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| RESEARCH ARTICLE

Performance of 200 Liter of Continuous Anaerobic Digester for Processing Animal Waste of Cattle Dung

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| ABSTRACT
This study aims to explore continuous anaerobic digesters that normally use cattle dung as a substrate. In this work, a 200-liter continues anaerobic digester was established to conduct the research. The digester was filled with mixture of cattle dung and water (50%:50%). The digester was operated in the batch system for about 1 month at the beginning. The digester was then operated by continuously feeding every day with 5 liter mixture of cattle dung and water (50%:50%) for 1 month observation. The digester was stirred during feeding time for easy flow of the substrate inside the anaerobic digester and also avoid the formation of scum. The biogas production was measured, methane and carbon dioxide composition were detected, and temperature inside digester as well as ambient temperature outside the digester was recorded. The pH inside the digester were measured to recognize the process that was involved. Biogas production is found to almost linearly increase with a rate around 15 liter/day. The average methane concentration is around 65.4 %. The average CO_2 content is found around 30.8%. The average temperature inside the digester is 33.6ºc and average ambient temperature outside digester is 30.1ºC. The average pH is found to be at a value of 6.7. The 200 liter continuous anaerobic digester is found sophisticated by feeding with 5 liter slurry of cattle dung every day.

| KEYWORDS

Performance, animal, waste, cattle dung, continuous, anaerobic, digester

| ARTICLE INFORMATION

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1. Introduction

There are four main processes that occur in the anaerobic process if using a batch system, namely hydrolysis, acidogenesis, acetogenesis, and methanogenesis. There are also other processes that also occur, namely sulfate and nitrate reduction which produce by-gases, namely ammonia or nitrogen. Hydrolysis reactions are facilitated by special extracellular enzymes produced by a consortium of hydrolytic bacteria. The hydrolysis process is a process of breaking down complex polymeric substrates (proteins, lipids and carbohydrates) into smaller monomeric compounds such as amino acids, sugars, and fatty acids. During the hydrolysis process, monomers are released. Monomers are then converted by acid-forming bacteria into hydrogen or formate, carbon dioxide, pyruvate, ammonia, volatile fatty acids, lactic acid, and alcohol. This process produces trace gases such as hydrogen sulfide (H_2S), hydrogen (H_2). While the main gases produced are carbon dioxide (CO_2) and methane (CH_4) [1,2].

The disadvantages of batch systems are, the quality of biogas is different every day, and at the beginning of the process the biogas cannot use as a fuel because of minimum or low methane content. Another disadvantage is by batch system, the waste cannot be processed daily. It developed then the continuous system of anaerobic digester that make it possible to process of organic waste daily with produce about high methane content of biogas so that can be used as a fuel daily and also can process the animal waste (cattle dung) daily. Unlike in batch systems, in continuous systems, the feeding volume and retention time must be studied carefully to produce optimum results because the four processes in the anaerobic digester (hydrolysis, acidogenesis, acetogenesis, and methanogenesis) will occur simultaneously. Various types of waste can be used as a substrate to produce biogas using anaerobic digester technology. Large amounts of lignocellulosic waste are generated from agricultural, municipal, and other activities. Common waste used in the energy industry is livestock waste, sewage sludge, municipal solid waste, and food waste [3].

2. Literature Review

Since animal manure contains methanogenic bacteria, it is not difficult to proceed with the use of animal dung in the anaerobic digester. Many projects were successfully in processing animal waste in anaerobic digester such as poultry [4], goat [5], elephant [6] and pig [7].

The use and development of biogas technology and biogas production to produce biomethane has been applied by various countries as an alternative to cogeneration internal combustion engines to produce electrical energy [8]. Household digesters could reduce the pressure on the environment by loss of cultivable land, soil erosion, greenhouse gas emissions, and reducing deforestation [9-11].

Large capacity biogas plants (natural rubber tube, floating-drum, and fixed-dome) were not attracted due to high investment costs, problematic access to spare parts as well as maintenance and difficulties in installing. This model has weaknesses, namely high costs, difficulties in transportation, lack of technical and labor skills in the field of biogas construction, operation, and maintenance work [12].

Many simple biogas constructions have been built to produce biogas, which is mainly used for cooking and lighting in India, China, Bangladesh, Vietnam, Pakistan, and Tibet. Most biogas digesters in these countries are made of concrete, plastic composite, bricks. All of these simple biogas constructions are without heating and also without stirring. Approximately 40% of CH_4 losses from small-scale digesters by emission from outlet and inlet, leaking from non-airtight gas valves, and intentional releases or broken/ cracked caps of digester [13].

In fixed-dome bio-digester, the design lacks agitation action that causes a slower anaerobic digestion reaction, which effects on volume of biogas produced. The gas pressure will fluctuate substantially depending on the volume of biogas stored which is invisible. Water particles get separated after some time and create two unusual layers [14]. Because it is underground, if such a leak, occurs in the digester construction, it would be difficult to repair. The leak certainly will cause the formation of the biogas process cannot take place as it should [15-17].

An improvement design from the fixed-dome bio-digester is a floating drum digester. A gasholder provides more space to store biogas with constant pressure. For this design, mild steel is commonly used to create the gas holder, making it less costly. The volume of stored biogas is visible directly as the drum rises when biogas is produced and moves down when it is consumed. The fixed dome type could last longer than the floating drum because the floating drum is not prone to corrosion [14,16,17].

Plug flow bio-digesters were introduced to separate two processes; therefore two-phase systems were produced, which are acetogenesis and methanogenesis longitudinally. Plug flow bio-digesters have a constant working volume [14].

A balloon bio-digester consists of a heat-sealed rubber bag or plastic, combining biogas storage and digestion parts. If the gas pressure exceeds the limit of the balloon's designed pressure, the balloon explodes. One limitation of this design is its shorter lifespan, which does not exceed 2–5 years [14, 17].

For optimum performance, anaerobic digestion depends on several different parameters. These parameters are: hydraulic retention time (HRT), Temperature, pH, mixing, C/N ratio, substrate, and Temperature [9,11]. The household digesters often stop use by people in the long run due to gas leakage, lack of knowledge, inadequate supply of substrate, low gas production, and slow recovery. A solution for these is needed. But it demands more research and development. For instance, straw is a potential substrate for household biogas digesters, [9].

This work specifically give attention to investigating the performance of 200 liter (0.2 M3) of anaerobic digester that was fed with 5 liter animal waste of cow dung every day. The information provided will be useful to understanding the process and utilization of the digester.

3. Methodology

In this work, around 200 liters of cylindrical continuous anaerobic digester was operated to conduct the research as presented in Fig. 1. The radius of the tank was around 270 mm with length around 875 mm. The tank is set horizontally. This type was established for ease of transportation of the digester to the site [18]. The digester was completed with a stirrer to mix the substrate. To facilitate the release of gas produced by bacteria to the biogas reservoir and also to mix methanogenic bacteria with substrates, biogas stirring is necessary. Stirring also reduces precipitation, preventing the formation of scum. Stirring increases both the biogas production and the degradation of organic compounds because it improves the hydrodynamics inside the reactor and the hydrodynamic has a great influence on mass transfer phenomena [19]. The advantages of making this mini-sized biogas digester are that it allows users to make repairs if something goes wrong at the time of manufacture and it has relatively low manufacturing cost. Mini-sized biogas digester can be a solution to energy shortages [15].

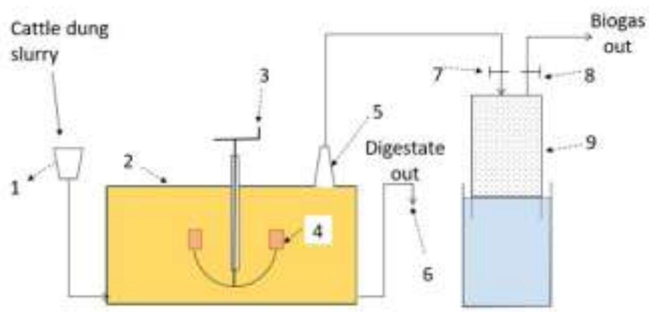


Figure 1. Schematic of 200 liter continuous anaerobic digester. 1. Inlet slurry, 2. Anaerobic digester tank, 3. Stirrer, 4. Agitator, 5. Biogas outlet 6. Digestate out, 7. Inlet biogas valve, 8. Outlet biogas valve, 9. Floating drum for biogas

The anaerobic digester tank in this research was using steel. The steel is easily corroded by hydrogen sulfide (H_2S) that is found in the biogas [11,14,17,20]. To overcome this problem, a small cut of magnesium metals was affixed outside the steel tank as a sacrificial anode to provide cathodic protection [21,22]. The most electrochemically active metal is Magnesium (Mg). This metal has very important uses in the field of engineering. Magnesium will immediately experience corrosion in certain environments. Magnesium metal and magnesium alloys are used to prevent corrosion through a sacrificial anode mechanism for structures made of steel such as pipelines and ship hulls [21].

As presented in Fig. 1, the anaerobic digester was filled with slurry in the inlet slurry (1). The digester tank (2) if filled full with slurry. The stirrer (3) was provided to rotate the agitator to make the slurry well mixed and flow from inlet (1) to outlet (6) during feeding the digester. The biogas was produced and collected in the floating drum (9) by opening inlet valve (7) and closing biogas outlet valve (8). If the biogas inside the floating drum will be used as a fuel, the inlet valve (7) should be closed and the outlet valve (8) should be closed.

The digester was operated in the batch system for about 1 month at the beginning. The digester was then operated by continuously added everyday with 5 liter mixture of cattle dung and water (50% : 50%) for 1 month. It is also the purpose of feeding was to keep supplying methanogenic bacteria in to the digester as an inoculum [23,24].
The source of cattle dung was from the species of Bali cattle (Bos javanicus). Bali cattle are an important livestock species for Malaysia and Indonesia because this livestock species reproduces easily, is very efficient even when fed with low-quality feed, and can adapt well to tropical areas [25].

For all process, the digester was stirred during feeding time for easy flow of the substrate inside the anaerobic digester and also avoid formation of scum [1]. Various researchers have observed the effect of stirring on anaerobic digesters on a laboratory scale and pilot scale. It was found that the anaerobic digester required an efficient and adequate stirring [26-28]. The system in this research is equipped with a stirrer. However, the stirring process is only carried out during feeding. This was done based on information from previous research which explained that minimal and intermittent stirring produced more biogas than if it was stirred continuously. This also means that performance will be better if stirred slowly compared to vigorously [29]. Also, too much mixing stresses the microorganisms. Without mixing, foaming and the formation of scum occur [1, 9]. Rapid mixing inhibits flock structure thereby disrupting the relationships between the nutrients of the organism (dystrophic). Meanwhile, stirring at medium speed was found to be optimal for substrate conversion [30].

The biogas production was measured and methane as well as carbon dioxide composition was detected. The data on pH and temperature inside and outside digester were provided to understand the process that may occur inside the digester. The biogas digester that was developed in this work, according to feed types was a continuous type. According to scale was a type of small-scale household [31], and it was from a dry digester [19].

4. Results and Discussion

The biogas production with cattle dung as a substrate is found to be almost linearly increase (with coefficient of determination R2=0.98) the biogas production rate is about 15.7 liter/day as is presented in Fig.2. The CH_4 content in the biogas is in the range of 41-78 % that is suitable for fuel [8,25,32,33] This condition is better if compared with a batch system in the same volume of a floating drum [19] that only can reach a maximum of 60.9% of methane yield.

The CH_4 content in the biogas only feeding with cattle dung is in the range 41-78 % which is suitable for fuel [25]. The methane is found about high level about 10 days range time. Methane is often targeted because it is well-pronounced in the characteristics of the gas [17]. This condition is better if compared with a batch system in the same volume of a floating drum [19] that only can reach a maximum of 60.9% of methane yield.

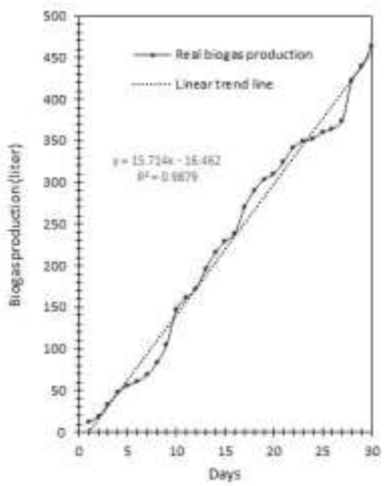


Figure 2. The biogas production rate is found linear about 15.7 liter/day

In the 200 L continuous anaerobic digester system developed in this study, methane gas was successfully formed. This shows that the system developed here successfully facilitates the methanogenesis process that produces methane. In fact, the system developed in this study successfully produces biogas with an average methane content of around 65.4% consistently. This is different from the batch system where at the beginning of the process methane gas will not be formed and will only be formed at the end of the process. This methane gas is formed through the acetogenesis process where in this process CO_2, acetate, and hydrogen gases are produced which are needed by methanogenic bacteria to be processed into methane [34]. It is found that the average CO_2 concentration in the biogas is about 30.8% with the lowest value is 22% and can reach the highest concentration of CO_2 at value 48%. The high CO_2 content in biogas reduces the combustion rate and the flammability limit. If biogas is used as fuel for an engine, CO_2 gas will fill more space in the combustion cylinder, requiring more energy for the compression process, which increases operating costs [35]. In this study, the CO_2 content was quite low, namely around 30.8%, so this system can produce biogas that can be used as engine fuel [25].

Temperature inside the digester for 30 days is presented in Fig. 5. The average temperature inside the digester if found 33.6°C with the lowest is 30°C and the highest is 37°C and. To be noted that the digester was operated in the tropical climate therefore the lowest ambient temperature was 25°C and the highest was 34°C and the average ambient temperature is 30.1°C. So the outside digester ambient temperature and temperature inside digester are in the range of mesophilic process [1]. For future work, to increase the temperature, the concept of a greenhouse coupled with a digester should be introduced for future work. In observations over a year, it was found that biogas production could increase by as much as 100% when the digester was placed in a greenhouse [36]. Anaerobic digestion is influenced by the concentration of hydrogen ions (pH) present in the digesting material. Because excess acidity prevents digestion, the hydrogen-ion concentration of the culture medium immediately influences microbial growth [11].

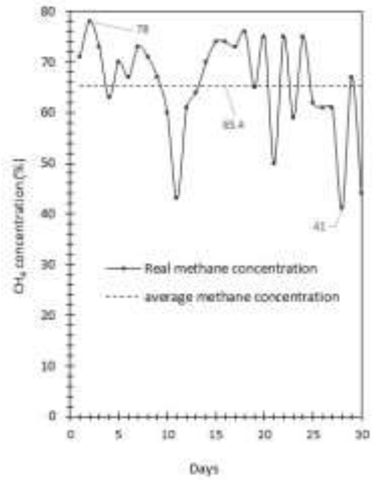


Figure 3. The methane (CH_4) content in the biogas. The lowest is 41% and the highest is 78%. The average is around 64.5%

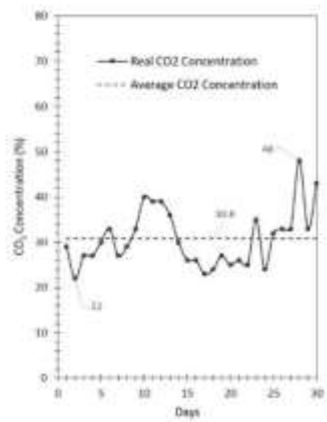
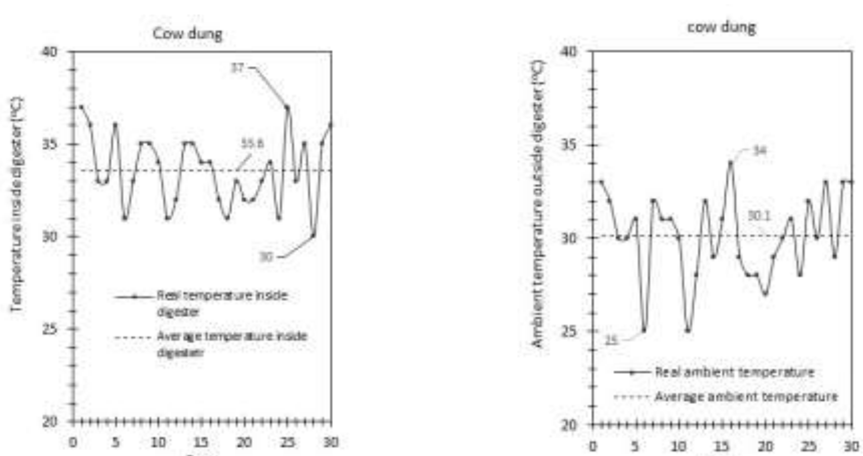


Figure 4. Carbon dioxide concentration in the in biogas that was produced in continuous aerobic digester feed with cattle dung

The pH for the system feeding with cattle dung is found swing up till 8.0 and down to 6.0 (Fig.6) with average value for 1 month is 6.7(Fig.3). This condition yield biogas with high CH_4 content. The swing in pH is indication that all process of anaerobic digestion (hydrolysis, acidogenesis, acetogenesis, and methanogenesis) to occur [1].



(a) (b)

Figure 5. Temperature Inside digester (a) and ambient temperature outside digester (b)

Methanogens thrive in neutral to slightly alkaline conditions and die in acidic environments. The optimum pH of the system is in the range of 7-8.5 [11], the nitrogen will be released and accumulate into ammonia which can raise the pH of the substrate [15].

Methanogens thrive in neutral to slightly alkaline conditions and die in acidic environments. The optimum pH of the system is in the range of 7-8.5, with values approaching 7 for optimal activity when the aerobic digestion process is stable. To overcome this situation the appropriate pretreatment should be discovered for suitable pH condition is achieved. The pretreatment could be thermal, chemical, or biological [3,37] which can be explored as future work of this research.

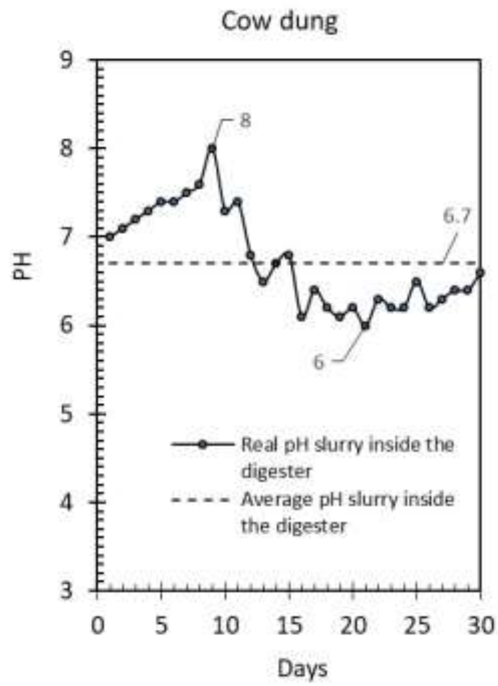


Figure 6. The pH of slurry inside an anaerobic digester

Concentration of the microorganisms ply as a vital role in anaerobic digester. In general, methanogenic microorganisms have a long regeneration time. To avoid being washed away from the reactor, hydraulic residence times must be at least 10-15 days if using a reactor that is not equipped with biomass storage and release [1].

Biogas production will be further improved if inocula (specialized microbial consortia) are used so that biogas production can be increased in anaerobic digesters. This can be achieved by using specialized inoculum obtained from raw pig slurry by implementing various innovations [38]. A unique and effective inoculum can be developed from wastewater treatment, thin stillage and agricultural waste with different retention time [39]. Other source of inoculum can be sewage sludge [24]. The ratio of inoculum and substrate should also become consideration [40]. In this work the ration of inoculum (cow dung) and substrate (waste cabbage) is 1:1. Other ratio should be introduce for future work. As other consideration, the inoculum can also be prepared from solid-state anaerobic digestion for substrate from empty fruit bunches, using recycling solid-anaerobic digested sludge and liquid-anaerobic digested sludge [41]. More complex method in preparing inoculum is by using rumen fluid. A flexible oral stomach tube with a metal strainer was inserted into the rumen, and the content was collected by suction [42]. Malaysia and Indonesia are countries that have produced a lot of palm oil products in the last decade and are used in various countries. The two countries produce 85% of the world's palm oil [43-45]. Anaerobic digestion for palm oil mill effluent (POME) is widely known for its potential in biogas production, and can be used as inoculum with cattle manure [46]. Therefore future work is addressed for finding suitable inoculum for enhance performance of processing waste of cattle dung in continuous anaerobic digestion.

Long-term acclimatization of anaerobic sludge is an example of this. It is carried out by operating mesophilic bacteria continuously and stirring in an anaerobic digester that is continuously filled with food waste and cow manure. During this long-term acclimatization, it was found that enzyme activity would increase continuously while the microbial structure tended to be stable and produced about 13 times more methane compared to the initial anaerobic sludge [24,47].The acclimatization even can introduce from other type of microorganism that is not related with established methanogenic bacteria in the system [48]. It is suggested acclimatization of the methanogenic bacteria in this work should experience acclimatization to enhance the performance of aerobic digester in producing higher CH_4 content in the biogas.

Rather than just throwing it away and causing environmental pollution and contamination, vegetable waste which is biomass residue can be used to produce bioenergy such as biogas, biohydrogen, bioethanol, and biodiesel. In this regard, this is a solution to various problems such as energy deficit, waste management, waste disposal and greenhouse gas emissions from incinerators, the emergence of unpleasant odors, protecting natural scenery and thousands of other problems. Despite the many benefits and potentials gained from converting fruit and vegetable waste into bioenergy, the technological developments available in processing fruit and vegetable waste for energy are very limited. This causes key stakeholders and active players in the global world to not have enough information to be involved in this area and no opportunity for scaling up [49]. Another thing that also needs to be considered is pre-treatment which has both advantages and disadvantages, especially if applied excessively causing a decrease in CH_4 content. It should be noted that various operational variations such as temperature, pH, carbon/nitrogen ratio, inoculum or correct types of microbes/substrate ratio, and particle size of feedstock are challenges where the values must be determined in the anaerobic digestion process [49]. Addition of vegetable waste in to the batch type of anaerobic digester was a common method that were practiced to processing organic waste and at the same times provide beneficial product of energy and fertilizer [50]. The addition of waste vegetable waste into the feeding system of continuous anaerobic digestion should be promoted for future work of this research.

Feedstock pretreatment is needed to prevent process failure. By applying pretreatment methods, the degradation of substrates can be optimized, thus efficiency can be obtained. Ways to accelerate the decomposition process can be done through chemical, thermal, mechanical, or enzymatic processes, although this does not always result in high biogas production which can be addressed for future work of this research [3]. Governments in various countries provide various funding for those who voluntarily build biogas installations. This program targets households, community groups such as farmer groups, and communities around forests [51]. From this viewpoint, the result of this research can be used as a consideration during the implementation of government programs.

5. Conclusion

For 200 liter continuous anaerobic digester system that is fed about 5 liter slurry of water and cattle dung (50%:50%) every day. The biogas production is found to almost linearly increase with a rate around 15 liter/day. The average methane concentration is around 65.4 % which is suitable as a fuel. The average CO_2 concentration is around 30.8%. The average temperature inside the digester is 33.6^oC and ambient temperature outside digester is 30.1^oC. The average pH is found in the value of 6.7 which is swing up till 8.0 and down to 6.0. This condition yields biogas with high CH_4 content. For more optimum results it is suggested that pretreatment of the waste of cow dung as well as addition of suitable inoculum, should be suggested as future work. Other concern for future work is acclimatization of methanogenic should be conducted for better results.

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References

[1] Deublein, D. & Steinhauser, A. (2011). *Biogas from Waste and Renewable Resources*, WILEY-VCH Verlag GmbH & Co. Weinheim. DOI:10.1002/9783527621705.

[2] Akunna, J.C. (2019). *Anaerobic Waste-Wastewater Treatment and Biogas Plants, Boca Raton*, Taylor & Francis Group, Boca Raton; https://doi.org/10.1201/9781351170529.

[3] Achinas, S., Achinas, V. & Euverink, G.J.W. (2017). A Technological Overview of Biogas Production from Biowaste, *Engineering*, 3(3), 299–307; https://doi.org/10.1016/J.ENG.2017.03.002.

[4] Marchioro, V., Steinmetz, R.L.R., Amaral, A.C.D., Gaspareto, T.C., Treichel, H. & Kunz, A. (2018). Poultry Litter Solid State Anaerobic Digestion: Effect of Digestate Recirculation Intervals and Substrate/Inoculum Ratios on Process Efficiency. *Frontiers in Sustainable Food Systems*, 2(46), 1-10. https://doi.org/10.3389/fsufs.2018.00046.

[5] Hanafiah, M.M., Ali, M.M.Y., Aziz, N.I.H.A., Ashraf, M.A., Halim, A.A., Lee, K.E. & Dris, M., (2017). Biogas Production from Goat and Chicken Manure in Malaysia. *Applied Ecology and Environmental Research*, 15(3), 529-535. DOI: 10.15666/aeer/1503_529535.

[6] Rangseesuriyachai, T., Boonnorat, J., Glanpracha, N., Khetkorn, W., Thiamngoen, P., Pinpatthanapong, K. (2023). Anaerobic Co-digestion of Elephant Dung and Biological Pretreated Napiergrass: Synergistic Effect and Kinetics of Methane Production. *Biomass and Bioenergy*, 175(106849), 1-11. https://doi.org/10.1016/j.biombioe.2023.106849.
[7] Gaworski, M., Jabłoński. S., Pawlaczyk-Graja. I., Ziewiecki, R., Rutkowski, P., Wieczyńska, A., Gancarz, R. & Tukaszewicz, M., 2017. Enhancing biogas plant production using pig manure and corn silage by adding wheat straw processed with liquid hot water and steam explosion, *Biotechnol Biofuels*, 10(259), 1-13. DOI: https://doi.org/10.1186/s13068-017-0922-x.
[8] Guimaraes, C.D.S. & Maia DRDS, (2023). Development of Anaerobic Biodigester for the Production of Biogas Used in Semi-Continuous System Bioprocesses: An Efficient Alternative for Co-Digestion of Low Biodegradability Biomass, *Biomass*, 3(1), 18–30. https://doi.org/10.3390/biomass3010002.
[9] Rajendran, K., Aslanzadeh, S. & Taherzadeh, M. J. (2012). Household Biogas Digesters—A Review. *Energies*, 5(8), 2911-2942. https://doi.org/10.3390/en5082911.
[10] Jegede, A. O., Zeeman, G. & Bruning, H. (2019), A review of mixing, design and loading conditions in household anaerobic digesters. *Critical Reviews in Environmental Science and Technology*, 49(22), 2117-2153. https://doi.org/10.1080/10643389.2019.1607441
[11] Banerjee, S., Prasad, N. & Selvaraju S. (2022). Reactor Design for Biogas Production-A Short Review. *Journal of Energy and Power Technology*, 4(1), 1-14: doi:10.21926/jept.2201004.
[12] Nguyen, V.C.N. (2011). Small-scale anaerobic digesters in Vietnam - development and challenges, *J. Viet. Env*. 1(1), 12-18. DOI: 10.13141/jve.vol1.no1.pp12-18.
[13] Pham, C.H.; Vu, C.C., Sommer, S. G. & Bruun, S. (2014). Factors Affecting Process Temperature and Biogas Production in Small-scale Rural Biogas Digesters in Winter in Northern Vietnam. Asian Australas. J. Anim. Sci., 27(7), 1050-1056. https://doi.org/10.5713/ajas.2013.13534.
[14] Zaki, M.B.A., Shamsudin, R. & Yusoff, M.Z.M. (2021). Portable Bio-digester System for Household Use — Areview. advances in agricultural and food research journal, 2(2), a0000148, 1-9. https://doi.org/10.36877/aafrj.a0000148.
[15] Randjawali, E. & Waris, A. (2016). Design and testing of mini-size biogas plant. *Journal of Physics: Conference Series*, 739(012038), 1-6. DOI 10.1088/1742-6596/739/1/012038.
[16] Budiman, I. (2020). The Role of Fixed-Dome and Floating Drum Biogas Digester for Energy Security in Indonesia, *Indonesian Journal of Energy*. 3(2), 83 – 93; DOI: https://doi.org/10.33116/ije.v3i2.88.
[17] Abubakar, A.M., (2022). Biodigester and Feedstock Type: Characteristic, Selection, and Global Biogas Production. *Journal of Engineering Research and Sciences*, 1(2), 170-187; DOI: 10.55708/js0103018.
[18] Taghinazhad, J., Abdib, R. & Adlc, M. (2017). Kinetic and Enhancement of Biogas Production for The Purpose of Renewable Fuel Generation by Co-digestion of Cow Manure and Corn Straw in A Pilot Scale CSTR System. *Int. Journal of Renewable Energy Development*, 6 (1) 37-44. DOI: https://doi.org/10.14710/ijred.6.1.37-44.
[19] Elsawy, K., Kadi, S., Elhenawy, Y., A Abdelmotalip, A. & Ibrahim, I.A. (2021). Biogas Production by Anaerobic Digestion of Cow Dung using Floating Type Fermenter. *Journal of Environmental Treatment Techniques*. 9(2), 446-451; DOI: 10.47277/JETT/9(2)451.
[20] Nindhia, T.G.T., Sucipta, I.M., Surata, I.W., Adiatmika I.K., Negara, D.N. K. & Negara, K.M.T. (2013). Processing of Steel Chips Waste for Regenerative type of Biogas Desulfurizer, *International Journal of Renewable Energy Research*, 3(1), 84-87. DOI (PDF): https://doi.org/10.20508/ijrer.v3i1.463.g6108.
[21] Pathak, S.S., Mendon, S.K., Blanton, M.D. & Rawlins, J.W., 2012. Magnesium-Based Sacrificial Anode Cathodic Protection Coatings (Mg-Rich Primers) for Aluminum Alloys, *Metals*, 2(3), 353-376. https://doi.org/10.3390/met2030353.
[22] Nindhia, T.G.T., Surata, I.W., Swastika, I.D.G.P. & Widiana, P. (2016). Processing Zinc from Waste of Used Zinc-Carbon Battery with Natrium Chloride (NaCl) for Biogas Desulfurizer. *Key Engineering Materials*, 705, 368-373. https://doi.org/10.4028/www.scientific.net/KEM.705.368.
[23] Maamri, S. & Amrani, M. (2014). Biogas Production from Waste Activated Sludge Using Cattle Dung Inoculums: Effect of total solid contents and kinetics study. *Energy Procedia*, 50, 352 – 359. https://doi.org/10.1016/j.egypro.2014.06.042.
[24] Bella, K. & Rao, P.V.(2022). Anaerobic co-digestion of cheese whey and septage: Effect of substrate and inoculum on biogas production, *Journal of Environmental Management*, vol. 308(114581): 1-11; DOI: 10.1016/j.jenvman.2022.114581.
[25] Nindhia, T.G.T., McDonald, M., Styles, D. (2021). Greenhouse Gas Mitigation and Rural Electricity Generation by a Novel Two-Stroke Biogas Engine. *Journal of Cleaner Production*, 280 (2),124473, 1-12. https://doi.org/10.1016/j.jclepro.2020.124473.
[26] Bridgeman, J. (2012). Computational fluid dynamics modeling of sewage sludge mixing in an anaerobic digester. *Advances in Engineering Software*, 44(1), 54–62; https://doi.org/10.1016/j.advengsoft.2011.05.037.
[27] Conklin, A.S., Chapman, T., Zahller, J.D., Stensel, H.D. & Ferguson, J.F. (2008). Monitoring the role of aceticlasts in anaerobic digestion: Activity and capacity. *Water Research*, 42(20), 4895–4904; https://doi.org/10.1016/j.watres.2008.09.024.
[28] Halalsheh, M., Kassab, G., Yazajeen, H., Qumsieh, S. & Field, J., (2011). Effect of increasing the surface area of primary sludge on anaerobic digestion at low temperature. *Bioresource Technology*, 102(2), 748–752. https://doi.org/10.1016/j.biortech.2010.08.075.
[29] Karapaju, P.L.N. & Rintala, J.A. (2008). Effects of solid-liquid separation on recovering residual methane and nitrogen of a digested dairy cow manure. *Bioresource Technology*, 99(1), 120–127. DOI: 10.1016/j.biortech.2006.11.046.
[30] Abdel-Hadi, M.A. & El-Azeem, S.A.M. (2008). Effect of heating, mixing and digester type on biogas production from buffalo dung. *Misr J. Ag. Eng*., 25(4),1454-1477; DOI: 10.21608/mjae.2008.190280.
[31] Rianawati, E., Damanhuri, E., Handajani, M. & Padmi, T., 2018. Comparison of Household and Communal Biogas Digester Performance to Treat Kitchen Waste, Case Study: Bandung City, Indonesia. *E3S Web of Conferences*, 73(010), 1-4. https://doi.org/10.1051/e3sconf/20187301019.
[32] Dana, IW.A.R., Lie, D., Adnyana IW.B., Nindhia, T.G.T., Khanal, S.K. & Nindhia, T. S. (2022). Comparison of Fuel Consumption and Emission of Small Two-stroke Engine of Electric Generator Fuelled by Methanol, Biogas, and Mixed Methanol-biogas. *Journal of Applied Engineering Science*, 20(4),1034-1039; https://doi.org/10.5937/jaes0-35699.
[33] Haryanto, A., Nindhia, T.G.T., Rahmawati, W., Hasanudin U, Saputrat W, Santosa AB, Tamrin and Triyono S. 2019. Effect of load on the performance of a family scale biogas-fuelled electricity generator. *IOP Conf. Series: Earth and Environmental Science*, 355 (012078), 1-11. DOI 10.1088/1755-1315/355/1/012078.

[34] Postawa, K., Szczygieł, J. & Kułażyński, M. (2021). Innovations in anaerobic digestion: a model-based study. *Biotechnol Biofuels*, 14(19), 1-11. DOI: https://doi.org/10.1186/s13068-020-01864-z.

[35] Aghel, B., Behaein, S., & Alobaid, F. (2022). CO2 capture from biogas by biomass-based adsorbents: A review. *Fuel*, 328, 125276, https://doi.org/10.1016/j.fuel.2022.125276.

[36] Sodha, M.S., Ram, S., Bansal, N.K. & Bansal, P.K. (1987). Effect of PVC greenhouse in increasing the biogas production in temperate cold climatic conditions. *Energy Conversion and Management*, 27(1), 83–90. https://doi.org/10.1016/0196-8904(87)90057-4.

[37] Mozhiarasi, V. (2022). Overview of pretreatment technologies on vegetable, fruit and flower market wastes disintegration and bioenergy potential: Indian scenario, *Chemosphere*, 288, Part 3 (132604),1-16. https://doi.org/10.1016/j.chemosphere.2021.132604.

[38] Marchetti, R., Vasmara, C. & Orsi, A. (2022). Inoculum Production from Pig Slurry for Potential Use in Agricultural Biogas Plants. *Sustainable Energy Technologies and Assessments*, 52, Part d (102310), 1-11. https://doi.org/10.1016/j.seta.2022.102310.

[39] Liu, T., Sun, L., Müller, B. & Schnürer, A. (2017). Importance of inoculum source and initial community structure for biogas production from agricultural substrates. *Bioresource Technology*, 245(part A), 768–777. https://doi.org/10.1016/j.biortech.2017.08.213.

[40] Owamah, H.I., Ikpeseni, S.C., Alfa, M.I., Oyebisi, S.O., Gopikumar, S., Samuel, O.D. & Ilabor, S.C., (2021). Influence of Inoculum/Substrate Ratio on Biogas Yield and Kinetics from The Anaerobic Co-digestion of Food Waste and Maize Husk. Environmental Nanotechnology, *Monitoring & Management*, 16(1005580), 1-10. https://doi.org/10.1016/j.enmm.2021.100558.

[41] Suksong, W., Mamimin, C., Prasertsan, P., Kongjan, P. & O-Thong, S., (2019). Effect of inoculum types and microbial community on thermophilic and mesophilic solid-state anaerobic digestion of empty fruit bunches for biogas production. *Industrial Crops & Products*, 133, 193–202. https://doi.org/10.1016/j.indcrop.2019.03.005.

[42] Sohail, M., Khan, A., Badshah, M., Degen, A., Yang, G., Liu, H., Zhou, J. & Long,R. (2022). Yak Rumen Fluid Inoculum Increases Biogas Production From Sheep Manure Substrate, *Bioresource Technology*, vol. 362(127801), 1-9. https://doi.org/10.1016/j.biortech.2022.127801

[43] Papilo, P., Marimin, M., Hambali, E., Machfud, M., Yani, M., Asrol, M., Evanila, E., Prasetya H., & Mahmud, J. (2022). Palm Oil-based Bioenergy Sustainability and Policy in Indonesia and Malaysia: A systematic review and future agendas. *Heliyon*, 8(10), (e10919), 1-17. https://doi.org/10.1016/j.heliyon.2022.e10919.

[44] Mahlia, T.M., Abdulmuin, M., Alamsyah, T.M. & Mukhlishien, D. (2001)' An Alternative Energy Source from Palm Wastes Industry for Malaysia and Indonesia. *Energy Convers. Manag*. 42(18), 2109–2118. https://doi.org/10.1016/S0196-8904(00)00166-7.

[45] Jayed, M.H., Masjuki, H.H., Kalam, M.A., Mahlia, T.M.I., Husnawan, M. & Liaquat, A.M. (2011). Prospects of Dedicated Biodiesel Engine Vehicles in Malaysia and Indonesia. Renew. Sustain. *Energy Rev*., 15(1), 220–235. https://doi.org/10.1016/j.rser.2010.09.002.

[46] Saidu, M., Yuzir, A., Salim, M.R., Salmiati, Azman, S. & Abdullah, N., (2013). Influence of Palm Oil Mill Effluent as Inoculum on Anaerobic Digestion of Cattle Manure for Biogas Production, *Bioresource Technology*, 141, 174–176. DOI: 10.1016/j.biortech.2013.03.111.

[47] Xinga, B.S., Hana, Y., Wanga, X.C., Caoa, S., Wena, J. & Zhanga, K. (2020). Acclimatization of Anaerobic Sludge with Cow Manure and Realization of High-rate Food Waste Digestion for Biogas Production, *Bioresource Technology*, 315(123830),1-12. https://doi.org/10.1016/j.biortech.2020.123830

[48] Wang, J., Cao, L., Liu, Y., Zhang, Q., Ruan, R. & Luo, X. (2021). Effect of Acclimatized Paddy Soil Microorganisms Using Swine Wastewater on Degradation of Rice Straw. *Bioresource Technology*, 332(125039), 1-8. DOI: 10.1016/j.biortech.2021.125039.

[49] Adamu, H., Bello, U., Yuguda, A.U., Tafida, U.I., Jalam, A.M., Sabo, A & Qamar, M. (2023). Production processes, techno-economic and policy challenges of bioenergy production from fruit and vegetable wastes. *Renewable and Sustainable Energy Reviews*. 186 (113686), 1-31; https://doi.org/10.1016/j.rser.2023.113686

[50] Lahbab, A., Djaafri, M., Kalloum, S., Benatiallah, A., Atelge, M.R. & Atabani, A.E. (2021). Co-digestion of vegetable peel with cow dung without external inoculum for biogas production: Experimental and a new modelling test in a batch mode. *Fuel*, 306(121627),1-9. https://doi.org/10.1016/j.fuel.2021.121627.

[51] Budiman, I. (2021). The complexity of barriers to biogas digester dissemination in Indonesia: challenges for agriculture waste management. *Journal of Material Cycles and Waste Management*, 23, 1918–1929; https://doi.org/10.1007/s10163-021-01263-y.