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Research article

ENERGY MANAGEMENT -DEMAND OPTIMIZATION AND BIOGAS PRODUCTION-

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ABSTRACT

Energy is the silver cord that delivers the needed nutrients to enrich the nerve of economy, social equity and environment. Worldwide, the growth of energy use is mainly driven by the expansion of population. Especially in the developing countries, a challenge is not simply to secure enough energy to meet demand, but also to minimize environmental impacts. In essence, renewable energy sources have become a topic of interest within the research community.

Every energy source has an impact on the environment; either positive or negative. While, debates over the advantages and disadvantages of various energy sources continues, it is agreed that renewable energy offers significant environmental benefits when compared to conventional ones. A case study of an egg carton manufacturing factory located in the Gaza Strip is presented in this paper. To establish a sustainable energy plan, this study documents a reduction in electric energy demand of such factory through optimization, as well as energy production by addressing a result of a pilot study; where an Anaerobic Digester was utilized to evaluate the energy potential associated with a composition of wastewater and solid waste. Finally, results reliability was confirmed by conducting a comparison between experimental and calculated outcomes.

Keywords: Anaerobic digestion, Biogas, Co-substrate, Renewable Energy

INTRODUCTION

Energy is the lifeblood that flows deeply through the veins of many sectors. It is a precondition to fulfilling the development goals, predominately those related to improving public health, exterminating poverty, driving food production and promoting economic growth. Consequently, access to affordable and reliable energy services is fundamental to achieving such goals.

Over time, the expansion of human population has been accompanied by a growth of energy demand. Thus, energy consumption patterns have significantly changed and new energy sources have been developed. Broadly,

energy sources can be classified into two types: conventional and renewable. The major source of energy comes from fossils fuels dominated by oil, gas and coal and regarded as being conventional energy sources. Meanwhile, the renewable energy is a natural source of energy that is not depleted by use. It includes: solar photovoltaic, wind, tidal power, geothermal and biomass.
Until today, fossils fuels remain the primary energy source worldwide. Yet, there is no escaping from the fact that this source is expected to be depleted one day. Simultaneously, the environmental impacts of fossil fuels use have become hard to ignore; as concerns arose over carbon dioxide emissions contributing to global warming. This situation is expected to be further aggravated as the global energy demand is forecasted to increase by 53% in 2030; consequently, the cost of fossil fuels is predicted to increase. Addressing fossil fuel depletion, climate change, scourge on public health and population growth mean that renewable energy sources will need to play a prominent role in securing the environment as well as meeting the fast-rising energy demand.

In this context, the twin challenge of securing energy and tackling climate change has dominated/occupied the universal agenda. Developing the capability to effectively and economically capture, store and use renewable energy marched up the priority list. In effect, many countries have started utilizing renewable energy sources extensively, while; others are still struggling to enact policies to promote such trend, (Terrapon-Pfaff, et *al.*, 2014) *and (UNEP, 2016).*

Projections on developing countries, much of the increase in energy demand will result from rapid population growth. Deepening the dialogue between 'environmental degradation' and 'energy poverty' in such areas, more attention on harnessing renewable sources of energy should be given. In particular, this study looks at the case of prevailing energy poverty in the Gaza Strip (GS), where; restrictions on material entry, fuel shortage, power cuts, lack of resources and dramatic environmental degradation disfigure the picture of the area (Ouda, 2013). Increasingly, the rapid growth of GS's population continues to add pressure on finding an alternative source of energy.

In recognition of varying potential of renewable energy across world, a close investigation is essential to make a decisive action relevant to each region/on regional level. Related to the case study under consideration, biomass has caught the eyes; as it seemed to answer the question of energy poverty as well as meeting environmental preservation goals.

In essence, this paper presents a case study of an egg carton manufacturing factory located in Beit- lahia in the Gaza Strip (GS), where, GS is a developing area suffering from a chronic crisis of energy shortage accompanied by a dramatic environmental degradation. Specifically, it aims at optimizing the electric energy demand of the factory and evaluating the bio-energy production through bio-mass conversion; by utilizing a pilot-scale Anaerobic Digester.
Results and recommendation from this work will pave the road towards the adaptation of a larger scale environmentally friendly solution to the problem at hand.

THE GAZA STRIP

The Gaza Strip (GS) is a narrow strip stretches along the east-south corner of the Mediterranean consisting of five governorates including: Gaza, Middle, Northern, Khanyounis and Rafah. It has a temperate climate, with mild winters and dry, hot summers. Due to the absence of fossil fuel resources, GS has to import all its needs of petroleum products. With a demand of 350 Megawatts (MW), it relies on three main sources of supply: 120 MW from Israel, 22 MW from Egypt and 92 MW from the Gaza Power Generation Plant. Considering this situation, Gaza Strip is experiencing an electricity deficit of about 160 MW towards meeting the overall demand.
Being a theatre of conflict for decades, GS's electric power supply is witnessing a sharp decline since 2007. As a result, people are living on less than eight hours of electricity a day.
In addressing the needs of the energy sector in the GS, planned actions are needed to secure the electric power demand before all aspects of life being paralyzed. Thus, the absence of adequate infrastructure in the area of the GS strongly ties with the existing environmental degradation.

To this end, the Gaza Strip is in despite need to find an alternative source of energy and in particular renewable one in order to meet the urge demand and protect the environment.

LITERATURE REVIEW

There has been a great interest in the topic of renewable energy over the past few years. With the vast majority of the world's energy is generated from non-renewable sources, clearly, resource scarcity is not the only reason for considering renewable energy. As, Current energy production and consumption habits have been tightly linked to global climate change, resource depletion, land-use conflicts, air pollution, soil contamination and adverse health implications.

The global renewable energy resources base is enormous. When hammering on the availability of renewable energy sources, it is essential to define various types of potential. In literature, Resource, technical, economical and market potential were debated. Resource deals with the theoretical potential for renewable resources in certain area, addressing geographical location, quantity and trends in supply. While, technical potential focuses on engineering and technological criteria related to different renewable energy sources. In addition to theoretical and technical potential, economic potential considered costs attached to various options. Finally, market potential depends upon the real-world market conditions driven by different policies and sizes of various markets. Extensive research have been documented with regard to renewable energy potential across the world ((Dincer, 2000), (Jacobson, and Delucchi, 2011). (Philibert, 2011), (Moriartya and Honnery, 2012), (Bhattacharyya, 2012), (Hinrichs-Rahlwes, 2013), (Alemán-Nava, et *al.*, 2014)).
Collectively, studies declared that the total potential for renewable energy is higher than current and forecasted future demand.

Coincident with the world accelerating energy demand, the net growth is taking place in the developing countries. Consequently, developing countries are faced with a two-fold energy challenge. One is meeting the growing energy need due to exponential population growth. Simultaneously, keeping-up with the global trend towards clean energy source is another issue. As considerable renewable energy source potential still exists in developing countries, careful planning is required to effectively manage and maximize available opportunities.

Although, some studies have been attempted to assess the renewable energy potential in the GS, it is still lagging behind those of other regions (Ismail, et *al.,* 2013). A study addressed solar photovoltaic as a highly appealing source of energy, as GS receives an approximate of 3,000 hours of sunshine per year and has an average daily solar radiation of 5.5 kWh/m^2 (Abu-Zarifa, 2014). Consequently, small-scale pilot solar power projects were implemented in the GS to generate and supply electricity to clinics, schools and residential areas. What limit the large scale use of solar panels are the space requirements. Meanwhile, wind applications are partially restricted due to topographical features of GS; as relatively low wind speed exists throughout the year; with an annual mean wind speed of 4.2 m/s (Alaydi, 2013). Furthermore, tidal power lacks the geographical circumstances to develop in GS; as no substantial water body to be utilized. Some insight into the geothermal source in GS shows low potential and inapplicability for large-scale production.

Notably, bio-energy remains the single most significant source of energy in the developing world today providing 35% of total primary energy supply in developing countries (World Economic Forum, 2013). The interest in such energy source has been driven by its potential to mitigate global warming as well as filling the gap between demand and supply. Although, bio-energy has a potential to account for in the area of the GS, lack of pilot projects and expertise are considered the main barriers to such application in the area.

ANAEROBIC DIGESTION

Anaerobic digestion is a process where micro-organisms, in the absence of oxygen molecular and produces biogas. Biogas primarily consists of a mixture of about 60-70% methane (CH_4), carbon dioxide (CO_2) and traces of other gases. Anaerobic digestion is a multi-stage process involving four fundamental steps as follow:

- Hydrolysis: large polymers are broken down into enzymes.
- Acidogenesis: this stage produces acetate as a main end product. Volatile fatty acids are also produced along with carbon dioxide and hydrogen.
- Acetogenesis: Breakdown of volatile acids to acetate and hydrogen.
- Methanogenesis: Acetate and hydrogen are converted to methane and carbon dioxide.

Mesophilic and thermophilic are the two temperature ranges that allow different species of bacteria to survive providing optimum digestion conditions. The optimum temperature range for the mesophilic and thermophilic is 35°C-45°C and 55°C-60°C respectively (Ji-shi *et al.* 2006). The methane can be captured from the anaerobic digesters and be used directly as Bio-fuel or converted to electricity.
Interest has recently been growing in using the anaerobic digestion as a result of current environmental problems. Specifically those related to both growing volumes of 'waste and wastewater' and to 'global

warming'. In essence, Anaerobic Digesters (AD) sparked as an attractive option for generating renewable energy and protects the environment of the GS.

METHODOLOGY

The factory started functioning in GS by 2008 using recycled paper and cardboard; with an electricity demand of 110kW covering two automatic pistons, two mixers, two compressors, two sieves, a pump, an oven and lightening. Currently, the factory manufactures up to 14000 egg cartons with a daily average production time of only eight hours as a result of electricity cut-age. The first step of the research was optimizing the electric energy demand of the egg carton manufacturing factory. Then, a calculation was carried out to approximately estimate the methane production using the Anaerobic Digester with a mixture of five components; co-substrate. With ambitious step towards a more secure and sustainable energy source, the pilot study was initiated at the end of January, 2016, and operated until the end of March, 2016. The first injection to the AD marked the start of the process on the second of February, 2016. However, the AD was operated in a manner similar to a full scale digester under controlled conditions; as the microorganism culture in the AD maintained a pH in the range of 6.8 to 7.8, while the temperature was 37°C with a tolerance of ± 2°C and a Hydraulic Retention Time (HRT) of 20 days. Furthermore, both experimental and calculated results were compared for a reliability check. *Process parameters, feed composition, description of the process units are followed.*

- ***PROCESS PARAMETERS***

Efficiency of the Anaerobic Digester depends on various operational parameters. Table (1) presents these parameters, especially, temperature, pH, Hydraulic Retention Time and the Organic Load Rate.

Process Parameter	Range	Dimension
Temperature	35-40	^{0}C
pH-Value	6.8-7.8	-
Reactor Volume (AD)	6000	L
Hydraulic Retention Time (HRT)	15-20	d
Mixer	200	rpm
TS	100	kg/m^3
Q_{Excess}	300	L/d
Organic Load Rate (OLR)	24	Kg VS/d

Table (1): AD Operating Parameters.

- ***FEED COMPOSITION***

The rate of methane production depends greatly on the characteristics of the co-substrate introduced to the AD. In essence, the reactor fed was made-up of a combination of primary sludge, fat, excessive sludge, cow and chicken dung. The typical composition and characteristics of the feed is detailed in Table (2), at a ratio of 1:1 for cow and chicken dung ((Sebola et al. 2015) and confirmed by Oechsner, 2016) as the cow dung can intercept the high concentration of ammonia associated with chicken dung.

component	Material	Rate of flow [l/d]	SS [g/l]	VS [%]	VS - Degradation [%]	Spec. Methane Yield [Nm^3/kg VS]
C1	Primary Sludge	1000	35	80	60	0.2
C2	Fat (used frying oil)	100	270	95	90	0.8
C3	Excessive Sludge	1000	7	70	30	0.2
C4	Cow Dung	3200	80	80	50	0.2
C5	Chicken Dung	700	450	75	50	0.25

Table (2): Composition & Characteristics of the Feed

- ***PROCESS UNITS***

The reactor was provided with suitable arrangements for feeding and gas collection. A schematic diagram of experiment set up used in this study is depicted in Figure (1). A feed preparation system, consisting of a mixing tank, sieve and homogenizer, was provided. Initial mixing of the influent/feedstock was necessary to create homogeneous feed. The feed was then filtered through a 2 cm sieve to remove large particles. Finally, the feed is homogenized and introduced to the AD with a help of a pump. The digester was constructed using (material), with a volume of 6 m^3. The effective volume of the reactors was maintained at 5.7 m^3 and homogenized with mixer propeller. The digester was sealed with a top lid, provided with one port for gas outlet. Additionally, the AD (was equipped with an outlet)/ (had one outlet) at the bottom of the AD for excessive sludge removal and sampling purposes. The resulted biogas is passed further to an absorber for the CO_2 removal and after that to a drying system. In the next step, the methane was compressed and ready to be used.

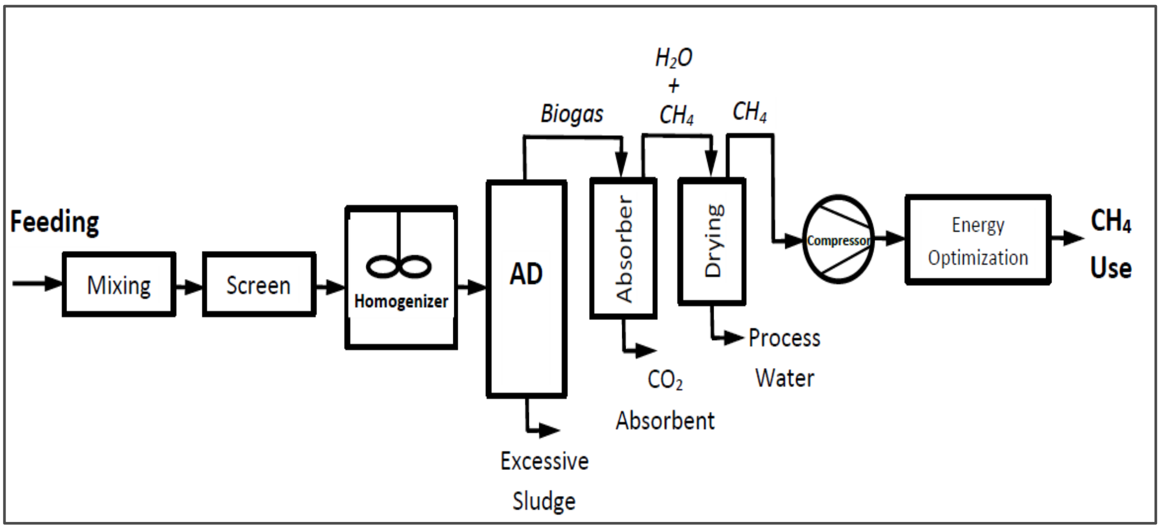


Figure (1): Schematic view of the experimental set up

RESULTS

In an effort to reduce the electric energy demand, information describing the current status of the factory demand has been collected. Then, optimizing the electric demand of the factory has been achieved by monitoring and assessing the factory operation. In particular, analysis of how much energy is needed to perform each activity has been deduced. Matching the electric demand for each activity, especially motors for mixers and compressors, to appropriate power supply resulted in a reduction of an electric demand from 110kW to 70kW.

This is followed by a theoretical calculation to approximately estimate the methane production with the five different components as shown in Table (3).

Parameter	C1	C2	C3	C4	C5	Total	
Rate of flow (m^3/d)	0.055	0.01	0.055	0.15	0.03	0.3	
SS (g/L)	35	270	7	80	450		
VS (%)	85	95	70	80	75		
Mass Flow							
in kg VS/d	1.64	2.57	0.27	9.60	10.13	24	
in kg COD/d	3.99	6.26	0.35	23.41	24.70	59	
in kg SS/d	1.93	2.70	0.39	12.00	13.50	31	
Digester							
Degredation (% VS)	60	90	30	60	50		
Specific Methane (Nm^3/kg VS-input)	0.2	0.8	0.2	0.2	0.25	0.33	
Mass Flow after Digester							
in kg VS/d	0.65	0.26	0.19	3.84	5.06		
in kg COD/d	1.60	0.63	0.46	9.37	12.35	24	
in kg SS/d	0.94	0.39	0.30	6.24	8.44	16	
SS- reduction (%)						46.5	
COD reduction (%)						58.4	
Total mass (kg SS tonne/a)						6	
Spec. Methane (Nm^3/kg VS-Input)						0.28	
Gas production (Nm^3/d)	0.3	2	0.054	2	3	**7**	**m^3 methane /d**
					Produced Energy	**26**	**kWh electicity**
						3	**kWelec.**
						4	**Kg Methane/d**

Table (3): Typical Methane Yield for AD Volume of $6m^3$

With refernce to Table (3), it can be seen that the average calculated methane production is 7 Nm^3/d. For an AD volume of $6m^3$, values for the Volatile Solids (VS) mass and specific methane for the used components, methane yield per day was manupilated. In this case, calsulations were based on an AD daily fed/Rate of Flow of 300L and an equivalent amount to be removed to maintain a HRT of 20 days. In addition, the SS reduction and the AD degredation efficiency were found to be approximately 50% and 60 respectively. Comparing the results of the suspended solid mass reduction of 50% to what is documented in literature, 60%, highlighted that the obtained results are relatively consistent. Thus, an apparent AD degredation efficiency of 60% is in the range of 40-60%; were reported in literature (Yung et *al*., 2000). In addition, specific methane production of 0.28 Nm^3/kg VS-Input. This is consistent with literture, as a value of 0.3 CH_4 /kg VS has been reported by Alvarez and G. Liden, 2008.

RESULTS FOR THE ANEROBIC DIGESTOR PILOT- STUDY:

Temperature and pH level are considered important parameters for the biogas yield and rate of production. Daily measurements for both parameters were taken and time record histories were presented graphically. Collected data were incorporated as follows for:

- ***TEMPERATURE*:**

The AD temperature target for the pilot study was 'mesophilic temperature' range (37 ± 2°C). During the start up of the process, low temperature, 15°C, was observed (see Figure (2)). Then, tendency of increasing from values of 35 up to 40 after ten days were confirmed. In turn, this implicates that the process maintained a steady mesophilic temperature for the remaining study period.

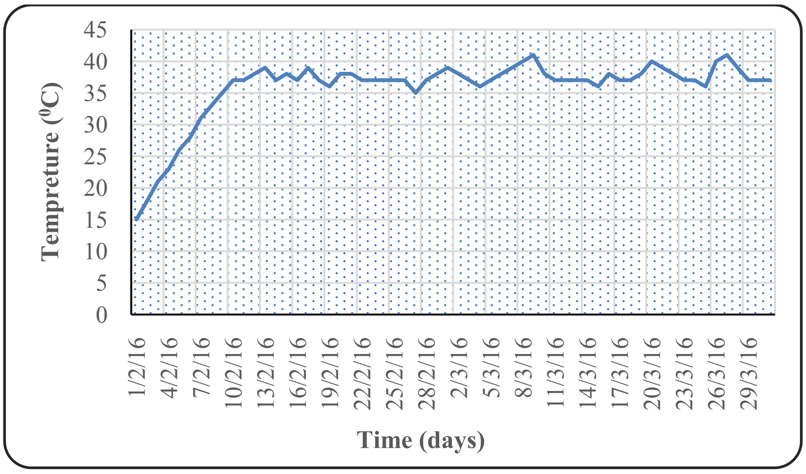


Figure (2): Temperature Variation

- ***pH*:**

Referring to Figure (3), the pH level in the AD was initially 6.5. The pH was then decreased progressively over a period of seven days reaching a value of 4.7. Based on literature (Rittmann, 2001), the pH was adjusted to 7.3 using NaOH solution of (500 to 900) mg/L; as been recommended among four economically feasible chemical additives, Lime, Sodium hydroxide, Ammonia and Bicarbonate. Throughout the rest of the study period, the pH was monitored daily with a pH meter and maintained at vicinity of 7.3.

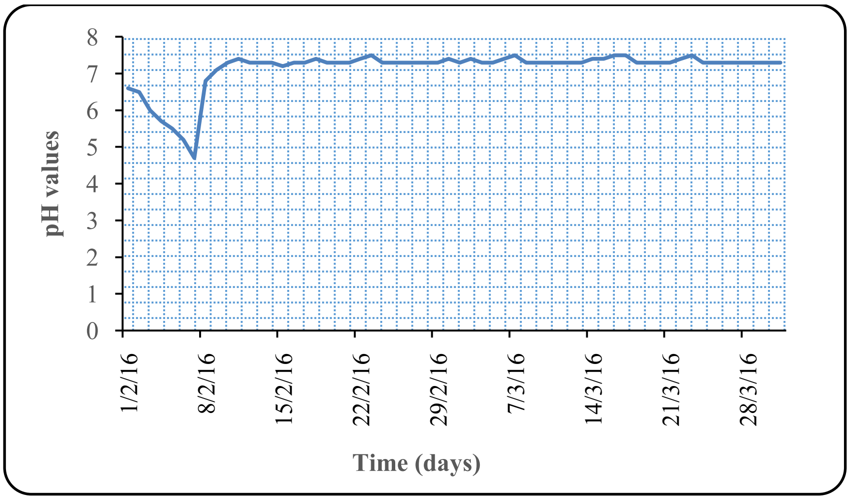


Figure (3): pH Variation

Daily biogas yield of the AD was monitored over the period of the study. The methane content in the biogas is shown in Figure (4). For the first 19 days, no methane was produced from the AD. Methane was first observed on day 20 and increases gradually until it reached a peak value of $18Nm^3$ on day twenty seven. Between day twenty seven and day thirty, the methane production remained almost constant. This is followed by a decline in the methane yield for three concessive days; reaching a value of 6 Nm^3 where it remained with this average value for the rest of the study time. Initial phase represents the AD batch stage; where the daily methane production builds-up to a maximum, then declines. Meanwhile, the methane yield pattern for the remaining period reflects the AD being operated with a continuous rate flow of 300L/d.

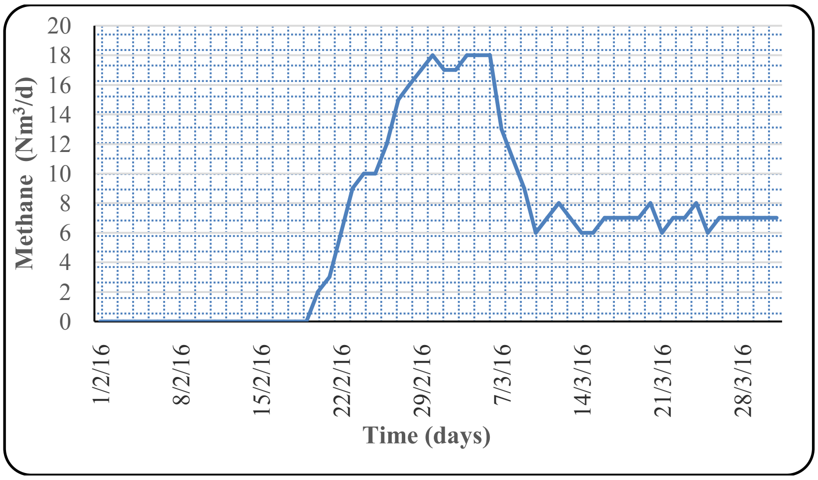
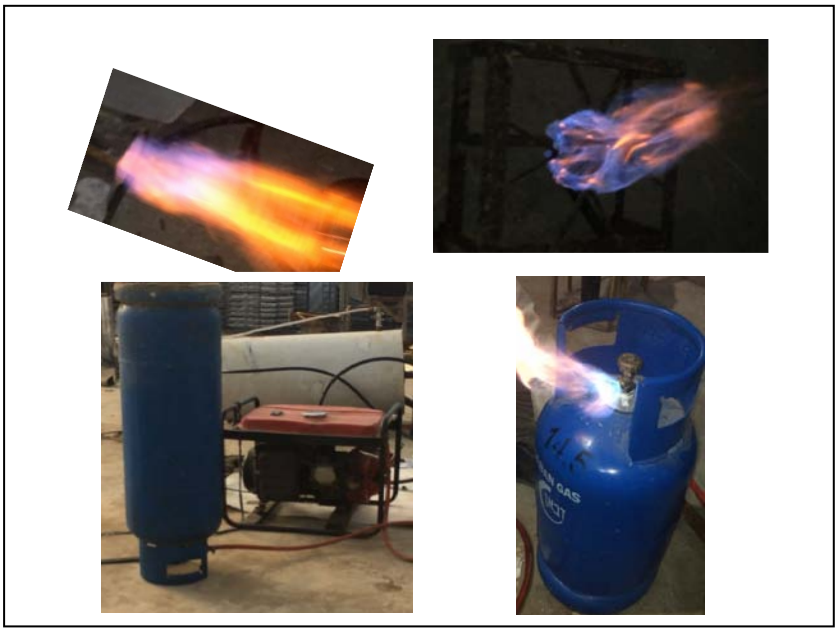


Figure (4): Methane yield over time

With refernce to Figure (4) and Table (3), it can be concluded that the average methane production reported for the AD in this study, 6 Nm^3/d, is comparable to those obtained from calculations; 7 Nm^3/d. Following are photos taken for different methane uses.



Photos for Methane Uses

From a strategic point view, a planning initiative was undertaken by performing similar calculations for methane yields for a 200 m^3 AD, see Table (4).

Parameter	**C1**	**C2**	**C3**	**C4**	**C5**	**Total**	
Rate of flow (m^3/d)	1.85	0.3	1.85	5	1	10	
SS (g/L)	35	270	7	80	450		
VS (%)	85	95	70	80	75		
Mass Flow							
in kg VS/d	55.04	76.95	9.07	320.00	337.50	799	
in kg COD/d	134.24	187.68	11.62	780.49	823.17	1,937	
in kg SS/d	64.75	81.00	12.95	400.00	450.00	1,009	
Digester							
Degredation (% VS)	60	90	30	60	50		
Specific Methane (Nm^3/kg VS-input)	0.20	0.80	0.20	0.20	0.25		
Mass Flow after Digester							
in kg VS/d	22.02	7.70	6.35	128.00	168.75		
in kg COD/d	53.70	18.77	15.48	312.20	411.59	812	
in kg SS/d	31.73	11.75	10.23	208.00	281.25	543	
SS reduction (%)						46.2	
COD reduction (%)						58.1	
Total mass (kg SS tonne/a)						198	
Spec. Methane (Nm^3/kg VS-Input)						0.28	
Gas production (Nm^3/d)	11.0	62	1.813	64	84	**223**	**m^3 methane /d**
					Produced Energy	**846**	**kWh electicity**
						85	**kWelec.**
						145	**Kg Methane/d**

Table (4): Typical Methane Yield for AD Volume of 200m^3

For an AD volume of 200m^3, values for the Volatile Solids (VS) mass and specific methane for the used components, methane yield per day was manupilated. In this case, calsulations were based on an AD daily Rate of Flow of 10m^3 and an equivalent amount to be removed to maintain a HRT of 20 days .As shown in Table (4), the average calculated methane production is 223 Nm^3/d. Apparently, generated electricity of 85 kW will fully cover the daily electric energy demand of 70 kW for the egg carton factory.

CONCLUSION

Clearly, energy strategies are striving towards securing a stable and reliable energy source to meet the worldwide energy demand. As electricity demand escalated and supply is largely dependent on fossil fuels, concerns arose over carbon dioxide emissions contributing to global warming. In essence, this research turns attention to biomass source of energy surging around in nature. It handled electrical energy management strategy from both the demand, by optimization, and supply sides by presenting an AD pilot-study. From one side, demand management yield an optimization of 40% reduction in the electric energy demand. Meanwhile, results of typical methane yield reported from the analytical calculations proven to be comparable to those orginating from the AD. Finally, the paper crafted a future strategic plan by scaling-up the AD.

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