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"CHARACTERIZATION AND BIO-CHEMICAL METHANE POTENTIAL OF MUNICIPAL SOLID WASTE FROM FARIDABAD AND GURUGRAM CITY, HARYANA"

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Abstract—*In India, the collection, transportation and disposal of MSW is unscientific. Urbanization contributes enhanced municipal solid waste (MSW) generation and unscientific handling of MSW degrades the urban environment and causes health hazards. The purpose of this research was to study the effects of four socio-economic characteristics (age, level of income, education, and occupation) of district residents on their attitudes, practices, and behavior regarding solid waste generation and to suggest the improvements in present waste management system in your city. An analysis of social factors affecting the quantity and composition of household solid wastes is reported in this paper.*

Per household quantities of six hundred sixty seven household solid waste components are analyzed. Age, level of income, education and occupation are the major variables affecting the quantities of these components. The results indicate that among these solid waste components (leather, metals, plastics, organic matter, paper, rubber, and textiles) organic matter quantity is found to be at the top. The data obtained from the study has been used to calculate the methane generation rate constant (k) and measurement of biochemical methane potential (BMP) in anaerobic biodegradation. In this study, the maximum biogas production was obtained at mesophilic conditions at food to microorganism ratio of 0.75.

1. INTRODUCTION

Solid Waste Management remains one of the most overwhelming environmental sanitation challenges facing the country today. Municipal Solid Waste Management (MSWM, 2016) is a globally challenging issue especially in developing countries, due to its adverse environmental effects (Zambrano *et al.,* 2009). The generation of solid wastes constitutes a serious environmental problem in the developing countries and also of great concern in the developed nations because of the attendant environmental challenges that cause its inappropriate handling and disposition. From a global viewpoint, the generation of solid waste is mainly driven by population growth, technology improvements and economic development. Increase in urban growth has further resulted in an increase in the generation of waste from residential sites, private and public service facilities, and construction and demolition activities as new subdivisions are established (Karaka *et al.,* 2012).

Solid waste management has several functional elements, including waste generation, waste handling and separation, storage and processing, collection, transfer and transport, and final disposal. Solid waste management refers to all activities pertaining to the control, collection, transportation, processing and disposal of waste in accordance with the best principles of public health, economics, engineering, conservation, aesthetics and other environmental considerations.

Waste characterization is a fundamental component in any municipal waste management scheme (MWMS) of urban solid waste in a city. Waste characterization data consists of information on the types and amounts of materials (paper, food waste, glass, yard waste, etc.) in the waste stream. It depends on a number of factors such as food habits, cultural tradition, socioeconomic and climatic conditions. It varies not only from city to city but also within the same city.Waste characterization thus will help in understanding how much of waste and what type of waste is being generated in order to deal with the growing problem of the municipal solid waste of the city.

Importantly, MSW characteristics in most Asian countries is known for its high organic and moisture content, and low calorific value which makes it unsuitable for direct landfill disposal and incineration because of potential emissions (Visvanathan et al. 2004).

The importance of anaerobic digestion for organic waste treatment is a growing interest towards sustainable MSW management and able to support for alternative renewable energy resources. The process involves the conversion of waste biodegradable fraction into biogas and stable residue that can be used as fertilizer or compost. Anaerobic biodegradation proceeds in the absence of oxygen and produce by-products after a series of metabolic interactions among various groups of microorganisms. Anaerobic system generates energy in the form of methane as a source of electricity that can be used to operate the process with energy surplus. From the life cycle assessment (LCA) perspective, anaerobic digestion is considered as the best LCA of all renewable energies like wind, water, etc. In life cycle assessment using eco-indicator method, it also showed an excellent LCA performance as compared to other treatment technology like composting and incineration (Edelman et al., 2004).

Anaerobic digestion is the process in which organic solid wastes are decomposed to produce CH_4, CO_2, and other trace gases by some specific microbes under oxygen deficient environment. In the digestion process, first organic substrates are hydrolysed followed by the formation of volatile fatty acids (VFAs) due to fermentation of organic materials by abiogenic bacteria. Acerogenin bacteria's are then oxidized VFAs into acetate, hydrogen, and CO_2 which are the suitable substrate for methanogens (Negi.S et.al 2018).

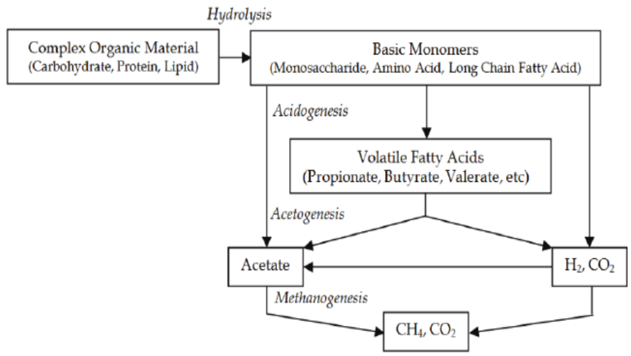


Fig. 1:Degradation steps of AD process

Another term biochemical methane potential (BMP) is useful to test the substrate biodegradability under optimal anaerobic conditions. The BMP is a bench-scale study to measure the maximum CH4 potential/gram VS. It is usually done for 30 to 45 days. In BMP study, the substrate is tested in a laboratory under optimal conditions. The results from BMP test showed the concentration of organics in a substrate that can be anaerobically converted to biogas (Kaparaju et al., 2009). The study should be carried out at neutral pH ranges from 7.0 to 7.8 as pH value below 6.5 inhibits the methanogenic activity (Esposito et al., 2012). The contact between substrates and microorganism gets maximize the intensity of stirring providing uniform moisture content.

2. LITERATURE REVIEW

Characterization of the municipal solid waste is done to understand the composition of the solid waste and to understand its various parameters. Characterization of MSW is done on the basis of Municipal Solid Waste Manual, 2016.

The characterization of the waste will help in categorizing them into different categories such as recyclable, non-recyclable, and compost. Depending upon which category they are placed in it will depend on whether the waste can be used again or needs to go directly into the disposal site. The results of this work will help to determine the best way of disposing and treating waste. It will also help waste managers and planners in making good decisions in terms of the waste usage.

National Environmental Engineering Research Institute (NEERI) has carried out extensive studies on characterization of solid waste from 43 cities during 1970-1994. The average characteristics have been presented in **Tables 1and 2**.The paper content generally varies between 2.9 to 6.5% and increases with the increase in population.

The biodegradable fraction is quite high, essentially due to the habit of using fresh vegetables in India. The high biodegradable fraction also warrants frequent collection and removal of solid waste from the collection points. The paper content generally varies between 2.9 to 6.5% and increases with the increase in population. The plastics, rubber and leather contents are lower than the paper content, and do not exceed 1% except in metropolitan cities. The metal content is also low, viz. less than 1%. The low values are essentially due to the large scale recycling of these constituents.

Table 1: Physical Characteristics of Municipal Solid Wastes in Indian Cities

Population Range (in million)	Number Of Cities Surveyed	Paper	Rubber, Leather And Synthetics	Glass	Metals	Total compostable matter	Inert
0.1 to 0.5	12	2.91	0.78	0.56	0.33	44.57	43.59
0.5 to 1.0	15	2.95	0.73	0.35	0.32	40.04	48.38
1.0 to 2.0	9	4.71	0.71	0.46	0.49	38.95	44.73
2.0 to 5.0	3	3.18	0.48	0.48	0.59	56.67	49.07
> 5	4	6.43	0.28	0.94	0.80	30.84	53.90

All values in table 3.4 are in percent, and are calculated on net weight basis

Source : Background material for Manual on SWM, NEERI, 1996

Table 2: ChemicalCharacteristics of Municipal Solid Wastes in Indian Cities

Population range (in million)	No. of Cities surveyed	Moisture %	Organic matter %	Nitrogen as Total Nitrogen %	Phosphorous as P_2O_5 %	Potassium as K_2O %
0.1-0.5	12	25.81	37.09	0.71	0.63	0.83
0.5-1.0	15	19.52	25.14	0.66	0.56	0.69
1.0-2.0	9	26.98	26.89	0.64	0.82	0.72
2.0-5.0	3	21.03	25.60	0.56	0.69	0.78
> 5.0	4	38.72	39.07	0.56	0.52	0.52

All values, except moisture, are on dry weight basis.
*Calorific value on dry weight basis

Source : Background material for Manual on SWM, NEERI, 1996.

The chemical characteristics indicate that the organic content of the samples on a dry weight basis ranges between 20 to 40%. The nitrogen, phosphorus and potassium content of the municipal solid waste ranges between 0.5 to 0.7%, 0.5 to 0.8% and 0.5 to 0.8% respectively. The calorific value ranges between 800-1000 kcal/kg. Knowledge of the chemical characteristics is essential in selecting and designing the waste processing and disposal facilities.

Anaerobic Digestion is the process by which organic matter breakdowns into CH_4, CO_2, ammoniac nitrogen, other trace gases and low molecular weight organic acids with the help of anaerobic microorganisms in the oxygen deficient atmosphere (Polprasert, 1989). The AD process has definite benefits over the aerobic digestion process such as the less energy consumption, fewer solids generation, low nutrients requirements and more energy recovery from CH_4 production (Stewart et al., 1995). AD is globally recognized as a method to control greenhouse gases and use widely for energy generation (Lettinga, 1995; Lettinga et al., 2001; Barton et al., 2008). By AD process, around 90% of biodegradable organic compounds can be converted into biogas (Chandra et al., 2012).

3. MATERIALS AND METHODS

3.1 Study Area

The sampling campaign covered residual waste collected from households in two municipalities, Gurugram and Faridabad.The area undertaken for present study has been divided in different zones before under taking the survey and execution of the study.

Gurugram City	Faridabad City
Zone 1-West	Zone 1-Old Faridabad

Zone 2-North	Zone 2-Nit Faridabad
Zone 3-East	Zone 3-Ballabhgarh
Zone 4-South	

3.2 Identification of Sampling Location in Study Area

All waste collected was emptied onto a tarpaulin sheet and weighed and recorded after confirming the type of waste.the classification table provided in the questionnaire).

Sampling locations are:

S1 – Labour chowk , sector 28, Gurugram.

S2 - YMCA Road, sector 8, NIT Faridabad.

S3 – East Chawla colony, Ballabhgarh , Faridabad.

S4 – Islampur ,Gurugram.

S5 – Main bus stand, Gurugram.

S6 – Puranisabjimandi , Old Faridabad.

S7 –Shivajinagar ,Gurugram.

(a) (b)

Fig 2 (a-b): sampling location (a) Gurugram (b) Faridabad

3.3 Methods for Characterization

There are various parameters such as moisture content, density ,dry density, volatile solids, ash content, total organic carbon, chemical oxygen demand, pH, conductivity, bio methane potential depending upon which the various characteristics and properties of municipal solid waste can be determined which will help in understanding the municipal solid waste to a much better extent.

3.4 Bio-Chemical methane potential

Bio-Chemical Methane potential was used to calculate the amount of methane that is being generated from the organic matter that is present in the municipal solid waste. To find out the methane generation Bio-methane potential bottles (BMP bottles) were used. In the BMP bottlesNaOH and methyleneblue indicator was used to absorb the other gas production that can take place in the bottles such as CO_2, NH3, etc.

3.4.1 Experimental Setup

BMP bottles of 500 mL capacity with 450 mL total working volumewere used for this study. Based on substrate VS percentage, inoculumsvolume was decided and filled into the bottles, and then the substratewas added. The remaining portion was filled with media, with the spaceleft blank to fill nitrogen gas to maintain anaerobic condition. All the sampleswere taken on doubling basis. The bottles were fitted with siliconand kept in a incubator at 30°C±2°.

Fig. 3: Setup of BMP bottles in an incubator

3.4.2Analytical Methods

Total solids (TS) and volatile solids (VS) of the substrates and inoculum were measured as per standard method (Bureau of Indian Standards (BIS) No. 10158-1982). Gas produced in each BMP bottle was measured on a daily basis. Blanks reactors were running parallel to the reactors in all the phases of the study. Batch experiment was performed in doubling basis. The values considered and reported were the average. Frictionless glass syringe was used to determine the biogas volume during the bio-methanation period. The gas volumes were measured at a temperature of 30°C±2ºC. The standard temperature of 30ºC±2ºC was maintained using an incubator where the BMP bottles were placed.

3.4.3 Statistical Methods

The experimental data was used to calculate the value of k. Time t starts after the lag phase. Y1, the initial CH_4 equivalent to 0.1 mL after blank error correction was assumed to correlate with the initial time after the lag phase. The cumulative CH_4 production profiles appeared to follow exponential growth curve (Kumar et al., 2016). The rate of CH_4 production from the organic substrate is a function of biomass concentration to be digested (Kumar et al., 2016).

Rate constant Eq. (1) was used to determine the kinetics of CH_4 production.

$dY/dt=k(Y_{max}-Y)$------------(Eq.1)

where, Y_{max}=maximum CH_4 yield (mL);

Y=cumulative CH_4 yield (mL);

k=rate constant expressed in d−1;

t=time in days.

On integrating the above Eq. (1) within the limits t=0 to t=t, the Eq. (1) is now presented as

$Y= Y_o(1-e^{-kt})$ --------------(Eq.2)

Eqs. (1) and (2) provide the rate of change of organic substrate and CH_4 generation. The experimental data was used to calculate the value of k. The curve formed with the experimental data was analyzed and the best fit to the curve was obtained by using the Quasi-Newton algorithm. This algorithm uses non-linear regression and evaluates model parameters values by depreciating the sum of squared differences between the calculated and experimental values using a Ky plot software to evaluate the value of k.

4. RESULTS AND DISCUSSIONS

4.1 Composition of Solid waste

The percentage of various physical components collected from various zones of Faridabad and Gurugram are as follows:

Table 3: Composition Solid Waste (Zone Wise)

Waste Type	Faridabad Zone 1	Faridabad Zone 2	Faridabad Zone 3	Gurugram Zone 1	Gurugram Zone 2	Gurugram Zone 3	Gurugram Zone 4
Paper	5.05	6.1	3.24	3.17	14.98	9.54	7.08
Leather	9.12	7.51	4.46	8.16	14.28	9.24	9.77
Plastic	7.83	8.22	4.97	10.96	6.07	9.14	6.63
O.M	54.14	58.1	70.04	33.06	40.49	45.75	54.97
Textile	5.52	5	7.87	17.22	11.76	11.24	5.39
Metal	8.61	7	4.25	13.77	4.47	8.84	9.37
Rubber	9.73	7.98	5.07	13.6	7.45	6.24	6.77

4.2. Characterization of Solid waste

The various parameters results are being described as follows:-

Table 4: COD Results of MSW

Sample	S1	S2	S3	S4	S5	S6	S7
Total COD (mg/L)	5184	5280	5248	5152	5312	5184	4800

Table 5: Results of Moisture Content, Dry Matter, Density of MSW

Sample	Moisture Content (%)	Dry Matter (%)	Density(kg/m³)
S1	42.35	44.13	218.6
S2	39.62	52.63	276.3
S3	53.29	37.66	447.0
S4	55.52	21.79	290.6
S5	42.12	40.02	222.0
S6	41.51	45.50	240.3
S7	45.37	33.71	163.3

Table 6: Results of Volatile Solids, Ash Content, Total Organic Carbon, pH, Conductivity of MSW

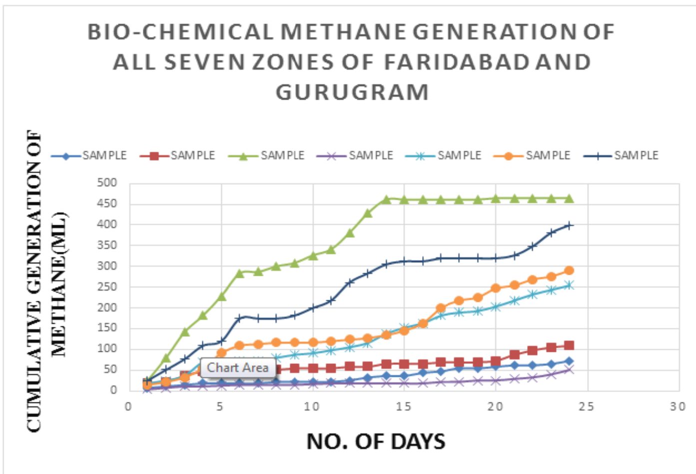
Sample	Volatile Solids (%)	Ash Content (%)	Total Organic Carbon (%)	pH	Conductivity
S1	25	8.24	42.6	6.48	12.1
S2	22	7.96	41.3	5.32	12.8
S3	24	11.37	43.7	4.54	12.9
S4	25	4.29	37.7	6.91	14.8
S5	27	4.16	35.2	5.4	12.6
S6	20	4.27	36.8	7.17	12.8
S7	23	5.14	40.4	8.64	11.6

4.3 Bio-Chemical Methane Potential of Solid waste

A total of 24 Bio-Methane Potential Bottles (BMP bottles) i.e. 12 sets were set up. The BMP bottles were set up in doubling of which the final result was taken as the average of the two. The readings of the BMP bottles were taken regularly for 24 days. After the readings were obtained, the graph between number of days and the total methane generation is obtained for all the seven zones

Table 7 : Result of Bio-Chemical Methane potential of solid waste

DAYs	S1	S2	S3	S4	S5	S6	S7
1	7.26	18.16	25.05	3.63	18.15	14.52	25.05
2	10.89	21.79	79.90	7.26	25.42	21.79	50.84
3	14.52	36.31	141.63	10.89	36.31	32.68	76.26
4	18.15	47.21	181.58	10.89	69.00	54.47	108.95
5	18.15	49.02	228.79	12.71	69.00	90.79	119.84
6	18.15	50.84	283.27	14.52	72.63	108.95	174.32
7	18.15	50.84	286.90	14.52	72.63	112.58	174.32
8	21.79	50.84	300.53	14.52	79.89	116.21	174.32
9	21.79	54.47	308.69	14.52	87.16	116.21	181.58
10	21.79	54.47	326.85	16.34	90.79	116.21	199.74
11	21.79	54.47	341.37	18.15	98.05	119.84	217.90
12	25.42	58.10	381.32	18.15	105.31	123.47	261.48
13	32.68	58.10	428.54	18.15	115.84	127.10	283.27
14	36.31	65.37	461.22	18.15	138.00	134.37	305.06
15	36.31	65.37	461.22	18.15	152.53	145.26	312.32
16	43.58	65.37	461.22	18.15	163.42	163.42	312.32
17	47.21	69.00	461.22	21.80	181.58	199.74	319.58
18	54.47	69.00	461.22	21.80	188.84	217.90	319.58
19	54.47	69.00	461.22	25.42	192.47	225.16	319.58
20	58.10	72.63	464.85	25.42	203.37	246.95	319.58
21	61.73	87.16	464.85	29.05	217.90	254.21	326.85
22	61.73	98.05	464.85	32.68	232.42	268.74	348.64
23	65.00	105.13	464.85	39.94	243.32	276.00	381.32
24	72.64	108.95	464.85	50.84	254.22	290.53	399.48

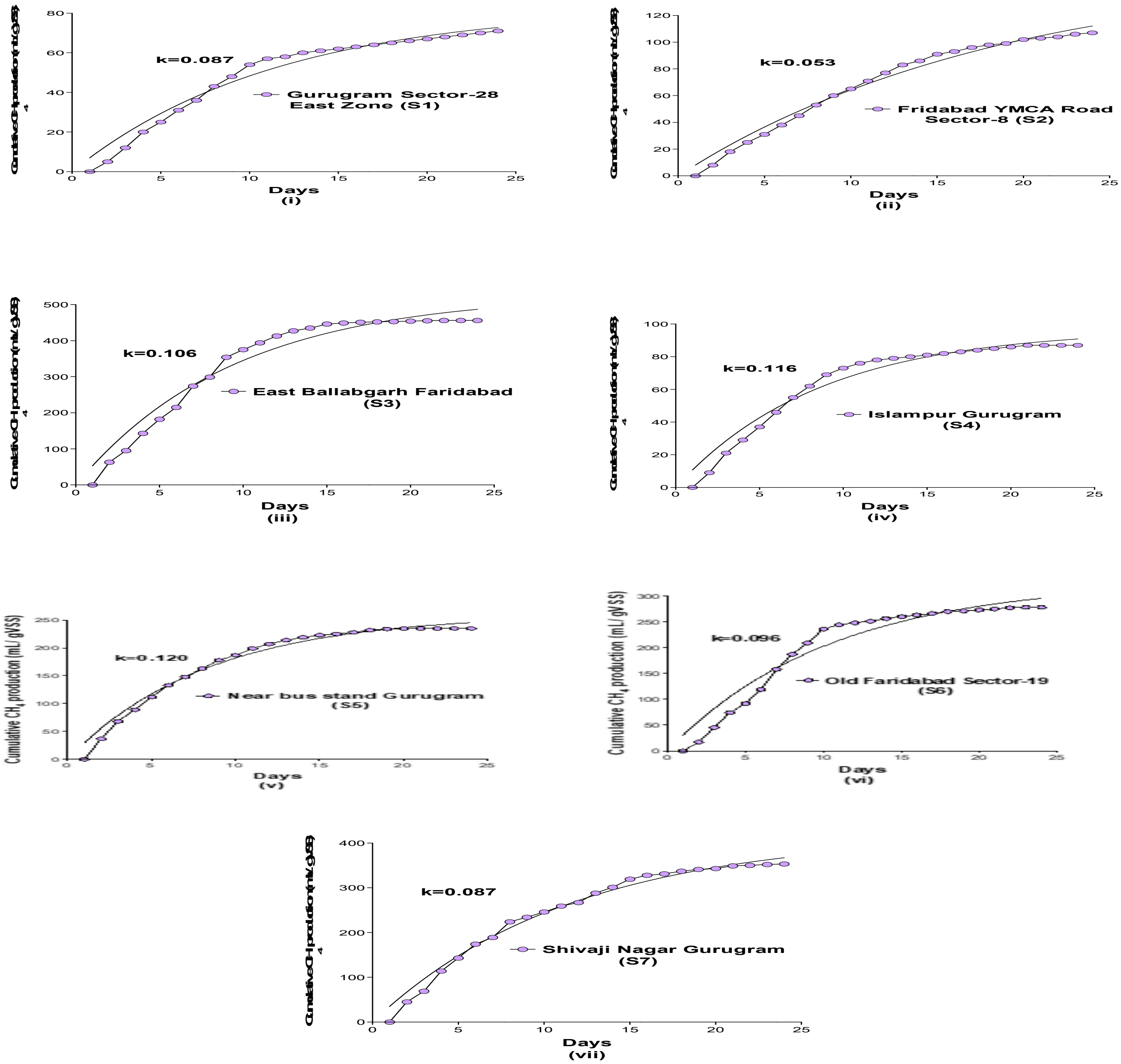


Graph 1: Methane generation of the different zones of Faridabad and Gurugram

Table 8: Parameters of Bio-Methane Potential

Parameters	S1	S2	S3	S4	S5	S6	S7
F/M	0.75	0.75	0.75	0.75	0.75	0.75	0.75
CH_4-COD (g\L) (a)	0.207	0.311	1.328	0.145	0.726	0.830	1.141
CODfeed (g\L) (b)	5.184	5.28	5.248	5.152	5.312	5.184	4.8
BMP (µ) (a/b)	0.04	0.058	0.253	0.028	0.136	0.16	0.237
k (per day)	0.087	0.053	0.106	0.116	0.120	0.096	0.087
Y_{max} (mL/gmCOD)	72.64	108.95	464.85	50.84	254.22	290.53	399.48
Sludge activity (gCH_4-COD)	0.03	0.043	0.189	0.021	0.102	0.12	0.177

The rate constant of bio-methane generation from the municipal solid waste of the different zones is calculated by the ky plot software.



Graph 7: The above 7 graphs (i to vii) are the cumulative CH_4 and the k value for the different solid sample from the seven different zones using the ky plot.

4.3.1 CH_4 Production

Graphs shows the cumulative methane (CH_4) production that has taken place in all the seven zones of Faridabad and Gurugram that has been selected for solid selection sampling. The graph shows how much maximum yield has been reached by the solid samples and how much methane production has taken place. It can be seen that S3 showed the maximum methane production yield of 464.85 mL/gmCOD and S4 with the minimum methane production yield of 50.84 mL/gmCOD.

4.3.2 Bio-Chemical Methane Potential

Biodegradability of the substrate in a batch study under anaerobicconditions can be expressed in terms of BMP, i.e. mL of CH4 generatedper g of COD fed subsequently to a specific time period. CH_4-COD/g COD_{fed} i.e. COD fed conversion to CH_4-COD (μ_b) is another term for the experimental efficiency. The results were evaluated in terms of μ_b. The μ_b values were recorded after 24 days as μb_{24}.

The maximum BMP was obtained for CH_4-COD value of 1.141 and COD_{feed} value of 4.8. The value of the maximum BMP is 0.237.

4.3.3 Sludge Activity

Utilization of substrate is affected by the F/M ratio which depends upon the activity of sludge (Hussain et al., 2009). With the F/M ratio of 0.5, substrate utilization solely depends upon the sludge activity. It is expressed as g of CH_4-COD formed/g VSS (sludge) or mL CH_4. It can be obtained with the following equation:

$$\mu b\frac{F}{M} = \frac{gCH4 - COD}{gCOD\ fed} \times \frac{g\ COD\ fed}{g\ VSS(sludge)} = gCH4 - COD/gVSS$$

It can be noted that sludge activity is the height in the East Chawla colony,Ballabhgarh, Faridabad Zone and the lowest in Islampur,Gurugram Zone.

5. CONCLUSION

The municipal solid waste collected from Faridabad showed a dominating nature of the organic waste followed by plastics, paper, and wood.

Due to moisture content in the solid waste, it results in high bulkiness of the waste which is difficult in transporting. Thus, moisture content needs to be removed from the waste in order to provide easy transportation and to reduce the effective cost as well.

The maximum yield which was equal to 464.85 mL/gmCOD that is observed for S3 i.e. at the East Chawla colony , Ballabhgarh , Faridabad .

The lowest yield of 50.84 mL/gmCOD is observed for S4 i.e. Islampur ,Gurugram.. The reason for such low methane generation is that the organic matter that

Was found to be low in this region. Thus reducing the F/M ratio which resulted in a low yield of methane.

In India, due to the presence of high moisture content in solid waste thermal decomposition is not possible thus biological decomposition of the solid waste needs to be done.

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