# Biogas Production Kinetics from Combined Municipal Solid Waste co-digested with Cow dung and sewage sludge in Batch Reactors

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**ABSTRACT:** This study aims at investigating the bio gas production kinetics of combined Municipal Solid waste( MSW) co digested with cow dung and sewage sludge on the anaerobic batch reactors. The results indicate that the cow dung slurry and sewage sludge is the best inoculums source of methane generation due to its biodegradation capacity. The cumulative biogas readings for reactors R1, R2, R3, R4, R5 and R6 was obtained as 337.365ml/gVS, 481.95ml/gVS, 567ml/gVS, 214.775ml/gVS, 321.198ml/gVS, and 383.52ml/gVS, respectively. In addition, biogas production accumulation was simulated using transference function, modified Gompertz equation and logistic function plots. Kinetic constants relate cumulative biogas production and the time of digestion through biogas yield potential (P), the maximum biogas production rate (Rm) and the duration of lag phase (λ) R2, RMSE values obtained from different inoculums are completely presented. Modified Gompertz plot had higher correlation than other plot for simulating cumulative biogas production for both co substrates.

## 1. INTRODUCTION

Global population increase, technological and industrial advancements as well as changes in life styles have led to increased pollution across the world. The pollution of water, air and soil by municipal, industrial and agricultural wastes is a major concern of public authorities who imperatively have to encourage the development of effective and non-expensive treatment technologies Municipal solid waste (MSW) generation is significantly increasing in Indian urban areas and started creating enormous waste disposal problems in the recent past. In India, MSW management is the duty of the local municipalities. More than 90 percent of the municipal solid waste which generated in India is dumped in an unsatisfactory way, what creates environmental hazards to water, air and land, which creates the need of Systems for MSW management development capable to minimize the production of these and able to reduce the environmental impact and danger to the public health. Presently most of the developed countries, Waste minimization and energy generation are the recent emerging concepts. The advantages of using biogas reactor system are under greenhouse gas initiative, minimize unpleasant odour, prevent disease transmission, and generate heat, power and by product such as solid and liquid fertilizers. Biogas is gas formed from degradation of organic materials under anaerobic condition. The degradation is consisted of four major phases that are hydrolysis, acidogenesis, acetogenesis and methanogenesis (Esposito et al., 2011). Many authors have studied the biogas production from organic materials. Budiyono et al. (2010) studied the biogas production from cattle manure. Adiga et al. (2012) produced biogas from water hyacinth, poltry litter, cow manure and primary sludge. Sumardiono et al. (2013) and Budiyono et al. (2013) investigated the potential of vinasse as feed stock of biogas under anaerobic condition. Zhu et al. (2009) utilized municipal solid waste as feed stock of biogas. Patil et al. (2012) studied biogas production from water hyacinth. Recently, some authors have made prediction of biogas production potential using modified Gompertz model (Budiyono et al., 2010; Adiga et al., 2012; Patil et al., 2012) and first order kinetic model (Raposo et al., 2009; Kafle et al., 2012). Modified Gompertz model was developed by Zwietering et al. (1990) to predict bacterial growth. By assume that biogas production rate had correspondence to methanogenic bacterial growth rate in digester, some authors (Budiyono et al., 2010; Adiga et al., 2012; Patil et al., 2012) used modified Gompertz model to predict biogasproduction potential. Besides that, kinetic of biogas production also could be modeled by using first order kinetic (Raposo et al., 2009; Kafle et al., 2012). The literature contains a number of interesting reports dealing with the application of co-digesting sewage sludge with other substrates such as crude glycerol (Fountoulakis et al., 2010), animals manure (Hassan, 2014) as well as agriculture wastes (Komatsu et al., 2007; Rughoonundun et al., 2012). While anaerobic co-digestion has been studied and practiced for a broad range of sewage sludge, however very few studies have been conducted on the co-digestion of sewage sludge and municipal solid waste as a co-substrate (Gomez et al., 2006; Agdag and Sponza, 2007; Lebiocka and Piotrowicz, 2012) and in these studies modelling of biogas production was not carried out. To bridge the existing gaps in the field of study, this work investigated the combined anaerobic digestion of cow dung slurry, municipal sewage sludge and combined municipal organic solid waste. For this purpose, biogas production rates were modelled using nonlinear and exponential equations. In addition, biogas production accumulation was simulated by transference function, modified Gompertz equation and logistic function, respectively. This solution will allow developing a cow dung, sewage sludge, and municipal waste co-utilization technology enabling the production of bioenergy and wastes utilization.

## 2. Material and Methods

MSW was taken as the substrate for this experiment. The Solid wastes were collected from Chidambaram municipality dumpsite, Tamilnadu, India. Only the combined OMSW was taken for feedstock. Non-biodegradable fraction of waste such as plastics, tin cans, bulky and inert materials was separated by manual segregation that could otherwise hamper the digestion process. The collected waste was thoroughly mixed to ensure homogeneity. The wastes were segregated and shredded, then thoroughly mixed several times and kept at room temperature until used.

Inoculum source is a very important operational parameter. The percentage of inoculation for acidogenic process of organic municipal wastes is approximately 30% (w/w) (Carreiro et al., 2006). The inoculum used in this study contains all the required microbes necessary for anaerobic digestion process. The inoculums were collected from nearby farm(cow dung) and sewage treatment plant(sewage sludge), kept at 4°C. The pH, total solids and volatile solids of the inoculum were analyzed.

### 2.1 FEASIBILITY OF SEED PRE-DIGESTION

To investigate the feasibility of pre-digesting the inoculum before being used in the batch reactors, the collected inoculums were stored in the laboratory under strict anaerobic conditions without substrate mixing at 32°C.

### 2.2 BATCH STUDY FOR AD OF MSW AT MESOPHILIC TEMPERATURE

The study was carried out with two different inoculum sources under anaerobic condition cow dung slurry and sewage sludge. The study was programmed to optimise the mesophilic digestion of MSW at three different initial inoculum concentrations (10%, 20%, 30%) and one control reactor Rc (0 %,) without inoculum. The inoculum concentration was expressed as ratio of weight of solids to total volume of solids plus water, assuming that the density of the solid is equal to the density of water. six (6) reactors were operated with different inoculums cow dung slurry (R1, R2and R3), sewage sludge (R4, R5and R6), Liquid samples were drawn from the reactors periodically and various parameters such as pH, volatile fatty acids, alkalinity, VSS and chemical oxygen demand were analysed. Once in 3 days, the pH was measured to maintain it in the range of 6.8 to 7.3 using 4M-Sodium Hydroxide solution. Daily biogas productions were measured using water displacement method. The substrate was mixed once in a day, at the time of the gas measurement, to maintain close contact between the substrate and microorganisms. All the manipulations were conducted under sterile conditions and experiments were carried out in triplicate gas measurement. Based on this batch study, the maximum biogas producing inoculums was considered for further study.

### 2.3. BIOGAS PRODUCTION SIMULATION

The study of the biogas production kinetics for the description and evaluation of methanogenesis was carried out by fitting the experimental data of biogas production to various kinetic equations. Biogas production rates of MSW co-digested with cow dung slurry and sewage sludge was simulated using exponential and Gaussian plots. The exponential plot for the ascending and descending limb can be presented by Eq. (2) (De Gionnis et al., 2009). Here it is assumed that biogas production rate will increase exponentially with increase in time and after reaching the high point it would decrease to zero exponentially with increase in time.

$$y = a + b \exp(ct) \quad \text{Eq. (2.1)}$$

Where, y, biogas production rate in ml/gmvs; t, time in day for digestion; a andb (ml/gmvs) are the constants; c = constant (day-1). For the ascending limb, c is positive and it is negative for the descending limb. In addition, cumulative biogas production was simulated using logistic kinetic model, exponential rise to maximum and modified Gompertz kinetic model. Logistic kinetic equation is shown in Eq. (3):

$$M = a\ 1 + b \exp(-kt)) \quad \text{Eq. (2.2)}$$

Where, M, cumulative biogas production (ml/gmvs); k, kinetic rate constant (day-1); t = hydraulic retention time (Days); a,b are the constants. Exponential rise to maximum is presented in Eq. (4) (De Gioannis et al., 2009; Lo et al., 2010):

M= A(1− exp(−kt)) Eq. (2.3)

Modified Gompertz kinetic model equation is a modified form of the Gompertz equation which is commonly used to simulate the cumulative biogas production (Lo et al., 2010). This model assumes that cumulative biogas production is a function of hydraulic retention time. The modified Gompertz equation can be presented as follows (Budiyono et al., 2010; Yusuf et al., 2011):

M =P exp {− exp [Rm*e/P (λ − t) + 1]} Eq. (2.4)

Where, Mis the cumulative of the specific biogas production (ml/gmVS), Pis the biogas production potential (ml/gmVS), Rm is the maximum biogas production rate (ml/gmVs/day), λ is the lag phase period or the minimum time required to produce biogas (day). Model and equations are presented in Table 3.1.

Table 2.1 Model and Equations

| Model | Equation | |
|---|---|---|
| Modified Gompertz Equation | $M = P \times \exp\left\{-\exp\left[\frac{R_m \times e}{P}(\lambda - t) + 1\right]\right\}$ | Eq. (2.5) |
| Transference Function | $M = P \times \left\{1 - \exp\left[-\frac{R_m(t-\lambda)}{P}\right]\right\}$ | Eq. (2.6) |
| Logistic Function | $M = \frac{P}{1 + \exp\left[4R_m(\lambda - t)/P + 2\right]}$ | Eq. (2.7) |

For the present investigation, three models were used to estimate the performance parameters. The logistic function corresponds to established trends of biogas production kinetics: an initial exponential increase and a final stabilization at a maximum production level. Moreover, the logistic function is based mainly on four assumptions and is designed to be as simple as possible in order to avoid unidentifiable parameters (Bhatta et al., 2015). Similarly, the modified Gompertz equation can be used to analyze methane production; however, the three parameters of this model were restricted to specific experimental conditions and cannot be used in a predictive mode (Ye et al., 2015). The transference function predicts maximum gas production solely based on CH4production (Pommier et al., 2007). In this study, after obtaining cumulative biogas production curves over time from the Anaerobic Digester (AD) tests, the parameters for each model were estimated by non-liner regression using EXCEL software. The modified Gompertz equation, logistic function and transference function constant parameters methane production potential (P), maximum rate of methane production (Rm) and duration of the lag phase (λ) were determined. Several simulations were performed to identify the best fitting between experimental and modelling data. In particular, the disintegration kinetic constant Ksbk (ML-2T-1) was changed several times in the model to estimate the value that permits the fitting of experimental data. The calibration was performed by comparing the model results with experimental data of cumulative biogas production for different inoculums and to define the unknown parameter by fitting experimental data with model results. The calibration procedure proposed by Espositoet al., (2011b) was used. The comparison between experimental data and model results was performed by applying the Root Mean Square Error (RMSE) (Esposito et al., 2011b; Janssen and Heuberger, 1995).

## 3. RESULTS AND DISCUSSIONS

After studying the various parameters of all varying inoculums concentration substrates of municipal solid waste, it was observed that the methane generation was lowest in Rc. The study revealed that the gas generation was directly based on the inoculums concentration and initial characteristics of the substrates. The results indicate that the cow dung slurry and sewage sludge is the best inoculums source of methane generation due to its biodegradation capacity. Biogas production from MSW was enhanced by adopting biotechnological applications. Fig. 3.1 shows the cumulative biogas readings for reactors R1, R2, R3, R4, R5 and R6 was obtained as 337.365ml/gVS, 481.95ml/gVS, 567ml/gVS, 214.775ml/gVS, 321.198ml/gVS, and 383.52ml/gVS, respectively. This result implies that effective for the production of biogas from the reactors R3 and R6, gave the best result with cumulative biogas volumes.

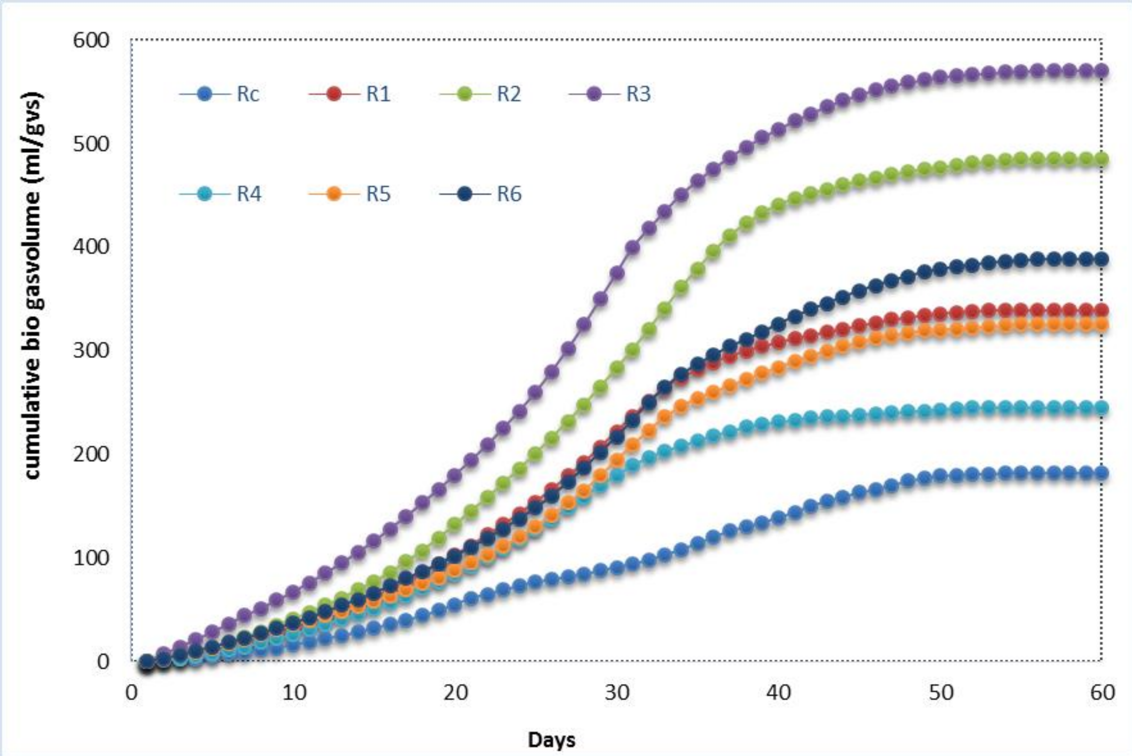


Fig. 3.1 Cumulative Biogas Production of varying inoculums concentration

### 3.1 MODELLING

The kinetic study results obtained from experimental data can be used for estimating biogas production of full scale reactors with similar operational conditions. This research was carried out to treat MSW using an anaerobic batch process in order to determine the process of kinetics and also generate biogas. To fulfil the existing gaps in the field of study, this work investigated the effects of various inoculums with different concentrations on the digestion of MSW as a substrate. For this purpose, biogas production rates in varying inoculums concentration and corresponding parameters were modeled using nonlinear equations. In addition, biogas production accumulation was simulated using transference function, modified Gompertz equation and logistic function plots. The kinetics of biogas production was studied by developing the equation closest to fundamental for biogas production in batch system. Kinetic constants of P, A, and λ, can be determined using nonlinear regression from equations (2.5, 2.6 and 2.7). In this study, data obtained were solved numerically using nonlinear regression. Kinetic constants relate cumulative biogas production and the time of digestion through biogas yield potential (P), the maximum biogas production rate (Rm) and the duration of lag phase (λ) R2, RMSE values obtained from different inoculums are completely presented in Table 3.1. By plotting experimental data of cow dung inoculum reactor and simulation of the transference function, modified Gompertz equation and logistic function equation (equations 2.5, 2.6 and 2.7) as depicted in Figs. 3.4 and 3.5. It has been observed that the cumulative biogas production was fit with the experimental and the predicted values of model equation as it was evident from the correlation coefficient R2 (0.9838, 0.9286, 0.9682). There was an overall agreement between the models and the experimental data. The best fit was obtained using the modified Gompterz equation, which gives the highest regression of coefficients in all cases (> 0.9838). In case of cow dung inoculum reactor, biogas production potential (P, in mL/gvs) was ranked as follows: transference function (628.06), logistic function (585.22) and modified Gompertz equation (577.23). Maximum specific biogas production rate (Rm, in mL/gvs) was ranked as follows: logistic function (42.84)> transference function (26.87) > Gompertz equation (22.05). The lag time (λ) was (15.58, 5.20, 4.28) in the cases of the logistic function, modified Gompertz equation and transference function respectively. From this table the observations of RMSE values concluded that modified Gompertz equation, gives comparable prediction with a lowest RMSE value of (0.0181). Based on RMSE value the modified Gompertz model was best fit compare then other models. In addition, biogas accumulation was simulated by exponential rise (nonlinear) to maximum as well as modified Gompertz equations which were commonly used in the simulation of methane and hydrogen production (Altas, 2009; Li and Fang, 2007; Lin and Shei, 2008; Wang and Wan, 2009). So far the investigations using cow dung, sewage sludge, sugar factory waste,milk and dairy product waste for co-digestion or co-disposal with MSW have rarely been undertaken (Demirel, et al., (2010) Nwabanne, et al.,(2009) Nweke et al., (2014) Igoni,et al.,(2008). Mathematical modelling and kinetics is necessary for the design of reactors to be used for AD(Prats and Rodriguez, 1992; Smith et al., 1998). Nwabanne and his co-workers studied the kinetics for the AD of MSW by considering the growth kinetics and substrate utilization.

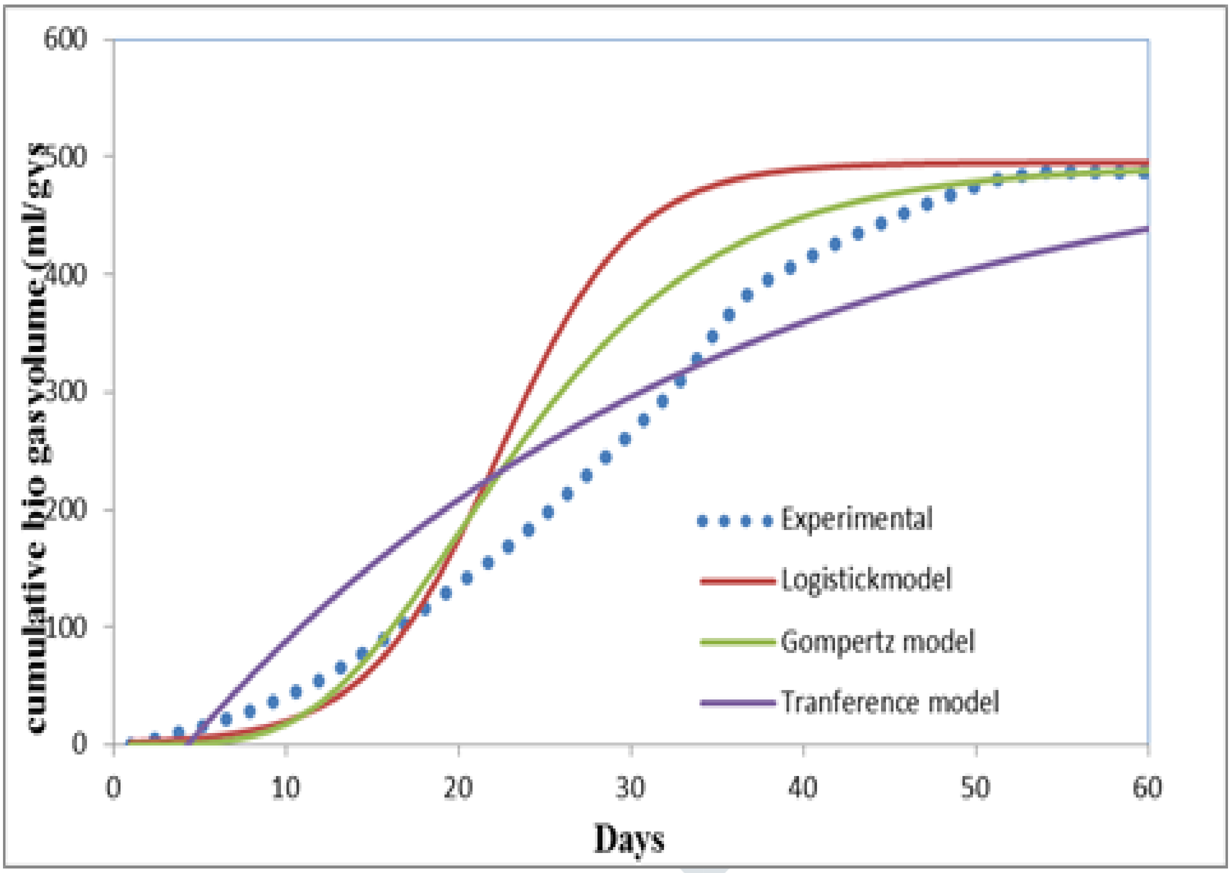


Fig. 3.2 Simulated data (line) and experimental data (points) of Cumulative Biogas Production from MSW with Cow Dung

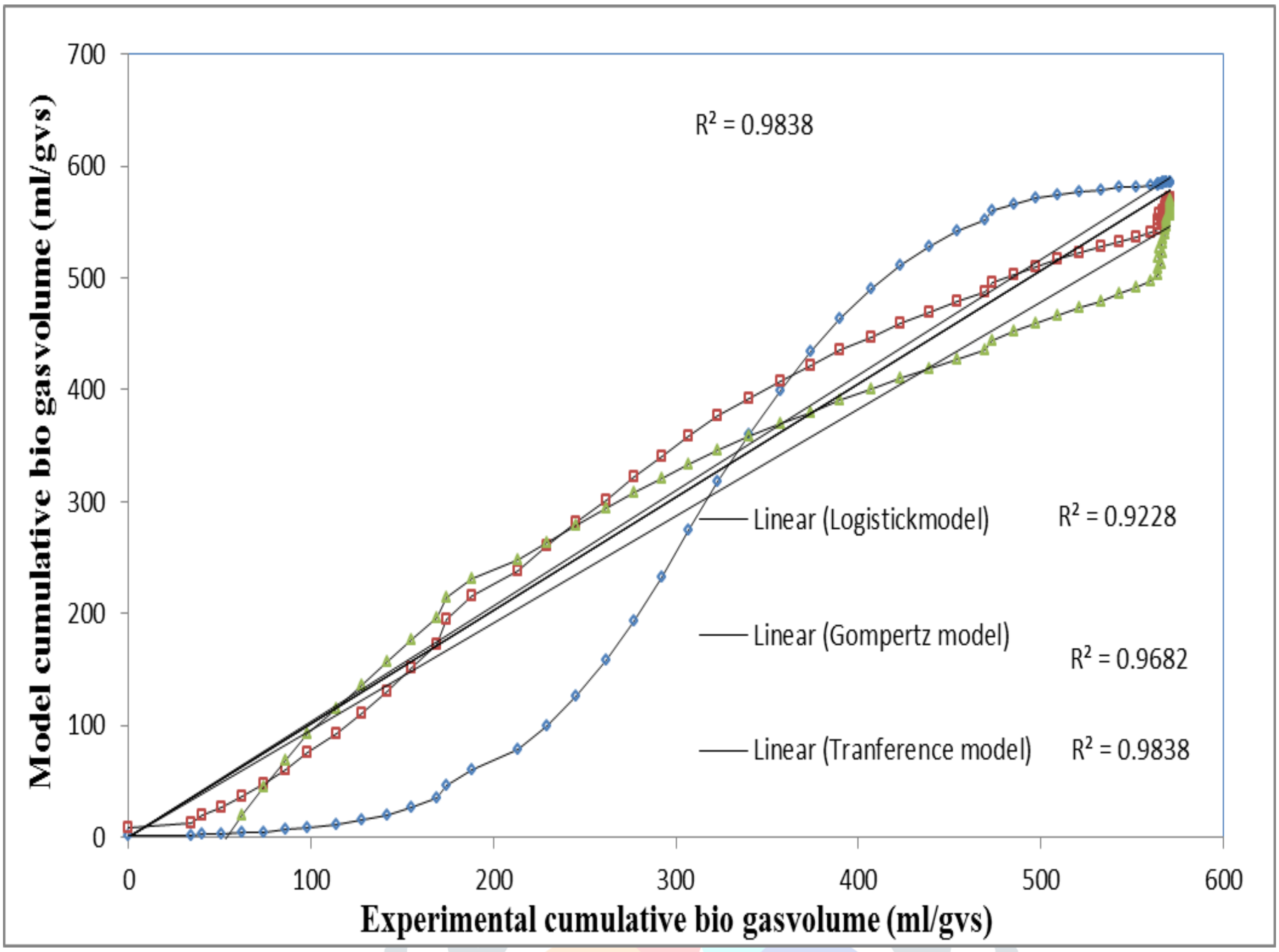


Fig. 3.3 The Correlation Coefficients (R2) for Experimental Data and Simulated Data (Cow Dung as Inoculum

Table 3.1.Parameters and Conformance to the Evaluated Models

| S.No. | Sample | Model | P (mL/(g·VS) | Rm (mL/(g·VS) | λ (day) | $R^2$ | RMSE |
|---|---|---|---|---|---|---|---|
| 1 | cow dung | Gompertz equation | 577.23 | 22.05 | 5.2 | 0.9838 | 0.0181 |
| | | Logistic function | 585.22 | 42.84 | 15.58 | 0.9286 | 0.0261 |
| | | Transference function | 628.06 | 26.87 | 4.28 | 0.9682 | 0.0211 |
| 2 | Sewage sludge | Gompertz equation | 393.23 | 20.05 | 9.2 | 0.9669 | 0.0214 |
| | | Logistic function | 395.22 | 35.84 | 10.58 | 0.9633 | 0.0218 |
| | | Transference function | 478.02 | 21.87 | 4.6 | 0.8621 | 0.0342 |

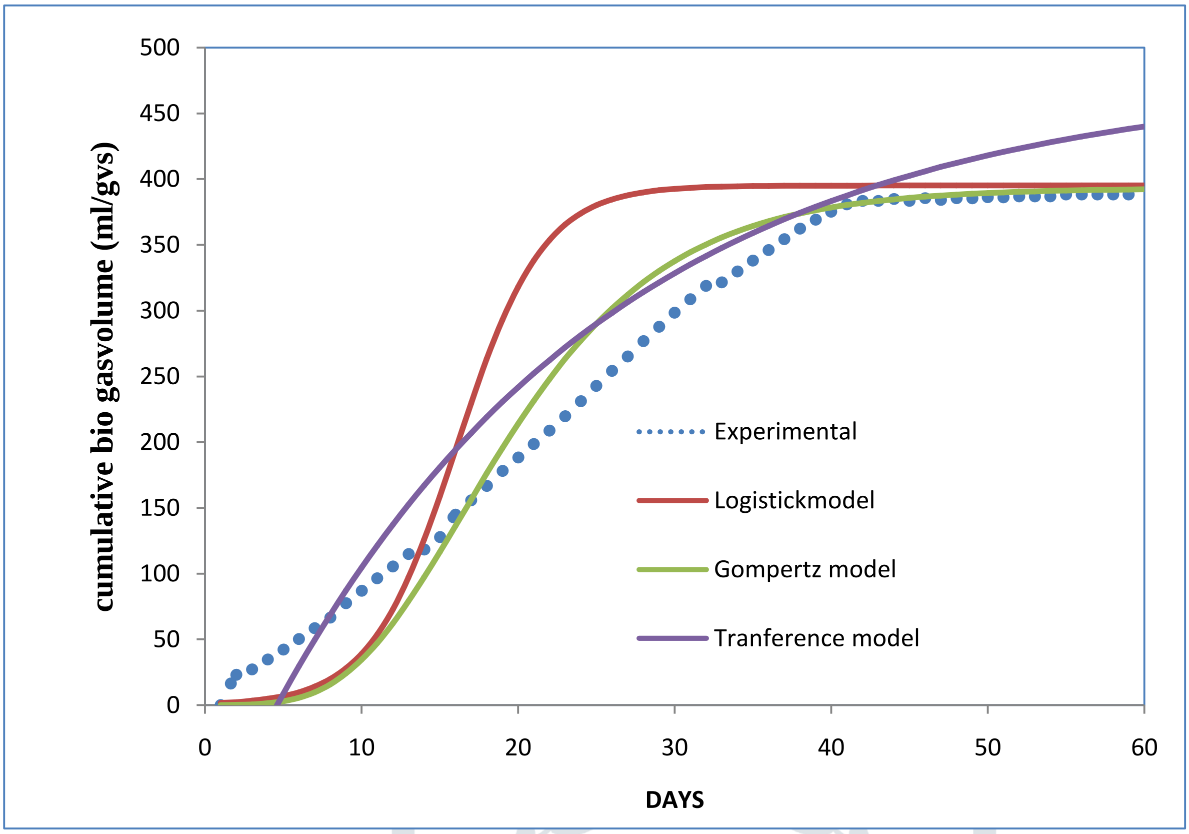


Fig.3.4 Comparison of Cumulative Biogas Production from Sewage Sludge (Simulated Data (line) and Experimental Data (points))

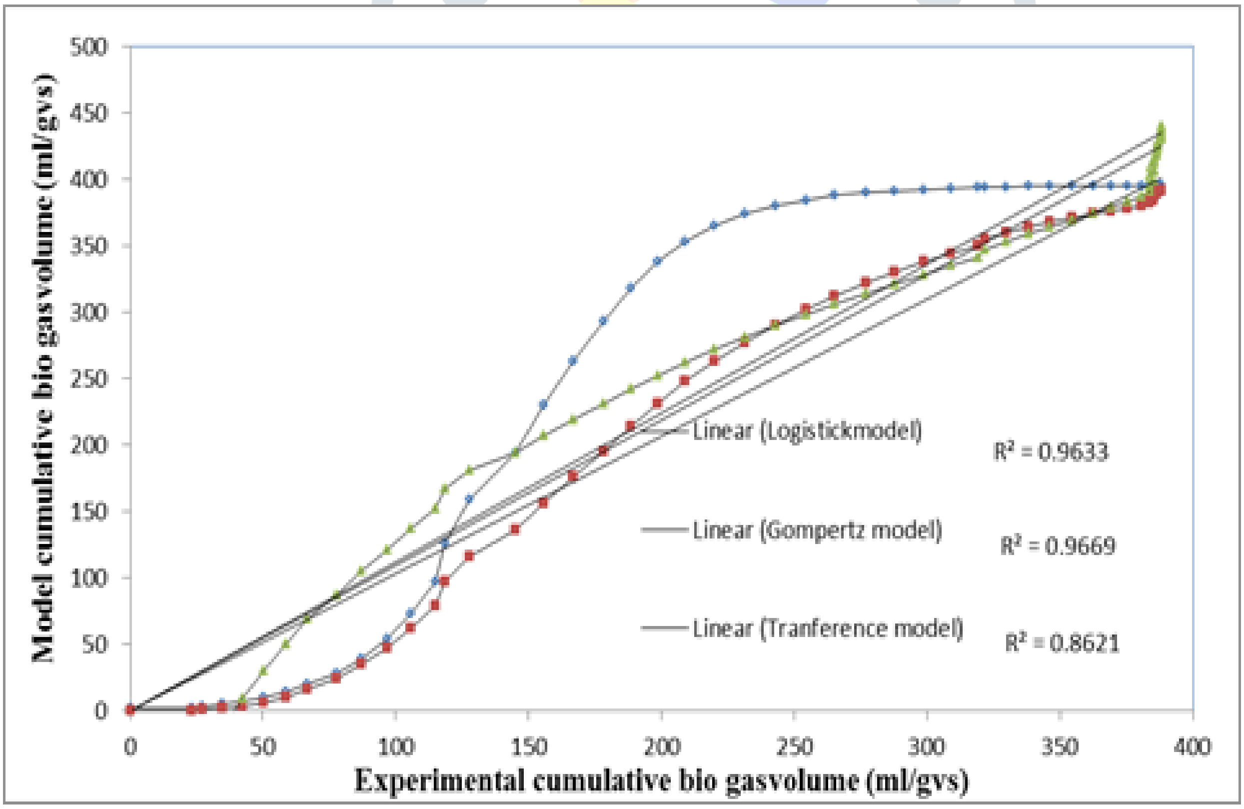


Fig. 3.5 The Correlation Coefficients (R2) for Experimental Data and Simulated Data (Sewage Sludge as Inoculum)

From Figs. 3.4 and 3.5 the Kinetic constants relate cumulative biogas production and the time of digestion through biogas yield potential (P), the maximum biogas production rate (Rm) and the duration of lag phase (λ), $R^2$, and RMSE values obtained from sewage sludge as inoculumn. The cumulative bio gas yield potential(P), was 393.23, 395.22 and 478.02 mL/g.vs . The maximum specific biogas production rate (Rm, in mL/(g·VS·day) was (20.05,35.84,21.87) and the lag time (λ) was (15.58, 5.20, 4.28). Furthermore, the correlation coefficients ($R^2$) of nonlinear analysis were (0.9669, 0.9633, and 0.8621) in the cases of the logistic function, modified Gompertz equation and transference function respectively. The best consistency was obtained RMSE(0.0214) in the modified Gompertz equation.

## 4. Conclusions

From the results obtained, it can be concluded that digesters should preferably be run under ambient temperature with a digestion time close to 60 days for optimum energy yield. Biogas production from Municipal Solid Wastes inoculated with cow dung slurry and sewage sludge, was established in this research work to be feasible at room temperature. This gives positive attribute towards a search for Sustainable Renewable Energy Source to substitute the fast depleting fossil fuels. The best performance of biogas generated was observed in reactor R3, subsequently followed by, R6, (567 > > 383.52 ml/gvs). Based on this result, the observation made was validated using, simulation of the transference function, modified Gompertz equation and logistic function equation. This model best describes the cumulative biogas produced as a function of time. Modified Gompertz plot had higher correlation than other plot for simulating cumulative biogas production.

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