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P072 - BIOGAS SYNTHESIS FROM HUMAN EXCRETA USING ZIRCONIA DOPED SILICA CATALYST

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ABSTRACT

Open defecation is an enormous environmental hazard that plagues the ecosystem. A laboratory scale batch biogas digestion using human excreta was undertaken with Zirconia doped silica catalyst (ZrO_2/SiO_2). The mass of gas produced, methane content were measured by electronic weighing balance and Mestek CGA02A methane detector respectively. The effect of catalyst doping and catalyst loading on yield were studied. The catalyst increased the yield of biogas from 7.22 L/KgVS (Litres per kilogram volatile solid) to 19.02L/KgVS and methane content from 14.00% LEL (lower explosive limit) to 97 00% LEL. This equals the purity level of externally purified biogas and meets the energy (Calorie value) need for domestic and industrial applications. This result of the biogas yield shows a remarkable 163.90% efficiency in yield of catalyzed digestion over un-catalyzed and 592.80% increase in methane content over the un-catalyzed system using the same substrate.

KEYWORDS

Open defecation, Biogas, Catalyst loading, Catalyst doping, Human excreta

1.0 INTRODUCTION

In recent years Biogas has gained much attention in energy application both in domestic and industrial settings, in areas such as; powering of cars, trains, electricity generation, as well as in cooking (*1*). The limitation of Biogas as low-caloric value product in relation to Liquefied Petroleum Gas (LPG) and Compressed Natural Gas (CNG) tend to limit its application. The most critical task in this regard, is to produce Biogas of higher methane content with little or no impurities, in order to enable its use without conversion to Bio-methane by purification, thereby increasing its caloric value, and the removal of moisture that accompanies its production, making it liquefiable without purification (*2*). Prominently, the number of impurities present in the Biogas determines in usage both in the domestic and industrial applications. Unpurified Biogas presents engineering problems such as; fouling of engine tappet, rusting of cylinder bore and emission of obnoxious gases from car exhaust and during combustion. The production of Biogas from sewage and kitchen waste by designing a sewage and kitchen waste bio digester to replace the present soak away system and kitchen waste disposal in waste dumps, will go a long way in enforcing the recently enacted federal legislation against open defecation and by extension reduction, if not elimination of deforestation. Open defecation and deforestation are of common knowledge in our society, and these have impacted negatively in the life of the inhabitant of the area, as water bodies and environment have been polluted by human faeces and forest depleted and land exposal to erosion with resultant loss of nutrients, leading to breading of diseases vectors, diseases and even death. The recent enactment of a law against open defecation and the subsisting law on deforestation necessitate a need to develop an efficient sewage-based digester system for converting human waste into renewable energy fuel for use in cooking and electricity generator, thereby reducing deforestation and open defecation; making open defecation unattractive since it could serve as a source of fuel for cooking. This work explores the possibility of developing a novel catalyst blend for biogas production. The research targets the improvement of the Biogas yield of Zirconia-Silica Catalyzed Biogas digester using human excreta as substrate.

1.1 DIGESTION OF HUMAN EXCRETA WITH AND WITHOUT CATALYST

Biogas has been produced with various compositions of catalyst, water and substrate. Biogas yield, methane content was used to evaluate the effect of catalyst on the digestion efficiency. It was observed that catalyst when used in the right proportion to feedstock can enhance yield and methane content instead of inhibiting the anaerobic digestion Biogas can be formed in nature from refuge dumps and rumen of ruminant animals in mild acidic environment, naturally occurring biogas, and results from anaerobic digestion of organic matter by (6). The substrates utilized also include agricultural waste and other activities that generate organic waste as by products. For example, rice straw, pruning, beet, beer and Alcohol production, grass clippings and other agricultural processing activities.

Synthetic biogas, unlike natural biogas, are synthesized either from organic fraction of municipal solid waste, sewage sludge, food waste, fish waste, animal manure, in artificial digesters. (3).

(4) used human faeces as substrate for biogas synthesis. In his work, the key result showed that specific biogas (SBP) of about $0.15m^3/m^3/kg/sv$ (in normal condition) with an organic loading rate (OLR) of about $0.417kgsv/m^3/day$ were obtained. However, longer digestion time, slurry composition variation, and environmental conditions were not considered without any use of catalyst.

(5) in their work examined the effect of metal addition (ions), such as trace metals in the anaerobic fermentation process, especially on the activities of the enzyme, hydrogenase. The result of their study shows that metal ion addition facilitates the intracellular electron transportation and the provision of essential nutrition for microbial growth, thereby increasing the production of biological hydrogen from anaerobic fermentation.

(6) in their study assessed the effect of different supports materials (expanded clay and activated carbon, Mutag Biochip) on microbial production of hydrogen in an anaerobic packed bed reactor (APBR), using synthetic waste water at low pH as main source of carbon. The result shows that the amount of hydrogen was highest in Mutag Biochip (R_1, 1.80molH_2/mol glucose) followed by clay (R_2, 1.74molH_2/molglucose) and activated carbon (R_3, 1.46molH_2/molglucose). These prove that the reactor with the highest yields (R_1andR_2) had the lowest acetate/butyrate ratios of 1.7 and 1.6 respectively, while those with the lowest hydrogen yield (R_3,) had the highest acetate/butyrate ratio of 4.8. This indicates that hydrogen is produced from the acetate and butyrate by the microbes under the influence of the support materials which has some immobility effect on the gas production.

(7) evaluated HRT and Solid Retention Time (SRT) effect on hydrogen production from organic solid waste using a sequencing batch reactor (SBR) under mesophilic conditions. The result obtained shows that a short SRT of 20h decreased the hydrogen production by up to 90%, and that, optimal hydrogen can be produced at an HRT of 16h and SRT of 55h, showing that HRT is the main parameter that determines the microbial community composition. The result showed that Olsenella genus was predominant at HRT less than 8h, Clostridium at an HRT of 16h when the slurry was analyzed for microbe composition.

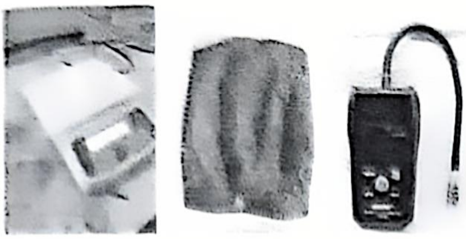
(8) studied biogas production using Silica gel as catalyst. A fictitious laboratory scale digester was used to synthesize biogas from poultry farm and domestic kitchen waste at a digestion temperature of between 26° C to 3° C. The result shows that 7921ml/kg (7921L/kg) was obtained without silica gel and 10545ml/kg (10.545L/kg) with catalyst, an improvement of 33.12% over digestion without catalyst.

(9) in their study investigated the effect of iron oxide nanoparticles (IONPs) on the anaerobic co-digestion in which olive mill wastewater and chicken manure were used as substrate under mesophilic conditions. Biogas yield, methane (CH4) content, the removal efficiency of TS, VS., acidification and hydrolysis percentage were also investigated. Their result showed 1.3% to 4.2% enhancement in methane generation yield over the control.

2.0 MATERIAL AND METHODS

2.1 Materials

The materials used for this research include Zirconia, Silica, Distilled water and human excreta. The human excreta were collected from kure village opposite Kure market in Minna, Nigeria. The substrate was reduced to 2mm grain size in a mortar. The water used was obtained from a local chemical store, Panlac Nigeria Limited. Zirconia and silica were also obtained from the store. The Mestek CGA02A Methane gas analyzer used in analyzing the produced biogas was obtained online as shown in plate 1.0.



a b c

Plate 1.0: (a) Zirconiumdioxide (b) Human excreta (c) Mestek CGA02A Methane Gas Analyzer

2.2 Methods

The dried sample of the substrate underwent physicochemical analysis in order to determine its moisture content, volatile solid and total solid (*10*). This analysis was carried out in the Unit Operations Laboratory, Department of Chemical Engineering, Federal University of Technology, Minna. Nigeria. Thermogravimetric analysis was also conducted on the catalyst sample developed. The catalyst samples were calcinated at 500 °C for about an hour and twenty minutes.

The catalyst were developed using the method specified by (*11*) in their work on the structureal characterization of $Ni/ZrO_2/SiO_2$ nanocomposites prepared by wet impregnation method. Alternate quantities of ZrO_2 was mixed with SiO_2 in various proportions of 10g, 20g, and 30g in the ratio of 3:7, 7:3 and 1:1 respectively. This resulted in three different catalysts doping of ZrO_2/SiO_2. The ZrO_2/SiO_2 mixed oxide was calcined at 500° c in an inert furnace atmosphere in order to prevent any oxidation reaction on the composite when heated.

The calcined catalyst was then added to the substrate at 10%, 20%, 30% catalyst loading and digested with 660g of distilled water in ten $3.5\times10^{(-3)}$ m^3 mini digesters, of which one digester without catalyst added, served as the control. The digestion was carried out for 35 days in the Unit Operation Laboratory, Chemical Engineering Department, Federal University of Technology, Minna. Niger State. Nigeria.

3.0 RESULT AND DISCUSSION

The Digestion result is presented herewith and hereby discussed

3.1 Effect of catalyst doping

The result of Balanced Design Analysis of Variance (BD-ANOVA) means plot of gas produced by catalyst doping (figure1.0) showed a large difference among the mean of gas produced between the three levels of catalyst doping when catalyst loading is at smallest index level. Also, at catalyst doping levels of 1 and 3, the mass of gas produced mean increases between catalyst loading levels, 10% and 20% while decreasing for level 2. When catalyst loading is at level 20% the curves start to parallel, indicating that there is not interaction effect between catalyst doping and catalyst loading of levels 10% and 30%. Therefore, the main effect of both factors (catalyst loading and catalyst doping) is zero at this level. However, the two effects are additive and the main effect of catalyst doping does not depend on (or interact with) the levels of catalyst loading of Levels 20% and 30%. Figure 1.0 depicts the effect on biogas production.

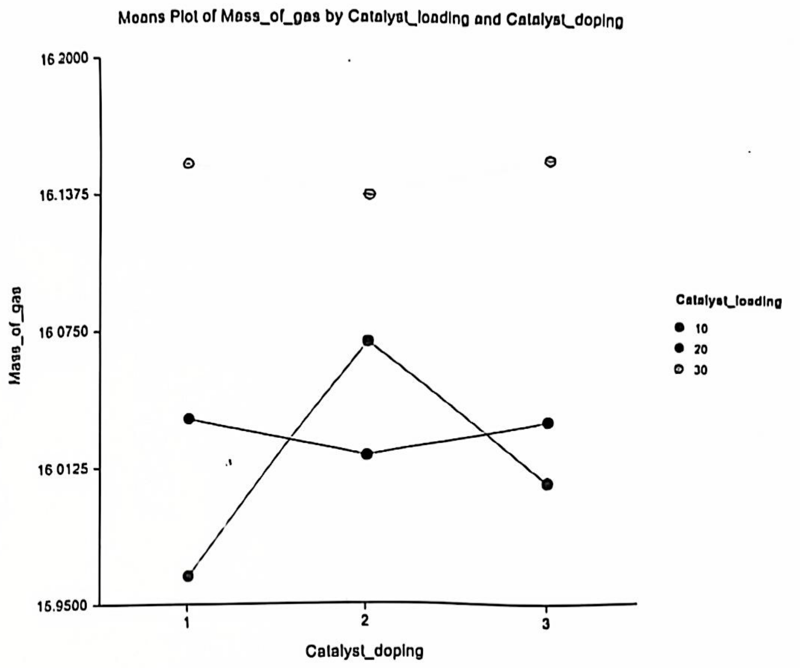


Figure 1.0 Mean plot of biogas production by catalyst doping

3.2 Effect of catalyst loading

The result of the BD-ANOVA means plot of biogas production by catalyst loading (Figure2.0) showed that catalyst doping has not effect, since catalyst loading levels 20% and 10% overlaps with one another. Moreso, as catalyst loading level of 30% and 20% are parallel to one another, it therefore means that, the effects of catalyst loading levels 30% does not depend on (interacts with) the levels of catalyst doping.

Figure 2.0 shows the mean plot of biogas production by catalyst loading.

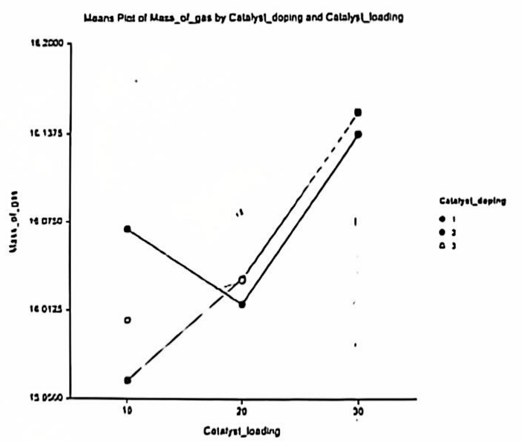


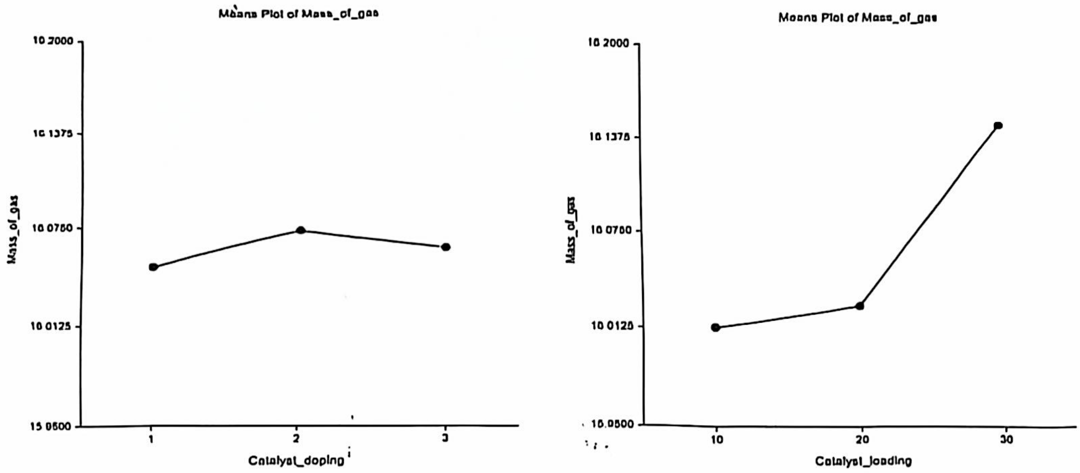
Figure 2.0 Mean plot of biogas production by catalyst loading

3.3 Effect of catalyst loading and doping on gas production

Table1.0 Summary of Balanced Design Analysis of Variance (BD-ANOVA) showing the effect of catalyst loading and catalyst doping on gas production

Model	DF	P-Value
A: Catalyst doping	2	0.88872
B: Catalyst loading	2	0.01961*
AB	4	0.85491
S	153	
Total Adjusted	161	
Total	162	

The Result of the BD- ANOVA (Table4.3) showed that catalyst loading had significant ($P \leq 0.05$) effect on biogas production while catalyst doping had not different significantly ($P > 0.05$).



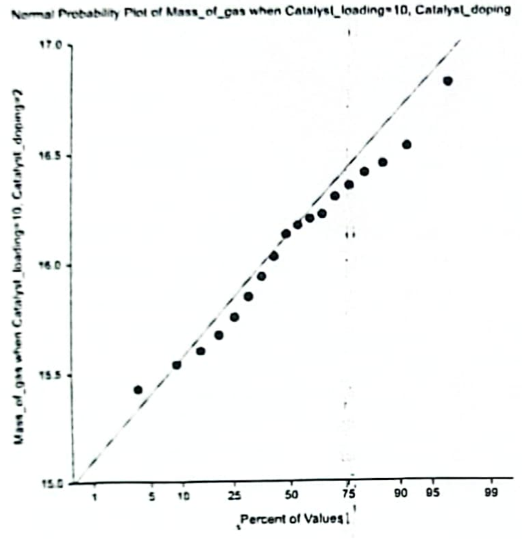
(a) (b)

Figure3.0 (a) Mean plot of mass biogas produced against catalyst doping, (b) Mean plot of mass of biogas produced against catalyst loading\

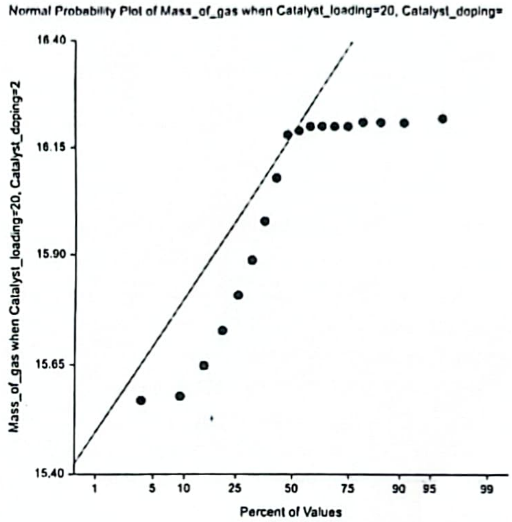
Table 2.0 Summary of yield of biogas produced

S/N	Experimental Setup	Yield(L/kgVS)
1	Control	7.22
2	Catalystdoping1loading10	10.77
3	Catalystdoping1loading20	11.30
4	Catalystdoping1loading30	12.75
5	Catalystdoping2loading10	19.05
6	Catalystdoping2loading20	13.30
7	Catalystdoping2loading30	12.48
8	Catalystdoping3loading10	13.30
9	Catalystdoping3loading20	11.17
10	Catalystdoping3loading30	12.75

The result of the mean plot of mass of biogas produced indicates that catalyst loading at level 10% produces the highest biogas yield at a catalyst doping of level 2, as shown in figure 3.0(a). While Figure 3.0(b) shows that the catalyst loading of 30% produces the highest cumulative mass of biogas in the first eighteen (18) days of digestion. Table 1.0 shows the BD-ANOVA result of the effect of catalyst loading and doping on mass of biogas produced.



(a)



(b)

Figure 4.0 (a) Normal probability plot of mass of biogas at catalyst loading=10, catalyst doping=2, (b) Normal probability plot of mass of biogas at catalyst loading=20, catalyst doping=2

3.4 Methane content

The digested biogas was analysed *in situ* with a hand-held combustible gas detector model CGD02A, calibrated in lower explosive limit (LEL) and part per minute of resolution 1%LEL and 1PPM and detection flow of 1L/min. The gases detected are Natural gas, coal gas and liquefied petroleum gas with a response time of 2 seconds, measurement range of 1% to 100%LEL and 50ppm to 50000ppm and measurement accuracy of + or -5%FS

The result of the measurement is shown in table 3.0

Table 3.0 Summary of amount of methane gas (CH_4) in generated biogas measured with Mestek CGD02A

Digester	Amount of Methane present(%LEL)	Measurement Temperature	Remark
Control	14.0	31.4	
Catalystdoping1, loading 10	0.0	31.4	
Catalystdoping1, loading 20	0.0	31.4	
Catalystdoping1, loading 30	0.0	31.4	
Catalystdoping2, loading 10	88.0	31.4	
Catalystdoping2, loading 20	97.0	31.4	
Catalystdoping2, loading 30	Gas bag spill	31.4	Digestesd spill into gas bag
Catalystdoping3, loading 10	62.0	31.4	
Catalystdoping3,loading 20	Gas bag Spill	31.4	Digestesd spill into gas bag
Catalystdoping3, loading 30	0.0	31.4	

The tabulated result of the methane content measurement shows that the digester of catalystloading=20doping=2 generate the highest amount of methane (97%LEL) followed by the digester catalyzed with catalystloading=10doping=2 (88%) and thirdly by catalystloading=30catalyst doping=3 (62%). While the control yielded only 14%LEL. The result, therefore, prove that biochemical reactions can be catalyzed with inorganic heterogeneous catalyst together with enzymatic catalysis.

4.0 CONCLUSION AND RECOMMENDATION

4.1 Conclusion

From the experiment conducted and the analysis undertaken, the following facts can be drawn: The human excreta are a viable substrate for biogas synthesis, which has a yield of both biogas and bio-methane content. The BD-ANOVA analysis of the mass of gas produced revealed that catalyst loading have significant effect on the yield, with a probability of 0.01961 which is less than significant level of α=0.05 while catalyst doping hat not effect. Therefore, catalyst loading had significant effect on the process yield. To further investigate and established the actual catalyst doping combination that has the highest effect on yield, the Two-Sample T- Test was conducted. This revealed that catalyst doping of 10% (Catalyst doping=2, loading=10) gave the highest yield as depicted in figure 4.0(a). The highest yield of biogas produced was 19.02L/KgVS which is 163.9% over the control of 7.22L/KgVS. The methane content obtained for the catalyzed doping of 20% (Catalyst doping=2, loading=20) gave the highest methane content of 97%LEL), while the control had only 14%LEL. The biogas produced from catalyzed digestion (Catalyst doping=2, loading= 20) can be used as bio-methane to power generators, cars and cooking meals drive turbines without necessarily purifying it.

4.2 Recommendation

From the foregoing further research should be undertaken to ascertain the optimum parameters that would give the highest yield of biogas and methane content from a single catalyst loading and doping combination.

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