Enhanced Co-digestion of Organic Fraction of Municipal Solid Wastes with Cow Dung and Poultry Droppings using Carbon to Nitrogen Ratio Proportioning

G. Usman, C.S. Ajinomoh, J. A. Muhammad, Y. Muhammad

Abstract— Biogas production was remarkably improved by the anaerobic co-digestion of manually sorted, size reduced simulated organic fraction of municipal solid wastes (OFMSW) with cow dung (CD) and poultry droppings (PD) by mixing the substrates to achieve reported optimum carbon to nitrogen ratio (C/N). The experiments were performed in four sets of laboratory scale, 4 litre slurry biodigesters in triplicates.
The Modified Gompertz equation was used to effectively describe the cumulative gas production from the process and zero order kinetic equations adequately described the COD removal rates of the effluents. The modified Gompertz equation showed that when simulated OFMSW is mixed with 38% and 22% CD and PD respectively to achieve a (C/N) of 30:1, biogas evolution was improved by 17% and 25% respectively under ambient conditions.

Index Terms— *biogas, carbon to nitrogen ratio, co-digestion, cow dung, modified Gompertz equation, municipal wastes, poultry droppings.*

1. INTRODUCTION

An enormous challenge confronting governments in many developed and developing countries today is Municipal solid waste (MSW) management especially in the major cities which is the result of increasing populations brought about by the mass migration of people from rural to urban areas, increase in economic activities, industrialisation, changing lifestyles and most importantly, lack of commensurate, safe and cost-effective waste disposal and treatment options.

Perhaps, trailing very close to the challenge of waste accumulation and treatment option is the need for countries and governments to find an alternative energy source and food for the sustenance of the ever growing populations. Roy *et al.*, (2006) reported that globally, the energy crisis redirects attention to alternative sources of energy instead of underground fossil fuels. While Budiyono *et al*, (1996) observed that renewable energy is one of the most important factors to global prosperity because relying on fossil fuels as the main source of energy had lead to global climate change, environmental degradation and human health problems. Thus, the utilization of energy in the form of biogas is one of the environmentally sound alternative renewable energy sources. Membere *et al.*, (2012).

Biogas is an excellent alternative source of energy which according to Karellas (2010) contains 50-75% CH_4, 25-48% CO_2 and other gases in small amounts and which can be produced by the anaerobic co-digestion of biodegradable material such as manure, sewage, plant materials, and crop residues amongst others. Hartman (2002) defined co-digestion as the anaerobic treatment of a mixture of at least two different waste types which has the advantages of contributing to the economy of the process due to the combination of different waste streams in one common treatment facility and the treatment of larger waste amounts in a centralized facility as well as the attainment of better handling of the wastes in the form of higher methane yields and an improved process.

Even as Kigozi *et al.*, (2014) had listed a number of merits of using OFMSW as a Substrate for biogas production including its availability at little or no cost, as a means of environmental

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conservation, high total and volatile solid content as well as good quality of produced biogas, the co-digestion of OFMSW with other wastes offers several advantages in relation to a balance of nutrients and adjusting the buffer capacity of the OFMSW.

Francesco *et al.*, (2009) stated that temperature, pH, electrical conductivity, total organic carbon, total nitrogen, and C/N ratio are common factors that affect the biodegradation process.

National Engineering Handbook (2000) reported that to obtain a mixture with a desired C/N ratio from two component parts X and Y, the equations to use are:

$$X_C a + Y_C b = C \qquad (1)$$

$$X_N a + Y_N b = N \qquad (2)$$

Where X_C is the carbon content of component X; *a* the mix proportion of component X;Y_C the carbon content of component Y;C the carbon content of mixture; X_N the nitrogen content of component X, Y_N the nitrogen content of component Y; *b* the mix proportion of component Y and, N the nitrogen content of mixture

Ahmadian *et al.*, (2013) gave the following relationships shown in table 1, for zero, first and second order kinetics for COD removal from MSW leachates.

Table 1 Equations and linear forms of COD removal kinetics model. Ahmadian *et al.*, (2013)

Kinetic model	Equation	Linear form	
Zero-order	$r_c = \frac{dc}{dt} = k_o$	$C - C_o = -k_o t$	(3)
first-order	$r_c = \frac{dc}{dt} = k_1 C$	$\ln \frac{C}{C_o} = -k_1 t$	(4)
Second order	$r_c = \frac{dc}{dt} = k_2 C$	$\frac{1}{C} = \frac{1}{C_o} = -k_2 t$	(5)

Where r_c is the rate of conversion, k_0, k_1, and k_2 are reaction rate coefficients for zero, first and second order respectively, t is time, and C_0 and C are the initial and final concentration of the constituent in the liquid. Ahmadian *et al.*, (2013). Thus, C and C_o can be COD (t) and COD (0), the COD at time t and initial COD respectively.

Syaichurrozi and Sumardiono (2014) reported that the modified Gompertz equation was developed by Zwietering *et al.* (1990) to predict bacterial growth. Lo *et al.*, (2010) found that for biogas evolution and accumulation simulations, the modified Gompertz plots showed better (higher R^2) correlation.

The modified Gompertz equation is usually applied on the assumption that the rate of biogas production in batch biodigesters is directly proportional to the specific growth rate of the methanogenic bacteria in the biodigester as reported by Zwietering *et al.*, (1990), Lay *et al.*, (1998) and Momirlan and Veziroglu, (1999), Mu *et al.*, (2007), Lin and Shei (2008), Altas (2009) and, Lo *et al.*, (2010).

Yusuf *et al.*, (2011) and Agulanna *et al.*, (2012) presented the modified Gompertz equation in the following form:

$$B_t = B_{\max} \exp\left[-\exp\{ \frac{R_b}{B_{\max}} e.(\lambda - t) + 1\} \right] \qquad (6)$$

Where B_t is cumulative of biogas produced (ml) at any time (t); Bmax, biogas production potential (ml); Rb; maximum biogas production rate (ml/day) and λ is the lag time. That is, the minimum time taken to produce biogas or time taken for bacteria to acclimatize to the environment (days) and t is the time of biogas production (days)

The constants B, R_b and λ can be determined using the non-linear regression approach with the aid of regression tools such as the SigmaPlot® (Lo *et al.*, 2010), solver function in the Microsoft office Excel® ToolPak (Yusuf *et al.*, 2011),), the polymath software (Adiga *et al.*, 2012), the curve fitting tool in MATLAB® (Agulanna *et al.*, 2012) and so on.

II. MATERIAL AND METHODS

2.1 Substrate collection and preparation

Substrates that were utilized in this research work included

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manually sorted, size reduced OFMSW collected and sorted from municipal Solid Wastes (MSW) which was collected from central dumpsites located in communities around the Ahmadu Bello University, Zaria, Nigeria using the stratified random sampling method as recommended by European commission (2004) following the guidelines of Sampling Methodology ASTM International (2011). The sorted MSW was reconstituted to form the simulated OFMSW. The CD and PD used were collected from the National Animal Production Research Institute (NAPRI), Shika, Kaduna state, Nigeria. The OFMSW was prepared for the purposes of the experiment, proximate, ultimate and microbial analyses in accordance with the criterion outlined by Agulanna (2012).

2.2 Substrate analyses

Waste composition, moisture content, waste particle size, waste density, temperature and pH which are important factors that affect the extent and rate of degradation of wastes, were determined on the mixed components of the solid wastes using the procedure outlined in APHA (1998) at the Chemistry Department of the Ahmadu Bello University (ABU), Zaria and the Institute of Agricultural Research (IAR), ABU, Zaria. Standard spread-plate dilution method described by Ogunmwonyi *et al.*, (2008) was adopted to identify the microbial contents of the simulated OFMSW, cattle dung and poultry droppings.

Each sample was mixed, and a suspension of one gram (dry weight equivalent) in ten millimetres of sterile water was prepared. One ml of the suspension was then diluted serially (tenfold) Identification of isolates was based on cultural, microscopic, and biochemical characteristics based on the procedure outlined in the Manual of Environmental Microbiology (2012) with reference to Bergey's Manual of Systematic Bacteriology (1989).

2.3 Experimental design

The experiment for the anaerobic co-digestion of OFMSW with CD and PD was carried out at room temperature by mixing the substrates in proportions as obtained from the ultimate analysis and then equations (1) and (2) to achieve literature reported optimum carbon to nitrogen ratio (C/N) of 30:1 as recommended by Manios (2004), Rai (2004) and Kangle (2012) by making a digestion slurry via the addition and vigorous mixing of total solid with an equivalent amount of water needed for maximum production according to the method of Ituen *et al.*, (2007) , Al-Imam *et al.*, (2013) and as described by Aremu and Agarry (2012) as well as Chibundo (2012). The experiments were performed in three sets of laboratory scale, 4 litre slurry biodigesters in triplicates labeled A, B and C with compositions as shown in table 2.

Table 2: Composition of biodigesters

Digester composition	OF-MSW (kg)	CD (kg)	PD	Water (kg)
A				
62%OFMSW+38% CD	0.992	0.608	-	1.6
B				
80%OFMSW+ 20% PD	1.28	-	0.32	1.6
C				
100%OFMSW	1.6	-	-	1.6

OFMSW; organic fraction of municipal waste, CD; cow dung, PD; poultry droppings.

2.4 Experimental Set-Up

A total of nine biodigesters each of 4 litres working volume was employed as adopted and modified from Bayard *et al.*, (2005). The digester was constructed using an acrylic column 150mm in diameter, 200mm in height, with a wall thickness of 5 millimetres.

Three layers of heat-insulating materials were employed to prevent loss of conductible heat. A heavy-duty aluminium foil was placed on the inner and outer layers for reflecting heat. Polyurethane foam insulation material was then used to fill the spaces between the heavy-duty aluminium foil as adopted and modified from Li *et al.*, (2008). A tap was placed at the bottom of the reactor to collect the leachates

The digesters were also equipped with a layer of gravel and a wire mesh at the bottom for leachate collection and to prevent waste saturation and a layer of wire mesh at the top of the digester for the homogenous escape of the gases from the top as adopted from Bayard *et al.,* (2005). Two perforations were made on the cover of the digester through which the gas hose and thermometer were tightly fixed. The thermometer was fixed tightly in one of the holes, while the other hole was placed the gas delivery tubing to pass the evolved gas from the digester into an inverted 250 ml graduated gas jar cylinder filled with saline water. The gas cylinder was held in position in a trough of the saline water by a clamp mounted on a retort stand as shown in plate I. .

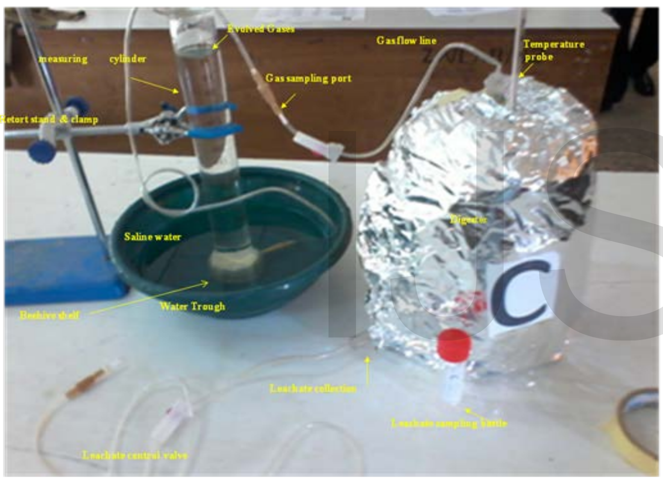

Plate I: Labeled experimental set -up

2.5 Analytical methods

Measurement of leachate COD was conducted at the Department of Chemical Engineering, ABU, Zaria, Nigeria using the dichromate method by utilising the closed reflux, 5220C, titrimetric method as described in the Standard Methods for Examination of Water and Wastewater (2012) while the measurement of the volume of evolved gases was carried out using the method described by Adeyemo and Adeyanju (2008) as well as Bareither *et al., (*2009) and modified by Yusuf *et al.,* (2011) and Tsunatu *et al.,*(2014) using the water displacement method in which the amount of saline water (20% NaCl (w/v), pH 4) displaced was proportional to the volume of biogas produced.

III. RESULTS AND DISCUSSIONS

3.1 COD Reduction Kinetics

Table 3 below shows the daily COD, COD reduction and percentage COD reduction in the three digesters. It is observed that digester A produced the leachate with the highest initial COD content of 4034mg/l it was followed by digesters B and D with initial leachates of 2056 and 956mg/l respectively. Also, the percentage COD reduction was in the order A > B > D. Figure 1 shows the daily COD percentage reduction profiles.

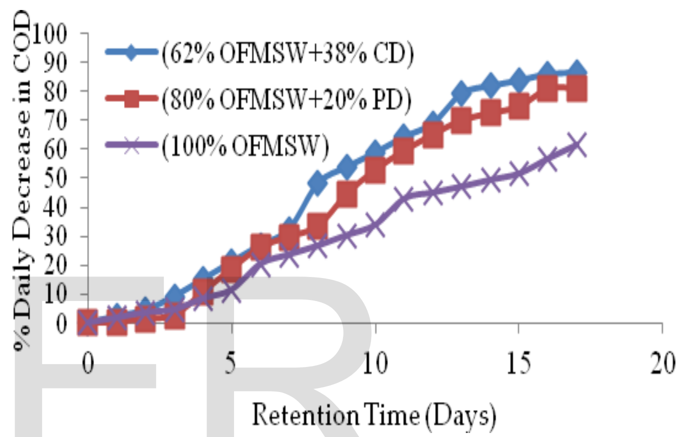

Figure 1: Daily % Reduction in Leachate COD

Table 3 Daily COD, COD reduction and percentage COD reduction

Retention time (Days)	A (62%OFMSW+38% CD)		B (80%OFMSW +20% PD)		C (100%OFMSW)	
	COD	% COD Reduction	COD	% COD Reduction	COD	% COD Reduction
0	4034	0.0	2056	0.0	956	0.0
1	3944	2.23	2031	0.29	939	1.78
2	3856	4.41	2008	1.5	922	3.56
3	3668	9.07	1846	2.6	912	4.60
4	3426	15.07	1676	10.48	876	8.37
5	3186	21.02	1525	18.72	847	11.40
6	2949	2690	1448	26.04	762	20.29
7	2727	32.4	1374	29.78	731	23.54
8	2090	48.19	1145	33.37	702	26.57
9	1862	53.84	972	44.47	667	30.23
10	1658	58.89	837	52.86	633	33.78

11	1440	64.30	721	59.41	547	42.78
12	1250	69.01	621	65.03	527	44.87
13	834	79.32	569	69.88	507	46.97
14	730	81.9	522	72.41	485	49.27
15	653	83.81	395	74.68	464	51.46
16	565	85.99	392	80.84	415	56.59
17	546	86.47	-	80.99	370	61.3

To investigate a suitable order for the COD reduction of the leachates produced from the process, zero, first and second order kinetics was investigated. The zero order kinetics was found to give the best fits (higher R^2). Values of COD from table 3 above were used in investigating the zero order COD kinetics. By plotting COD against the hydraulic retention time in days, using equation (3), straight line graphs were obtained with slopes representing the zero order rate constant k_0 and intercepts that represents the initial COD value.

$$COD(t) = COD(0) - k_o t \quad (3)$$

The zero order plots, equations and goodness of fit (R^2) are as shown in figures 2 to 4 below:

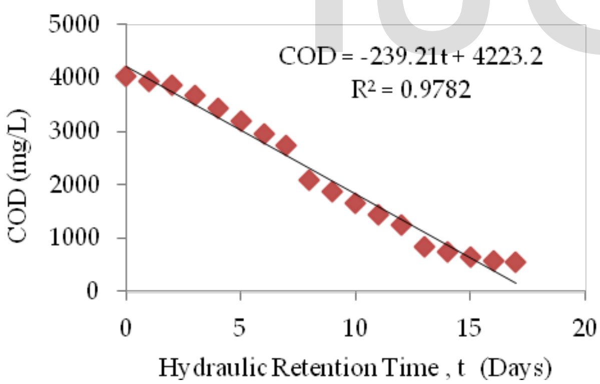

Figure 2: Zero order Kinetics for 62% OFMSW+38% CD

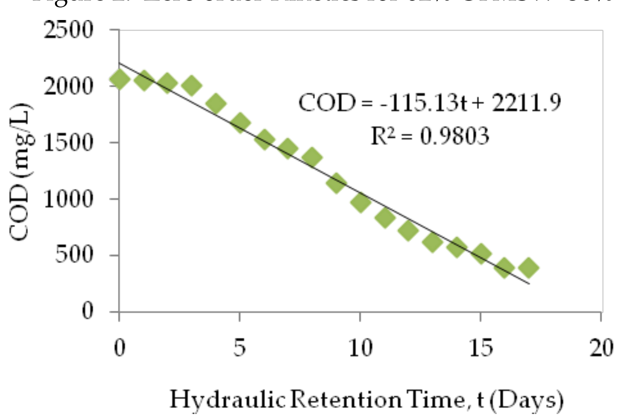

Figure 3: Zero order Kinetics for 80% OFMSW+20% PD

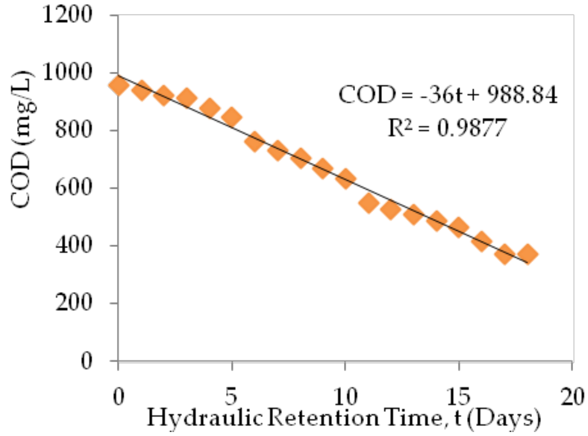

Figure 4: Zero order Kinetics for 100% OFMSW

The zero order kinetic constant, k_o, was found to be -239.21, -115.13 and -36mg/l.day for digesters A, B and C respectively. Since the more negative the value of k_o, the faster the rates of removal of the biodegradable fractions (Tsunatu, 2014), it showed that the biodigester with the fastest reaction was A while the slowest was the control, C.

This finding is in agreement with reports from Hamza *et al.*, (2009) who reported that the reaction is zero order at high substrate concentration and first order at low substrate concentrations, Guan *et al*. (2003) who observed that the rate of COD removal in wastewater is divided into rapid removal and moderate removal stages and Waterloo (2006) who explained that at high substrate concentration every site of the organism is saturated with the substrate that made the rate to be constant, that is zero order and that as the substrate concentration decreased, only few available site of the organism was covered and that made the rate of reaction to be proportional to the substrate concentration which is first order.

3.2 Modified Gompertz Plots for Cumulative Volume of Evolved Biogas

The daily biogas production from the biodigesters is as shown in Table 4 below:

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Table 4: Daily cumulative biogas production

Retention time (Days)	A (62% OF-MSW+38% CD)		B (80% OF-MSW+20% PD)		C (100% OFMSW)	
	Gas Prod (ml)	Cumm Gas Prod (ml)	Gas Prod. (ml)	Cumm Gas Prod. (ml)	Gas Prod. (ml)	Cumm. Gas Prod. (ml)
1	480	480	1014	1014	0	0
2	4317	4797	3838	4852	1250	1250
3	5947	10744	3645	8497	3096	4346
4	2902	13646	4027	12524	3887	8233
5	3142	16788	2645	15169	4014	12247
6	3118	19906	2776	17945	3027	15274
7	2278	22184	2962	20907	3022	18296
8	2731	24915	2000	22907	2347	20643
9	2853	27768	2921	25828	1997	22640
10	3213	30981	3187	29015	2181	24821
11	1750	32731	1979	30994	1493	26314
12	2216	34947	1931	32925	1479	27793
13	1932	36879	1131	34056	2188	29981
14	1004	37883	1062	35118	1330	31311
15	2	37885	6	35124	4	31315
16	2	37887	2	35126	2	31317
17	3	37890	2	35128	3	31320
18	0	37890	0	35128	2	31322
19	0	37890	0	35128	0	31322

The cumulative volume of the biogas evolved (B_t) from each digester, was further evaluated using the modified Gompertz equation as presented in equation.

$$B_t = B_{max}\exp\left[-\exp\left\{\frac{R_b}{-}.e.(\lambda - t)+1\right\}\right] \qquad (6)$$

The values of B_{max}, R_b and λ were determined by the non-linear regression approach using MATLAB® *(R2013a)* software programme at 95% confidence bounds and the resulting kinetic parameters and plots are presented in figures 5 to 7.

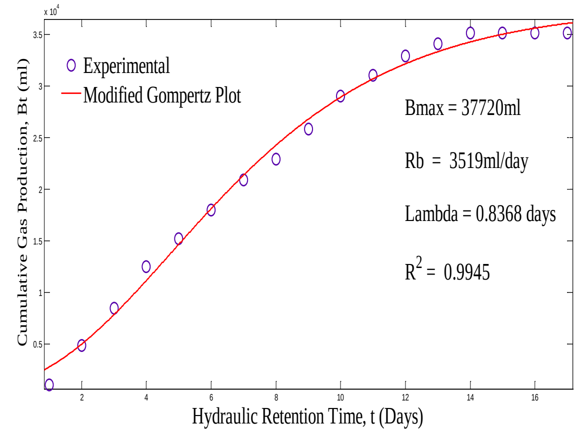

Figure 6: Experimental and Modified Gompertz Plots for 80% OFMSW +20% PD

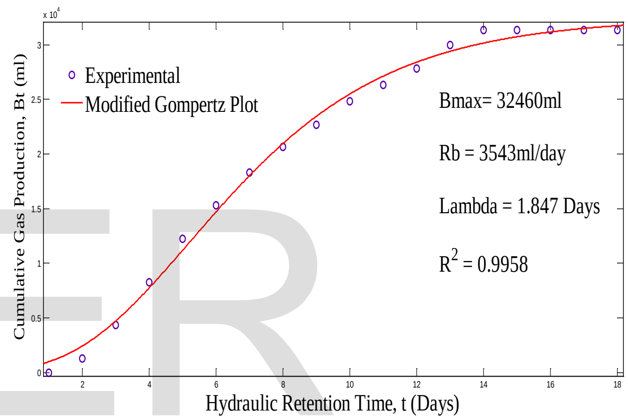

Figure 5: Experimental and Modified Gompertz Plot for 62% OFMSW +38% CD

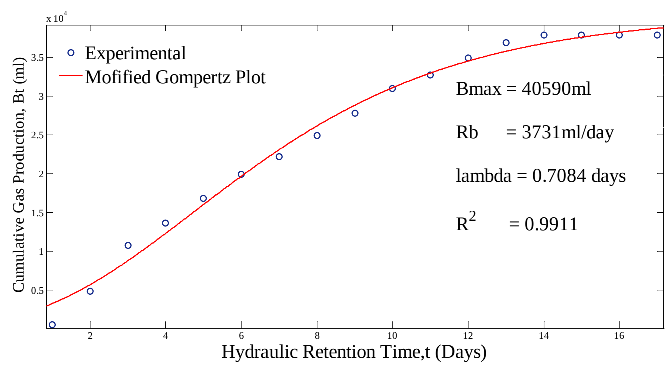

Figure 7: Experimental and Modified Gompertz Plots for 100% OFMSW

The values of maximum volume of cumulative gas evolved per kilogramme of the 3.2kg raw feedstock slurry as obtained using the modified Gompertz equation for digesters A, B and C of 12.68, 11.78 and 10.14L/kg conforms very closely to the experimentally obtained values of 11.84, 10.98 and 9.79 L/kg of raw feedstock respectively. However, it is observed that the values obtained from the modified Gompertz equation were slightly higher than the experimental; this may be attributed to the level of conversion of the feedstock and the dependence of the biodegradation process on several other operative parameters.

The lag time represented by lambda (λ) indicated that the time for the anaerobic biodegradation to begin was as short as 0.7084, 0.8368, and 1.847days. That is, 17.0, 20.1, and 44.33 hours for digesters A, B, and C respectively.

IV. CONCLUSION

Biodegradation was remarkably enhanced by the co-digestion of manually sorted, size-reduced simulated OFMSW with CD and PD using C/N ratio proportioning at ambient temperature. The production of biogas as an environmentally friendly energy source from OFMSW inoculated with animal wastes was established. The feasibility of the process was demonstrated through improved leachate COD reduction with 86.47, 80.99 and 61.3% leachate COD reduction for digesters A, B and C. respectively and with the process described best using zero order kinetics due to high COD concentrations. Also, the biogas yield as obtained using the modified Gompertz equation for digesters A, B and C of 12.68, 11.78 and 10.14L/kg conforms very closely to the experimentally obtained values of 11.84, 10.98 and 9.79 L/kg of raw feedstock respectively.

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