# Investigative Study on the Use of De-Oiled Palm Kernel Cake for Biogas Production

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***ABSTRACT:*** Availability of Palm Kernel Cake (PKC) has increased due to the increase in the number of cottage oil palm processing industries in developing countries. A quest for clean energy from bio-waste is also on the increase. This study aims at investigating the biogas generating capacity of de-oiled PKC and its corresponding methane content. De-oiled PKC and a mixture of de-oiled PKC and fresh sugar cane chips were used as the two bio-feed samples in a laboratory anaerobic digestion set up. A theoretical approach was also used to determine the expected methane content in the biogas. Laboratory results for de-oiled PKC gave the volume by weight of bio-feed for biogas and methane to be 12.7 ml/g and 4.2 ml/g respectively and that of the combination of de-oiled PKC and fresh sugar cane chips to be 3.15 ml/g and 1.25 ml/g respectively. The measured methane composition for de-oiled PKC and that of the combination of de-oiled PKC and fresh sugar cane chips to be 33% and 40% respectively while the theoretical estimates were 33.5% and 41.1% respectively. The study shows that de-oiled palm kernel cake has biogas/methane generation potential whose quality can be improved by the addition of other biogas producing wastes.

***KEYWORDS:*** Biogas, Agro-Industrial Waste, Palm Kernel Cake, Anaerobic Digestion, Wastewater.

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## I INTRODUCTION

Biogas is a mixture of gases mainly carbon dioxide and methane that results from anaerobic fermentation of organic matter by bacteria (GreenLearning Canada Foundation, 2017). Fig. 1 shows the schematic of the process. Biogas is mainly composed of 50 to 70 percent methane, 30 to 40 percent carbon dioxide ($CO_2$) and low amount of other gases (Hydrogen 5-10%, Nitrogen 1-2%, Water vapour 0.3%, and traces of hydrogen sulphide). Its calorific value is 20 MJ/m$^3$ and burns with 60% efficiency in a conventional biogas stove (Regattieri *et al*, 2018). Biogas and electricity are generated from effluent management, and several biochemicals such as ethanol, fatty acids, waxes and others which could be obtained through application of biotechnology. Conversion to energy is a good means of obtaining carbon credit facility for sustainable management (Sridhar and AdeOluwa 2009).

Closed tank digester system with biogas capture and utilisation can contribute to the sustainable development rather than open air disposal of palm oil industry wastes. This method has been developed for treating palm oil mill effluents (Understanding Energy, 2017). The biogas generated is captured and directed to flaring or used as boiler fuel or for power generation. For the controlled anaerobic tank digester method with mixing, the gross treatment efficiency has been estimated to be in the range of 90-95% in terms of BOD removal. COD treatment efficiency is experienced in the range of 80-90%. Methane content in the biogas generated has been reported in the range of 54-70% with an average of 64%. The major part of the balance of the biogas is $CO_2$ (36%) with traces of hydrogen sulphide (Understanding Energy, 2017).

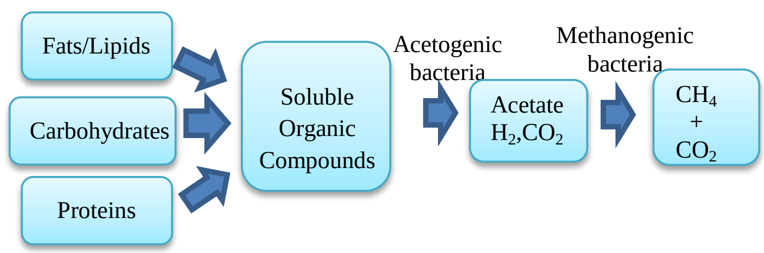


**Figure 1: Schematic biochemical process stages of anaerobic digestion (Source: Achinas and Euverink, 2016)**

Oil palm industry generates a large quantity of residues and wastes in the form of empty fruit bunch, palm kernel shells, trunk of the plant, fibre, leaves and others. Empty fruit bunches and palm kernel shells have been successfully converted into compost and were useful in developing oil palm nurseries and other food crops. The various uses of the by-products and waste from palm oil mills are shown in Figure 2.

Wastewater generated through typical palm oil processing averages 0.5 m³/ton of fresh fruit bunches (FFB). Some palm oil mill processes about 450,000 tons FFB and thus 210,000 m³ of wastewater per year. For such a company, a digester volume of 6,000 m³, will allow handling the daily load of about 700 m³ of waste water (Understanding Energy, 2017).

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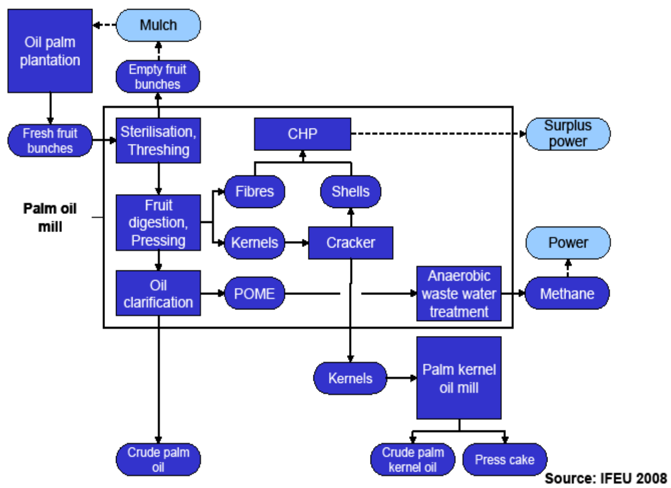


**Figure 2: Processing of palm oil mill by-products and waste**

Palm kernel cake (PKC) is a byproduct of oil extraction from palm kernel nut and it is abundant in the tropical areas of the world (Rhule, 1996). In recent times however, there has been an increase in the number of cottage oil palm processing industries in developing countries like Nigeria due to ban on the importation of vegetable oil which has resulted in abundant availability of PKC. The PKC so obtained varies considerably in chemical composition (protein, fibre or lipids), depending on source, the extent and methodology of oil removal and the proportion of endocarp remaining (Rhule, 1996; Adesehinwa, 2007). Presently PKC is being used as a filler in animal feeds, used for land filling or burnt directly as fuel. From the chemical composition of PKC, Adesehinwa (2007) showed that PKC is a potential energy source. This study therefore aims at investigating biogas production potential as an alternative use for PKC.

Chaikitkaewa *et al* (2015), evaluated three biomass residues from palm oil mill plant including empty fruit bunches (EFB), palm press fiber (PPF) and decanter cake (DC) for methane production by solid state anaerobic digestion at 25% total solids content. The highest cumulative methane production of 2180 mLCH4 was obtained from EFB followed by PPF (1964 mL CH4) and DC (1827 mL CH4). Methane production from EFB, PPF and DC by solid state anaerobic digestion was 55, 47 and 41 $m^3$ CH4/ton, respectively, which suggested that decanter cake could be a promising substrate for methane production by solid state anaerobic digestion.

This paper seeks to investigate the biogas potential after oil palm kernel oil has been extracted from Palm kernel cake with a focus on its quality in terms of the percentage methane content.

## II METHODOLOGY

### *A. Theoretical Calculation of Biogas Composition*

Based on chemical formula, Buswell devised the equation to predict theoretical yield of component products from bio-digestion. The Buswell's equation is given as

$$C_aH_bO_cN_d + \left(\frac{4a-b-2c+3d}{4}\right)H_2O + \left(\frac{4a+b-2c+3d}{8}\right)CH_4 + \left(\frac{4a-b+2c+3d}{8}\right)CO_2 + DNH_3$$

Where a, b, c, d are the moles of Carbon, Hydrogen, Oxygen and nitrogen respectively present in the waste sample.
The simplification of the Buswell equation and Boyle's law to give the contribution of some chemical components in waste samples is given in the Table 1 (Renewable Energy Concepts, 2018; Czepuck *et al*). These estimates were used to determine the theoretical gas composition of the waste samples.

**Table 1: Gas Composition from various substrates of waste materials.**

| Substrate | Gas Composition (%) | | | |
|---|---|---|---|---|
| | $CH_4$ | $CO_2$ | $NH_3$ | $H_2S$ |
| Carbohydrates | 50 | 50 | Nil | Nil |
| Fat | 71 | 29 | Nil | Nil |
| Proteins | 38 | 38 | 18 | 6 |

### *B. Experimental Procedure using de-oiled palm kernel cake only*

Two units labelled A and C (Figures 3 and 5) were set up simultaneously for the anaerobic digestion process and this was repeated twice (Experiment 1& 2). In each set-up, 50 g of de-oiled palm-kernel cake was measured into conical flasks (which served as mini-digesters). The wastes in the conical flasks were diluted with 500 ml of water to make a total solid value (TS) of 10% and were thoroughly stirred. The conical flasks were sealed at the top to prevent the escape of gas while a hose was fixed at the side opening. The hose serves as a passage for the gas to the point of collection.

### *C. Experimental Procedure using de-oiled palm kernel cake and sugar cane*

Two units labelled B and D (Figures 4 and 6) were set up simultaneously for the anaerobic digestion of the mixture and this was repeated twice (Experiment 1& 2). A mix of 50 g of de-oiled palm-kernel cake and 50 g of fresh sugar cane chips were measured into conical flasks (which served as mini-digesters). The wastes in the conical flasks were diluted with 500 ml of water and were thoroughly stirred. The conical flasks were sealed at the top to prevent the escape of gas while a hose was fixed at the side opening. The hose serves as a passage for the gas to the point of collection.

### *D. Volume Measurement*

In all the experiments, the volume of gas produced was measured through the displacement method. In set-ups A and B, the gas was collected directly while in set-up C and D the gas collected was passed through Calcium Hydroxide, $Ca(OH)_2$ to remove the $CO_2$ present. This leaves only the methane gas as the gas collected (Mel *et al*, 2014). The ambient temperature was measured and recorded daily using a thermometer. The data obtained from the volume measurement was recorded and compared to determine the amount of biogas that can be recovered from the amount of waste used for the experiment and the total energy potential of the waste samples.

**Figure 3: Set-up A.**

**Figure 4: Set-up B.**

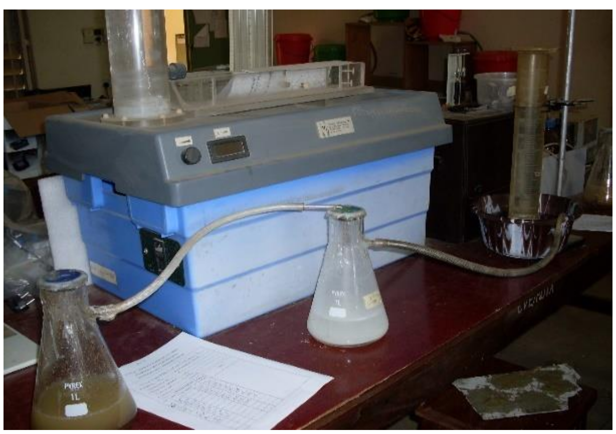

**Figure 5: Set-up C.**

**Figure 6: Set-up D.**

## III RESULTS AND DISCUSSION

### *A. Theoretical Gas Estimates*

Applying the composition percentage to de-oiled palm kernel cake gives the results in Table 2 while its result from the application to the mixture of de-oiled palm kernel cake and fresh sugar cane chips is shown in Table 3.

De-oiled palm kernel cake has a volatile solids content of 76.6% weight by weight of solids. Therefore, the expected theoretical methane content of de-oiled palm kernel cake is given by 0.766 x 43.75 which is equal to 33.51%. Fresh sugar cane chips have a volatile solids content of 97.7% weight by weight of solids. Therefore, the expected theoretical methane content of fresh sugar cane chips is given by 0.977 x 49.868 which is equal to 48.72%.

Expected theoretical methane content from mixture of de-oiled palm kernel cake and fresh sugar cane chips is a 50% contribution by both materials since an equal weight of 50g each was used. The value is given by 0.5(33.51 + 48.72) which is equal to 41.12%.

### *B. The Anaerobic Digestion Process*

The cumulative biogas volume measured with time from the anaerobic digestion of de-oiled palm kernel cake and fresh sugar cane chips is illustrated in Fig. 7. It was observed that there were traces of biogas production within 24 h. The average hourly production was 2.5 ml with peak production indicated at about 140 h for de-oiled palm kernel cake and 90 h for de-oiled palm kernel cake with fresh sugar cane chips. The production then began to decline with some negative values of gas volumes recorded. The negative values indicate that some other gases present within the biogas had dissolved in the water used to take measurement (Mel *et al*, 2014). For the weight of material used, a detention time of about 260 h

**Table 2: Theoretical Gas Components for De-Oiled Palm Kernel Cake.**

| **Substrate** | **% present in dry weight of material (Syamala *et al*, 2017)** | **Gas Composition** $CH_4$ | $CO_2$ | $NH_3$ | $H_2S$ |
|---|---|---|---|---|---|
| Carbohydrates (fibre inclusive) | 66 | 33 | 33 | Nil | Nil |
| Fat | 6.8 | 4.83 | 1.97 | Nil | Nil |
| Proteins | 15.58 | 5.92 | 5.92 | 2.80 | 0.93 |
| | Sub Total | 43.75 | 40.89 | 2.80 | 0.93 |
| Volatile solid = 76.6% w/w | Total | 33.51 | 31.32 | 2.15 | 0.71 |

**Table 3: Theoretical Gas Components for Fresh Sugar Cane Chips.**

| Substrate | % present in dry weight of material (Romao *et al* 2014) | Gas Composition $CH_4$ | $CO_2$ | $NH_3$ | $H_2S$ |
|---|---|---|---|---|---|
| Carbohydrates | 97.3 | 48.90 | 48.90 | Nil | Nil |
| Fat | 0.4 | 0.284 | 0.116 | Nil | Nil |
| Proteins | 1.8 | 0.684 | 0.684 | 0.324 | 0.108 |
| | Sub Total | 49.87 | 49.700 | 0.324 | 0.108 |
| Volatile solid = 97.7% w/w | Total | 48.72 | 48.56 | 0.32 | 0.11 |

was observed to be suitable, this is because very little or insignificant production was realized after 260 h. The daily temperature was observed to range between 25$^O$C and 27$^O$C with an average daily temperature of 26.4$^O$C which allows for anaerobic digestion.

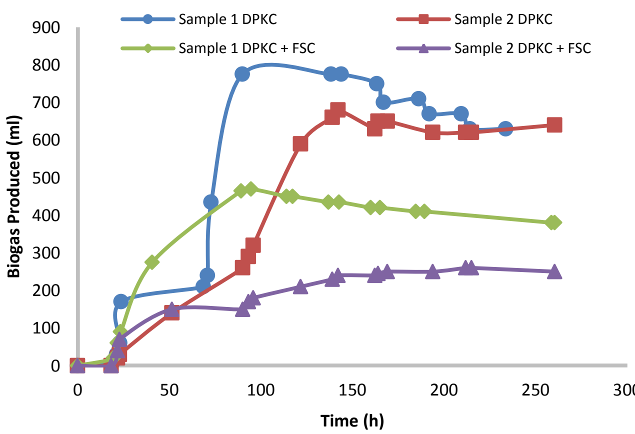


**Figure 7: Cumulative biogas production with time.**

### C. *Methane Measured in the Laboratory*

Methane content within the biogas was noticed within 24 h. The cumulative volume measured with time is shown in Figure 8. From the results, it was observed that the volume of methane was considerable low when compared with the volume of biogas produced by the same sample. $CO_2$ removal from biogas is mandatory to meet the specifications of a natural gas grid since $CO_2$ reduces the heating values of natural gas. The percentage of methane present in biogas as against that of $CO_2$ determines the quality of the biogas.

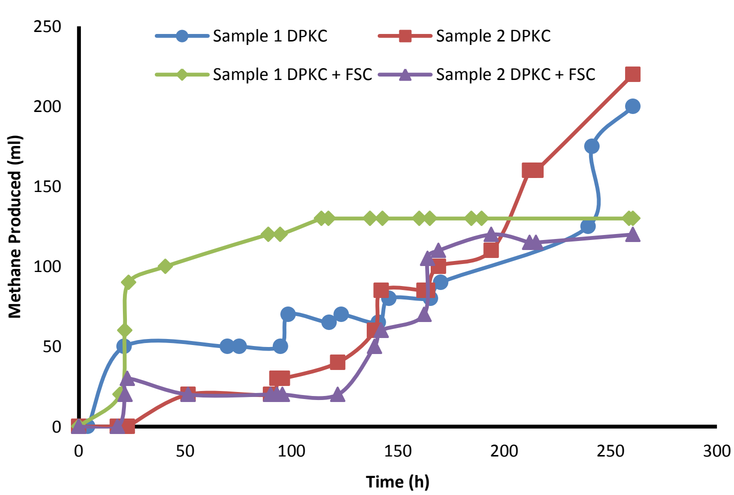


**Figure 8: Cumulative methane production with time.**

The comparison of the total volume and percentage of biogas present in the waste samples is shown in Table 4. It was observed that the waste sample containing only de-oiled palm kernel cake waste produced an average biogas and methane of 12.7 ml/g and 4.2 ml/g of waste respectively while the sample containing fresh sugar cane chips produced an average of 3.15 ml/g and 1.25 ml/g respectively. The methane yield from the sample containing de-oiled palm kernel cake and fresh sugar cane chips was higher than that of de-oiled palm kernel cake only. In terms of methane content in the measured biogas, the methane content from the de-oiled palm kernel cake is 33% while that of de-oiled palm kernel cake and sugarcane is 40%.

**Table 4: Parameters of substrates and biogas in the anaerobic fermentation**

| Type of Waste | DPKC | | DPKC+ FSCC | |
|---|---|---|---|---|
| Weight of Waste (g) | 50 | 50 | 100 | 100 |
| Volume of Water Added (ml) | 500 | 500 | 500 | 500 |
| Biogas Yield ($CH_4$+$CO_2$) (ml) | 630 | 640 | 380 | 250 |
| Methane Yield ($CH_4$) (ml) | 200 | 220 | 130 | 120 |
| Average Biogas Yield (ml) | 635 | | 315 | |
| Average Methane Yield (ml) | 210 | | 125 | |
| Biogas Yield/Weight of Waste (ml/g) | 12.7 | | 3.15 | |
| Methane Yield/Weight of Waste (ml/g) | 4.20 | | 1.25 | |
| Methane Composition in Biogas (%) | 33 | | 40 | |

DPKC: De-oiled Palm Kernel Cake, FSCC: Fresh Sugar Cane Chips

Good biogas quality is expected to have a methane content of at least 50%. The sugar cane content added resulted in an increase in the methane content indicating that de-oiled palm kernel cake has a biogas generation potential which can be boosted by the addition of other products such as sugar cane.

### D. *Comparison of Laboratory and Theoretical Values*

The laboratory measured methane content in de-oiled palm kernel cake was 33% which is 1.5% lower than the theoretical value of 33.5%, while the methane content of the sample with de-oiled palm kernel cake and fresh sugar cane chips is 40%, which is 2.68% lower than the theoretical value of 41.1%.

Variations between experimental and theoretical values have been noticed by other researchers, stating that the theoretical value is an indication of the maximum amount of methane that can be produced by the sample under ideal conditions. Factors responsible for the variations include Temperature, Heat, Mixing, Carbon/Nitrogen ratio, Volatile solids content and Lipid content in waste sample (Czepuck *et al*, 2006; Chaikitkaewa *et al*, 2015).

## IV CONCLUSION

The results of the test digesters used for the laboratory research showed that de-oiled Palm kernel cake after going through anaerobic digestion produced biogas. Addition of other types of waste such as fresh sugar cane chips increased the amount of methane present in the biogas and therefore its quality. A comparison of the percentage of methane in the biogas from theoretical calculation and the laboratory showed a variation of less than 3%. It can therefore be concluded that de-oiled palm kernel cake has biogas/methane generation potential whose quality can be improved by the addition of other biogas producing wastes.

## REFERENCES

**Achinas, S. and Euverink, GJW. (2016).** Theoretical Analysis of Biogas Potential Prediction From Agricultural Waste, Resource-Efficient Technologies, 2 (3): 143-147, ISSN 2405-6537, https://doi.org/10.1016/j.reffit.2016.08.001.(http://www.sciencedirect.com/science/article/pii/S2405653716300264). Accessed February 26, 2018.

**Adesehinwa A.O.K. (2007).** Utilization of Palm Kernel Cake as a Replacement for Maize in Diets of Growing Pigs: Effects on Performance, Serum Metabolites, Nutrient Digestibility and Cost of Feed Conversion. Bulgarian Journal of Agricultural Science. National Centre for Agrarian Sciences, 13, 593-600.

**Chaikitkaewa, S.; P. Kongjanb and S. Thong (2015).** Biogas Production from Biomass Residues of Palm Oil Mill by Solid State Anaerobic Digestion. International Conference on Alternative Energy in Developing Countries and Emerging Economies. Energy Procedia 79: 838 – 844.

**Chongrak, P. and Nittalya, K. (1990).** Treatment and Utilization of Solid Agro-industrial waste. Overviews Technical information Services (TIS)/KMUTT, Thailand.

**Czepuck, K.; H. Oechsner; B. Schumacher and A. Lemmer (2006).** Hohenheim Biogas Yield Test: Comparing Theoretical Yields with Actual Batch Yields. Landtechnik 61(2): 82-83.

**GreenLearning Canada Foundation. (2017).** Build Your Own Biogas Generator. The Pembina Institute. Available online at: http:// www.re-energy.ca. Accessed on December 28, 2017.

**Ifeu, (2008).** LCA of palm oil biodiesel (PME): Life cycle comparison. Screening Life Cycle Assessment of Hydrotreated Jatropha Oil. Ifeu-Institute for Energy and Environmental Research Heidelberg GmbH. Available online at: www.ifeu.de. Accessed on December 28, 2017.

**Mel, M.; W.N. Wan Muda; S. I. Ihsanl; A. F. Ismail and S. Yaacob (2014).** Purification of Biogas by Absorption into Calcium Hydroxide $Ca(Oh)_2$ Solution. Persidangan Kebangsa An Kedua Program Pemindahan I Lmu Kedua (Ktp02), Prosiding Ktp XX (2014) XXX-XXX, 9-11 September 2014 Hotel Marriott, Putrajaya. Available online at https://www.researchgate.net/publication/268443998_. Accessed Feb 26 2018.

**Ready B. S. (1998).** Energy for Urban Poor in Developing Countries-Potential Solutions from Waste Materials. Workshop Report on Urban Waste and Energy in Developing Countries. Boiling Point No. 42 - Household Energy and the Environment (ITDG, 1999, p44.)

**Regattieri, A.; M. Bortolini; E. Ferrari; M. Gamberi and F. Piana (2018).** Biogas Micro-Production from Human Organic Waste—A Research Proposal. *Sustainability*, *10*(2): 330; doi:10.3390/su10020330, http://www.mdpi.com/journal/sustainability. Accessed on February 26, 2018.

**Renewable Energy Concepts (2018)** Biogas Basics. http://www.renewable-energy-concepts.com/biomass-bioenergy/biogas-basics/buswell-and-boyle.html.Accessed 28/2/2018.

**Rhule, S. W. A. (1996).** Growth Rate and Carcass Characteristics of Pigs Fed on Diets Containing Palm Kernel Cake. Animal Feed Science Technology., 61: 167-172.

**Romão, C.O.; G.G.P. Carvalho; V.M. Leite; A.S. Santos; D.M.T.Chagas; O.L. Ribeiro; P.A. Oliveira; A.F. Magalhães; and A.J.V. Pires (2014).** Chemical Composition and Dry Matter Digestibility of Sugar Cane Oxide Treated with Calcium. Arq. Bras. Med. Vet. Zootec., 66(2): 529-538.

**Sridhar M. K. C. and AdeOluwa O. O. (2009).** Biotechnology for Agro-Industrial Residues Utilization, chapter 18: Palm Oil Industry Residues. Springer science+ Business Media B.V, Springer Netherlands. p342-354. ISBN 978-1-4020-9941-0.

**Syamala, K.; W.S. Lakra; N.K. Chadha; N.P. Sahu and K.P. Prasad (2017).** Effect of De-Oiled Oil Palm Kernel Meal Based Biofloc System on Growth and Digestive Enzyme Activity of Pacific White Shrimp, Litopenaeus Vannamei. International Journal of Current Microbiology and Applied Sciences ISSN: 2319-7706 6(6):1806-1816.

**Understanding Energy (2017).** Waste Methanisation. Available online at: www.Planete-energies.com. Accessed on December 28, 2017.