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Biogas Production from Palm Oil Mill Effluent Co-Digested with Selected Animal Wastes in a Batch System Bioreactor

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Abstract: ***This study evaluated biogas production from palm oil mill effluent (POME) co-digested with pig dung (PD), cow dung (CD) and poultry manure (PM). Ten liter (10L) capacity batch bioreactors were used, and operated at ambient temperature ($28^{O}C$-$36^{O}C$) and pH range of 6.5-8.5 for 45days. The bioreactors were charged with different ratios (3L/520g, 3L/600g and 3L/680g) of POME/PD, POME/CD, POME/PM while POME alone was the control. Proximate composition of the substrates was estimated, and the methane content of the produced biogas determined by using Gas Chromatography. Microbial analysis was done by standard methods. The result indicated the presence of Escherichia coli, Staphylococcus, Pseudomonas, and Bacillus among others. The cumulative biogas production observed in bioreactor charged with POME/PD 520g, POME/PD 600g, POME/ PD 680g; POME/CD 520g, POME/CD 600g, POME/CD 680g; POME/PM 520g, POME/PM 600g and POME/PM 680g were (6.529dm^3), (6.171dm^3), (9.306dm^3); (8.035dm^3), (10.344dm^3), (7.570dm^3); (4.601dm^3), (6.462dm^3), (7.995dm^3) respectively and POME control (4.635 dm3). The result showed that POME/CD3L: 600g exhibited the highest performance in biogas production (10.344dm3), and the highest percentage methane content (77.89%). Analysis of variance (ANOVA) indicated that biogas yield in POME/CD 600g was significant different (P = 0.05) from every other treatment. These results show that biogas and its methane content production can be enhanced efficiently through co-digestion process.***

Keywords: POME, animal manure, co-digestion, gas chromatography, methane

1. Introduction

One of the most important factors for human development and global prosperity is Energy which about 80% of it comes from fossil fuel [1]. Furthermore, the increasing price and depleting supply of fossil fuel have caused a lot of crisis globally in terms of energy utilization and this has triggered the interest in the use of agricultural waste as a substitute [2]. Also, the negative environmental impact associated with fossil fuel which is non-renewable, increased the interest of researchers in exploring for alternative source of cleaner energy such as biogas (energy from plant and animal origin) resources which are more sustainable, affordable and eco-friendly [3].

Palm oil industry is among the main agro based industries in Nigeria. The processing and production of palm oil leads to the generation of huge quantities of wastes which 50% of it is the wastewater commonly referred to as palm oil mill effluent (POME) [4]. Oswal *et al* [5] reported that high values of 80, 000mg/l chemical oxygen demand (COD) and biochemical oxygen demand (BOD) of POME have made it to be an important source of pollution when released into the environment without proper treatment.

Cows generate a lot of wastes called cow dung/ manure. It serves as manure to soil but if it is not properly disposed, undergoes uncontrolled anaerobic digestion and emits toxic greenhouse gases such as methane and carbon-dioxide that cause global warming. The rapid growth of piggery industry and the increase in demand of pork (pig meat) have led to a large increase in the pig manure worldwide and the pollution impact of the waste on water; soil and air have caused a growing concern in many countries [6]. Large quantity of manure is produced through poultry farming due to increase in human consumption of the meat and this result in large quantities of the manure which if not properly managed may result to environmental pollution [7]. All these wastes produced in the agricultural sector pose severe environmental impacts if not properly managed, including odour, attraction of rodents, harmful insects and pests and release of animal pathogens, atmospheric methane, ammonia, nitrogen etc. [8]. Also these animal wastes which could cause health hazards and environmental problems could be turned to biogas production through anaerobic digestion.

Biogas is a product of anaerobic digestion of organic materials from industrial/ agricultural wastes and sludge stabilization. It is a gas made up of methane (CH_4), carbondioxide (CO_2), water and some trace of gases [9]. Biogas has a number of attractive qualities which include the following: it is derived from plants and animals, non-fossil fuel hence its combustion does not have increase net atmospheric carbondioxide levels as it is a greenhouse gas that causes global warming. Furthermore, it can be produced domestically, thereby offering the possibility of remarkable reduction in the importation of petroleum products. Biogas production does not require advanced and complex technology rather it is very simple to use and apply [10].

Anaerobic digestion is a biological process in which microorganisms act in synergy to convert organic waste into biogas and other useful products (Bio-fertilizer) for agricultural practices without having any harmful effect on the environment, hence it is eco-friendly [11]. Co-digestion with plant waste, animal manure or sewage sludge is recommended in order to optimize the C/N ratio of agricultural residue [12, 13].

In Nigeria a wide range of biodegradable organic wastes are generated daily from various processing industries and agricultural activities from farmers with their inability to use these agricultural wastes in the appropriate ways as agricultural production increase. The wastes which are deemed for disposal indiscriminately into the rivers, roadside or land where they become sources of environmental pollution causing environmental degradation, diseases and health hazard to human can be used for the production of biogas which can be collected and passed through pipes to different sections of the farm where needed or as a fuel to power car, heating purposes or electricity generation. This study therefore investigates the biogas production potential of palm oil mill effluent co-digested with selected animal wastes in a batch system bioreactor.

2. Materials and Methods

Bioreactor Feeds: The palm oil mill effluent (POME) used in this study was collected from a palm oil mill industry at Umuagwo in Ohaji-Egbema LGA, Imo State Nigeria. The sample was allowed to stand for 48hrs and then it was filtered to remove the debris.

The pig dungand poultry dropping were collected from Federal University of Technology Owerri farm in Owerri West LGA, Imo State. The cow dung was collected from an abattoir near 34 artillery brigade Obinze, Imo State. The samples were sun dried until they were sufficiently dry, milled to a finely reduced particles size, sieved and subsequently stored in an air-tight polythene container to preserve the substrate. The samples were used as substrates to feed the digesters when required.

Cow rumen waste was used as the inoculum to stabilize wastes and it was collected from a slaughtered cow in an abattoir at Obinze, Imo State, Nigeria. It was filtered in cheesecloth and stored in, air-tight container in order to maintain the anaerobic environmental condition required by the microorganisms (methanogens) needed for methane production.

Proximate analysis: Proximate analysis of Palm oil mill effluent (POME), pig dung (PD), cow dung (CD) and poultry manure (PM) were carried out using standard methods [14] to determine the Total solid (TS), Volatile solid (VS), Carbon to Nitrogen (C: N) ratio, Ash content, Moisture content. Physico-chemical properties such as pH, temperature, Crude fat, Crude fibre, Crude protein, BOD, COD metals like Potassium, Magnesium, Phosphorus, Calcium etc, were also determined.

Experimental Design: The experimental design and set-up of Opurum *et al* [15] was adopted in this study but with some modifications. Ten (10L) capacity batch bioreactor systems were used for the anaerobic digestion of the substrates. Each bioreactor was equipped with a thermometer for measuring the temperature and an outlet for gas passing to the gas collecting system. The hose from the bioreactor was connected to a 13L transparent bucket and 3L transparent bucket inverted in it which served as a gas collector. A short hose was attached on the 13L bucket for collection of displaced water. The experimental set up which was in triplicate is shown in Figure 1. The bioreactors were charged at different ratios with POME/PD, POME/CD and POME/PM each; 3L: 520g, 3L: 600g and 3L: 680g respectively for digesters 1, 2, 3, 4, 5, 6, 7, 8 and 9 of each co-digested substrate while digester 10 (control) contained 3L of POME.

Freshly strained cow rumen waste (20% of the total slurry volume) was used as the inoculum which provided the source of methanogens. Digestion of the substrates under anaerobic condition was at room temperature which varied between $28^{O}C$- $36^{O}C$. Each bioreactor was manually mixed in order to prevent sedimentation. The daily biogas yield for each bioreactor was recorded by adopting the downward water displacement method [15]. The volume of biogas yield was measured and the mean values recorded on daily basis at every 24hrs.

Microbiological analysis:

Samples for microbial analysis were collected in sterile bottles immediately after the digesters were set up. The various bacterial and fungal species in the digesting slurry were determined by the use of various culture media using the spread plate technique as described by Bergey's Manual of Determinative Bacteriology [16]. The inoculation of each prepared medium was done after 10 fold serial dilution. From each of the 10 fold diluted samples, 0.1ml was inoculated onto Nutrient agar (NA), Eosin Methylene Blue agar (EMBA), MacConkey agar (MCA), Potato Dextrose agar (PDA), Salmonella-Shigella agar (SSA), Mannitol Salt agar (MSA), Centrimide agar (CA) and Sabouraud Dextrose agar (SDA) prepared according to manufacturers' instructions. Microscopic examination, biochemical tests and Gram staining were carried out by adopting standard methods [16].

Gas Chromatography (GC) analysis:

The flammability test was also carried out on daily basis to determine the flammable biogas which was collected and the co-digested substrate ratios with the highest biogas yield were analyzed using Gas Chromatography (GC), GC-TCN (M910) with helium as a carrier gas at 5psi, with a flow rate of 20ml per minute to ascertain the biogas composition. The experiment was monitored for 45days hydraulic retention time (HRT).

Statistical Analysis of Data: The cumulative biogas yield in all the treatments and control were statistically analyzed using analysis of variance (ANOVA).

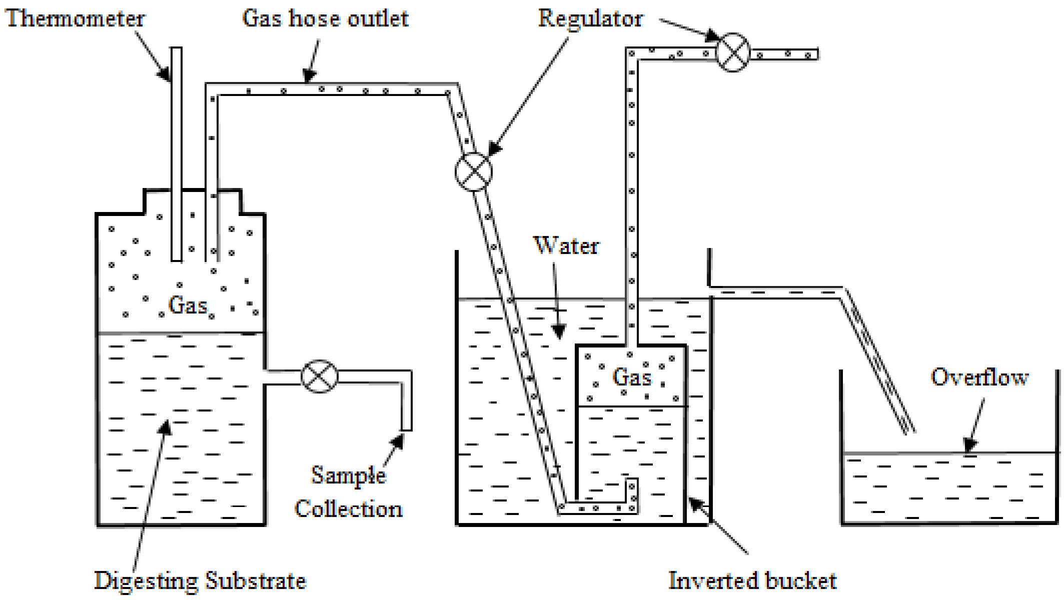

Figure 1: Bioreactor Design

Source: Opurum *et al* [15]

3. Results and Discussion

Physicochemical Characteristics of the Substrates.

The physico-chemical parameters of the POME, PD, CD and PM were determined and the results are shown in Table 1. ThePOME has a Carbon to Nitrogen (C/N) ratio of 10:1, PD6:1, CD18:1 and PM14:1. It was observed that none of the substrate has an optimum C: N ratio, hence there is need for co-digestion.

Anaerobic Digestion and Biogas production.

This study shows that co-digestion of POME/CD, POME/PD and POME/PM in the ratios of 3L:520g, 3L:600g and 3L:680g respectively had higher cumulative biogas yield of (8.035dm^3), (10.344dm^3), (7.570dm^3); (6.529dm^3), (6.171dm^3), (9.306dm^3) and (4.601dm^3), (6.462dm^3), (7.995dm^3) respectively than POME alone that had cumulative biogas yield of 4.635dm^3 (Table 2). Co-digestion of these substrates was capable of improving the efficiency of biogas production. The bioreactors charged with POME/CD, 3L: 520g and 3L: 600g ratios started biogas production on day 1, while 3L:680g ratio started on day 2. Flammability test indicated that flammable biogas production in 3L: 600g ratio started on day 2, while in 3L: 520g and 3L: 680g ratios flammable biogas productions started on day 3.

Co-digestion of POME/CD 3L:600g which had the highest biogas yield and percentage methane content, started biogas production on the 1stday, flammable gas on the 2nd day and the peak recorded on the 6th day with biogas yield of 2.216dm^3. The cumulative biogas yield was 10.344dm^{3}asshown in table 2, hence considered to be a very good substrate for biogas production.

POME co-digested with pig dung, 3L: 520g ;3L: 600g and 3L: 680g ratios biogas production started on day 1 and flammability test indicated that 3L: 680g started flammable biogas production on day 3, while 3L: 520g ratio started on day 4, then 3L: 600g ratio started on day 5. POME co-digested with pig dung (3L: 680g) which started biogas production on the 1st day, started producing flammable gas on the3rd day and the peak recorded on the4th day with biogas yield of 1.679dm^{3}and cumulative biogas yield of 9.3 06dm^{3}as shown in table 2, is another good substrate for biogas production.

POME co-digested with poultry manure, 3L: 520g biogas production started on day 2, while 3L: 600g and 3L: 680g ratios biogas productions started on day 1. Flammability test indicated thatin3L: 680g, flammable biogas production started on day 33, while 3L: 520g and 3L: 600g ratios did not produce flammable biogas. POME co-digested with PM, 3L: 680g which started biogas production on the 1stday, recorded the peak on the 3rd day with biogas yield of 1.196dm3 and cumulative biogas yield of 7.995dm^{3}as shown in Table 2. In the control (POME alone) biogas production started on the 2nd day, flammable biogas production started on the 4th day, the peak recorded on the 5th day with biogas yield of 1.210dm3 and cumulative biogas yield of 4.635dm^3 as shown in Table 2, which was one of the lowest biogas yield had in the study. This could be attributed to the low volatile solid concentration of 13.39%and low total solid concentration of 13.93%which is the amount of the POME convertible to gaseous element and providing nutrients to the microorganisms for their function, along other parameters like the low C/N ratio of 10.13%.

Gas Chromatography.

The result showed that the highest percentage methane yield was achieved from co-digestion of POME/ CD (3L: 600g) as shown in Table 3. The methane level achieved was 77.89%for POME/CD (3L: 600g), 76.66% for POME/PD (3L: 680g), 44.14% for POME/PM (3L: 680g) and 56.53% for POME (control). From this study, the mixing ratio of POME/CD (3L: 600g) has been recognized as suitable mixture for biogas production as well as methane content.

Microbial Analysis.

Some of the bacterial isolates from the digesting slurry were: *Escherichia coli, Staphylococcus, Pseudomonas, Bacillus, Enterococcus, Enterobacter, Micrococcus* species and fungal isolate, *Saccharomyces* species.

Statistical Analysis.

Statistical analysis indicated that POME /CD 600g is significantly different from every other treatments, POME / PM 520g and POME alone are significantly lower while other treatments are not statistically different from each other.

4. Discussion

Results of the physico-chemical parameters analysis of the substrates showed that some of the substrates have low C: N ratio, indicating the necessity for co- digestion with suitable substrate. Carbon to Nitrogen ratio (C: N) is one of the important factors that influence biogas production from different substrates and this makes it a vital parameter that is considered in enhancing biogas production from feedstock [17]. It is very imperative to maintain a suitable composition of the feedstock for optimum plant operation so that the C: N ratio in the substrate remains within the desired range.

The improvement in the cumulative yield in biogas generated by the co-digested substrates could be attributed to these factors mentioned above, similar result was observed by Aragwa [18] who reported that co- digestion of different feedstock substantially enhanced the biogas yields by 24 to 47% over the control (organic kitchen waste and dairy manure only). Also, biogas yield depends on C: N ratio of the various feed stocks used in the anaerobic digestion [19], and the optimum range of C: N ratio for biogas yield is 20-30: 1 [13]. Similarly, biogas yields of POME co-digested with other substrates are higher than that of POME alone.

The cumulative biogas yield of the co-digested substrates had higher cumulative biogas yield of (8.035dm^3), (10.344dm^3), (7.570dm^3); (6.529dm^3), (6.171dm^3), (9.306dm^3) and (4.601dm^3), (6.462dm^3), (7.995dm^3) respectively than POME alone that had cumulative biogas yield of 4.635dm^3 (Table 2), showing that co-digestion of these substrates was capable of improving the efficiency of biogas production. Similar result was observed by Murto *et al* [20] who reported that co-digestion can improve biogas production by 50-200% depending on the operating condition and the substrates used in the anaerobic digestion. Ibrahim *et al* [21] also reported that anaerobic digestion of POME alone affected its methanogenesis process which is very important in anaerobic digestion as it is the terminal step of producing biogas. Secondly, low amount of methanogens will contribute to the slow rate of the biogas production.

The microorganisms isolated from the digesting slurry in this study are in agreement with previous research as demonstrated by Asikong *et al* [22]. The biogas produced in the anaerobic digestion process was flammable in bioreactors co-digested with POME/CD, POME/PD (3L: 520g, 3L: 600g and 3L: 680g), POME/PM (3L: 680g) only and POME alone. The delay in flammable biogas production of POME/PM (3L: 680g) which started on the 33rdday may be attributed to the production of ammonia due to imbalance in C/N ratio. This delay period was also reported by Ofoefule and Uzodinma [23] in the blend of cassava peels waste with pig dung in anaerobic digestion process.

The result also shows that the highest percentage methane yield was achieved from co-digestion of POME/CD (3L: 600g) as shown in Table 3. The methane level achieved was 77.89% for POME/CD (3L: 600g), then other mixtures, it was 76.66% for POME/PD (3L: 680g), 44.14% for POME/PM (3L: 680g) and 56.53% for POME (control). The remaining percentages were constituted by the following: Carbon-dioxide, Carbon-monoxide, and trace elements namely; hydrogen (H_2), oxygen (O_2), nitrogen (N_2) and water (H_2O). From this study, the mixing ratio of POME/CD (3L: 600g) has been recognized as suitable mixture for biogas production as well as methane content. In this study also, only 56.53% of methane was produced from the anaerobic mono-digestion of POME. The potency of co-digestion is once more proven as the production level was elevated from 56.53% to much as 76.66% to 77.89% in term of methane content.

Table 1: Proximate analysis of substrates

Parameters (%)	Substrates			
	POME	PD	CD	PM
Fat content	8.23	11.39	5.43	6.98
Fibre content	-	7.20	7.58	10.40
Ash content	0.54	34.73	31.31	12.50
Crude Protein	3.25	22.09	6.34	9.68
Organic carbon	48.90	20.61	17.96	22.05
C:N Ratio	10.13	5.84	17.50	14.24
Nitrogen	5.12	3.53	1.02	1.55
Moisture content	86.08	15.45	5.62	10.74
Carbohydrate	1.90	9.14	43.72	49.70
Volatile Solids	13.39	49.82	63.07	76.76
Total Solids	13.93	84.55	94.38	89.26
pH	4.06	7.8	6.5	6.9

Table 2: Cumulative biogas Yieldfrom the different substrate ratios (dm^3)

Treatment	3L:520g	3L:600g	3L:680g
POME/PD	6.53	6.17	9.31
POME/CD	8.04	10.34	7.57
POME/PM	4.60	6.46	8.00
POME control	4.64	4.64	4.64

Table 3: Percentage biogas composition of bioreactors with the highest methane yield.

Substrates (g)	**Percentage composition (%)**	
	Methane (CH4)	Carbon-dioxide (CO_2)
POME/CD, 3L/600	77.90	13.34
POME/PD, 3L/680	76.66	15.74
POME/PM, 3L/680	44.14	38.80
POME control	56.54	30.92

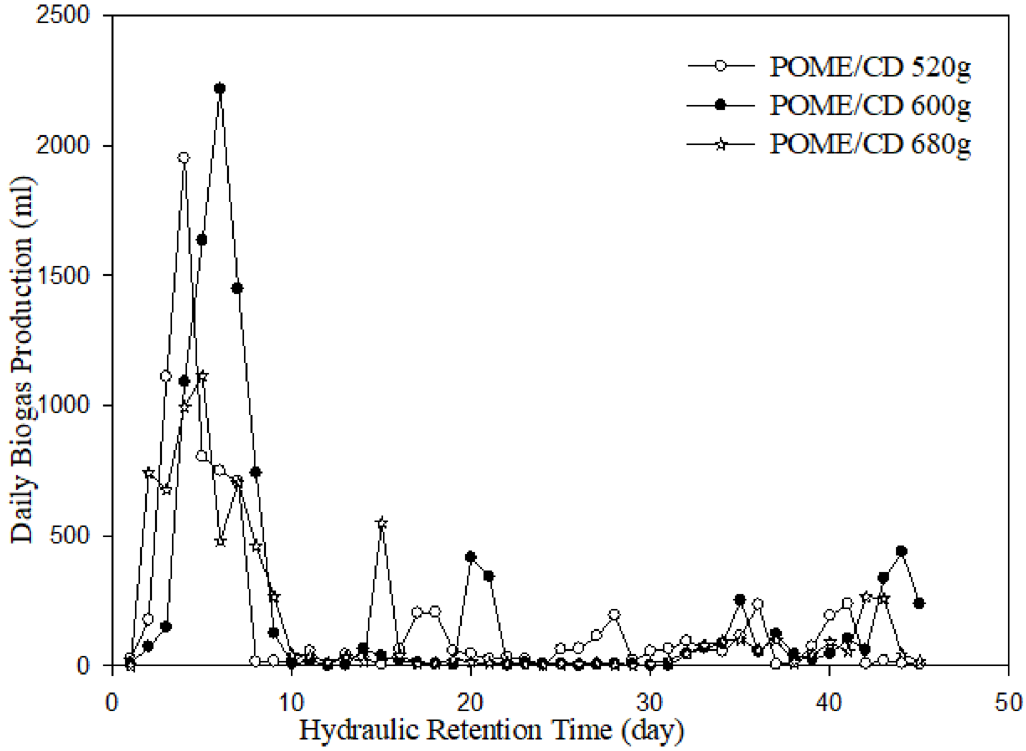

Figure 2: Profile of Daily biogas production from Mixtures of POME/CD

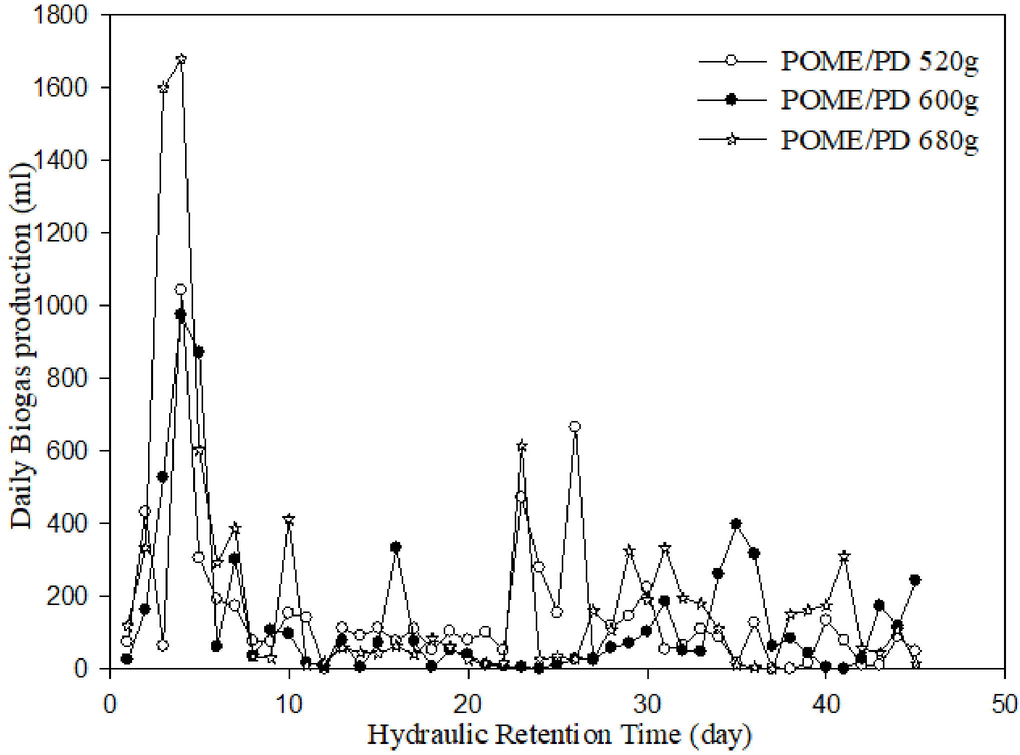

Figure 3: Profile of Daily biogas production from Mixtures of POME/PD.

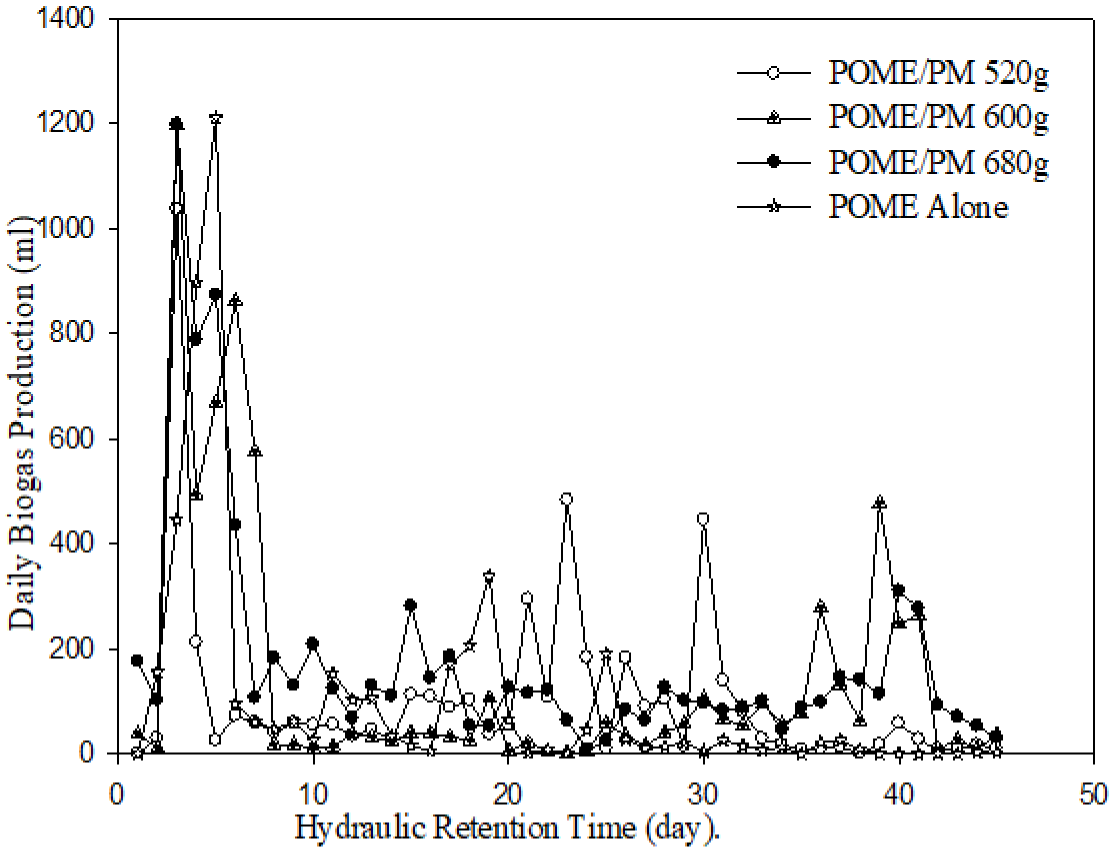

Figure 4: Profile of Daily biogas production from Mixtures of POME/PM and POME alone.

5. Conclusion

The result of the study has shown that anaerobic co-digestion of palm oil mill effluent (POME) co-digested with cow dung (3L: 600g) is significantly different from every other treatment, POME co-digested with poultry manure (3L:520g) and POME alone are significantly lower while other treatments are not statistically different from each other. Also the cumulative biogas yield of the co-digested substrates was improved when compared to POME alone. The best performance in biogas production was noted in bioreactor charged with POME/CD 600g, followed by POME/PD 680g and POME/PM 680g. Palm oil mill effluent and other agro - wastes that are disposed indiscriminately, causing environmental pollution and health hazard can be converted through anaerobic digestion and biogas technology to bio-methane and the sludge used as soil conditioner (Biofertilizer).

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