BIOGAS PRODUCTION FROM VEGETABLE WASTE AT THERMOPHILIC CONDITIONS

By

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***Abstract* -** The present study was based on a pilot biogas plant of 1.2 m^3 installed at IESE which demonstrated to be an efficient setup. The focus was on analyzing the potential of food waste being produced at NUST for biogas production. The process was repeated twice until maximum biogas yield was achieved. The ideal feed size for food waste was 2.5 cm, with the retention time of 17 days in batch mode. The co-digestion of food waste with fresh cow dung as a starter gave significantly better results. The process was successfully demonstrated by using temperature controlled system to maintain thermophilic conditions. It resulted in the biogas production of 0.03 m^3 per kg of food waste. The biogas with high methane content of 60% was burnt with a transparent flame. The process resulted in the production of nutrient rich slurry with high NPK content and high C/N ratio. This slurry can be used as a natural fertilizer after drying. Thus the food waste proved to be a valuable alternate source of energy. The setup confirmed to be cost effective as it was not only a cheap source of energy but also a source of nutrient rich organic fertilizer. In the long run it will help in minimization of solid waste disposal and ultimately the reduction in green house gas emissions from the waste. Therefore, the application of biogas technology has economic, environmental, health and social benefits. It ultimately contributes towards sustainable development.

***Keywords*:** Biogas; alternate energy source; food waste; anaerobic digestion; thermophilic conditions; batch mode; effluent slurry.

1. Introduction

Energy has become an important prerequisite for the economic development of a country. Pakistan is presently facing a serious energy crisis, which is costly and multi-dimensional. This extreme shortage of energy resources in the country has lead to increase in fossil fuel prices. Therefore, research for developing alternative biomass for bio-energy has become increasingly important. Food waste is a very good source of biomass to be used in biogas plants for generating energy. Pakistan has great potential for the production of biogas. This technology will not only produce energy but will achieve waste minimization as well.

Minimization of waste has always been a serious problem. Food waste is mainly organic matter, which can be converted to useful energy by biochemical process (Angelidaki *et al.,* 2003). It results in two by-products: biogas and digested organic slurry (Hessami *et al.,* 1996). Biogas is a mixture of gases produced naturally from the decay of organic wastes (Igoni *et al.,* 2008). A variety of factors affect the rate of digestion and biogas production including temperature, pH, water/solids ratio, carbon/nitrogen ratio, mixing of the digesting material, the particle size of the material being digested, and retention time (Vindis *et al.,* 2009).

The significance of biogas all over the world shows that we can implement this technology in Pakistan. Therefore, a research study was conducted on the biogas plant being installed at IESE, NUST, H-12 sector Islamabad, for converting the organic waste into a renewable source of energy. The study was started in September 2010, which was successfully completed in August 2011.

2. Materials and Methods

A specially designed fixed dome biogas plant of 1.2 m^3 was installed. The plant was fabricated with fibre glass in such a way to keep the temperature of waste inside at a suitable temperature, which is necessary for its decomposition. The main part of biogas plant was the digester, its food inlet for the waste and an outlet for the slurry. A pretreatment tank was constructed to treat

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specifications were volume 1.2 m^3, diameter 0.9 m and height 1.8 m. The digester had a waste and an effluent tank to collect the effluent slurry. The study includes three phases, the first batch was processed just to acclimatize the newly installed biogas plant. Therefore it is called as Acclimatization phase. The duration of this batch was of 30 days. No production of biogas was observed during this phase. The actual study started from batch-I, in which the biogas production started. The results of this batch were analyzed and compared with the next batch. The last batch was the most successful batch, as maximum production and ideal conditions were maintained successfully during the batch-II.

2. 1. Start-Up of Biogas Plant and Operational Parameters

2.1.1. Collection of Waste: The food waste including leftover of vegetables and fruits was collected from local vegetable market located in sector-I-11, Islamabad. Almost 550 kg of food waste was processed for batch-I and batch-II each, including leftovers of cabbage, cauliflower, cucumber, eggplant, potato, capsicum, water melon, spinach, bottle guard, beans, mango, banana and tomato. The waste was analyzed and segregated and then it was weighed at the plant site using a weighing balance.

2.1.2. Preparation of Waste: In batch-I food waste was shredded by using an electric shredder. The feed size was about 3.5 cm. In batch-II the waste was cut manually by using a knife to reduce the feed size to 2.5 cm. After shredding, the waste was added in the pretreatment tank along with water and was left for 3 to 4 days (from the date of receiving it) before putting it into the digester.

2.1.3. Batch Condition: The batch conditions were applied to all the phases, in which the organic waste was loaded for certain fixed period. The process of anaerobic digestion was allowed to proceed. It was emptied after a fixed retention time, when the production of biogas had completely stopped.

2.1.4. Temperature Controller: An electronic sensor circuit with an LCD was installed to monitor the temperature inside the digester and water tank, combining a thermocouple and a temperature regulator. A-4 m long heating coil made up of 1 inch diameter copper pipe was fixed inside the digester, to allow the hot water to flow through the pipe, making the digester content warm. The temperature of circulating water was maintained at 60 to 65^oC for thermophilic conditions.

2.1.5. Water Recirculation System: A water tank was placed near the plant, in which water was heated using an electric rod. A recirculation pump was also installed inside the water tank, to help recirculate the water. The thermocouple kept the temperature of water at the required temperature.

2.1.6 Organic Loading Rate: The total capacity of the plant was 1200 litres (1.2 m3), 50 % of which should be waste and 50% should be water, for proper mixing of the digestate. All the prepared food waste was added in the digester in one day for all the batches, along with water and slurry or cow dung.

2.1.7. Seeding: For seeding, almost 100 litres of processed slurry was added in the plant in batch-I, to make up 50% of the organic matter. It was brought from an already working biogas plant installed in Chak Shehzad Town, Islamabad. In batch-II only 100 kg of fresh cow dung along with equal amount of water was added in the digester, which was brought from a cattle farm in G-12 on Kashmir Highway, Islamabad. The processed slurry or cow dung was added to speed up the biological degradation of waste.

2.1.8. Hydraulic Retention Time: The HRT depends upon the size of the digester and the amount of waste being digested. The thermophilic conditions, when maintained properly, reduce the HRT of the feed material. In the present study all batches were processed in summer, which speeds up the anaerobic decomposition. The HRT of acclimatization phase was 30 days, and that for batch-I and II was 21 and 17 days respectively.

2.1.9. Head Space for Biogas: The headspace to be left for biogas collection in the digester should be 5 to 10% of the total volume of digester. As the volume of digester is 1.2 m^3, so its capacity for digestate is about 1.05 m^3. The remaining space should be left for biogas to be collected in the dome.

2. 2. Sampling

A representative sample of the feed material was taken from the raw waste, as received from the generation source. The digestate samples were taken in 100 ml plastic bottles, by opening the cap of the outlet channel of the plant. In order to take a representative sample, the inner material was thoroughly mixed manually by using a metal rod before taking the sample. A gas collection fixture was installed on the opening on the dome of digester for taking samples of biogas in football bladders. The slurry samples were taken in plastic bottles from the slurry collected in the effluent tank.

2. 3. Analytical Procedure

All the parameters tested during the study for the performance evaluation of biogas plant were analyzed using standard methods.

2.3.1. Analysis of Feed Material

The proximate analysis was done to analyze the potential of food waste to produce biogas. The initial analysis of feed material includes the analysis of feed size by using a measuring scale. According to EPA report by Hedman (2009), the appropriate feed size for a biogas plant is between 0.6 to 5 cm. To measure the moisture content the sample was dried in the oven Model WTC Blender for about 24 hours at 103^oC till a constant weight was obtained. The sample was placed in muffle furnace Model NEY M 525 Series-III at 550^oC for 5 hours, to measure the ash content (APHA, 2005).

2.3.2. Analysis of Digestate

The analysis of digestate was carried out to check the trend of reduction in the organic content of food waste. Electrometric method was used to measure the pH of the digestate samples. A glass electrode pH meter Model Cyberscan 500^{pH} was used to measure sample pH daily. The temperature of digester and ambient temperature were recorded three times a day, by using the electronic temperature sensor. Gravimetric method was used to determine TS and VS of the sample on daily basis. For TS an accurately measured volume of sample in the evaporation dish was placed in the oven at 105^oC and allowed it to dry. Total Solids is the material residue left in the vessel. VS are solids that were removed by igniting a sample in a 550^oC muffle furnace for 1-hour. The weight lost on ignition is the volatile solids. The closed reflux titrimetric method was used to determine COD of the samples daily. The samples were analyzed in duplicate and their average value was taken (APHA, 2005). The percentage removal of organic matter is expressed as COD removal, TS removal and VS removal, which gives the strength of effluent slurry (Qureshi, 2005)**.**

2.3.3. Analysis of Biogas

The volume of gas was measured three times a day by installing a liquid displacement setup. Following todo *et al.* (2007) a manometer was made to measure the pressure of biogas three times a day. The difference in the liquid column gave the reading of pressure in cm, which was converted into pascal (SI Unit). The gas pipe was connected to a bunsen burner. The gas was ignited to observe the flame of biogas. If combustion is perfect, the flame is dark blue and almost invisible in daylight. Ghani and Idris (2009) used gas chromatography, therefore, the composition of biogas samples was analyzed in triplicate by gas chromatography. The gases including CO_2, CH_4, H_2 and O_2 were determined using a Perkin Elmer Sigma 2000 Capillary chromatograph with a PE Nelson 1020 Personal Integrator (Perkin Elmer, Norwalk, Connecticut, USA).

2.3.4. Analysis of Effluent Slurry

The analysis of slurry was done once at the end of batch process by following the standard methods. The total nitrogen was examined by Kjeldahl method. Phosphorus was determined by wet digestion method through spectrophotometer at 410 nm wavelength. Potassium was measured by wet digestion using a flame photometer (Jenway) at 767 nm wavelength. The organic carbon content in the slurry was determined by the rapid titration procedure of Walkley-Black method involving chromic acid wet oxidation. The C:N ratio was estimated by dividing the amount of N into the amount of C, which gave the C:N ratio where N = 1 (APHA 2005).

3. Results and Discussion

3.1. Quality of Feed Material

3.1.1. Moisture Content: The results of the proximate analysis of feed material showed that the moisture content of food waste in the batch-I and II was 88.4 and 90.1% respectively. Zhang *et al.* (2007) carried out the study on food waste and found that the optimum moisture content was 74 to 90%.

3.1.2. Ash Content: The ash content of batch-I was found to be 17.6%. In batch-II the ash content was measured to be 13.6%. According to Khan (2010), the ash content of waste was 15%.

3.2. Quality of Digestate

The analysis of digestate showed that it was thick slurry, blackish in color. It was very smelly in the start, but the smell reduced with the passage of time as the degradation proceeded.

3.2.1. pH: The trend of variation in pH during the process showed that the pH of digestate increases as the process proceeds. The value of pH for batch-I ranged from 6.1 to 8.1. The optimum pH on which biogas production was observed in batch-I was ranging from 6.6 to 7.6. The pH for batch-II ranged from 6.3 to 8.2, shown in figure-1. The biogas production started when pH of the digestate was 6.6 and the maximum production was seen at 7.0. Ayu and Aryati (2010) conducted a study on biogas production from cassava starch effluent in which the pH was maintained between 6.8 to 7.2 to get maximum yield.

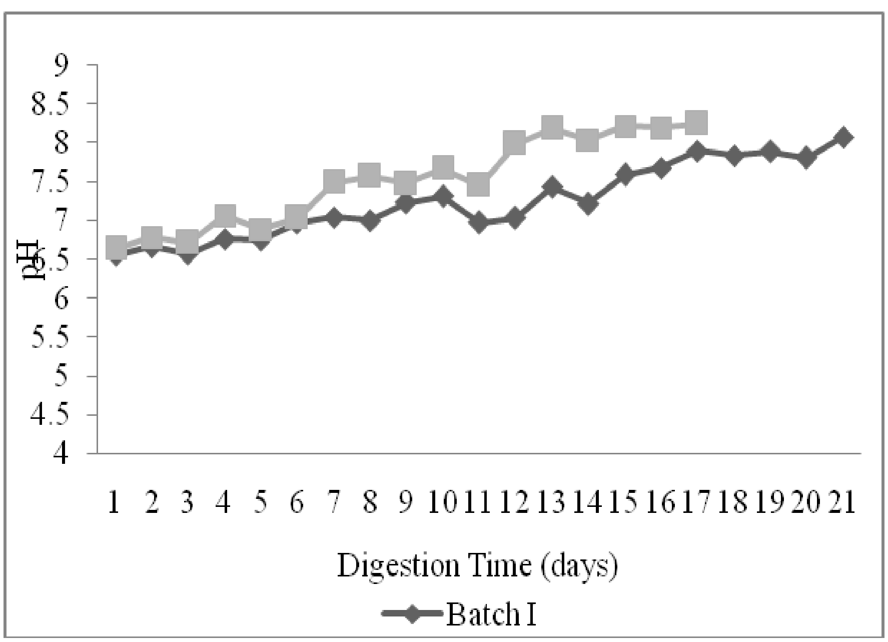

Fig. 1. Variation of pH for batch-I and batch-II

3.2.2. Total Solids: The initial and final TS for batch-I was 12% and 6% and for batch-II was 10% and 3% respectively. The TS reduction for batch-I was 50.2% and for batch-II was 77.5%, shown in figure-2. Zhu *et al.* (2009) established that TS reductions ranged from 50.2% to 65.0%.

3.2.3. Volatile Solids: In the present study the initial and final value of VS for batch-I was 82.4% and 38.5%, and for batch-II was 86.3% and 17.8% respectively. The VS reduction for batch-I and batch-II is shown in figure-2. Chen *et al.* (2009) explored that the VS reduction for cafeteria waste was 87%.

3.2.4. COD: The initial and final COD for batch-I was 17287 mg/l and 6416.9 mg/l, and for batch-II was 19340 mg/l to 4254.8 mg/l respectively. The comparison of percentage removal of COD for batch-I and batch-II is given in figure-2. Sakar *et al.* (2009) found that COD removal for livestock waste ranged from 57 and 78%.

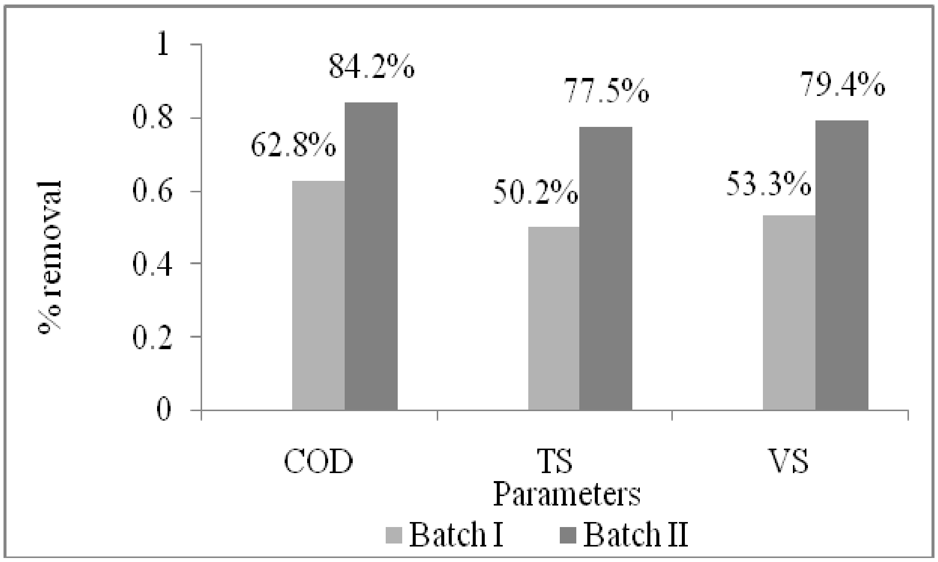

Fig.2. Comparison of percentage removal of organic matter

3.3. Biogas Production

3.3.1. Production in Batch-I: In this phase 550 kg of pretreated food waste was added along with 100 L of effluent slurry from a biogas plant as seeding. This batch was started on 23rd June and production started after 7 days on 29th June. The gas production remained steady for almost 5 days and then started declining. The production ended on 19th July 2011, after 21 days of HRT, given in figure-3. The average production for this batch was 1.7 L/hr. The average temperature of digester was 57.9 ^{o}C and the ambient temperature was 32.8 ^{o}C. The cumulative biogas production was 0.001 m^3/kg of food waste. The main reason for lower production was the large feed size of 3.5 cm. The high TS of 12%, scum formation due to lack of any mixing system and low percentage removal of organic matter, decreased the potential of biogas production. Pound *et al.* (1981) observed that low production is due to lack of methanogenesis, with alcohol fermentation and high amount of CO_2.

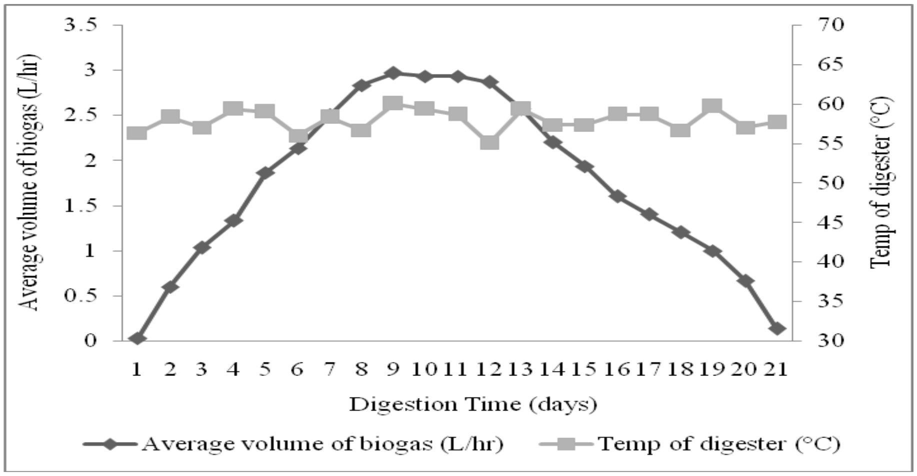

Fig. 3. Trend of biogas production for batch-I

3.3.2. Production in Batch-II: In this phase 550 kg of food waste, water and fresh cow dung were added in the digester on 3rd August. The production of biogas started after 5 days on 8th August with 15 L/hr. The maximum production of 80 L/hr was seen on 14th August with 57.5 °C of digester temperature. The biogas production remained high for 4 days. It started decreasing on 17th August and it ceased after 22nd August with 7 L/hr, given in figure-4. The average biogas yield was 52.3 L/hr. The average digester temperature was 56.3 °C, whereas the average ambient temperature was 30.2 °C. The cumulative biogas production was 0.035 m^3/kg of food waste. This was the most effective batch as it showed maximum percentage removal of organic matter due to efficient working of the digester. The HRT was also reduced to 17 days. The maximum production was also due to relatively small feed size of 2.5 cm, low TS of 10%, addition of cow dung and manual mixing of digestate reduced the risk of the formation of scum. All these factors lead to maximum production of biogas. Islam *et al.* (2009) carried out a study on vegetable waste along with cow dung and results showed maximum gas production of 1200 mL/kg of total waste.

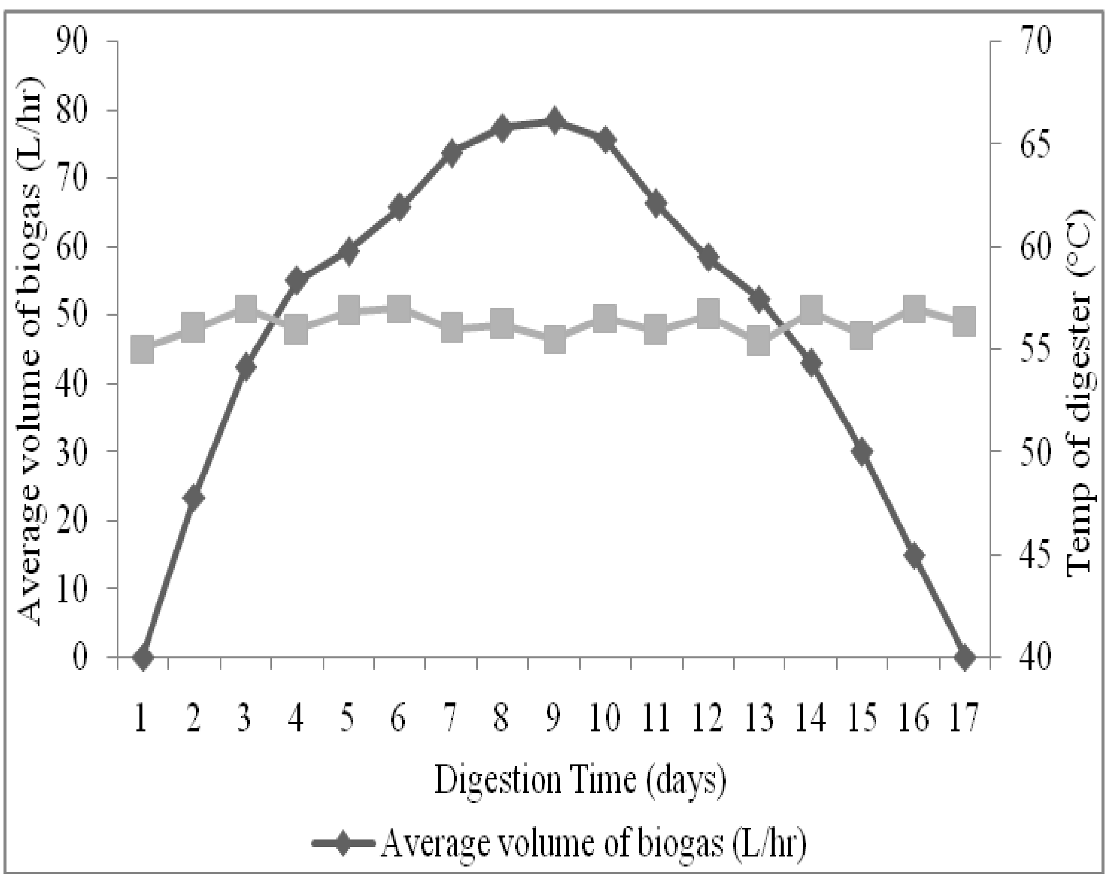

Fig. 4. Trend of biogas production for batch-II

3.3.3. Biogas Pressure: In batch-I the very low pressure was not measurable with manometer. Therefore the gas did not burn a flame on ignition. But in batch-II a sudden increase in pressure was observed. The initial value of pressure was 388 Pa on 8th August 2011. The increase in pressure lead to burning of the flame of biogas on 10th August. The maximum pressure reading was observed as 1785 Pa on 14th August. The pressure remained high for 4 days, when the biogas production was also high, given in figure-5. The pressure started decreasing on 17th August with the value of 1408 Pa. The minimum value of 0 Pa was observed on 22nd August. The average value of pressure was 1166 Pa. According to Vivekanandan and Kamaraj (2011) the pressure of biogas was achieved as 1600 Pa.

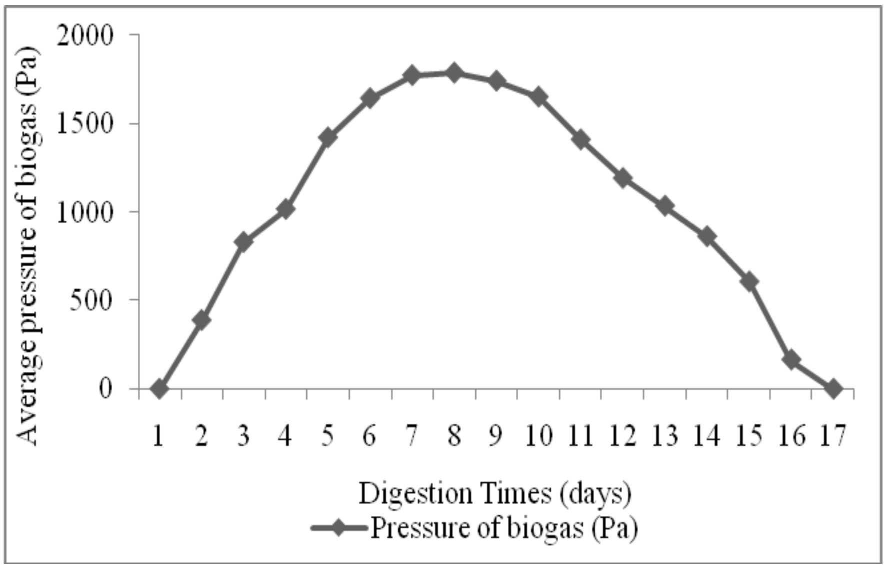

Fig. 5. Pressure of biogas for batch-II (Pa)

3.3.4. Biogas Flame: No flame was obtained for batch-I due to low pressure of biogas. According to Mandal *et al.* (1999) the burning of flame depends on the change in the methane content of biogas. In batch-II the biogas burned with a transparent flame on 10th August 2011, with increased production of biogas. Water and two eggs were boiled on the flame, on 14th of August. It did not burn after 19th August, with the decline in the production of biogas. The experiment showed that this process of biogas production from food waste was successful and the biogas can be used for heating and cooking purpose.

3.3.5. Biogas Composition: The resulting biogas for batch-I was composed up of 30.2% of CH_4, 65.9% of CO_2, 0.9% of O_2 and 3.1% of N_2. The biogas composition for batch-II consisted of 60.8% of CH_4, 33.6% of CO_2, 1.5% of O_2 and 4.1% of N_2, given in figure-6. Thus the methane content was high in batch-II. According to Voegeli *et al.* (2009) the methane in biogas produced from food waste was 56.8%.

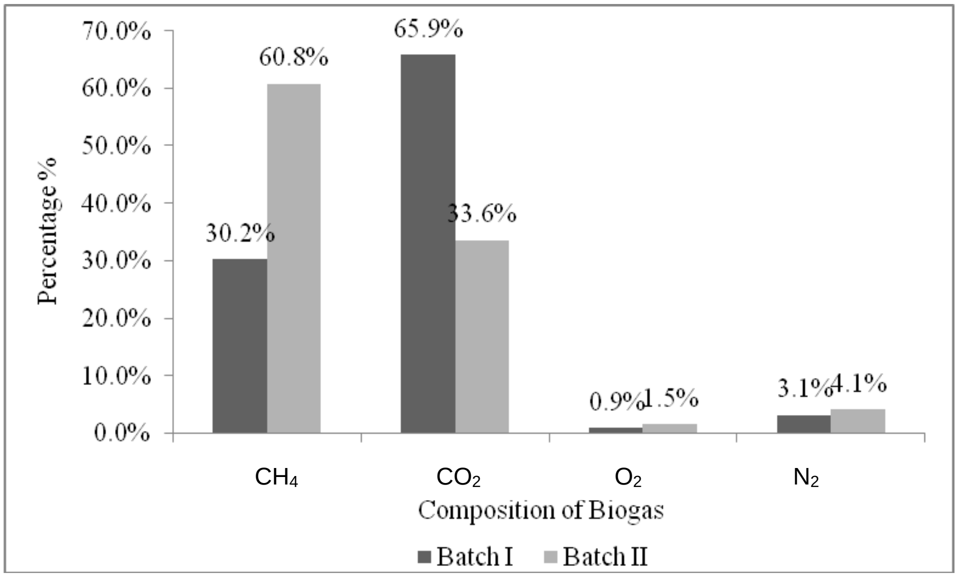

Fig. 6. Comparison of biogas composition for batch-I and batch-II

3.4. Effluent Slurry Production

The average slurry produced during batch-I was analyzed to be 1.5 litres per day. The total slurry produced for this batch was 31.5 litres for 21 days. The average amount of slurry produced during batch-II was 10 litres per day. This accounted for total production of 170 litres for a batch of 17 days. The slurry can be used as organic fertilizer after drying in sunlight, and its weight will reduce to half.

3.4.1. Nutrient Content in Effluent Slurry: For batch-I the N was 56.4 mg/L, P was 22.6 mg/L and K was 26.6 mg/L. The slurry from batch-II consisted of 84.9 mg/L of N, 33.4 mg/L of P and 34.8 mg/L of K. The comparison of results showed that the slurry from batch-II has more concentration of nutrients as compared to slurry from batch-I, because of the maximum reduction in the organic material. Voegeli *et al.* (2009) evaluated that the effluent had 225 mg/L PO_4-P and 74.1 mg/L of NH_4-N for food waste.

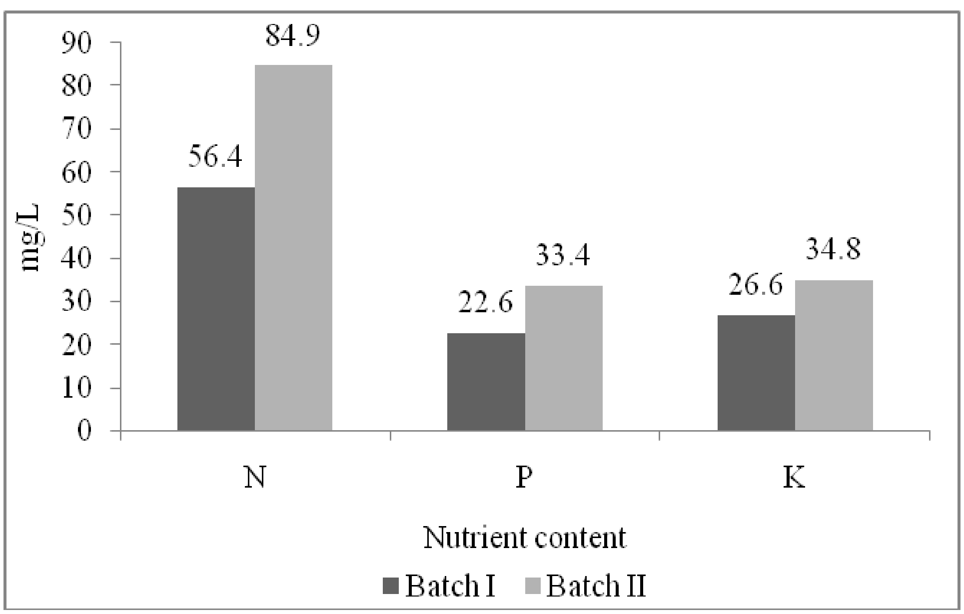

Fig. 7. NPK analysis of effluent slurry from batch-I and batch-II

3.4.2. C/N Ratio of Effluent Slurry: Total carbon content in effluent slurry of batch-I was 959.1 mg/l and in batch-II was 2123.5 mg/l. The result of C/N ratio for batch-I was 17:1and for batch-II was 25:1, which was relatively high due to addition of cow dung in the food waste. The C/N ratio of cow dung was calculated to be 30:1, which was productive for the slurry. According to Verma (2002) the optimum C/N ratio in anaerobic digestion is between 20 to 30.

4. Conclusion

In the present study, 1.2 m^3 of fixed dome biogas plant at IESE demonstrated to be an efficient setup. The codigestion of food waste and fresh cow dung proved to be suitable with feed size of 2.5 cm. The process was successfully demonstrated by using temperature controlled system to maintain thermophilic conditions in batch mode. The resulting successful production of biogas was 0.03 m^3 per kg of food waste, which can be used for heating purpose such as cooking. The nutrient content of the effluent slurry indicated its potential use as a fertilizer in the botanical garden of campus. This would certainly contribute to the projection of NUST as a truly Green Campus and a Zero Waste University.

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