6	72
5	15	9	135

Table 4. The results of the calculation of the maximum potential capacity of the solar module

No.	Length (m)	Width (m)	Area (m2)	Number of Modules (N)	Potential Peak Power (kWp)
1	9	9	81	49	12
2	32	6	192	116	29
3	9	9	81	49	12
4	12	6	72	44	11
5	15	9	135	82	20

*) Using 250Wp solar module size

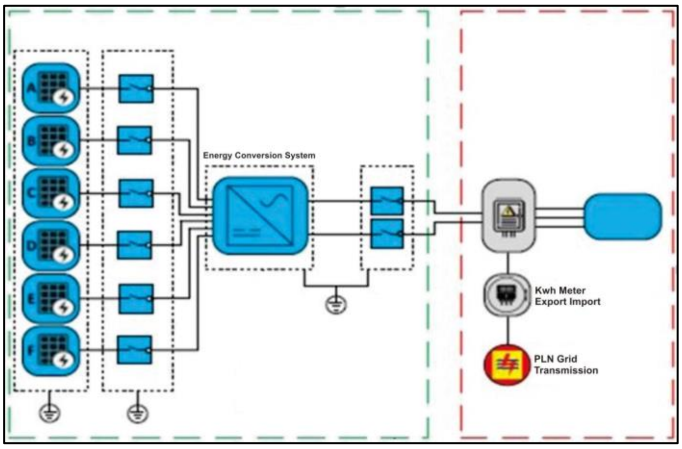


Figure 3. Rooftop PV Plant network topology on-grid system

3.2.2. Potential capacity of the solar module

Using the data on the length and width of each measured area, it is possible to determine the number of solar modules installed in the rooftop area. At this stage, the assumption is that each area will be covered entirely using a 250Wp solar module with dimensions of 1,650mm x 991mm (units and spare parts are often found in the market). To determine the number of solar modules that can be installed and the maximum potential capacity of PLTS generators in each rooftop area, it is calculated using equations (1) and (2) so that data on the number and maximum potential capacity of solar modules for each rooftop area is obtained as written in Table 4.

3.3. PV Plant Design and System

3.3.1. Rooftop PV Plant system topology

The topology of the Rooftop PV Plant system that is suitable for installation in the Central Java Provincial DPRD Secretariat Ofice is the topology of the Rooftop PV Plant grid-tie system or on-grid system, where the energy produced by solar modules is converted directly for consumption in the internal electricity network from the Office. If there is excess energy production, the rest will be sold to PT. PLN (Persero) through a bi-directional energy meter to reduce electricity bills (Rizkasari, Wilopo, & Ridwan, 2020). In simple terms, the topology of the Rooftop PV Plant system is as shown in Figure 3 below.

3.3.2. Determination of building block system

The type of solar module used as a design building block is 250Wp which is widely available. This can guarantee the availability of goods and after-sales services. The selected solar module is Conergy production type Conergy E 250P with 250Wp power in this simulation. In this plan, an inverter with grid-tie or on-grid capability used PT. PLN (Persero). This function aims to directly convert direct current (DC) energy from solar modules into alternating current (AC) energy which will then be used to operate the Central Java Provincial DPRD Secretariat Office. In this simulation, the inverter selected is Huawei Technologies' production type SUN2000-33k TL with a power of 30kWac. The inverter used has the term string-inverter, where the direct current input voltage (DC input voltage) has an extensive range with a maximum voltage of 1,000VDC. When designing a large generating capacity, solar modules can be connected in series (string). No current losses occur in the power transmission cable that connects the solar module with the string-inverter. The wiring configuration used is as many as 20 (twenty) solar modules arranged in series into a string to increase the voltage so that there is no current loss per string, as shown in Figure 4.

Furthermore, as many as 6 (six) strings of solar modules are arranged in parallel to increase the total current capacity, converted by the string-inverter into alternating current (AC) energy. With 20 (twenty) modules, the capacity per array is 5kWp. The layout of the solar modules per 5kWp array can be seen in Figures 5 and 6.

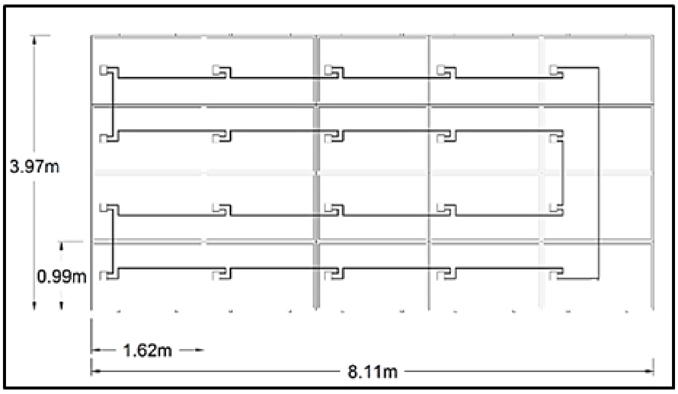


Figure 4. Solar module wiring diagram

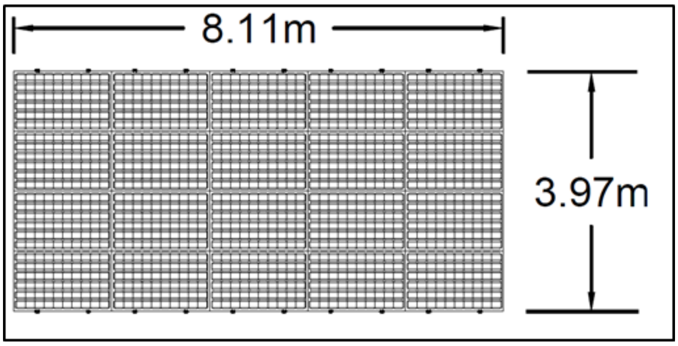


Figure 5. The layout of solar modules per 5kWp array array

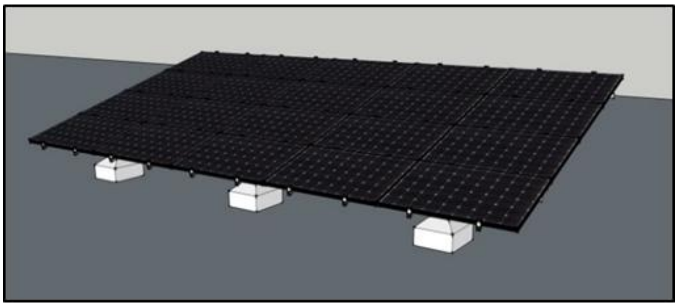


Figure 6. The 3D layout of solar modules per 5kWp array (angle/tilt 15o)

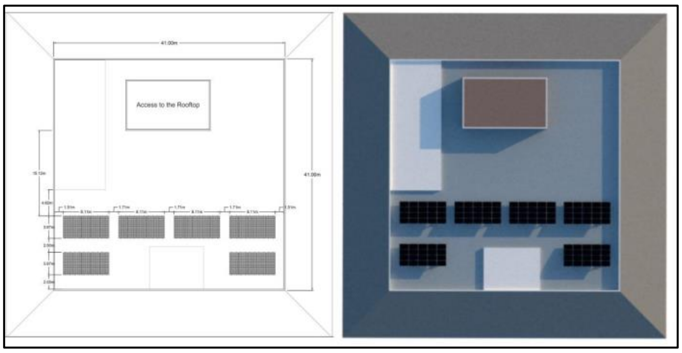


Figure 7. The layout of the placement of solar modules on the rooftop area of the building

3.3.3. Determination of the installation location of the solar module

In this plan, the area chosen for the placement of solar modules on the rooftop of the Central Java Provincial DPRD Secretariat Office took into account several factors, including:

1. The area is free from permanent shadings such as buildings and other buildings,
2. The area has the most optimal performance ratio compared to other prospective locations,
3. This area has the potential for additional solar module capacity in the future.
4. The area is adjacent to the location of the inverter system control room so that, technically, it does not cause losses in the wiring from the solar module array to the inverter.
5. This area can be used to install a Rooftop PV Plant and is visible from the outside of the building. It can also socialize the use of renewable energy, especially photovoltaic solar energy.

Based on the preceding, the most optimal areas for installing Rooftop PV Plants are areas 1, 2, and 3, 354 m2. They are symmetrical, are easy to maintain, and do not interfere with access routes in and out. Areas 4 and 5 can be used for other things, such as adding an outdoor air conditioning unit so that the design will focus on these three areas. The layout of the placement of solar modules in the rooftop area can be seen in Figure 7.

3.3.4. Generating capacity

Rooftop PV Plant design at the Central Java Provincial DPRD Secretariat Office in a predetermined area using 6 (six) PV arrays. Each PV array is installed with 20 (twenty) solar modules. The total number of solar modules installed is 120 (one hundred and twenty) solar modules with a 250Wp/solar module capacity. The calculation of the peak power of the Rooftop PV Plant generator installed following the design made using equation (2), and the peak power result is 30 kWp.

3.4. Estimated Potential Energy Yield Per Day

Based on the Rooftop PV Plant generation capacity obtained from the previous calculations, it is possible to calculate the energy potential generated every day. The calculation of the potential energy yield per day is carried out using equation (3) and using an estimate of the average adequate solar radiation time (peak sun hour) of 4 hours per day so that the potential for energy yields per day from Rooftop PV Plant at the Central Java Provincial DPRD Secretariat Office is 120kWh. The calculations above are estimates, wherein actual conditions, the energy yield per day may exceed or be less than the estimate. This is due to external factors such as weather, the condition of the PV Plant system (including solar module materials, inverter types, wiring installation materials, and circuits), and power consumption in the building. A computational simulation will use PVSyst 6.4.3 software for more detailed estimation results.

3.5. Shadow Analysis Simulation And Performance Ratio

The computational simulation using PVSyst 6.4.3 software includes a system loss diagram, energy yield, performance ratio, and shadow analysis. The performance ratio is obtained from the annual energy yield compared to the simulated generating capacity by considering the solar module's system losses, shading, location coordinates, direction, and slope. The simulation parameters used to adjust to the actual conditions in the rooftop area include:

1. The area to be installed solar modules,
2. The slope (tilt) of the solar module,
3. Orientation (azimuth) of the solar module,
4. The coordinates of the location are 6.993296 South Latitude and 110.420595 East Longitude,
5. The capacity of the solar module and inverter used,
6. The configuration of the solar module wiring was adjusted to the available area and the electrical parameters of the inverter.

All simulation parameter data entered into the PVSyst 6.4.3 software can be seen in Figure 8.

Shadow analysis simulation was carried out using the data mentioned above. The analysis results showed a shading factor with a value of 0 (zero), which means that there are no shadows from buildings around the installation location of the Rooftop PV Plant. This condition is beneficial because a good PV Plant placement must be free from permanent shadows (Mansur, 2019).

Based on the simulation results using PVSyst 6.4.3 software in Figure 11, the Rooftop PV Plant system at the Central Java Provincial DPRD Secretariat Office can produce electricity up to 43,420kWh per year, equivalent to 118.9kWh per day, with a performance ratio of 79.4%. Then the performance ratio is declared good because the results are included in the 70-90% value. Suppose adjusted to the Peraturan Menteri Energi dan Sumber Daya Mineral Nomor 28 Tahun 2016 tentang Tarif Tenaga Listrik yang Disediakan oleh PT. PLN (Persero), where for Government Offices and Public Street Lighting with a capacity above 200kVa, the basic electricity tariff per kWh is Rp. 1.115,- (Menteri Energi dan Sumber Daya Mineral, 2016), then the potential for large electricity cost savings felt by the manager of the Central Java Provincial DPRD Secretariat office in 1 (one) year can reach Rp. 48,413,300,- or equivalent to Rp. 4,034,441.- per month.

Grid-Connected System: Simulation parameters

Project :	**PLTS Rooftop Gedung DPRD I Jawa Tengah**			
Geographical Site	**Gedung DPRD I Jawa Tengah**		Country	**Indonesia**
Situation	Latitude	7.0°S	Longitude	110.4°E
Time defined as	Legal Time	Time zone UT+7	Altitude	50 m
	Albedo	0.20		
Meteo data:	**Gedung DPRD I Jawa Tengah**	Meteonorm 7.1 (2010-2014), Sat=100% - Synthetic		
Simulation variant :	**SUN2000 30kTL**			
	Simulation date	23/03/19 16h20		
Simulation parameters				
Collector Plane Orientation	Tilt	15°	Azimuth	-30°
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	Linear shadings			
PV Array Characteristics				
PV module Si-poly	Model	**Conergy E 250P**		
Original PVsyst database	Manufacturer	Conergy		
Number of PV modules	In series	20 modules	In parallel	6 strings
Total number of PV modules	Nb. modules	120	Unit Nom. Power	250 Wp
Array global power	Nominal (STC)	**30.0 kWp**	At operating cond.	26.80 kWp (50°C)
Array operating characteristics (50°C)	U mpp	538 V	I mpp	50 A
Total area	Module area	**197 m²**	Cell area	175 m²
Inverter	Model	**SUN2000-33k TL**		
Original PVsyst database	Manufacturer	Huawei Technologies		
Characteristics	Operating Voltage	480-800 V	Unit Nom. Power	30.0 kWac
Inverter pack	Nb. of inverters	1 units	Total Power	30 kWac
PV Array loss factors				
Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	180 mOhm	Loss Fraction	1.5 % at STC
Module Quality Loss			Loss Fraction	1.5 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05
User's needs :	Unlimited load (grid)			

Figure 8. Simulation parameter data using PVSyst 6.4.3. software

Status: Show existing table — Recompute

Plane orientation: Fixed Tilted Plane — **Tilt = 15°, Azimut = -30°**

Shading factor table (linear), for the beam component

Azimuth / Height	-180°	-160°	-140°	-120°	-100°	-80°	-60°	-40°	-20°	0°	20°	40°	60°	80°	100°	120°	140°	160°	180°
90°	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
80°	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
70°	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
60°	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
50°	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
40°	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
30°	0.042	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.123	0.167	0.167	0.042
20°	0.042	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.181	0.736	0.524	0.333	0.042
10°	0.042	0.005	0.000	0.000	0.000	0.000	0.014	0.055	0.056	0.016	0.000	0.000	0.000	0.000	0.406	1.000	0.881	0.500	0.042
2°	1.000	0.010	0.000	0.013	0.049	0.218	0.529	0.501	0.494	0.536	0.239	0.056	0.000	0.000	0.632	1.000	1.000	1.000	1.000

Shading factor for diffuse: 0.015 and for albedo: 0.430

Figure 9. Shading factor at the installation location of the Rooftop PV Plant

3.6. Rooftop PV Plant Investment Cost

The initial investment costs for the Rooftop PV Plant at the DPRD Secretariat Office of Central Java Province include costs such as solar module costs, inverter system costs, installation and distribution system costs, integrated monitoring system costs, grounding and lightning rod costs, as well as operating-worthiness certificate fees (SLO).), training, and documentation. The total initial investment costs incurred for installing a Rooftop PV Plant with a total capacity of 30kWp is Rp. 903.342.000,-. This fee is the contract value for constructing a Rooftop PV Plant at the Central Java Provincial DPRD Secretariat Office.

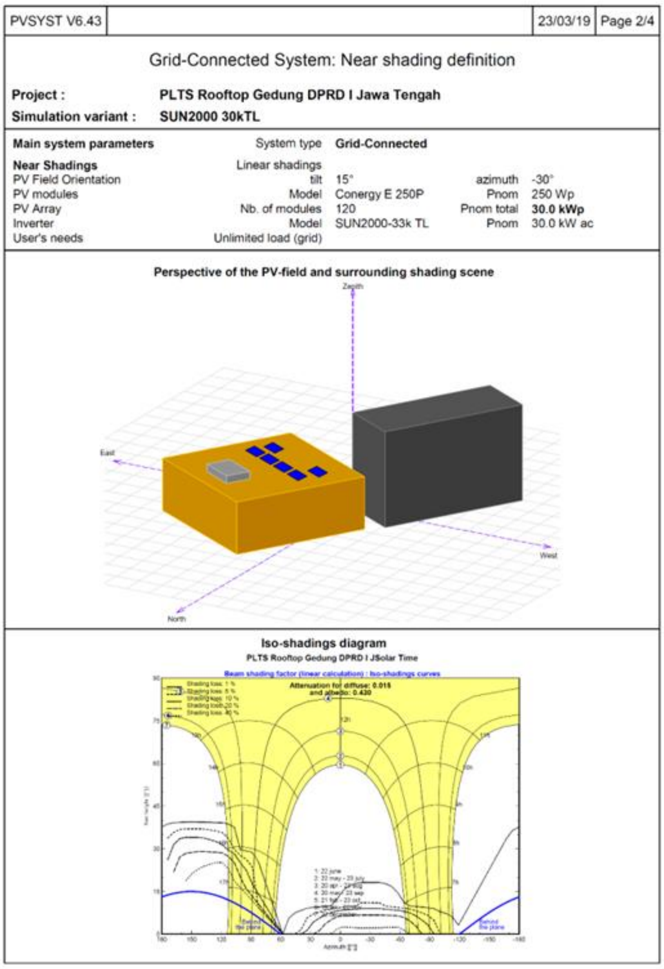
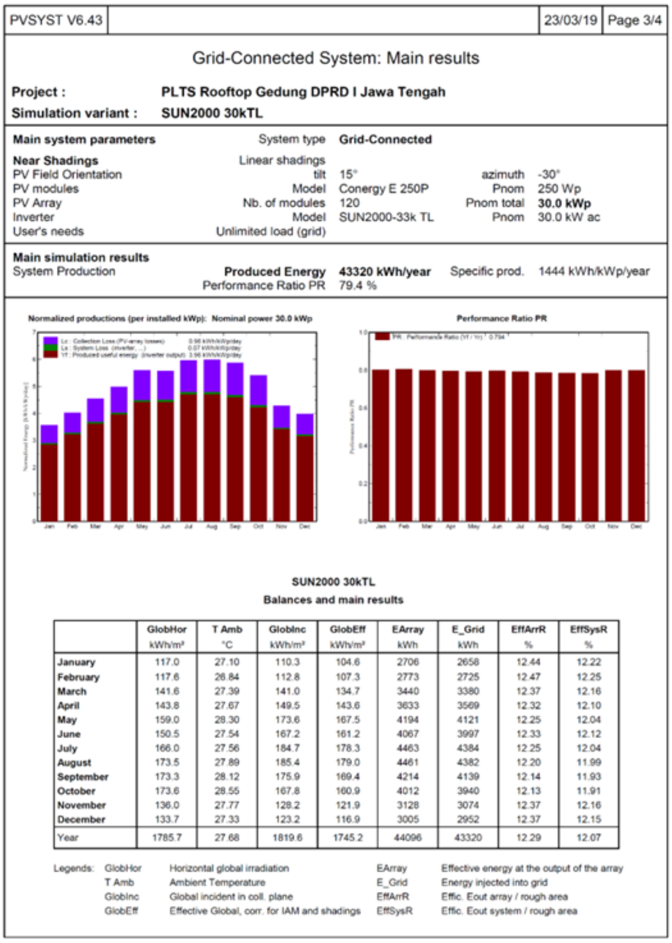


Figure 10. Shadow analysis simulation results using PVSyst 6.4.3. software

Table 5. Results of recording the production of electrical energy on the Rooftop PV Plant monitoring system

No.	Year	Month	Power Production (kWh)
1	2020	January	3,153
2	2020	February	2,999
3	2020	March	3,253
4	2020	April	3,311
5	2020	May	3,027
6	2020	June	3,188
7	2020	July	3,817
8	2020	August	4,113
9	2020	September	4,111
10	2020	October	3,544
11	2020	November	3,304
12	2020	December	2,739
	Total		40.558



	GlobHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh	E_Grid kWh	EffArrR %	EffSysR %
January	117.0	27.10	110.3	104.6	2706	2658	12.44	12.22
February	117.6	26.84	112.8	107.3	2773	2725	12.47	12.25
March	141.6	27.39	141.0	134.7	3440	3380	12.37	12.16
April	143.8	27.67	149.5	143.6	3633	3569	12.32	12.10
May	159.0	28.30	173.6	167.5	4194	4121	12.25	12.04
June	150.5	27.54	167.2	161.2	4067	3997	12.33	12.12
July	166.0	27.56	184.7	178.3	4463	4384	12.25	12.04
August	173.5	27.89	185.4	179.0	4461	4382	12.20	11.99
September	173.3	28.12	175.9	169.4	4214	4139	12.14	11.93
October	173.6	28.55	167.8	160.9	4012	3940	12.13	11.91
November	136.0	27.77	128.2	121.9	3128	3074	12.37	12.16
December	133.7	27.33	123.2	116.9	3005	2952	12.37	12.15
Year	1785.7	27.68	1819.6	1745.2	44096	43320	12.29	12.07

Legends: GlobHor Horizontal global irradiation; T Amb Ambient Temperature; GlobInc Global incident in coll. plane; GlobEff Effective Global, corr. for IAM and shadings; EArray Effective energy at the output of the array; E_Grid Energy injected into grid; EffArrR Effic. Eout array / rough area; EffSysR Effic. Eout system / rough area

Figure 11. Performance ratio simulation results using PVSyst 6.4.3. software

Figure 12. Results of recording the realization of the amount of power produced

Table 6. The use of electrical energy after the installation of the rooftop PV plant

No.	Code	Payment Date	Rate	Power (Va)	Usage (kWh)	Total Bill (Rp.)
1	202001	17 Jan 2020	P2	865000	88,020	94,494,209
2	202002	12 Feb 2020	P2	865000	82,434	88,057,873
3	202003	16 Mar 2020	P2	865000	76,506	82,193,286
4	202004	15 Apr 2020	P2	865000	81,450	87,129,814
5	202005	8 May 2020	P2	865000	77,450	82,914,189
6	202006	15 Jun 2020	P2	865000	64,930	69,568,164
7	202007	13 Jul 2020	P2	865000	88,020	93,779,521
8	202008	10 Aug 2020	P2	865000	71,180	76,678,793
9	202009	10 Sept 2020	P2	865000	77,010	82,836,505
10	202010	8 Oct 2020	P2	865000	86,490	92,448,544
11	202011	16 Nov 2020	P2	865000	67,690	72,722,114
12	202012	11 Dec 2020	P2	865000	68,838	73,735,107
		Total			930,018	996,558,119

3.7. Evaluation of the Results of Using Rooftop PV Plant

Evaluation of the results of the use of the Rooftop PV Plant carried out through identification and data collection of the realization of the amount of electrical energy produced by the Rooftop PV Plant in the Central Java Provincial DPRD Secretariat Office building through recording on the inverter monitoring system. The recordings carried out within 1 (one) year after installation show that the electrical energy produced is 40,558kWh. If calculated using the P2 tariff group (Government Offices and Public Street Lighting with a capacity above 200kVa), the basic electricity tariff per kWh is Rp. 1.115, -, then obtained a saving rate of Rp. 45.222.170,- or equivalent to Rp. 3,768,514.- per month. This figure is not much different from the simulation results using the PVSyst 6.4.3 software at planning. A detailed description of the amount of electrical energy produced by the Rooftop PV Plant in the Central Java Provincial DPRD Secretariat Office building, which is listed in the monthly data of the inverter monitoring system, can be seen in Table 5 and Figure 12.

4. CONCLUSION

The use of electrical energy in the Central Java Provincial DPRD Secretariat office building in the last 1 (one) year prior to installing the Rooftop PV Plant is 1,021,480kWh with a bill to be paid of Rp. 1,095,699,874,- or equivalent to Rp. 91.308.323,- per month.

The PV design recommended in 197 m2 is a Rooftop PV Plant system with 6 PV arrays in which 20 solar modules are installed in each PV array. The total number of solar modules installed is 120 solar modules with a capacity of 250Wp/solar module or a total capacity of 30kWp.

Based on the simulation results using the PVSyst 6.4.3 software, the Rooftop PV Plant system can generate electricity up to 43,420kWh per year or equivalent to 118.9kWh per day with a performance ratio of 79.4%. The potential for saving electricity costs from the simulation results can reach Rp. 48,413,300,- or equivalent to Rp. 4,034,441.- per month.

Furthermore, the recording and calculation of data on payment of electricity bills of PT. PLN (Persero) every month at the Central Java Provincial DPRD Secretariat Office building within 1 (one) year after the Rooftop PV Plant installation and obtained an electrical energy usage figure of 930,018kWh with a bill to be paid in the amount of Rp. 996,558,119,- in 1 (one) year or equivalent to Rp. 83,046,509,- per month, as can be seen in Table 6.

Based on the data above, there is a difference between the average monthly bill before and after installing the Rooftop PV Plant of Rp. 8.261.814,-. If you look at the savings in electricity payment costs from recording electrical energy production on the Rooftop PV Plant inverter monitoring system, which is around Rp. 3,768,514.- per month, there is a difference in cost savings of Rp. 4,493,300,- in 2020. This was due to the influence of the COVID-19 pandemic, which resulted in changes to the employee work system by implementing work from home (WFH) alternately, resulting in a significant reduction in the use of electrical energy in the Secretariat Office of the Provincial DPRD Central Java.

The results of the evaluation of the utilization of the Rooftop PV Plant through the recording of the inverter monitoring system within 1 (one) year after installation show the amount of electrical energy produced is 40,558 kWh, so that the manager of the Central Java Provincial DPRD Secretariat office can save a budget of Rp. 45.222.170,- or equivalent to Rp. 3,768,514.- per month from the use of the Rooftop PV Plant. This figure is not much different from the simulation results at planning.

Based on the realization of electricity bill payments within 1 (one) year after installing the Rooftop PV Plant, the electricity usage figure is 930,018kWh, with the bill to be paid Rp. 996,558,119,- or equivalent to Rp. 83,046,509,- per month. The difference between the average monthly bill before and after the Rooftop PV Plant installation is Rp. 8.261.814,-.There is a difference in the cost of electricity payments from saving the use of the Rooftop PV Plant with the realization of electricity payments during 2020 of Rp. 4,493,300, - due to the implementation of the work from home (WFH) system during the COVID-19 pandemic, which resulted in a significant reduction in the use of electrical energy at the Secretariat Office of the Central Java Provincial DPRD.

ACKNOWLEDGMENT

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