Optimization of Biogas Production from Co-digesting Minced Chicken-Goat and Cow Manure at Different Inoculum and Total Solid Levels

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Introduction

❖Kenya's Big 4 AGENDA 2: (food security) => agro-waste generation [includes: chicken, goat & cow manure (CM,GM & CD)] whose improper management can lead to environmental pollution (e.g. GHGs) that can be remedied by their anaerobic digestion

❖Uptake of CM & GM for AD is low :

- low C/N ratios - 5:1-10:1 (Yangin-Gomec & Ozturk, 2013) & Avg. 18:1 (Zhang *et al.*, 2013) respectively
- low specific surface area (SSA)
- high dry matter (Chen *et al.*, 2008)

❖Improper TS & S/I ratios of CM &GM => failure digester failures, fluctuating level of microbial activity & unavailability of nutrients for AD bacteria (Masinde *et al.*, 2020).

❖Information on optimal level combinations of manure sizes, total solids and inoculum levels:

- assist AD plant designers/ operators improve biogas production from these systems
- Reduce uncontrolled greenhouse gases from manure storage pits

Study Objectives

Overall Objective

To evaluate the effect of pretreatment, inoculum and total solids levels of chicken and goat manure on biogas production when co-digested with cow manure

Specific Objective

1. To optimize biogas production based on selected minced chicken-goat manure size, inoculum and total solid levels when co-digested with cow manure

Materials and Methods

Experimental set-up

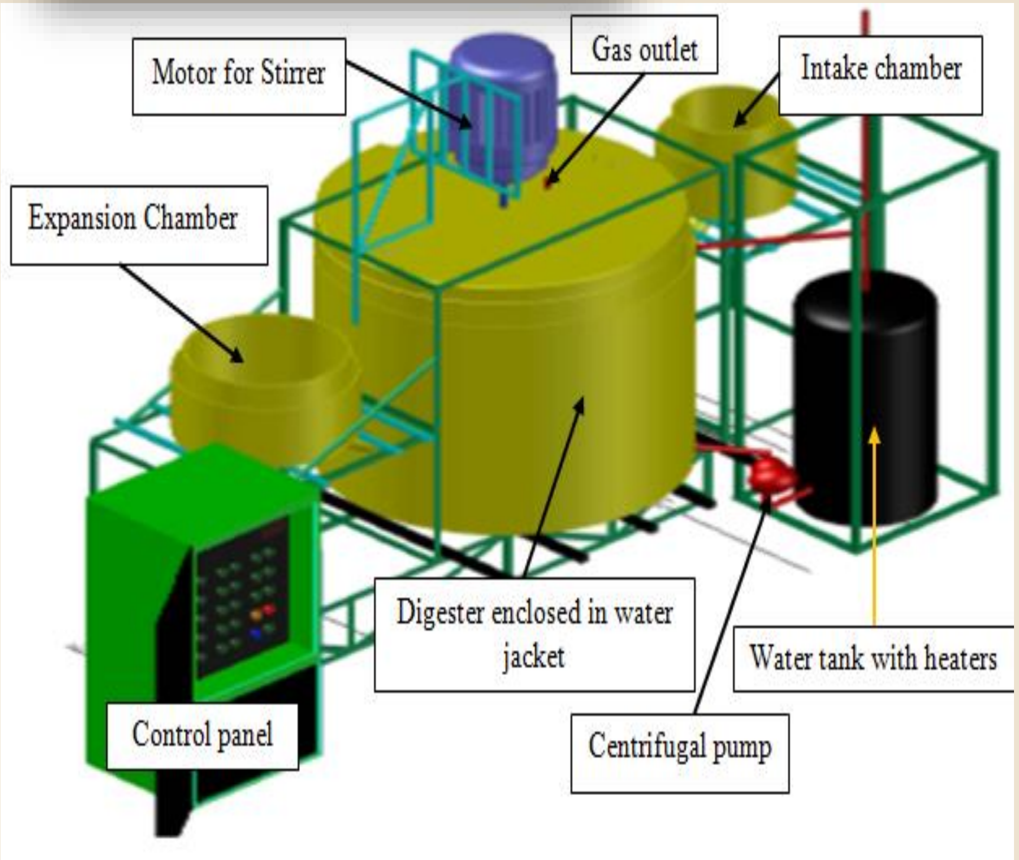

Fig 1: Experimental set-up

Experimental Set Up

- ❖Fixed dome Lab bio-digester at Egerton University
- ❖Batch AD of: Chicken (CM), goat (GM) & cow (CD) manure

AD Conditions

- Temperature = 35 ± 0.5˚C
- C/N ratio = 20.16 ± 0.09: 1
- pH = 7.0 ± 1.0
- Feed stock mix ratio = 1:1:1
- Stirring interval = 3min/ 6hr at 100 rpm

Substrate pretreatment

- CM-GM crushed by metallic meat mincer
- Aperture sizes: 2mm 3mm and 4 mm

Preparation of S/I ratios & TS

- S/I ratios = 2:1, 3:1, **4:1**, 5:1 & 6:1 (distributed around 4:1)

-Dennis (2015); Haider *et al.*(2015)

Materials and Methods (Cont'd)

TS range : 8-10% (Guided by Orhorhoro *et al.* (2017); Paramaguru et *al.*(2017))

<u>Optimization</u>

❖Response Surface Methodology (RSM) & Central Composite Design (CCD): Designed experiments & determined optimal conditions on response that was affected by independent variables

- Independent variables: S/I ratios (X_1), TS (X_2), minced particle size PS (X_3)
- Coded variables (X_1, X_2 & X_3) were divided into 3 levels
- Coding in design range;
  - highest = +1
  - centre point = 0
  - lowest = –1
- Real values = -α and +α
- Distance range, $\alpha = 2^{k/4} = 1.68$
- Number of variables, k = 3
- Real and coded variables were computed by using Eqn (1) that resulted in Table 1

$$\text{Coded Variable} = \frac{X - X_0}{\lambda}$$

Table 1:Independent Experimental Variables and their Coded Values

Factor	Symbol	Units		Coded and Real Values				
			Coded:	- α (-1.68)	-1.00	0.00	+1.00	+ α (+1.68)
Size	x_3	mm		1.32	2.00	3.00	4.00	4.68
S/I	x_1	Ratio	**Real:**	0.64	2.00	4.00	6.00	7.36
TS	x_2	%		7.32	8.00	9.00	10.00	10.68

Materials and Methods

- CCD helped know factors' effect on response beyond/ below chosen factor levels

- 20 experimental runs (6 centre &14 axial points) were designed in Table 2 using Table 1

- Relationship between response and coded variables was given by a 2nd second order polynomial Eqn (2) (Khoobbakht *et al.*, 2016)

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \sum_{1 \le i \le j}^{k} \beta_{ij} x_i x_j + \varepsilon \qquad (2)$$

where; X_0 = value of variables at the central level: for X_1 = 3mm, X_2 = 2 and X_3 = 9%

X = input variable: for X_1 = 2, 3, 4; X_2 = 2:1, 4:1, 6:1 and X_3 = 8%, 9%, 10%

λ = step change of the variable: for X_1 = 1mm, X_2 = 2 and X_3 = 1%

Y = Biogas yield (m^3/m^3d)

x_i, x_j = independent variables

β_0 = offset co-efficient

β_i, β_{ii}, β_{ij} = Linear, quadratic and interactive coefficients, respectively

ε = Residuals associated

Results and Discussions

Table 2: Experimental and Predicted Biogas Production Rate

.	A:S/I (ratio)	B: TS (%)	C:Size (mm)	Actual (m^3/m^3d)	Predicted (m^3/m^3d)	Deviation (m^3/m^3d)	Deviation (%)
1	6.00	10.00	4.00	0.36	0.42	+ 0.05	+ 12.52
2	**4.00**	**9.00**	**3.00**	**0.59**	**0.58**	- 0.01	- 1.17
3	7.36	9.00	3.00	0.39	0.37	- 0.02	- 6.74
4	4.00	10.68	3.00	0.47	0.46	- 0.01	- 2.95
5	6.00	8.00	4.00	0.38	0.40	+ 0.02	+ 5.72
6	2.00	10.00	2.00	0.41	0.38	- 0.02	- 5.87
7	2.00	8.00	4.00	0.45	0.46	+ 0.01	+ 2.46
8	4.00	7.32	3.00	0.51	0.53	- 0.02	+ 4.10
9	6.00	8.00	2.00	0.48	0.47	- 0.01	- 3.05
10	0.64	9.00	3.00	0.33	0.36	+ 0.03	+ 9.10
11	**4.00**	**9.00**	**3.00**	**0.58**	**0.58**	0.00	+ 0.53
12	6.00	10.00	2.00	0.46	0.45	- 0.01	- 2.51
13	**4.00**	**9.00**	**3.00**	**0.57**	**0.58**	+ 0.01	+ 2.48
14	4.00	9.00	4.68	0.50	0.44	- 0.06	- 12.51
15	2.00	8.00	2.00	0.53	0.48	- 0.05	- 10.79
16	2.00	10.00	4.00	0.38	0.40	+ 0.01	+ 3.61
17	**4.00**	**9.00**	**3.00**	**0.58**	**0.58**	0.00	+ 0.15
18	**4.00**	**9.00**	**3.00**	**0.59**	**0.58**	- 0.01	- 1.72
19	4.00	9.00	1.32	0.42	0.49	+ 0.06	+ 13.02
20	**4.00**	**9.00**	**3.00**	**0.57**	**0.58**	+ 0.01	+ 1.22
Mean				**0.48**	**0.48**	**0.00**	**+ 0.35**

❖Model (Eqn. 1) suggested by the software for biogas production rate was quadratic;

$$Y = -275.20 + 12.25A + 69.42B + 28.16C + 1.53AB - 0.97AC + 1.22BC - 2.88A^2 - 4.57B^2 - 6.22C^2$$

❖Highest production rate = $0.59 m^3/m^3d$

(S/I=4:1; TS=9%; PS= 3mm)

❖Differences between actual & predicted values were <20% (Subha *et al.*, 2015) hence a good relationship.

- Caused by experimental errors

❖Values slightly above reported $0.50 m^3/m^3d$ (Masinde *et al.*, 2020) for CD attributable to;

- CM + GM particle size reduction
- Co-digestion: balanced nutrient availability & reducing inhibition by toxic compounds to increase substrate degradation

Aichinger *et al.*, (2015); Labatut *et* al.(2014)

Results and Discussions (Cont'd)

- Terms :
  - Quadratic (S/I - A^2, TS - B^2 & PS - C^2) & interactive (AC) had antagonistic effects
  - Linear & interactive (A, B, C, AB & BC) had synergistic effects on production rate

- Model, individual and interactive factor effects on biogas yield were tested using probability of F-statistics. Model had:
  - $F_{suggested} = 7.99 > F_{critical} = 0.002$; is significant & could adequately be used to predict experimental data
  - $R^2 = 0.7681$: good co-relation between observed & predicted data
  - Adequate Signal : Noise ratio = 7.5, greater than recommended base value of 4 (Sadhukhan *et al.*, 2016)
  - Co-efficient of Variation = 8.59%; below the 10% limit, hence reliability of experiments

- Verifying model suggested conditions: yield rate was 0.61, 0.60 & 0.60 m^3/m^3d, indicating an adequate match

- Experimental results confirmed that biogas production from CM-GM-CD could satisfactorily be experimentally designed & developed by RSM & CCD.

Conclusion and Recommendations

Conclusion

❖Optimum production (0.59m^3/m^3d) was achieved from co-digestion at S/I = 4:1, TS = 9% & PS = 3 mm, a 34% increase above reported values for cow manure.

❖With the positive results, local farmers can improve uptake of chicken and goat manure as substrates for sustainable renewable energy production and reduce uncontrolled greenhouse gas emissions from open manure dumps.

Recommendation

Undertake the research in ordinary field conditions for proper advice to biogas producers versus policy, management and economic quantification & qualifications

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