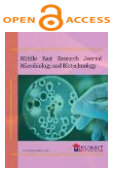

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Use of Modified Gompertz Kinetic Modelling to Predict Biogas Production from Co-Digestion of Two Substrates and Other Treatments

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Abstract: This research was conducted with the aim of using Gompertz kinetic model to predict biogas production. The substrates used are the co-digestion of pig and poultry dungs. Batch culture of anaerobic digestion was used while MgSO4, Bovine blood, Charcoal water and water of pH 8 were used as various treatments. Three batches of digestions were done. From the results and statistical kinetic modelling, magnesium sulphate which serve as source of water hardness proved to enhance biogas production. This is because it serves as both salt and catalyst. Bovine blood also showed the same effect. For the charcoal water, it enhanced methane production by the increase of carbon level in C:N ratio. The research recommends as follows. That the quantity of the substrates should be enough to ensure more gas yield. The volume of blood should not be more than the water used in the slurry formation as this could affect proper mixing. The carbon content of the lignocellulose should be increased using charcoal water in slurry preparation to ensure formation of Methane (CH_4) which is the main biogas. And finally that measured amount of bovine blood, Magnesium Sulphate and Charcoal can be used as additive in biogas production.

Keywords: Substrate, Co-Digestion, Anaerobic, Biogas, Methanogen, Fermentation.

Research Paper

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INTRODUCTION

The high standards of living has increased the release of pollutants and greenhouse gases (GHGs) into the environment (Teghammar, 2013). This has led to a global crisis as the use of fossil fuel are still being consumed at a high rate in most cases, these forms of energy originate from oil, coal, and natural gas, as many countries depend largely on a few countries for their fuel sources. For these reasons, there is a driven need for an alternative and suitable technology which is affordable and easy to manage. This alternative is biogas. Biogas is a household name and has become a project many individuals, nations and organizations would want to invest into its large scale production. Though biogas is environmentally friendly, it has negative implications. These implications can come when the processes that will lead to biogas generation are not followed. Also, because the gas is generated from household, compost and other degradable waste. If the wastes are not properly handled, it will become a threat to the environment (Fagerström *et al*., 2018).

MATERIALS AND METHODS

Research Materials

Fresh piggery and poultry dung (feed sample) were collected from Onyewuchi Ejiaku Farms at Ubah in Mbaoma autonomous community in Owerri North Local Government Area of Imo State. Batch culture anaerobic fermentation method was used.

Sample Collection

The piggery and poultry samples were collected using 10 empty paint buckets of 20 litre capacity.

Fabrication of Local Digester for the Anaerobic Batch Culture Fermentation

The following were used for the fabrication of the digester:

1. Ten (10) white plastic gallons of 20 litre capacity.
2. Ten (10) pieces of Rubber hose of 3 feet length.
3. Ten (10) pieces of T-valve (Control)
4. Ten (10) pieces of wheel barrow tube
5. Adhesive glue
6. Ten (10) Bronze nozzle
7. Electric hole borer

The electric hole-borer was used to bore hole on the ten corks of the white gallons according to the circumference of the bronze nozzle (0.4cm). The bronze nozzles were fitted into the hole created on the corks. The glue was applied to make the connection airtight as well as watertight. This is as shown in the diagram below.

Fig. 1: Fabricated digesters

Slurry Preparation

This was done by measuring out 2000g of piggery dungs to 500g of poultry dungs at the ratio of (4:1). This was done using a digital weighing balance and an empty custard plastic container of 4 litre capacity. This was done in ten (10) places according to the number of treatments to be applied. Each of the measurements was put in a separate empty paint bucket of 20 litre capacity. Water of five (5) litre by volume was added to each of the ten(10) buckets. A strong iron rod was used to mix the pig/poultry dung with the five litres of water.

Different Treatments on the already Prepared Slurry

Out of the ten (10) buckets used for slurry preparations, the following were used to treat the slurry before feeding them into the already fabricated digester.

1. Slurry one (1): Raw Sodium Carbonate (200g) was added
2. Slurry two (2): Shigella flexineri was added after inoculum development
3. Slurry three (3): Bacillus paramycoides was added after inoculum development
4. Slurry four (4): Bovine blood was added
5. Slurry five (5): Protein/ Meat extract was added (200g)
6. Slurry six (6): Charcoal water (500g of crushed charcoal in 1000dm^3 of water) was added
7. Slurry seven (7): Zinc Nitrate (200g) was added
8. Slurry eight (8): Nothing was added (as control)
9. Slurry nine (9): Magnesium sulphate added (200g/dm^3 of water) was added
10. Slurry ten (10): water of pH 8 was added.

Each of the mixtures of the slurry and the treatments were poured in the already fabricated digesters using a funnel and the diagrams as shown below. The corks of the digesters with the tubes connected with hose and T-valve were used to cover the digesters as shown below. This was allowed to stay for 21 days (hydraulic retention time. Also some of the different treatments were varied to ascertain the biogas production in each case. Later the data were fed into in Gompertz kinetic model to help predict the gas production capacity. This was achieved by performing two different batch of anaerobic fermentation using varied measures of the treatments. This was allowed to run for 14 days pending when there will be no gas production. This were done as shown below.

Fig. 2: Batch A showing the ten fabricated digesters with gas in the tubes

Fig. 3: Batch B for kinetic modelling of biogas production

Fig. 4: Batch C for kinetic modelling of biogas production

RESULTS

Biogas Production during Substrate Digestion

At the end of the initial 21 and double 14 days of anaerobic digestion, the following data were generated as a result of the various treatments

Table 1: Raw data (Mass of Tubes and gas in 21 days)

Day	substrate mixed with raw Na_2CO_3	substrate mixed with *shigella flexneri*	substrate mixed with *bacillus paramycoides*	substrate mixed with bovine blood	substrate mixed with protein or meat extract	substrate mixed with solution of charcoal water	substrate mixed with zinc nitrate	substrate mixed with water only (control)	substrate mixed with $MgSO_4$ (hard water)	substrate mixed with water of pH 8.
0	420.00	420.00	420.00	670.00	420.00	420.00	420.00	420.00	420.00	420.00
1	426.10	430.00	424.20	690.00	423.00	427.10	421.30	424.20	444.00	428.40
2	428.10	434.20	428.10	702.30	429.20	430.30	422.10	429.00	461.10	431.50
3	432.50	438.20	439.20	710.50	431.50	433.40	424.00	432.40	470.50	436.70
4	460.30	447.50	448.10	721.70	447.00	440.10	424.50	452.10	488.00	445.10
5	480.50	455.70	450.10	750.40	450.80	449.10	424.50	461.50	490.80	452.80
6	486.90	478.30	455.50	757.80	455.60	453.80	424.60	472.00	497.20	459.40
7	493.60	480.50	461.70	770.60	470.40	460.20	424.70	481.10	510.10	465.60
8	494.10	487.20	476.30	778.60	473.50	465.30	424.50	487.90	517.00	468.50
9	495.00	495.00	499.00	785.70	478.00	466.00	424.50	489.00	520.70	494.10

Day	substrate mixed with raw Na_2CO_3	substrate mixed with *shigella flexneri*	substrate mixed with *bacillus paramycoides*	substrate mixed with bovine blood	substrate mixed with protein or meat extract	substrate mixed with solution of charcoal water	substrate mixed with zinc nitrate	substrate mixed with water only (control)	substrate mixed with $MgSO_4$ (hard water)	substrate mixed with water of pH 8.
10	498.00	498.00	510.00	795.20	479.90	467.10	424.50	495.00	523.40	495.00
11	498.70	499.70	510.70	880.10	480.00	468.00	424.50	496.00	540.10	498.00
12	499.10	499.80	510.90	890.00	480.00	468.40	424.50	497.10	549.00	498.70
13	499.30	500.30	511.30	892.80	481.10	468.90	424.00	498.20	550.00	499.10
14	500.20	503.20	512.20	891.90	483.00	469.00	423.50	499.00	550.40	499.30
15	500.20	510.20	513.20	899.10	484.00	470.00	423.40	500.00	556.90	500.20
16	500.30	515.10	515.10	901.40	484.00	477.20	424.40	500.00	556.90	500.20
17	500.40	515.20	520.20	902.90	483.80	478.00	425.40	500.20	557.00	500.10
18	500.50	515.30	520.40	902.00	483.80	478.20	426.40	500.20	558.10	510.00
19	500.60	515.50	520.50	902.20	483.90	478.30	427.40	510.00	559.20	520.00
20	500.60	515.50	520.50	902.20	483.90	478.30	427.40	510.00	559.20	520.00

Table 2: Calculated Mass of Gas Produced in 21 Days

Day	substrate mixed with raw Na_2CO_3	substrate mixed with *shigella flexneri*	substrate mixed with *bacillus paramycoides*	substrate mixed with bovine blood	substrate mixed with protein or meat extract	substrate mixed with solution of charcoal water	substrate mixed with zinc nitrate	substrate mixed with water only (control)	substrate mixed with $MgSO_4$ (hard water)	substrate mixed with water of pH 8.
0	0	0	0	0	0	0	0	0	0	0
1	6.1	10	4.2	20	3	7.1	1.3	4.2	24	8.4
2	8.1	14.2	8.1	32.3	9.2	10.3	2.1	9	41.1	11.5
3	12.5	18.2	19.2	40.5	11.5	13.4	4	12.4	50.5	16.7
4	40.3	27.5	28.1	51.7	27	20.1	4.5	32.1	68	25.1
5	60.5	35.7	30.1	80.4	30.8	29.1	4.5	41.5	70.8	32.8
6	66.9	58.3	35.5	87.8	35.6	33.8	4.6	52	77.2	39.4
7	73.6	60.5	41.7	100.6	50.4	40.2	4.7	61.1	90.1	45.6
8	74.1	67.2	56.3	108.6	53.5	45.3	4.5	67.9	97	48.5
19	75	75	79	115.7	58	46	4.5	69	100.7	74.1
10	78	78	90	125.2	59.9	47.1	4.5	75	103.4	75
11	78.7	79.7	90.7	210.1	60	48	4.5	76	120.1	78
12	79.1	79.8	90.9	220	60	48.4	4.5	77.1	129	78.7
13	79.3	80.3	91.3	222.8	61.1	48.9	4	78.2	130	79.1
14	80.2	83.2	92.2	221.9	63	49	3.5	79	130.4	79.3
15	80.2	90.2	93.2	229.1	64	50	3.4	80	136.9	80.2
16	80.3	95.1	95.1	231.4	64	57.2	4.4	80	136.9	80.2
17	80.4	95.2	100.2	232.9	63.8	58	5.4	80.2	137	80.1
18	80.5	95.3	100.4	232	63.8	58.2	6.4	80.2	138.1	90
19	80.6	95.5	100.5	232.2	63.9	58.3	7.4	90	139.2	100
20	80.6	95.5	100.5	232.2	63.9	58.3	7.4	90	139.2	100

This was done by subtracting the subsequent masses from the mass of tube (day 0)

Results of the (Masses of Tube with Gas) Analysis Done to Predict the Biogas Gas Production Using Gompertz Kinetic Model

Table 3: Pig, Poultry, Blood, pH and $MgSO_4$

Day	10		11		12	
	Pig=100g Poultry= 50g pH=8 $MgSO_4$= 20g	Cum. Gas prod..	Pig=100g Poultry= 50g pH=8 $MgSO_4$= 50g	Cum. Gas prod.	Pig=100g Poultry= 50g pH=8 $MgSO_4$= 80g	Cum. Gas prod.
0	0	0	0	0	0	0
1	2.6	2.6	3	3	5	5
2	2.9	5.5	3.4	6.4	5.9	10.9
3	3	8.5	4	10.4	7	17.9
4	5.5	14	12.8	23.2	20.2	38.1
5	7.9	21.9	15.3	38.5	20.8	58.9
6	8.1	30	16.1	54.6	21.2	80.1
7	8.5	38.5	16.8	71.4	25.5	105.6
8	8.9	47.4	17.1	88.5	30	135.6
9	10.1	57.5	18.3	106.8	35.5	171.1
10	10.8	68.3	18.9	125.7	38.3	209.4
11	11.3	79.6	20.1	145.8	40.1	249.5
12	12.7	92.3	20.2	166	40.1	289.6
13	12.7	105	20.2	186.2	40.1	329.7

Table 4: Pig, Poultry, Charcoal and $MgSO_4$

Day	7		8		9	
	Pig=100g Poultry= 50g Charcoal=50g $MgSO_4$=20g	Cum. Gas prod.	Pig=100g Poultry= 50g Charcoal=100g $MgSO_4$=50g	Cum. Gas prod..	Pig=100g Poultry= 50g Charcoal=150g $MgSO_4$=80g	Cum. Gas prod.
0	0	0	0	0	0	0
1	2.7	2.7	8.3	8.3	10.8	10.8
2	5.9	8.6	9.9	18.2	12.9	23.7
3	8.3	16.9	10.9	29.1	15.2	38.9
4	10.7	27.6	15.9	45	20.2	59.1
5	10.1	37.7	20.1	65.1	29.5	88.6
6	15.8	53.5	27.7	92.8	33.7	122.3
7	19.4	72.9	30.2	123	36.6	158.9
8	22.3	95.2	37.4	160.4	40.4	199.3
9	24.4	119.6	38.5	198.9	45.5	244.8
10	25.4	145	39.1	238	47.2	292
11	26.8	171.8	41.4	279.4	50.7	342.7
12	28.9	200.7	42.5	321.9	53.7	396.4
13	28.9	229.6	42.5	364.4	53.7	450.1

Kinetics of Biogas production:

The kinetic parameters of biogas production was obtained by fitting biogas production-time data to the modified Gompertz model (Eq. 3.1) for single step curve on the assumption that the rate of biogas production in batch condition is equivalent to specific growth rate of the methanogens in the digester (Budiyono & Sumardiono, 2014).

$$Y_t = P_{m1}.\exp\left\{-\exp\left[\frac{R_{m1}.e}{P_{m1}}(\lambda_1 - t)+1\right]\right\} \qquad (3.1)$$

Where: Yt= The cumulative biogas production (g), P_{m1} = the maximum biogas production potential (g), R_{m1} = the maximum biogas production rate (g/day), λ_1 = Lag phase period (day), t = time for production of biogas (day) and e = mathematical constant (2.718282)

Diauxic biogas production pattern with multiple peaks of biogas production were fitted with (Eq. 3.2), a bilogistic function (Opurum *et al*., 2021). The nonlinear curve fitting procedures were implemented in Sigmaplot 10.

$$y = \frac{P_{m1}}{1+\exp\left[\frac{4R_{m1}(\lambda_1 - t)}{P_{m1}} + 2\right]} + \frac{P_{m2} - P_{m1}}{1+\exp\left[\frac{4R_{m2}(\lambda_2 - t)}{P_{m2} - P_{m1}} + 2\right]} \quad (3.2)$$

Where, y is the biogas yield (dm3) with respect to time t (days) P_{m1} is the maximum biogas potential of the substrate (dm3) before the second lag P_{m2} is the maximum biogas potential of the substrate (dm3) in the second phase R_{m1} is the maximum biogas production rate (dm3) before the second lag R_{m2} is the maximum biogas production rate (dm3) in the second phase λ_1 is the first lag phase time (days) λ_2 is the second lag phase time (days).

Table 5: The kinetic Constants estimated from modified Gompertz and Bi-logistic Gompertz Models

Treatments	P_{m1}(g)	R_{m1} (g/days)	λ_1 (days)	P_{m2}(g)	R_{m2} (g/days)	λ_2 (days)	R^2
Pig=100g, Poultry 50g, Blood 100ml	3.17 (2.27-4.07)	5.36 (-6.73-17.45)	3.08 (2.64-3.53)	10.92 (9.34-12.50)	0.73 (0.63-0.82)	3.54 (2.17-4.92)	0.997
Pig=200g, Poultry = 100g, Blood= 200ml	6.78 (5.03-8.53)	10.14 (-1.88-22.16)	3.09 (2.65-3.53)	17.99 (11.63-24.51)	0.78 (0.62-0.94)	2.24 (-0.45-4.93)	0.995
Pig=300g, Poultry= 150g, Blood=300ml	36.72 (35.20-38.24)	25.62 (15.53-35.72)	3.60 (3.33-3.87)	-	-	-	0.989
Pig=100g, Poultry= 50g, $MgSO_4$= 20g	3.17 (2.27-4.07)	5.36 (-6.73-17.45)	3.08 (2.64-3.53)	10.92 (9.34-12.50)	0.78 (0.62-0.94)	3.54 (2.17-4.92)	0.997
Pig=100g, Poultry= 50g, $MgSO_4$= 50g	6.78 (5.03-8.53)	10.14 (-1.88-22.16)	3.09 (2.65-3.53)	17.99 (11.63-24.35)	0.78 (0.62-0.94)	2.24 (-0.45-4.93)	0.995
Pig=100g, Poultry= 50g, $MgSO_4$= 80g	26.48 (20.12-32.83)	25.03 (19.37-30.70)	3.87 (3.67-4.07)	37.87 (36.52-38.66)	1.43 (-0.19-3.05)	0.26 (-2.23-2.76)	0.999

Treatments	P_{m1}(g)	R_{m1} (g/days)	λ_1 (days)	P_{m2}(g)	R_{m2} (g/days)	λ_2 (days)	R^2
Pig=100g, Poultry= 50g, pH= 8	20.42 (17.06-23.78)	1.99 (1.68-2.30)	2.23 (1.58-2.97)	-	-	-	0.990
Pig=100g, Poultry= 50g, pH= 10	27.92 (24.3-31.52)	3.29 (2.67-3.92)	2.28 (1.58-2.97)	-	-	-	0.988
Pig=100g, Poultry= 50g, pH= 12	17.86 (13.35-22.37)	17.41 (0.26-34.55)	2.64 (2.19-3.09)	35.39 (35.85-37.93)	2.07 (1.57-2.56)	3.24 (1.22-5.26)	0.998
Pig=100g, Poultry=50g, pH=8, $MgSO_4$=20g	9.33 (5.70-12.94)	1.63 (0.98-2.29)	0.54 (-0.65-1.72)	13.09 (9.51-16.67)	0.96 (-0.41-2.32)	8.52 (2.78-14.86)	0.980
Pig=100g, Poultry=50g, pH=8, $MgSO_4$=50g	17.10 (14.24-19.95)	5.42 (2.92-7.92)	1.86 (1.07-2.65)	20.27 (17.81-22.72)	1.21 (-2.34-4.77)	8.29 (2.52-14.16)	0.981
Pig=100g, Poultry=50g, pH=8, $MgSO_4$=80g	23.11 (14.20-32.03)	6.36 (2.78-9.94)	1.30 (0.22-2.37)	40.13 (36.87-43.40)	6.03 (0.596-11.47)	6.88 (4.38-9.37)	0.986
Pig=100g, Poultry=50g, blood=100ml $MgSO_4$=20g	12.49 (10.09-14.90)	10.42 (3.66-17.16)	3.10 (2.46-3.56)	30.62 (24.58-36.66)	3.63 (2.25-5.01)	7.84 (6.37-9.30)	0.993
Pig=100g, Poultry=50g, blood=300ml $MgSO_4$=80g	29.43 (28.22-30.63)	13.53 (10.76-16.31)	1.87 (1.62-2.12)	39.10 (37.60-40.60)	4.21 (1.55-6.01)	8.51 (7.62-9.54)	0.998

Values in parentheses are confidence limits

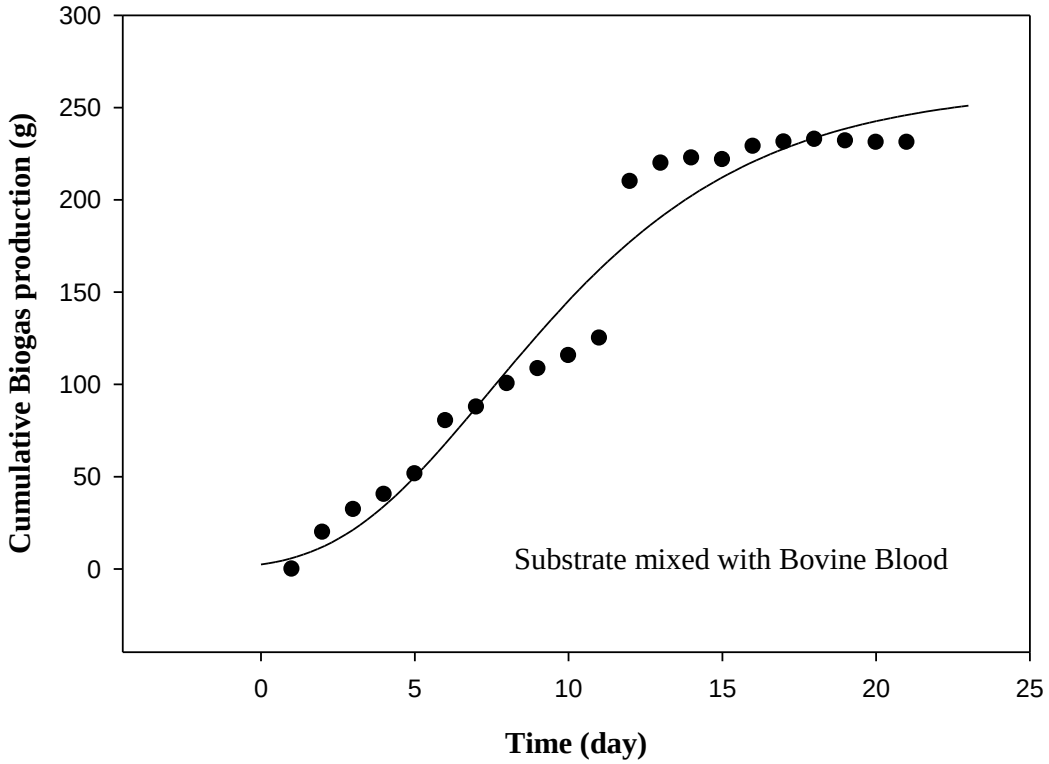

Figure 5: Graph of substrate mixed with Bovine Blood

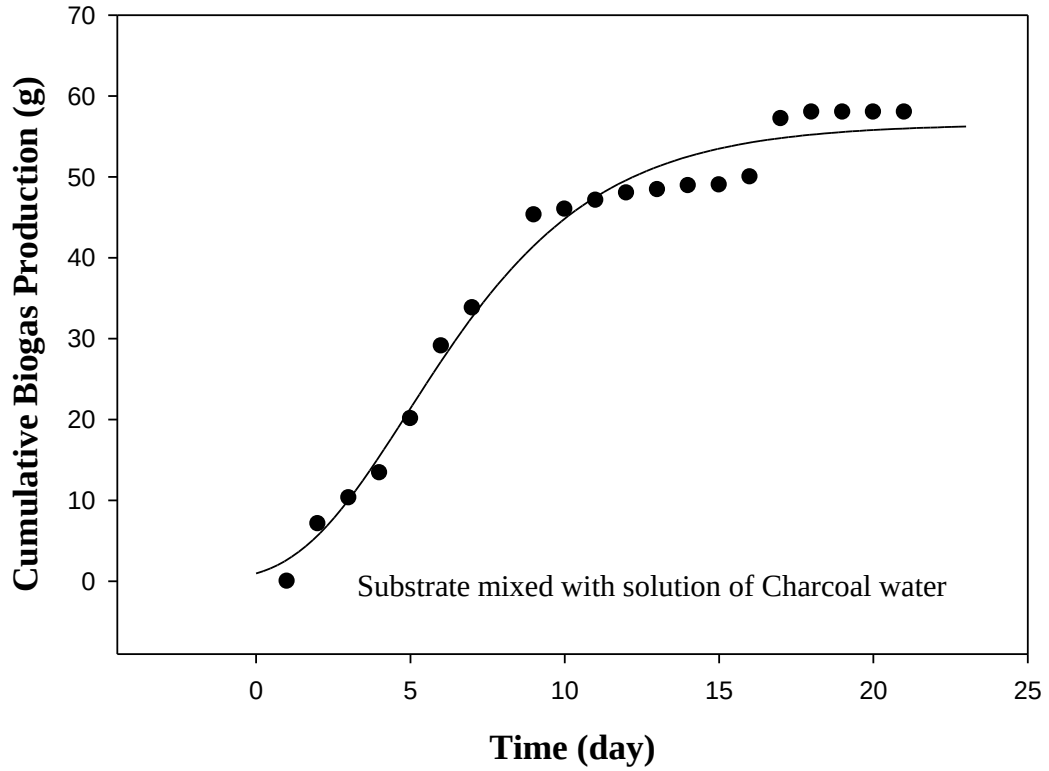

Figure 6: Graph of substrate mixed with Charcoal water

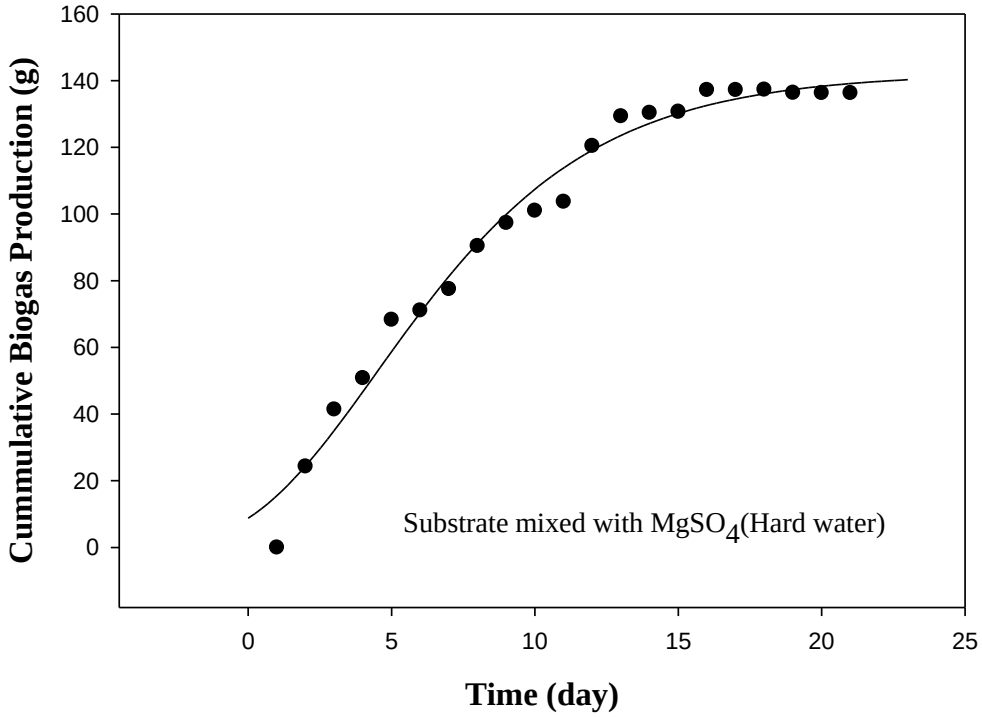

Figure 7: Graph of substrate mixed with Magnesium Sulphate

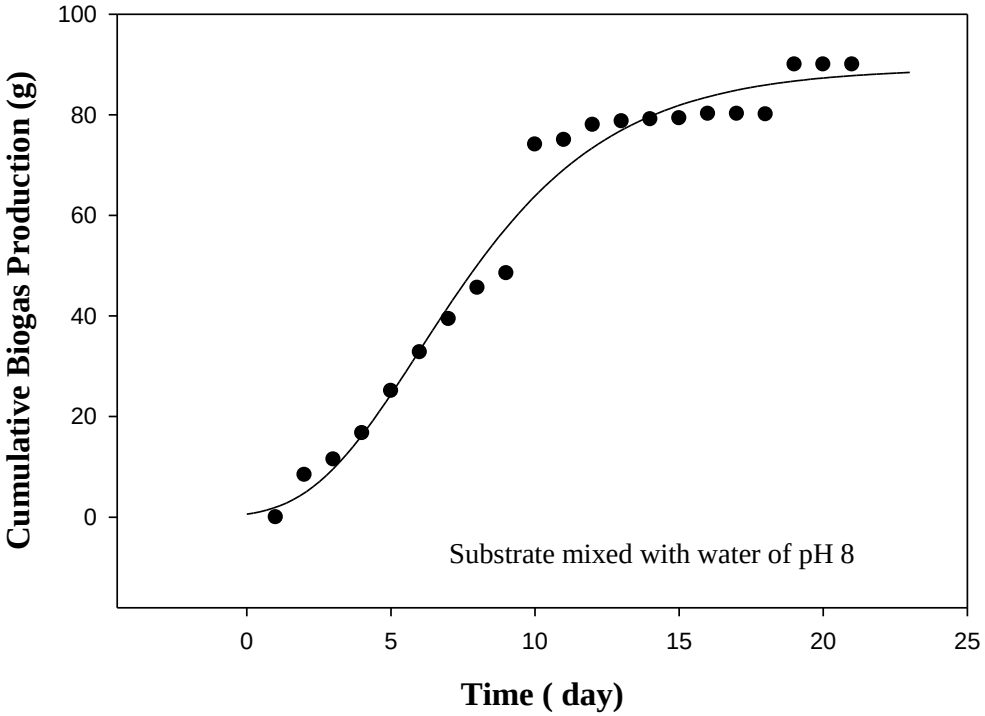

Figure 8: Graph of substrate mixed with Water of pH 8

DISCUSSION

Different treatments for Biogas production for batch A, tables 1 and 2 showed the various treatments for Biogas production for batch A. The treatment is 10 in groups and they showed the maximum biogas production potential, the maximum biogas production rate, Lag phase period and the R2. The Substrate mixed with bovine blood showed the most prominent biogas production other than other treatments.

Various treatments for Biogas production for batch B Figure 3, showed the various treatments for Biogas production for batch B. The treatment is 14 in

groups and they showed the treatments, the maximum biogas potential of the substrate before the second lag, the maximum biogas potential of the substrate in the second phase, the maximum biogas production rate before the second lag, the maximum biogas production rate in the second phase, the first lag phase time (days), the second lag phase time (days) and the R2.

Various treatments for Biogas production for batch C Figure 4, showed the various treatments for Biogas production for batch C. The treatment is 14 in groups and they showed the treatments, the maximum biogas potential of the substrate before the second lag, the maximum biogas potential of the substrate in the second phase, the maximum biogas production rate before the second lag, the maximum biogas production rate in the second phase, the first lag phase time (days), the second lag phase time (days) and the R2.

Conclusion and Recommendation

Conclusion

For Figure 5.0, for pig and poultry dungs amended with Bovine blood, day 0 showed no gas production. Immediately after bacteria are inoculated into fresh medium, during this period bacteria remains temporarily unchanged. Although there is no apparent cell division occurring, the cell may be growing in volume or mass, synthesizing enzymes, proteins, RNA and increasing in metabolic activity. This doesn't mean that there is no reaction but the microbes are in Lag phase trying to get acquainted with the new environment. From day 1-3, there was little production of gas. This explains that the barrier in the lignocellulose (the lignin) has been broken. Sugar has been released followed by its fermentation (Osuji *et al.*, 2022). After the limiting factor was broken, gas production rate increased. This can be shown from the cumulative gas production from day 1-14 in table 3. This gas increase can be attributed to the removal of lignin and the nutrient-rich blood bacterial growth responsible for acidogenesis, acetenogenesis and methanogenesis.

For Figure 6, where Charcoal water was used as additive. This shows that as the Carbon in C:N ratio increased; the volume of methane production increased.

$C + 2H2O$ ---------- $CO2 + H2$

$C6\ H12O6 + 8H2$ ---------- $6CH4 + H2O$

The carbon added will react with the water part of the slurry and hydrogen is formed. The hydrogen formed will react with the sugar from the lignocellulose. This will lead to the formation of methane.

From Figure 7, for the pig and poultry dungs amended with Magnesium Sulphate (MgSO4). The same trend was observed in gas production. After the removal of the limiting factor; the lignin, cumulative gas production rate increased. Apart from the natural anaerobic fermentation, Magnesium Sulphate (MgSO4), which functions as both basic salt and catalyst helped in increasing gas production as observed. This means that the anaerobic digestion can be enhanced by Magnesium Sulphate (MgSO4) as stated by Osuji *et al.*, 2024. Also, the quantity of Magnesium Sulphate (MgSO4 should be measured. It should not exceed 200g/dm3 for 1kg of substrate (Ikeokwu *et al.*, 2023, Osuji *et al.*, 2022). Another significant observation is that the cumulative gas production for one with blood and Magnesium Sulphate (MgSO4 are almost the same (as the volume of substrate and MgSO4 increases, the volume of gas produced increased).

From the tables and figures shown above, it was ascertained that co-digestion of substrates is a good strategy to enhance biogas production. This was also supported by Torkian *et al.*, 2023. These substrates are lignocellulose. As they stay in the biodigester, reactions will take place leading to breakdown of the cellulose, lignin and Hemicellulose (Osuji *et al.*, 2024). This research showed that as the amount of the substrates increases, the volume of gas produced increases. This supports the work of Ikeokwu *et al.*, 2023.

Recommendation

Addition of charcoal water was done to increase the carbon content of C:N ration in the substrate (Lignocellulose). Pratima *et al.*, (2012) have studied in previous works and reported that as the nitrogen level increases, there is the possibility of ammonia formation which will affect the Methanogens and the actions,

This research is recommending as follows:

- That that the quantity of the substrates should be enough to ensure more gas yield as shown in series three (3) of the tables and the graphs in appendix and chapter four.
- That the volume of blood should not be more than the water used in the slurry formation as this could affect proper mixing.
- That carbon content of the lignocellulose should be increased using charcoal water in slurry preparation to ensure formation of Methane (CH4) which is the main biogas.
- That measured amount of bovine blood, Magnesium Sulphate and Charcoal can be used as additive in biogas production.

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