ANAEROBIC DIGESTION OF ORGANIC FRACTION OF MUNICIPAL SOLID WASTES: KINETIC STUDY

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Abstract: Energy crisis and waste management is one of the serious issues faced today. Anaerobic digestion is a biological process used for conversion of organic fraction of municipal solid wastes (OFMSW) in to biogas. Thus anaerobic digestion is a promising technology for energy production along with the effective disposal of wastes. In this study batch anaerobic digestion of OFMSW was carried out for 100 days at room temperature (32 ºC) for varying substrate concentration (total solid concentration, TS) of 115 g/l , 99 g/l and 83 g/l .The performance of reactors was evaluated by measuring the daily biogas production. Kinetics of anaerobic digestion of OFMSW was described by using, a first order model based on the availability of substrate as the limiting factor. At the end of the 100 days digestion, the biogas yield at TS concentrations of 115 g/l, 99 g/l and 83 g/l were 22.7, 55.9 and 43.1 L /kg VS respectively. The values of kinetic constants (k) obtained were 0.0196, 0.0292 and 0.0319 (day-1) respectively for the reactors 1,2 and 3.

***Index Terms* - Anaerobic digestion, municipal solid wastes, biogas, kinetics.**

I. INTRODUCTION

The role played by energy is overwhelming. Energy affects all aspects of development like social, economical and environmental. Hence the provision for an efficient, reliable affordable and an adequate supply of energy is inevitable. But in the present scenario the world is facing a serious energy crisis. Out of the many renewable forms of energy the energy recovery from biomass stands as versatile method where energy production can be made along with the effective disposal of wastes. Biogas production by the anaerobic digestion (AD) of biomass can be done effectively which serves the purpose as a fuel that can be used for domestic and industrial combustion processes in an environmental friendly way. Biogas is the ultimate waste product of the bacteria feeding off the input biodegradable feedstock and is mostly methane and carbon dioxide, with a small amount hydrogen and trace hydrogen sulfide. The methane in biogas can be burned to produce both heat and electricity, where the electricity and waste heat generated are used to warm the digesters or to heat buildings. Electricity produced by anaerobic digesters is considered to be renewable energy. Biogas does not contribute to increasing atmospheric carbon dioxide concentrations as well. So the problem of pollution is also reduced to certain extent by using biogas. The residue obtained after biogas production can be used as biofertilizer. Hence this technology serves the purpose of stable waste management along with energy generation.

Municipal solid waste (MSW) stream in Asian cities is almost similar, composed of high fraction of biodegradable material of more than 50% with high moisture content, and the generation rate is increasing with time [Visvanathan C et al. 2004]. More than 90 percent of the municipal solid waste generated in India is dumped in an unsatisfactory way, what creates environmental hazards to water, air and land. At the same time the organic fraction of MSW is about 40-60 percent [Mufeed Sharholy et al. 2008].

The massive generation of biological wastes is a serious issue in the present scenario. The rapid increase in population, urbanization, industrialization etc has accelerated the pace of the accumulation of municipal wastes globally. Increasing urbanization and economic development in developing countries have greater impact on management of society's solid wastes. The waste disposal methods depend on the nature and characteristics of waste generated. It in turn depends on the features of the locality of generation and the characters of the inhabitants of the locality. So choosing a safe and significant method of waste management is invariably depended on the nature of the region from where it is originated. Since the nature of wastes varies from place to place, the disposal methods by knowing the characteristics of the wastes will be better and efficient[Visvanathan C et al. 2004].

Solid waste streams should be characterized by their sources, by the types of wastes produced, as well as by generation rates and composition. Accurate information in these areas is essential in order to monitor and control existing waste management systems and to make regulatory, financial, and institutional decisions. Hence waste characterization is very significant in the field of solid waste management. According to Mufeed sharsholy et al. waste characterization is normally conducted as a part of waste management studies or environmental impact assessment studies. Waste from all sources must be tested for the following properties: (a) composition; (b) physical properties; (c) chemical properties; (d) biological properties; (e) thermal properties; (f) toxic properties and (g) geotechnical properties [Mufeed Sharholy et al. 2008].

Several studies have been reported on the bioconversion of biomass by different researchers, for example Mata-Alvarez et al. (1992) carried out experiments on Barcelona's central food market organic wastes, Owens J.M. and Chynoweth D.P on municipal solid wastes, Dhanalaxmi sridevi V and Ramanujan R.A (2012) on fruit and vegetable wastes and Krishna N et al. (1991) on canteen wastes. M.S Rao and Singh S.P, (2004) have studied the ultimate Bioenergy production potential of municipal garbage in batch reactors. There is a large number of factors which affect biogas production efficiency such as environmental conditions like pH, temperature, type and quality of substrate, mixing , process inhibitory parameters like high organic loading, formation of high volatile fatty acids, inadequate alkalinity etc. Therefore, the amenability of substrate for biogasification, gas yield–organic loading relationships and process inhibitory parameters vary from substrate to substrate, and for different environmental and operating conditions. [M.S Rao and Singh S.P, (2004)]. Therefore the purpose of the present study is to develop feasible anaerobic digestion process for the treatment of OFMSW for potential energy recovery and sustainable waste management and to describe the kinetics of AD of OFMSW.

II. MATERIALS AND METHODS

2.1 Reactor feed

Organic fraction of MSW was taken as the substrate for this experiment. The waste was collected from nearby vegetable market and households at Thrissur, Kerala, India. The composition of feed stock is shown in Table 2.1. The wastes were sorted and shredded, then mixed several times in laboratory and kept at 4°C until used. The inoculum used in this study was fresh cattle dung which contains all the required microbes essential for anaerobic digestion process. The inoculum was collected from nearby farm and kept at 4°C until used. The pH, total solid and volatile solid of the inoculum were 6.5, 25.2% and 85.9% respectively.

Table 2.1 Composition of substrate

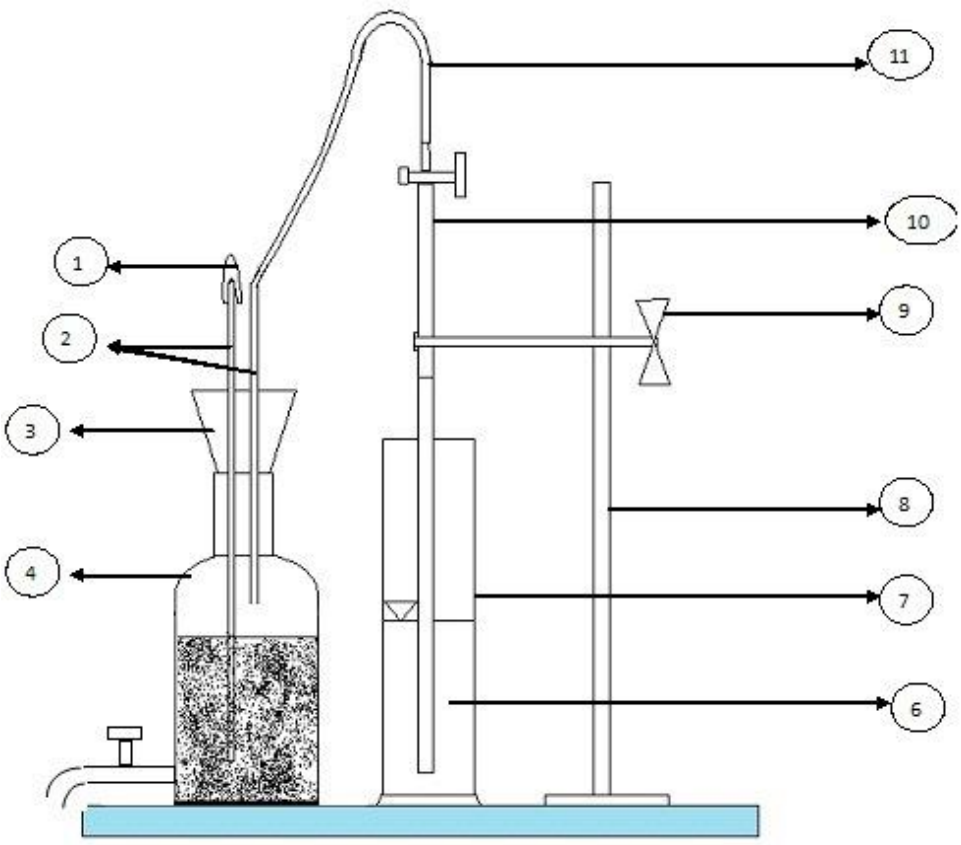
Feed stock type	Percentage (%)
Vegetable waste	35
Fruit waste	25
Food waste	37
Paper	3

2.2 Experimental set up

The experiments were carried on batch laboratory scale reactor (aspirator bottle) with total capacity of 2 L. The reactor was made of borosilicate glass with bottom sampling outlet. The bottles were closed by rubber stoppers equipped with glass tubes for gas removal and for adjusting the pH. The glass tube was dipped inside the slurry to avoid gas loss during the pH adjustments. The effective volume of the reactor was maintained at 1.6 L. Biogas production from the reactors was monitored daily by water displacement method. The volume of water displaced from the burette was equivalent to the volume of gas generated. The reactor was mixed manually by means of shaking and swirling once in a day. The reactors were operated at room temperature (32 ºC). The schematic diagram of the experimental set up is shown in Fig. 2.1.

2.3 Experimental procedure

The study is programmed to evaluate the mesophilic digestion of OFMSW at three different initial substrate concentrations. The substrate concentration was expressed as weight of solids/total volume of solids plus water, assuming that the density of the solids is approximately equal to the density of water. Three reactors (R1, R2 & R3) were used of 2 L total volume and 1.6 L effective volume at discontinuous condition but different total solids concentrations of 115 g/l, 99 g/l and 83 g/l respectively. All the reactors were fed with municipal garbage, tap water and cattle dung slurry (inoculum), used as the starter in the reactors. Liquid samples were drawn from each reactor periodically and analysed for pH, volatile fatty acids, alkalinity chemical oxygen demand and ammonia nitrogen. The pH was measured every 2 days and it was maintained in the range of 6.5 to 7.5 using 6 N sodium hydroxide solution as which is the optimum range for methanogens growth (Pavan et al., 2000). Volatile fatty acids, alkalinity chemical oxygen demand and ammonia nitrogen were analysed once in a week. Daily biogas production was measured by water displacement method. The substrate was mixed once each day, at the time of the gas measurement, to maintain intimate contact between the microorganisms and the substrate.



1. Sealing Clip
2. Glass tubes
3. Rubber stopper
4. Anaerobic digester
5. Outlet pipe
6. Saturated NaCl solution
7. Graduated cylinder
8. Stand
9. Clamp
10. Graduated burette
11. Rubber hose

Figure 2.1 Schematic diagram of the experimental set up

2.4 Analytical methods

The parameters analyzed for the characterization of substrates were as follows: Total Solids (TS), Volatile Solids (VS), pH, Volatile fatty acid (VFA), Total Kjeldahl Nitrogen (TKN), Total Organic Carbon (TOC).Following quantities were monitored during the digestion process: pH, VFA, alkalinity, Ammonia nitrogen(NH3-N),COD and production of biogas. All analytical determinations were estimated according to the procedures recommended in the Standard methods for examination of water and waste water (APHA,1998), pH was measured using digital pH meter. TS samples were dried in an oven at 105-110 ºC, and for VS to the dried ash waste in a muffle furnace at 500 ±50 ºC. TKN and NH3-N content were examined using the spectrophotometer (HITACHI,U-2900 UV/VIS spectrophotometer). VFA and alkalinity were done using simple titration method (Anderson and Young, 1992).TOC analysis was carried out using Shimadzu TOC-LCPH/CPN analyser for non- purgeable Organic Carbon from the standard methods. Gas production was measured at a fixed time each day by the water displacement method, with water prepared as specified in standard methods.

III. RESULTS AND DISCUSSION

3.1 Feed Stock Characteristics

The OFMSW used in this experiment was composed of four different types of waste that are mixed to simulate the municipal solid waste composition used in this study. The composition of the substrate is given in the Table 2.1. Zeshan (2012) used similar simulated composition of municipal solid waste for anaerobic digestion. The summary of the characterization of substrate and reactor feeds is shown in Table 3.1. The weight of substrate used in the reactors R1, R2 and R3 were 700 g, 600 g and 500 g (wet weight) respectively.

3.2 Performance of batch reactors

The experiments were carried out for 100 days at room temperature, 32°C (mesophilic digestion) at three different initial substrate concentrations of 115 g/l, 99 g/l and 83 g/l respectively. The experiments were concluded when there was no significant variation of cumulative biogas production. In an anaerobic system, the acetogenic bacteria convert organic matter to organic acids, and then the value of pH is decreased. This result in a reduction of methane production rate this may be due to the consumption of acid by the methanogens. pH in the range of 6.8 to 7.4 should be maintained in the anaerobic digestion process, which is the optimum range for methanogens growth [Velmurugan B and Alwar Ramanujan, 2011].A decrease in pH was observed during the initial days of digestion (up to 15-25 days) this may be due to the high volatile fatty acids formation, hence the pH was adjusted to 7 using 6N NaOH solution.

Daily and cumulative biogas productions for 3 reactors are indicated by Fig.3.1 and Fig.3.2 respectively, where the biogas production is high in the beginning which was due to the entrapped air inside the reactor and the waste itself. The reactors R1, R2 and R3 were operated with total solid concentration of 115 g/l, 99 g/l and 83 g/l. Initially in the reactors R1 and R2, the biogas

production was stopped due to the reduction of pH. So after adjusting the pH value in the optimum range by addition of 6N NaOH to the system, the production was increased. In reactor 3 optimum range of pH was initially made up, hence the biogas production was not stopped in R3. In R1 initially thick slurry was formed due to high solid contents in the reactor. So the production of biogas was reduced in the initial stages. The maximum daily biogas production obtained for R1 was 120 ml in 69th day and that for R2 and R3 were 340 ml in 58th day and 180 ml in 29th day. At the end of the 100 days digestion total cumulative biogas for R1, R2 and R3 were obtained as 3.574 L, 7.474 L and 4.957 L respectively. The biogas production was decreased from 85-100 days due to lack of amount of substrate.

The biogas yield, biogas produced per kg organic solids (volatile solids) for different concentrations of organic loading over a 100 days digestion time at room temperatures are shown in Fig. 3.3. The rates of biogas production differed significantly according to the organic loading. It can be observed from Fig 3.3 that bulk of substrate degradation takes place up to a period of approximate 80 days suggesting that the digesters should preferably be run at a digestion time close to 80 days for optimum energy yield. At the end of the 100 days digestion, the biogas yields at TS concentration of 115 g/l, 99 g/l and 83 g/l were 22.7 L/kg VS, 55.9 L/kg VS and 43.1 L/kg VS respectively. These values are comparable with the values obtained by M. S. Rao and S. P. Singh (M. S. Rao and S. P. Singh, 2004). C: N ratio is most often used to indicate both the stability of organic matter and the quality of the digested substrate for its further use. In this study, C: N ratio of digested substrate was in the range 12:1–17:1,which is considered to be stable and high quality compost. However, the effluent chemical oxygen demand concentration indicates that it should be treated before using it for other applications.

Table 3.1 Characteristics of the substrate and feed

Parameter	OFMSW	R1	R2	R3
pH	6.15	6.42	6.75	6.64
TS (%)	18.5	12.32	10.5	9.4
VS (%)	89.6	85.37	84.5	86.6
VFA(meq /l)	10.85	8.65	9.57	6.98
COD (mg/l)	42835	41152	37318	31987
TKN (g/l)	1.05	1.1	1.09	0.85
TOC (g/l)	20.32	23.87	20.5	16.76

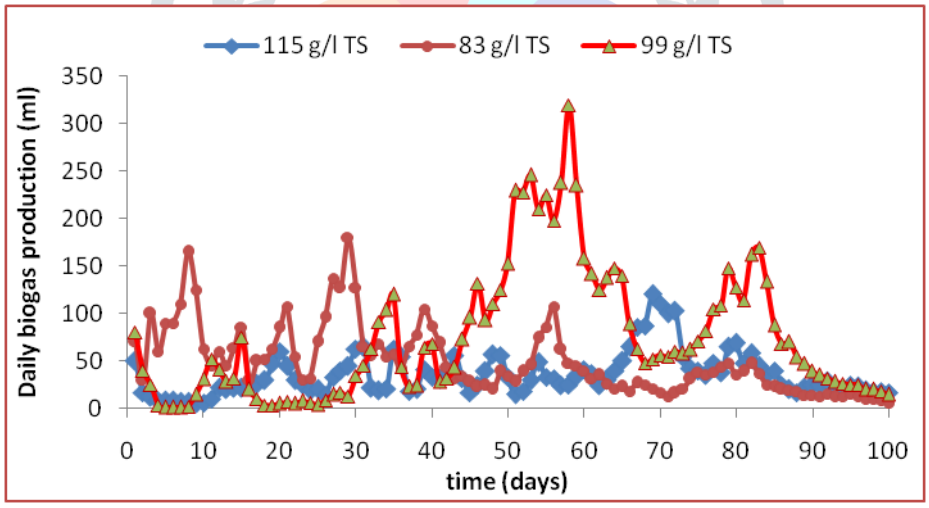


Figure: 3.1 Variation of daily biogas production versus days for different substrate loading

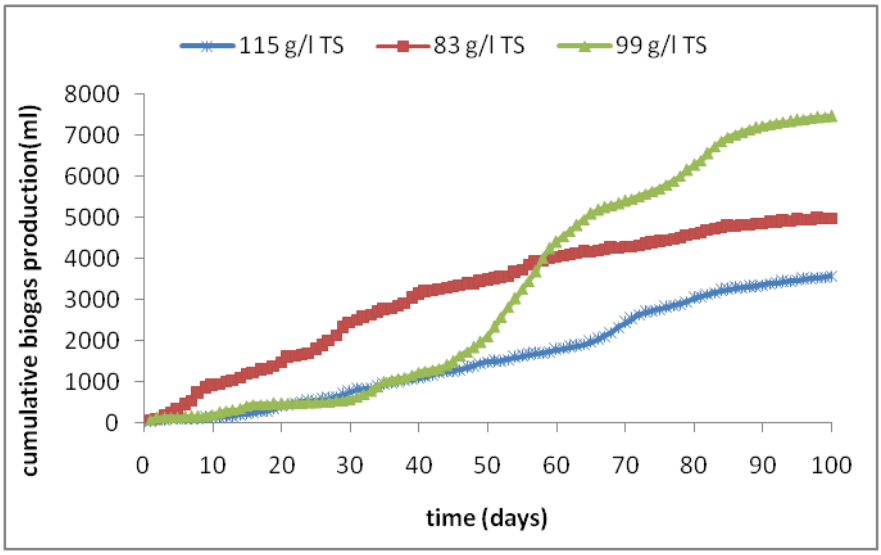


Figure 3.2 Variation of cumulative biogas production versus days for different substrate loading

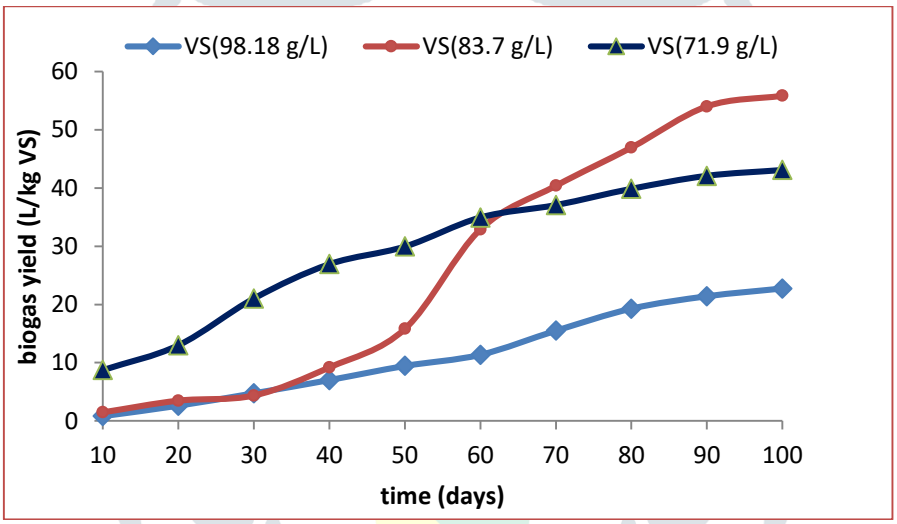


Figure 3.3: Biogas yield at different organic loading

3.3 Kinetic study

Kinetic studies of anaerobic digestion process are useful to predict the performance of digesters and design appropriate digesters. Kinetic studies are also helpful in understanding inhibitory mechanisms of biodegradation. First-order kinetic models are the simplest models applied to the anaerobic digestion of complex substrates as they provide a simple basis for comparing stable process performance under practical conditions. Therefore, a first order model based on the availability of substrate as the limiting factor was used to perform the present study. The basic equation is

$$\frac{dB}{dt} = -kB \qquad (1)$$

where k is the first-order substrate utilisation rate constant(time^{-}1) and B (mg/l) represents the biodegradable substrate concentration. On integration, Eq. (1) becomes

$$B=B0 \exp(-kt) \qquad (2)$$

where B0 (mg/l) represents initial substrate concentration.

Substrate concentration can be correlated with biogas production (G), as mentioned below.

$$\frac{G_\infty - G}{G_\infty} = \frac{B}{B_0} \qquad (3)$$

where G_∞ is the ultimate biogas production. From Eqs. (2) and (3), the integrated equation for the first order model which gives an analytical relation between the volume of biogas produced and digestion time was obtained and used to quantify the extent of process inhibition is as follows:

$$G = G_\infty[1 - e^{-kt}] \qquad (4)$$

Where k (time-1) is the first-order biogas production rate constant [Rao M.S & Singh S.P, 2004].

Taking Napierian logarithms in the above equation and ordering the terms the following equation is obtained.

$$ln\left(\frac{G_\infty}{G_\infty - G}\right) = kt \qquad (5)$$

Indicating that $ln\left(\frac{G_\infty}{G_\infty - G}\right)$ versus t should give a straight line of slope equal to k with intercept zero. The value of G_∞ has been considered equal to the volume of biogas accumulated at the end of each experiment. Representation of the experimental data in the above equation gives straight lines with intercept practically zero and slope equal to k. [Dhanalaxmi sridevi V and Ramanujan R.A, 2012]. The values G_∞ of k obtained from a non-linear regression analysis using Curve Expert 1.4.

It has been observed that the cumulative biogas production was fit well with the first-order kinetic model as is evident from the correlation coefficient between the experimental and predicted value .The values of kinetic constants for R1, R2 & R3 were calculated from the Fig. 3.4-3.6 respectively. The values of kinetic constants (k) obtained for R1, R2 & R3 were 0.0196, 0.0292 and 0.0319 (day^{-1}) respectively. These values are comparable with the values obtained by M. S. Rao and S. P. Singh (M. S. Rao and S. P. Singh, 2004). The summary is given in Table 3.2.

Table 3.2: Values of fitting functions and statistical measures for the kinetic model

TS concentration (g/l)	Ultimate Biogas production G∞ (ml)	Biogas production rate constant k (day^{-1})	Correlation Coefficient (R^2)
115	4025	0.0196	0.8684
99	7540	0.0292	0.929
83	5050	0.0319	0.9076

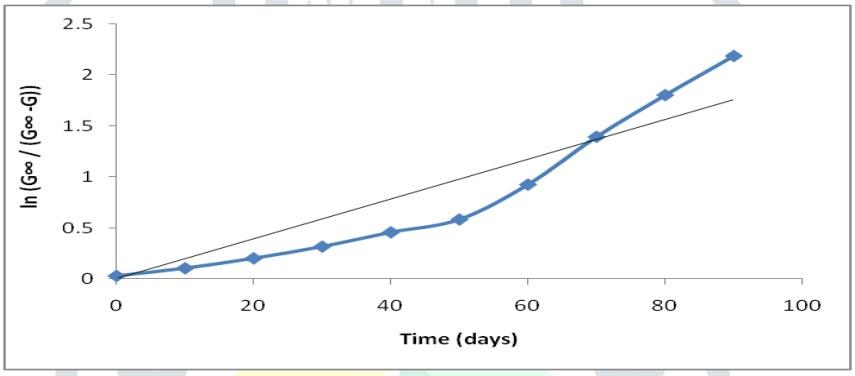


Figure 3.4: Plot for the determination of k for TS concentration of 115 g/l

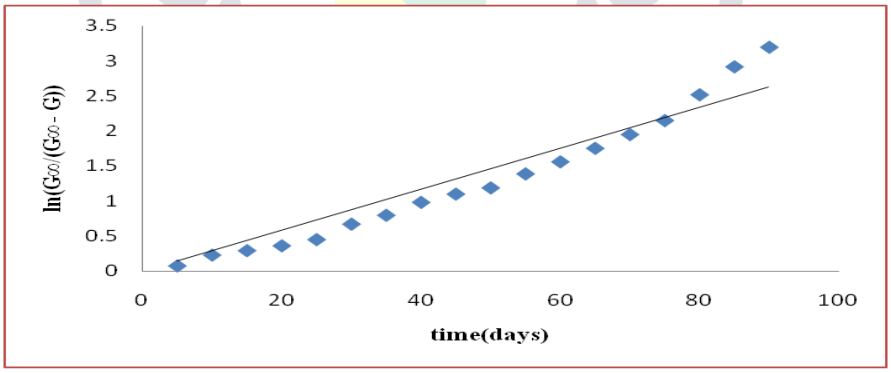


Figure 3.5: Plot for the determination of k for TS concentration of 99 g/l

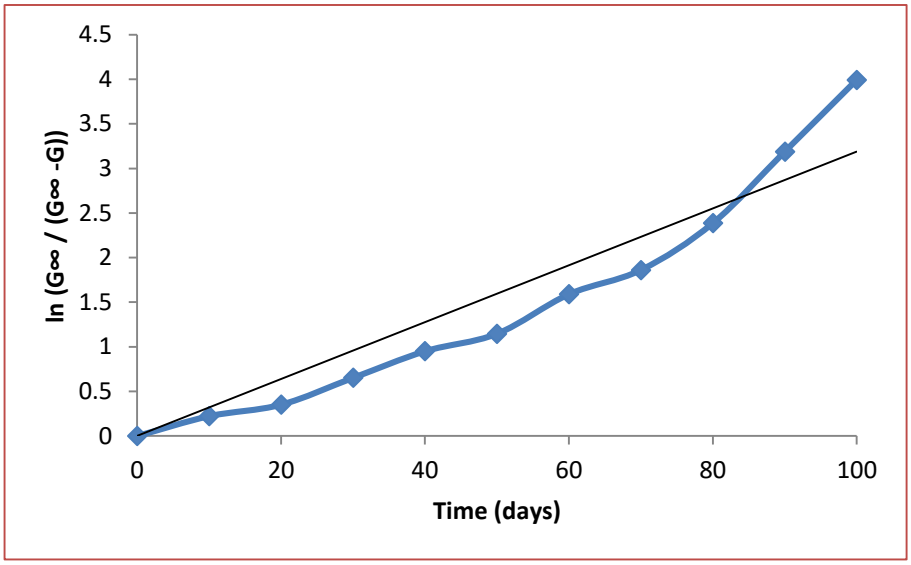


Figure 3.6 : Plot for the determination of k for TS concentration of 83 g/l

IV. CONCLUSIONS

Batch anaerobic digestion of OFMSW was done successfully for 3 reactor having TS concentration of 115 g/l, 99 g/l and 83 g/l respectively. Based on the performance of the anaerobic digester following observations and conclusions are made. This study found that maximum biogas production was obtained at total solid concentration of 99 g/l. It was observed that on decreasing the concentration, the production was reduced and this may be due to lack of substrate. On increasing the concentration the production was reduced and this may be due to accumulation of large amount of substrate. At the end of the 100 days digestion total cumulative biogas for R1, R2 and R3 were obtained as 3.574 L, 7.474 L and 4.957 L respectively. The ultimate biogas production for R1, for R2 and R3 were obtained as 4025,7540 and 5050 respectively At the end of the 100 days digestion, the biogas yield at TS concentrations of 115 g/l, 99 g/l and 83 g/l were 22.7, 55.9 and 43.1 L /kg VS respectively. The values of reaction rate constant, k, calculated for the reactors at TS concentrations of 115 g/l, 99 g/l and 83 g/l using first order kinetics were 0.0196, 0.0292 and 0.0319 (day^{-1}) respectively.

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