# A Comparative Experimental Study on the Effect of Third Generation Biomass on Biogas Production

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***Abstract:* - The pursuit of sustainability and reduction of green-house gas emission has led to increased interest in alternative energy sources. Anaerobic digestion of biological substances is a process that utilizes biomass in a four-stage biodegradation to yield biogas which comprises mainly $CO_2$ and $CH_4$ and traces of other gases in minute quantity and can be used as energy source for cooking, lighting and fuel for automobile engines.Biogas can be obtained from various plant and animal waste but this research examines the production from POME and a blend of POME and Algae in varying proportions. The algae were pre-treated and both samples finely crushed to improve the degradability before chemical analysis (such as the moisture content and the percentage of volatile solid in the samples) was carried out.The experimental set up comprises three digesters labeled A, B, C and D containing POME and algae blend in the ratio of 100%:0%; 50%:50%and 66.6%:33.3% respectively. Daily production for a 20day period was examined and the biogas kinetic model for evaluating production yield developed from the mass balance equation was used to validate the experimental results. A lower retention time was observed for digester B compared toC and A respectively but the cumulative yield over the given time periodfor B compared to C and A. This indicates that Algae; a third-generation biofuel can be used to improve the performance of POME in biogas production.**

***Keywords:* Biomass, Biogas, Algae, Anaerobic digestion, Methane.**

## I. INTRODUCTION

The drift in attention from fossil fuel to renewable energy sources to meet with individual and societal energy demands in the last decades has led to intensive research on methods of harnessing and improving these renewable energy techniques. Anaerobic digestion of biomass (plant and animal products including their waste) is a process that leads to the release of gaseous substance known as biogas which comprises basically methane ($CH_4$) 60-70%, carbon dioxide ($CO_2$) 30-40% and other trace gases like nitrogen ($N_2$) Ammonia ($NH_3$) and oxygen ($O_2$) [1]-[3].AD process involves three, major stages which are hydrolysis (microbial breakdown of macro-molecules into micro-molecules) acidogenesis, (microbial conversion of the glucose generated from the hydrolysis phase to acetic acid) and methanogensis (which involves the conversion of volatile acid to $CH_4$ and $CO_2$ and other trace gases called biogas). Biogas can be used domestically for cooking, lighting purposes and also as fuel for automobile engine when purified and compressed. Studies have shown that, the biogas production potential as well as the methane composition is a function of the of biomass utilize as substrate among other factors such as the temperature, acidity of the slurry, total solid content, etc[4]. Furthermore, the biochemical composition of the substrate in addition to the above listed environmental factors may also affect the rate of biodegradability resulting in difference in hydraulic retention time (HRT) of the production process, therefore, substrate selection for biogas production process especially in cases of co-digestion should be based on knowledge of the biochemical and physiochemical properties of the substrates like the moisture content, fraction of volatile solid carbon to nitrogen ratio (C:N)etc [2]. An optimum C:N of 20-30 has been shown to be suitable for biodegradation since very low or high value is unfavourable to microbial activities resulting in reduction in biogas production yield [8]. Hence, the use of algae in co- digestion with other substrate has been shown to improve the biogas production as a co-digestion substrate with cowdung and palm oil mill effluent (POME) and other biomass since it has a low C:N that improves the C:N value of such blend [6]-[8]. Therefore, this study investigates the effect of algae on biogas production yield in co-digestion with POME at varying algae proportions.

Comprehensive studies have been done on the kinetics of algae in co-digestion with other substrates like cowdung, with rice straw; POME etc. Authors [1],[5],[9],[10] have developed kinetic models for validating and evaluating biogas production yield but in this study, the kinetic model developed from mass balance equation would be used to evaluate the biogas production yield and a model relating proportion of gas produced at any given time was developed to determine the degradability constant k for a given substrate.

## II. MATERIALS AND METHODS

### *A. Substrate Collection:*

The substrate used in this experimental research are POME and algae. The POME was collected from the oil palm mill located at Omuhuewhan community, Aluu in Ikwerri Local Government Area of Rivers State. The POME was taken for analysis of the physiochemical properties before feeding it into the digester. The algae were collected from an abandoned residential site in Rumualogu community in Obio/Akpor Local Government Area of Rivers State after which pre-treatment was done on them bysubjection to heat from boiling water at 100$^0$C for 30minin line with [7]before removal of the attached soil and other particles by decantation and filtration techniques. The surface area of the substrate exposed to biodegradation was increased by grinding into finer particles with the use of manual grinder beforesimilar method of analysis of the moisture content and fraction of volatile solid as well as the C:N ratio was applied as for POME.Table 1 gives the physiochemical properties of the samples.

*B. Experimental design*

The experiment setup comprised a close system biogas reactor designed with internal and external gas storage at the top of the digester and a tire tube respectively with the substrates fed into it in batches. The substrate composition for each of the sample is as shown below.

Sample A: Comprised 100% POME (that is, 24L of POME slurry)

Sample B: Comprised 50% POME and 50% Algae (8Kg of algae in 4L of water making 12L of algae slurry and 12L POME)

Sample C: Comprised 66.3% POME and 33.3% Algae. (that is, 12L of POME and 4Kg of algae in 8L of water making 12L of slurry).

## III. RESULTS AND DISCUSSION

*A. Experimental Results*

The daily biogas production yield for a 20-day period for the three samples are shown in Fig 1. The production yield curve for each of the samples as shown in Fig 1 is similar for all three samples with difference in the drift from the origin indicating different hydraulic retention time(HRT) (the delay in production commencement accounting for microbial activities from biodegradation to gas production). The production commencement period for samples A, B and C were observed to be 5days, 3days and 4 days respectively with a corresponding volume yield of 7.04L, 11.84L and 10.36L.The production profile curve depicts a more stable production from start-up to end for sample C followed by B then A; however, in terms of production potential, sample B performed better followed by C then A.

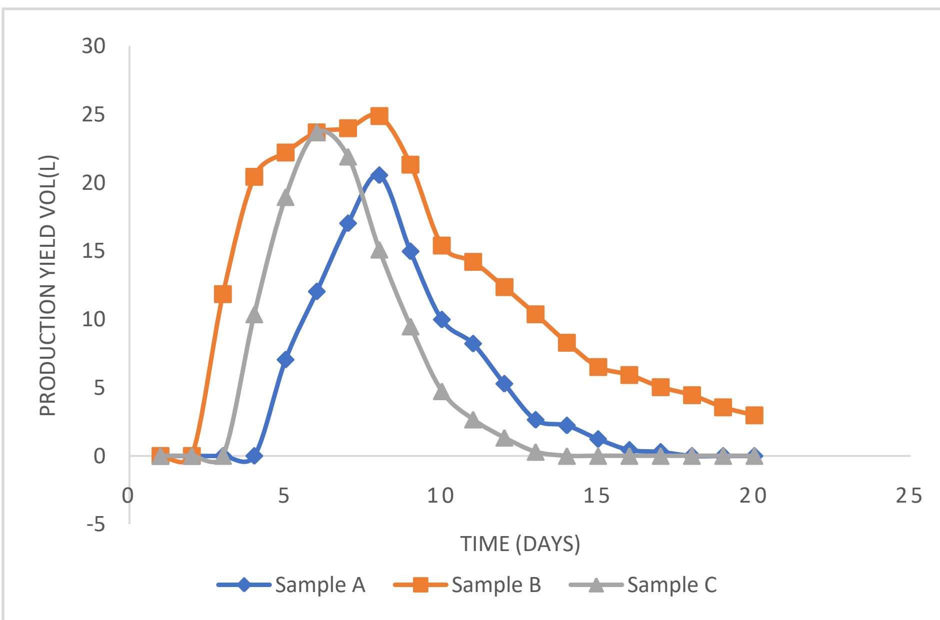


Fig. 2: Daily biogas production in volume

Maximum production volume was observed for sample B, C and A on day 8, 8 and 7 with a corresponding value of 20.53L, 24.86L and 21.9L while production was observed to end on day 17 and 13 for samples A and B with a corresponding yield of 0.296l and 0.293l respectively but production as at day 20 for sample C was still in progress with a value of 2.96L.In terms of highest biogas potential which is an indication of the production yield value for each sample, B was highest with a value of 236L followed by C and A with values 108L and 101L respectively as shown in Fig 2.This result is an indication that as the amount of algae present in the sample increased the biogas production potential also increased and this can be attributed to the low carbon to Nitrogen ratio value of algae which improves the value of the blend sample when compared with the pure sample and this result is in line with [6].

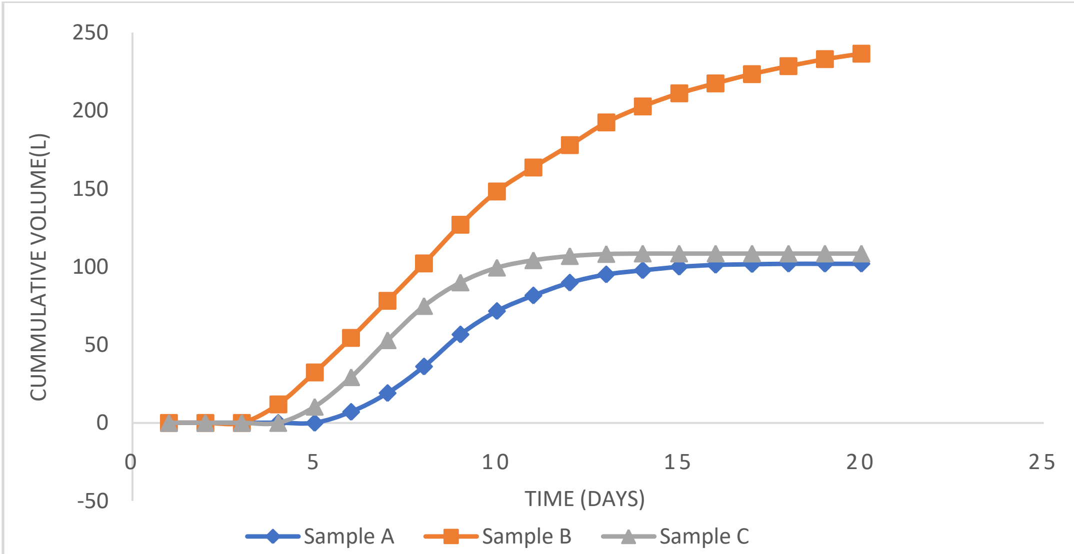


Fig. 3: Cumulative biogas production in volume

*B. Model development*

The evaluation of the biogas production yield at any given time(t) was assessed by the kinetic model using the mass balance equation. In the model development as used by [1] certain assumptions were made such as the system being in steady state condition and all biodegradable substrate is converted to biogas (Although this is not the actual case in a real situation).The mass balance equation which is given by equation (1) with mathematical expression depicted in equation (2) can be used to model the relationship between the biodegradability of the substrate and the biogas production yield at any given time(t).

$$\begin{bmatrix} \text{The rate of} \\ \text{increase in storage of } i \text{ in the cv} \end{bmatrix} = \begin{bmatrix} \text{Net rate of advection} \\ \text{of } i \text{ into the CV} \end{bmatrix} + \begin{bmatrix} \text{Net rate of ormation} \\ \text{of } i \text{ by reaction inside the CV} \end{bmatrix} \quad (1)$$

$$\frac{dVC}{dt} = \sum Q_i C_{i_{inflow}} - \sum Q_i C_{i_{outflow}} + rv \quad (2)$$

The net rate of advection of materials into the controlled volume is neglected since there is no inflow into the controlled volume and the net effect of material outflow is negligible since the produced gas is refrained within the digester as at the period of initial production. Therefore, equation (2) is reduced to equation (3) given below.

$$\frac{VdC}{dt} = rV \quad (3)$$

Where, $C$ is the concentration of the substrate, $r$ is the rate of reaction within the control volume and $V$ is the material volume. Dividing equation(3) through with $V$ and replacing $r$ with $-KC$ gives:

$$\frac{dC}{dt} = -KC \quad (5)$$

Taking the integral from the time production begins to any time (t), we have:

$$\ln \frac{C_t}{C_0} = -Kt \quad (6)$$

The above equation gives a relationship between the substrate degradation in terms of initial concentration of the volatile solid and the volatile solid concentration at any given time without information of the biogas production. A transformation of the biodegradable solids into biogas can be correlated as shown in Fig.3[1], which can further be described by Eq(7) as;

$$\frac{C_t}{C_0} = \frac{y_m - y_t}{y_m} \quad (7)$$

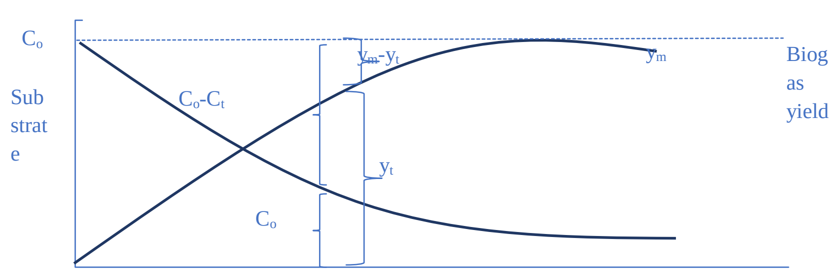


Fig. 3: Pattern of transformation of volatile solid into biogas

$C_t$ and $C_0$ are the volatile solid concentration at any time(t) and the initial concentration of volatile solid respectively. Substituting Eq(7) into Eq(6) and taking the natural logarithm of both sides gives;

$$y_t = y_m[1 - e^{-Kt}] \quad (8)$$

Where;

$y_t -$ biogas production yield at any given time

$y_m -$ maximum biogas production yield

$K -$ degradability rate

$t -$ time under consideration

The above equation can be used to compute the biogas production yield at any given time prior to maximum production (if information about the maximum production yield, the rate constant associated with the degradation is known) in a reactor that is assumed to be in steady state during biodegradation.

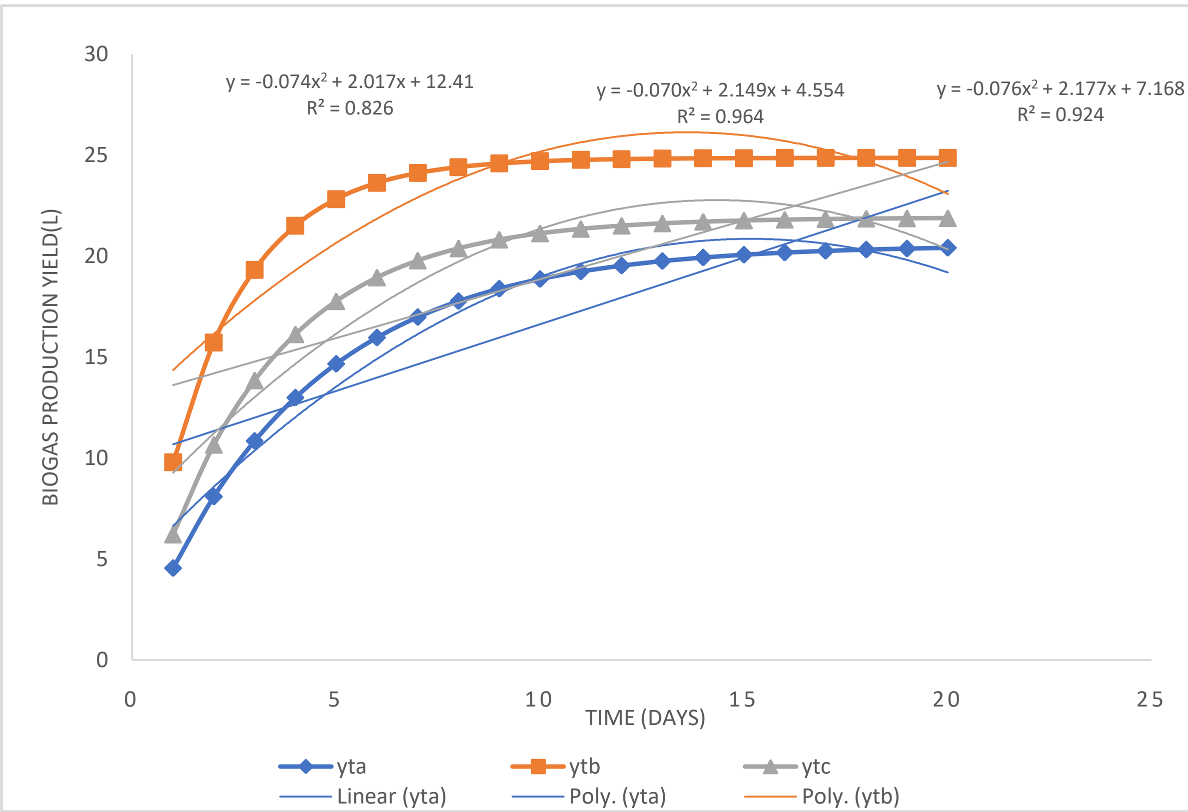


Fig. 4: Model biogas production yield($y_t$) for the three samples

The proportion of gas produce can be estimated from (8) by replacing $y_t$ with $py_m$ and substituting it into (8)

$$py_m = y_m[1 - e^{-Kt}] \quad (9)$$

Dividing (9) by $y_m$ and taking the natural logarithm of both side yields:

$$\ln p = \ln(1) + kt \quad (10)$$

Since $\ln(1) = 0$, (10) reduces to:

$$\ln p = kt \quad (11)$$

The above equation can be considered as a straight-line equation therefore, a plot of lnp against t will result in a straight-line graph passing through the origin with k as the slope. Thus, assuming different proportions of maximum yield produced at different time interval, provides one with charts that can be used to estimate the value of K for any given sample. The plot of lnp against t for the three samples with their respective goodness of fit value as obtained from the MS excel linear regression analysis tool Pak is shown in Fig 5-7.

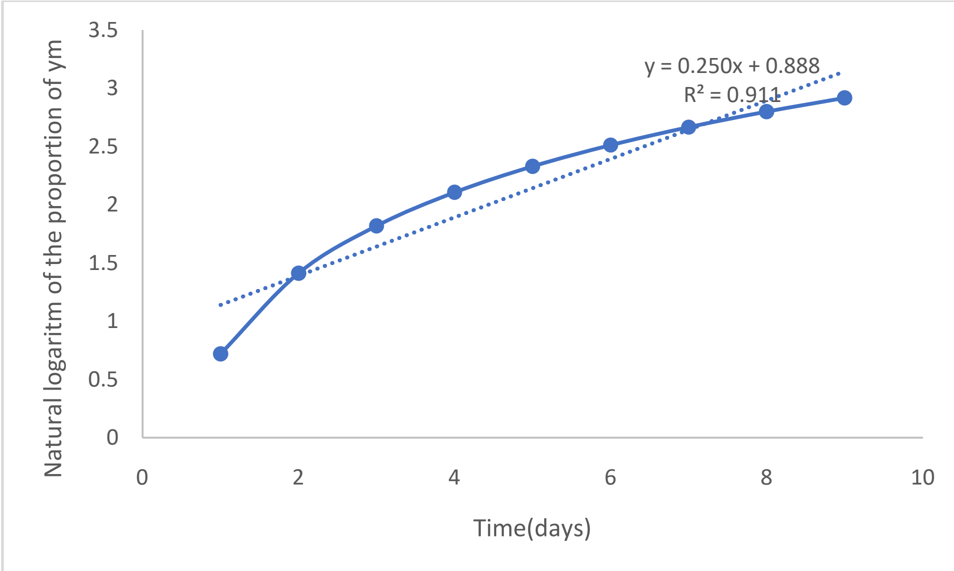


Fig. 5: A plot of lnp against t for sample A

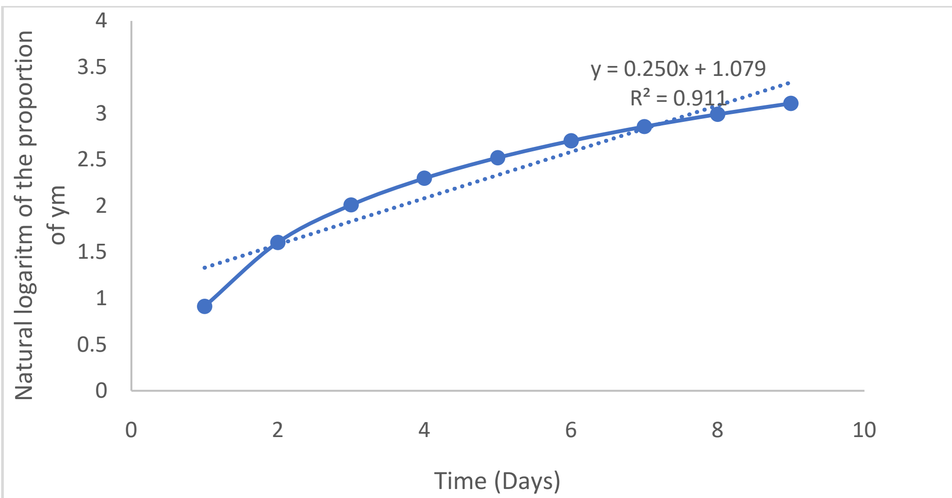


Fig. 6: A plot of lnp against t for sample B

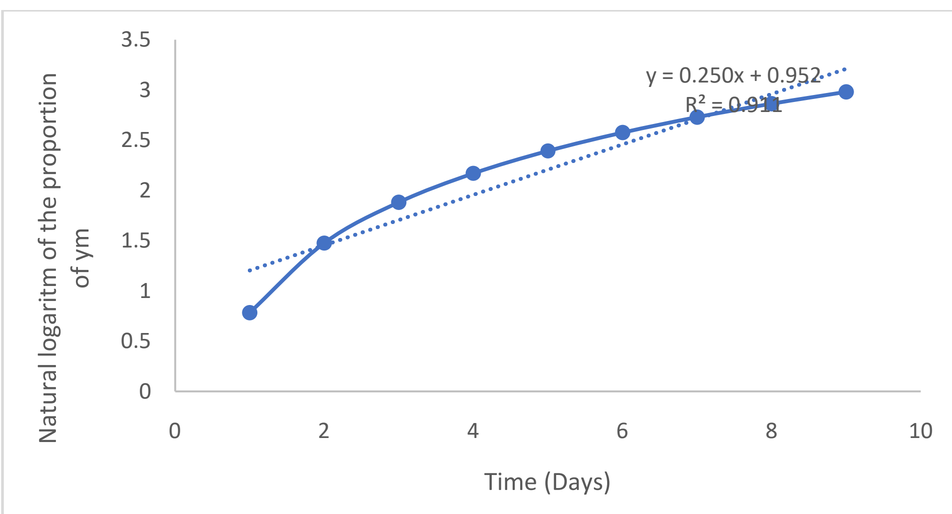


Fig 7: A plot of lnp against t for sample C

The results of the linear regression MS excel plot for the biogas production yield for the three samples gave a goodness of fit value of 0.82, 0.96 and 0.92 for samples A, B and C respectively which is an indication that the model is close approximate of the experimental yield for sample B followed by C then A. Furthermore, examination of the linear equation from the MS excel linear regression analysis plot of lnp against t showed a slope of approximately 0.25, 0.25 and 0.5 for samples A, B and C which according to (11) represent the K value of each of the samples. The model k value for sample A corresponded to the experimental value with slight variation of 0.25 and 0.08 for samples B and C respectively.

## IV. CONCLUSION

The application of algae as co-digestate with POME is a feasible anaerobic digestion process at a blend ratio of 2:1 and 1: 1 because as the proportion of algae in the sample increases the C:N moves closer to the required optimum performance value. A blend ratio of 1:1 which corresponds 50% of POME and 50% of algae in 16l yielded optimal performance in this study. More also, maximum production yield of 20.53L, 24.86L and 21.9Lwas observed for samples B, C and A.

Table 1: Physiochemical Properties of the Samples

| Digester | Weight of POME (Kg) | Weight of Algae (Kg) | C:N | K($day^{-1}$) | $y_m$(l) | $R^2$ |
|---|---|---|---|---|---|---|
| A | 24 | 0 | 36.7:1 | 0.25 | 20.54 | 0.82 |
| B | 12 | 8 | 21.4:1 | 0.5 | 24.86 | 0.96 |
| C | 12 | 4 | 25.3:1 | 0.333 | 21.9 | 0.92 |

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