

Healthy-Smart Concept as Standard Design of Kitchen Waste Biogas Digester for Urban Households

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Abstract

This paper aims to analyse the healthy-smart concept as a standard design of kitchen waste biogas for urban people. The anaerobic digester (AD) is designed for family size. The planned vertical digester is a one-stage- semi-continuous type because this AD type is easy to operate in urban areas. Kitchen waste or food waste can be generalized as all bio-materials produced from kitchen activities (including vegetables, fruits, bread, rice, coffee ground, tea leaves, etc). The biggest problem with household waste is the non-uniformity of feedstock entering the digester biogas. Five steps will be carried out: to establish technical standards in designing kitchen waste; to calculate the biogas potential from kitchen waste; to simulate the methane demand and generation profile; to calculate the geometry of the biogas digester; and to analyse the operation parameter for gas production into the healthy-smart concept. With a simple simulation of two people in the household for 1 d, the results show that biogas produced from kitchen waste is sufficient for cooking purposes. For the healthy-smart concept of biogas production, some operation parameters must be considered, such as; pH, alkalinity, temperature, volatile fatty acid concentration, volatile solids, and C/N ratio. The results can be used in overcoming the urban household waste and also as a reference in sustainable urban planning.

Keywords: Biodegradation, Circular economy, Eco-friendly technology, Green energy, Methane capture, Municipal solid waste, Waste management, Welfare improvement

1. Introduction

The demand for renewable energy is increasing along with emission reduction campaigns by the use of fossil energy (Nizami *et al.*, 2020; Owusu and Asumadu-Sarkodie, 2016). Every alternative deserves to be explored regardless of scale so long as source availability exists. Countries like China, India, Indonesia, Pakistan, which have a big population, produce biomass energy sources from inhabitant activities (Abbasi and Abbasi, 2010; Helwani *et al.*, 2020; Khan and Khan, 2020). Humans

produce organic waste daily. In this case, organic waste is waste that can be converted into energy, such as agricultural waste, household kitchen waste, human waste (excreta disposal from septic tanks), animal waste, and so on (Adinurani *et al.*, 2018; Herry, *et al.*, 2020; Heryadi *et al.*, 2018; Heryadi *et al.*, 2019a; Heryadi *et al.*, 2019b, Leela *et al.*, 2018; Prabowo *et al.*, 2017; Syaifudin *et al.*, 2018a; Syaifudin *et al.*, 2018b; Setyobudi *et al.*, 2012a; Setyobudi *et al.*, 2012b; Setyobudi *et al.*, 2018; Setyobudi *et al.*, 2019). The term household kitchen waste is not limited to civilian household kitchen waste but includes food waste generated by hotel kitchens, restaurants, and

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also the waste food from supermarkets (Ramadhita *et al.*, 2021). Kitchen waste or food waste can be generalized as all bio-materials produced from kitchen activities (which include: vegetables, fruits, remains of food such as gravy, oils, bones, fish remains, bread, rice, coffee filters, coffee ground, tea bags, and tea leaves, etc. The Ministry of National Development Planning (Indonesian: *Kementerian Perencanaan Pembangunan Nasional Republik Indonesia*) (abbreviated Bappenas) states that food waste in Indonesia is $112 \times 10^6 \text{ t yr}^{-1}$ (Hidayat, 2021).

Anaerobic digester (AD) is one technology used to digest organic waste and produce energy as renewable energy (Adinurani *et al.*, 2017; Yusuf *et al.*, 2020). AD can be developed from small to large sizes for cooking or energy generation purpose. AD for cooking purposes is very popular for the rural people in China, Bangladesh, India, Indonesia, and Nepal. Mostly, the digester is supplied with animal dung, such as cow manure, chicken manure, and pig manure. On the contrary, AD is not so popular for urban people. Urban people may think of AD as dirty, impractical, and low technology for rural people.

AD can also be fed with organic waste that is generated greatly in an urban household. In other words, to supply the energy for cooking in an urban household, AD can be applied to produce biogas. One of the major components of organic waste in municipal solid waste (MSW) is household kitchen waste. But, this waste is non-uniformity that allows process instability in AD (Adinurani *et al.*, 2017; Setyobudi, *et al.*, 2015).

Based on studies from Shenzhen, family size and household income levels are the main factors affecting the production of household kitchen waste (Zhang *et al.*, 2018). Compared to wind and solar energy (Hendroko *et al.*, 2013; Slorach *et al.*, 2019), the electrical energy produced from AD requires lower energy. AD also has the potential to reduce toxicity, heavy metals, and pathogen. Unfortunately, AD has a higher global warming potential, mainly for methane capture. Biodegradation in AD is eco-friendly technology for welfare improvement through a circular economy because AD produces solid and liquid organic fertilizers (Setyobudi *et al.*, 2012a; Setyobudi *et al.*, 2012b).

For urban households, we focus on the healthy-smart concept as the standard design of kitchen waste. That means that it has to meet several criteria such as: being

odorless or non-pollutive to the air; the effluent liquid waste is non-pollutive to the surrounding water-source and soil; the gas can be used safely for cooking without leaking; no remaining waste in the process (all must be processed); modular systems for ease of installation, operation, and maintenance. We determined the digester was a one-stage- semi-continuous type with multiple feedstocks (household kitchen waste mixed with excreta disposal from septic tanks). However, this design can be changed to two stages if there are processing difficulties due to the diversity of feedstocks.

The process of methane with AD is explained in Figure 1. While acting on biodegradable materials in an anaerobic condition, the bacteria methanogenic can produce a mixture of gas, called biogas. The composition of biogas contains 50 % to 60 % CH_4 , 38 % to 48 % CO_2 , and the rest 2 % (H_2 , H_2S , etc.). To facilitate the conversion process, there are two key groups of bacteria (Khalid *et al.*, 2011; Setyobudi *et al.*, 2015). Group 1 acts as the fermenting bacteria. It uses extracellular enzymes. It works as successive fermentation of the hydrolyzed products. Through hydrolysis, it transforms the organic material into short-chain fatty acids. Alcohol, CO_2 , and H_2 are the other products of the fermentation process. The organic materials are transformed into advantageous ingredients for the bacteria during the process of hydrolysis. Group 2 acts as the acidogenic bacteria. It burns the short-chain fatty acids under the forming of H_2 , formic acid, acetic acid, and CO_2 . During the transformation processes, there are two additional groups of bacteria. Group 3 acts as the methanogen bacteria. It transforms the CH_3COOH , H_2 , and CO_2 into CH_4 . From the metabolism, it benefits more energy at high hydrogen concentrations. Group 4 acts as the homoacetogens bacteria. Under the production of CH_3COOH , it agitates a wide range of ingredients. Group 5 acts as the acetic acid oxidizers bacteria. If the H_2 is detached at the same time by other processes, it will oxidize the CH_3COOH to H_2 and CO_2 . The hydrolysing process becomes gradual when the biomaterial accommodates a high quantity of cellulose. The intensification of acetic acid plays a meaningful role in AD to produce CH_4 and CO_2 (Setyobudi *et al.*, 2013).

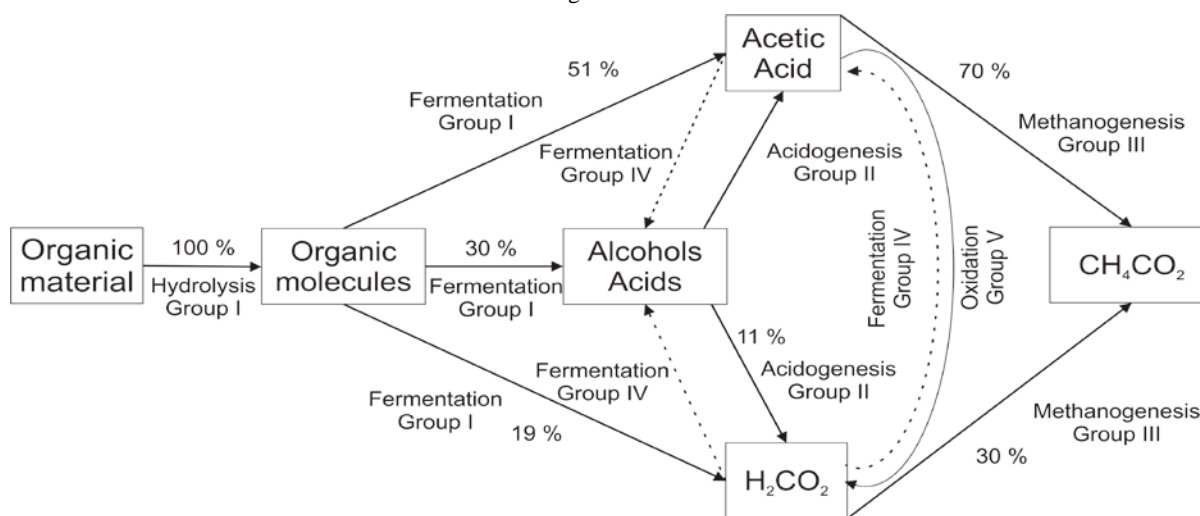


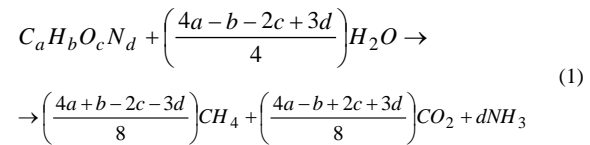
Figure 1. Schematic of the anaerobic process adopted (Poulsen, 2003)

A feasibility study of kitchen waste for biogas plants as an alternative energy source contributing around 50 % of total solid waste in urban areas has been carried out by Hanafi *et al.*, in 2016. As a feasible solution for low organic load and a decentralized strategy to improve MSW management, Muñoz (2019) suggested anaerobic digester food waste at psychrophilic temperatures. Alexander *et al.* (2019) analysed the domestic urban biogas digester to accomplish the brine decarbonisation of the system of energy. Tasnim *et al.* (2017) suggested combining cow manure with kitchen waste and other waste materials such as sewage. Rianawati *et al.* (2018) suggested the household scale biogas digester as the most feasible to be implemented due to the small amount of waste needed. Oguntoke *et al.* (2019) classified the positive proportions of bio-digestible waste based on the family size and income level of households in a city in Nigeria. Nwaigwe *et al.* (2018) estimated the potential of 0.7 kg household wastes per person per day generated in Johannesburg, South Africa. Gandhi *et al.* (2019) reported a lot of food waste from the different classes of hotels in Jaipur, India. Gaballah *et al.* (2020) reported that solar energy can be integrated with biogas digester to accomplish the ideal temperature for biogas production. Amir *et al.* (2016) studied some technical failures of AD to produce biogas due to the compliance of people. Curry and Pillay (2012) investigated the analysis of production with molecular formula and computer simulation for the AD model. Gebreegziabher *et al.* (2014) reviewed the potential, opportunities, challenges, and demanding conditions for the success of biogas in urban applications. Kjerstadius *et al.* (2015) studied how biogas production can increase more than 70 % compared with a conventional system with the source control systems. Igoni *et al.* (2008) synthesised the key issues design of a high-performance AD. Apte *et al.* (2013) identified the potential of biogas production based on the kitchen waste survey from several cities. Kayhanian and Hardy (1994) investigated the methane production rate as the contrary comparable to the moderate size of feedstock, the ratio of C/N organic, and the retention times. Clercq *et al.* (2016) reported the previous project of urban AD with food waste facing similar operational issues in China. Setyobudi *et al.* (2012a), Setyobudi *et al.* (2012b), and Herry *et al.* (2020) showed impacts one-stage, and two-stage AD in the circular economy on household scale biorefinery. Akkoli *et al.* (2015) created a more cost-effective, eco-friendly organic processing facility to generate biogas.

Based on the literature review above, there have been many studies with various topics related to biogas in urban areas. However, it seems that there is no clear healthy-smart concept for the standard design of kitchen waste biogas digesters for urban households. The purpose of this study is to analyse the healthy-smart concept as the standard design of kitchen waste biogas digesters for urban households. The digester is designed as family size, as one of the efforts in realizing national energy security, (Yandri *et al.*, 2017; Yandri *et al.*, 2020). Other goals to be achieved with AD are suppressing global warming, welfare improvement with a circular economy, and improving human health in urban areas (Herry *et al.*, 2020; Setyobudi *et al.*, 2012a; Setyobudi *et al.*, 2012b).

2. Materials and Methods

To achieve the objectives of this study, five steps were carried out, as follows; *First*, establishing the technical standards in designing kitchen waste biogas digesters for urban households. The standard becomes a reference in subsequent calculations. *Second*, calculating the biogas potential from kitchen waste with AD. The composition of typical waste organic matter is



Under standard conditions (0 °C, 1 atm), the specific theoretical methane yield (B_{th}), Nm³ CH₄ per ton volatile solids (VS), defined as agitation loss at 55 °C);

$$B_{th} = 22.4 \left(\frac{4a + b - 2c - 3d}{8} \right) / (12a + b + 16c + 14d) \quad (2)$$

Under anaerobic conditions, Lignin is formed from parts of organic material that cannot be broken down. The estimation of Biodegradable fraction (BF) for lignin content LC;

$$BF = 0.83 - 0.028LC \quad (3)$$

The formulation as a function of design for methane yield (B) per mass of COP or VS input;

$$B = \frac{B_0 S_0}{HRT} \left(1 - \frac{K}{HRT \mu_m - 1 + K} \right) \quad (4)$$

where: B_0 is the ultimate methane yield can be found by plotting the steady-state methane production against $1/HRT$ for different levels of HRT (hydraulic retention time) for a given constant temperature and extend the plot to infinity ($1/HRT = 0$). The input biodegradable substrate concentration, S_0 , in terms of chemical oxygen demand (COD):

$$S_0 = \frac{\text{Dry Matter} \times (1 - \text{Inert solids})}{Vol_{input}} \times BF \quad (5)$$

where; S_e = input biodegradable effluent substrate concentration S_e has relation with S_0

$$S_e = (1 - VS_{design}) \times S_0 \quad (6)$$

where; μ_m is the optimum growth rate of the bacteria in the biogas digester, can be estimated;

$$\mu_m = 0.013T - 0.129 \quad (7)$$

where; T and K are the temperature [°C] and the dimensionless kinetic parameter, respectively. The degree of digestion is controlled by HRT, as the reactor volume V_f is divided by input volumetric flow rate Q .

$$HRT = \frac{V_d}{Q} \quad (8)$$

Third, simulating the methane demand and generation profile for a household. The aim was to determine the potential kitchen waste generated and gas requirements in an urban household with several family members. *Fourth*, calculating the geometry of the biogas digester which be used to estimate the exact area requirement and

appropriate location for the biogas digester. *Fifth*, analysing the operation parameter for gas production into a healthy-smart concept, included site location, operational parameters, construction, effluent treatment, utilization: single/hybrid.

For analysis, there were some estimations and assumptions. The purposes were to know how much biogas demand and also how much kitchen waste will be generated for this family. The digestion processes determined the control of temperature. The mesophilic processes (30 °C to 40 °C) were operated by the experienced AD. Recently, thermophilic processes (50 °C to 60 °C) have become more common to use. Table 1 was used to estimate the chemical composition of input organic matter.

Table 1. Standard design for biogas digester

Parameter	Unit	Value	
Kitchen Waste	Estimate inert solid of dry weight	[%]	1
	The estimated water content of input weight	[%]	80
	The design water content of input weight	[%]	90
	Design dry matter weight	[%]	10
	Design biodegradable VS reduction eff.	[%]	80
Household	Biogas consumption for cooking	[Nm ³ /person d ⁻¹]	1
	Design cooking behaviour	[times d ⁻¹]	80
	Person supplied per unit digester	[persons/digester]	90
	Number of person per household	[person]	4
	Kitchen waste generation per person (wet)	[kg/person d ⁻¹]	1

3. Results

To know how much biogas can be produced from kitchen waste, some calculations were done to find several parameters. Using Table 1, the other parameters were calculated. Methane potential from kitchen waste was calculated using some steps. There were specified references to explain the chemical composition of the food waste. In this case, its chemical composition was considered so close to kitchen waste.

Table 2 used the weight percentage of organic atoms data for food waste. The chemical composition of kitchen waste was calculated by assuming it as food waste. The CH₄ yield kg⁻¹ of biodegradable VS degraded in the digester was calculated from Equation (1) and Equation (2).

Table 2. Design biogas potential from kitchen waste

Description	Unit	Calculation	Equation
Total Solid (TS) of actual input weight	kg d ⁻¹	0.8	
Water Content (WC) of actual input weight	kg d ⁻¹	3.2	
Water Content (WC)	kg d ⁻¹	7.2	
Volume input after dilution	m ³ d ⁻¹	0.008	
Constant mass flow rate, <i>m</i> (kg s ⁻¹) during 24 h	kg s ⁻¹	9.26 × 10 ⁻⁵	
Biodegradable Factor (<i>BF</i>)	kg m ⁻³	0.819	Eq.(3)
Input biodegradable substrate concentration <i>S_o</i>	kg m ⁻³	81.061	Eq.(5)
Input biodegradable effluent substrate concentration <i>S_e</i>	kg m ⁻³	16.212	Eq.(6)
Hydraulic Retention Time (HRT)	D	16	Eq.(8)
Methane yield kg ⁻¹ of biodegradable vol. solids <i>B_m</i>	Nm ³ kg ⁻¹ × VS	0.507	Eq.(2)
	Nm ³ d ⁻¹	0.329	
	Nm ³ h ⁻¹	0.014	
	Nm ³	0.4113	

Methane content in biogas was approximately 60 % of the total biogas volume. For initial estimation, the digester was designed for two persons. The needs of biogas for two persons must be supplied by the digester. Two persons also can produce 4 kg of kitchen waste (wet) to supply to the digester. This was the reason to make the digester small, easy to maintain, less space, and modular system. member of the family has also increased. Methane demand for a household that must be produced per digester was calculated as;

$$B_{design} = 0.25 \text{ Nm}^3 / \text{person} / \text{d} \times 60 \% \times 2 \text{ person} = 0.3 \text{ Nm}^3 / \text{d} \quad (9)$$

So, for one-time cooking, methane consumed by one person (*B_{con, person}*) was described in Equation (10).

$$B_{cons.person} = \frac{0.25 \text{ Nm}^3 / \text{d}}{3 \text{ cooking} / \text{d}} \times 60 \% = 0.05 \text{ Nm}^3 / \text{d} \quad (10)$$

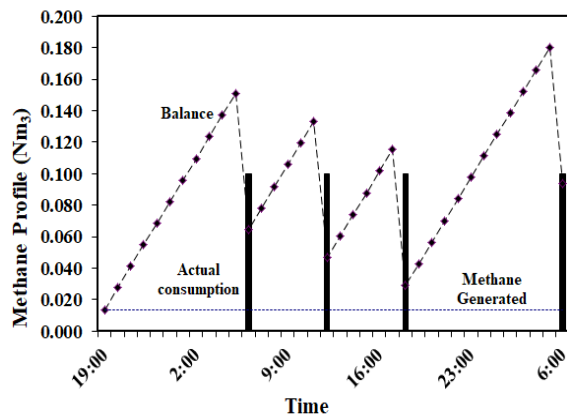


Figure 2. Methane generation and consumption profile vs time

Methane demand and generation profile was plotted by using data from the previous calculation as shown in Figure 2. The standard methane demand for cooking per person per day was 0.05 Nm^3 [3], which means 0.10 Nm^3 for two persons. Methane generated per hour by digester from the previous calculation was 0.014 Nm^3 . The total volume of the digester geometry:

$$V_{tot} = V_f + V_s + V_g \quad (11)$$

where: V_{tot} is the total digester volume, V_f is the fermentation chamber volume, V_s is the sludge chamber volume (assumed 5 % of V_f), V_g is the gas chamber volume (6 h to stored hourly biogas production from 18.00 to 06.00). The digester height was calculated as a cylinder. The design radius geometry of the cylinder was 0.25 m. Then, the digester height was also calculated, as shown in Table 3.

Table 3. Geometrical summary of the digester

Item	Volume (m^3)	Height (m)
Fermentation chamber	V_f 0.128	H_f 0.620
Gas chamber	V_g 0.140	H_g 0.033
Sludge chamber	V_s 0.006	H_s 0.699
Digester chamber	V_{tot} 0.274	H_{tot} 1.352

For the healthy-smart concept biogas production, some operation parameters must be considered, such as pH, temperature, alkalinity, volatile fatty acid (VFA) concentration, volatile solids, C/N ratio. Table 4 shows a summary of operational control for gas production. All parameters must be controlled by a computer-based instrument in real-time to produce optimal biogas with safe operation. For this reason, the control value of these parameters must be known by reference to existing standards, which must be ensured during the initial biogas digester testing.

Table 4. Summary of operational for gas production

Parameters	Controlled items	Optimum values
pH	Acid concentration vs buffer materials	refer to standard and testing
Temperature	Medium or high temperature	refer to standard and testing
Alkalinity	Acid concentration vs bicarbonate & fatty acid	refer to standard and testing
VFA	degradation of organic material into acetate and hydrogen	refer to standard and testing
VS	The degradation efficiency of output to input	refer to standard and testing
C/N	The amount of carbon and nitrogen	refer to standard and testing

4. Discussion

Based on what has been analysed so far, two things need to be discussed. The first issue concerns the design and operational parameters, which were very important to be understood and anticipated from the beginning. This means that, from the initial design stage, the cost, performance, and failure of biogas can be anticipated. The organic material will not be fully degraded if the HRT is too short, resulting in low gas yields and possible inhibition of the process. If the HRT is shorter than their rate of multiplication, this results in a washout of the methanogenic bacteria. The main contribution failures of biogas digester were caused by some factors, such as the unrealistic assumptions on bio-waste quantity quality, unsuitable AD designs and overestimation of economic returns from biogas, underestimation of the complex bio-waste supply chain (Breitenmoser *et al.*, 2019). The second issue concerns the layout area of urban households. Households in large cities are generally located in densely populated areas with small layouts. For this reason, the location of the biogas digester must be determined using certain analysis to minimize the environmental and social impact (Akther *et al.*, 2019). Both points must strongly adopt the defined healthy-smart concept.

This research discussed the concept of healthy-smart kitchen waste biogas digesters ideas for urban households. Our results are very useful in overcoming the problem of urban household waste that is used as a source of biogas energy. The results can also be contributed as a reference in sustainable urban planning, as well as the hi-tech cookstove concept (Yandri *et al.*, 2021). This concept can also be applied in other urban buildings, such as offices or campuses as a complement to green buildings and industries with energy efficiency (Purba *et al.*, 2021; Yandri *et al.*, 2020). For future research directions, the healthy-smart concept design of the kitchen biogas digester needs to be developed. It has to be complemented with the other studies, such as: how to analyse in detail the potential of biogas from a variety of kitchen waste materials in different cities, how to design an appropriate electronic or mechanical control system so that biogas digester operates with healthy and optimal conditions, and also how to get greener by utilizing renewable energy as energy mix from solar energy such as photovoltaic (PV) module (Faturachman *et al.*, 2021; Suherman and Astuty,

2020), or hybrid photovoltaic-thermal (PVT) collector to produce electricity and heat (Yandri, 2019). The initial target of implementation should be focused on established urban households, or hotel management that is considered more adaptable to the operating/technical system as required by advanced biogas technology.

However, the authors plan further studies on possible process instability in AD due to feedstock non-uniformity. Therefore, this follow-up study will expand the AD design by implementing a two-stage modification as has been carried out by Adinurani *et al.* (2017) and Setyobudi *et al.* (2015).

5. Conclusion

Kitchen waste as a source of urban waste can be processed by every household into biogas with biogas digester technology with a healthy-smart design concept. This design is very important in controlling the material to produce optimal biogas without causing effects on the environment, such as air and water pollution. Based on a simple simulation for two people in the household, the biogas produced from kitchen waste biogas digester is sufficient for a day's cooking purposes. With a vertical design, the total volume and height of a digester unit are 0.274 m³ and 1.352 m, respectively. If the need for biogas increases as the number of families increases, then the next units can be connected in parallel. For the healthy-smart concept biogas production, some operation parameters must be controlled properly, such as pH, alkalinity, temperature, volatile fatty acid (VFA) concentration, volatile solids, and C/N ratio. The results can be used in overcoming the problem of urban household waste that is used as a source of biogas energy, can also be contributed as a reference in sustainable urban planning.

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References

Abbasi T and Abbasi SA. 2010. Biomass energy and the environmental impacts associated with its production and utilization. *Renew. Sust. Energ. Rev.* **14**(3): 919–937.

Adinurani PG, Setyobudi RH, Nindita A, Wahono SK, Maizirwan M, Sasmito A, Nugroho YA, and Liwang T. 2015. Characterization of *Jatropha curcas* Linn. capsule husk as feedstock for anaerobic digestion. *Energy Procedia* **65**:264–273.

Adinurani PG, Setyobudi RH, Wahono SK, Mel M, Nindita A, Purbajanti E, Harsono SS, Malala AR, Nelwan LO, and Sasmito A. 2017. Ballast weight review of capsule husk *Jatropha curcas* Linn. on acid fermentation first stage in two-phase anaerobic digestion. *Proc. Pakistan Acad. Sci. B Life Environ. Sci.* **54**(1): 47–57.

Akkoli KM, Dodamani BM, Jagadeesh A, and Ravi C. 2015. Design and construction of food waste biogas plant for hostel mess. *Int. J. Sci. Res.* **3**(03): 101–104.

Akther A, Ahamed T, Noguchi R, Genkawa T, and Takigawa T. 2019. Site suitability analysis of biogas digester plant for municipal waste using GIS and multi-criteria analysis. *Asia-Pacific J. Reg. Sci.* **3**(1):61–93.

Alexander S, Harris P, and McCabe BK. 2019. Biogas in the suburbs: An untapped source of clean energy? *J. Clean. Prod.* **215**: 1025–1035.

Amir E, Hophmayer-Tokich S, and Kurnani TBA. 2016. Socio-economic considerations of converting food waste into biogas on a household level in Indonesia: The case of the city of Bandung. *Recycling* **1**: 61–88.

Apte A, Cheernam V, Kamat M, Kamat S, Kashikar P, and Jeswani H. 2013. Potential of using kitchen waste in a biogas plant. *Int. J. Environ. Sci.* **4**(4): 370–374.

Breitenmoser L, Gross T, Huesch R, Rau J, Dhar H, Kumar S, Hugl C, and Wintgens T. 2019. Anaerobic digestion of biowastes in India: Opportunities, challenges and research needs. *J. Environ. Manage.* **236**:396–412.

Curry N and Pillay P. 2012. Biogas prediction and design of a food waste to energy system for the urban environment. *J. Renew. Energy* **41**: 200–209.

De Clercq D, Wen Z, Fan F, and Caicedo L. 2016. Biomethane production potential from restaurant food waste in megacities and project level bottlenecks: A case study in Beijing. *Renew. Sustain. Energy Rev.* **59**: 1676–1685.

Faturachman D, Yandri E, Tri Pujiastuti E, Anne O, Setyobudi RH, Yani Y, Susanto H, Purba W, and Wahono SK. 2021. Techno-economic analysis of photovoltaic utilization for lighting and cooling system of ferry Ro/ro ship 500 GT. *E3S Web Conf.* **226**(00012): 1–10.

Gaballah ES, Abdelkader TK, Luo S, Yuan Q, and El-Fatah Abomohra A. 2020. Enhancement of biogas production by integrated solar heating system: A pilot study using tubular digester. *Energy* **193**(116758): 1–11.

Gandhi P, Kumar S, Paritosh K, Pareek N, and Vivekanand V. 2019. Hotel generated food waste and its biogas potential: A case study of Jaipur city, India. *Waste and Biomass Valorization.* **10**(6):1459–68.

Gebreegziabher Z, Naik L, Melamu R, and Balana BB. 2014. Prospects and challenges for urban application of biogas installations in Sub-Saharan Africa. *J. Biomass Bioenergy* **70**: 130–140.

Hanafi BM, Bhattacharjee L, Rahman SMR, and Basit MA. 2016. Application of kitchen waste in biogas system: a solution for solid waste management in Chittagong. In: *Proceedings of 3rd International Conference on Advances in Civil Engineering* p. 21–23.

Helwani Z, Fatra W, Fernando AQ, Idroes GM, and Idroes R. 2020. Torrefaction of empty fruit bunches: Evaluation of fuel characteristics using response surface methodology. *IOP Conf. Ser.: Mater. Sci. Eng.* **845**(1): 1–10.

Hendroko R, Liwang T, Adinurani PG, Nelwan LO, Sakri Y, and Wahono SK. 2013. The modification for increasing productivity at hydrolysis reactor with *Jatropha curcas* Linn. capsule husk as bio-methane feedstocks at two-stage digestion. *Energy Procedia* **32**:47–54.

Herry S., Roy H.S., Didik S., Syukri M.N, Erkata Y., Herianto H., Yahya J., Wahono S.K., Praptiningsih G. A. ,Yanuar N. and Abubakar Y. 2020. Development of the biogas-energized livestock feed making machine for breeders. *E3S Web Conf.*, **188** (00010): 1–13.

- Heryadi R, Uyun AS, Yandri E, Nur SM, Abdullah K, and Anne. O. 2019a. Biomass to methanol plant based on gasification of palm empty fruit bunch. *IOP Conf. Ser. Earth Environ. Sci.* **293(012036)**: 1–10.
- Heryadi R, Uyun AS, Yandri E, Nur SM, and Abdullah K. 2018. Palm empty fruit bunch gasification simulation in circulating fluidized bed gasifier. *E3S Web Conf.* **67**: 1–10.
- Heryadi R, Uyun AS, Yandri E, Nur SM, and Abdullah K. 2019b. Single-stage dimethyl ether plant model based on gasification of palm empty fruit bunch. *IOP Conf. Ser.: Mater. Sci. Eng.* **532(012009)**: 1–9.
- Hidayat AAN. 2021. Bapenas: without policy intervention, food waste is 112 million tons per year. *Tempo.Co.* June 9, 2021 [Internet] <https://bisnis.tempo.co/read/1470633/bapenas-tanpa-intervensi-kebijakan-sampah-makanan-112-juta-ton-per-tahun> (Accessed on June 20, 2021).
- Igoni AH, Ayotamuno MJ, Eze CL, and Ogaji SOT. 2008. Designs of anaerobic digesters for producing biogas from municipal solid waste. *Applied Energy* **85(6)**: 430–438.
- Kayhanian M and Hardy S. 1994. The impact of four design parameters on the performance of a high - solids anaerobic digestion of municipal solid waste for fuel gas production. *Environ. Technol.*, **15(6)**:557–567.
- Khalid A, Arshad M, Anjum M, Mahmood T, and Dawson L. 2011. The anaerobic digestion of solid organic waste. *Waste Manag.* **31(8)**: 1737–1744.
- Khan M and Khan H. 2020. Choice of alternative energy sources of farm households for cooking in rural areas of Peshawar. *Sarhad J. Agric.* **36(1)**: 367–374.
- Kjerstadius H, Haghighatafshar S, and Davidsson A. 2015. Potential for nutrient recovery and biogas production from blackwater, food waste and greywater in urban source control systems. *Environ. Technol.* **36(13)**: 1707–1720.
- Leela D, Nur SM, Yandri E, and Ariati R. 2018. Performance of palm oil mill effluent (POME) as biodiesel source based on different ponds. *E3S Web Conf.* **67(02038)**: 1–9.
- Muñoz P. 2019. Assessment of batch and semi-continuous anaerobic digestion of food waste at psychrophilic range at different food waste to inoculum ratios and organic loading rates. *Waste and Biomass Valorization* **10**: 2119–2128.
- Nizami A, Ali J, and Zulfiqar M. 2020. Climate change is real and relevant for sustainable development, an empirical evidence on scenarios from North-West Pakistan. *Sarhad J. Agric.* **36(1)**: 42–69.
- Nwaigwe KN, Agarwal A, and Anyanwu EE. 2018. Biogas potentials evaluation of household wastes in Johannesburg metropolitan area using the automatic methane potential test system (Ampts) II. In *ASME 2018 12th International Conference on Energy Sustainability collocated with the ASME 2018 Power Conference and the ASME 2018 Nuclear Forum*. American Society of Mechanical Engineers Digital Collection, p. 1–7.
- Oguntoke O, Amaefuna BA, Nwosisi MC, Oyedepo SA, and Oyatogun MO. 2019. Quantification of biodegradable household solid waste for biogas production and the challenges of waste sorting in Abeokuta Metropolis, Nigeria. *Int. J. Energy Water Resour.* **3**: 253–261.
- Owusu PA and Asumadu-Sarkodie S. 2016. A review of renewable energy sources, sustainability issues and climate change mitigation. *Cogent. Eng.* **3(1)**: 1–15.
- Poulsen TG. 2003. **Anaerobic Digestion – Solid Waste Management**. Aalborg University, Denmark.
- Prabowo B, Yan M, Syamsiro M, Setyobudi RH, and Biddinika MK. 2017. State of the art of global dimethyl ether production and it's potential application in Indonesia. *Proc. Pakistan Acad. Sci. B. Life Environ. Sci.* **54(1)**: 29–39.
- Purba W, Yandri E, Setyobudi RH, Susanto H, Wahono SK, Siregar K, Nugroho YA, Yaro A, Abdullah K, Jani Y, and Faturahman D. 2021. Potentials of gas emission reduction (GHG) by the glass sheet industry through energy conservation. *E3S Web Conf.* **226(00047)**: 1–12.
- Ramadhita AN, Ekayani M, and Suharti S. 2021. Do hotel restaurant consumers know the issue of food waste? *Jurnal Ilmu Keluarga & Konsumen* **14(1)**: 88–100.
- Rianawati E, Damanhuri E, Handajani M, and Padmi T. 2018. Comparison of household and communal biogas digester performance to treat kitchen waste, case study: Bandung city, Indonesia. *E3S Web Conf.* **73**: 1–4.
- Setyobudi, R.H., Tony L., Salafudin, Praptiningsih G.A, Leopold O.N., Yohannes S and Wahono S.K. 2012a. Synergy of bio-methane made from *Jatropha curcas* L. waste, and food in the implementation of sustainable food home area program. Prosiding Simposium dan Seminar Bersama PERAGI-PERHORTI-PERIPI-HIGI, Bogor, Indonesia, pp. 437–443.
- Setyobudi R.H., Tony L., Salafudin, Leopold O.N. and Wahono S.K. 2012b. Household scale biorefinery: Integration of renewable energy - biogas and food. Seminar Hasil Penelitian Semester Ganjil 2011/2012, Lembaga Penelitian, Pemberdayaan Masyarakat dan Kemitraan Universitas Darma Persada, Jakarta, Indonesia. pp. 1–13.
- Setyobudi RH, Sasmito A, Adinurani PG, Nindita A, Yudhanto AS, Nugroho YA, Liwang T, and Mel M. 2015. The study of slurry recirculation to increase biogas productivity from *Jatropha curcas* Linn. capsule husk in two-phase digestion. *Energy Procedia* **65**: 300–308.
- Setyobudi RH, Wahono SK, Adinurani PG, Wahyudi, Widodo W, Mel M, Nugroho YA, Prabowo B, and Liwang T. 2018. Characterisation of arabica coffee pulp - hay from Kintamani-Bali as prospective biogas feedstocks. *MATEC Web Conf.* **164(01039)**: 1–13..
- Setyobudi RH, Wahyudi A, Wahono SK, Adinurani PG, Salundik S, and Liwang T. 2013. Bio-refinery study in the crude *Jatropha* oil process: Co-digestion sludge of crude *Jatropha* oil and capsule husk *Jatropha curcas* Linn. as biogas feedstock. *Int. J. Technol.* **4(3)**: 202–208.
- Setyobudi RH, Zalizar L, Wahono SK, Widodo W, Wahyudi A, Mel M, Prabowo B, Jani Y, Nugroho YA, Liwang T, and Zaebudin A. 2019. Prospect of Fe non-heme on coffee flour made from solid coffee waste: Mini review. *IOP Conf. Ser. Earth Environ. Sci.*, **293(012035)**: 1–24.
- Slorach PC, Jeswani HK, Cuéllar-Franca R, Azapagic A. 2019. Environmental sustainability of anaerobic digestion of household food waste. *J. Environ. Manage.* **236**:798–814.
- Suherman E and Astuty EY. 2020. Designing a solar power plant model as an energy mix at Darma Persada University. *J. Phys. Conf.* **1469(012103)**: 1–6.
- Syaifudin N, Nurkholis, Handika R, and Setyobudi RH. 2018a. Formulating interest subsidy program to support the development of electricity generation from Palm Oil Mill Effluent (POME) biomass: An Indonesian case study. *MATEC Web Conf.* **164(01033)**:1–9.
- Syaifudin N, Nurkholis, Handika R, and Setyobudi RH. 2018b. The importance of credit program scheme on waste to energy program in Indonesia: Case study on tofu industry. *MATEC Web Conf.* **164(01032)**:1–10.

- Tasnim F, Iqbal SA, and Chowdhury AR. 2017. Biogas production from anaerobic co-digestion of cow manure with kitchen waste and water hyacinth. *Renewable Energy* **109**: 434–439.
- Yandri E, Ariati R, and Ibrahim RF. 2017. Improving energy security model through detailing renewable and energy efficiency indicators: A concept for manufacture industry. In: *Proceedings of the SIGER 2017 Universitas Lampung*, p. 9.
- Yandri E, Ariati R, Uyun AS, and Setyobudi RH. 2020. Potential energy efficiency and solar energy applications in a small industrial laundry: A practical study of energy audit. *E3S Web Conf.* **190(00008)**: 1–9.
- Yandri E, Novianto B, Fridolini F, Setyobudi RH, Wibowo H, Wahono SK, Abdullah K, Purba W, and Nugroho YA. 2021. The technical design concept of Hi-Tech cook stove for urban communities using non-wood agricultural waste as fuel sources. *E3S Web Conf.* **226(00015)**: 1–9.
- Yandri E, Setyobudi RH, Susanto H, Abdullah K, Nugroho YA, Wahono SK, Wijayanto F, and Nurdiansyah Y. 2020. Conceptualizing Indonesia's ICT-based energy security tracking system with detailed indicators from smart city extension. *E3S Web Conf.* **188(00007)**: 1–7.
- Yandri E. 2019. Development and experiment on the performance of polymeric hybrid Photovoltaic Thermal (PVT) collector with halogen solar simulator. *Sol. Energy Mater. Sol. Cells.* **201(110066)**: 1–11..
- Yusuf I, Arzai KI, and Dayyab AS. 2020. Evaluation of pre-treatment methods and anaerobic co-digestions of recalcitrant melanised chicken feather wastes with other wastes for improved methane and electrical energy production. *Jordan J. Biol. Sci.* **13(4)**: 413–418.
- Zhang H, Duan H, Andric JM, Song M, and Yang B. 2018. Characterization of household food waste and strategies for its reduction: A Shenzhen City case study. *J. Waste Manag.* **78**: 426–433.