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Anaerobic co-digestion of food waste and septage – A waste to energy project in Nashik city

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Abstract: The samples for food waste (FW) and septage were collected from six localities of Nashik city. Physical and chemical characterizations of the wastes were carried out. A Biomethanation potential (BMP) assay was developed to determine the ultimate biodegradability and associated methane yield during the anaerobic methanogenic fermentation of organic substrates. BMP assays of individual substrate, FW and septage were carried out by taking into account the volatile solids/total solids (VS/TS) ratio of each while keeping the inoculum's VS constant. BMP of FW and septage mixture was carried out in different ratios (1:1, 1.5:1, 2:1, 1:1.5 and 1:2) to find the optimum mixing ratio for maximum biogas production. The average methane yield for different locality FW was found to be 503 ±17.6 ml/g VS and for septage it was 56 ±10.8 ml/g VS. Based on the above results, the total biogas yield and total methane yield for 10 tons of FW would be 2178 m^3/d and 1306 m^3/d respectively. The total biogas yield and total methane yield for 20 m^3 of septage would be 65m^3/d and 39m^3/d respectively. From our co-digestion studies we also conclude that the mixture of FW to septage at 1:2 ratio gives 2896 m^3/day of biogas. The role of septage is to provide essential trace elements that are required for methanogens.

Key words: Food waste, septage, anaerobic, co-digestion, energy, biogas, methane

1 Introduction: India is the second most populous country in the world and fourth biggest consumer of energy worldwide. The per capita energy consumption of the growing population in India is increasing day by day [1]. Urban population in India has grown from 25 million in 1901 to 286 million (27%) in 2001 to 377 million in 2011 (31%). It is projected to increase to 590 million by 2030 with 68 cities having one million plus population. As per 2011 census, there are 7935 cities & towns in the country; the number has increased by 2774 since 2001 census [2].

Improper solid waste management and deficiencies in sanitation form a major environmental and health threat in Indian cities [3]. Around 38 % of urban households are using septic tanks and community toilet complexes (CTC's) for their daily needs. The often used septic tanks are devoid of any kind of treatment for septage/fecal sludge or environmentally sound disposal systems. The total quantity of solid waste generated in urban areas of the country is about 1.15 lac tons per day out of which approximately 85-90 % of solid waste is untreated and disposed-off on land **[4-5]**. Unscientific treatment and disposal of such large quantities of septage imposes major threats in Indian cities leading to environment and surface water pollution, greenhouse gas (GHG) emission, etc.**[5-6]**.

In the light of rapidly rising costs associated with energy supply and waste disposal and increasing concerns with environmental quality degradation, conversion of organic wastes to energy is a more economically viable solution. Within the framework of the "International Climate Initiative" (IKI) the Federal Ministry of Environment, Nature Conservation and Nuclear Safety of Germany (GIZ-ASEM) is supporting an innovative "Waste to Energy" project **[7]**. The objective of this project is to contribute towards environmental protection and the use of renewable energies and to increase energy efficiency through production of bioenergy and recovery of nutrient content of septage and food waste (FW). The project is expected to demonstrate financially viable and technically feasible solutions for the current solid waste and sanitation situation in urban areas in India.

In the last couple of decades anaerobic digestion (AD) of organic matter has been regarded as the most appropriate sustainable technology for renewable energy recovery and nutrient rich fertilizer production [5]. Septage and FW are currently the most abundant and problematic organic wastes in India. Septage is rich in nitrogen and trace elements but sometimes low in biodegradable organic matter **[8-9]**. Hence its biomethane potential (BMP) is very low. Food waste is very rich in volatile solids (90%), which can be easily converted to methane using the anaerobic process, but usually has a low amount of minerals, micronutrients and macronutrients **[10]**.

Food waste comprises various components which are rich in protein, lipids and carbohydrates **[11]**. The hydrolysis of these components generates substantial concentrations of inhibitory substances such as ammonia, long chain fatty acids and other fatty acids **[12]**. Failure to maintain the balance between these leads to a poor operational stability and to failure of the reactors **[13]**.

Co-digestion is the process of digesting two different kinds of wastes in a single bioreactor. In co-digestion, the favorable wastes improve stabilization of the biological system and during the process complex wastes are 'co-digested'. Anaerobic co-digestion has proven to improve digester operating characteristics and end performance both by increasing gas production and solid destruction **[8-14]**. A feasibility study for the co-digestion of FW and septage was investigated in order to improve the BMP of both the substrates. The nutrient requirement during the co-digestion process was also evaluated. The project will lead to the construction of a biogas digester with a capacity to treat 30 t/d of organic waste. In this biogas digester FW and septage will be subjected to anaerobic co-digestion resulting in the production of biogas and nutrient rich slurry **[15]**.

2 Materials and Methods

2.1 Collection of substrate and inoculum: Food waste and septage were collected from the city of Nashik, India. There are six divisions in the city of Nashik; Panchavati, Nashik East (NE), Nashik West (NW), Satpur, New Nashik - A township built by City & Industrial Development Corporation Ltd. (CIDCO), and Nashik Road (NR).The samples for the FW and septage were collected from these six localities. Food waste samples were collected from the vehicles that collect hotel waste from respective places. Septage samples were taken from tankers that collect septic tank samples from respective areas. Effluent from the anaerobic pilot plant treating FW in our institute campus was used as the inoculum. The effluent was brought in the laboratory in a closed container and was monitored for gas production. It was pre-incubated at 32^{o}C until it reached the endogenous respiration stage and was then used for the

BMP assay. The characteristics of this inoculum were a pH of 7.4 and a volatile solid (VS) content of 23.2 g/L.

2.2 Characterization of food waste and septage: Food waste mostly comprised cooked rice, cooked pulses, potato, beans, onion peels, used tea powder, roti, lemons, bones and brinjal. A total solid (TS), volatile solids (VS), pH, total nitrogen (TKN) and total ammonia nitrogen analysis was performed in accordance with APHA standard methods **[16]**. Chemical Oxygen Demand (COD) was estimated as described previously **[17]**.

2.3 Biomethanation Potential assay of food waste and septage: The BMP assays for each individual substrate (FW and septage) from all six localities were performed according to Angelidaki I et al. **[18]**. The assay was performed in 125 ml serum bottles. The concentration of the substrate used was 1 g VS/L in each bottle. Inoculum, an appropriate amount of substrate and 5ml of 5% $NaHCO_3$ were added to each (individual) bottle. The final volume was made to 100ml with distilled water. A control without substrate was set-up to account for the endogenous biogas produced from the inoculum. The bottles were flushed with nitrogen gas followed by immediate sealing. All the bottles were incubated at 32^oC. The experiments were carried out in duplicate.

Biogas produced from each bottle was measured daily using the water displacement method for the period of 40 days. Biogas composition was analyzed using a gas chromatograph (GC) (Chemito GC 7610) equipped with a thermal conductivity detector TCD detector and with hydrogen as carrier gas. Packed stainless steel columns with a solid support of spherocarb (length 2m, diameter of 1/8th) were used. The GC oven temperature was programmed to increase from 60 - 120^oC at the rate of 5^oC per min. The temperatures of injector and detector were at 150^oC and 183^oC respectively.

2.4 Statistical analysis: Statistical analysis of methane production and degradability with respect to place and ratio of FW to septage mixing were performed using ANNOVA software.

2.5 Biomethanation Potential of co-digestion of food waste and septage: The BMP of co-digestion of FW and septage was studied. The substrates taken were composite samples from the six localities. The total concentration of substrate was 1 g VS/L in each bottle for the admixture of the substrate. To determine the optimum mixing ratio, FW and septage were mixed in ratios of 1:1, 1.5:1, 2:1, 1:1.5 and 1:2 on the basis of VS. Inoculum, appropriate amount of FW, septage and 5ml of 5% $NaHCO_3$ were added to each individual bottle. The final volume was made to 100 ml with distilled water. A control without substrate was set-up to account for the endogenous biogas produced from the inoculum. The bottles were flushed with nitrogen gas followed by immediate sealing. All the bottles were incubated at 32^oC. The experiments were carried out in duplicate.

2.6 Trace element study: Experiments were performed to find the trace element requirement by the FW during anaerobic digestion. Mixed FW (1g VS/L), inoculum (60ml), $NaHCO_3$ (5ml of 5%), were added to the 125ml serum bottles. To this 1ml trace element solution was added, and the final volume was made to 100 ml with distilled water. Similar setups were made with addition of different trace elements solution except one element in each setup.

In the similar set-up, the FW was mixed with the septage in 1:2 ratio to get a final concentration of 1g VS/L in the 125 ml serum bottle. The trace elements requirement experiments were conducted as described above. Controls were kept with no trace element and with all trace elements. The experiments were carried out in duplicate.

3 Results and Discussion

3.1 Characteristics of food waste and septage: Physical as well as chemical characterization of organic waste is important for the operation of the anaerobic digestion process, because they affect biogas production and process stability during anaerobic digestion. The FW samples consisted mainly of cooked rice, chapattis, cooked potatoes, dal/pulses, cooked vegetables, and onion peels. Apart from this only the CIDCO sample comprised cooked meat and bones. Sample from Satpur and CIDCO were rich in oil. The pH values of all FW samples were in the range of 6.5 - 7.5 whereas for septage it was between 7 - 8.

The results of the physical and chemical analysis of FW and septage from different regions of Nashik are shown in Table 1. The TS of FW and septage samples were between 18.08-32.01 % and 1.10-5.69 % respectively. The VS contents for FW and septage samples were between 16.80-27.45 % and 0.8-3.9 % respectively. The TS and VS content of FW was 79.11 % and 79.97 % higher than septage. The anaerobic degradability of FW and septage samples was between 85-95 % and 65-76 % respectively, indicating that FW is better degradable than septage.

Table 1: Physical and chemical composition of the used FW and septage.

Parameters	Panchavati	NE	NW	Satpur	CIDCO	NR	Mixed
				Food waste			
pH	7.5	7.5	6.5	6.5	7.5	7.0	6.5
TS (%)	32.0	25.9	23.7	27.7	28.0	18.1	32.6
VS (%)	27.5	24.5	22.6	26.0	24.8	16.8	22.2
VS/TS	0.9	0.9	1.0	0.9	0.9	0.9	0.7
TN(%)	0.5	0.7	0.4	0.8	0.9	0.7	0.7
T NH_3-N (mg/kg)	205.0	77.0	49.0	175.0	210.0	82.4	82.4
COD (mg/kg)	240000.0	341800.0	348000.0	320000.0	345000.0	344000.0	214000.0
C/N Ratio	12.13	11.28	18.98	9.14	9.31	12.18	7.21
				Septage			
pH	8.0	7.5	7.5	7.5	7.0	7.0	7.0
TS (%)	5.7	1.8	4.7	4.8	2.7	1.1	6.8
VS (%)	4.0	1.4	3.6	3.5	1.7	0.8	4.4
VS/TS	0.7	0.8	0.8	0.7	0.7	0.7	0.6
TN(%)	0.2	0.1	0.0	0.1	0.0	0.0	0.2
T NH_3-N (mg/L)	45.9	12.3	15.7	28.0	16.8	22.4	22.4
COD (mg/L)	1800.0	3240.0	4280.0	5040.0	1280.0	1720.0	2920.0
C/N Ratio	0.03	0.11	0.42	0.10	0.14	0.10	0.05

The COD values for the FW samples were between 240000 and 348000 mg/kg which is 98 % higher compared to the septage COD values of1280-5040 mg/L. Total ammonia-nitrogen contents for FW samples and septage were 49-210 mg/kg and 15-45.92 mg/L. TKN for FW and septage were between 0.47 to 0.88 % and 0.02 to 0.16 %.

The average C/N ratio of mixed solid FW was 11.46 (VS weight) indicating that it contains a higher amount of carbon whereas the mixed septage had C/N ratio of only 0.13 (VS weight) which indicates that it has less organic carbon and a high amount of nitrogen. Therefore the co-digestion of FW and septage makes it a better choice **[19]**.

3.2 Biogas production from food waste and septage: Anaerobic digestion of FW and septage were done individually at a concentration of 1 g VS/L. The amount biogas that was produced during 40 days of the batch tests for FW ranged from 647-952 ml/g VS and for septage it ranged from 89-96 ml/g VS. Cumulative biogas production during individual digestion of FW and septage from different regions of Nashik is shown in Figure (1).

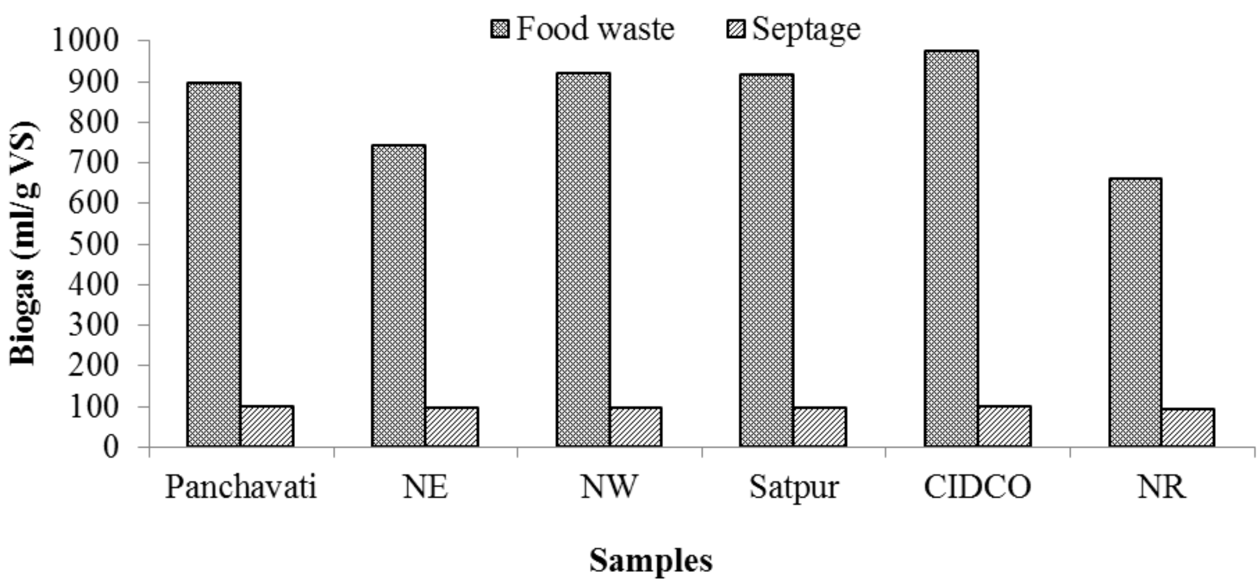

Figure (1): Biogas production from FW and septage.

Individual anaerobic digestion tests of FW and septage were carried out at an organic loading rate of 1 g VS/L using lab scale batch tests. The biogas production during 40 days of BMP tests for FW and septage were 897, 744, 922.5, 919, 976.5, 661.5 ml/g VS and 102, 97, 97, 98, 101, 93 ml/g VS respectively for Panchavati, NE, NW, Satpur, CIDCO and NR.

On an average FW produced 88.5 % more biogas than septage. The methane content of FW was 37 % higher than septage. Different values of methane content in co-digestion of FW and septage can be assessed from the 2-D interaction plot between different places and ratios as shown in Figure (2).

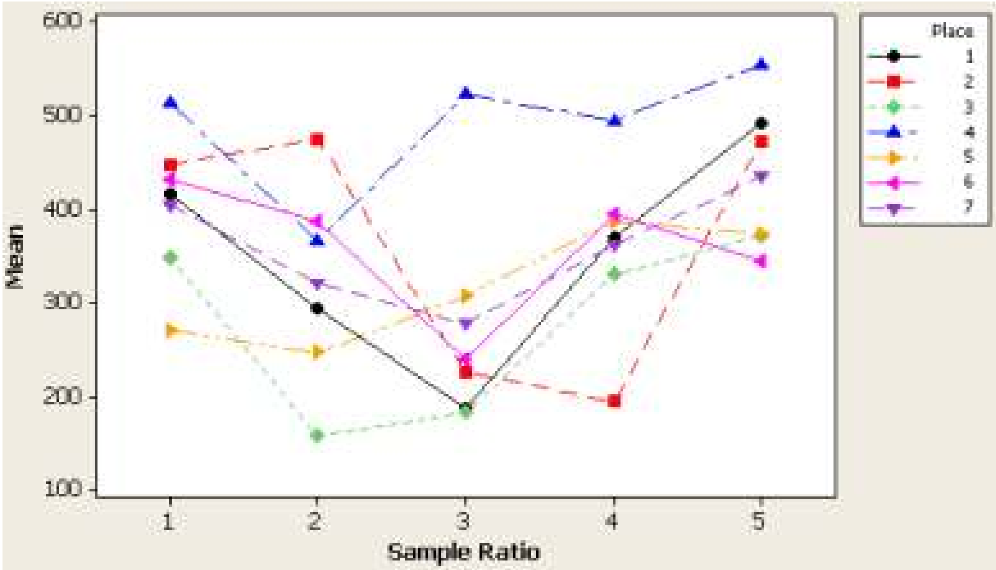

Figure (2): 2-D Interaction plot of methane production for different samples. X-axis, sample mixing ratios 1, 2 , 3, 4 and 5 correspond to 1:1, 1.5:1, 2:1. 1:1.5 and 1:2 respectively. Places 1, 2, 3, 4, 5, 6 and 7 correspond to Panchavati, Nashik East (NE), Nashik West (NW), Satpur, CIDCO, Nashik Road (NR) and mixed samples.

Statistical analysis for methane production shows that sample origins as well as ratios significantly influence the methane content. Satpur has shown a high methane content for all ratios except the ratio 1.5:1. The highest value of methane content can be seen at Satpur having a ratio 1:2. NW has shown lowest methane content for sample ratio 1.5:1. A decreasing trend can be seen for the ratio from 1:1, 1.5:1, 2:1 and then again increase from 2:1, 1:1.5, 1:2. Thus a dip in the response can be observed. An interaction exists between the place and ratio for methane content as can be seen from the highly nonparallel response lines shown in Figure (3). Thus individual plots may predict pseudo-convergent results.

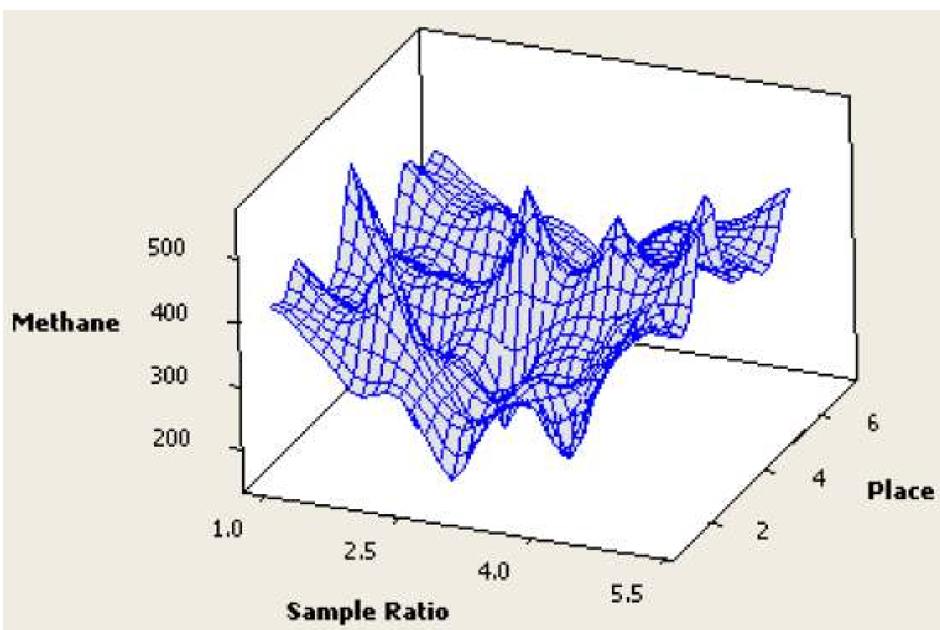

Figure (3): 2-D surface plot for methane production v/s place and samples. Different values of methane content on co-digestion of FW and septage can be assessed from the 2-D interaction plot between different places and ratios.

3.3 Co-digestion of food waste and septage: Experimental co-digestion of mixed FW and mixed septage at different ratios were investigated in order to confirm the 2-D interaction plot results. The biogas production at different ratios of FW and septage were measured and is shown in Table (2).

Table (2): Total biogas production, methane production and degradability at the end of the digestion experiment with different mixing ratios at the same organic loading rate.

Sample		Mixing Ratio				
		01:01	**1.5:1**	**02:01**	**01:01.5**	**01:02**
Panchavati	Biogas (ml/g VS)	693.00	489.00	313.00	616.00	818.50
	Methane (%)	63.55	48.38	31.23	56.03	54.30
	Methane (ml/g VS)	440.41	236.57	97.75	345.17	444.44
	Degradation (%)	72.02	67.29	70.93	71.06	67.99
NE	Biogas (ml/g VS)	746.50	790.50	376.00	323.50	787.00
	Methane (%)	60.73	46.43	43.05	58.14	57.71
	Methane (ml/g VS)	453.38	367.05	161.86	188.07	454.22
	Degradation (%)	73.99	70.37	63.42	72.06	69.85
NW	Biogas (ml/g VS)	581.50	262.00	304.00	549.50	620.00
	Methane (%)	53.52	36.74	50.11	60.10	54.31
	Methane (ml/g VS)	311.24	96.27	152.34	330.27	336.70
	Degradation (%)	75.12	66.61	59.30	71.59	66.99
Satpur	Biogas (ml/g VS)	854.00	610.50	870.00	824.00	922.50
	Methane (%)	57.86	53.33	54.09	60.61	60.81
	Methane (ml/g VS)	494.10	325.56	470.54	499.43	560.98
	Degradation (%)	84.62	69.45	65.77	72.33	74.07
CIDCO	Biogas (ml/g VS)	451.50	410.50	512.50	644.00	622.00
	Methane (%)	62.56	57.14	52.62	58.14	59.23
	Methane (ml/g VS)	282.45	234.55	269.68	374.44	368.41
	Degradation (%)	84.35	70.03	61.32	87.19	73.39
NR	Biogas (ml/g VS)	718.50	644.00	400.00	658.00	574.00
	Methane (%)	59.16	45.51	41.51	57.33	56.44
	Methane (ml/g VS)	425.05	293.09	166.02	377.26	323.97
	Degradation (%)	77.29	62.20	77.86	91.07	78.82

Food waste to septage at 1:2 ratio showed higher biogas production compared to other ratios as predicted by the 2-D interaction plot studies. Higher FW to septage ratio inhibited gas formation probably due to acid accumulation which was indicated by lower pH. Food waste has a very high hydrolysis rate which leads to increased VFA formation and methanogens have to bear up with the conversion rate. Table (3) shows the biogas production in the co-digestion plant when operated at different mixing ratios of FW and septage.

Table (3): showing total biogas yield for different ratio of admixture

01:01	Food waste	Septage	Total input	Total output
Input (t/d)	15	15	30	30
Specific Dry Solids (TS) %	26.87	3.95		5.06
Dry Solids (tons)	4.03	0.59	4.62	1.52
Specific Organic Dry Solids (VS) %	88.62	70.10		19.39
Organic Dry Solids (tons)	3.57	0.42	3.99	0.29
Degradability of Organic Solids (%)	89.44	71.12		
specific COD (mg/L)	250000 (mg/kg)	3400 (mg/L)		1213.33
Biogas Yield (m^3/ton VS)				2272.47
Specific Gas Yield (methane (m3/ton VS))				1363.48
Biogas Yield (m3/ton TS)				2696.67
Specific Gas yield (methane (m3/ton TS))				1618.00

1.5:1	Food waste	Septage	Total input	Total output
Input (t/d)	18	12	30	30
Specific Dry Solids (TS) %	26.9	3.9		2.1
Dry Solids (tons)	4.8	0.5	5.3	0.6
Specific Organic Dry solids (VS) %	88.6	70.1		51.2
Organic dry solids (tons)	4.3	0.3	4.6	0.3
Degradability of Organic Solids (%)	89.4	71.1		
specific COD	250000 (mg/kg)	3400 (mg/L)		2473.33
Biogas Yield (m3/ton VS)				2137.67
Specific Gas yield (methane (m3/ton VS**))**				1282.60
Biogas Yield (m3/ton TS)				2128.84
Specific Gas yield (methane (m3/ton TS**))**				1277.31

02:01	**Food waste**	**Septage**	**Total input**	**Total output**
Input (t/d)	20	10	30	30
Specific Dry Solids (TS) %	26.87	3.95		2.68
Dry Solids (tons)	5.37	0.39	5.77	0.80
Specific Organic Dry solids (VS) %	88.62	70.10		50.71
Organic dry solids (tons)	4.76	0.28	5.04	0.41
Degradability of Organic Solids (%)	89.44	71.12		
specific COD (mg/L)	250000 (mg/kg)	3400 (mg/L)		2840
Biogas Yield (m3/ton VS)				1850.33
Specific Gas yield (methane (m3/ton VS**))**				1110.20
Biogas Yield (m3/ton TS)				1555.20
Specific Gas yield (methane (m3/ton TS**))**				933.12

01:01.5	**Food waste**	**Septage**	**Total input**	**Total output**
Input (t/d)	12	18	30	30
Specific Dry Solids (TS) %	26.87	3.95		2.35
Dry Solids (tons)	3.22	0.71	3.93	0.71
Specific Organic Dry solids (VS) %	88.62	70.10		30.74
Organic dry solids (tons)	2.86	0.50	3.36	0.22
Degradability of Organic Solids (%)	89.44	71.12		
specific COD (mg/L)	250000 (mg/kg)	3400 (mg/L)		1846.67
Biogas Yield (m3/ton VS)				2410.00
Specific Gas yield (methane (m3/ton VS**))**				1446.00
Biogas Yield (m3/ton TS)				2269.77
Specific Gas Yield (methane (m3/ton TS**))**				1361.86

01:02	Food waste	Septage	Total input	Total output
Input (t/d)	10	20	30	30
Specific Dry Solids (TS) %	26.87	3.95		2.11
Dry Solids (tons)	2.69	0.79	3.48	0.63
Specific Organic Dry solids (VS) %	88.62	70.10		37.54
Organic dry solids (tons)	2.38	0.55	2.93	0.24
Degradability of Organic Solids (%)	89.44	71.12		
specific COD (mg/L)	250000 (mg/kg)	3400 (mg/L)		2233.33
Biogas Yield (m3/ton VS)				2896.00
Specific Gas yield (methane (m3/ton **VS))**				1737.60
Biogas Yield (m3/ton TS)				2248.04
Specific Gas yield (methane (m3/ton TS**))**				1348.83

3.4 Trace element study: Although organic FW has high energy potential, it usually has lower concentration of trace elements than septage which are required for anaerobic digestion **[10-20]**. Septage might be advantageous when co-digested with FW by overcoming trace element limitation **[21]**. Trace elements are important for activating and maintaining enzyme activities of anaerobic microorganisms. The availability of certain trace elements has been showed to strongly impact the biogas production. From BMP of FW alone it was observed that deficiencies of some of the elements such as Cobalt, Iron, and zinc lead to less biogas production Figure (4).

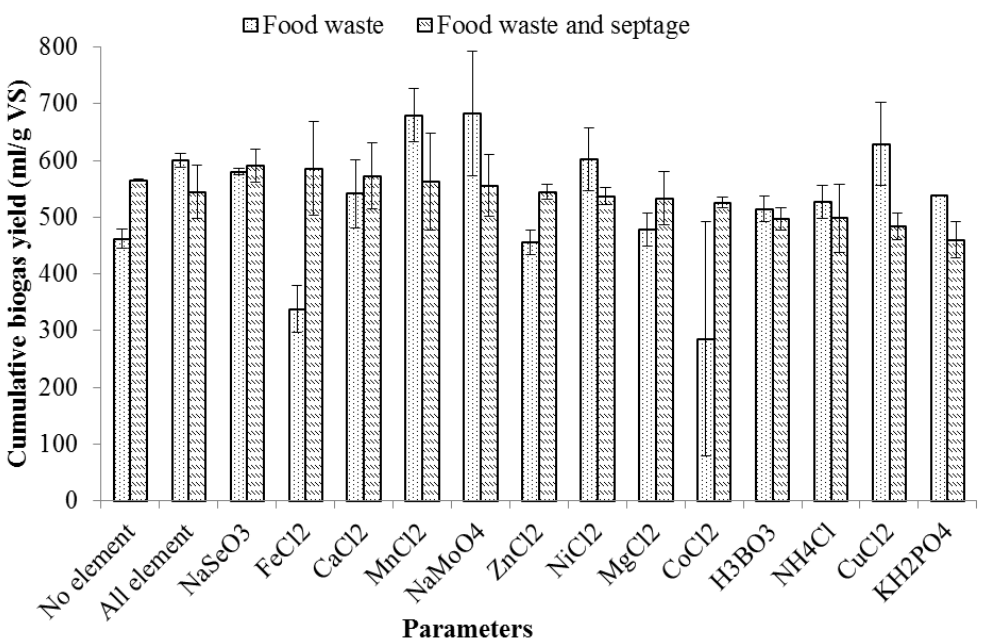

Figure (4): The cumulative production in ml/g VS of biogas from FW and mixture of FW and septage with nutrient limiting condition. The results show that co-digestion of FW and septage with proper mixing ratio can improve biogas production probably supplementing trace elements.

The septage is naturally rich in many of the trace nutrient element required for microorganisms to produce maximum biogas from food. In the presence of septage, AD of FW had no effect in the presence and absence of trace elements. Absence of Zinc, Cobalt and Iron reduced the amount of biogas produced from FW alone. However co-digestion of septage and FW showed no inhibition of anaerobic digestion in the absence of essential trace elements. From these studies it is evident that the septage addition improved AD of FW even when certain trace elements like Zn, Co, Fe were limiting.

4 Conclusions: Admixture of organic waste to fecal sludge at 1:1.5 and 1:2 ratios gives better biogas production as compared to other ratios. The biogas yield of these samples was in a range of 1600 to 2300 m^3/per day. Co-digestion of FW and septage is a better strategy than the digestion of each waste alone since FW provides the chemical energy necessary for high biogas productivity and septage supplements the methanogens with the required trace elements. The advantage of this will be in producing sustainable energy and reducing greenhouse gas emissions. For example at a production of 2100 m^3/day of biogas, it saves 4700 tons per year of carbon dioxide equivalents.

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