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The kinetic of Biogas Production from Municipal solid waste & Sewage using two stages Fermentation

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Abstract: - Municipal solid waste (MSW) management is becoming a serious issue in all over the world. Anaerobic digestion (AD) is one of the technologies to convert that waste into useful form of energy. To fulfill the need, the present paper deals with the review of various operating parameters and their effects on AD. This paper also reviews different pre-treatment methods including mechanical, thermal, chemical and biological methods to improve the effectiveness of AD of MSW. In this research work the quality and content of methane in biogas generated from biogas plant is improved by co-digestion of MSW, cow dung along with the urine with better carbon to nitrogen (C/N) Ration. We took number of experiment using different ratio of MSW and additives to improve biogas. Rigorous experimentations concluded that the co-digestion of the MSW, cow dung and urine in the proportion of (50:40:10) with equal amount water in a portable bio digester for anaerobic digestion results into better methane production with maintaining C/N ratio and reducing time duration for flammable biogas production.

Key words: Bio-methanization, MSW, biogas, two stage anaerobic digestion.

Introduction: - Pune is one of the fast developing urban agglomerations in Asia and ranked eighth at national level. The present growth is due to various factors such as industrialization, educational institutes, information technology (IT) hubs and location of state and central government establishments. Pune, with a population approaching 3400000, is estimated to generate about 1400 metric tons of MSW daily (Mali et al. 2012). Methane and carbon dioxide are produced during the testing period due to the anaerobic degradation of organic contents of the substrate. The methane generated from the substrate is then measured and the methane potential of the substrate which is expressed as per mass of volatile solids added or chemical oxygen demand (COD) added can be calculated by subtracting the methane volume from a blank. As the organic material in the substrate is degraded through a series of complex microbiological processes, biogas is continually produced during incubation until there is no biodegradable material left. (**Feodorov,V. (2016)**.

The process of anaerobic digestion is a biological process which makes use of anaerobic bacteria to break down organic waste, converting it into a stable solid and biogas, which is a mixture of carbon dioxide and methane. The anaerobic digestion process is very attractive because it yields biogas which can be used as renewable energy resources and also produce reduced stabilized material after treatment (**Wang et al., 2002**). Thus, this study is designed to carry out a controlled high-rate biomethanization of Unsorted Municipal Solid Waste by the double-stage dry-wet digestion as pre-treatment option prior to landfill is given in Fig -1.

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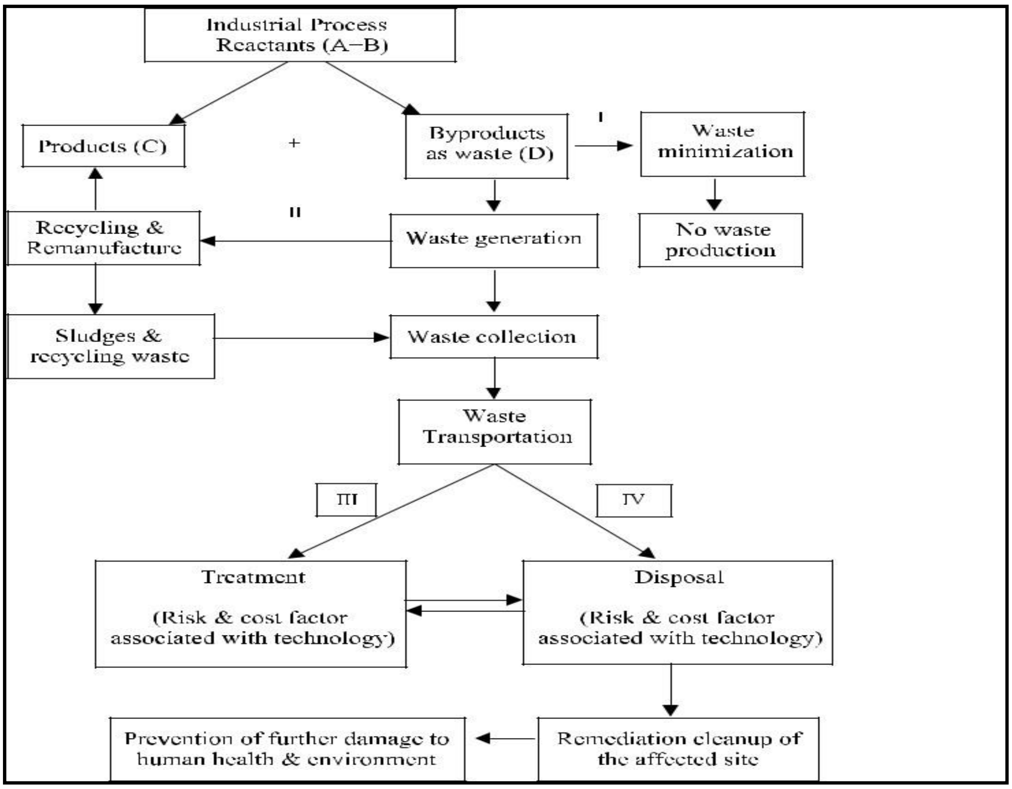

Fig.1. Hazardous waste management

Ali, A. H. et al. 2016 investigated a two-stage fermentation process treating the mixture of the organic fraction of municipal solid wastes (OFMSW) and Slaughter house waste in order to produce hydrogen in the first stage and methane in the second stage. Two stage concepts was first introduced by Pohland and Ghosh (1971) and by Ghosh (1975). This two-phase system was first used for soluble substrates and liquid waste, then phase separation has been studied by digestion of solid vegetable waste. Brummeler, E.T (1992) Three mainly advantages compare with single anaerobic digestion, including less detention time, higher gas conversion efficiency and higher methane concentration. The mixing facilitate co-digestion of more than one substrate and progressively the acculturate the C/N Ratio Srinivas, S. V., (2003).Optimum mixing ratio of food waste to cowdung 3:1reported highest methane production.In order to reduced the contain of this unwanted gases certain additives is use. Cow urine has important N component and traces of P, K, Ca and Mg Cohen, A.1983. According to literature survey, The animal urine can use as additive with MSW. C/N ratio is moderately higher in urine due to its nitrogen content promising way to enhance the biogas production. Carbon (C) /Nitrogen (N) ratio of 20: 1 to 30:1 is generally maintained. Methane contents were enhanced by the mixing cowdung, food waste and organic portion of MSW when applied in the optimum condition with lesser retention time model of 30 days Channakya, H. N 2002 surprisingly, the optimum combination were not evaluated in the study.The two stages of AD can be subdivided into four interrelated steps, consisting of the following:

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(i) Hydrolysis,
(ii) Acidogenesis,
(iii) Acetogenesis, and
(iv) Methanogenesis.

The four steps of AD and their interrelationship are presented in Figure 2.

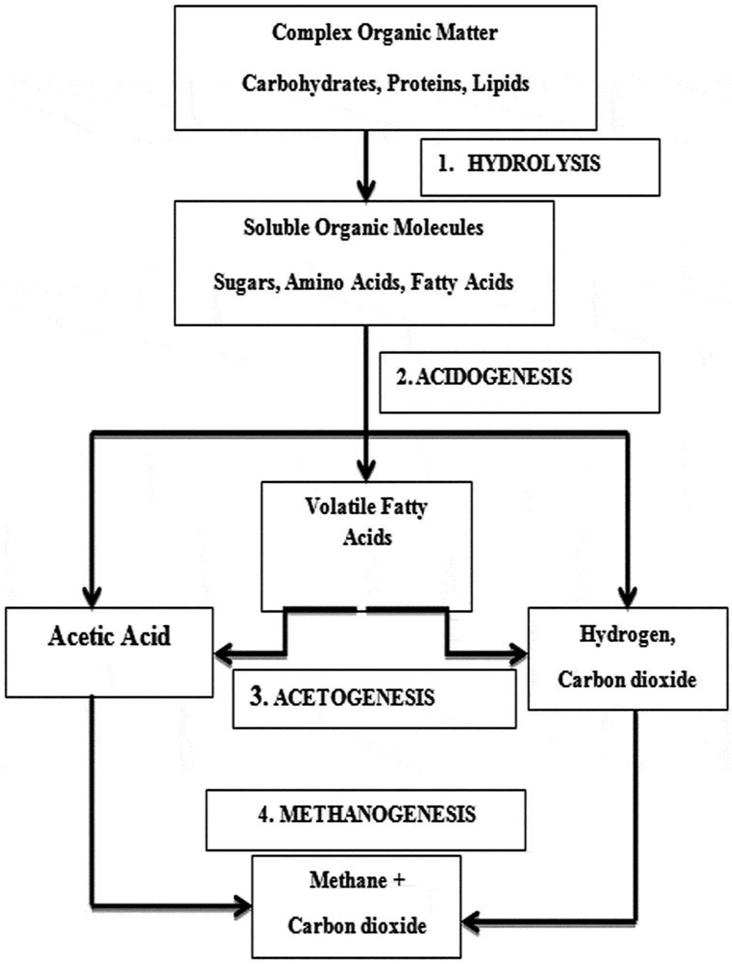

Fig 2. Anaerobic Digestion Process

Factors influencing anaerobic digestion:-

In an anaerobic digestion system, anaerobic microorganisms are highly susceptible to changes in environmental conditions. Some of the environmental conditions are temperature, pH, and toxicity. The two-stage system can use one, two, or all three water recirculation loops (R1, R2, and R3, shown in Fig. 3) in case of need. Using these recirculation loops brings many advantages, such as further controlling of pH (reduction of acidity due to using the high alkalinity effluent from the second reactor); mixing/ diluting of the high solid feedstock; and improving activities of bacteria.

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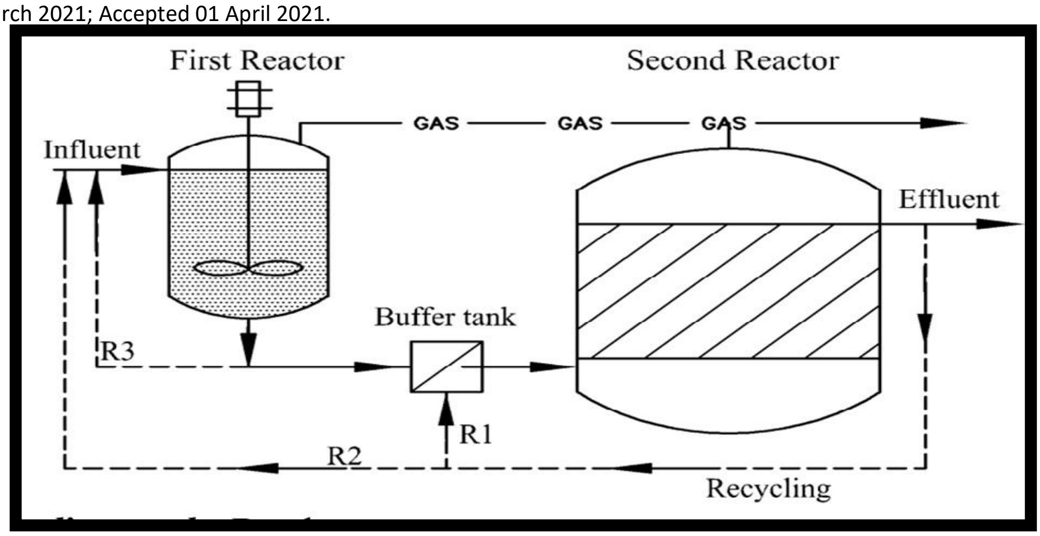

Figure 3:- Two-Stage Systems

Limitations to biogas production

But not everything that is used for anaerobic digestion can be converted to biogas, in other words there is no substrate that is digested to 100%. There are quite a few reasons for this; some of these are improper physical-chemical factors, usage of biomass to form new bacterial cells and presence of substances that are not easily biodegraded such as lignin. Carbon to Nitrogen ratio(C: N) is one of the most important physicochemical factor that effects the bio-conversion of biomass to biogas. 25-30 is the optimum C: N ratio that is ideal for biogas production. pH and temperature also effects the biogas production by interfering with microbial activity.

A pH which is around 7.0 to 7.2 is the best for maximum production but anywhere between 6.6 to7.6 is good. When pH drops to 5.0 it drastically effects the biogas production, because at this pH the growth and multiplication of cellulose degrading bacteria and amylolytic organisms is hampered. It was also found that microbial population was reduced by 2 to 4 times when pH drops below 5. In thermophilic anaerobic digestion a lot of biogas can be produced because of the faster reaction time, more methane content can be obtained and low hydrogen sulphide content in the biogas produced etc .Thermophilic anaerobic digestion can be hard to maintain at the high temperatures, can be more sensitive to fluctuations in temperature and heavy metals. Despite of the disadvantages thermophilic anaerobic digestion is often preferred over mesophilic digestion because of higher gas production yield and higher methane content (Cavinato C 2013).

Table 1 . Indicator for process imbalance in anaerobic digestion

Indicator	Principle
Gas production	Changes in specific gas production
Gas composition	Changes in the CH_4/CO_2 concentration ratio
pH	Drop in pH due to VFA accumulation
Alkalinity	Detects changes in buffer capacity

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Total volatile fatty acids (VFA)	Changes in total concentration of VFA
Individual VFA	Accumulation of individual VFA
COD or volatile solids reduction	Changes in degradation rate

Liquid displacement gas measurement The majority of laboratory volumetric gas meters are based on the liquid displacement method. These meters can be constructed with simple materials like glass/plastic jars or cylinders. Liquid displacement meters are simple, economic and they can work for a long period of time without maintenance. The preservation and collection of gases is the most important operation for any liquid displacement gasometer. Gasometers are the classical gas measuring unit which works with the principle of gas storing and does not provide the flowrates directly. The collection of the gas is usually done with the use of vessels containing a suitable liquid which is displaced as the gas gets collected. Wang J Y et al. 2002.

The gas pressure inside the tube collected over the liquid solution is the sum of the biogas pressure and the vapor pressure. The pressure of biogas, (Pbio) can be obtained by subtracting the vapor pressure of liquid (Pw) at the temperature of measurement from the pressure of collected moist gas (P).

$$\mathbf{P_{Bio} = P - P_w}$$

If the gas is collected over liquid, static pressure acts due to the difference of level (P_{level}),

$$\mathbf{P_{Bio} = P - P_w - P_{level} \ \text{or} \ P_{Bio} = P - P_w + P_{level}}$$

The produced biogas volume in normal condition can be converted to STP using Combine Gas law:

$$V_0 = V \times \frac{T_0}{T} \times \frac{P_{bio}}{P_0}$$

Here, V is the measured gas volume, V_0 is the volume of gas in standard temperature and pressure, P_0 is the standard pressure, T is gas temperature at the time of measurement, and T_0 is the standard temperature. Modified Arden Buck Equation can be suggested for the calculation of vapor pressure. Mohd. S. N. et al. 2015.

$$P_w = 6.1121 \exp\left(\left(18.678 - \frac{T_c}{234.5}\right) \times \frac{T_c}{257.14 + T_c}\right)$$

Tc is the temperature of gas in degrees Celsius. Pw is pressure in hP (1 hP = 0.1 kPa) Gasometers are usually height or weight types.Yu L et al.2013.

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Material and Methods:- A floating-drum biogas plant consists of a cylindrical digester and a movable, floating gasholder (drum). The digester is generally constructed underground (Fig 4) whereas the floating gasholder is above ground. Smaller household-scale systems may also be fully above ground (see Fig 4).

Fig:- 4 **Two stages bioreactor for experiment set**

Floating-drum **plants** consist of an underground digester (cylindrical or **dome-shaped**) and a moving gas-holder. The gas-holder **floats** either directly the fermentation slurry or in a water jacket of its own. The gas is collected in the gas drum, which rises or moves down, according to the amount of gas stored. Factors affecting floating-drum biogas plant is given in Table 2

Sl.No.	Factor	Floating drum
1	Gas storage	Internal Gas storage drum size (small)
2	Gas pressure	Up to 20 mbar
3	Skills of contractor	High: masonry, plumbing, welding
4	Availability of Material	yes
5	Durability	High; drum is weakness
6	Agitation	Manual steering
7	Sizing	Up to 20 m³

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8	**Methane emission**	**Medium**

Table 2

The secondary digestor or fermenter was purchased from above …………………………… company. This fermenter works on floating dome principle. gasbag collected in this floating dome .The done rises upwards as the gas production begins & increases. The total gas production is to be measured with liquid displacement method.

Preparations of Feeding Constituents

MSW (Municipal Solid Waste) was collected from different part of city for mixing in biodigester. For additive purposes, we have selected animal urine and cow dung [9] as it maintains C/N ratio after anaerobic digestion and animal urine easily available. Thus, we collected cattle urine from cattle farm nearby to our experimentation location. The properties of the MSW, cow dung and urine are shown in table 3.

Table3. Properties of feeded mixtures and types of the digesters

	MSW	**COW DUNG**	**URINE**
VFA (g/l)	**8.7**	**0.3**	**155 µmole/l**
VS (g/l)	**170.2**	**13.8**	**-**
COD (g/l)	**12.8**	**155.3**	**-**
TS (g/l)	**229.6**	**24.2**	**-**
PH (g/l)	**6.6**	**9.2**	**5.7–5**
C/N RATIO	**30**	**8**	**19.56**

*Traces of P, K, Ca and Mg found in PPM

Construction of biodigester For experimentation purpose we have prepared a lab scale portable biodigestor.Pawan P et al. 2000.

- **20L container.**
- **Connecting tube.**
- **Balloon for gas storage**
- **Flow control valve**
- **PVC pipe for inlet and outlet.**

Experimentations

The experiments were conducted in three different biodigesters as per tests. The biodigester compramises of the 20L container, Ballon for gas storage, PVC pipie for inlet and outlet,

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Connecting tube and flow control valves. The pressure is maintained on the top of biodigester by weight. The Biodigster is covered to restrict extrageneous factors like sunlight etc. The flow control valves are used to regulate the flows. The digester temperature kept at around the 35^{O}c.

Test 1: MSW with equal quantity of water.

Test 2: MSW mixed with sludge (3:1) and equal amount of water .Biogas collected in the storage tube, observations were recorded a regular intervals. For formation of biogas at small scale it needs at least 7-8 days. The reading were taken upto 25 to 30 days of feeding when biodigeter attains the stability .The tests were rigoursly repeated to confirm the results.

Test 3: MSW, Cow dung and urine (50:35:10) with equal amount of water.

Analytical Methods

The PH, TS, COD, VFA and TVS were determined by APHA 2005 standards. Gas chromatograph (Method-TCD) used to measure quality of the biogas.Model development for biogas production kinetic in batch mode. Biogas production kinetic in was studied by developing the equation closest to fundamental for biogas production in batch system. By assuming biogas production rate in batch condition is correspond to specific growth rate of methanogenic bacteria in the biodigester, biogas production rate predicted will obey modified Gompertz equation [A] as follows:

$$P = A \times \exp\left\{-\exp\left[\frac{Ue}{A}(\lambda - t) + 1\right]\right\}$$

In these equation, P is cumulative of specific biogas production, ml/gVS; A is biogas production potential, ml; U is maximum biogas production rate (ml/gVS.day); λ lag phase period (minimum time to produce biogas), day; and t cumulative time for biogas production, day. A, λ, and U constants can be determined using non linear regression. From the above equation, kinetic constant of biogas production rate will be expressed by U constant. The higher U exhibits the higher biogas production rate. Bodnar M et al. 2013

Sampling and Analysis

About 100 kg of fresh MSW samples are collected for sampling from different locations in Pune city. The samples are analyzed from January 2020 to November 2020 at intervals of one month. Two to three samples are collected for each month. Total twenty five samples are collected to get a representative characterization of MSW. The collected samples are physically segregated into seven categories. Physico chemical characteristics of MSW from different part of city are given in Table. 4 & Table. 5

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Table 4. Physical analysis of MSW of from different Part of City(% on wet weight)

	MSW Composition							
		Plastic	Paper	Cloth	Metal	Stone	Glass	Organic
Minimum		2.4	1.2	0.4	0	1.4	0	46.0
Maximum		19.3	24.7	20.2	1.8	18.3	5.2	85.4
Average [1]		7.1	6.9	7.8	0.7	7.0	1.2	69.3
Stdev.		±4.1	4.5	5.4	0.6	5.2	1.4	9.6

[1]Average of 25 values.

Table 5. Chemical analysis of MSW of from different Part of City.

	pH	Moisture content %	Organic matter* %	Volatile solids*, %	C* %	N* %
Minimum	7.3	38.91	18.51	48.03	4.05	0.18
Maximum	8.9	58.91	48.86	74.47	19.28	0.97
Average[1]	7.85	48.08	32.83	62.61	11.62	0.59
Stdev.	±0.37	5.29	8.85	7.92	4.77	0.24

[1]Average of 25 values on dry wet basis

Results and Discussion:-

The Test 2 and Test 3 explored that the biogas was collected in the tank at faster rate as compared to Test 1 of mono-digestion. The time required for formation of biogas (test 2 and test 3) was reduced as compared to standard time required for biogas formation without additives (test 1). The collected biogas was feed into gas chromatography (Method TCD) machine and the outputs were recorded. Biogas consists of methane, nitrogen, carbon dioxide, hydrogen sulphite.

The Experimentations were done with different Co-digestion and mono-digestion the Bio gas generation was evaluated.

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- **Test run 1 (MSW)**
- **Test run 2 (MSW+ COWDUNG)**
- **Test run 3 (MSW+COWDUNG+URINE)**

a) Effect of co-digestion on the production of the Biogas

Above tests gave peak biogas production and burnable biogas at 26 days, 24 days and 22 days respectively. The Methane yield and Quality is found out to be best in test run 3. Urine contains the nitrogen which is favourable for the bacteria growth. The co-digestion with cowdung and urine enhances the concentration of soluble organic constituents which in turns reduces the time required for hydrolysis stage of Methanogenesis process and results into better biogas production.

b) Effect of co-digestion on Contents of Methane in produced biogas

The Methane contents were experimentally tested on weekly basis by Gas Chromatographs (Method TCD). The Experimentations were done to evaluate methane contents in biogas generated from different compositions. The Test run 1 (MSW), Test run 2 (MSW+ COWDUNG) and Test run 3 (MSW+COWDUNG+URINE) gave directly proportional biogas production along bio-digestion time in weeks. The Methane yield and Quality is found out to be best in test run 3.The co-digestion with Cowdung and urine breed the methanogenic bacteria and developed the better culture of bacteria which results into improved methane contents in generated biogas.

c) Effect of co-digestion on the pH

The pH is most drubbing factor for the growth and survival of microbes during AD methanogenesis. The drastic pH reduction inhibits the methane formation. The pH is a function of the Volatile Fatty Acid and carbon dioxide generations. Stable maximum pH obtained during co-digestion of the cow dung and MSW is 6.7 to 7.2. In all the tests with different additives the digester reaches to the stable pH that means the digestion is neutral at the end of the experimentations .The co-digestion helps to stabilize the PH which is essential for bacterial growth and hence the biogas production.

Physico chemical characteristics of MSW of landfill are given in Table 6 and Table 7.

Table 6. Physical analysis of MSW of Pune Nagar Nigan (% on wet weight

	MSW Composition							
		Plastic	Paper	Cloth	Metal	Stone	Glass	Organic
Minimum		2.4	1.2	0.4	0	1.4	0	46.0
Maximum		19.3	24.7	20.2	1.8	18.3	5.2	85.4
Average [1]		7.1	6.9	7.8	0.7	7.0	1.2	69.3

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Stdev.								
		±4.1	**4.5**	**5.4**	**0.6**	**5.2**	**1.4**	**9.6**

[1]Average of 25 values.

Table 7 Chemical analysis of MSW of Pune Nagar Nigan

	pH	**Moisture**	**Organic**	**Volatile**	**C***	**N***
		content %	**matter* %**	**solids*, %**	**%**	**%**
Minimum	**7.3**	**38.91**	**18.51**	**48.03**	**4.05**	**0.18**
Maximum	**8.9**	**58.91**	**48.86**	**74.47**	**19.28**	**0.97**
Average[1]	**7.85**	**48.08**	**32.83**	**62.61**	**11.62**	**0.59**
Stdev.	**±0.37**	**5.29**	**8.85**	**7.92**	**4.77**	**0.24**

[1]Average of 25 values on dry wet basis

The COD trend is in conformity with the other pollutants like OA, TS, VOS. Table 4.3 represents the effect of different operating temperature in terms of pollutant cumulative load production expressed as g/kgOTS. The parameters presented include COD and OA. Degradation and OA/COD ratio as percentages are also presented. It is important to note that the first-stage mechanism (dilution and liquid recirculation) regarded as optimum condition was maintained for the test conditions.

Table 8 Summary of essential parameters measured at the studied conditions.

Parameter	**Ambient (26-28^{0}C)**	**30^{0}C**	**35^{0}C**
COD/OTS(g/kg)	453±7.7	487±149	611±24
OA/OTS (g/kg)	113±10.8	136±51	169±4.4
Degradation (%)	35±0.9	34±2.0	36±5.0
OA/COD (%)	24±1.8	28±0.8	28±0.9

NB: Values expressed as mean ± standard deviation.

Anaerobic activities in the hydrolytic reactor. The gas phase study of the hydrolytic reactor was carried out by measuring the daily gas composition as presented in figure 4.7.

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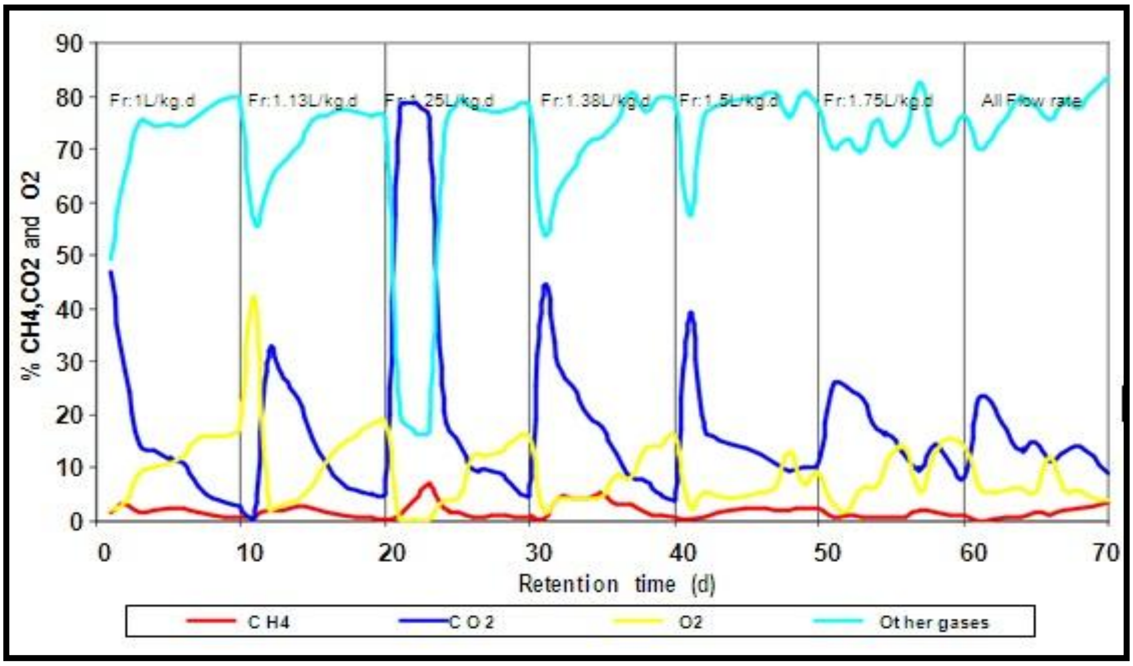

Figure 4. Gas production during hydrolysis as a function of operational time of each test.

Methane production in the hydrolytic reactor was generally not significant with an average value of 1.8±1.3% ranging from a minimum of 1% to a maximum of 7.2%. This behaviour of gas production was expected, due to the low methanogenic biomass concentration in the hydrolytic reactor as a result of the low pH and the effect of micro oxygen (average oxygen composition 8.3±5.1%) in the reactor. The methanogens are sensitive to oxygen, therefore the micro-oxygen application based on the reactor design was aimed at suppressing any appreciable methanogenic activity during hydrolysis.

These were obtained by solving the non-linear first–order equation by exponential regression analysis and the main parameters shown in Table 4.9.

Table 9. Statistical analysis of COD values

Flow rate (L/kg.d)	**Correlation coefficient**	**K_H– Values**	**Standard deviation of error**
		day^{-1}	
1	0.98	0.052	0.022
1.13	0.99	0.083	0.018
1.25	0.98	0.241	0.028
1.38	0.99	0.141	0.019
1.5	0.99	0.128	0.013
1.75	0.99	0.112	0.015
Stepwise decrease	0.98	0.268	0.029
(all flow rate)			

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Table 10. Hydraulic retention time, determined first-order hydrolysis rate constant and starting concentration of biodegradable waste

HRT (d)	**K_H (d-1)**	**Starting COD concentration(g/l)**
0.61	0.052	3190
0.54	0.083	2680
0.49	0.241	1800
0.44	0.141	2030
0.41	120	1627
0.35	0.112	1630
All HRTs	0.268	1630

The values of the kinetic constants obtained in this research are comparable with values of other studies on double stage fermentation of MSW. Two-stage anaerobic treatment system was operated for 30 days.

Conclusion:-

The Test run 1 (MSW), Test run 2 (MSW+ COWDUNG) and Test run 3 (MSW+COWDUNG+URINE) gave peak biogas production and burnable biogas at the 25 days, 23days and 21 days respectively. Methane yield is found out to be best in test run 3 due to the better C/N ratio maintained. Stable maximum pH obtained during co-digestion of the cow dung and MSW and mono digestion is 6.7 to 7.2.The Test 2 and Test 3 concluded that the biogas was collected in the storage tube at faster rate as compared to ideal rate of biogas formation Test 1 of mono-digestion. The retention time required for formation of burnable biogas (test 2 and test 3) was reduced as compared to standard time required for biogas formation without additives (test1). The maximum methane content in biogas obtained from the co-digestion of MSW, cow dung and urine was found out be around 69%.

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