Istraživanja i projektovanja za privredu
ISSN 1451-4117
DOI:10.5937/jaes0-35699
www.engineeringscience.rs

iipp publishing

Journal of Applied Engineering Science
Vol. 20, No. 4, 2022
Original Scientific Paper
Paper number: 20(2022)4, 1009, 1034-1039

COMPARISON OF FUEL CONSUMPTION AND EMISSION OF SMALL TWO-STROKE ENGINE OF ELECTRIC GENERATOR FUELLED BY METHANOL, BIOGAS, AND MIXED METHANOL-BIOGAS

I Wayan Agus Rantia Dana[1], David Lie[1], I Wayan Bandem Adnyana[2] Tjokorda Gde Tirta Nindhia[3]*, Samir Kumar Khanal[4], Tjokorda Sari Nindhia[5]

[1] *Master Student at Study Program of Master in Mechanical Engineering, Engineering Faculty, Udayana University, Denpasar, Bali, 80234, Indonesia*
[2] *Study Program of Industrial Engineering, Engineering Faculty, Udayana University, Jimbaran, Bali,80361, Indonesia*
[3] *Study Program of Mechanical Engineering, Engineering Faculty, Udayana University, Jimbaran, Bali,80361, Indonesia*
[4] *Dept. of Molecular Biosciences and Bioengineering, the University of Hawaii at Manoa, Honolulu, Hawaii, 96822, USA*
[5] *Faculty of Veterinary Medicine, Udayana University, Denpasar, Bali, 80234, Indonesia*

** tirta.nindhdia@me.unud.ac.id*

A two-stroke engine run with flexible fuel of biogas or methanol is not established yet. It is the objective of this work to provide 2 stroke engine for an electric generator that can be run by using flexible fuels namely: methanol, biogas, and mixed methanol-biogas. A small single cylinder 2 stroke engine of an electric generator was set to be able to be fuelled by using 3 different types of fuel namely biogas (50% vol. CH_4, 15% vol. CO_2, 0 ppm H_2S), methanol (CH_3OH) with 97% vol. purity and mixed biogas-methanol. The electric generator that is used is for providing 750-watt electricity. The compression pressure was around 10 Bar with cylinder volume around 63 cc. The engine was set with an easy switch system of fuel. Since methanol is used as one type of fuel that is used, then special lubricant should be prepared for this purpose. It is generally known that commercial synthetic lubricant that is usually used and mixed with gasoline for 2-stroke engines is found not well mixed with methanol. The castor oil is selected to be used as a lubricant to be mixed with methanol with a ratio of methanol to castor oil of 50:1. During using only biogas as a fuel, the castor oil was dripped around 3 drops/minute in the biogas-air mixer chamber. The emission, as well as fuel consumption, were investigated both in idle position and loaded at 200 watts. It is found that for only biogas fuel, the fuel consumption is 18.83 L/minute and increases to become 15, 17 L/minute at a load of 200 watts. By using only methanol as a fuel, the fuel consumption is found 0.009 L/minute and increases to become 0.011 during loading at 200 watts. If mixed fuel is applied the biogas consumption becomes 2.06L/minute in idle position and 4.43 L/minute at a load of 200 watts. The lowest CO emission in idle position was found with biogas as fuel at 0.18 % vol., followed by mixed fuel biogas+ methanol at 0.26% vol. and the highest is methanol fuel at 0.25%vol. for a load of 200 watts, the lowest CO emission is found the same at biogas fuel at 0.18% vol., followed by mixed biogas + methanol at 0.011 % volume, and the worst is found for methanol fuel with CO emission of 0.33 % vol.

Keywords: emission, fuel, consumption, 2 strokes, engine, biogas, methanol

1 INTRODUCTION

Processing organic waste by using anaerobic digester technology become more popular because this technique can be operated at a low cost and is simple technology. The outcome of anaerobic digester technology is useful products such as fertilizer and biogas. The raw biogas composition mainly is methane (CH_4), carbon dioxide (CO_2), water vapor (H_2O), and minor quantities of impurity gas of hydrogen sulfide (H_2S) [1]. With biogas purification, the biogas can be utilized as a fuel for the engine, especially for the engine of the electric generator. The result of electricity can be used for any purpose, therefore the biogas availability becomes useful.

An attempt of using biogas as a fuel for the engine electric generator has already been initiated [2,3,4], especially for 4 stroke engine spark compression engine. It can be done by a simple method of injecting the biogas into the carburetor, but this method was not proper because the air-fuel ratio is difficult to be arranged or because the quality of biogas is not appropriate (low methane content). The use of biogas as a fuel for electric generators especially in rural or isolated farms is promising. It can simultaneously process the farm waste as well as provide energy. The biogas should be purified from H_2S impurities as well as moisture so that the engine will be free from corrosion.

The two-stroke engine is a unique engine in which is the fuel is mixed with the lubricant. Not like 4 strokes engine that makes it possible to provide oil in the crankcase and make it possible to operate the engine with separate fuel and lubricant. The 2-stroke engine requires mixed fuel and lubricant so a special design of the engine should be prepared if the fuel is in the form of gas, especially biogas. The detailed design of a small 2-stroke engine electric generator that is fueled by biogas was already initiated and working well [5]. The designs consisted of biogas and a lubricant mixer. The design also makes it possible for the engine to be run using gasoline. In this regard, there were not so many problems that were found during the operation. The Methane and CO_2 ratio in the biogas also already become a concern during the operation of the 2-stroke engine fueled with biogas. The higher the ratio of methane

and CO_2 will make the fuel consumption decrease. It can be summarized that the use of 2 stroke engine is suitable to be fueled with biogas for mitigation of greenhouse gas emissions [6].

The 2-stroke engine of an electric generator fueled with biogas or gasoline was already established [6]. The use of gasoline in the previous publication addressed nonrenewable energy that will be replaced in this research by using methanol. it is necessary to realize a small 2 stroke engine of electric generator that can run by using biogas, or methanol individually, and in the case of low-quality biogas, the 2 stroke engine can also be operated by using mixed of biogas and methanol. It is the purpose of this work to establish 2 stroke engine of an electric generator that can be run by using 3 types of fuel, namely, biogas, methanol, and mixed biogas-methanol. The fuel consumption will be investigated and the emission will be observed. The engine was operated in an idle position and loaded with a 200-watts electric load.

2 MATERIALS AND METHOD

The two-stroke engine is a unique engine in which the fuel is mixed with the lubricant. Not like 4 stroke engine that makes it possible to provide oil in the crankcase and make it possible to operate the engine with separate fuel and lubricant.

In this work, the small single cylinder of 2 stroke engine of the electric generator (750 watts) was prepared to be able to be fuelled with flexible fuel of Biogas or methanol individually with an easy switch system. The engine also is provided to be able to be fueled with mixed biogas and methanol in case of low-quality biogas are available. The emission and fuel consumption during operation with biogas, methanol, or mixed methanol and biogas is reported and analyzed. In this work, the Engine was running in an idle position to be compared with loaded at 200 watts.

The modified 2-stroke engine that was used in this research was the same as the previous publication [5-6]. The rated current of the coupled generator is 2.9. A, voltage result: 220-260 V/50 Hz/1Ph, maximum output is around 750 W. The engine type of electric generator is air cooling, single cylinder (63 cc), the compression pressure was set to reach 10 bar (1000 kPa) in order possible to be operated with biogas, methanol, or mixed biogas-methanol.

The lubricant that was used for this research was castor oil. The castor oil was prepared from castor beans (*Ricinus communis* L.) as can be seen in Fig 1. The use of a commercial 2-stroke lubricant engine is not possible for methanol. The Methanol will not be well mixed with commercial lubricant oil of 2 stroke engine.

The biogas that was used in this work has come from the conventional fixed dome type of anaerobic digester with cow dung as material that was filled inside the digester. The Biogas obtained was purified from H_2S and moisture with final composition was 52%CH_4, 35% CO_2, and 42 ppm H_2S.

The setup for the fuel arrangement in the engine can be seen in Fig 2. The raw biogas should enter through desulfurization to eliminate H_2S impurities. The bag dehumidifier was prepared after the desulfurization process to dry the biogas from moisture.

For the choice of using biogas as a fuel, the valve 1, 2, and 3 were opened, meanwhile, valve 4 was closed. The engine also can be run by using only methanol as fuel. For this purpose, valve 1 was opened, valve 2 was closed and valve 3 was closed and valve 4 was opened to let the mixed methanol and lubricant (50:1) enter the carburetor of the engine. The unique feature of our design was the engine was possible to be fueled with mixed fuel of biogas and methanol. For mixed biogas and methanol that will be operated, the valve 1, 2, and 3 were opened and then valve 4 was closed and then the engine started running. After running for a short time valve 3 then was closed and continued by opening valve 4. The fuel consumption, as well as emission of the engine of an electric generator, were investigates

The two-stroke engine is a unique engine in which the fuel is mixed with the lubricant. Not like 4 stroke engine that makes it possible to provide oil in the crankcase and make it possible to operate the engine with separate fuel and lubricant.

In this work, the small single cylinder of 2 stroke engine of the electric generator (750 watts) was prepared to be able to be fuelled with flexible fuel of Biogas or methanol individually with an easy switch system. The engine also is provided to be able to be fueled with mixed biogas and methanol in case of low-quality biogas are available. The emission and fuel consumption during operation with biogas, methanol, or mixed methanol and biogas is reported and analyzed. In this work, the Engine was running in an idle position to be compared with loaded at 200 watts.

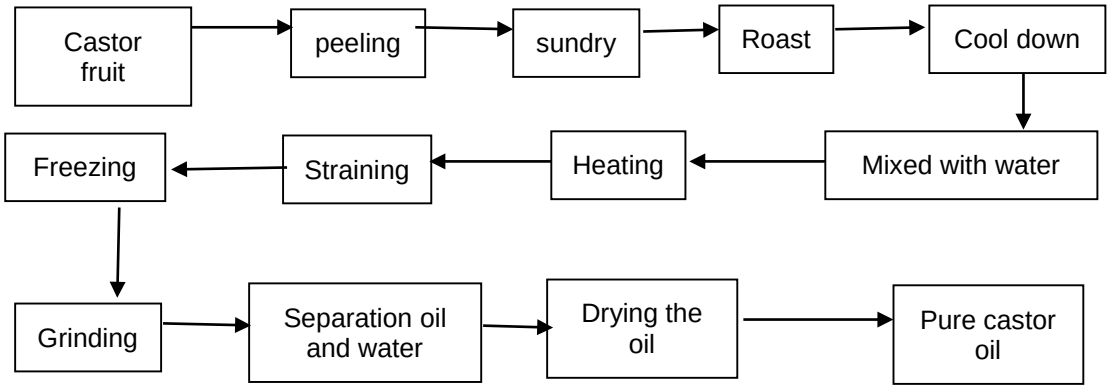
The modified 2-stroke engine that was used in this research was the same as the previous publication [5-6]. The rated current of the coupled generator is 2.9. A, voltage result: 220-260 V/50 Hz/1Ph, maximum output is around 750 W. The engine type of electric generator is air cooling, single cylinder (63 cc), the compression pressure was set to reach 10 bar (1000 kPa) to be operated with multiple fuels of biogas, methanol, or mixed biogas-methanol.

The lubricant that was used for this research was castor oil because The use of a commercial 2-stroke lubricant engine is not possible for methanol. The Methanol will not be well mixed with commercial lubricant oil of 2 stroke engine. . The castor oil was prepared from castor beans (*Ricinus communis* L.) as can be seen in Fig 1(a) and the route on obtaining the castor oil from castor beans is provided in Fig 1(b). The castor fruits were peeled to get the castor beans. The castor beans were sundried and subsequently roasted at medium heat (110-140oC) and were observed until a golden brown color appear on the surface of the beans. After the beans was cooled, the beans is placed in a grinder to process to become a paste and mixed with water to dissolve the paste. The paste then was

heated for about 2 hours to loosen the oil from the paste. The paste then was strained to the castor seed residue. The liquid obtained from the straining process was put in the fitting lid and frozen for about 3 hours and the oil will separate and float above the water. Take the oil and dry once again to remove the rest of the water. The final pale yellow oil is castor oil which can be used as a lubricant.

The biogas that was used in this work has come from the conventional fixed dome type of anaerobic digester with cow dung as material that was filled inside the digester. The Biogas obtained was purified from H_2S and moisture with final composition was 52%CH_4, 35% CO_2, and 42 ppm H_2S.

(a)



(b)

Fig. 1. The appearance of castor fruit. In raw and ripe condition (a). The schematic on the production of castor oil (b)

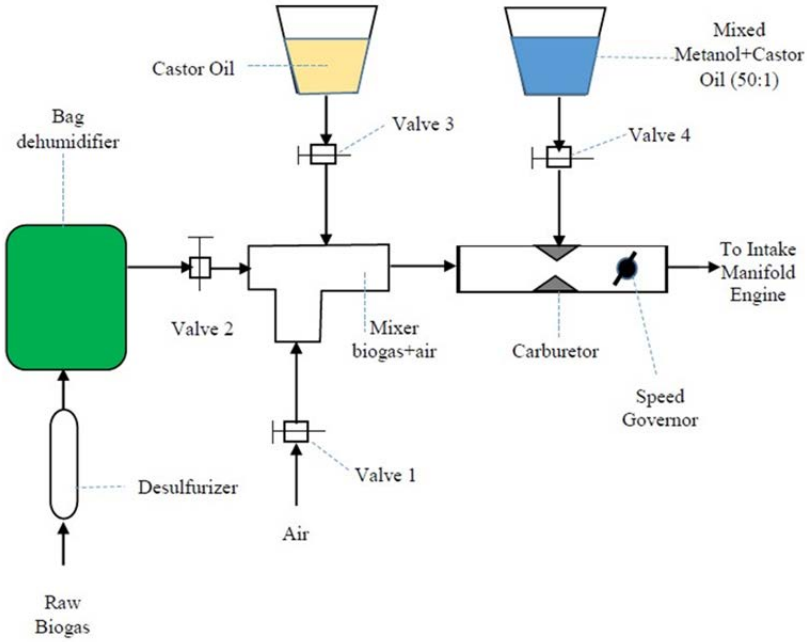


Fig. 2: The schematic design inlet of the multiple fuels (biogas, methanol, and mixed biogas-methanol) for the single cylinder of 2 stroke engine electric generator

The setup for the fuel arrangement in the engine can be seen in Fig 2. The raw biogas should enter through a desulfurizer to eliminate H_2S impurities. The bag dehumidifier was prepared after the desulfurization process to dry the biogas from moisture.

For the choice of using biogas as a fuel, the valve 1, 2, and 3 were opened, meanwhile, valve 4 was closed.

The engine also can be run by using only methanol as fuel. For this purpose valve 1 was opened, valve 2 was closed and valve 3 was closed and valve 4 was opened to let the mixed methanol and lubricant (50:1) enter the carburetor of the engine. The unique feature of our design was the engine is possibly be fueled with mixed fuel of biogas and methanol.

For mixed biogas and methanol that will be operated, the valve 1, 2, and 3 were opened and then valve 4 was closed and then the engine started to run. After running for a short time valve 3 then was closed and continued by opening valve 4.

The fuel consumption, as well as emission of the engine of the electric generator, were investigated.

3 RESULT AND DISCUSSION

In this work, the small 2-stroke engine of the electric generator is possible to be realized which is possible to be run by using several fuels and one of the fuels is biogas. If biogas is not available the engine also can be run individually by using methanol. And If the quality of biogas is low, the engine can be run by using mixed fuel of biogas and methanol. Special lubricant should be used for this purpose and castor oil is prepared from castor beans.

The data on the fuel consumption is presented in Table 1. For both biogas and methanol the fuel consumption increase if operated with a 200-watts electric load compared to an idle position. The fuel consumption for biogas is 13.83 in idle position and increases to become 15.17 L/minute if loaded at 200 watts.

Similarly, the methanol fuel consumption increased from 0.009 L/minute in idle position and increase to have come 0.011 L/minute with an electrical load of 200 watts. If mixed fuel of biogas-methanol is used, the biogas consumption becomes very low (2.06 L/minute) compared if using full biogas (13.83 L/minute) in an idle position. But the methanol consumption becomes increased to become 0.0482 L/minute compared to using full methanol (0.009 L/minute in an idle position. If loaded with a 200-watt electrical load, a similar pattern is found, the biogas consumption becomes low (4.43 L/minute) during loaded with 200 watts compared to using full biogas(15.15 L/minute), but the methanol consumption increase from 0.011 L/minute if using full methanol to become 0.0599 L/minute if using mixed biogas-methanol.

Table 1. Fuel Consumption of 2 Stroke engine of the electric generator. The engine was fueled with 3 different fuels, namely: biogas, methanol, and mixed biogas-methanol. The lubricant is castor oil

Fuel Types		Fuel Consumption (L/minute)	
		Idle position	Load 200 watt
Biogas		13.83	15.17
Methanol		0.009	0.011
Mixed Biogas+ methanol	Biogas	2.06	4.43
	Methanol	0.0482	0.0599

Table 2. The comparison of emissions by using 3 types of different fuels namely: biogas, methanol, mixed biogas-methanol in the small 2 stroke engine of an electric generator

Fuel Type	Emission					
	Idle position			Load 200 watt		
	CO (% vol.)	CO_2 (% vol.)	HC (ppm)	CO (% vol.)	CO_2 (% vol.)	HC (ppm)
Biogas	0.18	8.2	1331	0.18	10.6	1098
Methanol	0.42	5.0	8323	0.33	8.4	4913
Mixed biogas+methanol	0.26	4.3	977	0.21	6.2	881

The result of the emission test is presented in Table 2. It is found that the lowest CO emission is found for the use of full biogas (0.18%) and this value is the same if the engine is loaded with a 200-watt electric load. The 2nd position for CO emission is found for the mixed fuel which is around 0.26% with idle position and becomes better in the loaded condition which values around 0.21 %. The worst CO emission is found for the use of full methanol as a fuel which is the value of around 0.42% and the condition is better if loaded with a 200-watt electric load (0.33%).

The higher the CO_2 Emission means the better the combustion. In this regard, the biogas fuel provided the best CO_2 (8.2%). The condition is better for biogas as fuel if loaded at 200 watts and provides CO2 emission of 10.6%. Methanol is in the second-best position with CO_2 emission of 5.0% in idle position and increases to become 8.4% at loaded 200 watts. It should be noted that the lowest CO2 emission in this research is found for the uses of mixed fuel of biogas-methanol (4.3%) and increased to become 6.2% in loaded 200 watts.

The worst in HC emission is found for the use of methanol as a fuel, which is about 8323 ppm at an idle position and interestingly decreases to become around 4913 ppm if loaded with a 200-watt electric load. It is important to report here that biogas as a fuel resulting HC emissions lower compared to methanol. The HC emission for biogas is about 1331 ppm in idle position and around 1098 ppm at a 200-watt electric load.

Previous publications inform about consumption and emission of 4 stroke engine of electric generator that can provide 1000 watt electricity [4]. The engine is fueled with biogas. At the idle position, the fuel consumption with biogas is about 9.97 L/minute which is better compared to 2 stroke engine in this work. The 4-stroke engine also provides a very low emission of biogas as a fuel which is in the range of 0.02 % comparing the 2-stroke engine (0.18%) if fueled with biogas as in this work. The HC emission of 2 stroke engine if using biogas in an idle position is very high (1331 ppm) compared with 4 stroke engine (19.60 ppm). This is due to the burning of castor oil that is used in the 2-stroke engine as a lubricant.

In this work, the desulfurization process of biogas was using iron chips as informed in the previous publication [1]. Other methods that can provide better clean biogas from H2S impurities should be used to eliminate H2S from biogas totally [7]. Hydrogen sulfide causes acidity in the lubricant [8] there is the effect of the H2S on the castor oil that is used in this work as lubricant should be continued in future work.

The CO_2 was not eliminated in this work. For better results, the CO_2 should be removed. Various method has already been established especially by using activated carbon [9-13].

Biogas that is used in this work is from the traditional type of digester of the fixed dome. This conventional biogas digester is not provided high-quality biogas. Better design of small size biogas digester is available and should be promoted to obtain high-quality biogas for perfect combustion in the engine [14-16]

4 CONCLUSION

The small single cylinder of 2 strokes engine of an electric generator with multiple fuels is provided in this work. The engine can be run by using biogas or methanol or mixed biogas-methanol. The key feature that makes the system work well is the utilization of castor oil as a lubricant. The system that is developed in this work with a very easy switch from one type of fuel to other types that is available. The data of fuel consumption as well as emissions from different types of fuel are provided in this work that can use as consideration for using 2 stroke engine of an electric generator if fueled with biogas, methanol, or mixed biogas-methanol.

5 AUTHOR CONTRIBUTIONS

I Wayan Agus Rantia Dana and David Lie researched to obtain data related to the fuel consumption and emission of the engine. I Wayan Bandem Adnyana and Tjokorda Gde Tirta Nindhia were provided analyses of the result and prepared the manuscript. Samir Kumar Khanal and Tjokorda Sari Nindhia were supervised in preparing the biogas for this research. All authors had approved the final version.

6 ACKNOWLEDGMENT

The authors wish to thank The Engineering Faculty, Udayana University for providing financial support for the publication of this paper.

7 REFERENCES

[1] Aghel, B., Behaein, S.,Wongwisws, S.,Shadloo, M. S., (2022). A review of recent progress in biogas upgrading: With emphasis on carbon capture, *Biomass and Bioenergy*, vol. 60, article 106422. DOI: 10.1016/j.biombioe.2022.106422

[2] Negara, I G. A., Nindhia, T.G.T., Surata, I W., Nindhia, T. S. , Shukla, S. K., (2021). Method on Utilization of Low-Quality Biogas as a Fuel for 4 Stroke Spark Ignition Engine for Electric Generator, *Key Engineering Material,* vol. 877, 145-157. DOI: 10.4028/www.scientific.net/KEM.877.147

[3] Haryanto, A. Nindhia, T. G. T., Rahmawati, W., Hasanudin, U., SaputraT. W., A. B. Santosa,A. B., Tamrin and Triyono, S., (2019), Effect of Load on The Performance of a Family Scale Biogas-fuelled Electricity Generator, *IOP Conf. Ser.: Earth Environ. Sci*., vol. 355 012078, 1-11. DOI: 10.1088/1755-1315/355/1/012078

[4] Lie, D., Nindhia, T. G. T., Surata, I W. , and Wirawan, N., (2021). Design of Small Single Cylinder 4 Stroke Spark Ignition Engine for Electric Generator with Flexible Fuel: Biogas, Liquefied Petroleum Gas (LPG) or Gasoline, *Key Engineering Materials*, vol. 877 KEM, 153-159. DOI: 10.4028/www.scientific.net/KEM.877.141

[5] Wijaya, I W. G., Nindhia, T. G. T.,Surata, I W., Sukmawati, N. M. D. D., (2020). The Effect of Methane and Carbon Dioxide Ratio in The Biogas to The Fuel Consumption of 2 Strokes Single Cylinder (63cc) Engine of 750 watts Electric Generator, *Key Engineering Material*, vol. 877, 166-171. DOI: 10.4028/www.scientific.net/KEM.877.166

[6] Nindhia, T.G.T., McDonald, M., Styles, D.,(2021). Greenhouse Gas Mitigation and Rural Electricity Generation by Novel Two-stroke Biogas Engine, *Journal of Cleaner Production*, vol. 280, no. 124473, 1-12. DOI: 10.1016/j.jclepro.2020.124473

[7] Nindhia, T. G. T., Surata, I W. , Swastika, I D. G. P., Widiana, I P., (2016). Processing Zinc from Waste of Used Zinc-carbon Battery with Natrium Chloride (NaCl) for Biogas Desulfurizer. *Key Engineering Materials*, vol.705, no.1, 68-373. DOI: 10.4028/www.scientific.net/KEM.705.368

[8] Nindhia, T. G. T., Surata, I W. and Wardana, A.,(2017). The Stability of Lubricant Oil Acidity of Biogas Fuelled Engine due to Biogas Desulfurization, *IOP Conf. Series: Materials Science and Engineering*, vol. 201, no. 012021,1-5. DOI: 10.1088/1757-899X/201/1/012021

[9] Negara, D. N. K., Nindhia, T. G. T., Surata, I W., Sucipta, M., Hidayat, F., (2019). Activated Carbon Characteristics of Tabah Bamboo that Physically Activated Under Different Activation Time*, IOP Conf. Series: Materials Science and Engineering*, vol. 539, no. 012011, 1-6. DOI: 10.1088/1757-899X/539/1/012011.

[10] Negara, d. N. K., Nindhia, T. G. T., Surata, I W., Sucipta, M., (2017). Chemical, Strength and Microstructure Characterization of Balinese Bamboos as Activated Carbon Source for Adsorbed Natural Gas Application, *IOP Conf. Series: Mater. Sci. Eng*. Vol. 201 012033, 1-6. DOI: 10.1088/1757-899X/201/1/012033

[11] Negara, D. N. K., Nindhia, T. G. T., Surata, I W., Sucipta, M., (2016). Development and Application of Bamboo Activated Carbons and Their Potency as Adsorbent Material for Adsorbed Natural Gas (ANG); An Overview, *Key Engineering Materials*, vol. 705, 26-130. DOI: 10.4028/www.scientific.net/KEM.705.126

[12] Negara, D. N. K.P., Nindhia, T. G. T., Surata, I W., Hidajat, F., Sucipta, M., (2019). Nanopore Structures Surface Morphology and Adsorption capacity of Tabah Bamboo-activated Carbons, *Surfaces and Interfaces*, vol. 16, 22-28. DOI: https://doi.org/10.1016/j.surfin.2019.04.002

[13] Negara, D. N. K., Nindhia, T.G.T, Surata, I W., Hidajat, F., Sucipta, M., (2020). Textural Characteristics of Activated Carbons Derived from Tabah Bamboo Manufactured by Using H_3PO_4 Chemical Activation, *Materials Today: Proceedings*, vol. 22, no. 2, 148-155. DOI: 10.1016/j.matpr.2019.08.030

[14] Khanal, S. K., Nindhia, T. G. T., Nitayavardhana, S., (2019). Biogas from Wastes: Processes and Applications, in: Mohammad J. Taherzadeh, Kim Bolton, Jonathan Wong, Ashok Pandey, Sustainable Resource Recovery and Zero Waste Approaches, Elsevier,1st edition, Missouri, 165-174.

[15] Atmika, I K. A., Sebayuana, K, T. G. T. Nindhia, I W. Surata, Astawa, I P. A., Komaladewi, A. A. I. A., (2019). The Effect of Loading Rate to Biogas Production Rate of the 500-liter Anaerobic Digester Operated with Continuous System*, E3S Web of Conferences* , vol. 120, no. 02004, 1-4. DOI: 10.1051/e3sconf/201912002004

[16] Sebayuana, K., Nindhia, T. G. T., Surata, I W., Nindhia, T. S., Shukla, S. K, Khanal, S. K., (2001). Performance of 500 Liter Stainless Steel Portable Biogas Anaerobic Digester with Agitator Designed for the Tropical Developing Country, *Key Engineering Materials*, vol. 877, 160-165. DOI: 10.4028/www.scientific.net/KEM.877.160

Paper submitted: 01.01.2022.

Paper accepted: 01.05.2022.