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Studies on the Feasibility of Producing Biogas from Rice Waste

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Abstract.

Biogas is considered as one of the alternative sources of energy which is used in many applications such as power generation, heating and refrigeration. The quantity and quality of biowastes vary due to the intensity and nature of human activity. Since the methane (CH_4) composition in biogas is influenced by the ingredients of the biowaste, specific research is needed to check the biogas yield from locally available biowastes and to predict the usage of biogas as alternative energy in all levels. In countries like India, rice is a staple crop and the common food source for people. The food waste collected from common places like student's hostels, restaurants and houses consists of wasted rice along with other wastes of meat, fish, vegetables and fruits.In this study, analytical & experimental work was done on the biogas production from various biowastes collected from an engineering college campus. The Anaerobic Digestion Model 1 (ADM1) was used for analytical studies, and four anaerobic digesters were used in the experimental investigation. Mesophilic condition was considered for this study. From the experimental studies it is observed that the methane content in the biogas produced from rice waste, mixed rice waste, cow dung and vegetable waste are 52.01%, 52.98%, 61.13%and 51.11% respectively. The results obtained from the simulation study are also close to the experimental values.

Keywords: Anaerobic digestion, Biogas, Cow dung, Vegetable waste, Rice waste.

1. Introduction

The Kitchen Waste (KW) produced in hostels, canteens, cafeteria, etc. of an educational institution pollutes the environment in various ways due to high organics and moisture content. Effective treatment and disposal of waste is highly essential to avoid such harmful effects. Sterilisation and effective resource recycling are being used in the waste disposal process [1]. Anaerobic Digestion (AD), an alternative processing technology as it offers ways for the recovery of valuable resources [2, 3, 4].

Biogas is obtained from the decomposition of organic waste by anaerobic bacteria. Methane is the primary constituent of biogas [5, 6]. AD method provides a way for kitchen waste management. KW can be used as a sustainable fuel in the form of biogas and bio-fertilizers. AD is commonly applied throughout the world as a wastewater treatment method for livestock manures. The methane yield through this process is in the range between 12 and 13.9 m^3/m^3 of influent substrate [7]. However, in order to enhance economic viability of an anaerobic digestion system, yield of biogas per ton of waste has to be achieved more than 30 m^3 [8]. AD can improve the energy consumption structure and reducethe use of chemical fertilizers in agricultural sector, thus it makes the waste disposal management effective [9].In the early stage of digestion process, lactic acid gets accumulated, and leads to decrease in pH. This is due to high oil content, which was considered as one of the problems during the digestion of KW [10]. The various other barriers for digestion process are the inhibitory levels of ammonia, sulphide and long-chain fatty acids [11]. The inhibitions which arise due to these problems are removed by Chemical and thermal methods [12]. To improve the properties of organic wastes to produce biogas, new techniques were suggested. Co-digestion of the wastes with substances containing high level of ammonium nitrogen and alkalinity was one of the techniques which promote the production of biogas. This method not only improves the biogas production but also provides better organic load removal efficiency [13]. The mixing of different substrates is not only desirable for improving methane recovery rates and reducing life cycle costs, but it also provides better organic load removal efficiencies as an effect of Carbon/Nitrogen ratio(C/N ratio) correction, pH balancing and improvement on the buffering capacity of the treatment systems [14]. Besides, being an anaerobic digestion system, such an anaerobic digestion can be integrated into pre-standing urban buildings or into new buildings for a paradigm shift towards a more renewable and sustainable future [15].Parameters which affect the efficiency of biogas production are C/N ratio, Volatile Solid (VS), Organic Loading Rate (OLR), temperature, pH, toxicity, dilution, retention time and mixing ratios [16]. In a biogas plant, 0.25-0.70 m^3 biogas per kg of volatile solid is normally produced for a loading rate of 1-1.5 kg volatile solids per day, under standard conditions of7-7.4 pH and 1:1 water dilution ratio [17]. The retention time should be 30-60 days for mesophilic digestion [18] and it varies depending on the operating conditions and nature of the feed. Based on the operating temperature, anaerobic digestion is classified as psychrophilic (<30ºC), mesophilic (30-40ºC) and thermophilic (50-60ºC). It is also reported that the production of biogas increases with the increase in operating temperature and retention time [16].

The quality of biogas obtained from different co-digestion strategies shows that fish and grease trap wastes have inhibition to microorganisms during the initial period of batch digestion under thermophilic conditions [19]. Continuous digestion of the mixed food waste under mesophilic conditions to control pH of the digester is successful with the addition of Sodium Hydroxide (NaOH) [15]. The degradation rate of fresh maize and maize silage is very high and are considered as good substrates for anaerobic digestion. On the other hand, full-scale applications should not rely on maize alone [20]. Apple waste was found to be a best substrate for co-digestion with swine manure [21]. An experimental study on fruit wastes conducted in a laboratory scale digester [22] shows3 to 4% variation of Total Solids (TS) which has no effect on fermentation stability when pH remains between 6.8 and 7.4. However, an inhibition of methanogenic bacteria is observed when TS has been kept at five percentage. Compared to mesophilic conditions, the production of biogas from mixed weed is very high under thermophilic conditions. However there is no significant difference in the composition of methane [19].ADM1 has been used to study the mono fermentation of grass silage without the addition of manure over a period of 345 days under mesophilic conditions (38^oC).The model shows a positive agreement with experimental measurements and hence ADM1 has been identified suitable for the modelling of anaerobic digestion of grass silage [23].Based on the above studies it is clear that biogas production depends on the nature of food waste[24] and operating conditions. Therefore further study is needed to predict the possibility of getting biogas from the locally available biowastes.

Cow Dung (CD) and biowastes such as cooked rice (RW), mixed cooked rice with vegetables (MRW) and cooked and uncooked vegetable wastes (VW) are some of the common biowastes available in the area where the study was conducted. A tool box in Matlab [25] that uses the Anaerobic Digestion Model1 (ADM1), was used in the mathematical model to predict the quality and quantity of biogas yield in a bio digester for different feeds. An experimental study has been carried out to check the validity of the proposed model.

2. Materials and methods

2.1 Identification and characterization of feed stocks

The feedstock is collected from the campus of an engineering college situated in the southern part of India. The campus consists of hostels and canteens to meet the needs of 3000 students. The common biowastes generated in the campus are cooked rice waste, cooked mixed rice waste, cooked and uncooked vegetable waste, fruit waste, etc. and they are disposed in large amount without any further use. Apart from food wastes, cow dung is also available from the cattle farm situated within the campus. The important properties measured to check the quality of biowastes are pH, TS and VS. They are measured as per the standard procedure discussed below.

2.2 Content of Total solids (TS)

As per standards [26], the following procedure was used to determine the TS of the feed. In the pre-weighed porcelain vessels 50 g from each biomass was taken and heated at 60°C for 24 hours and then at103°C for 3 hours in a hot air oven. The dried samples with the container was weighed. After drying, the weight of the samples along with container was measured in a weighing balance of accuracy 0.001g. The percentage TS of each sample was calculated by

$$TS = \left[\frac{W_d}{\mathrm{W_w}}\right] \cdot 100 \qquad (1)$$

Where W_d and W_w are the weight of dry and wet samples respectively

2.3 Content of Volatile solids (VS)

The standard method [26] was followed for the determination of VS of feed materials. The dried samples obtained from the oven were further dried at550°C ± 50°C for about 1 hour and ignited completely inside the muffle furnace. The cooled samples from the desiccator were weighed and VS of the samples were calculated using the formula

$$VS = \left[\frac{(W_d - W_a)}{W_a}\right] . 100 \qquad (2)$$

Where W_d - Weight of dry samples

W_a– Weight of dry ash obtained after complete ignition

pH of the feed materials (CD, MRW, RW and VW) was determined with pH electrode.

Table 1 shows the chemical characterization of the biowaste taken in this study.

Table 1. Chemical characterization of feedstock.

Sl. No.	FEED	pH %	TS %	VS %
1	CD	6.50	15.98	64.99
2	MRW	4.91	20.25	90.15
3	RW	6.61	30.28	90.11
4	VW	6.35	10.55	90.45

The results obtained from the above methods show a clear agreement when compared with the literature [27].

2.4 Simulation of Anaerobic Digestion Process using ADM1

Anaerobic digestion basically involves three phases namely; (i) hydrolysis (ii) acid producing bacteria and (iii) the methanogenesis [28, 29] (Figure 1).

In all organic wastes, carbohydrates are mostly in the form of cellulose and other components of plant fibres. The monomeric components released during the hydrolysis phase act as substrate for acid-forming phase. During the acid phase, while the acid forming bacteria decomposes complicated molecules such as proteins, fats and carbohydrates into organic acids, carbondioxide, hydrogen, ammonia and some impurities. Acetic acid is a common by-product of the digestion of fats, starch and proteins.

During the methane phase, the methane-forming bacteria convert fatty acids into methane. Methanogenic bacteria are selective in their reaction with substrate components. They react with acetic acid, methanol, carbon dioxide (CO_2) and hydrogen to produce methane. The presence of oxygenretards the activity of methanogenic bacteria. Methanogenic bacteria are sensitive to the pH of the digester contents. The optimal pH value of methanogenesisis around 7.0 [30].

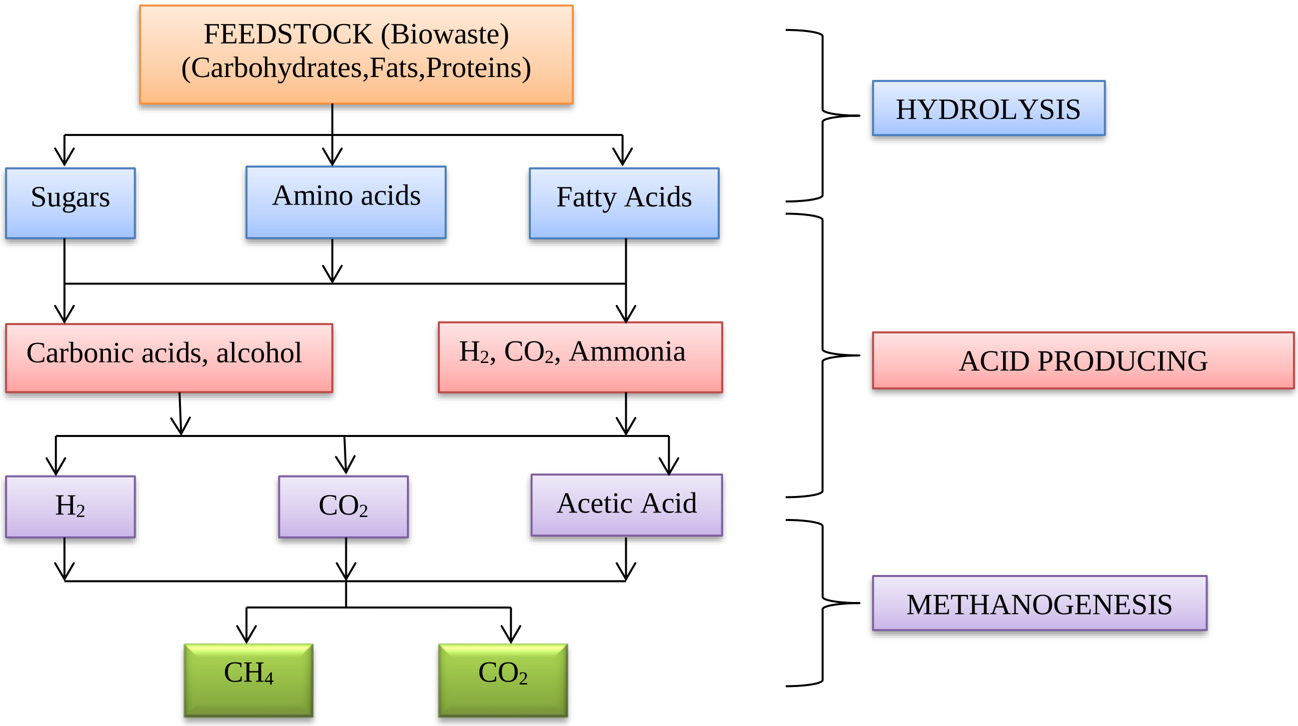

Figure 1. Flow chart for simulation procedure

The Anaerobic Digestion Model No. 1 (ADM1) was used for simulation based on the above steps. 19 biochemical conversion processes and 24 dynamic state variables were used for the characterization of this highly complex model. Simulations were executed with Matlab/Simulink [31].

In ADM1 the measured properties of the feed were given as input parameters. The change in properties of the feed and methane percentage of each day was recorded. Graphs are plotted based on the observations for each feed for comparing with experimental values.

2.5 Experimental Setup

The schematic of the experimental setup is shown in Figure 2.The experiment is carried out in four anaerobic digesters (AD1, AD2, AD3 and AD4) of 2 m^3, 1m^3, 0.25 m^3 and 0.25 m^3, made by reinforced glass fibre composite. Each Anaerobic Digester (AD) consists of an inlet and outlet to load the feed and drain out the digested feedstock. It consists of a floating drum which floats upwards to store the generated gas. Water jacket is provided to seal the floating drum. The gas outlet from the digesters is connected to a multigas analyser (NUCON) of 0.3 % accuracy and a thermal gas flow meter (mass flow measurements of liquids) of accuracy 0.5 % Full Scale (F.S). A pH electrode and a thermometer are kept inside the digester to measure the pH and temperature of the substrate respectively [32].

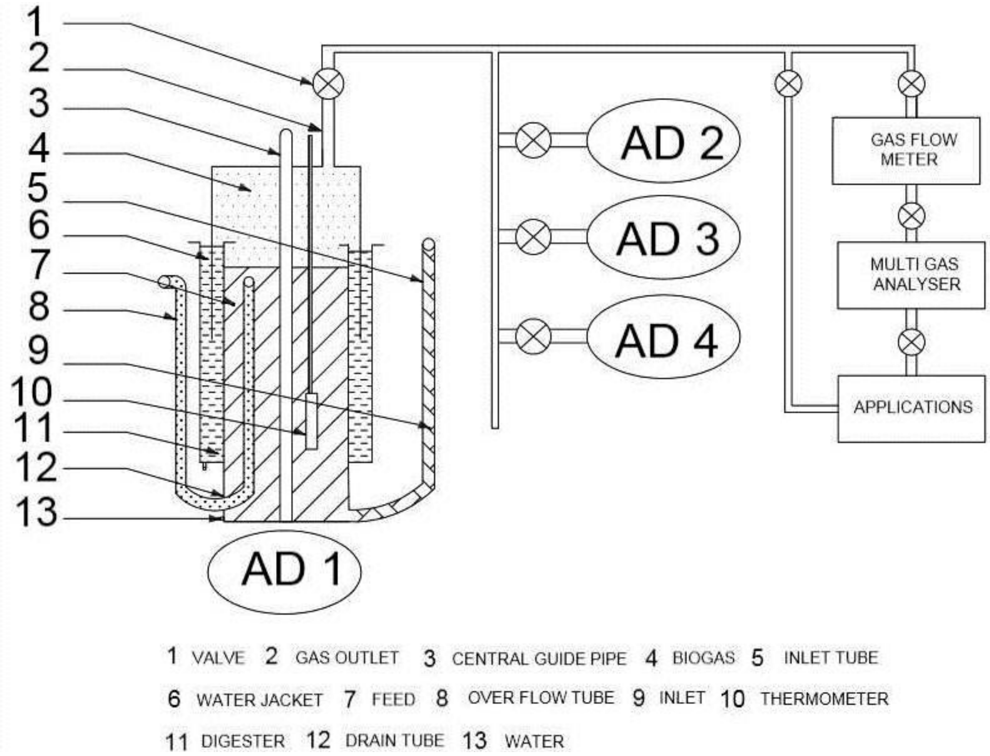

Figure 2. Schematicdiagram of the experimental setup

2.6 Experimental procedure

All the four digesters were first loaded with cow dung and mixed with water for producing the methanogen bacteria. Approximately 50 days are required for the complete digestion of the cow dung [33].The gas generated is released using cooking stove. After ensuring that the biogas production has stopped and bacteria is starving for feed, the biowastes collected from college campus is loaded gradually in each digester as mentioned in table 2. Biogas production has been observed and its quantity per day was measured using the gas flow meter. The temperature, pH and quality were also recorded for a minimum of four times per day and the average was calculated. The feedstock was loaded in each digester uniformly and daily.

Table 2. Summary of the experimental design

Digester	Digester Size	Feedstock	Test Duration (days)	Mixing Ratio (Feed + water)	Temperature	State
AD1	2 m^3	Cow dung	45	1:1	32 ± 2^0C	Mesophilic
AD2	1 m^3	Mixed Rice Waste	45	1:1	32 ± 2^0C	Mesophilic
AD3	0.25 m^3	Rice waste	45	1:1	32 ± 2^0C	Mesophilic
AD4	0.25 m^3	Vegetable waste	45	1:1	32 ± 2^0C	Mesophilic

3. Result Analysis and Discussion

Methane is the combustible component of the biogas and it decides the quality of the biogas. Since the quality of biogas was stable after 30 days, all the figures are presented with the results obtained for the first 30 days. The average content of methane in CD, MRW, RW and VW observed from experimental and simulation work is depicted in Figure 3 to Figure 6.

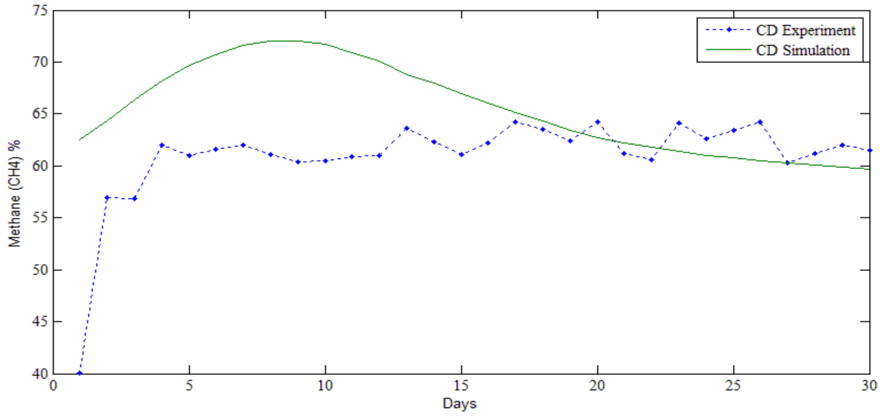

Figure 3. Methane Composition of Cow Dung

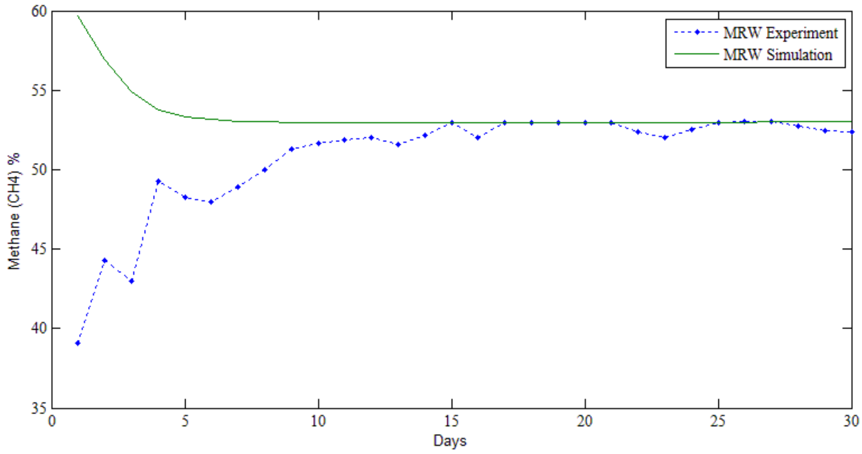

Figure 4. Methane Composition of Mixed Rice Waste

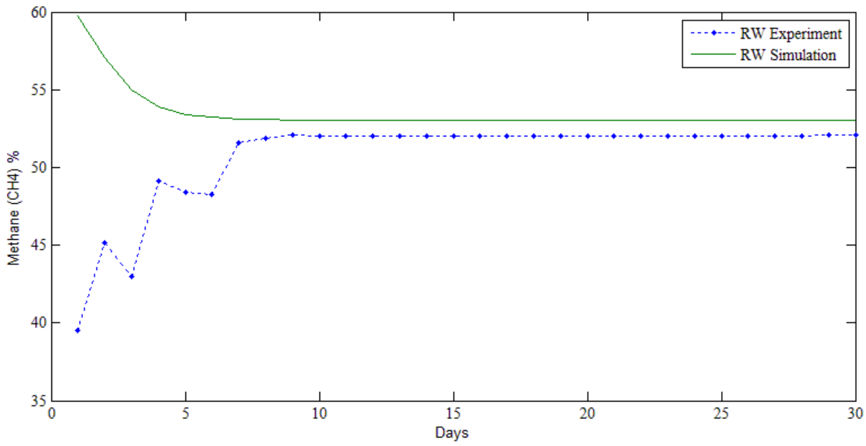

Figure 5. Methane Composition of Rice Waste

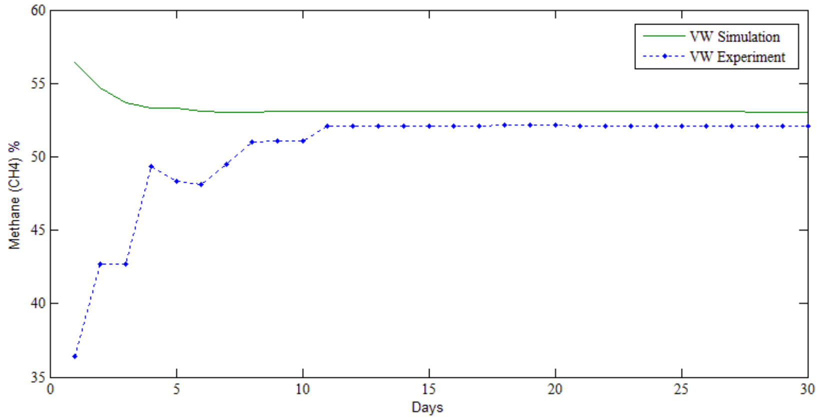

Figure 6. Methane Composition of Vegetable Waste

In the case of cow dung even though many studies have been reported in the literature [30], the same has been investigated to validate the experimental and simulation procedures used in the study. The experimental and theoretical studies show that the methane yield is61.13 % and 66.97 % respectively (Figure 3). This is in accordance with the findings of various researchers, moreover the variations between experimental and theoretical values are within 5%. Hence the validity of the present approach is confirmed. As the methane production from the cow dung proves the suitability of this method, besides the same procedure has been used to study MRW, RW and VW.

From the results, it is observed that all the feed produced more than 50% of methane, which shows that they can be used for biogas production. Similar results were recorded from various other biowastes by other researchers [19].Figure4 shows that the theoretical and experimental values of methane production are53.97 %and 52.98 % respectively.

All the figures (Figure 3 – Figure 6) show that there is an initial lag of biogas generation in experimental results. This is due to some of the following parameters like pH, temperature, substrate concentration, enzyme production, hydrostatic pressure, loading rate, climatic conditions, C/N ratio and efficiency of microorganisms in biogas production [18, 34, and 35]. During the first seven days the variation has been very high and after 15 days both theoretical and experimental values of methane generation has been close to each other. Similar trend is also observed in Figure5. In the case of cow dung the trend of both the curves (experimental and theoretical values of CH_4) is almost similar, whereas there is a large variation in the beginning which is observed in Figure4 to Figure6. This is due to the well-defined mechanism available for cow dung to have a theoretical model in all the stages [36]. Figure 5 shows that the rice waste can give a stable methane yield of 51 % after 6 days. Added to that, the theoretical and experimental values are close to each other after six days. Compared to the other wastes studied, RW gives the stable production, within a short duration of six days.

Using scrubbers, the biogas generated can be enriched to 98% of methane content which can be used as fuel in I.C. engines [37]. The digested feedstock which is drained out can be further used as fertilizers through proper mixing ratios. Hence, the proper digestion of biowaste can convert the campus of an engineering institution to be environmental friendly.

4. Conclusion

In this study, both analytical and experimental work were done on the production of biogas from biowastes such as cow dung, rice waste, vegetable waste and a mixture of rice and vegetable wastes, collected from various places in an engineering college campus. Analytical studies show the percentage composition of methane to be66.97 %, 53.97 %, 53.01 %, and 53.12 % respectively for all the four types of biowastes. For the above cases, the experimental values are61.13 %, 52.98 %, 52.01 %, and 51.11 % respectively. The study shows that the simulation and experimental results have a similar trend of methane production after 7 to 15 days from the beginning of digestion process. In this regard, it is concluded that like other existing wastes, rice wastes can be used for biogas production in an effective way in which the average methane content is 52%. Hence this work has proved that the cooked rice waste can be used for biogas production in an effective way without adding any ingredients.

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References

1. A. KHALID, M. ARSHAD, M. ANJUM, T. MAHMOOD, L. DAWSON. The anaerobic digestion of solid organic waste. *Waste Manage,* 31: 1737-1744 (2011).
2. F. CARVALHEIRO, L.C. DUARTE, F. M. GIRIO. Hemicellulose biorefineries: a review on biomass pretreatments. *J SciInd Res* 67: 849-864 (2008).
3. O. STABNIKOVA, X.Y. LIU, J.Y. WANG. Digestion of frozen/thawed food waste in the hybrid anaerobic solid-liquid system. *Waste Manage,* 28(9): 1654-1659 (2008).
4. IONICA HOLBAN, CARMEN-MIHAELA BOTEANU, MARIUS PETRESCU. Green energy from agriculture and Romanian firms' competitive advantage. *Romanian Biotechnological Letters*, 18(6): 8761-8768 (2013).
5. TOM BOND, R. MICHAELTEMPLETON. History and future of domestic biogas plants in the developing world. *Energy for Sustainable Development*, 15: 347–354 (2011).
6. CRISTINEL POPESCU, STEFANA JURCOANE. Evaluation of biogas potential of some organic substrates from agriculture and food industry and co-digestion in large scale biogas plant. *Romanian Biotechnological Letters,* 20(4):10648-10655 (2014).
7. L. ZHANG, Y. LEE, D. JAHNG. Anaerobic co-digestion of food waste and piggery wastewater:focusing on the role of trace elements. *Bioresour Technol,* 102:5048-5059 (2011).
8. H. HARTMANN, B. K. AHRING. Anaerobic digestion of the organic fraction of municipal solid waste: influence of co-digestion with manure. *Water Res,* 39: 1543-1552 (2005).
9. WENGUANG DING, HEWENNIU, JINSONG CHEN, JUN DU, YANG WU. Influence of household biogas digester use on household energy consumption in a semi-arid rural region of northwest China. *Applied Energy,* 97: 16 – 23 (2012).
10. A. VEEKEN, S. KALYUZHNYI, H. SCHARFF, B. HAMELERS. Effect of pH and VFA hydrolysis of solid waste. *J Environ Eng ASCE,* 126(12): 1076 – 1081 (2000).
11. A.L. AMARAL, M. A. PEREIRA, M. DAMOTTA, M. N. PONS, M. MOTA, E. C. FERREIRA. Development of image analysis techniques as a tool to detect and quantify morphological changes in anaerobic sludge: II application to a granule deterioration process triggered by contact with oleic acid. *Biotechnol Bioeng,* 87(2): 194 – 199 (2004).
12. LI. YANGYANG, YIYING JIN. Effects of thermal pretreatment on acidification phase during two phase batch anaerobic digestion of kitchen waste. *Renewable Energy*, 77:550-557 (2015).
13. H. G. ZHU, W. PARKER, R. BASNAR, A. PRORACKI, P. FALLETTA, M. BELAND. Bio-hydrogen production by anaerobic co-digestion of municipal food waste and sewage sludges. *Int J Hydrogen Energy,* 33(14): 3651 –3659 (2008).
14. E. ATHANASOULIA, P. MELIDIS, A. AIVASIDIS. Co-digestion of sewage sludge and crude glycerol from biodiesel production. *Renew Energy*, 62: 73 – 78 (2014).
15. NATHAN CURRY, PRAGASEN PILLAY. Biogas prediction and design of a food waste to energy system for the urban environment. *Renewable Energy,* 41: 200 – 209 (2012).
16. T. N. VEZIROGLU. Solar energy Applications, bioconversation and synfuel. *Energy and Environmental Progress I – Volume B, New york, USA : Nova Science Publishers,* (1991).
17. RUIHONG ZHANG, M. HAMED EL-MASHAD, KARL HARTMAN, FENGYU WANG, GUANGQING LIU, CHRIS CHOATE, PAUL GAMBLE. Characterization of food waste as feedstock for anaerobic digestion. *Bioresource Technology,* 98: 929–935 (2007).
18. D. DIVYA, L. R. GOPINATH, P. MERLIN CHRISTY. A review on current aspects and diverse prospects for enhancing biogas production in sustainable means. *Renewable and Sustainable Energy Reviews*, 42: 690–699 (2015).
19. XIGUANG CHEN, T. ROWENA ROMANO, RUIHONG ZHANG. Anaerobic digestion of food wastes for biogas production. *Int J Agric&BiolEng,* 3: 4-61 (2010).

20. EMILIANO BRUNI, ANDERS PETER JENSEN, ERIK SILKJÆR PEDERSEN, IRINIANGELIDAKI. Anaerobic digestion of maize focusing on variety, harvest time and pretreatment. *Applied Energy,* 87: 2212–2217 (2010).
21. GOPI KRISHNA KAFLE, SANG HUN KIM. Anaerobic treatment of apple waste with swine manure for biogas production: Batch and continuous operation. *Applied Energy,* 103: 61–72 (2013).
22. J. RAJESH BANU, ESSAKI RAJ, S. KALIAPPAN, DIETER BECK, ICK-TAE YEOM. Solid state biomethanation of fruit wastes. *Journal of Environmental Biology,* 28: 741-745 (2007).
23. KONRAD KOCH, MANFRED LÜBKEN, TITO GEHRING, MARC WICHERN, HARALD HORN. Biogas from grass silage – Measurements and modelling with ADM1. *Bioresource Technology*, 101: 8158–8165 (2010).
24. MARTA OLESZEK, ALEKSANDRA KROL, JERZY TYS, MARIUSZMATYKA, MARIUSZKULIK. Comparison of biogas production from wild and cultivated varieties of reed canary grass. *Bioresource Technology,* 156: 303–306 (2014).
25. D. GAIDA, CHRISTIAN WOLF, MICHAEL BONGARDS, THOMAS BACK. MATLAB Toolbox for Biogas Plant Modelling and Optimization. *Progress in Biogas Stuttgart-Hohenheim*, (2011).
26. APHA/AWWA/WEF. Standard methods for examination of water and waste water 21st edition Baltimore, New york, USA, (2005).
27. V.A. EZEKOYE, B.A. EZEKOYE. Characterization and Storage of Biogas Produced from the Anaerobic Digestion of Cow Dung, Spent Grains/Cow Dung, and Cassava Peels/Rice Husk. *The Pacific Journal of Science and Technology,* 10: 2 (2009).
28. D. RAVITA PRASAD. Empirical Study on Factors Affecting Biogas Production. *Renewable Energy,* (2012).
29. IULIAN ZOLTAN BOBOESCU, VASILE DANIEL GHERMAN, MARIANA ILIE, ION MIREL, TEODOR VINTILA, GERGELY MAROTI1. Exploitation of experimental design methods and mathematical modeling for improving fermentative biohydrogen production processes. *Romanian Biotechnological Letters*, 19(2): 9097-9109 (2013).
30. MEENA KRISHANIA, VIRENDRA KUMAR, VIRENDRA KUMAR VIJAY, ANUSHREE MALIK. Analysis of different techniques used for improvement of biomethanation process: A review. *Fuel*, 106: 1–9 (2013).
31. D. J. BATSTONE, J. KELLER, I. ANGELIDAKI, S. V. KALYUZHNYI, S. G. PAVLOSTATHIS, A. ROZZI, W. T. M. SANDERS, H. SIEGRIST, V. A. VAVILIN. The IWA Anaerobic Digestion Model No 1 (ADM1). *Water Science and Technology,* 45(10): 65–73 (2002).
32. G. MOICEANU, G. H. VOICU, M. DINCA, M. FERDES, G. PARASCHIV,V. VLADUT, L. TOMA. Influence of Different Types of Substrate on the Anaerobic Fermentation Process. *Romanian Biotechnological Letters*, 21(2) 11281-11289 (2016).
33. R. SINGH, R. K. MALIK, P. TAURO. Anaerobic Digestion of cattle dung at various retention times – a pilot plant study. *Agric Wastes*, 12(3): 313–316 (1985).
34. PAUL DOBRE, FARCASNICOLAE, FLORENTINAMATEI. Main factors affecting biogas production - an overview. *Romanian Biotechnological Letters,* 19(3): 9283-9296 (2014).
35. CARMEN MATEESCU. Influence of the hydrostatic pressure on biogas production in anaerobic digesters. *Romanian Biotechnological Letters*, 21(5): 11941-11948 (2015).
36. GEORGIANA MOICEANU, GHEORGHE VOICU, MARIANA FERDES, GIGEL PARASCHIV, MIRELA NICOLETAD INCA, VALENTIN VLADUT, IULIA GAGEANU, MIHAI CHITOIU. Comparative study on biogas production using cow and swine manure mixed with Miscanthus x giganteus as substrate. *Romanian Biotechnological Letters,* 21(5): 11968-11973 (2013).
37. KAPDI S.S., V.K. VIJAY, S.K. RAJESH, RAJENDRA PRASAD. Biogas scrubbing, compression and storage: perspective and prospectus in Indian context. *Renewable Energy*, 30: 1195–1202 (2005).