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Prediction of Biochemical Methane Potential of Palm Oil Mill Effluent

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ABSTRACT

Exploring green energy options constitute a contemporary tenet in designing a sustainable future. This study investigated the independent variables (milling scales, types of fresh fruit bunches and seasons) that define the dynamics of biochemical methane potential (BMP) or bio-methane and organic content in palm oil mill effluent (POME) generated in ADAPALM (large-scale mill) and palm oil mills in its surrounding communities, located in Ohaji/Egbema LGA, Imo State, Nigeria. The eight communities that constitute ADAPALM were categorised into three strata in relation to the number of small-scale mills in each community (1-5mills, 6-10mills, 11-15mills). Besides the lone large and medium-scale mills, a small-scale mill was randomly sampled from a community in each stratum. Four homogenous samples of POME were collected from each mill for laboratory analysis of biochemical oxygen demand (BOD), chemical oxygen demand (COD), total organic carbon (TOC) and total carbon (TC) using standard methods for wastewater analysis. Prediction of BMP for each sample of POME composition and fraction of substrate used for cell synthesis (fs) wherein POME is classified was computed using biogas package. Data was analysed using tools of SPSS. Multiple linear regression reveals that there is a significant relationship between the predicted volume of BMP with milling scales and seasons ($p<0.01$), $R^2=0.927$. Similarly, multivariate analysis of variance (MANOVA) shows that the organic content of POME is significantly related to milling scales and seasons ($p<0.01$). At fs=8% in methanogenic condition, BMP is 22.800±0.282LCH$_4$/m^{3}POME and 75.532±0.149LCH$_4$/m^{3}POME in the wet and dry seasons respectively. These respectively correspond to methane production capacity of 0.057±0.005KgCH$_4$/KgCOD and 0.014±0.001KgCH$_4$/KgCOD. The variance explained by the dependent variable (R^2) indicates the importance of these independent variables in determining the BMP and organic content of POME in the area. The predicted dynamics of BMP and their associated wastewater composition provide useful tools in regulating the wastewater content and evaluating its feasibility for bio-energy development.

Keywords: Dynamics, Bio-methane, Prediction, POME, ADAPALM, Biogas package

1.0 Introduction

Increasing environmental challenges associated with fossil fuel use and achieving energy needs is necessitating green energy options to sustain human progress. Consequently, in some developing countries, wastewater generated in the course of processing crude palm oil, commonly termed palm oil mill effluent (POME) is being transformed through anaerobic digestion to biogas and avert energy insecurity (Chotwattanasak and Puetpaiboon, 2011; Begum and Saad, 2013; King and Yu, 2013). However, the composition of POME varies in space and time, and this composition could be used in determining its biochemical methane potential (BMP) and facilitate planning in waste-to-energy programs (Rupani *et al.*, 2010; Ng *et al.*, 2011; Wang *et al.*, 2015). Studies on anaerobic digestion in determining biogas generation from waste have usually employed pilot and laboratory experiments, as well as theoretical calculations and process modelling (Hafner *et al.*, 2018; Ojo, 2021). The laboratory experiment approach makes use of biochemical methane potential (BMP) tests in order to determine the quantity of methane that can be obtained (Gunaseelan, 2004; Carrere *et al.*, 2016). Theoretical calculations involve transforming laboratory measurements into biochemical methane potential (Shahidul *et al.,* 2018). Several of these models such as Gompertz model equation, modified Gompertz model equation, Vedrenne model, CDM model, COD equivalent model, COD proportional model, modified COD equivalent model have been used to estimate the methane potential of POME and municipal solid waste. The computations involved in these models vary among groups, lack details and reproducibility, as well as characterised with high likelihood of bias in their results (Hafner *et al.,* 2018). Among these models, COD proportional model and modified COD equivalent model have been found relevant and widely used in the estimation of methane potential of POME.

Again, the calculations involved when using the models in the estimation/prediction of methane potential of wastewater are tedious and seldom done (Shahidul *et al*., 2018; Hafner and Rennuit, 2019). Consequently, simple tools that can facilitate design of experiments and optimisation of biogas plants require accurate estimates of BMP of the substrate. In this regard, predicting bio-methane potential of wastewater based on substrate parameters and degradability is well-developed using the biogas package or its web-based interface termed Online Biogas App (O BA) (Hafner *et al*., 2018; Hafner and Rennuit, 2019). The package and its web-based interface is based on the premise of BMP tests and has clarified and standardised the differences among the several models in estimating methane potential (Hafner *et al.,* 2018). Since the biogas package and OBA were uploaded in 2015, there is growing interest in their utilisation in biogas research. There are more than 22,000 downloads in the software and increasing use of the App, hence constituting the contemporary approach in predicting biogas from substrate. According to Holliger *et al.* (2017), the biogas prediction software is being used by 33 institutes as a reference in data processing in a large inter-laboratory study on bio-energy.

The parameters required for prediction could be from defined substrates such as cellulose, wastewater with known content of COD (e.g. POME) and complex substrates with contents such as carbohydrates, protein, lipid, volatile fatty acids (VFA), lignin among others. Other parameters required for the prediction are substrate degradability and substrate partitioning parameters (Hafner and Rennuit, 2019). The substrate degradability is the fraction of the substrate that is completely consumed by bacteria and archaea. The fractions of the substrate that are used for cell synthesis (fs) and energy production (fe) are termed the substrate partitioning parameter; and these parameters (fs and fe) always sum up to unity. While the value of fs varies with substrate content, fs values in wastewater (Figure 1) and methanogenic activities do not exceed 0.08 (Rittmann and McCarty, 2001; Hafner and Rennuit, 2019).

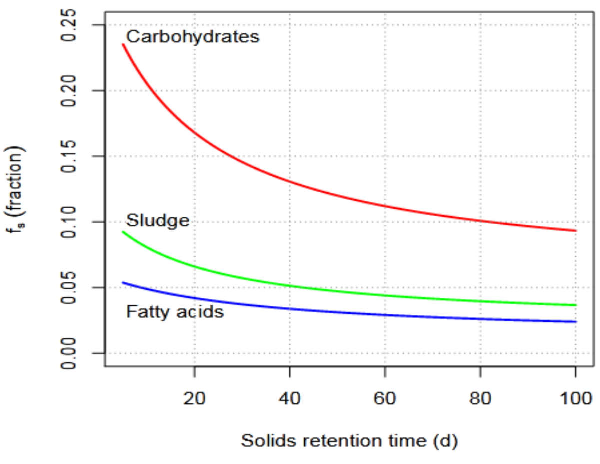

Figure 1: Fraction of Different Substrates used for Cell Synthesis during Anaerobic Digestion.
Source: Hafner and Rennuit (2019).

In Nigeria, crude palm oil production is increasing at the rate of 2.2% annually (Global Palm Oil Conference, 2015). Ohaji/Egbema LGA of Imo State, Nigeria is the home of the largest oil palm plantation, ADAPALM (Agricultural Development Authority Palm) in south-east Nigeria, with a medium-scale mill and several small-scale mills. Tambe *et al.* (2022) have deciphered the dynamics of the volume of POME generated in the area, with this volume significantly increasing with CPO production. Like any other Nigerian community, these palm oil communities celebrate in blackout, though an energy-embedded resource is disposed at their backyard. However, studies that have addressed POME composition and its relationship with types of FFBs, seasons and milling scales with a view of predicting its BMP in the area and planning waste-to-energy have not been uncovered. Following the location specific nature of POME composition, it is imperative to address how the various independent variables related to the wastewater do influence its energy defining parameters. In this regard, the biogas package is employed in this research to predict the bio-methane potential of POME in the study area using the COD content of the wastewater, biodegradability index and the baseline data on substrate partitioning parameters (fs and fe).

2.0 Methodology

The study was carried out in ADAPALM and its surrounding communities located in Ohaji/Egbema LGA, Imo State, Nigeria (Figure 2). The local government area is located between latitudes 5º10'0''N and 5º20'0''N of the equator and longitudes 6º30'0''E and 6º50'0''E. The large-scale processing palm oil industry is housed in eight communities, operating several small-scale mills and a lone medium-scale mill. The communities were categorised into three strata in relation to the number of small-scale mills in each community (1-5mills, 6-10mills, 11-15mills). Besides the lone large and medium-scale mills, a small-scale mill was randomly sampled from each stratum. Four homogenous POME samples were collected from each mill for laboratory analysis of biochemical oxygen demand (BOD), chemical oxygen demand (COD), total organic carbon (TOC), and total carbon (TC) using standard methods for wastewater analysis (American Public Health Association, 1999; Poh *et al.*, 2010; Aziz and Hanafiah, 2017). The BOD was determined using the 5-Day BOD test. Each portion of POME sample for the analysis was made chlorine free and at pH=6.5 - 7.5. The sample was diluted in a specialised 300mL bottle, dissolved oxygen (DO) was measured and sample was allowed for five days in a dark incubator at 20^0C. After the fifth day, the DO was measured again and the difference between the DO was multiplied by the dilution factor to obtain the BOD expressed in mg/L. COD was determined using the Open Reflux Method. POME sample was refluxed in a strongly acidic solution (H_2SO_4) with a measured excess of potassium dichromate ($K_2Cr_2O_7$) for 2hours. After digestion, the excess unreduced dichromate was titrated with ferrous ammonium sulphate (FAS) in order to determine the amount of chromate consumed. The oxidisable matter was computed in terms of oxygen equivalence to determine the COD in mg/L. TC and TOC was determined using High-Temperature Combustion Method. Each POME sample was made homogenous and subjected to a heated reaction chamber of Cobalt Oxide for oxidation. Organic and inorganic carbon (TC) in the sample was oxidised to CO_2, transferred into carrier-gas stream and measured by coulometric titration. Inorganic carbon was removed and measured from TC by acidification. TOC was obtained from the difference in TC and inorganic carbon.

For each sample collected in wet and dry season, its related type of fresh fruit bunch (FFB) and season was recorded. Using the biogas package, the BMP or bio-methane (in volume) content of POME was computed from the input of measured parameters (COD, BOD/COD=BI) and the standard substrate degradability of sludge wherein POME is classified (Hafner and Renuit, 2019). Similarly, the volume of bio-methane predicted was converted to kilogram at standard temperature and pressure (0^0C and 1atm) using the package. Data relating bio-methane and organic content of POME to their independent variables were analysed using tools of SPSS (version 22.0).

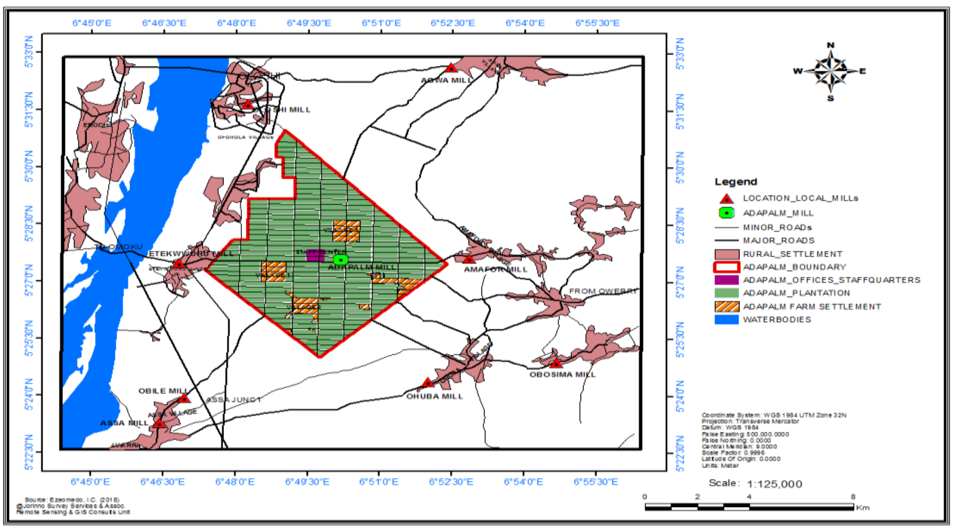

Figure 2: Map of ADAPALM and Surrounding Communities, Imo State, Nigeria

3.0 Results and Discussion

From the results of the laboratory analysis of each sample of POME and its related independent variables (milling scales, types of FFBs and seasons), the biochemical methane potential (BMP) was computed for the sample using the biogas package at fs=0.08 (Tables 1 and 2).

Table 1: Composition of POME and computed methane (L) in the wet season

BOD	COD	TC	TOC	BI (BOD/COD)	MS	TFFBs	BMP (L)
53.1	163.41	3358.1	218	0.325	1	2	0.0171
52.2	163.3	3359.2	147	0.32	1	2	0.0168
63.1	301.8	3519.2	290	0.209	1	2	0.0202
63	301.84	3520.1	293	0.209	1	2	0.0202
56.22	152.14	3345.3	190	0.37	2	3	0.0181
55.1	153.2	3347.4	163	0.36	2	3	0.0178
53.15	167.34	3345.4	245	0.318	1	3	0.0171
52.24	167.36	3240.2	245.2	0.312	1	3	0.0167
62	254.2	3305.5	263	0.244	1	2	0.02
62.61	255.26	3305.9	261	0.245	1	3	0.0201
51.22	171.81	3459.2	162	0.298	1	3	0.0165
51.24	170.84	3457.3	164	0.3	1	3	0.0165
49.64	159.23	2566.8	292	0.312	1	3	0.016
50.11	160.2	2560.2	290	0.313	1	3	0.0161
50.21	266.12	3165.1	368	0.187	1	1	0.016
52.32	267.12	3166.3	286	0.196	1	2	0.0168
36.5	557.17	3526.1	163	0.066	3	2	0.0118
36.06	652	3611.7	218	0.055	3	2	0.0115
45.51	612.52	3425.5	136	0.074	3	2	0.0145
41.25	635.15	3430.4	143	0.065	3	2	0.0132
56.1	152.3	3348.3	182	0.368	2	3	0.018

MS (Milling scale): 1,2,3=small, medium and large-scale mills respectively. TFFBs (Types of fresh fruit bunches): 1,2,3=Duru, Tenera and Mixed (Duru/Tenera) variety respectively. All values of POME composition are in mg/L.

Table 2: Composition of POME and computed methane (L) in the dry season

BOD	COD	TC	TOC	BI (BOD/COD)	MS	TFFBS	BMP(L)
260	4800	24734.15	1591.89	0.054	1	2	0.0834
250	4600	28841.97	1761.09	0.054	1	2	0.0799
200	3600	6144.23	255.35	0.056	3	2	0.0648
190	3100	233.62	0.97	0.061	3	2	0.0608
220	3300	4981.74	141.98	0.067	1	3	0.071
230	3500	7051.7	211.06	0.066	1	2	0.0742
240	3600	4041.13	125.71	0.067	1	1	0.0776
190	3100	420.83	1.645	0.061	3	2	0.0608
180	2900	248.13	0.295	0.062	3	2	0.0578
230	3700	10030.97	565.847	0.062	1	3	0.0737
210	3600	16945.95	896.78	0.058	1	3	0.0672
220	3500	14225.53	677.989	0.063	1	3	0.0708
250	4700	28567.48	1777.469	0.053	1	2	0.08
270	4700	25484.58	1717.701	0.057	1	2	0.0861
230	3400	3610.52	111.998	0.068	1	3	0.0743
360	3600	15431.28	795.328	0.1	1	3	0.1159

MS (Milling scale): 1,2,3=small, medium and large-scale mills respectively. TFFBs (Types of fresh fruit bunches): 1,2,3=Duru, Tenera and Mixed (Duru/Tenera) variety respectively. All values of POME composition are in mg/L. No data for medium-scale mill was available in the dry season due to shutdown of the plant prior to the end of the study.

The computed BMP is analysed in relation to milling scales, types of FFBs and seasons. Multiple linear regression reveals that there is a significant relationship between volume of methane generated by POME with milling scales and seasons ($p<0.01$) (Table 3). With reference to the large-scale mill (redundant category), small-scale mills tend to significantly ($p<0.01$) increase the volume of bio-methane generation by 0.013L, while medium-scale mill tend to indicate no significant increase ($p>0.05$) in bio-methane generation. Similarly, with reference to the dry season, the volume of bio-methane tends to significantly ($p<0.01$) reduce by 0.059L (hence negative value) during the wet season. On the contrary, the types of FFBs tend not to significantly ($p>0.05$) influence the volume of bio-methane generation. With reference to mixed variety of FFBs, Duru variety, tends to reduce the volume of methane generation of POME by 0.001L while Tenera variety tends to increase it by 0.002L. However, this decrease and increase are not significant ($p>0.05$). The variation of the dependent variable explained by the model is 92.7% (R^2=0.927). These independent variables, therefore are contributing immensely to the parameters that determine the content of bio-methane in the substrate. Thus, other characteristics of the FFBs (number of unripe nuts, rotten nuts, duration between harvesting and processing), milling process among others could be accounting for the other 7.3% variance of the dependent variable.

Table 3: Volume of methane generation of POME in relation to milling scales, types of FFBs and seasons

Parameter	B	Std. error	T	Sig. (p-value)
Intercept	.065	.005	13.822	.000
Small-scale mill	.013	.004	3.278	.003
Medium-scale mill	.012	.007	1.812	.080
Large-scale mill	0^a	.	.	.
Duru variety	-.001	.006	-.158	.875
Tenera variety	.002	.003	.495	.624
Duru/Tenera (mixed) variety	0^a	.	.	.
Wet season	-.059	.003	-20.726	.000
Dry season	0^a	.	.	.

a: This parameter is set to zero because it is redundant. (Adjusted R^2=0.927). B: The regression coefficient and it is the estimated value of methane generation for a unit change in each of the independent variables. T: This measures the significance of the regression- the regression is significant when T is greater than the critical value at a given level of significance (p=0.05 or 0.01) and degree of freedom (df). It is the F equivalence in ANOVA.

The relationship between volume of bio-methane generation by POME with milling scales and seasons could be attributed to the variation of the parameters (COD and BI) and other interconnected parameters (organic content) that bio-methane potential depends on. Examining and analysing these parameters (BOD, COD, TC, TOC, BI), multivariate analysis of variance (MANAOVA) reveals that the bio-methane determining parameters of POME are also significantly related to milling scales: Wilks' Lambda=0.268, F(10,54) =5.024, p=0.000; and seasons: Wilks' Lambda=0.009, F(5,27)=602.462, P=0.000. Similarly, like the determinants of bio-methane generation, these parameters are not significantly related to types of FFBs: Wilks' Lambda=0.571, F(10,54)=1.747, P=0.094 (Table 4). The proportion of variance (Wilks' Lambda) in POME composition that is not accounted for by intergroup variations is quite small for milling scales (0.268) and seasons (0.009) relative to types of FFBs (0.571). Therefore, types of milling scales and seasons are important independent variables to be considered when addressing the composition dynamics of BOD, COD, TC, TOC, BI and their implications on bio-methane content in POME.

Table 4: Relationship between organic content of POME and milling scale, types of FFBs and seasons

Effect	Value	F	Hypothesis df	Error df	Sig. (p-value)
Milling scales Wilks' Lambda	0.286	5.024	10	54	0.000
Types of FFBs Wilks' Lambda	0.571	1.747	10	54	0.094
Seasons Wilks' Lambda	0.009	602.462	5	27	0.000

Post hoc analysis using Duncan Multiple Range Test (DMRT) shows significant difference of some of these parameters in the wastewater across milling scales (Table 5). This could be attributed to all techniques related to processing, such as volume of water use, removal of empty fruit bunches (EFBs) and variability of deposits of plant materials in the wastewater.

Table 5: Organic content of POME across milling scales

Parameters	Milling scales		
	Small-scale	Medium-scale	Large –scale
BOD	143.610^a	55.807^b	114.915^{ac}
COD	1921.917^a	152.547^b	1894.605^{ac}
Total carbon	8818.288^{ab}	3347.000^{bc}	2630.064^{ac}
Total organic carbon	534.579^{ab}	178.333^{bc}	114.783^{ac}
BI (BOD/COD)	0.175^a	0.366^b	0.063^c

a, b, c: Means with similar or overlapping subscripts indicate no significant difference. Mean value of POME composition is statistically significant at p=0.05 using Duncan Multiple Range Test (DMRT) for pairwise comparison

Independent sample T-test reveals that the mean values for each of these organic parameters of POME are statistically highly significant ($p<0.01$) across seasons (Table 6). Across seasons, the palm fruit strives more in the dry season compared to the wet season and this subsequently produce more organic matter in the wastewater during fresh fruit processing. Increasing organic matter in the dry season for POME in the study area tends to enhance bio-methane availability; hence this explains the significant increase in the predicted bio-methane production in the dry season (Table 3).

Table 6: Organic content POME across seasons

Parameters	Seasons		p-value
	Wet (Mean±SE)	Dry (Mean±SE)	
BOD	52.042±1.669	233.125±10.674	0.000
COD	280.205±38.059	3731.250±154.574	0.000
Total carbon	3303.010±59.112	11937.113±2581.601	0.000
Total organic carbon	224.724±14.189	664.569±171.439	0.006
BI (BOD/COD)	0.245±0.023	0.063±0.003	0.000

All values of parameters are in mg/L. SE=Standard error.

Considering the data for seasonal variations, methanogenic condition with fs value not exceeding 0.08, and at standard temperature and pressure, the COD content and biodegradability index of POME in the study area, and using the biogas package, the predicted bio-methane yield significantly ($p<0.01$) varies across seasons (Table 7). For example, at fs=0.08 (8%), predicted bio-methane is 22.800±0.282LCH_4/m^3POME and75.532±0.149LCH_4/m^3POME in the wet season and dry season respectively. This respectively corresponds to methane production capacity of 0.057±0.005$KgCH_4$/KgCOD and 0.014±0.001$KgCH_4$/KgCOD in the wet and dry season. A decreasing methane potential per kg of COD is observed in the dry season due to decreasing substrate degradability (BI) across seasons.

Table 7: Bio-methane prediction across seasons at different fs and fe

Input						Output	
Seasons				Substrate partitioning parameter (%)		LCH_4/m^3POME and $KgCH_4$/KgCOD (Mean±SE)	LCH_4/m^3POME and $KgCH_4$/KgCOD (Mean±SE)
Wet		Dry		fs	fe	Wet	Dry
$gCOD/m^3$	BI (%)	$gCOD/m^3$	BI (%)				
280.205±38.059	24.5±2.3	3731.250±154.574	0.063±0.003	0	100	24±0.306 0.061±0.006	82.1±0.162 0.016±0.001
280.205±38.059	24.5±2.3	3731.250±154.574	0.063±0.003	5	95	22.800±0.291 0.057±0.006	77.995±0.154 0.015±0.001
280.205±38.059	24.5±2.3	3731.250±154.574	0.063±0.003	8	92	22.08±0.282 0.057±0.005	75.532±0.149 0.014±0.001

Correlation analysis reveals a significant and very strong positive correlations between predicted volume of methane and COD content of POME ($r=0.957$, $r^2=0.916$, $p=0.000$), and a significant and modest negative correlation between the predicted volume of methane and BI ($r=-0.691$, $r^2=0.477$, $p=0.000$) (Table 8). The coefficient of determination (r^2) (proportion of the variability of one variable that is accounted for by variability in another) indicates the extent to which COD ($r^2=0.916$ or 91.6%) and BI ($r^2=0.477$ or 47.7%) account in BMP for POME produced in the area. Thus, the contribution of BI to methane yield is lower when compared to COD content.

Table 8: Correlations between predicted volume of methane, COD and BI

		Methane potential of POME	COD	Biodegradability index
Methane potential of POME	Pearson Correlation	1	.957**	-.691**
	Sig. (2-tailed)		.000	.000
	N	37	37	37

**Correlation is significant at the 0.01 level (2-tailed).

Irrespective of the bio-methane determining independent variable, the methane content per m^3 of POME predicted in the study area is quite low when compared to the methane content produced by other studies. Wang *et al.* (2015) showed that POME samples collected from palm oil mills in Malaysia contain high organic strength as expressed in the BOD and BI. In the study, $1m^3$ of POME produced $27.65m^3$ of biogas, with over 65% methane. In a similar study by Ng *et al.* (2011), 1 metric ton of POME (equivalent to $1m^3$) produced $28m^3$ of methane. Loh, *et al.* (2013) reported that $1m^3$ of POME generated $15\text{-}21m^3$ of biogas. Chotwattanasak and Puetpaiboon (2011) maintained that $1m^3$ of POME can produce $20m^3$ of biogas with over 65% methane composition. The content of POME in these studies have high level of organic content as seen in their values for BOD, COD and high biodegradability index. POME is described as moderately biodegradable when BI is between 0.3 to 0.5, and highly biodegradable when it is between 0.5 and 1.0 (Poh *et al.*, 2010; Verla *et al.*, 2014). On the contrary, POME generated in the study area has BI less than 0.3 across seasons (Table 6). This necessitates for chemical treatment prior to biological treatment and co-digestion of POME with local organic materials to generate greater volumes of bio-methane (Bhattacharya *et al.*, 2018; Jung and Pandit, 2019; Ojo, 2021).

High organic content of POME is aligned to high methane production capacity ($KgCH_4/KgCOD$), hence more energy content of the wastewater (Poh *et al.*, 2010; Chotwattanasak and Puetpaiboon, 2011). The methane production capacity of POME in the current study at fs=8%, for example of $0.057\pm0.005KgCH_4/KgCOD$ in the wet season and $0.014\pm0.001KgCH_4/KgCOD$ in the dry season is quite low when compared to $0.21KgCH_4/KgCOD$ reported by Chotwattanasak and Puetpaiboon (2011) in a POME to biogas study. The low methane content of the wastewater produced by palm oil mills in the study area could be attributed to the low organic strength of the wastewater and its low biodegradability index- essential baseline parameters that determine methane potential of wastewater. These parameters and their associated bio-methane potential provide options for decision making in transforming the wastewater to energy.

Despite the low methane potential of POME in the study area, the content of the wastewater cannot be relegated as its energy measuring value (COD) and other parameters exceed national and international guideline values for wastewater disposal (NESREA, 2011; World Bank Group, 2015). Studies with similar organic strength of the wastewater (and higher than guideline values) have uncovered the impacts of POME on environmental quality and suggest appropriate treatment and containment of the wastewater to safe environmental health (Ohimain *et al.,* 2012; Edward *et al.,* 2015; Eno *et al.,* 2017). Consequently, as the organic strength of the POME exceeds guideline values and the necessity to treat it, organic substrate of wastes generated in the study area such as pig and poultry wastes could be studied and co-digested to the copious volumes of POME in order to facilitate treatment and generate greater volumes of bio-methane.

Conversion of COD in POME to bio-methane strengthen domestic energy resources, enhance electrification rate and boost national revenue (Poh *et al.*, 2010; Chotwattanasak and Puetpaiboon, 2011; Loh *et al.*, 2013). Chotwattanasak and Puetpaiboon (2011) posit that $1m^3$ of biogas (with 65% methane) can generate 2.5KHh of electricity. Reducing the level of COD in POME through treatment and conversion to bio-methane will reduce its equivalence of CO_2 emissions into the atmosphere and avert its interconnected detrimental impacts on our global environment and human wellbeing. For example, access to energy is a tenet in measuring multidimensional poverty and such conversion of waste-to-wealth cannot be relegated by a government that seeks progress (OPHI and UNDP, 2019). Consequently, initiating programs or exploring opportunities to earn carbon emission reduction (CER) credits, such as transformation of POME to bioenergy for domestic use in ADAPALM and palm oil mills in its surrounding communities will reduce burden on fuelwood use, improve on human health, reduce ecological footprint and strengthen access to energy for the residents. These outcomes are interconnected to reducing deprivations and could assist the State and Federal governments to achieve sustainable development goals.

4.0 Conclusions

Bio-methane potential of POME predicted in ADAPLAM and palm oil mills in its surrounding communities is significantly related to milling scales and seasons. These independent variables also define the organic content associated with bio-methane yield. Consequently, the bio-methane content of POME and the variables that define its dynamics are essential tools in evaluating its feasibility for planning waste-to-energy through direct use as domestic fuel or its energy content in KWh for electricity generation. Despite the relatively low bio-methane content of the POME, the wastewater cannot be relegated as its composition does not fall within the safety limit for disposal. Thus, recovering the wastewater and co-digestion with local substrates will strengthen its methane production capacity. Employing this practice in the area will improve on domestic energy access and reduce agriculture-related greenhouse gas emissions.

References

American Public Health Association. (1999). *Standard methods for the examination of water and wastewater (20th ed.),* Washington: American Public Health Association / American Water Works Association / Water Environment Federation.

Aziz, N. I. H. and Hanafiah, M. M., (2017). The potential of palm oil mill effluent as a renewable resource. *Acta Scientifica Malaysia,* 1(2), pp. 01-11.

Begum, S. and Saad, M. F. M., (2013). Techno-economic analysis of electricity generation from biogas using palm oil waste. *Asian Journal of Scientific Research,* pp. 1-9.

Bhattacharya, J., Dev, S. and Das, B., (2018). Design of wastewater bioremediation plant and systems in *Low cost wastewater bioremediation technology: Innovative treatment of sulphate and metal-rich wastewater.* Elsevier Inc., pp. 265-313.

Chotwattanasak, J. and Puetpaiboon, U., (2011). Full scale anaerobic digester for treating palm oil mill wastewater. *J. of Sustainable Energy and Environ.,* 2, pp. 133-136.

Edward, J. B., Idowu, E. O. and Oyebola, O. E., (2015). Impact of palm oil mill effluent on physicochemical parameters of a southwestern river, Ekiti State, Nigeria. *Journal of Natural Sciences Research,* 5(14), pp. 26-30.

Eno, E. O., Antai, S. P. and Tiku, D. R., (2017). Microbiological and physicochemical impact of palm oil mill effluent on the surrounding soil at selected factory location within Calabar and Uyo. *Imperial Journal of Interdisciplinary Research,* 3(10), pp. 760-773.

Hafner, S. D., Koch, K., Carrere, H., Astals, S., Weinrich, S., et al., (2018). Software for biogas research:Tools for measurement and prediction of methane production. *Software,* 7, pp. 205-210.

Hafner, S. D. and Rennuit, C., (2019). Predicting methane and biogas production with the biogas package, pp. 1-15.

Holliger , C., Fruteau , L. H. and Hafner , S., (2017). *A new protocol and software tool for standardizing biomethane potential tests: results of an inter-laboratory study.* Beijing.

Jung, S. P. and Pandit, S., (2019). Important factors influencing microbial fuel cell performance in *Microbial electrochemical technology: Sustainable platform for fuels, chemicals and remediation, edited by S. V. Mohan, S. Varjani and A. Pandey* . Elsevier, Amsterdam.

King, L. S. and Yu, L. C., (2013). A retrofitted palm oil mill effluent treatment system for tapping biogas. *European International Journal of Sc. and Techn.,* 2(5), pp. 106-114.

Loh, S. K., Lai, M. E., Ngatiman, M., Lim, W. S., Choo, W. M., et al., (2013). Zero discharge treatment technology of palm oil mill effluent. *Journal of Oil Palm Research,* 25(3), pp. 273-281.

NESREA. (2011). *National environmental (surface and groundwater quality) regulations,* Lagos: NESREA.

Ng, F. Y., Yew, F. K., Basiron, Y. and Sundram, K., (2011). A renewable future driven with Malaysian palm oil based green technology. *Journal of Oil Palm and the Environment,* 2, pp. 1-7.

Ohimain, E. I., Seiyaboh, E. I., Izah, S. C., Oghenegueke, E. V. and Perewarebo, G. T., (2012). Some selected physico-chemical and heavy metal properties of palm oil mill effluents. *Greener Journal of Physical Sciences* , 2(4), pp. 131-137.

Ojo, O. M., (2021). Biogas production through anaerobic co-digestion of water hyacinth and poultry manure. *Nigerian Research Journal of Engineering and Environmental Sciences* , 6(2), pp. 735-740.
OPHI and UNDP. (2019). *Global multidimensional poverty index: Illuminating inequalities,*: OPHI & UNDP.

Poh, P. E., Yong, W. and Chong, M. F., (2010). Palm oil mill effluent (POME) characteristics in high crop season and the applicability of high rate-rate anaerobic bioreactors for the treatment of POME. *Ind. Eng. Chem. Res.,* 49, pp. 11732-11740.

Rittmann , B. E. & McCarty, P. L., (2001). *Environmental biotechnology: Principles and applications.* McGraw-Hill. Boston.

Rupani, P. F., Singh, R. P., Ibrahim, M. H. and Esa, N., (2010). Review of current palm oil mill effluent (POME) treatment methods: Vermicomposting as a sustainable practice. *World Applied Science Journal,* 11(1), pp. 70-81.

Shahidul, M. I., Malcolm, M. L. and Eugene, J. J., (2018). Methane production potential of POME: A review on waste to energy (WTE) model. *Sci. Int.,* pp. 717-727.

Tambe, E. B., Okonkwo, A. U. and Eme, L. C., (2022). Determinants of volume of POME generation in palm oil mills for planning wastewater recovery in biogas energy development. *J. Appl. Sc. Environ. Manage.,* 26(3), pp. 369-376.

Verla, A. W., Adowei, P. and Verla, E. N., (2014). Physicochemical and microbiological characteristics of palm oil mill effluent (POME) in Nguru: Aboh Mbaise, Eastern Nigeria. *Acta Chimica Pharmaceutica Indica,* 4(3), pp. 119-125.

Wang, J., Mahmood, Q., Qiu, J. P., Li, Y. S. and Chang, Y. S., (2015). Anaeobic treatment of palm oil mill effluent in pilot-scale anaerobic EGSB reactor. *BioMed Research International,* pp. 1-7.

World Bank Group. (2015). *Environment, health, and safety guidelines for vegetable oil production and processing,* World Bank Group.

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