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THE APPLICATION OF IMAGINEERING CONCEPT IN BIOGAS –TO – ELECTRICITY GENERATION FOR DOMESTIC USES: NIGERIA PERSPECTIVE

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Abstract

There is shortage in electricity supply for household use, which has resulted to prevalent massive subscription to fossil fuel powered electricity generating sets (of various capacities) otherwise known as generators. There exists the need for an adaptable sustainable alternative energy sources to the fossil fuels. The paper presents an Imagineering concept of running a holistic analysis of biogas to electricity conversion system to ascertain adaptability of biogas as alternative fuel source for electricity generation in Nigeria. Backward integration was applied, determining the electricity demand of household, the biogas need, and the capacity of the digester as well as the feedstock, to fulfill this. A typical household in the urban or sub-urban cities in Nigeria; with daily consumption capacity of 20 KWh per day to 30 KWh per day on 6 hours per day supply from the national grid, and 24 hours electricity need, was found to have need of 239kg to 358kg of the organic matter per month and a $12m^3$ to $18m^3$ digester size. This shows that the system with the current situation is not sustainable. The paper suggests various means of improving the sustainability and adaptability of the system.

Keywords: Biogas Production, Energy Modelling, Biomass Biodegradation, Electricity Generation, System Optimization

1. Introduction

Electricity can be generated by combusting gas generated from biodegradable organic matter, in a Spark Ignition (S.I.) Engines. In developing nations (particularly Nigeria), public electricity supply for domestic use has remained a big challenge, to the extent that most household must have standby generator(s), which they have to fuel at great cost in order to have electricity that will meet their basic domestic need.

Thus the problem remains a twin in the main; raising enough money to sustain operating and maintenance cost, because petroleum products are expensive, and having to deal with the issue of environmental hazard caused by the use of this fuel. The environmental unfriendliness of fossil fuel calls for immediate replacement of fuel from this source. The one way to address the challenge is to generate gas from bio-degradable waste such as cow dung; animal droppings; kitchen waste; sewage sludge; energy – rich, non edible vegetables (e.g. water hyacinth) etc.

Waste to wealth conversion is one of the world's acknowledged philosophies that are geared toward the optimization of system's productivity. This concept when adapted goes a long way in solving the national problem of electricity, as well as serve as an efficient and economic waste management technique.

Admitted that various past research efforts have focussed on gas production using various types of biodegradable organic waste as outlined above, but the issue has been that the innovative technology adopted had been a little better than damp squibs. This therefore has created a yawning gap. The proposed research and development is meant to bridge this gap (a desideratum).

The approach advocated is a systematic approach that involves backward integration to the design of the system and sourcing of important waste that can generate copious gas supply and sustain the supply, such that the electricity production will be sustainable just like the feedstock used for gas production is. To the best of the innovators' knowledge, there is no complete supply system of such nature that is available in the market

Review of Related Work

With the rapid growth in population density all over the world, the yearning for energy for domestic, commercial and industrial purpose is continually increasing. Based on the United Nation prediction of world population growth to 9-10 billion people by 2040, it is obvious that copious production or conversion of various energy forms will be required for effective and efficient production in various work systems. Baki (2004), as emphasized by Rabah et al (2010) opined that civilization of any region of the world is predicated on the abundant availability of energy for domestic, agricultural and industrial purposes.

Nwachukwu, Ezedinma and Jiburum (2014) compared the electricity consumption among Residential, Commercial and Industrial Sectors of the Nigeria's Economy using a 35 years period data (1970 to 2004). It was then revealed that the residential sector has the highest mean electricity consumption (396.405 MW per hour) when compared with the industrial and commercial sector of the economy. Also the consumption by the three sectors fell short of the 500MW per hour energy demand by each of the sectors. The 104 MW shortfalls are augmented by the standby generators. Most of these are powered by either diesel or petrol (which is of fossil fuel origin).

The world fossil fuel reserve is continually depreciating. Its adverse effect on the wellbeing of the environment has also been a matter of great concern. The UN Secretary-General on November 1st, 2011 presented the vision statement as "*Sustainable Energy for All".* Hence, the urgent search for sustainable renewable alternative source of energy was advertised, and biogas from waste organic biomass was enlisted among the alternative sources found.

Singh (2012) as cited by Olowoyeye (2013) defines biogas as a clean bio-fuel produced by micro-organism or bacteria during anaerobic digestion of organic matter. Rajendran, Aslanzadeh and Taherzadeh (2012), noted that biogas is a value-added product of anaerobic digestion of organic compounds. Basically, biogas is produced by Anaerobic Digestion (AD) process, creating values from waste. Many organizations in the world have shown significant interest in this technology. Alberta Innovates – Energy and Environment, are currently researching on technologies that capture energy from bio-waste (biomass) and other values from these materials (Xiaomei 2014).

In recent past, optimization of biogas production has been pursued using various approaches; Change/ choice of substrate (feed stock) *Olowoyeye (2013); the u*se of co-substrate (feed stock) *Oliveira, Alves and Costa (2014), Manfred et al (2007);* Feed pattern or/and rate, *Manfred et al (2007);* sustainability of agricultural supply of biomass, Imdadul et al (2009); Pre-treatment of substrate (feed stock) *Tumutegyereize et al (2011), and Montgomery and Bochmann (2014)*; Improvement in heat utilization and/ or sub layer temperature, *Elena et al (2015);* Upgrading from small scale digester to larger size; Transformation from on-site power supply biogas plant to bio methane plant feed into the national grid i.e. economy of scale; and Optimization of the system parameters and operating condition(e.g. temperature, pH, substrate concentration, Total Organic Carbon (TOC) content, optimum particle size, Total Solids (TS), Total Volatile Solids (TVS));. *(Premsunder et al (2015), Sajeena, Jose and Madhu (2014), Rabah et al (2010), Wu, Bibeau and Gebremedhin. (2009), Abu Qdais, Bani Hani and Shatnawi (2009)).* Wu, Bibeau and Gebremedhin (2009), developed a simplified first-order kinetic model as part of an overall effort to develop a three-dimensional numerical model that can link digester-process controls, fluid flow conditions and anaerobic digestion for different digester designs, climatic conditions and manure compositions with respect to C/C0.

Also in the bid to optimize the biogas production, Agnieszka et al (2013) highlighted the need to employ standards measure for classification of biomass and assessing biodegradability of whatever is classified as biomass. The improvement of microorganisms genetically was discovered also as an efficient means of degrading the plant biomass. Enzymatic cocktails that can be introduced commercially was also developed. (eds. Anuj and Silvio , 2013)

Corseuil and Weber Jr.(1994), Pe´rez et al (2002), Arutchelvi et al (2007), Katarzyna and Grażyna (2010), Camarero, Martínez and Martínez (2013), Adam and Stephen (2014), Isikhuemhen et al (2014), have worked in the area of efficient degradation of lignocellulosic biomass, with respect to understanding the various make up of the plant cells, the improvement of the microorganism genetic makeup for better degradation of the biomass and developing conducive situation/ environment for the process.

Biogas is a good substitute for firewood and cattle dung that can meet the energy needs of the rural population, (Rajendran, Aslanzadeh and Taherzadeh 2012). The question is; what is its propensity to replace fossil fuel in electricity generation? Martins das Neves, Converti and Vessoni Penna, (2009), as cited by Rajendran, Aslanzadeh and Taherzadeh (2012) used International recommended Standards of testing to ascertain the energy content of different fuel. The energy content of 1.0 m^3 of purified biogas was found to be equal to 1.1 L of gasoline, 1.7 L of bio ethanol, or 0.97 m^3 of natural gas. This shows a great deal of difference in energy content, i.e. 1.0 m^3 of biogas is equivalent to 1.1 L of gasoline. There is need for work on its production rate, economic analysis of the project, and re-engineering of the production system with efficiency and cost reduction as the major factors.

Despite the huge potentialities and biomass resources for anaerobic digestion in Africa, Mulinda, Hu and Pan (2013) noted that the dissemination rate of biogas in Africa is struggling to meet biogas market demand. Due to number of challenges in the field which led to underestimation of the benefits of biogas technology, over reliance on wood and fossil fuels has remain significantly overwhelming. Unreliable and inefficient use of biomass fuel, which contributes to the greenhouse gas emissions still, was listed as the challenge.

Also, Patrick, Abdullahi and Bello (2013), among some other challenges facing the biogas production in Nigeria, highlighted the issue of sustainability over a long period of time to meet industry requirements. This was also highlighted by Marco (2011), in his dissertation on learning challenges in biogas production for sustainability -an activity theoretical study of a network from a swine industry chain. Mshandete and Parawira (2009) in their review of Biogas technology research in selected sub-Saharan African countries made a clarion call on African scientists to carry out research in biogas technology to locally demonstrate the feasibility, application, and adaptation of this technology, to help improve the quality of energy supply in their respective countries.

There exists a need to investigate these issues, to ascertain the root causes of the challenges and proffer viable solution(s) to them, in order to enhance the adaptability of the technology in providing electricity – especially for domestic uses.

2.0 Material and methods

The biomass to electricity system consist of three 3 main subsystem as shown in figure 1;

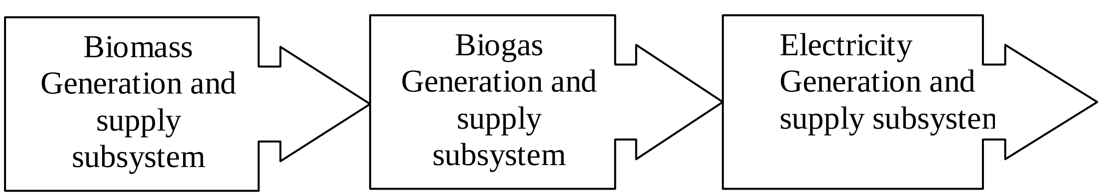

Figure 1: Schematic Representation of the Biomass – to – Electricity System

Backward integration method was applied to ascertain the interdependency of the entities or components of the system (biomass to electricity conversion system). The identified entities were used to develop a Binary Interaction Matrix (B.I.M.), which was further developed into dependency equations.

Given the electricity demand of the household, the amount of monthly supply from national grid and few other variables as shown in table 1, the required bio-digester volume, expected gas consumption (m^3/month), and quantity of biomass needed for electricity generation in household were computed using the inputs. The factors, unit of measurement, source of computation and the interrelationship equations developed were shown in table 2. The data collected and analyzed, alongside with application of expert opinion technique, were employed in developing the Binary Interaction Matrix (BIM) for the system.

Table 1: Identified Key Factors in Biomass to Electricity Generating System

Factor	Description of Factor	Factor	Description of Factor
A	monthly electricity consumption from	K	biogas calorific value
B	daily hours of supply from national grid	L	biogas consumption rate
C	desired daily hours of electricity supply	M	monthly biogas consumption for electricity supply (bridging
E	energy consumption per hour	O	retention time
F	Actual household daily electricity demand	P	monthly demand of organic matter (biomass)
G	Daily shortage (gap) of electricity supply	Q	Bio digester's organic matter capacity per volume
H	Generator specification (power and	R	Required digester's size
I	Generator efficiency	S	digesters' production cost per m3
J	Biogas Combustion efficiency	T	digesters' total production cost

Table 2: Interdependency of the Systems' Entity and the Derived Equations

Entity	Description of Entity	Unit	Source for computation	The interrelationship equation
A	monthly electricity consumption from national grid	kwh/ month	Electricity bill from distribution companies (DISCOs).	
B	daily hours of supply from national grid	Hours/ day	consumers' response	
C	desired daily hours of electricity supply (Where x is the fraction of the hours of the day, electricity supply is needed)	Hours/ day	consumers' response	=(X% *24)
D	number of days in a month	days/ month	Calendar	Approx. to 30
E	energy consumption per hour	Kw	A,B,D	={A/(B*D)}
F	Actual household daily electricity demand	kwh/day	C,E	={C*E}
G	Daily shortage (gap) of electricity supply	kwh/day	B,E,F	={F – (B*E)}
H	Generator specification (power and efficiency)	kw, %	E	>= E
I	Generator efficiency	%	H	
J	Biogas Combustion efficiency	%	Literature and experiment	
K	biogas calorific value	kwh/m^3	Literature : Sasse (1988)	= 6
L	biogas consumption rate	m^3/Kwh	I,J,K	=(I*J)/K
M	monthly biogas consumption for electricity supply (bridging the gap)	m^3/month	D,G,L	={ D* G*L}
N	Biomass to biogas conversion rate	m^3/kg$_{om}$	literature and experiment	0.036 to 0.092 (winter to summer) for cow dung
O	retention time	Days (months)	literature and experiment	25 to 35 days ≈ 1 month
P	monthly demand of organic matter (biomass)	kg$_{om}$/ month	M,N	={M/N}
Q	Bio digester's organic matter capacity per volume	kg$_{om}$/m^3	literature Sorathia, Rathod and Sorathiya (2012)	17 to 20
R	Required digester's size	m^3	O,P,Q	=(O*P/Q}
S	digesters' production cost per m3	Naira/ m^3	literature and personal computation	20,000 to 25,000
T	digesters' total production cost	Naira	R, S	={R*S}

Factors	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	Total
A																					0
B																					0
C																					0
D																					0
E	1	1		1																	3
F			1		1																2
G		1			1	1															3
H					1																1
I								1													1
J																					0
K																					0
L									1	1	1										3
M				1			1					1									3
N																					0
O																					0
P													1	1							2
Q																					0
R															1	1	1				3
S																					0
T																		1	1		2
Total	1	2	1	2	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	

Figure 2: Binary Interaction Matrix (B.I.M) for interrelationship between various entities (key players) of the system.

3.0 Result and Analysis

The above relationships between the entities were programmed into the Microsoft Excel sheet to compute the feedstock requirement per month and the digester size required for the various classes of electricity users and supply scenarios. The estimate of the digester production cost could also be obtained by multiplying out the digesters' size in m^3 and the unit production cost per m^3 of the digester. This was done to ascertain the adaptability of the system to household use in Nigeria. The result of the computation is shown in table 3a to 3c.

Table 3a: Required Digesters' size and Organic waste requirement (cow dung in kg) for various scenarios (hours of supply from national grid, daily electricity consumption rate, and 24hours/day demand of electricity)

	hours of supply from national grid									
	8 hours		6 hours		4 hours		2 hours		0 hours	
daily electricity consumption (KWh/day)	**digesters size (m^3)**	**Organic waste requirement (cow dung) (kg)**	**digesters size (m^3)**	**Organic waste requirement (cow dung) (kg)**	**digesters size (m^3)**	**Organic waste requirement (cow dung) (kg)**	**digesters size (m^3)**	**Organic waste requirement (cow dung) (kg)**	**digesters size (m^3)**	**Organic waste requirement (cow dung) (kg)**
8	4.24	84.78	4.77	95.38	5.30	105.98	5.83	116.58	6.36	127.17
10	5.30	105.98	5.96	119.23	6.62	132.47	7.29	145.72	7.95	158.97
12	6.36	127.17	7.15	143.07	7.95	158.97	8.74	174.86	9.54	190.76
14	7.42	148.37	8.35	166.92	9.27	185.46	10.20	204.01	11.13	222.55
16	8.48	169.57	9.54	190.76	10.60	211.96	11.66	233.15	12.72	254.35
18	9.54	190.76	10.73	214.61	11.92	238.45	13.11	262.30	14.31	286.14
20	10.60	211.96	11.92	238.45	13.25	264.95	14.57	291.44	15.90	317.93
22	11.66	233.15	13.11	262.30	14.57	291.44	16.03	320.58	17.49	349.73
24	12.72	254.35	14.31	286.14	15.90	317.93	17.49	349.73	19.08	381.52
26	13.78	275.54	15.50	309.99	17.22	344.42	18.94	378.87	20.67	413.32
28	14.84	296.74	16.69	333.83	18.55	370.92	20.40	408.02	22.26	445.11
30	15.90	317.93	17.88	357.68	19.87	397.42	21.86	437.16	23.85	476.90

Table 3b: Required Digesters' size and Organic waste requirement (cow dung in kg) for various scenarios (hours of supply from national grid, daily electricity consumption rate, and 18hours/day demand of electricity)

daily electricity consumption (KWh/day)	Hours of Supply From National Grid									
	8 hours		6 hours		4 hours		2 hours		0 hours	
	digesters size (m^3)	Organic waste requirement (cow dung) (kg)	digesters size (m^3)	Organic waste requirement (cow dung) (kg)	digesters size (m^3)	Organic waste requirement (cow dung) (kg)	digesters size (m^3)	Organic waste requirement (cow dung) (kg)	digesters size (m^3)	Organic waste requirement (cow dung) (kg)
8	2.65	52.99	3.18	63.59	3.71	74.18	4.24	84.78	4.77	95.38
10	3.31	66.24	3.97	79.48	4.64	92.73	5.30	105.98	5.96	119.23
12	3.97	79.48	4.77	95.38	5.56	111.28	6.36	127.17	7.15	143.07
14	4.64	92.73	5.56	111.28	6.49	129.82	7.42	148.37	8.35	166.92
16	5.30	105.98	6.36	127.17	7.42	148.37	8.48	169.57	9.54	190.76
18	5.96	119.23	7.15	143.07	8.35	166.92	9.54	190.76	10.73	214.61
20	6.62	132.47	7.95	158.97	9.27	185.46	10.60	211.96	11.92	238.45
22	7.29	145.72	8.74	174.86	10.20	204.01	11.66	233.15	13.11	262.30
24	7.95	158.97	9.54	190.76	11.13	222.55	12.72	254.35	14.31	286.14
26	8.61	172.21	10.33	206.66	12.06	241.10	13.78	275.54	15.50	309.99
28	9.27	185.46	11.13	222.55	12.98	259.65	14.84	296.74	16.69	333.83
30	9.94	198.71	11.92	238.45	13.91	278.19	15.90	317.93	17.88	357.68

From the result presented in table 3a to 3c, it was observed that, the organic matter (in form of cow dung) required for electricity generation, considering various consumption capacities, hours of demand and supply from national grid, ranges from 21.20kg to 477kg per month.

Table 3c: Required Digesters' size and Organic waste requirement (cow dung in kg) for various scenarios (hours of supply from national grid, daily electricity consumption rate, and 12 hours/day demand of electricity)

daily electricity consumption (KWh/day)	Hours of Supply From National Grid									
	8 hours		6 hours		4 hours		2 hours		0 hours	
	digesters size (m^3)	Organic waste requirement (cow dung) (kg)	digesters size (m^3)	Organic waste requirement (cow dung) (kg)	digesters size (m^3)	Organic waste requirement (cow dung) (kg)	digesters size (m^3)	Organic waste requirement (cow dung) (kg)	digesters size (m^3)	Organic waste requirement (cow dung) (kg)
8	1.06	21.20	1.59	31.79	2.12	42.39	2.65	52.99	3.18	63.59
10	1.32	26.49	1.99	39.74	2.65	52.99	3.31	66.24	3.97	79.48
12	1.59	31.79	2.38	47.69	3.18	63.59	3.97	79.48	4.77	95.38
14	1.85	37.09	2.78	55.64	3.71	74.18	4.64	92.73	5.56	111.28
16	2.12	42.39	3.18	63.59	4.24	84.78	5.30	105.98	6.36	127.17
18	2.38	47.69	3.58	71.54	4.77	95.38	5.96	119.23	7.15	143.07
20	2.65	52.99	3.97	79.48	5.30	105.98	6.62	132.47	7.95	158.97
22	2.91	58.29	4.37	87.43	5.83	116.58	7.29	145.72	8.74	174.86
24	3.18	63.59	4.77	95.38	6.36	127.17	7.95	158.97	9.54	190.76
26	3.44	68.89	5.17	103.33	6.89	137.77	8.61	172.21	10.33	206.66
28	3.71	74.18	5.56	111.28	7.42	148.37	9.27	185.46	11.13	222.55
30	3.97	79.48	5.96	119.23	7.95	158.97	9.94	198.71	11.92	238.45

Considering the case of typical household in the urban or sub-urban cities in Nigeria; with daily consumption capacity of 20 KWh to 30 KWh per day on 6 hours per day supply from the national grid, and 24 hours electricity need, the organic matter need will fall within the range of 239 kg to 358 kg per month per household. This is pretty large, and with the rate of generation of cow dung in the country, the system will not be sustainable. In places like India, where cow dung is reported to be produced to the tune of 700 million tons per annum (Sorathia, Rathod and Sorathiya, 2012), the system may be sustainable, but not in Nigeria.

Table 4: interdependency of the entities of the system

ENTITIES	NO OF DEPENDANTS	NO OF DEPENDENCY	DEPENDANTS - DEPENDENCY	CATEGORIZATION
A	1	0	1	Pure Input Factor
B	2	0	2	Pure Input Factor
C	1	0	1	Pure Input Factor
D	2	0	2	Pure Input Factor
E	3	3	0	Pure Intermediate Factor
F	1	2	-1	Partial Intermediate Factor
G	1	3	-2	Partial Intermediate Factor
H	1	1	0	Pure Intermediate Factor
I	1	1	0	Pure Intermediate Factor
J	1	0	1	Pure Input Factor
K	1	0	1	Pure Input Factor
L	1	3	-2	Partial Intermediate Factor
M	1	3	-2	Partial Intermediate Factor
N	1	0	1	Pure Input Factor
O	1	0	1	Pure Input Factor
P	1	2	-1	Partial Intermediate Factor
Q	1	0	1	Pure Input Factor
R	1	3	-2	Partial Intermediate Factor
S	1	0	1	Pure Input Factor
T	0	2	-2	Pure output Factor

More so, considering the size of the digester needed for the transformation of the biomass to gas, a $12m^3$ to $18m^3$ digesters is quite large for each household to posses, in order to have a 24 hour per day supply of electricity instead of the 6 hours per day supply from the national grid. A quick calculation of the production cost of the digester, by multiplying the size by the unit production cost of #20,000 per m^3 (with respect to underground fixed dome concrete wall design) will discourage most household from subscribing to the system for alternative supply of electricity.

There exist a need for re-engineering of the system with respect to feedstock choice and its availability for sustainable supply, design and construction of the digester. This will be aimed at improving gas production per quantity of organic matter, reduction in size of digester as well as the production cost. This is the crux of the ongoing PhD research work of the researchers, and new sets of feedstock (processed elephant grass and extract from plantain stem) have been developed.

Table 4 was developed from the analysis of the binary interaction matrix. It shows the categories of the entities of the system. Focus was directed to the pure input parameters as area of possible research and improvement. These are:

1. An increase in A (monthly consumption from the national grid) and B (daily hours of supply from the national grid) will yield a significant reduction in demand for supplementary electricity source, subsequently the biomass demand and digester production and operating cost. But this factor is beyond the control of the users, thus it is tagged uncontrollable. It is decreasing yearly due to some factors outside the scope of this work.
2. C, (a descriptive variable distinguishing various users with respect to hours of demand of electricity)
   Although most household will wish to have electricity supply for 24 hours per day, but for some reasons, some system may demand less than that. That is why 24, 18 and 12 were considered in the analysis.
3. Number of days (D) is virtually constant ranging from 28 to 31. Although in the analysis, 30 days was used.
4. Biogas combustion efficiency (J) could be accommodated in the design of the generators' internal combustion engine. This will improve the system performance

5. Biogas calorific value (K) is a function of the methane content, improvement on the purification system and use of optimal temperature will improve the calorific value. This will improve the biogas to KWh conversion rate.
6. Biomass to biogas conversion rate (N) is a very important input factor that can be improved via; Digesters' design, Choice of substrate (feedstock), Temperature, Availability and activity level of the microorganism, and Retention time etc.
7. Retention time (O); is a controllable factor that need be modelled for optimum value.
8. Bio digesters' organic matter capacity per m^3 could be increase based on the digesters' design.
9. Production cost per m^3 of digester is another controllable factor that can be improved based on the system's design, production process, and material selection for the construction.

Finally, the outlined input variables are potential area of research for improvement of biomass to electricity conversion system.

5.0. Conclusion

The biomass to electricity conversion system was analyzed with the current prevalent situation, cow dung as feedstock and other characteristics of the system, the organic matter demand and the digester size (using fixed dome digester characteristics) were computed and analyzed with respect to sustainability. It was found that, there is need for improvement in biomass to biogas conversion (digestion) subsystem through; productive selection of substrate (feedstock) based on sustainability, redesign of the digester, determination of retention time for optimal output (biogas or/and methane), and the use of digestion enhancing additives, among others.

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