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Bio-energy potential of different food wastes

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ABSTRACT

Converting waste into biogas has the benefits of reducing emission to the atmosphere and adding energy to the society for improving livelihood of the people. An extensive amount of food waste is generated regularly from residential area, student hostels, restaurants, markets. Thus food waste can be a fruitful alternative for biogas production. Therefore, an experimental research work was commenced at the GEKH (Green Energy Knowledge Hub) laboratory of the department of Farm Power and Machinery, Bangladesh Agricultural University to analyze the potentiality of biogas production of different food wastes. Four ladies halls were selected for the study. An approximate amount of total food waste of these halls was estimated through survey and visual inspection. Furthermore, food wastes were collected from these halls for conducting batch experiment for understanding gas production potential from the wastes. Food wastes such as various vegetable wastes like potato, cauliflower, cabbage, bean; chicken slaughter and fish waste were classified; wastes from the plates were selected for this study. The whole experiment was conducted in an incubator where all the substrates were mixed with a seeding inoculum (same volatile solid ratio) for 54 days retention time with three replications at 35˚C temperature. Total waste production from the four female student halls was 860 kg/day among which vegetable wastes was 40%, slaughter and fish wastes was 20% and wastes from peoples plate was 40%. It was found that slaughter and fish waste mixture was more potential substrate in biogas production than other selected substrates respectively. The cumulative biogas production of slaughter and fish waste mixture and cumulative bio-methane potentiality of slaughter and fish waste mixture were found 256.13 ml/g VS and 190.08 ml/g VS, respectively. From the total wastes, about 11.68 m³/day methane can be produced for mixed type waste by which 44.16% natural gas consumption of four student halls can be substituted.

Introduction

People all over the world are using conventional energy in their daily life. Because of rapid growth of population, uncontrolled and unmonitored urbanization, conventional energy sources are decreasing day by day. It is predicted that the conventional (oil, coal, natural gas etc.) energy may last for another six to seven decades which may led to global climate change, environmental and human health problem (Mamun and Torii, 2015). For these reasons, substitution of these energy sources is a must. Solar energy, wind energy, biogas, different thermal and hydro sources of energy are renewable energy resources. From all of these sources, biogas has been successfully set itself as a significant energy source and used in different parts of the world with great advantages. Propagation of energy by using waste is a current emerging thought. Most energy is provided by combusting natural gas and oil globally. According to Energy and Mineral Resources Division (EMRD) of Bangladesh, in 2018 domestic customers got only 15.75% natural gas of total production whereas requirement for gas is increasing but gas reserve is decreasing day by day. Furthermore, the contribution of energy form renewable resources is almost negligible in our country. But with the increasing prices of oil, energy from renewable resources has become necessary. In this context, environment friendly biogas produced from renewable sources could play a vital role in solving energy and environmental problems (Huda, 2016). Development of biogas technology has received serious attention since 2000. The total number of domestic and commercial biogas plants installed in Bangladesh by different organizations is 91,350 (GEKH, 2015). Most of the biogas plants are installed for managing the animal dung or slaughter house wastes. However, biogas technology or anaerobic digestion technique can be used for producing energy from kitchen or food wastes.

The kitchen waste refers to spoiled fruits, spoiled rice, spoiled milk, broken paper, spoiled fish, cooked food but not eaten, spoiled eggs, and spoiled cooking ingredients, vegetable peeling etc. (Nasrin, 2017). Kitchen wastes contain high moisture content (approx. 75%) which is required for the substance of the methanogenic bacteria

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(Apte *et al.,* 2013). At present, for biogas production in many countries, kitchen waste is used as one of the secondary raw materials in the process of wet or dry anaerobic fermentation (Zhang *et al*., 2009). The combination of kitchen waste and cow dung produces more gas than cow dung digestion (Dupade and Shekhar, 2013). One kg of kitchen waste in 24 hours can produce the same amount of biogas as 40 kg of cow dung in 40 days; 400 times efficiency can be achieved by using kitchen waste as compared to cow dung (Ogur *et al.,* 2013). The type of waste has significant effect on biogas production. Carbohydrate type waste degrades faster than protein, fats and vitamins/ minerals type waste which commencing the production of gas (Aliyu, 2017). In Bangladesh, food/kitchen wastes are generated from residential area, student hostels, restaurants, markets. These wastes are creating environmental problem releasing greenhouse gas and odour nuisance in the localities. These wastes could be useful feedstock for generating energy or biogas through anaerobic digestion for cooking and electricity generation.

Therefore, this study was undertaken to understand the type and amount of wastes produced from the student kitchen, and biochemical methane production potential of different types of food waste.

Materials and Methods

Study site and duration

Four students halls namely Sultana Razia Hall, Taposhi Rabeya Hall, Sheikh Fojilatunnesa Mujib Hall, Begum Rokeya Hall, Bangladesh Agricultural University, Mymensingh were selected for this study. The study was conducted during October 1, 2018 to October 5, 2018 and December 31, 2018 to January 4, 2019 for understanding seasonal variability of the wastes.

Type and amount of wastes

Food wastes are of different types in manner generated from kitchen and whole halls. These types are: (i) vegetable wastes, (ii) fish wastes, (iii) slaughter or poultry wastes, and (iv) wastes from peoples' plates. These waste types were being identified through survey and visual inspection in the kitchen of the halls and adjacent areas. A questionnaire was used for collecting the information from the cook and students. Two cooks working in the kitchen of the hall were asked to answer all the questions of the questionnaire to quantify the amount of wastes. Wastebaskets and adjacent areas of halls were inspected visually for understanding and collecting information regarding the food wastes. The visual inspect following the same procedure, the amount of waste from all the four ladies halls was determined and the total amount of wastes generated from the halls was obtained.

Experimental site

The experiment was conducted at the Biogas laboratory of GEKH (Green Energy Knowledge Hub), Dept. of Farm Power and Machinery, Bangladesh Agricultural University, Mymensingh.

Selection of co-substrates

For conducting experiment it is necessary to choose specific biomass source for increased biogas production without any experimental hazards. The collected food wastes which were easily degradable, selected for the batch study (Table 1).

Table 1. Selected co-substrates for batch assay

Types of food waste	Selected food waste
Vegetable waste	Available vegetable (potato, cauliflower, cabbage, bean)
Fish waste	Fish parts which are easily decomposed
Chicken slaughter waste	Chicken slaughter parts which are easily decomposed
Plate waste	Left-over foods from people's plate

Inoculum selection and preparation

As inoculum, the anaerobic sludge of dairy manure from biogas plant was selected for this experiment. During the batch assay to minimize the biogas production from inoculum, it was stored for 2 weeks in an incubator at 35 ^{0}C.

Pretreatment

Pretreatments of substrates are essential parameter for conducting this experiment to avoid hazardous circumstances. Pretreatment is the process of pre-making the substrate easily degradable by removing the substances that obstructs the biogas production and decelerates the hydrolysis step before being introduced into the digester. Cutting and chopping into small pieces by using knives and scissors was the main pretreatments of the substrates for this experiment. Sieving the inoculum was done to remove the clod particles to perform the experiment smoothly.

Temperature condition

For the batch study, mesophilic condition was selected. Methanogenesis bacteria are inactive in extreme high and low temperatures; the most suitable temperature for mesophilic condition is 35 ^{0}C (Lund *et al.,* 1996). This temperature condition was maintained for conducting this experiment.

Experimental set-up and procedure

Among a number of digestion systems', batch system is the simplest form. At first biomass is added to the digester in a batch and is sealed for the whole duration of the process. Odor problem becomes a severe when batch digesters are emptied. The key parameter of designing and operating a successful real-scale biogas plant is the biochemical methane potential (BMP), the maximum methane production capacity of each feedstock. This test is done under specific conditions. In addition, a rough evaluation of the presence of inhibitory components is made. The ultimate methane yield is the indicator of methane yield of a biomass.

The ultimate methane yield was determined in batch tests. Inoculums of active microbial biomass from a functioning digester were mixed with the feedstock of interest. The batches were placed in incubated for a period of time (54 days) during which the biogas and methane production was measured. Measurement of methanogenic potential (BMP) was done as described by Møller *et al.* (2004). The 500 mL batch bottles were used as the digester which was placed in an incubator (ICP 110; Merck; Germany; volume: 108 L). The incubator can heat the interior upto 60 ºC and cool it down to -12 ºC or 0 °C (depending on appliance). Each substrate samples as well as a control containing only inoculums were triplicated. The quantity of substrate and inoculums were calculated roughly in order to obtain same (1:1) VS (volatile solid) of substrate and inoculum. The total masses of 15 sample substrates were calculated based on VS by using equation (1) (Rahman *et al.*, 2018).

$$P_i = \frac{m_i \times C_i}{m_s \times C_s}$$

Where, P_i= mass ratio = 1;
m_i = amount of inoculum (g),
C_i = concentration of inoculum as VS (%),
m_s = amount of substrate (g), and
C_s = concentration of substrate as VS (%) of fresh mass.

The reactor bottles were each filled with approx. 250 ml gently homogenized inoculum. After mixing substrates with inoculums, all reactors were closed carefully with butyl rubber bungs. To ensure anaerobic conditions, the headspace of all reactors was flushed with nitrogen gas for 2 minutes. All the reactors were maintained at 35 °C in the incubator. Incubation period for this study was 54 days.

Measurement of different parameters

The total volume of biogas produced in each bottle was measured periodically. The amount of biogas produced from each bottles were measured by volume displacement of glass syringe (SGC, Australia, capacity: 500 ml). Gas samples were taken for analysis periodically by Gas analyzer (Korno GT-1000; China) with the help of gas sampling bags according to manufacturer procedure. With calibrated pH/Conductometer (914 pH/Conductometer, Metrohm, Switzerland) the pH-value was measured. Total solid (TS) and volatile solid were determined using standard method (APHA, 1998). Total ammonium nitrogen (TAN) was determined using photometric kits (Spectroquant kit, Merk, USA) and photometer (NOVA 60, Memmert, Germany). The total nitrogen (TN) was measured using thermo-reactor (TR 420, Merck, Germany) and photometer following manufacturer procedure.

Data collection and analysis

During the experiments, the data from the batch studies were accumulated in MS excel 2010 for further analysis.

Analysis of batch study

Triplication of each substrates samples and a control containing only inoculum was done for analysis. These triplicates were carried out for this batch study experiment including a control that indicated the productivity of the inoculum. In order to obtain the production of the sole substrate, methane produced from each sample was corrected by subtracting the volume of methane produced from the inoculum control. The specific methane yield was calculated by using equation (2) (Moller *et al.*, 2004).

$$BMP_{observed} = \frac{V_{(ino+feedstock)} - V_{ino}}{mVS_{feedstock}}$$

Where, $BMP_{observed}$ = observed biochemical methane potential (mL CH_4 (g VS)$^{-1}$),
$V_{(ino + feedstock)}$ = volume of methane produced by inoculum and substrates (mL CH_4),
V_{ino} = volume of methane produced by inoculum alone (mL CH_4) and
$mVS_{feedstock}$= mass of volatile solids in substrate (g VS).

The same procedure was followed to determine biogas yield of specific substrates. Then cumulative biogas and methane yield were calculated. A degradation curve can be drawn and compared depending on the daily gas production.

Results and Discussion

Amount of total waste from the student halls

From the four ladies halls of BAU, about 860 kg waste is generated daily. Amount of total wastes form the four halls are given in Table 2. In different seasons types of vegetable wastes change with the time. In summer, it was found that vegetables wastes were potato, papaya, bitter gourd, leaves mostly in quantity. On the other hand, in winter, vegetable wastes were found from potato, cauliflower, cabbage, bean mostly. Composition of different food materials present in the wastes that were used in conducting the whole experiment is shown in Figure 1. From Figure 1 (i) and (ii) it is clear that type of vegetables differs from one season to another. The percentage of vegetable waste in both seasons was almost same in total mixed waste which was generated from halls. From Figure 1(ii), cauliflower was higher in quantity in the composition of vegetable wastes. However, the availability of boiled rice was highest in the composition of wastes from plates (Figure 1(iv)). It is evident from Figure 1(v) that amount of vegetable wastes and mixed wastes were higher in the total wastes and slaughter and fish wastes were less in quantity.

Table 2. Amount of total wastes from four halls

Name of the Hall	No. of Students	Average Food Wastes from Kitchen (kg/day)	Average Food Wastes from Whole Hall (kg/day)
Sultana Razia Hall	450	15	160
Taposhi Rabeya Hall	750	30	200
Sheikh Fojilatunnesa Mujib Hall	1000	30	250
Begum Rokeya Hall	800	15	160
Total	3000	90	770
Total waste		860 kg/day	

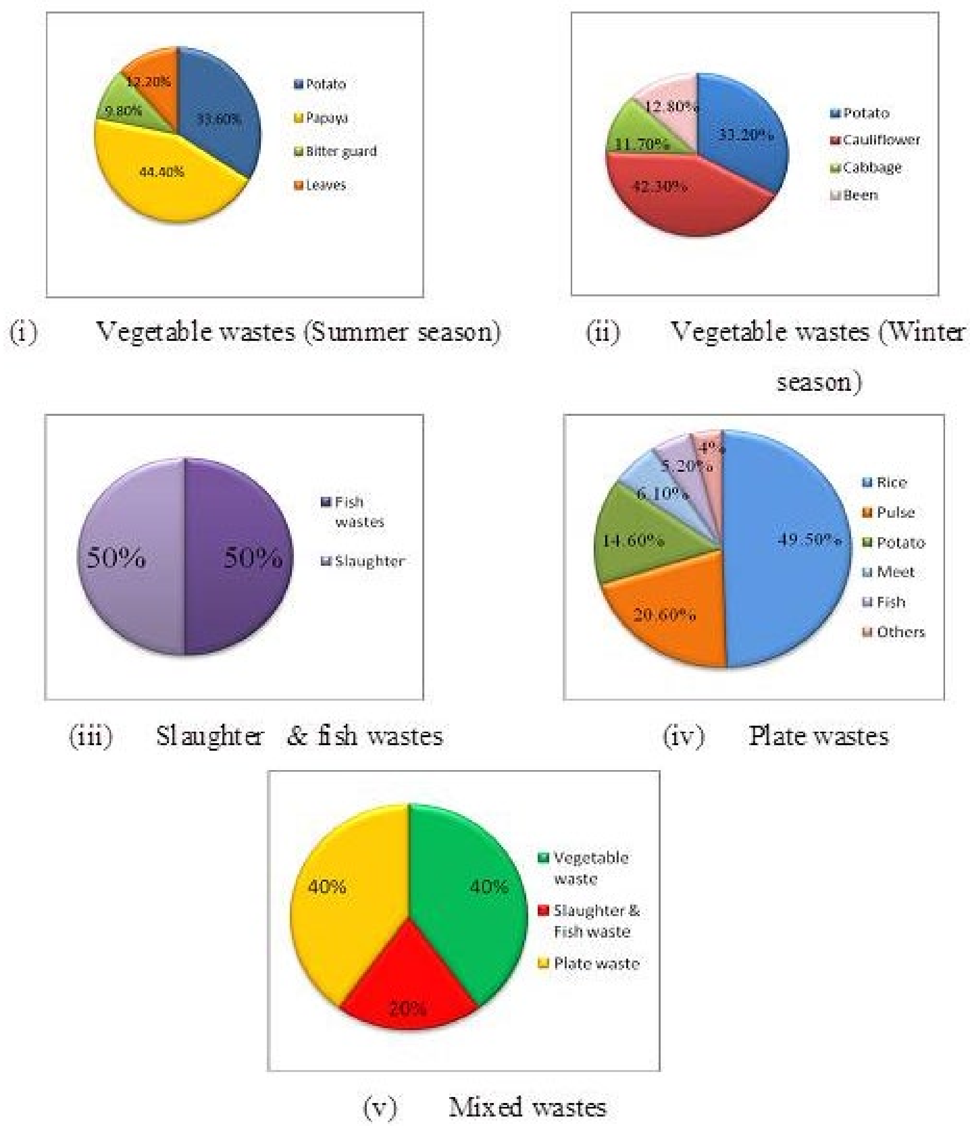

Fig. 1 Composition of different food materials in the wastes

Table 3. Characteristics of substrates and inoculum used in the batch assay

	Vegetable waste	Slaughter & fish Waste	Plate waste	Mixed waste	Inoculum
pH	5.98	6.67	6.64	6.74	8
TS (%)	11.78	22.50	25.88	19.68	5
VS [wb] (%)	11.06	18.74	24.8	18.26	3.275
Ash (%)	0.72	3.76	1.08	1.42	1.72
NH_4-N(g/l)	0.034	0.035	0.046	0.044	0.048
TN (g/l)	0.197	0.213	0.268	0.161	0.163

Characteristics of substrates and inoculum

Different characteristics of substrates and inoculums used in this experiment are summarized in Table 3. From Table 3, the initial pH of mixed type waste was 6.74. For anaerobic digestion, pH range is one of the important factors. Generally, the pH value around 7 is considered as neutral range. If the pH value of the input substrate mixture in the digester is around 7, optimum biogas production can be obtained as methanogenic bacteria are very sensitive to pH characteristics. Availability of total solids and volatile solids were higher in plate waste than other substrates, 25.88 % and 24.8 % respectively. On the other hand, the highest ash content was 3.76% in slaughter and fish waste mixture. Highest total ammonia nitrogen was 0.034 g/l in vegetable waste and then 0.035 g/l in slaughter and fish waste mixture, 0.044 g/l in mixed waste and 0.046 g/l in plate waste. If the total ammonia nitrogen concentration is low, then it is helpful for the anaerobic digestion, while the higher total ammonia nitrogen decreases the methane production (Sheng *et al.,* 2013; Sterling *et al.,* 2001).

Comparison of biogas production and methane yield

Specific average biogas production and cumulative biogas production attained through this experiment are shown in Figure 2 and Figure 3, respectively. From the trend in Figure 2, at the beginning the biogas production from slaughter and fish waste mixture was higher (75.26 ml/g VS) than any other kitchen wastes and continued till 30th day. On 46th day the biogas productions from the slaughter and fish waste mixture fall down. In case of vegetable waste, biogas production decreased continuously from the start to the end of the test. The range of biogas production for vegetable wastes, slaughter and fish wastes mixture, plate wastes and mixed type waste were 3.71-31.11 ml/g VS, 4.95-78.44 ml/g VS, 8.71-28.95 ml/g VS and 6.65-29.85 ml/g VS respectively. From Figure 3, the highest cumulative biogas productions for slaughter and fish waste mixture were 256.13 ml/g VS. Biogas productions from other three types of waste were very low compared to the slaughter and fish waste mixture. For identifying the potential biomass, specific average methane yield and the final cumulative methane productions attained during the batch assay are shown in Figure 4 and Figure 5.

From Figure 4, initially the methane production was higher for vegetable waste and it started decreasing with time continued till the end. The range of methane yield for vegetable wastes, slaughter and fish wastes mixture, plate wastes and mixed type waste were 2.45-23.73 ml/g VS, 3.68-57.21 ml/g VS, 5.98-20.08 ml/g VS and 4.70-21.07 ml/g VS respectively. The bio-chemical methane production potential (BMP) of slaughter and fish wastes mixture was found 190.08 ml/g VS which was higher than other substrates as shown in Figure 5. Second best was mixed waste (74.40 ml/g VS) followed by plate waste (66.95 mg/l VS) and vegetable wastes (61.30 mg/l VS). TS content in other three types of waste was much higher than that of vegetable waste. High TS content frequently causes overloading and ultimately reduces methane production (Wu *et al*., 2009).

Evaluation of BMP test

To evaluate the BMP test of the batch study a standard degradation curve can be used. We can evaluate a BMP test comparing the degradation curve as shown in Figure 6 in accordance with the steepness of the graph. Flat curves mean slow feedstock availability or slight inhibition, while very steep curves mean very good availability and degradability. If a sign of very strong inhibition or toxicity of the feedstock is seen that indicates degradable organic matter is added and no (or negative) net biogas production occurs. Comparing the standard curve types along with experimental result showed in Figure 3, it was found that only slaughter and fish waste mixture curve showed normal degradation. However, vegetable waste, plate waste and mixed waste showed slightly inhibited degradation. This happened because the fish waste/viscera may have good amount of enzymes, which enhance the first stage of fermentation namely hydrolysis. Unpaprom *et al*. (2015) found that when microorganisms are able to produce suitable enzymes, the hydrolysis step is going to speed up; however, for vegetable waste and plate waste, hydrolysis may become a rate-limiting step if the substrate is hardly accessible by the enzymes because of their rigid structural composition. From this batch study experiment, bio-methane production potential (BMP) were found higher in vegetable waste than other substrates (Figure 5). On the other hand, biogas yield was higher in slaughter and fish waste mixture (Figure 2).

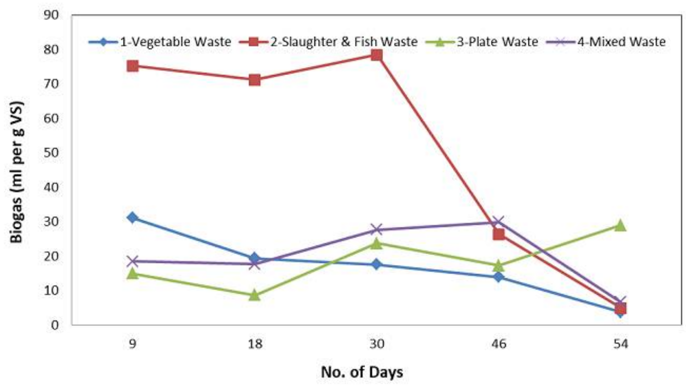

Fig. 2 Specific biogas production from selected substrates during the batch assay

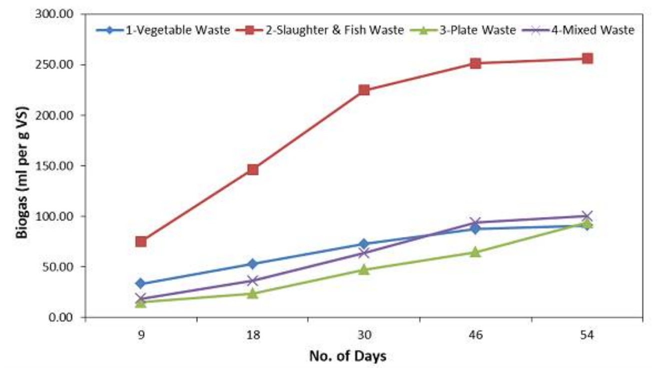

Fig. 3 Cumulative biogas production from selected substrates during the batch assay

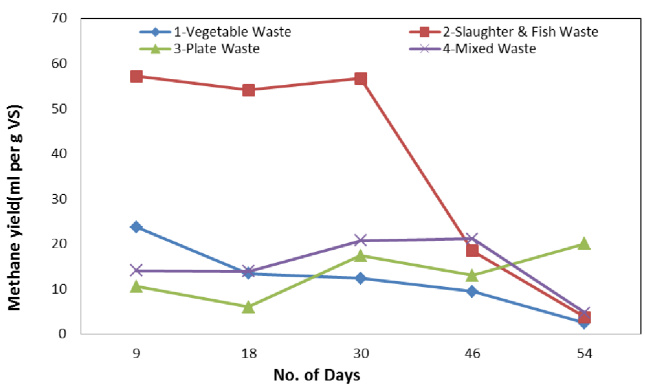

Fig. 4 Specific average methane yield

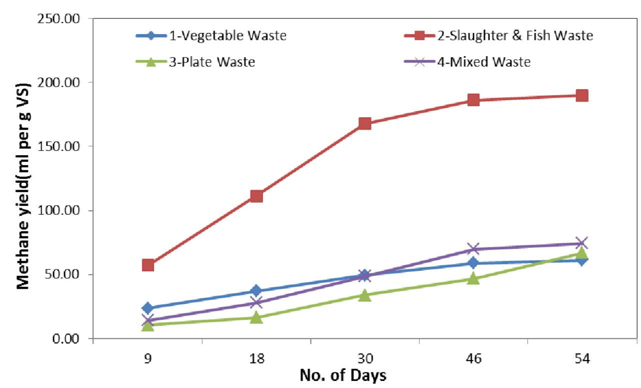

Fig. 5 Cumulative bio-methane production from selected substrates

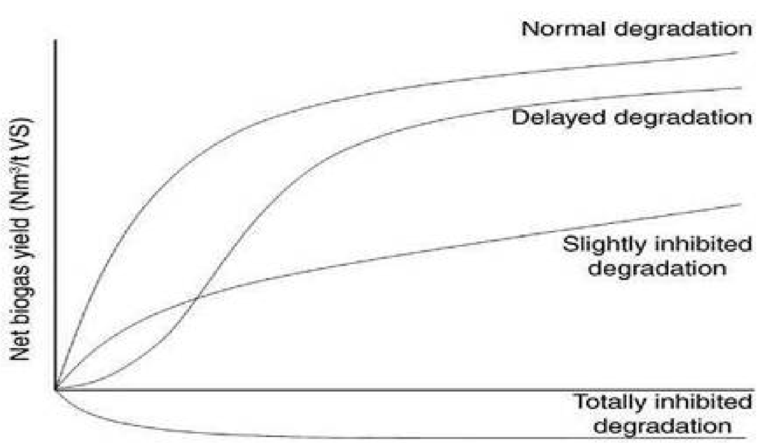

Fig. 6 BMP degradation curves (adapted from The Biogas Handbook by Wellinger *et al.* (2013)

Biogas production from total mixed wastes

No meter is used in our country to meter the gas consumption. Sabikunnahar (2008) conducted an experiment on household energy consumption pattern in Mymensingh municipality area. She commented that a gas burner consumes 0.56663 m³ gas per hour. As the natural gas which are to delivered to households contain 85-95% methane (Marchese *et al.,* 2018). So, a gas burner burns 0.4811 m³ methane per hour. In the student halls the burners are operated approx. 5 hours every day. From the total 860 kg wastes per day, about 11.68 m³/day methane can be produced from mixed type waste. From the total wastes, about 11.68 m³/day methane can be produced for mixed type waste which can replace 44.16 % natural gas consumption of four student halls and approximately equivalent to the need of almost two halls. From the experimented data it was found that slaughter and fish waste mixture was holding the potentiality of producing more methane than other sets of wastes. So, it can be said evidently that the above mentioned percentage can be increased if the amount of slaughter and fish waste mixture in the mixed wastes is increased.

Conclusion

Different types of food wastes collected from halls were digested experimentally in the laboratory and their behavior on biogas production as well as methane production was monitored. From the batch study of selected biomass it was figured out that slaughter and fish waste mixture was generating more methane than other biomass. Total amount of food wastes generated from four ladies halls of BAU was found about 860 kg/day (approx.). Almost about 11.68 m³/day methane from mixed type waste can be produced from total wastes generated from four ladies halls. About 44.16% of natural gas consumption can be substituted by the total produced biogas from these wastes generated every day from four ladies halls. The percentage of biogas production can be increased if the amount of slaughter and fish waste mixture in the mixed waste is increased as these wastes were holding more potentiality of producing methane than other substrates.

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