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Full Length Research Paper

Potential of biogas production from palm oil mills' effluent in Nigeria

Elijah Ige Ohimain* and Sylvester Chibueze Izah

Bioenergy and Environmental Biotechnology Research Unit, Department of Biological Sciences, Faculty of Science, Niger Delta University, Wilberforce Island, Bayelsa State, Nigeria.

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In the recent years, global energy demand has increased. Several bio-wastes are capable of producing energy during treatment preferably through bio-methanation route, thereby preventing the challenges associated with the disposal of the same. In Nigeria, several kiloliters/tonnes of palm oil mill effluent (POME) are produced during processing of crude palm oil. This study evaluated the potential of biogas production from POME that is being discharged into the environment without treatment. Historical study period of this paper remained from 2004 to 2013. Palm oil production data and literature on biogas production using different anaerobic bio-digesters to convert POME to biogas was used for estimation. Projections of the production rate at three scenarios (high, low and current status) were made. Among the several anaerobic bio-digesters evaluated, Expanded Granular Sludge Bed (EGSB) reactor was found to produce the highest methane gas at the lower hydraulic retention time. Four groups of microorganisms, including hydrolytic, acetogenic, acidogenic and methanogenic bacteria, are capable of degrading complex polymers of POME to produce methane and carbon dioxide as the principal gases. The concentration and yield of methane is depended on properties of the POME including pH, mixing, operating temperature, nutrient availability and organic loading rates and microbial activity. Thermophilic temperature range (45 to 65°C) and neutral pH provides good conditions for other parameters to react well to produce the desired product. Based on the above criteria, it is estimated that Nigeria has lost 312 million m^3 of methane in 2004 which reached 367 million m^3 in 2013 by wasting POME road side in place of processing it through EGSB reactor. Projections depict that 555, 457 and 409 million m^3 of methane gas could be produced under high, low and current status production rates scenario respectively up to 2030, if Nigeria harnesses the energy contained in POME. The biogas produced from POME could be useful in generation of combined heat and power (CHP).

Key words: Anaerobic digestion, biogas, biogas reactors, energy from POME, methanogenic bacteria, microbial amylase, Nigeria.

INTRODUCTION

Nigeria is a country blessed with several energy resources including both renewable and non-renewable. Over the years, the non-renewable resources have been the center of energy mix contributing to gross domestic product of the country while creating employment. Petroleum production dominated Nigeria on non-renewable resources. In the current situation, the petroleum products which have been largely reported as the main cause of greenhouse gases leading to global warming is depleting in reserve. The renewable energy resources include biomass, hydropower, solar, wind etc. The biomass has a substantial advantage over other renewable resources due to their ability to mitigate carbon dioxide emissions through the mechanism of photosynthesis and providing energy without any interruption. In both developed and developing countries like Nigeria, several feedstocks have emerged as having potential for energy production. These feedstocks include

*Corresponding author: E-mail:eohimain@yahoo.com.

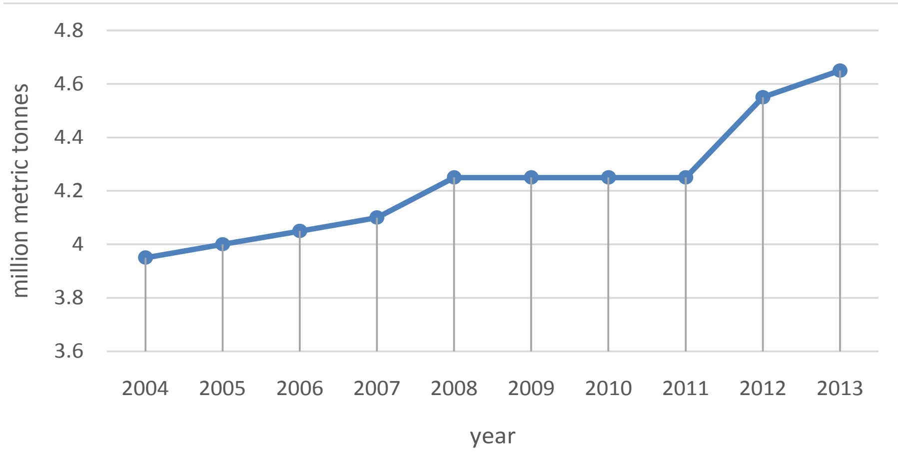

Figure 1. The total FFB produced in Nigeria (2004 – 2013).

cassava, sugar cane, sweet sorghum and oil palm. Oil palm is the most productive oil bearing crop in the world that thrives in both tropical and subtropical regions (Izah and Ohimain, 2013a). The crude palm oil produced has found applications in food and biodiesel production (Ohimain et al., 2012a; Izah and Ohimain, 2013b). During oil palm processing, enormous wastes are generated that so far remained underutilized in palm oil mills in Nigeria. These wastes from oil palm processing include both solid (Empty fruit bunch, palm press fiber, palm kernel shell and chaff) (Ohimain et al., 2013a; Ohimain and Izah, 2013a, 2014a) and liquid wastes (Palm oil mill effluents) (Ismali et al., 2010; Ohimain and Izah, 2013b; Ohimain et al., 2013c, 2012b,c). POME is generally discharged into the ecosystem the stream/water bodies in mills close to rivers and find its way into the soil without adequate treatment, while the unutilized solid waste is burnt on the road side adjacent to the mill leading to loss of energy and air pollution (Ohimain et al., 2013a).

During palm oil production, large volume of water is used, of which substantial quantity ends up as POME. Ahmad et al. (2003) and Wu et al. (2009) reported that in the processing of one tonne of Fresh Fruit Bunch (FFB) about 5 to 7.5 tons of water is used. Out of this water quantity, as Ohimain and Izah (2013b), Singh et al. (2010), Okwute and Isu (2007), Awotoye et al. (2011) and Chavalparit et al. (2006) reported that about 50 to 79% ends up as POME. In Nigeria, over the years, several million tonnes of water is being used for oil palm processing and a large quantity of the same ends up as POME, which is normally discharged into the ecosystem untreated leading to loss of biodiversity including flora and fauna especially fisheries (Sridhar and Adeoluwa, 2009; Awotoye et al., 2011). In addition to above losses odor pollution is also associated with POME if discharged especially during the rainy season thereby causing environmental nuisance to inhabitants of the region. Figure 1 shows the estimated values of FFB production in Nigeria, while Figure 2 shows the POME generated during oil palm processing in the last 10 financial years starting from 2004 to 2013.

The POME discharged into the environment emits greenhouse gases including methane and carbon dioxide. Methane and carbon dioxide are produced under anaerobic conditions, but under aerobic condition, carbon dioxide and water are produced. Basically greenhouse gases contribute to climatic change impacting on biodiversity that include change in the breading pattern, population and ecosystem deterioration. Methane gas is 21 times deleterious compare to carbon dioxide (Energy Wise, 2011). Ohimain and Izah (2014b) reported that the possible contribution of methane and carbon dioxide from POME to greenhouse gases is rising and going on unnoticed. Figure 3 shows the possible methane and carbon dioxide that could have been emitted from POME in the last 10 years (2004 - 2013). The authors reported that the value could be significantly lesser since POME is discharged after processing in aerobic/oxidation ponds.

POME is degraded by the activities of hydrolytic, acetogenic, acidogenic and methanogenic microorganisms in anaerobic digestion. Biogas is produced from POME using aerobic (open pond system) and anaerobic digester (closed pond/digester). High concentration of biogas is produced under anaerobic conditions compared to aerobic state. In this regard, different anaerobic bio-digesters have been developed to capture methane gas from POME in different countries. These include:

Up-flow anaerobic sludge blanket (UASB) reactor,
Up-flow anaerobic sludge fixed-film (UASFF) reactor,
Modified anaerobic baffled reactor (MABR),
Continuous stirred tank reactor (CSTR),
Anaerobic pond, anaerobic digester,
Expanded granular sludge bed (EGSB) reactor,

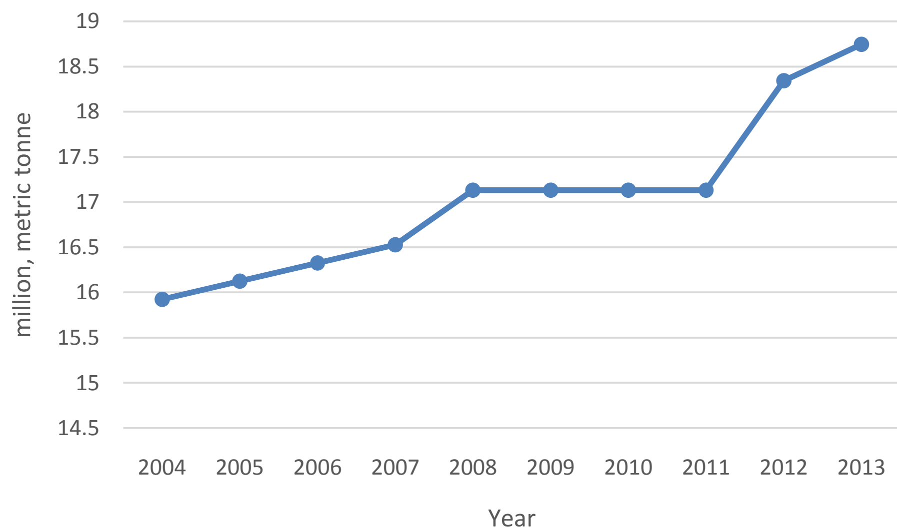

Figure 2. The total POME generated in Nigeria (2004 – 2013).

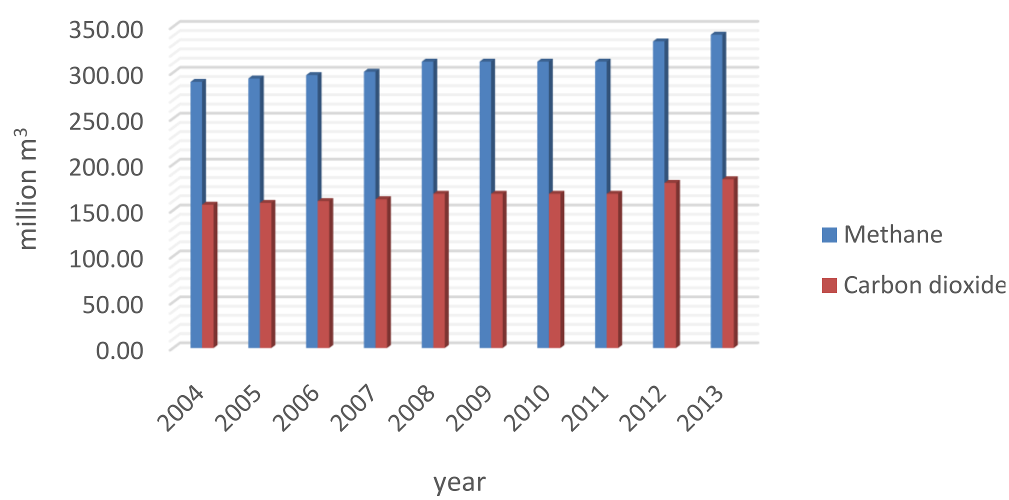

Figure 3. Methane and carbon dioxide emission from POME in Nigeria since the past 10 years.

Ultrasonic Membrane Anaerobic System (UMAS),
Membrane Anaerobic System (MAS) and
Anaerobic filtration.

During bio-methanation process, several factors including pH, mixing, operating temperature, nutrient availability and organic loading rates (Abdurahman et al., 2011, 2013; Poh and Chong, 2009), and microbial activity influence the overall methane yield. In anaerobic digestion, the microorganisms in anaerobic/anoxigenic conditions help in the stabilization of the organic matter by converting it into methane and other useful product (Irvan et al., 2012).

Microorganisms utilize the nutrient found in POME thereby reducing the organic reduction rate to produce methane under anaerobic condition. The population of the POME microorganisms could be a function of methane formation rate. Ujoji, (1997), Ohimain et al. (2012b) reported that POME microbial population range of 10^6cfu/ml. Similarly, Ohimain et al. (2013c) reported a lower population of 10^5cfu/ml in a semi-mechanized palm oil mill in Nigeria. In most bioreactor, biogas production decrease at increasing HRT. Faisal and Unno (2001) reported at HRT of 10 days biogas production per day was 12.21% which increased to 42.11% at 3 days HRT using MABR technology. Hydraulic Retention Time (HRT) indicates the average time the POME resides in a reactor during biogas production. Several quantum of methane yield at varying HRT have been reported.

Faisal and Unno (2001) reported optimum yield of methane (67.3%) at HRT of 3 days using MABR. Anaerobic digester produces 66.41% methane concentration at 6.5 days HRT (Chotwattanasak and Puetpaiboon, 2011), UMAS produced 68.5% methane at 5.40 days HRT (Abdurahman et al., 2013), 68.7% methane at 5.70 days HRT using MAS technology (Abdurahman et al., 2011). These HRT properties could affect other biogas production such as bio-hydrogen. Vijayaraghavan and Ahmad (2006) reported an average hydrogen gas generation of 57% at 7 days HRT, 0.42L/g COD destroyed, using anaerobic contact filter technology. Ismali et al. (2010) reported that 52% hydrogen is produced at 2 day HRT.

The organic loading rate (OLR) is the quantity of organic matter that is fed into the digester over a period of time. Yejian et al. (2011) reported that EGSB reactor have a high efficiency in POME treatment at high and short OLR and HRT respectively. The authors reported a CODremoval efficiency of 90.5% at HRT of 3 days and OLR of 10.5 kg COD/m^3day, which led to 46%organic matter of the POME forming methane. According to Poh and Chong (2009), the organic loading rate of POME and HRT needs to be balanced to achievegood digester operation properties. The organic loading rate is often challenged by the activities of hydrolytic and acidogenic microorganisms which produce intermediary products fast. Methanogenesis is often very slow; therefore methanogens would not be able to convert fatty acids to useful product swiftly.

The pH value of anaerobic digester determines the performance and stability of the system for the production of methane. Methanogensis process influences the pH of the reaction by swerving it away from normal. According to Abdurahman et al. (2011, 2013) these could be resolved by adding NaOH to maintain the pH of the system at optimum range (6.8 - 7.0), mixing to provide good contact between the POME and the microorganisms, reduce the formation of intermediate products and stabilizes the reaction environmental conditions. The intermediate products like fatty acid can enhance dropping of pH leading to system failure due to the activities of methanogens. Microorganisms during biomethanation adapt to pH change toward acid or alkalinity. Though, most pH tends to move toward alkalinity during the process. Most methane producing microorganisms during biomethanation produce optimum yield at the pH of 6.8 to 7.6. In Nigeria POME is usually discharged at a pH of 5.21 – 6.56 (Awotoye et al., 2011; Ohimain et al., 2012c; 2013c). Nayono (2010) reported that optimum yield is attained at neutral pH (7.0). For adjusting the POME to required pH level bicarbonates of sodium and potassium and lime are added due to their soluble properties and low harmful impact (Nayono, 2010).

During anaerobic digestion, the microorganisms need nutrient to produce optimum yield. Several nutrients including potassium, sodium, magnesium, calcium, iron, cadmium, chromium, nitrogen etc are required for effective performance. Ohimain et al. (2012c, 2013c), Awotoye et al. (2011), Borja et al. (1996), Wood et al. (1979), Begum and Saad, (2013) have reported that POME is rich in nutrients. The authors reported that POME contains high chemical oxygen demand (COD) and biochemical oxygen demand (BOD). During reaction, the COD and BOD are reduced to set standard values harmless to the environment on discharge. POME nutrient and other inhibitory materials lead to failure of the microbial consortia to adapt/acclimatize during anaerobic digestion. According to Nayono (2010), acclimatization is the capacity of microorganism to reorganize their metabolic resources to overcome the metabolic shock produced by the inhibitory substances when their concentrations increase.

Also, Khong et al. (2012) stated that acclimatization can be achieved by adding biomass to adjust the properties of the mixture in a certain proportion over a period of time. The authors stated that these could enhance the tolerance level, lag phase reduction prior to methane production and overall decrease in toxicity build up. The nutrients especially light ions have the ability to cause inhibition. Nutrient concentration is important for the stimulation of microbial growth. Therefore, low level of these nutrients could reduce growth leading to inhibition. Heavy metals are toxic especially when they exceed their threshold value.

According to Chen et al. (2008), the toxicity is associated to the inability of heavy metals to activate extensive range of enzymes by binding the metals and protein molecules they contain. To a larger extent, inhibition is caused by reaction conditions including temperature and pH (Nayono, 2010).

Internal temperature of the biogas reactor affects the biomethanation processes and the effectiveness of biogas production. In Nigeria during the point of discharge of POME the temperature is estimated between 60 - 80°C. Several microorganisms including mesophilic (35°C) and thermophilic (55°C) have been extensively studied for biogas production in anaerobic bioreactor. At thermophilic temperature, more methane gas is produced as compared to mesophilic temperature under the same conditions. Irvan et al. (2012) reported optimum methane concentration of 67% at HRT 4, 6 and 8 days using CSTR under thermophilic temperature range. Yejian et al. (2011) reported that EGSB reactor could produce 70% methane in 3 days HRT under mesophilic temperature range (20 to 45°C). Yeoh (2004) reported that methane concentration of 60% at 35°C and 65% at 45 - 55°C, though at varying temperature (i.e. 45°C, 50°C and 55°Cat 0.60, 0.65 and 0.92 m^3/kg – BOD respectively) an increase of 42% and 53% in methane yield wasnoted when the temperature was raised to 55°C from 45°C and 50°C respectively. The author also stated that under mesophilic temperature range, on the other hand, the methane yield (0.47 m^3/kg – BOD added) was almost doubled, with a 96% increase. Therefore, thermophilic bacteria are more vigorous in tolerating temperature changes (Nayono, 2010). According to Yeoh (2004) several energy resources are lost under mesophilic temperature conditions. According to the author, Malaysia can generate about 5% renewable energy demand using thermophic temperature as against 2% generated under mesophilic condition.

The biogas produced through these approaches/reactors has high combustion characteristics i.e. high calorific value. Production of biogas is environment friendly and economically and socially desirable to produce energy for better living of the inhabitants hence should be sustained as long as palm oil mills are producing palm oil and allied effluents. Biogas produced from POME could be used for both heat and power generation. The utilization of POME for biogas production could prevent the harmful environmental impacts associated with the discharge into the ecosystem. Biogas is a type of biofuel that environmental sustainable as compared to petroleum products. Energy and environmental degradation are major problems confronting humanity in the recent times. Due to the intense search of environmental friendly fuel and discharge that could reduce pollution or degradation, biofuel stands as a means of achieving both ends. Therefore, this study evaluates potential of biogas captured from POME in Nigeria. Also, the study could be beneficial to the government, policy makers and individuals involved in renewable energy production and combating the ill effect of greenhouse gas emissions in Nigeria.

METHODOLOGY

Baseline information used for this study was obtained from literature review. Data obtained were used to estimate the biogas potential from POME that have remained un-tapped in Nigeria from 2004 to 2013 and future projections up to 2029 based on three projection scenarios i. e. high, low and current production status.

Estimation of total biogas using optimized anaerobic system

Biogas produced from anaerobic system is a mixture of 65% methane and 35% carbon dioxide. It could be optimized to produce more at varying hydraulic retention time (HRT) and anaerobic system. Faisal and Unno (2001) reported that MABR could produce 69.1, 68.0, 70.2, 67.3, 69.1 and 71.2% methane gas at 3, 5, 6, 7, 8 and 10 days HRT. 67.3% methane gas production is the best because it has 27.4 methane gas rates (1 per day) at 3 days HRT (Faisal and Unno, 2001), Zinatizadeh et al. (2006) reported a methane gas in the range of 30 – 84%. The authors stated that 61.41% methane concentration is the best due to lower HRT of 1.5 days using UASFF. Yacob et al. (2006) reported that anaerobic pond could produce 54.4% methane at 40 days HRT. Yacob et al. (2005) reported that anaerobic digester could produce 36% methane gas at HRT of 20 days. Chotwattanasak and Puetpaiboon (2011) have similarly produced 70.3, 69.29, 66.83 and 66.41% methane gas at HRT of 14, 10, 7 and 6.5 days respectively in anaerobic digester. Methane production rate of 66.41% was the best due to lower HRT. Irvan et al. (2012) reported methane concentration of 67, 66 and 63% at HRT 4, 6 and 8 days respectively using CSTR at thermophilic temperature conditions. The authors reported that 67% methane concentration is the best yield due to lower HRT of 4 days. Yejian et al. (2011) reported that expanded granular sludge bed (EGSB) reactor could produce 70% methane in 3 days HRT under mesophilic temperature conditions. Abdurahman et al. (2013) reported that Ultrasonic Membrane Anaerobic System (UMAS) could generate 79% 75.5% 70.2% 71.8% 70.6% and 68.5% at HRT of 480.3, 76.40, 20.3, 8.78, 7.36 and 5.40 days respectively. The authors reported that 68.5% methane yield at 5.40 HRT is the best due to the ability to produce 0.59 l/g. Abdurahman et al. (2011) reported that Membrane Anaerobic System (MAS) could produce 74.2% 72.6% 69.7% 70.8% 69.1% and 68.7% methane at HRT of 400.6, 63.6, 20.4, 11.6, 8.86 and 5.70 days respectively. The authors reported that 68.7% methane at 5.70 days HRT is the most suitable due to the methane yield of 0.58 l/g. Borja and Banks (1994a) reported that UASB could produce 54.2% methane in 3 days HRT. Borja and Banks (1994b) reported that anaerobic filtration could produce 63% methane in HRT of 15 days. Therefore, in this study the anaerobic configuration that produced above 65% methane concentration at <10 days HRT retention time was considered for the calculation of methane yield. The total potential of biogas that could have been produced in Nigeria using various anaerobic bio-digester for the last 10 years and projections up to 2029 based on the scenarios (i.e high, low and current production status) (Figure 4).

RESULTS AND DISCUSSION

Biogas which mainly consists of methane and carbon dioxide are produced in large amount during anaerobic digestion. Methane is the major product produced from biomethanation process. Several configurations of anaerobic bioreactors have been utilized to produce methane with high concentration at low HRT. Table 1

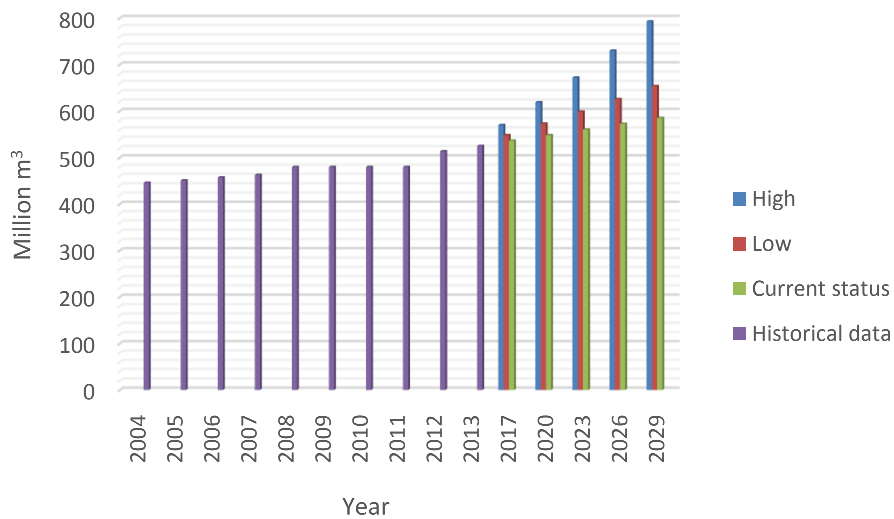

Figure 4. Estimated potential of biogas production from POME in Nigeria (2004 – 2013) and project scenario (2017 – 2029).

Table 1. Potential methane yield from POME in Nigeria using various anaerobic bio-digesters based on historical data.

Year	Biogas, m^3					
	MAS	**UMAS**	**EGSB**	**CSTR**	**Anaerobic digester**	**MABR**
2004	306,303,243.8	305,411,513.3	312,099,375	298,723,687.5	296,093,135.6	300,061,256.3
2005	310,180,500.0	309,277,500.0	316,050,000	302,505,000.0	299,841,150.0	303,859,500.0
2006	314,057,756.3	313,143,468.8	320,000,625	306,286,312.5	303,589,164.4	307,657,743.8
2007	317,935,012.5	317,009,437.5	323,951,250	310,067,625.0	307,337,178.8	311,455,987.5
2008	329,566,781.3	328,607,343.8	335,803,125	321,411,562.5	318,581,221.9	322,850718.8
2009	329,566,781.3	328,607,343.8	335,803,125	321,411,562.5	318,581,221.9	322,850718.8
2010	329,566,781.3	328,607,343.8	335,803,125	321,411,562.5	318,581,221.9	322,850718.8
2011	329,566,781.3	328,607,343.8	335,803,125	321,411,562.5	318,581,221.9	322,850718.8
2012	352,830,318.8	351,803,156.3	359,506,875	344,099,437.5	341,069,308.1	345,640,181.3
2013	360,584,831.3	359,535,093.8	367,408,125	351,662,062.5	348,565,336.8	353,236,668.8

presents the quantity of methane gas that would have been produced in Nigeria, if POME produced from palm oil mills for the period of study i.e. from 2004 to 2013 would have been collected and treated using various anaerobic bioreactors at different HRT and conditions. Also projections made are presented in Table 2.

The result indicated that Nigeria could have produced 306 million m^3 in 2004 of methane which was estimated to have reached 360 million m^3 in 2013, if MAS bioreactor were used under 5.7 days HRT in MAS. At high, low and current status projection scenario, 544, 449 and 402 million m^3 of methane respectively could be produced up to 2030.

Using EGSB treatment system, Nigeria would have produced 312 million m^3 of methane gas in 2004 which could have reached 367 million m^3 in 2013 at 3 days HRT, and it was projected to reach 555, 457 and 409 million m^3 at high, low and current status projection scenario respectively by 2029.

CSTR could have been used to treat POME to produce 298 million m^3 in 2004 of methane which could have reached 351 million m^3 2013 at days HRT. Projection showed that using CSTR technology, Nigeria could produce 531, 359 and 392 million m^3 of methane at high, low and current status projection category respectively by 2029.

The use of UMAS technology could have generated 305 million m^3 in 2004 of methane, which could have reached 359 million m^3 in 2013 at HRT of 5.4 days, and projections indicated that high, low and current status scenario could produce 543, 447 and 400 million m^3 of methane respectively up to 2030.

The use of anaerobic bio-digester showed that 296 million m^3 in 2004 of methane which could have reached 348 million m^3 in 2013 at HRT of 6.5 days. High, low and current status projection scenario indicated that Nigeria could produce 526, 434 and 388 million m^3 of methane respectively up to 2030.

Table 2. Potential methane yield from POME in Nigeria using various anaerobic bio-digesters in projection scenarios.

Year	Biogas, m^3					
	MAS	**UMAS**	**EGSB**	**CSTR**	**Anaerobic digester**	**MABR**
2017	(391,595,126.7) [376,712,009.0] {368,517,697.5}	(390,455,111.8) [375,615,321.9] {367,444,865.8}	(399,005,223.8) [383,840,474.9] {375,491,103.8}	(381,904,999.9) [367,390,168.9] {359,398,627.9}	(378,541,955.8) [364,154,942.0] {356,233,774.3}	(383,615,022.3) [369,035,199.5] {361,007,202.5}
2020	(425,272,307.7) [393,692,291.7] {376,625,086.9}	(424,034,251.4) [392,546,171.5] {375,528,562.9}	(433,319,673.0) [401,142,073.1] {383,751,908.1}	(414,748,829.9) [383,950,269.9] {367,305,397.7}	(411,096,564.1) [380,569,215.3] {364,070,917.3}	(416,605,914.2) [385,669,450.3] {368,050,048.7}
2023	(461,845,729.2) [411,369,075.9] {384,910,838.4}	(460,501,200.1) [410,171,494.9] {383,790,283.2}	(470,585,168.0) [419,153,352.5] {392,194,450.0}	(450,417,232.2) [401,189,637.3] {375,386,116.4}	(446,450,871.5) [397,656,773.4] {372,080,477.5}	(452,434,025.8) [402,986,008.9] {377,066,949.8}
2026	(501,564,461.6) [429,839,547.4] {393,378,877.0}	(500,104,303.0) [428,588,195.4] {392,233,669.2}	(511,055,492.2) [437,973,338.3] {400,822,727.6}	(489,153,113.9) [419,203,052.4] {383,644,610.7}	(484,845,646.2) [415,511,562.8] {380,266,247.7}	(491,343,324.8) [421,080,081.0] {385,362,422.4}
2029	(544,699,005.6) [449,139,343.7] {402,033,212.4}	(543,113,273.4) [447,831,805.6] {400,862,810.0}	(555,006,264.8) [457,638,341.5] {409,640,827.8}	(531,220,282.0) [438,025,269.7] {392,084,792.3}	(526,542,372.1) [434,168,032.3] {388,632,105.3}	(533,598,880.3) [439,986,576.9] {393,840,395.8}

( ) = High; [ ] = Low; { } = Current status production rates projections.

In Malaysia, Yussof (2006) reported that 3.45 tons of Fresh Fruit Bunch (FFB) could generate 1.55 GJ of biogas which is being utilized to solve energy and power challenges. Under this study it is found that EGSB technique might be considered to be the best treatment technology due to its ability to produce higher methane gas at shorter HRT. Similarly, the anaerobic bio-digester produced the least methane due to lower methane concentration and higher HRT. The production of methane is carried out by four major steps including hydrolysis, acidogensis, actogenesis and methanogensis.

The POME hydrolytic microorganisms such as *Bacillus* species (Ohimain et al., 2012b; 2013c) could breakdown the complex polymer i.e. carbonhydrate, protein and lipid found in POME to respective monomers i.e sugar, amino acids and fatty acids (Lam and Lee, 2011). Beside, Bacillus species other hydrolytic enzymes of microbial origin such as protease, amylase, xylanase could convert the polymers to their smaller units under anaerobic conditions. Ohimain et al. (2013c) have reported *Bacillus* species, *Pseudomonas* species and *Staphylococcus aureus* as amylase hydrolytic enzymes found in POME. The POME acidogenic microorganisms such as *Bacillus* species, *Pseudomonas* species, *Staphylococcus aureus, E. coli* and *Desulfovibrio* species (Ohimain et al., 2012b; 2013c; Ugoji, 1997) can degrade the sugar, amino acid and fatty acids to produce acetate, hydrogen and carbon dioxide (Lam and Lee, 2011).

This step is carried out by acteogensis where propionate, butyrate, lactate and ethanol produced help to convert the monomers to acetate, hydrogen and carbon dioxide. These products are acted upon by two groups of methanogens including actetotrophic and hydrogenotrophic microorganisms. According to Lam and Lee (2011), Demirel and Scherer (2008) acetotrophic methanogens converts acetate to methane and carbon dioxide while hydrogenotrophic methanogens uses hydrogen and carbon dioxide as electron donor and acceptor respectively to produce methane. The authors also reported that methanogens that could utilize hydrogen could also use formate as electron donor to reduce carbon dioxide to methane.

Biogas have been produced using varying anaerobic digestion, which utilizes microorganisms in anoxigenic conditions to produce methane and other inorganic products and carbon dioxide as the principal gas using varying anaerobic digester (Irvan et al., 2012). According to Yejian et al. (2011), EGSB reactor, which is basically a modification of UASB treatment system, helps to enhance substrate-biomass contact through expansion of the sludge bed and increase hydraulic mixing, reactor performance and overall stability. This technology has a superior performance in methane concentration at lower HRT apart from UASFF compared to other treatment technologies.

UMAS is one of the suitable anaerobic treatment technologies of POME due to its relative small volume as compared to conventional digester. Abdurahman et al. (2013) reported that UMAS has an enhanced and successful system that could achieve high COD removal efficiency in a short HRT. MABR has high HRT and proven to be successful for POME treatment. MABR is a modified form of anaerobic baffled reactor which is simple and inexpensive to construct (Faisal and Unno, 2001).

Biogas is basically a mixture of methane and carbon dioxide. According to Faisal and Unno (2001) a 3630 COD/mg could produce 27.4 l of methane per day with 68.1% concentration under HRT of 3 days using MABR. Depending on the type of bioreactor used the concentration of the POME with its HRT could differs. Abdurahman et al. (2011) have reported that under steady state of 5.70 OLR, 13 kg COD/M^3/day could yield optimum methane concentration of 68.7% using MAS. Irvan et al. (2012) reported methane generation per COD in POME to yield 0.16 kg/COD at 3.94 HRT using anaerobic digester with thermophilic anaerobic reactor. Abdurahman et al. (2013) reported that 5.4 days HRT with 9.45 kg/COD/m^3/day substrate utilization rate to produce 68.5 methane concentration using UMAS. EGSB reactor operated at 35°C and HRT of 3 days, later 2 day, has its OLR increased from 1.45 to 16.5 kg COD/m^3/day showing COD removal of 90.5% at 3 days HRT and OLR of 10.5 kg COD/m^3/day, which transform only about 46% organic matter in POME to methane (Yejian et al., 2011). Chotwattanasak and Puetpaiboon (2011) reported that at HRT of 6.5 days with OLR 8.70 kg/COD/$m^{3/}$day at 65% and 93% COD and BOD removal respectively, 66.41% of methane gas will be generated. The authors also reported that under 7 days HRT, corresponding to OLR 6.50 kg COD/m^3/day, a specific methane gas generation of 0.35 m^3CH4/kg/COD could be achieved with an average methane concentration of 67% using anaerobic digesters, which could be a cheap source of energy for a gas engine to produce electricity. This could be successful due to high heating content. Foo and Hameed (2009) have reported the calorific value of POME biogas as 34.5 MJ/m^3. During biogas conversion to usable energy, a supporting power demand is necessary for the cooling of the compressor system and it is estimated to account for 12% of the gross power generation, therefore producing a net power output of 88% (Gopal and Ma, 1986 cited in Yeoh, 2004).

The potential for biogas could yield a positive result in Nigeria due to large oil palm plantation across the country especially in southern Nigeria were they are found in both wild and plantations. Oil palm industry is carried by three scale of processors including smallholder (traditional), semi-mechanized and mechanized scale. The semi-mechanized and mechanized processors account for about 20%, which is scarcely located across the major oil palm processing states in Nigeria. The smallholder dominates the oil palm estates and mills accounting for about 80% of the oil palm coverage. According to PIND (2011) several million smallholders plantation are spread over an estimated area of 1.65 - 3.00 million ha (PIND, 2011). The estimate for oil palm plantations in Nigeria ranges from 169,000 ha (72,000 ha of estate plantations and 97,000 ha of smallholder plantations) to 360,000 ha of plantations (PIND, 2011). Similarly recent report in 2013 states that approximately 24 million hectares land is ideal for oil palm plantation, but only about 3.0 million hectares is put to use representing 12.5% (Business Day, 2013). Of these, Niger Delta region have an estimated range of 1.4 – 1.8 million hectares of oil palm plantation and over 1.1 million hectares of wild grove plantation. The processing of fresh fruit bunch of oil palm lead to the generation several metric tonnes of palm oil the range of 790,000 (2004) 800 (2005), 810,000 (2006), 820,000 (2007), 850,000 (2008 to 2011), 910,000 (2012) and 930,00 (2013) (Ohimain and Izah, 2014b). Also projections made indicate that, there could be a significant increase in palm oil production in few years to come due to intensive approach taken by stakeholder and government to reactivate the sector. These could also lead to the production of high volume of POME. The estimated quantity of POME for the period (2004 – 2013) is presented in Figure 2. Projections made could be higher which could lead to having higher biogas potentials from it under anaerobic condition.

Conclusion

POME is rich in nutrients and microorganisms. The microorganisms are able to mineralize the nutrient alongside with other pollution indicators like BOD and COD to produce biogas using various designs of anaerobic bio-digesters and choosing the most appropriate one out of the lot. The study found that EGSB treatment technology is the best due to its ability to produce higher percentage of methane gas at higher concentrations and low HRT of POME respectively. The capture of biogas from POME and potential utilization in electricity generation and supplying cooking fuel could reduce demand of convectional fossil fuel like kerosene and diesel. This could also increase renewable energy share in Nigerian energy mix by management of POME, thereby reverting environmental degradation.

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