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Comparative Study on Ignition Time of Biogas From Cattle Dung and Mixtures of Cattle Dung With Cassava Peels

Yaru, S.S.[1], Adegun, I.K.[2], Akintunde, M. A.[1]

1 Department of Mechanical Engineering, Federal University of Technology, Akure, Nigeria
2 Department of Mechanical Engineering, University of Ilorin, Ilorin, Nigeria.

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Ignition time, cattle dung, mixture, cassava peels, biogas

A B S T R A C T

This paper investigated the ignition time of biogas from cattle dung and mixtures of cattle dung with cassava peels. The cattle dung was sourced from FUTA agricultural farm and cassava peels from a gari processing farm in Akure. The cassava peels was mashed before mixing with the cattle dung. The substrates were charged to four digesters each with a radius 0.173 m, 0.66 m high and 2 mm thick. 8 kg of cattle dung was mixed with equal mass of water and charged to the first digester; the second digester was charged with 1 kg cassava peels and 7 kg cattle dung; the third with 2 kg cassava peels and 6 kg cattle dung while the fourth digester was filled with 4 kg each of cassava peels and cattle dung. The substrates with water were made to two-third the volume of each digester before they were closed gas tight and then subjected to anaerobic digestion for 55 days in an open workshop in FUTA. Biogas from each digester was daily tested for combustion. The pH of the substrates was measured with digital pH meter before they charged to the digesters for incubation. That of the effluent was determined after the biogas was tested for ignition and the volume measured. Biogas from each digester was measured by water displacement method. Ambient and digester temperatures were also daily monitored at 10 a.m. and 4 p.m. using mercury-in-glass thermometer already installed on top surfaces of the digesters. The biogas from the first digester ignited with a blue flame on day 14, while the one obtained from digester 2 ignited on the 27th day of incubation. Biogas from the 3rd digester ignited on day 48 as that from 4th digester got ignited on the 55th day of incubation. The ambient and digester temperatures in the mornings were generally lower than those for the evenings for the days of incubation. On cold days, as a result of rainfall or cloud formation, the morning ambient and digester temperatures fell below even morning environmental temperatures. It showed that cattle dung produced biogas earlier than the mixture of the two wastes and the combustion time increases with increase in the mass of cassava peels in the mixture. The PH for cattle dung slurry and those of the mixtures in order of increasing mass of cassava peels were respectively 6.9, 6.6, 6.4 and 6.3 while the pH of the effluents are 7.12, 7.16, 7.14 and 7.21.The volume of biogas in the same order were 4500 ml, 5200 ml, 5400 ml and 6500 ml.

Biogas is a green house gas (GHG) with a global warming potential (GWP). Intergovernmental panel on climate change reported that the GWP of biogas is 21 times that of carbon dioxide. It is produced from the anaerobic digestion of organic and biodegradable materials. For instance, methane, the principal component of biogas records an annual global emission of about 590 to 800 million tons to the atmosphere as a result of anaerobic digestion of organic matter (Bond and Templeton, 2012).This implies that it can also be produced in the gut of living organism especially man and ruminants like the bovines that regurgitate and chew the cuds as fermentation, to some extent, it takes place in them because of bacteria activities in these organisms (Kitani, *et al*,1999) The biogas with the concerned challenge is that produced from the wastes of plants and animals in open areas and places when the condition for the growth of fermentative bacteria becomes favourable. This happens in places like the refuse dump sites, marshy areas, soak ways and so on. In addition to the global warming phenomenon, biogas has offensive and unpleasant odours since it is a combination of gases, some with characteristic odours. In addition the wastes become breeding places for diseases and disease vectors like mosquitoes, flies, cockroaches and even rodents.

To arrest all these challenges, biogas collection and use as a renewable energy source becomes imperative. But the biogas becomes useful when it is combustible. So the ignition time of biogas from a given waste becomes crucial in order to serve as a guide for treatment of wastes from different biological sources of organic origin. A lot of work had been done on biogas from the animal wastes like cattle dung, poultry droppings, piggery wastes, etc.and the

Correspondence:
E-mail address: ssyaru@yahoo.com /ajyinka@gmail.com
kadegun@unilorin.edu.ng

ignition time especially for cattle dung has been established by different authors to be two weeks at mesophilic temperature range. But not much has been established for biogas from plant wastes and combination of plant and animal wastes. For example, Okoroigwe, *et al.,* (2014), generated combustible biogas from the fermentation of dog wastes (excreta) within 20 days at a mesophilic temperature range between 24 °C and 44 °C, and at almost a neutral value of pH 7. They reported that the biogas generated was lower than those biogases from other animal wastes. Biogas comprises 50-70% methane (CH_4), 30-40% carbon dioxide (CO_2), 5-10% hydrogen (H_2), 1-2% nitrogen (N_2) and traces of hydrogen sulphide (H_2S) and water vapour (Prasad, 2012). Ogiehor and Ovueni (2014) investigated the effect of temperature, pH and solid concentrations at mesophilic temperatures of 25 °C and 35 °C on biogas production from poultry wastes.

They reported that these three parameters had effect on biogas production and their composite effect was most efficient at 35 °C, pH 7 and 25% solid concentration. Pandey and Soupir (2012) worked on the temperature effect of anaerobic digestion of dairy manure at 25 °C, 37 °C and 52.5 °C. They reported that largest quantity of biogas was produced at 52.5 °C followed with that at 37 °C and then that of 25 °C brought up the rear. The pH value was however higher than neutral at 52.5 °C, lower than neutral at 37 °C but neutral at 25 °C. The bacteria involved in an anaerobic digestion can only work and produce the biogas if the substrate is sufficiently bloated with water to at least 50% (Vindin, et al, 2008). Adegun and Yaru (2013) were able to generate combustible biogas from cattle dung within 13 days at mesophilic temperature range from 26 °C to 30 °C and Wantel, *et al.*, (2014) obtained biogas from the co-digestion of cattle and goat dung. Ukpai and Nnabuchi (2012) compared the biogas production from cow dung, cow pea and cassava peeling in a 45 litre bio-digester in a mesophilic ambient and slurry temperature range of 20-32 °C and 22-36 °C respectively. They reported that the cattle dung recorded the highest cumulative biogas production followed by cow pea and then cassava peeling.

Adelekan (2012) succeeded in producing ethanol only from the fermentation of cassava peels alone. He however obtained biogas when the cassava peels was seeded with live stock wastes like cattle dung, poultry droppings and pig dung. While cassava peel/pig dung mixture at 1:1 recorded highest production of biogas, he also reported that cassava peels failure to produce biogas was as a result of the presence of lignin and cellulose which were difficult to hydrolyze during fermentation. Yaru, *et al.,* (2013) compared biogas production of cattle dung and a mixture of cattle dung with plantain peels and they reported that the mixture produced more biogas than cattle dung alone. Eze and Ojike (2012) also studied biogas production from maize cobs, stalks and chaffs. They reported that the maize chaffs produced the biogas followed by the stalks and then the cobs.

The objective of this paper therefore is to determine the ignition time of the biogas from the fermentation of cattle dung and mixtures of cattle dung with cassava peels.

2.0 Theory of biogas production

Biogas production follows three stages in the process of incubation; these are: hydrolysis; acetogenesis and methanogenesis. Some authors split acetogenesis into acidogenesis and acetogenesis thus bringing the processes to four. In the hydrolysis stage, polysaccharides, proteins, lipids and cellulose are broken down into monosaccharide and amino acids. The bacteria act on carbohydrates, to produce hydrogen, fatty acids and carbon dioxide (Appel*, et al.,* 2008). Wirth, *et al.,* (2012) reported that bacteria such as clostridium spp, bacteriodes, clostridium cellolitian, among others take part in this process.

\ They also added that in the acidogenesis of the fatty acids, amino acids and simple sugar, slackia, hellotrini reducers, candidales clocamonas and streptococcus spp are some of the microbes that take part in the process. In the acetogenesis, volatile fatty acids, propionate, butyrate, succinate and alcohols produce acetate and carbon dioxide in the presence of carboxydotherms and hydrofomers. The methanogensis of these compounds to produce methane and carbon dioxide takes place in the presence of acetotrophs such as methanosacrina bakeri and hydrogenotrophs. The methane bacteria are most active at neutral pH 7 or slightly alkaline condition at 8.5 for optimum performance. A digester with high volatile acid concentration would require high pH as the pH of 6.2 or below is toxic to methanogenic bacteria (Asgari, *et al.,* 2011).

3.0 Materials and experimental procedure

The materials used for the digesters were made of mild steel with 2 mm thickness, internal radius of 0.173 m and 0.66 m high. Mercury in glass thermometers were installed on the top surface of the digesters for the monitoring of digester temperatures. Gas valves were also installed on the top surface of the digesters to test for the combustion of the biogas. The substrates used were cattle dung and cassava peels. The cassava peels were mashed so as to increase the surface area of the cassava peels in order to aid digestion. Four digesters were fed with the substrates. The first digester was fed with 8 kg of cattle dung; the second with 1 kg of cassava peels and 7 kg of cattle dung; the third digester was charged with 2 kg cassava peels and 6 kg cattle dung; and the fourth digester with 4 kg each of cassava peels and cattle dung.

` The substrates were separately mixed thoroughly and then with equal mass of water before they were charged to the respective digester. The mixture in each digester was then made to three quarter of its volume and thoroughly stirred before the lid with a seal of the digester was closed gas tight. The digesters were then placed in an open workshop in the Federal University of Technology, Akure, Nigeria. Temperatures of the digesters were taken twice daily, at 10 am and at 4 pm and were also stirred daily with a stirrer already incorporated in each of them. Combustion of the biogas from each digester was also tested every day through the gas valve. This was done for 55 days from 4th May, 2014 to 27th June, 2014. The pH of the each slurry was determined before charging it to the digester. The digestates pH was determined immediately after the gas in the respective digester ignited. The digestates were accessed by opening the digesters after the test for ignition and the collection of biogas over water. This was done with a digital pH meter of the make "Combo pH and EC", "waterproof by Hanna, HI98130 and made in Mauritius. The biogas from each digester was collected over water using a 500 ml measuring cylinder. A rubber hose was connected to the valve in each digester which was then extended to a rubber containing water and then inserted at a beehive shelf at the bottom of the container. The measuring cylinder filled with water was turned upside down so that its mouth rested on the beehive shelves. As the gas valve was opened the gas bubbled in the cylinder to displace the water in it. Heat transfer across the digester walls were as well estimated using Fourier′s equation of heat conduction as shown in equations (1) and (2) with the assumption that the heat transfer takes place across all the digester surfaces.

$$Q = -KA\frac{dT}{dx} \qquad (1)$$

For a cylindrical digester in which heat conduction takes place across all the surfaces including the top and bottom surfaces, the heat transfer is as expressed in equation (1) as given by Rajput, (2004) is,

$$Q = \frac{2\Pi Kl(T_1 - T_2)}{\log_e\left[\frac{r_2(r_1+l)}{r_1(r_2+l)}\right]} \qquad (2)$$

Radius, r_1 = 0.173 m; r_2 = 0.175 m; Height = 0.66 m,
K = 20 W/m^{2}K Rajput, (2004).

Where, Q is the rate of heat transfer; A is the surface area; K is the thermal conductivity of material (mild steel); dT/dX is the temperature gradient; r_1 and r_2 are respectively internal and external radius of the cylindrical digester; and l is the height of the digester

4.0 Results and Discussions

The equation of reaction for the test of combustion of biogas is as presented in equation 3. Methane is the principal component of biogas and this combines with air to produce carbon dioxide and water. During combustion, a molecule of methane reacts with two molecules of oxygen to produce a molecule carbon dioxide and two molecules of water.

$$\underbrace{CH_4}_{methane} + \underbrace{2O_2}_{Oxgen} = \underbrace{CO_2}_{Carbon-dioxide} + \underbrace{2H_2O}_{Water} \qquad (3)$$

The plotted ambient and digester temperatures as well as the heat energy transfer across the digesters are also shown in Figures 1 to 8, while Figure 9 shows the column chart for ignition time of biogas for cattle dung and mixtures of cattle dung and cassava peels. Table 1 presents the pH of the substrates and the respective effluents while the volume of biogas from each digester is as shown in Table 2. The plotted ambient and digester temperatures as well as the heat energy transfer across the digesters are also shown in Figures 1 to 8, while Figure 9 shows the column chart for ignition time of biogas for cattle dung and mixtures of cattle dung and cassava peels. Table 1 presents the pH of the substrates and the respective effluents while the volume of biogas from each digester is as shown in Table 2.

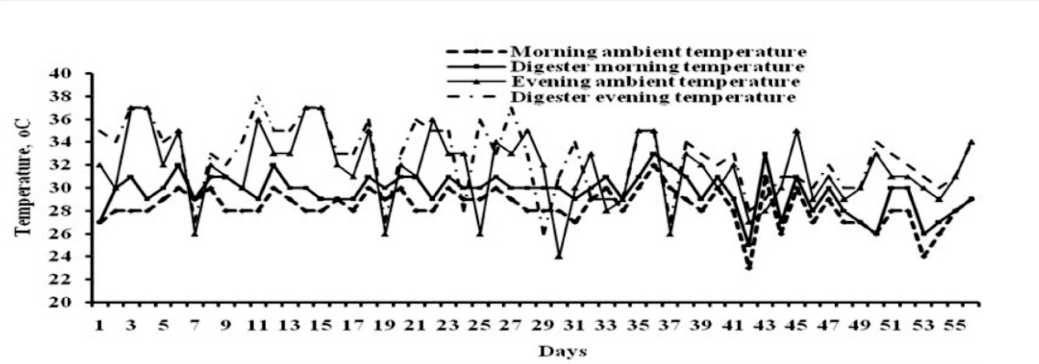

Figure 1: Variation of ambient and digester temperatures with days of incubation for 8 kg cattle dung

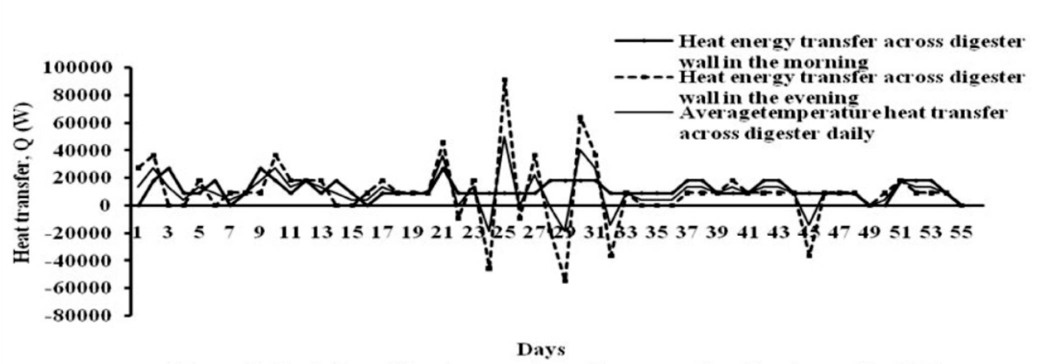

Figure 2: Variation of heat energy transfer across the digester wall with days of incubationfor 8 kg cattle dung

The graph of the ambient and digester temperatures monitored at 10 a.m. and 4 p. m. is as shown in Figure 1. The ambient and digester temperatures in the morning were always lower than those in the evening. This is because the temperatures are low in the nights of the previous days which had carryover effects and at the same time the atmosphere had not warmed up enough from the effect of solar energy, hence their low temperatures. In the evening the atmosphere would have relatively been warmed enough and with this interaction, the digester temperature increased as that of the environment. This was observed for day 12. The morning ambient temperature was 30 °C and that of the digester was 32 °C while these values for the evening were respectively 33 °C and 35 °C. This fell in line with the claim of Aremu and Agarry (2012) that anaerobic digestion can take place at the mesophilic temperature range of 75-100 °F (26 °C-43 °C).

There was however a situation where the evening temperatures of the environment and that of the digester fell below those in the morning. This was as a result of change in weather conditions due to rainfall or cold breeze resulting from the formation of clouds. This was the case for example with days 7, 19, 24, 29, 37 and 43. The ambient and digester temperatures in the morning were 29 °C each while the evening values were respectively 26 °C and 27 °C. So also for day 19, 29 °C, 30 °C, 26 °C and 27 °C were morning and evening respective ambient and digester temperatures.

It also happened that the temperature of the digester was lower than that of the ambient as environmental temperatures became so low especially when it rained over the previous night as the anaerobic reaction is exothermic.

Figure 2 shows three graphs indicating the heat transfer across the digester walls and the environment for morning, evening and the one using difference between the daily average digester and ambient temperatures. The heat energy transfer is heavily dependent on the temperature difference. It therefore increased with increase in the temperature difference and decreased with its decrease. These were noticeable on days 9, 20, 22, 24, 25, 27, 29, 31, 32 and 45. The plots showed that on days 9, 20, 25, 27 and 31, there were positive temperature differences. For example, the heat transfer in morning, evening and the evening were respectively 27356.89 W, 9118.964 W and 18237.93 W on the 9th day of incubation. Then days 22, 24, 29, 32 and 45 recorded negative heat transfer from the digester as the substrates became exothermic as digester temperatures were lower than environmental temperatures. It was also observed that the energy transfer from digester to the environment and vice versa through the digester wall in the evening was the highest, followed by the one with daily average temperature while those in the morning brought up the rear.

Ambient and digester temperatures monitored in the mornings and evenings are also plotted as shown in Figure 3. The temperatures in the evenings were always higher than those in the mornings for the same reasons as they were for Figure 1. The exceptional case of temperature rise of this digester in the evening was observed on days 19, 23 and 26 because sun rays directly fell on the digester as the sun went down before setting. On day 19, the ambient temperature in the morning was 29 °C while that of the digester was 31°C. The evening ambient temperature was 35 °C and that of the digester was 45°C.

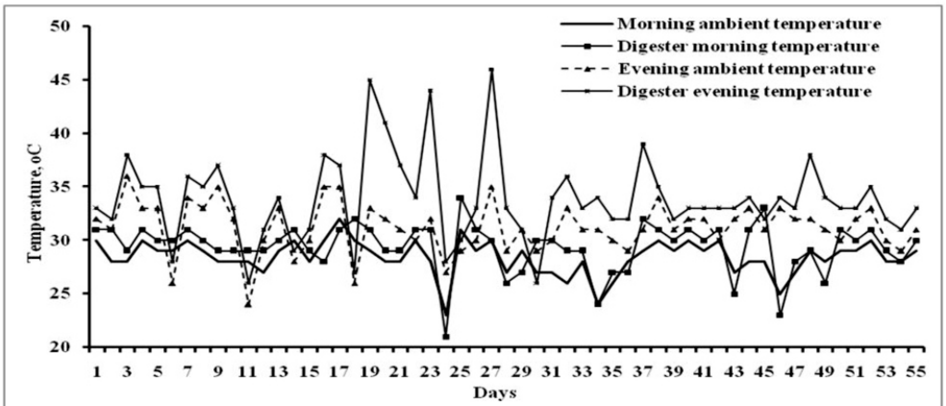

Figure 3: Plots of ambient and digester temperatures for 1 kg cassava peels with 7 kg cattle dung

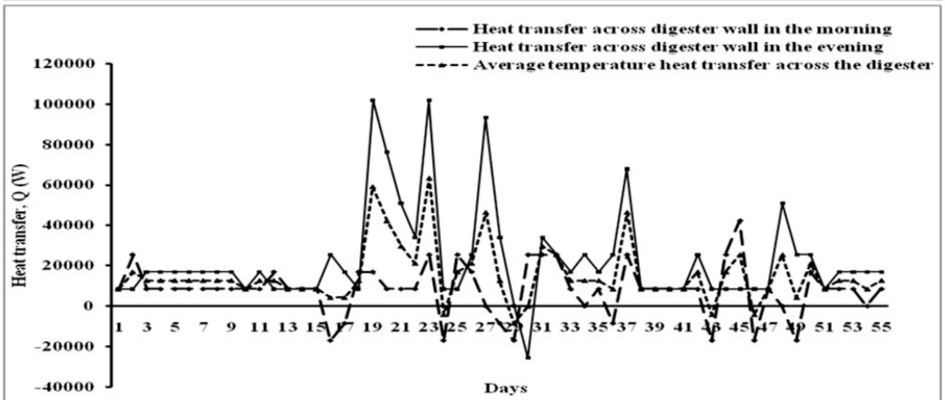

Figure 4: Graphs of heat transfer across the digester walls with the environment for 1 kg cassava peels with 7 kg cattle dung

On the 23rd day , the temperatures in the same order were 28 °C, 31 °C, 32 °C and 44 °C while the values for day 26 were 30 °C, 30 °C, 35 °C and 46 °C respectively. Other observations made are same as those made for Figure 1. The temperature range at which this digester was monitored also agreed with the mesophilic range of 24 °C - 44 °C as reported by Okoroigwe, *et al.,* (2014)

Figure 4 shows the plots of the heat transfer across the wall of the digester for the parameters considered as in digesters earlier discussed. On day 1, the transfer in the morning, evening and for average heat transfer were each 8472. 115 W. Between day 1 and day 3 heat transfer went up a bit to about 20000 W for daily average temperature above others thus indicating positive heat transfer as the anaerobic reaction of the substrate in the digester was exothermic. These values respectively rose to 25416.35 W, 8472.115 W and 16944.20 W on the 3rd day. From day 3 to 10, a plateau was formed in the heat transfer phenomenon with the morning, evening and average temperature values at 8472.115 W, 16944.23 W and 12708.17 W respectively.

This was as a result of equal temperature differences between the digester and the environment. Subsequent daily heat transfers were interwoven up to 16th day with the negative values value of -16944.20 W for the heat transfer in the morning as the ambient temperature was higher than that of the digester, 25416.23 W for the evening and 4236.056 W for the average temperature heat transfers respectively where digester temperatures were higher than the ambient ones. The heat transfer process went up especially on days 19, 23, 27 and even 37 with heat transfer in the evenings being the highest to almost 12000 W. For example, the heat transfer values for the morning, evening and average temperatures for day 19 were respectively 16944.23 W, 101665.40 W and 59304.81 W. This was due to the effect of the sun rays which fell directly on the digester in the evenings.

The heat transfer process increased with rise in temperature and then dropped as temperature went down even to a stage that temperatures were lower than those of the environment. Figure 5 shows the plots of the daily morning and evening readings of the ambient and digester temperatures. As with other digesters already discussed the morning ambient and digester temperatures were ordinarily lower than those in the evening. But on a cold day, as a result of rain or cloud cover, evening temperatures of the environment and those of the digester fell so low and even lower than the morning parameters. These occurred on days 5, 11, 18, 20, 23, 29 and 40. The digester temperatures were higher than the ambient ones because the whole anaerobic digestion process in the digester was an exothermic reaction.

The heat transfer from the digester across digester wall to the environment is as shown in Figure 6. On the first day the heat transfer for the morning, evening and for the average temperatures each was 9121.45 W. On day 2, it was the heat transfer for the morning that dropped to zero while that for the evening remained at 9121.45 W and the one for the average temperature was 4560.73 W. The zero value was possible because the ambient and the digester temperatures were equal while their difference for the average temperature was higher but less than that for the evening. From day 3 to 5, a plateau was formed for the three values thus indicating that their temperature difference were equal.

On the 7th day, the morning value was -9121.45 W, that for the evening was 9121.45 W and that for the average temperature was zero. The negative value was because of cold weather due to may be rain that had caused drop in temperature over the night such that the digester temperature fell below that of the ambient. All these reasons accounted for the zigzag nature and plateau formation of the three plots throughout the days of incubation.

There are four graphs on the plot in Figure 7. The morning ambient temperature and the digester temperature always read in the morning at 10 am and for the same parameters read in the evening at 4 pm. The morning ambient temperature was the lowest with that of the digester slightly above with maximum of 2 °C. The evening ambient and digester temperatures were higher than those for the morning. This could be seen from the first day of charging with morning ambient and digester temperatures as 28 °C and 29 °C respectively while those of the evening were 37 °C and 39 °C.

This is because the weather is always cool in the night and therefore the low ambient and digester temperatures in the morning as the digester was placed in open workshop where the air flow was not controlled. In the evening the heat energy resulting from the solar energy rays during the day would have warmed the atmosphere thus culminating in relatively higher ambient and digester temperatures. The digester temperatures were usually higher than those of the ambient as fermentation; an exothermic reaction was taking place in the digester. The digester temperatures were proportional to those of the ambient as the temperatures of the digesters were not controlled. There was however a drop in the evening ambient and digester temperatures to almost those morning values and even lower in most cases.

This phenomenon occurred in days 5, 11, 19, 21, 23, 29, 33, 39and 45. This was due to rainfall during the day thus making the temperature to fall so low below the level of the morning values or even lower. For instance on day 5 the ambient temperature was 26 °C while that of the digester was 27 °C; 24 °C and 28 °C for the ambient and digester respectively on the 11th day.

Figure 8 shows the plots of the heat transfer across the the digester was for the mornings, evenings and for the daily average temperature of the mornings and evenings. On day 1, heat transfer was higher than that for day 2 because the digester temperature was higher. The plateau formed for the three plots from the second to the eighth day was as a result of their temperature difference. The heat transfer went up to about 20000W because of the high temperature of the digesters. The heat transfer is dependent on temperature and it rose as the temperature increased and dropped as the temperature decreased. The particular cases of days 20, 34 and 36 showed that the heat transfer fell to zero. This was due to rain during the day which brought temperature so low.

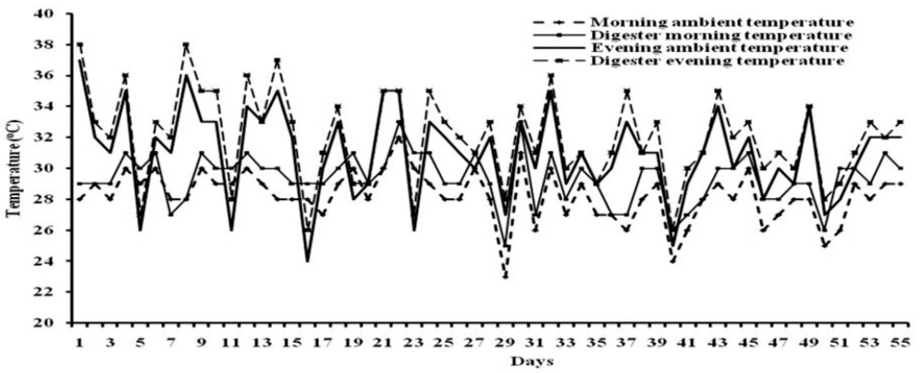

Figure 5: Plots of ambient and digester temperatures against days for 2 kg cassava peels with 6 kg of cattle dung

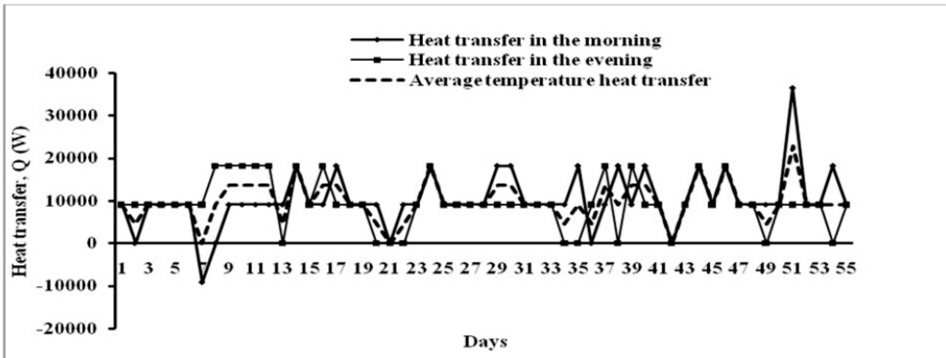

Figure 6: Heat transfer across digester wall for 2 kg cassava peels 6 kg cattle dung versus days of incubation

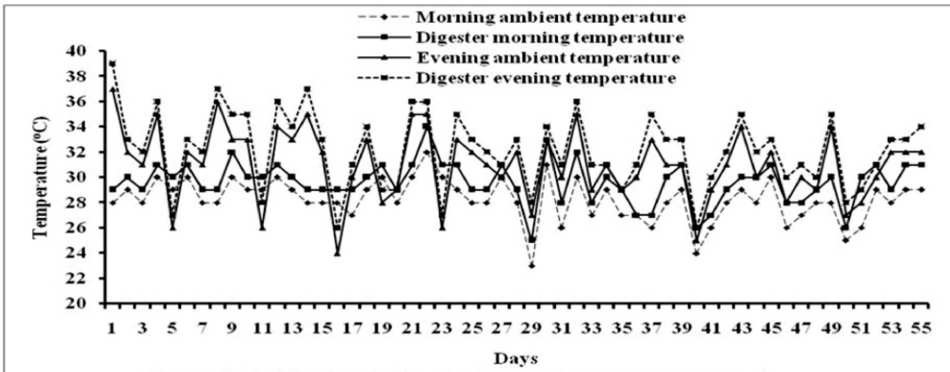

Figure 7: Ambient and digester temperatures versus days of fermentation for 4 kg cassava peels and 4 kg cattle dung digester

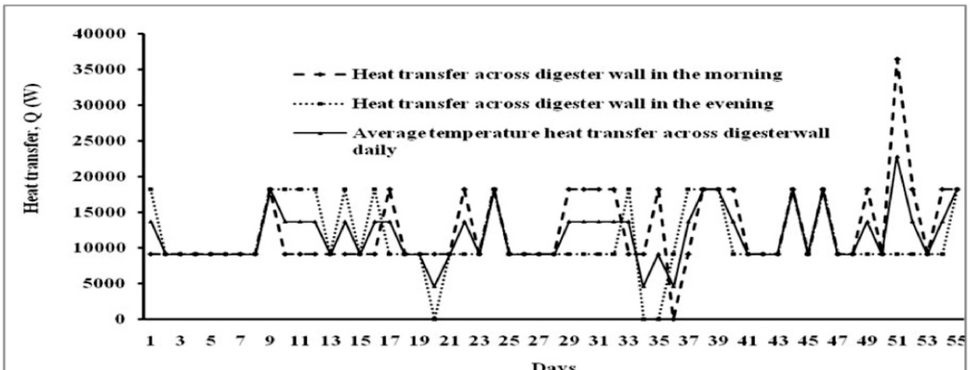

Figure 8: Graphs of heat across digester walls for 4 kg cassava peels and 4 kg cattle dung

Figure 9 shows a column chart of the ignition time against the digester substrate for cattle dung and mixtures of cattle dung with casssava peels. The biogas produced from the digester with 8 kg cattle dung ignited with a blue flame on the 14th day while that from the mixture of 1 kg cassava peels and 7 kg cattle dung burnt on the 27th day of incubation. 2 kg cassava peels with 6 kg cattle mixture biogas had its combustion on the 48th day of digestion as that from the mixture of 4 kg cattle and 4 kg cassava peels biogas burnt on the 55th day of the incubation. This showed that the ignition time of biogas increased with increase in the mass of cassava peels those of cattle dung decreased. The delay in the biogas production with the introduction and increase in the mass of cassava peels could be as a result of the presence of cellulose and lignin in the peels which are difficult to hydrolyze during fermentation and also the presence of the hydrogen cyanide (Adelekan 2012)

The substrates pH and that for the effluents are as presented in Table 1. The pH for the 8 kg cattle dung was the highest and this decreased as the cassava peels were added. This decrease indicated that the pH value tilted to the acidic condition. The acidic content in cassava peels is as a result of the hydrogen cyanide (HCN) (Adelekan 2012). The pH of the digestes rose to a little above the neutral point, 7 for all digesters. This was in line with report of Wirth, *et al.,* (2012) that combustible biogas, during fermentation, is produced at a neutral pH 7 in a mesophilic temperature range. .

The volumes of the biogas obtained from the digesters are as shown in Table 2. The cattle dung digester recorded lowest biogas volume of 4500 ml. This increased as cassava peels were introduced and even with the increase in their masses in the substrates. This is possibly because the cassava peels contain cellulose and hemicelluloses with little or no lignin. These were eventually broken down and produced more biogas than cattle dung alone.

5. Conclusion

The results show that ambient and digester temperatures in the evenings were always higher than those for the mornings. The digester temperatures were also higher than those of the environment for the mornings and evenings. However on cold days especially when it rained or due to cloud formations the evening ambient and digester temperatures fell even below those of morning temperatures.

The phenomenon for heat transfer across the digesters walls also followed the same trend as this was dependent on the ambient and digester temperatures. The biogas generated from 8 kg cattle dung ignited on the 14th day of incubation, that from the mixture of 1 kg cassava peels and 7 kg cattle dung burned on day 27 while the one from 2 kg cassava peels with 6 kg cattle dung was on 48 day as that from 4 kg each of cattle and cassava peels occurred on the 55th day of incubation. The pH of cattle dung slurry was 6.9 and those for the mixture with increasing amount of cassava peels were respectively 6.6, 6.4, and 6.3. The pH for each of the four digester effluents was 7.12, 7.16, 7.14 and 7.21.The volume of biogas in that order was 4500 ml, 5200 ml, 5400 ml and 6500 ml. It is concluded that the substrate containing more cattle dung produced combustible biogas earlier than those with more plant wastes because of the acidic content and the cellulose component of cassava peels. The acid was also responsible for the low pH values of the mixture slurries. The effluent of each digester was almost at neutral pH thus indicating that biogas production at mesophilic temperatures are produced at this concentration. The cellulose on digestion aided by cattle made the mixture of cattle dung produce more biogas than the cattle dung only.

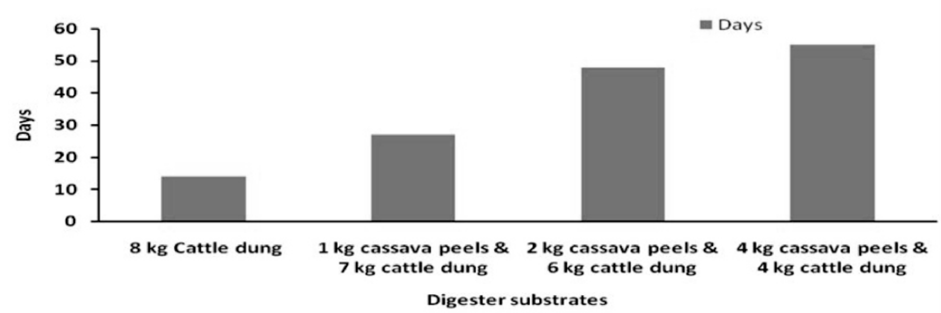

Figure 9: A column chart showing the combustion time for cattle dung and given mixtures of cattle dung with cassava peels

Table 1: The pH of substrates before digestion and digestes after Biogas ignition

Digester	Before digestion	After ignition of biogas
8 kg cattle dung	6.90	7.12
1 kg cassava peels & 7 kg cattle dung	6.60	7.16
2 kg cassava peels & 6 kg cattle dung	6.40	7.14
4 kg cassava peels & 4 kg cattle dung	6.30	7.21

Table 2: The quantity of biogas from substrates in each digester

Digester	Volume of biogas (ml)
8 kg cattle dung	4500
1 kg cassava peels & 7 kg cattle dung	5200
2 kg cassava peels & 6 kg cattle dung	5400
4 kg cassava peels & 4 kg cattle dung	6500

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