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ANAEROBIC CO-DIGESTION OF SEWAGE SLUDGE AND KITCHEN WASTE FOR BIOGAS PRODUCTION

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Abstract*- The research work was conducted to investigate the production ability of biogas from sewage sludge with co-digestion of kitchen waste through anaerobic digestion. Firstly three digesters were prepared to observe the individual degradation rate of kitchen waste, sewage sludge and co-digested SS with KW at temperature 37°C (mesophilic digestion). Secondly, four digesters were constructed where KW and SS were co-digested at ratios of 2:1, 4:1, 6:1 and 8:1 respectively at loading rates of 100, 200, 300 and 400 g/L. Thirdly, three digesters were constructed to observe the effect of alkalinity at temperature 37°C at a loading rate 200 g/L. Three alkali (NaOH) doses 1.0%, 1.5% and 2.0% on wet matter basis of kitchen waste were applied to improve biodegradability and biogas production. The highest degradation rate was obtained from 1.5% NaOH. Finally, a portable biogas reactor was fabricated for pilot-scale biogas production which included an agitator and heating system.*

Keywords: Anaerobic Digestion, Sewage Sludge, Kitchen Waste, Biogas

1. INTRODUCTION

Bangladesh is an energy starved under developed country. With a population of 150 million living in an area of 147,000 sq. km. it is one of the most densely populated countries too. For several decades, it has been a gas based mono-energy nation with most of the commercial energy requirements met by indigenous natural gas. Since 2005, the increased gas demand outpaced gas supply resulting a gas shortage and due to its non-renewable nature, the reserve will be depleted one day. So we should focus our view on the alternative renewable energy sources such as solar energy, biogas, biodiesel, wind power, tidal energy etc. **[1].**

MSW contains an easily biodegradable of up to 40%.Conventional MSW management has been primarily disposal by land filling. Treatment of municipal wastewater results worldwide in the production of large amounts of sewage sludge. Sewage sludge is characterized by a high content of organic compounds and this is the cause of its putrescibility. The sludge also contains a substantial amount of inorganic material and a small amount of toxic components. Therefore, sludge before landfill disposal or agricultural application should undergo chemical and hygienic stabilization. There are many sludge-management options in which production of energy (heat, electricity, or bio-fuel) is one of the key treatment steps. One possible method of stabilization and hygienization involves methane fermentation through AD **[2].**

Anaerobic digestion is a complex biological process in which microorganisms break down biodegradable organic matter i.e. cattle manure, kitchen waste, poultry dropping, sewage sludge, agriculture residues, and other organic garbage in the absence of oxygen and thus produced biogas **[3].**

In comparison with the rural area there is a huge amount of sludge produced in urban area of Bangladesh. Among them drainage sludge occupies a major portion. Therefore, cow manure has limited availability in many areas particularly in urban area. Preparation of biogas from CM have been using mainly in rural areas but there is also plenty amount of biomass(KW, SS etc.) in urban area, which will be a potential source of biogas **[4].** Due to high biodegradability, calorific value and nutritive value to microbes, these large amounts of kitchen waste & sewage sludge can be utilized to produce biogas which will generate a high quality renewable fuel and which will be more cost effective. Moreover, production of biogas will reduce the use of fossil fuels, thereby reducing CO_2 and poisonous gas emission. This is accord with Kyoto Summit agreement **[5].**The prime object of this work was to utilize KW & SS and this paper demarcates briefly the prospect of these wastes for biogas production in Bangladesh. The aim of this paper was also investigate the effects of organic loading rate (OLR), temperature and treatment of KW with NaOH. A portable biogas reactor was also fabricated for efficient biogas production and ultimate protection of environment from the bad effect of methane gas that would be produced by uncontrolled AD.

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2. MATERIALS AND METHODS

2.1 Waste Collection and Processing

The kitchen wastes used in this study were collected from different halls of Shahjalal University of Science & Technology and Surma residential area, Sylhet. Sewage sludge's were collected from the drain of SUST. In kitchen waste, total amount of rotten vegetables and rotten rice were near about 70%. Potato, eggs, fruits etc. were relatively low in mass. After removing the bones, plastic bags, metals and inorganic residues, wastes were cut into small size in order to reduce size to get efficient biogas production **[6].** Then these wastes were mashed into pest by using hopper.

2.2 Experimental Design

A simple lab-scale experiment was fabricated using ten digesters. Each digester was made of glass. The volume of digester was 1L each and working volume was 0.5 L. In this study the volume of produced gas was measured by water displacement method considering the volume of the generated gas equal to that of expelled water in the water collector. Each digester was connected to water chamber (plastic bottles) by a plastic pipe (gas pipe) which was used to pass the produced gas into water chamber. Another plastic pipe (water pipe) was used to take the displaced water from the water chamber to the water collector which was fitted air sealed by M-seal. Both the ends of the gas pipe were inserted just at the top of the digester and the water chamber. The water pipe was inserted just bottom of the water chamber and top of water collector. The set up is illustrated in Figure-1:

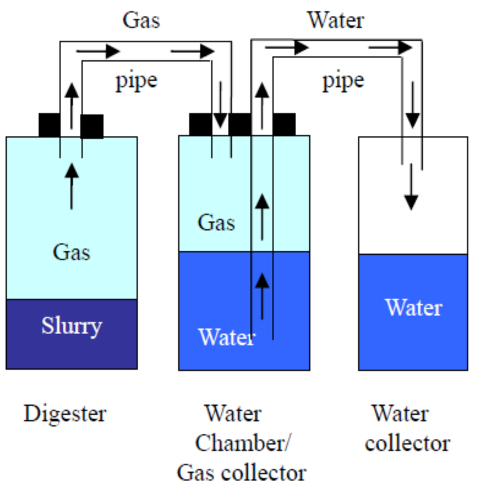

Fig.1: Schematic diagram of the lab-scale experimental set-up (adapted from **[7]**).

2.3 Lab Scale Experiment

At first, three digesters were prepared; D-01, D-02 and D-03 for KW, SS and co-digested KW with SS respectively. The digesters were operated in batch mode and were run at room temperature and a temperature of 37°C (mesophilic digestion) respectively. The substrate composition of the digesters is given in the Table-1.

Table 1: Feed stocks in batch digesters at room temperature and a temperature of 37°C

No. of Digester(D)	Organic biomass KW(g)	Bacteria seed, SS(g)
D-01	100	00
D-02	00	100
D-03	100	25

Further four digesters (D-3.1, D-3.2, D-3.3 & D-3.4) were constructed by mixing KW and SS at different mixing ratio of 2:1, 4:1, 6:1 and 8:1 respectively. The amount of SS of all digester was same. For the subsequent studies, another three digesters (D-04, D-05 & D-06) were set up to observe the effect of alkalinity at a loading rate of 200 g/L. The mixing ratio of KW to SS was also 4:1 in all digesters. The temperature maintained in all digester was about 37°C. Three NaOH doses of 1.0%, 1.5% and 2.0 % on wet matter basis of KW were applied, where 1.0% was given in D-04, 1.5% in D-05 and 2.0% in D-06. To maintain optimum temperature (37°C) for mesophilic digestion, all digester were kept into water bath. Retention time of digestion was 7-10 days depending on the gas production.

Table 2: Digesters specification

No. of Digester (D)	Mixing ratio of KW to SS	KW (g)	SS (g)	Loading rate of KW(g/L)	Parameter to be optimized
Optimization of loading rate					Loading rate (g/L)
D-3.1	2:1	50	25	100	100
D-3.2	4:1	100	25	200	200
D-3.3	6:1	150	25	300	300
D-3.4	8:1	200	25	400	400
Optimization of alkalinity					NaOH (%)
D-04	4:1	80	20	200	1.0
D-05	4:1	80	20	200	1.5
D-06	4:1	80	20	200	2.0

2.4 Pilot Scale

A simple pilot-scale experiment was fabricated by using a digester which was made of plastic and the volume of the digester was approximately 60 liter. Here volume of produced gas was also measured by water displacement method. According to the lab-scale experiment, the loading rate of 200 g/L was carried out in this experiment. An amount of 30 liters water, 6 Kg KW and 1.5 Kg SS were poured into the digester. A metal agitator was placed from the top surface of the reactor for homogeneous mixing of biomass. The agitator was agitated by manually. To maintain optimum temperature (37°C) for mesophilic digestion a heating spiral coil was placed inside the reactor and hot water from water bath was passed through the digester by pump. The reactor was operated in batch mode. The temperature was maintained for first 12 hours at 37°C and then next 12 hours at room temperature and again 12 hours at 37°C and gradually so on. Figure-2 illustrates the schematic diagram of the set up.

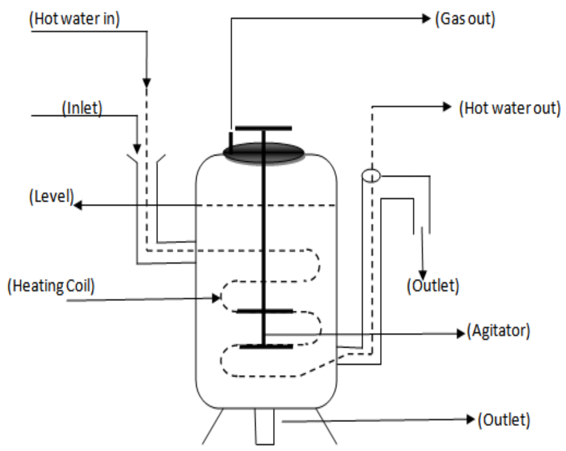

Fig.2: A portable biogas digester set up.

3. RESULTS AND DISCUSSION

3.1 Comparisons of Biogas Production from KW, SS and Co-digested KW with SS at Room Temperature.

In same loading rate and same temperature the biogas production was investigated for digester D-01, D-02 and D-03.

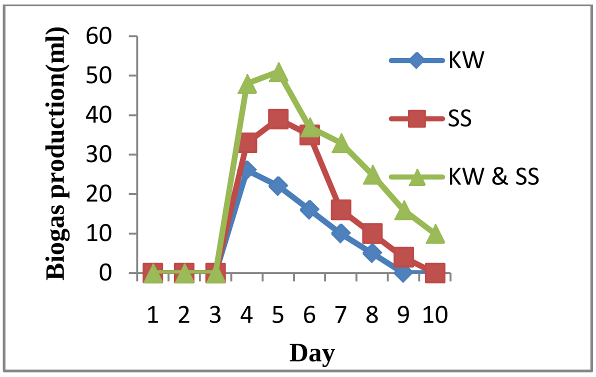

Fig.3: Comparisons on biogas production (ml) among KW, SS and co-digested KW with SS at room temperature and loading rate 200 g/L.

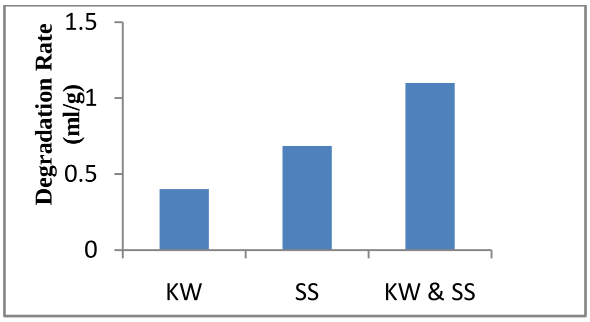

Fig.4: Comparisons on degradation rate (ml/g) among KW, SS and co-digested KW with SS at room temperature and loading rate 200 g/L.

KW contained more readily biodegradable compositions and it was easily converted to biogas but it had low buffer capacity and it was easy to acidify. Co-digestion with animal manure or sewage sludge as base feed stock was an effective way to improve buffer capacity and achieved stable performance **[8].** Co-digestion of sewage sludge with agricultural wastes or MSW as well as KW can improve the methane production through anaerobic digestion processes **[9]**.

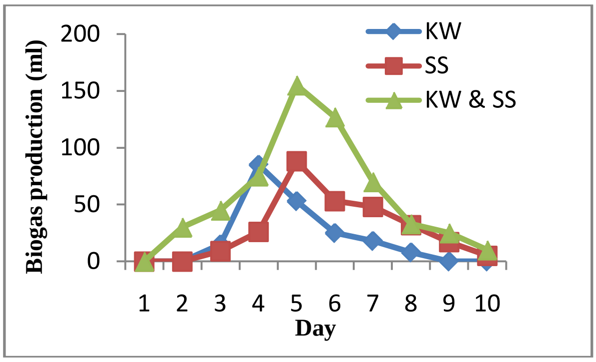

Fig.5: Comparisons on biogas production (ml) among KW, SS and co-digested KW with SS at temperature of 37°C and loading rate 200 g/L

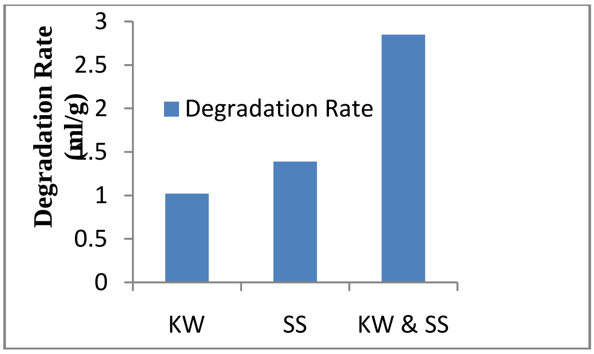

Fig.6: Comparisons on degradation rate (ml/gm) among KW, SS and co-digested KW with SS at temperature of 37°C and loading rate 200 g/L

Figure-4 shows that the digester D-03(KW and SS) produces more biogas than KW and SS alone at room temperature. The degradation rate for digester D-01 was 0.40 ml/g, D-02 was 0.685 ml/g and D-03(KW & SS) was 1.1 ml/g. Figure-6 shows that the digester D-03(KW and SS) produces more biogas at temperature of 37°C than room temperature. The degradation rate at a temperature of 37°C for digester D-01 was 1.02 ml/g, D-02 was 1.39 ml/g and D-03(KW & SS) was 2.85 ml/g. Co-digestion is the simultaneous digestion of a homogenous mixture of two or more substrates. The use of co-substrates usually improves the biogas yields from anaerobic digester due to positive synergisms established in the digestion medium and the supply of missing nutrients by the co-substrates **[5].** So, among two experiments it was observed that the biogas production rate was higher at temperature of 37°C than room temperature and co-digestion of KW & SS gave more biogas production than KW & SS alone.

3.2 Effect of Organic Loading Rate for Co-digestion of KW with SS

It was important to evaluate process performance in term of biogas production or degradation rates. To optimize the loading rate Digesters D-3.1, D-3.2, D-3.3 and D-3.4 were run at mesophilic condition (37°C). Biogas production or degradation rate during anaerobic process at different loading rates is shown in figure 7.

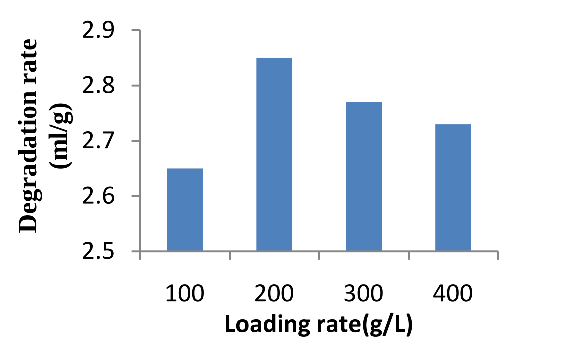

Fig.7: Degradation rate (ml/g) of co-digested KW with SS at temperature 37°C for various loading rates.

Figure 7 represents the biogas production per gram of KW during the digester's operation at different loading rates. The degradation rates (ml/g) for 100 g/L, 200 g/L, 300 g/L and 400 g/L loading rates were 2.65 ml/g, 2.85 ml/g, 2.77 ml/g and 2.73 ml/g respectively. The degradation rate of 200 g/L was higher than other loading rate.

3.3 Effect of Addition of NaOH for Co-digestion of KW with SS

Sodium hydroxide (NaOH) was added with KW in liquid state to improve biodegradability and biogas production. Anaerobic co-digestion of KW and SS with different percentages of NaOH for biogas production for digesters D-04, D-05 & D-06 was investigated. In the loading rate (200 g/L) and temperature at 37°C, the effects of percentages of NaOH were illustrated in figures 8 and 9.

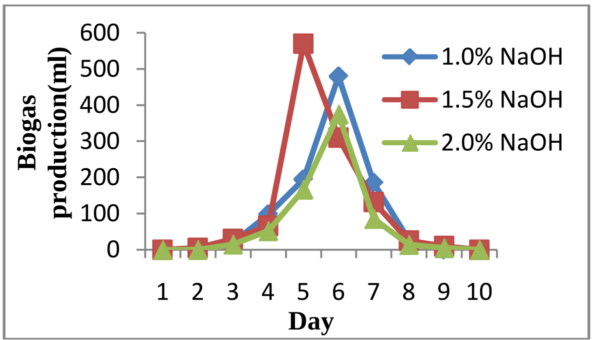

Fig.8: Daily biogas production from KW with treated by various percentages NaOH in loading rate of 200 g/L at temperature of 37°C

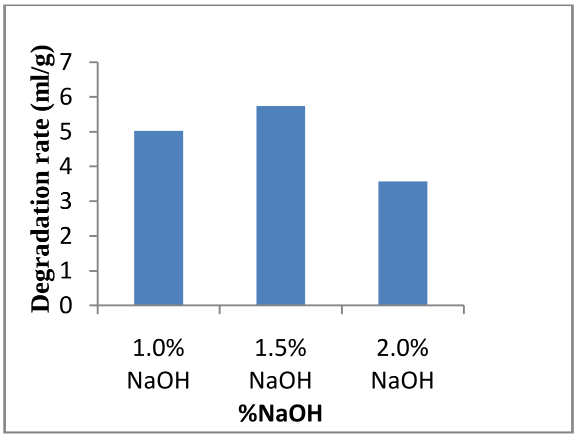

Fig.9: Degradation rate (ml/g) of co-digested KW and SS with treated by various percentages NaOH in loading rate of 200 g/L at temperature of 37°C

From figures 8 and 9, it was observed that the daily biogas production and degradation rates (ml/g) for 1.0%, 1.5% and 2.0% NaOH doses were 5.03 ml/g, 5.74 ml/g and 3.57 ml/g respectively. It was also found that the retention time for digesters D-04, D-05 and D-06 were 6, 8 and 7 days respectively. Although, retention time was longer for 1.5 % of NaOH but biogas production was higher than others. Therefore, KW incorporated by 1.5% NaOH was optimum in this experiment.

3.4 Comparisons on Biogas Production from Untreated and NaOH-Treated KW for the Digester D-03 and D-05(1.5% NaOH)

The results of daily biogas production of the untreated KW and treated KW by NaOH are shown in figures 10 and 11.

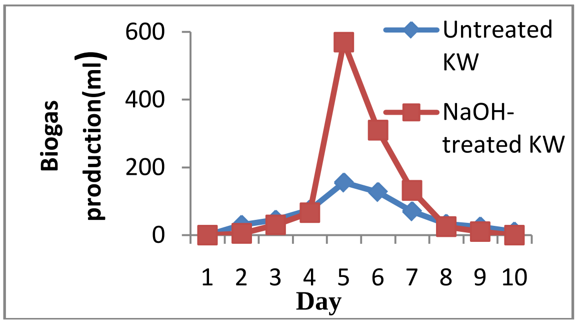

Fig.10: Comparisons on biogas production from untreated and NaOH-treated KW at temperature of 37°C

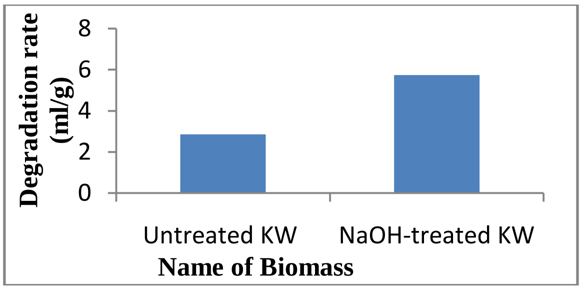

Fig.11: Comparisons on degradation rate (ml/g) for untreated and NaOH-treated KW at temperature of 37°C.

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The major differences between the untreated and NaOH-treated KW were daily biogas production value and digestion time. It was found that, the KW treated by NaOH produced more biogas than the untreated KW and it was also found that the treated KW took shorter time to produce biogas as compared to the untreated one. At the loading rate of 200 g/L, the highest daily biogas production of 155 ml was achieved for the untreated KW at digester D-03, while 570 ml for NaOH-treated KW at digester D-05. It took approximately 9-10 days for the untreated KW to complete the digestion process, while 7-8 days for NaOH-treated KW. On the other hand, the degradation rate of 5.74 ml/g was achieved for the NaOH-treated KW, while 2.85 ml/g for untreated KW. The enhanced biogas production and shortened digestion time imply that NaOH-treated KW were more efficiently used and more quickly digested by anaerobic microorganisms.

3.5 Effect of Temperature

Biogas production from organic substances is strongly affected by the temperature where anaerobic digestion takes place. The room temperature in the laboratory was 25°C-30°C. The temperature range required for AD is 3°C-70°C. Temperature between 35°C-38°C is considered optimal. Three temperature ranges are common, the psychrophilic (below 20°C), the mesophilic (between 20°C and 40°C) and the thermophilic (above 40°C) ranges **[10].** It has been observed that higher temperatures in the thermophilic range reduce the required retention time. However, it is rarely done because the energy requirement in maintaining the temperature is more expensive than the biogas yields. Moreover, the thermophilic bacteria are more sensitive than that mesophilic bacteria, so higher costs are needed to control the temperature in the thermophilic range. Thus, a mesophilic digester must be designed to operate at temperatures between 30°C and 37°C for its optimal functioning **[11].** Comparisons on biogas production from D-03 and digester for pilot-scale experiment at room temperature and at temperature of 37°C are shown in figures 12 and 13 respectively.

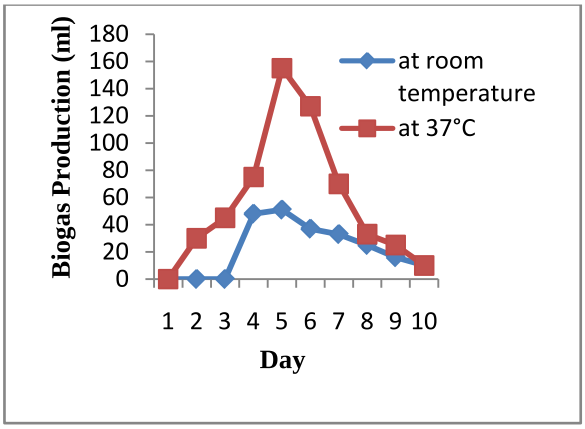

Fig 12: Comparisons on biogas production at D-03 from KW with co-digestion of SS in loading rate of 200 g/L at room temperature and a temperature of 37°C.

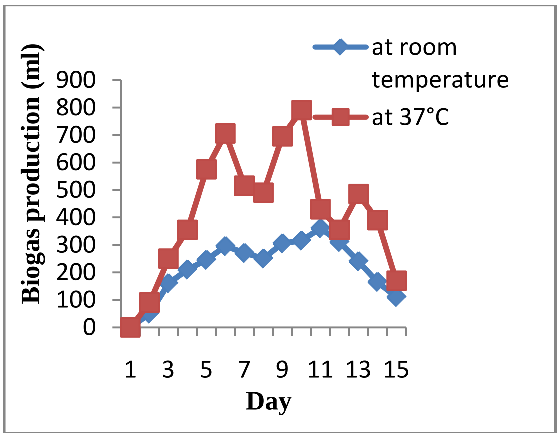

Fig 13: Comparisons on biogas production at digester for pilot-scale experiment from KW with co-digestion of SS in loading rate of 200 g/L at a temperature of 37°C and room temperature.

When temperature dropped down microbial activity decreased, as a result biogas production or degradation rate was also decreased. From figures 12 and 13, it was observed that at 37°C the biodegradability was higher than room temperature.

4. CONCLUSION

Biogas can be considered as a low cost waste treatment because the microorganisms involved in the process can degrade a wide range of organic substances. Research and dissemination of biomass fuel throughout the country should be given priority in solving our energy crisis**.** Under mesophilic digestion (37°C), maximum biogas was produced under the conditions- OLR 200 g/L and treated with 1.5% NaOH. Finally, a portable biogas digester was fabricated and it was working efficiently under the optimum conditions. Energy recovery from available biomass materials through biogas production can be a strong alternative option to supplement rural energy demand, which can consequently reduce higher level of deforestation, net greenhouse gas emissions as well as use of fossil fuels. By generating biomass fuel from the abundance sources, Bangladesh can solve a big portion of energy deficiency.

5. ACKOWLEDGEMENT

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7. NOMENCLATURE

Symbol	Meaning	Unit
OLR	Organic loading rate	(g/L)
KW	Kitchen waste	(-)
AD	Anaerobic digestion	(-)
SS	Sewage sludge	(-)
MSW	Municipal solid waste	(-)
CM	Cow manure	(-)
D	Digester	(-)
OF	Organic fraction	(-)