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COMPARATIVE STUDY OF THE KINETICS OF BIOGAS YIELD FROM THE CODIGESTION OF POULTRY DROPPINGS WITH WATERLEAF AND POULTRY DROPPINGS WITH ELEPHANT GRASS

ABSTRACT

This study was carried out to produce biogas from two sets of feedstock poultry droppings with waterleaf (*Talinum triangulare*) and poultry droppings with elephant grass (*Pennisetum Purpureum S.)*. Two 25 litre-plastic drums were modified and used as bio-digesters. One digester was used to digest poultry droppings with waterleaf while the other was used to digest poultry droppings with elephant grass. A fixed mass (8kg) of the feedstock and distilled water (4kg) were anaerobically digested in the ratio of 2:1 in each digester and their derivable energy were measured for biogas. The feed materials where sourced locally. It was observed that the pH for each set of feedstock was stable and within the optimal range of 6.5-7.5 indicating that the by-product obtained from the digester can be used as organic fertilizer after biogas recovery. Biogas production started on the 18th day for the poultry droppings with waterleaf, whereas, it started on the 26th day for poultry droppings with elephant grass. The cumulative mass of gas produced was 2600g for poultry droppings with waterleaf; and 1300g for poultry droppings with elephant grass. The average temperature range in the bio-digester during this study was between 37-40℃ for poultry droppings with waterleaf and 35-40℃ for poultry droppings with elephant grass. Hence, this study has shown that biogas can be produced from poultry droppings with lignocellulosic materials like elephant grass and waterleaf, but using waterleaf as co-digestate gives higher biogas energy potential than elephant grass, thus, waterleaf is a better seeding agent.

Keywords: Anaerobic Digestion, Biogas Yield, Temperature, Waterleaf, Elephant Grass

1. INTRODUCTION

Over the past few years, the overdependence on fusil fuels have given rise to the search for renewable energy that are readily available for economic consumption. That is because the utilization of these fossil fuels by the increasing world population can result in global climatic change and environmental pollution, thereby, posing threats to living things. According to Alvarez, by year 2040, the world will have 9-10 billion people and this populace must be provided with energy. The

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growing demand for energy in the world has led to a search for sustainable and alternative sources of energy other than fossil fuels [1 and 2]. Production and utilization of energy is a very important part to human life, as various sources of energy like solar, wind, hydropower etc. are required to meet the basic needs of man which are food, clothing and shelter. For example, sunlight (solar energy) is required for plant growth, electrical energy obtained from hydropower or fossil fuels (crude oil) are also needed for power generation at homes and industries [3]. Studies have shown that less than 10% of the population of 21 Sub-Saharan African countries, have access to sufficient electricity supply, showing that there is need for alternative sources of energy particularly in the African settlements [4]. According to Sharma [5], most developing countries have resulted to solid forms of energy such as biomass wood fuel for cooking due the limited access to electricity. In Nigeria, increase in the demand for fuel in several sectors of the economy especially the power and transportation sectors has led to large export of crude oil (fossil fuel) to foreign countries for refining. The refined products (i.e. kerosene, petrol, diesel etc.) which are imported back to the country are purchased at higher prices by indigenes, causing an increase in the cost of living in the country. It is also important to note that these energy resources are not environmental friendly because they produce greenhouse gases, hence, bioenergy is advocated as an alternative source of energy [6].

Survey carried out by Ikpe et al. [7], revealed that Municipal Solid Waste (MSW) predominantly contains organic or biodegradable waste materials which can be converted to energy through anaerobic digestion process, but it is dumped every day at several Nigerian dumpsites [8 and 9] due to lack of fit for purpose technology to harness the energy content present in the waste materials. Bioenergy is a type of renewable energy that in recent times is utilized as alternative source of energy in most developing countries like USA, United Kingdom, Canada, France etc. Bioenergy refers to the energy produced from biodegradable materials like agricultural wastes, urban wastes and animal wastes. These organic wastes are also called biomass. Recently, different technologies have been developed for convert biomass into usable forms of energy and one of such technology is anaerobic digestion of organic materials for biogas production [10]. Biogas technology is known to be a reliable, economically feasible and renewable source of energy. This technology can contain the pollution problems caused by organic wastes decomposition and reduces the amount of greenhouse gases released into the atmosphere. Anaerobic digestion of organic substrate produces two useful products namely: biogas and digestates [11].

Biogas is a mixture of colorless flammable gases obtained from the anaerobic digestion of organic waste materials. Biogas is a mixture of methane (about 60%), carbon (iv) oxide (about 40%) and other gases in trace quantities [12]. The bio-methane content in biogas is used for cooking, generation of heat and electricity and can also be compressed into Internal Combustion Engines (ICE) as fuel, while the digestates can be used by farmers as organic fertilizers to improve soil fertility for plant growth. Anaerobic digestion has been established as a proven technology for the treatment of organic wastes for biogas production in recent times. It involves the digestion of organic matter (biomass) fed into bio-digesters by microorganism in the absence of oxygen. Some examples of organic materials include animal wastes (e.g. cow dung, poultry droppings, pig dung etc.), agricultural wastes (maize silage, water hyacinth etc.), kitchen wastes amongst others. The digestion process is a more effective and viable means of extracting energy from these biomasses than other methods like incineration and pyrolysis because of its ability to produce reasonable amount of biogas with zero pollution level [13 and 14].

Wastes from livestock (i.e. animal manure) serves as one of the main feedstock for biogas production because of its high nitrogen content and low carbon/nitrogen ratio. Nowadays, a process known as co-digestion is adopted for biogas production. It is a process where animal manure is mixed with crop residues to maintain balance of the carbon/nitrogen composition of the feedstock, to enhance bacterial growth and decrease the risk of ammonia inhibition and acidification and to increase the biogas yield [15]. In this research, two sets of feedstock (poultry droppings with elephant grass and poultry droppings with waterleaf) were co-digested to determine biogas yield.

2. RESEARCH SIGNIFICANCE

This study was carried out to produce biogas from two sets of feedstock poultry droppings with waterleaf (*Talinum triangulare*) and poultry droppings with elephant grass (*Pennisetum Purpureum S.)*. Two 25 litre-plastic drums were modified and used as bio-digesters. One digester was used to digest poultry droppings with waterleaf while the other was used to digest poultry droppings with elephant grass. A fixed mass (8kg) of the feedstock and distilled water (4kg) were anaerobically digested in the ratio of 2:1 in each digester and their derivable energy were measured for biogas.

3. MATERIALS

The materials used to carry out this study includes the following:

- Samples: Poultry droppings, water leaf, elephant grass and distilled water.
- Apparatus: Plastic vessel, bio-digester fitted with plastic pipes, rubber hose, ball valves, pressure gauge, pH meter, temperature gauge.

3.1. Sample Collection

Poultry droppings used for the experimental process was obtained from a poultry farm in Ikpoba-Okha local government, Benin, Edo state. The elephant grass was obtained from the University of Benin and its environs while the water leaf used was purchased from the open market in Uselu, Ugbowo, Benin City, Edo state, Nigeria.

3.2. Experimental Set-up of the Bio-digester

The experimental set-up comprised of a plastic bio-digester (25litres capacity) equipped with:

- Control valves at the inlet and the outlet for regulating substrate feeding and removal.
- Gas extraction hose (4-inch in diameter).
- Pressure gauge: It was used to measure the pressure of the gas produced
- Thermometer: Used to determine the temperature of organic waste decomposing inside the bio-digester.

- pH meter: Used to determine the pH of substrate before and after digestion.

Table 1 shows the technical details of measuring probes employed in the experimental process while Figure 1 is an illustration of the experimental set-up.

Table 1. Technical details of measuring probes

Pressure Gauge	Thermometer	pH Meter
Measuring Media: Gas	TDS Range: 0-9990ppm (mg/L)	pH range of 0-14.0pH
Weight: 115g	Hand Held Digital Thermometer	Resolution 0.1pH
Product Size: Diameter 76*32cm (with rubber protector)	Resolution: 0-999ppm: 1-ppm; 1000-9990; 10ppm	Accuracy: ±0.1 pH
Sensor Type: Silicon Semiconductor Sensor	Temperature Resolution: 0.1℃	Battery: 3*1.5V (LR44 Button Cell)
Accuracy: ±1% F.S @ 20℃	Accuracy: ±2%	Operating Temperature: 0℃-60℃
Resolution: 0.1psi	EC-to TDS Conversion Factor: NaCl	Calibration: 1 Point Manual Calibrate
Pressure Range: 0-60psi	ATC: Built-in Sensor for Automatic Temperature Compensation of 1 to 50	Dimensions: 150mm×29mm×20mm
Operating Pressure: 0-45℃		Weight: 50g
Storage Temperature: -10-75℃		pH range of 0-14.0pH
Instrument Power Supply: DC3V (2*1.5V AAA Battery Powered)		

Figure 1. Experimental set-up for anaerobic digestion

3.3. Description of the Experimental Setup

The experimental setup comprised of a bio-digester equipped with ball valves at the inlet and outlet, biogas gas extraction hose, pressure gauge (5 bar), thermometer and deflated bicycle tube. The feedstock was fed into the digester through the inlet while the substrate was removed from the digester through the outlet after digestion. The ball valves mounted at the inlet and outlet was used to control the substrate feeding and removal rate into and from the digester. The gas extraction hose conveyed the gas from the digester into the deflated tube. Deflated bicycle tube of known mass (496g) mounted at the other end of the gas extraction pipe was used to store the biogas produced which in the process of entering the rubber tube caused it to inflate.

4. METHODS

The experimental procedure was carried out for two sets of different organic feedstock namely: Poultry droppings (4kg), distilled water (4kg) and elephant grass(4kg); and Poultry droppings (4kg), distilled water (4kg) and water leaf (4kg) for biogas production (i.e ratio 1:1:1 respectively). The elephant grass and waterleaf used for the experiment were sliced into smaller pieces before feeding into the digester. The experimental procedures are outlined as follows:

- Using weighing balance, the total mass of each set of the two substrates used for the experiment weighed 8kg
- 4kg of distilled water and each set of substrates were thoroughly mixed together until the mixture became slurry.
- The distilled water and substrates mixture were poured into the bio-digester (through the inlet and after which, the digester inlet valve was closed).
- The initial gauge pressure was calibrated to 0.0 bar and recorded.
- pH of substrate was tested before and after the digestion process (using digital handheld pH meter).
- The anaerobic digestion process temperature was measured using thermometer.
- The biogas produced was collected in the bicycle tube and measured with the help of a weighing balance to know the actual quantity produced at each gas evacuation time.
- The same procedure was applied for the other set of substrates introduced into the digester.
- Biogas yield for the two sets of feedstock were compared.

4.1. Justification for Using Plastic Bio-Digester

- Considering the investment cost which is a major factor in the design of bio-digesters as well as the type of construction materials required for proper designs of the system, plastic vessel (amongst other materials such as stainless steel, polyethylene (PE)) was selected for the design of the bio-digester.
- The availability and the ease of purchase of the plastic vessel is another factor that was considered in the digester design.
- Portability and ease of assembly was also considered.
- The ease of disposability of the plastic material after digestion.
- Non-reactivity of the plastic material with substrate in the digester. (Unlike brick-constructed bio-digester which is made of

materials that can affect or impede microbial growth in the digester. Digesters constructed with metals can also corrode releasing ions which can affect the decomposition of substrate in the digester.

5. RESULTS

The experimental results obtained during the period of the experiment are presented in Tables 2 and 3 and further analyzed using statistical graphs as shown in Figure 2, Figure 3, Figure 4, and Figure 5.

Table 2. Co-digestion of poultry droppings with water leaf (talinum triangulare)

10	Temperature (°C)	Pressure (Bar)	Biogas Yield (g)	Cumulative Biogas Yield (g)
18	37.8	0.02	20	20
19	37.5	0.01	10	30
20	38.0	0.03	25	55
21	37.8	0.02	20	75
22	38.0	0.03	25	100
23	38.2	0.04	30	130
24	38.4	0.05	50	180
25	38.5	0.06	90	270
26	38.7	0.07	120	390
27	38.5	0.08	150	540
28	40.1	0.09	190	730
29	40.2	0.09	190	920
30	39.8	0.09	190	1110
31	40.0	0.09	190	1300
32	40.1	0.09	190	1490
33	40.2	0.09	190	1680
34	40.0	0.09	190	1870
35	40.1	0.09	190	2060
36	39.0	0.08	160	2220
37	38.7	0.07	120	2340
38	38.5	0.06	80	2420
39	38.4	0.05	60	2480
40	38.3	0.04	40	2520
41	38.2	0.04	30	2550
42	38.0	0.03	25	2575
43	37.7	0.02	15	2590
44	37.5	0.01	10	2600

Table 3. Co-digestion of Poultry droppings with Elephant grass (Pennisetum Purpureum S.)

HRT (Days)	Temperature (°C)	Pressure (Bar)	Biogas Yield (g)	Cumulative Biogas Yield (g)
26	35.6	0.01	6	6
27	35.3	0.02	10	16
28	36.0	0.01	8	24
29	35.8	0.01	7	31
30	36.2	0.02	10	41
31	36.3	0.01	15	56
32	36.4	0.03	20	76
33	36.5	0.03	25	101
34	36.6	0.04	33	134
35	36.7	0.05	48	182
36	36.8	0.06	56	238
37	36.9	0.07	72	310
38	37.0	0.07	84	394
39	37.2	0.07	84	478
40	37.0	0.07	84	562
41	37.1	0.07	84	646
42	37.3	0.07	84	730
43	37.1	0.07	84	814
44	37.4	0.07	84	898
45	37.3	0.07	84	982
46	36.8	0.07	84	1066
47	36.5	0.05	62	1128
48	36.3	0.04	78	1206
49	35.7	0.03	37	1243
50	35.5	0.02	40	1283
51	35.2	0.01	15	1298
52	35.0	0.01	10	1300

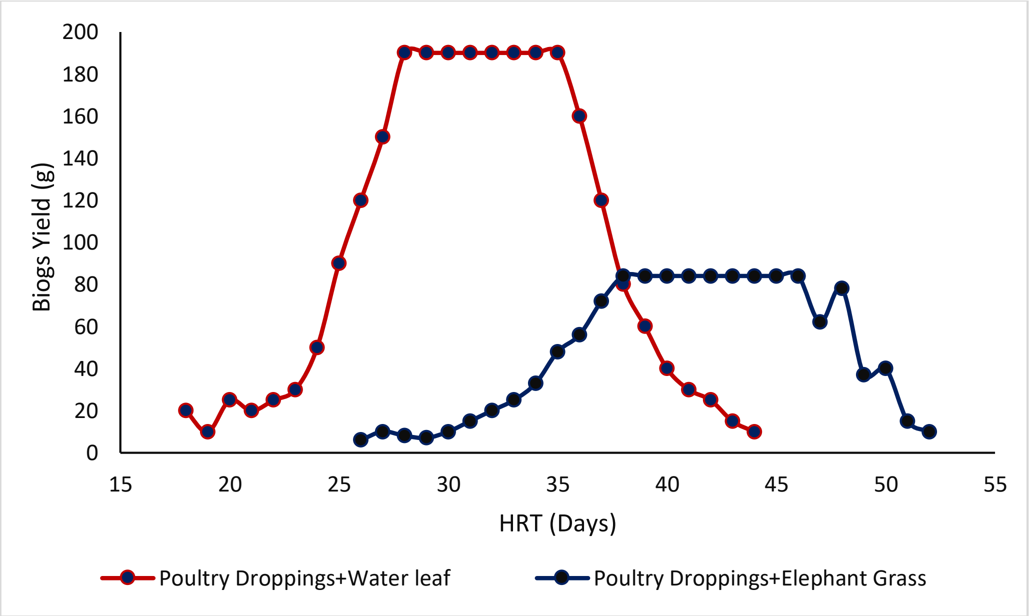

Figure 2. Daily biogas production for the two sets of substrates

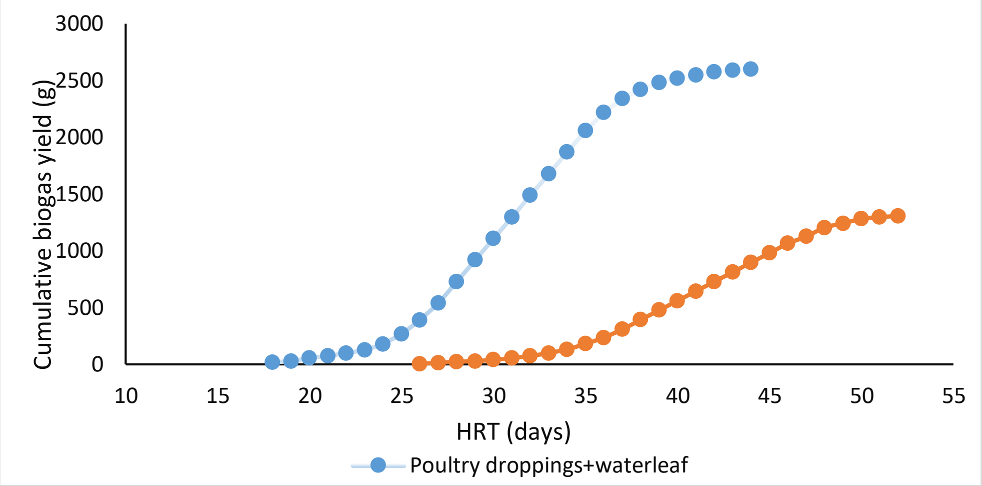

Figure 3. Cumulative biogas production for the two sets of substrates

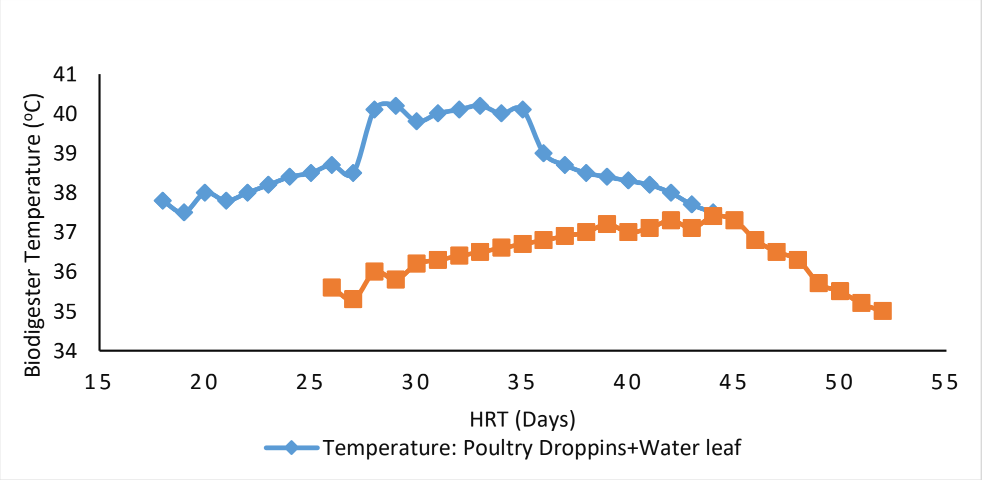

Figure 4. Daily digester temperature of the substrates

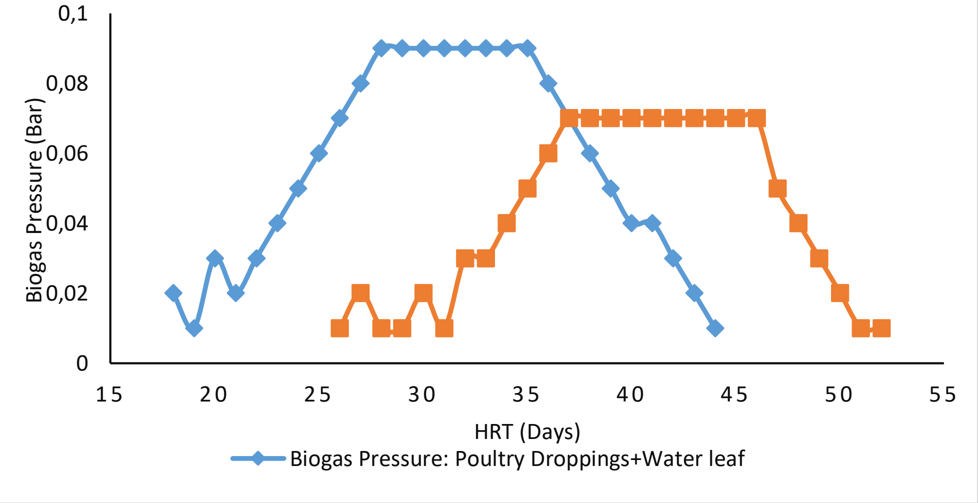

Figure 5. Daily digester pressure readings

6. DISCUSSION

6.1. Measurement of the Gas Production Rate

Figure 2 shows the daily gas production rate for the two set of substrates in this study. It indicates that the production of biogas from the co-digestion of poultry droppings with waterleaf started on the 18th day and ended on the 44th day while the co-digestion of the poultry droppings with elephant grass started on the 26th day and ended on day 52 after feeding the substrate into the digester. This implies that the digestion of poultry droppings and waterleaf has a shorter lag phase and shorter hydraulic retention time (HRT) compared to the digestion of poultry droppings with elephant grass. This also implies that the co-digestion of poultry droppings with waterleaf substrate faster than the co-digestion of poultry droppings with elephant grass. As also shown in Figure 2, a maximum daily biogas production of 190g was obtained from the co-digestion of poultry droppings with water leaf from day 28 to day 35 while, a maximum daily biogas production of 84g was obtained from the co-digestion of poultry droppings with elephant grass from day 38 to day 46. This indicates the stationary phase for biogas production i.e. the period within which the daily biogas production was constant. During this period, the daily substrate decomposition by microorganisms is constant, hence the growth of microorganisms and the biogas yield is also constant. The higher biogas yield from the co-digestion of poultry droppings with waterleaf also indicates that substrate consumption by microorganisms is faster in in co-digestion of poultry droppings with waterleaf than co-digestion than in co-digestion of poultry droppings with elephant.

Figure 3 indicates the graphic representation of the daily cumulative gas production rates for the two set of substrates used in this study. It shows that the co-digestion of poultry droppings with waterleaf produced a total biogas yield of 2600g, while the co-digestion of poultry droppings with elephant grass gas produced a cumulative biogas yield of 1300g. This could be attributed to the nature and chemical composition of the feedstock. Water leaf (*Talinum triangulare*) has a high moisture content (81.9%) which favors the hydrolysis phase (stage 1) of anaerobic digestion. In the hydrolysis stage, complex insoluble organic matter (polymers) such as protein, cellulose etc. are present in the substrate which are broken down into soluble fermentable sugars (monomers) before fermentation and methanogenesis takes place [16]. On the other hand, elephant grass (*Pennisetum Purpureum S*) contain small amounts of water (12%) [17], and this does favor the hydrolysis stage of anaerobic digestion. The lignin content in the feed materials is another factor that could have resulted in the higher yield of biogas using waterleaf as a co-digestate as compared to elephant grass. Generally, lignin does not favor the fermentation stage and therefore there is need to reduce or if possible, eliminate the lignin content in organic materials which are involved in the fermentative processes [18] like biogas production. Elephant grass contains about 8.20% lignin [19], while waterleaf contains about 8% of indigestible lignin in the form of dietary fiber [20]. The water to lignin ratio in water leaf (10:1) is higher than that of elephant grass (1.5:1), it serves as seeding agent which enhances production of biogas when used as a co-digestate with poultry droppings. This indicates that water leaf is a better seeding agent compared to elephant grass.

6.2. Biogas Temperature

Figure 4 shows the temperature ranges for the two sets of feedstock used in this study. The co-digestion of poultry droppings with water leaf produced biogas within temperature range of 37°-40°C while the co-digestion of poultry droppings with elephant grass produced biogas within a temperature range of 35°-37°C. These two temperature ranges fall within the mesophilic temperature range which favors biogas production. As shown in Figure 4, bio-digester temperature increases to a peak height and begins to decline gradually. The continuous increase is the period where sufficient nutrients are present in the co-digested substrates for the microbes to engage in the decomposition process. On the other hand, the gradual decline in bio-digester temperature indicates that nutrients present in the substrates are gradually depleting, thus, decrease in microbial activities, decomposition rate and biogas yield. The temperature at which fermentation take place affects biogas production. Methanogens operate optimally in mesophilic (20-45°C) temperature ranges. The rate of biogas production increases with a corresponding increase in temperature and vice versa. It is important to maintain a constant optimum temperature in the digester, as the bacteria available for substrate consumption are temperature sensitive [21]. Despite the fact, that the temperature of a digester depends on the type of feedstock and the type of digester used, temperature ranges between 25°C and 40°C is optimum, and can favor biogas production. However, temperature above this range of temperature (25°-40°C) is known as thermophilic temperature and will accelerate substrate decomposition rate, microbial activities and above all, biogas yield. This means that the climatic condition in the moderate temperature regions (like Nigeria which has monthly temperature between 28-35℃) will favor biogas production while climatic condition with higher temperature ranges will significantly favor biogas yield.

6.3. Biogas Pressure

The pressure at which anaerobic digestion takes place is also a very important factor to be considered in biogas production. The operating pressure in a digester is dependent on the generation of the gas within the system. This obeys the general gas law, ($PV=nRT$, where P is the pressure of gas and n is the number of moles (quantity) of gas produced). When there is a build-up of gas produced in the bio-digester, the pressure begins to rise, and this is indicated by the pressure gauge. It is imperative to evacuate the gas from the system from time to time to avoid undesired occurrence like gas explosion. The optimum pressure for biogas production varies with the type of process (batch or continuous process). Figure 5 is a graphical representation of biogas pressure profile as a function of hydraulic retention time for the two sets of feedstock. The pressure of the gas for the two substrates increased initially at the start of production, and was later maintained before declining. The increase in pressure signifies an increase in microbial activities as well as the rate of biogas produced while the declining pressure indicates a decrease in microbial activities as well as the quantity of biogas produced. The pressure readings on the graph (ranging from 0.1 to 0.9 bar) also indicates the trend of biogas production from the anaerobic digestion process in the bio-digester.

7. CONCLUSION

From the study conducted, the following conclusions were drawn:

- Biogas can be produced by co-digesting lignocellulosic biomass such as elephant grass and waterleaf with animal wastes such as poultry droppings
- Anaerobic digestion process can serve as an alternative method for treating organic wastes like poultry droppings before disposal. The process recovers the energy content in the waste, neutralizes the smell and makes it suitable as organic manure.
- The use of plastic vessels as bio-digester is an indication that cheap available materials can be used for the design of biogas plant.
- The anaerobic digestion took place under mesophilic temperature conditions (35°C-45°C) and low pressures (0.1-0.9 bar), and this corresponds with the conditions given in literature.
- pH of 6.8 was measured before anaerobic digestion of feedstock while pH of 7.2 was observed after anaerobic digestion of the feedstock. Feedstock with a pH of 7.2 is considered to be in the neutral range, and can be processed into compost manure.
- The moisture content in feed materials affects biogas production process. It enhances the hydrolysis stage (stage 1) of the anaerobic digestion process.
- Water leaf (*Talinum triangulare*) is better seeding agent compared to elephant grass *(Pennisetum Purpureum S.)*.

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