CHEMICAL ENGINEERING TRANSACTIONS
VOL. 72, 2019
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet
Guest Editors: Jeng Shiun Lim, Azizul Azri Mustaffa, Nur Nabila Abdul Hamid, Jiří Jaromír Klemeš
Copyright © 2019, AIDIC Servizi S.r.l.
ISBN 978-88-95608-69-3; **ISSN** 2283-9216
DOI: 10.3303/CET1972054

Low Carbon Emissions Energy Production Strategies from Solid Waste-Coal Combination for Bauchi Metropolis, North-Eastern Nigeria

Saeed I. Ahmed[a,*], Zakari Abdullahi[a], Anwar Johari[b]

[a]Department of Chemical Engineering, Abubakar Tafawa Balewa University, Bauchi, Nigeria
[b]School of Chemical and Energy Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, Johor
alsaeedng@yahoo.com

Energy is a necessity for development but its sustainable production is questionable in most metropolitan settlements in developing countries, particularly Nigeria. The combination of fossil fuel with Municipal Solid Waste (MSW) for electricity generation is justified due to the acute inadequacy of electricity in Nigeria coupled with the abundance of coal. Therefore, this research investigates strategies for electricity generation from coal-MSW mix for Bauchi metropolis, North-Eastern Nigeria. Population and MSW generation for the study area were determined from year 2010 to 2070. In 2020, the population of the metropolis will be over 668,000 people generating more than 195,000 t of MSW. The characterization studies showed high proportion of plastics and other combustibles which makes the MSW a good stock for combustion in turbines. The calorific values were determined for various coal-MSW mix and the results range from 8,762 kJ/kg (0 % coal and 100 % MSW) to 11,044.65 kJ/kg (100 % coal with 0 % waste). The energy production strategies for the metropolis was based on five scenarios (A – E) depending on coal-MSW mixture and time frame. Results showed that Scenario A can produce 16.7 MW (146,719 MWh) of electricity in the year 2020 for the metropolis which gradually increases to 32 MW in the first year of Scenario E. In addition, the economic and environmental evaluations of the scenarios revealed that Scenario A is the most attractive in terms of revenue from electricity but least in revenue from carbon credit. Although, Scenario E generates the least per capita revenue, it was found to be the best in terms of environmental considerations. This research therefore provides flexible mechanisms for the production of energy in urban areas to contain MSW problems and reduce CO_2 emission from the use of whole coal.

1. Introduction

Increase in population, urbanization and economic growths has increased MSW generation rates and composition. The handling and disposal of MSW is a growing concern as the volume of waste generated in Nigeria continues to rise. Finding a sustainable option for MSW disposal remains a major challenge to waste management (Harir, 2015). The 7th goal of the Millennium Development Goal is to ensure environmental sustainability which is essential for the health and well-being of humanity. According to the World Health Organization, improved solid waste management is an important aspect of environmental sustainability which offers opportunities for income generation, health improvements and reduced land vulnerability (Babayemi and Dauda, 2009). Many efforts to manage wastes through various means such as open-air mass burn, landfills etc. are yet to provide a sustainable solution to this problem. This concern is one of the motivations for this research. It is an established fact that electrical energy is a necessity for the development of any society since it contributes to improving the quality of life and the social and economic growth of the country (Saeba et al., 2017). Therefore, the provision of regular, affordable and efficient electricity is extremely important for the growth, prosperity, security as well as the rapid industrialization of any society. Any country whose energy supply is epileptic has her development prolonged and risks losing potential investors in key sectors of the economy. Electricity is an unavoidable prerequisite to any nation's development because it provides the needed platform for economic activities to thrive. It is also a major tool needed by the government to achieving its Millennium Development

Paper Received: 30 July 2018; Revised: 25 September 2018; Accepted: 27 November 2018

Please cite this article as: Ahmed S.I., Abdullahi Z., Johari A., 2019, Low carbon emissions energy production strategies from solid waste-coal combination for bauchi metropolis, north-eastern nigeria, Chemical Engineering Transactions, 72, 319-324 DOI:10.3303/CET1972054

Goals (Babayemi and Dauda, 2009). Unfortunately, this important amenity (electricity) is grossly inadequate and epileptic in Nigeria.

Bauchi metropolis, which is the case study of this research is the capital of Bauchi state and covers an area of 3,687 km^2. The state is located in the North-East geopolitical zone of Nigeria, however on the geological map, it is located adjacent to the Upper Benue Trough. The population of the entire state is about 4.7 M people. The state occupies 5.3 % of the total landmass of Nigeria, with an area of 49,259 km^2 endowed with natural resources which include; Kaolin, Gold, Limestone and some quantities of petroleum deposits have been discovered. In addition, the state and its neighbouring Gombe state is blessed with natural resources (including Coal) (Felix and Yomi, 2013).

Therefore, this research is aimed at investigating the energy potentials of coal-solid wastes combination for sustainable energy production in Bauchi metropolis. This entails study of the generation and characterization of the MSW in the metropolis. Power generation potentials of various coal-MSW mix with associated economic and environmental benefits will be studied. The coal-MSW mixtures are worked out on a five energy scenarios strategy spanning from the year 2020 to 2070.

2. Methodology

The section briefly explains methods for MSW generation, characterization, scenarios for Coal-MSW mix, energy and environmental benefit estimation.

The MSW generation was determined by taking into consideration the average waste generation rate per person of 0.86 kg/day and the population (Bogoro et al., 2014). The characterization included the determination of waste compositions and proximate analysis of the waste samples for chemical and thermal properties. For the composition, a random collection of wastes from various dumpsites was carried out. Wastes were collected from eight different dumpsites traversing the entire metropolis. The selection of the sources of MSW sampling were randomly predetermined to accommodate all types of sources i.e. high-, medium-, and low-income residential households, institutional and commercial sources.

After the determination of the waste composition, proximate analysis was carried out to determine some important parameters which includes moisture content, total ash, crude fibre total carbohydrate and calorific value of the dried samples according to standard procedures (Abur et al., 2014).

The Scenarios for Coal-MSW mixture involved five schemes A -E: Scenario A is 100:0 Coal-MSW mixture, where only coal is to be used for electricity generation for a period of 2020 to 2029. Scenario B combines 75 % Coal and 25 % MSW for power production from 2030 to 2039 and so on (Table 1). Electricity (energy) generation, using turbine efficiency of 35 % was adopted from the method of Ahmed et al. (2015), while Carbon dioxide emission/reduction was from Johari et at. (2012). Carbon dioxide emission from combustion of coal was estimated by assuming that 0.34 kg of CO_2 is emitted per kWh of electricity (0.34 t CO_2/MWh) (Ahmed et al., 2015). The economic and environmental benefits were determined by estimating the revenues generated as a result of electricity sale and CO_2 reduction (Carbon credit) (Ahmed et al., 2015).

Table 1: Proximate analysis of the Coal-MSW mix

Scenario	Mixing ratio of Coal and Waste	Moisture content (%)	Ash content (%)	Carbohydrate (%)	Fibre (%)	Calorific value (kJ/kg)
A	0:100	5.460	15.075	79.465	-	11,044.65
B	75: 25	6.775	17.690	67.175	8.36	10,473.99
C	50: 50	6.545	17.885	67.210	8.36	9,903.33
D	25: 75	7.740	17.130	66.770	8.36	9,332.66
E	0:100	10.70	20.475	60.465	8.36	8,762.00

3. Results and Discussions

3.1 Population and solid waste generation projections for Bauchi Metropolis

Figure 1 shows the population of Bauchi metropolis which was estimated based on Bogoro et al. (2014). The projected populations from 2010 to 2070 range from 538,380 people to 1,972,799 people. The figure also gives MSW generation projections values of 157,207 t in the year 2010 and 576,057 t in 2070. The population and MSW projections were estimated using a yearly growth factor of 1.02188 and solid waste generation per capita of 0.86 kg/d (Bogoro et al., 2014). The MSW projection in this research is in line with the studies of Ogwuche (2013).

In addition, it can be deduced from the figure that this year (2017) about 182,924 t of wastes will be generated, and this perfectly mirrors the deplorable state of the metropolis today – heaps of waste at dumpsites, street littering, drainage blockage, and repeated disease outbreaks. Degradation of the wastes also contributes to CO_2

emissions. These problems are likely to worsen if mitigation measures are not taken because as population is increasing so is waste generation. For instance, in 2070 waste generation will triple the present value – to what degree do is the problem expected? Three times what is being experiencing now? If this is correct (i.e. 3-fold of the present problem) then there is a catastrophe coming. Converting the wastes to energy resource is one clean mitigation measure to adopt as envisaged in the present work, however the energy potential of the wastes strongly depends on their characteristics.

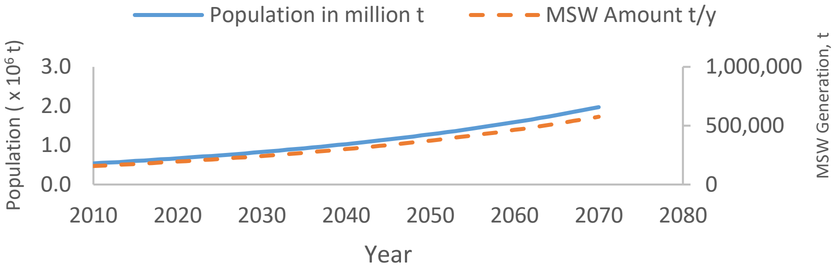

Figure 1: Projected population and waste Generation in Bauchi Metropolis

3.2 Solid waste characteristics of the study area

The results for the characterisation of Bauchi municipal solid wastes and proximate analysis of the Coal-MSW mixtures are presented here.

The MSW characterization showed that almost all the components are combustible (organic 57 %, plastic 24 %, paper 7 %, textile 4 %) with the exception of glass and metals (glass 4 %, metals 3 %, other 1 %). The organic component makes the highest proportion followed by plastic waste. The proportion of plastic is really high and this is typical of Nigerian MSW (Abur et al. 2014). Plastics being non-biodegradable makes landfilling inappropriate for Nigerian MSW disposal. Combustion with energy recovery is one of the promising measures. Table 1 shows the results for the proximate analysis showing moisture content, total ash, crude fibre, total carbohydrate and calorific value. In scenario A (whole Coal) the calorific value of the whole coal sample was 11,044.65 kJ/kg which is the highest calorific value determined. The other extreme case scenario with whole waste (Scenario E, whole MSW) which has the lowest calorific value (8,762 kJ/kg); this represents the calorific value of a typical Bauchi metropolis MSW. This value is however less than the calorific values obtained by Ujam et al. (2013). Nevertheless, the values they obtained were not for bulk wastes and did not include organic components. Omari et al. (2014) obtained a higher calorific value of 15 MJ/kg (15,000 kJ/kg) for bulk MSW in Arusha, Tanzania. This value is most likely determined as the Higher Energy Value of the wastes (Jegla et al., 2017). Furthermore, Chin and Franconeri (1980) obtained a calorific value ranging from 11,320 to 9,565 kJ/kg for selected municipal wastes and agree with the values obtained in this study.

3.3 Energy (Electricity) potential from Coal-MSW combustion

Energy in form of electricity that can be produced from the combustion of the mixture of Coal-MSW in turbine is presented in Figure 2 for Bauchi metropolis.

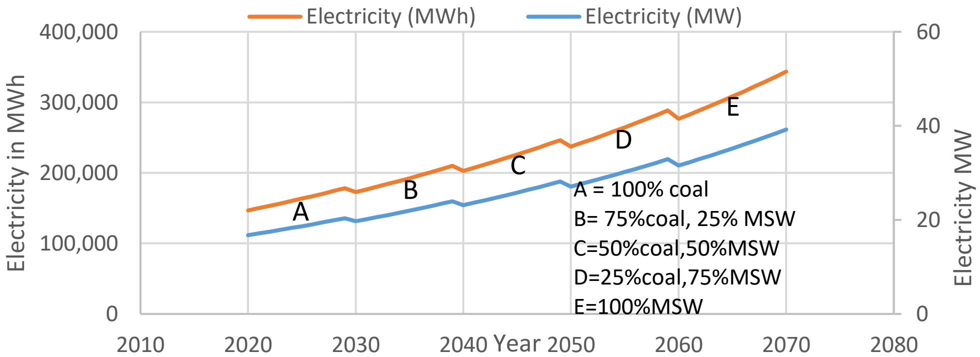

Figure 2: Energy (electricity) potentials for Scenarios A – E

Results are for the five energy Scenarios (A – E) spanning from 2020 to 2070. The input material (Coal/MSW) for each year is obtained from Figure 1; that is, input for 2020 is 195,196 t coal:0 t MSW (Scenario A), for 2030 it is 181,774 t Coal:60,591 t MSW (Scenario B) and so on. This input material is increasing in line with the increase in population.
It can be seen that in Scenario A, 100 % coal was used for power generation. This proportion of coal was gradually reduced and replaced with MSW to Scenario E when 100 % MSW was used. These Scenarios were planned out based on the electricity needs and CO_2 emission footprint of the study area and Nigeria at large. Nigeria being a developing nation that presently generates 4,000 MW of electricity is one of the lowest CO_2 emitters in the world. The idea is to maximize the power production for the city while keeping the CO_2 emissions as low as possible, hence the gradual fading of coal out of the energy mix as represented by the various scenarios. From Figure 2 it is can be seen that Scenario A can produce 16.7 MW (146,719 MWh) of electricity in the year 2020 for the metropolis which is more than the electricity the metropolis gets from the national grid based on present (2017) supply of 13.2 MW (Oluwatoyin et al., 2015). The electricity production will become fully renewable in 2060 and beyond (Scenario E) when 100 % MSW will be used. At that point (Scenario E), the production will start with generation of about 32 MW of clean energy in 2060, which will then be increasing in direct correlation to population growth and other factors. Scenario E is the best-case design in terms of environmental sustainability compared to the other scenarios.
The gradual transition from the use of fossil fuel to a waste-to-wealth strategy in this work (Scenario A-E) is practically a shift from CO_2 emission to CO_2 reduction as shown in Figure 3. Scenario A produced the highest CO_2 emission (zero CO_2 reduction) while Scenario E (with whole MSW) resulted in the highest CO_2 reduction (113,357 t) due to zero emissions.

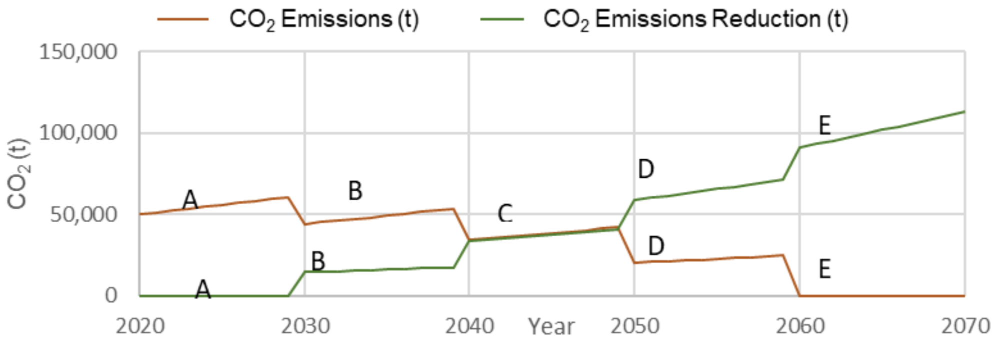

Figure 3: Carbon dioxide emission/reduction for Scenarios A – E

A carbon-neutral power production process was achieved in Scenario C as the amount of CO_2 emitted equals amount reduced. Reduction in CO_2 emission generally increases across the various timeframes due to a gradual switch from fossil to renewable energy. The adopted energy production strategy also allows for increasing power output with time (Figure 2) to mitigate CO_2 the growing energy demand in the city within the time frame considered (2020-2070).

3.4 Economic and environmental benefits for the Coal-MSW usage

The revenue generated from sale of electricity and CO_2 reduction (Carbon credit) is presented in Figure 4, while Figure 5 presents total and per capita revenue generation based on the five case scenarios proposed in this work.
In Figure 5, for Scenario A, revenue of about 5.4 million USD will be generated in year 2020 from electricity sale (based on 0.037 USD/kWh) and this amount will increase gradually to about 6.6 million USD in 2029. In the same scenario, no revenue will be generated from Carbon credit because whole coal was used for the electricity generation. In Scenario B, revenue from electricity sale fell slightly to 6.4 million USD in 2030 but with additional revenue of about 167,000 USD from carbon credit (based on 11.7 USD/t CO_2) due to the substitution of coal with MSW (25 % fuel). Scenario E has the highest revenue generation from Carbon credit but least in terms of per capita income generation. This is due to the increasing population of the metropolis leading to lower energy per capita. However, Scenario E is the cleanest and most environmentally sustainable strategy. Although the whole coal scenario is the most economically attractive, it is unsustainable due to stringent regulations on CO_2 emissions.

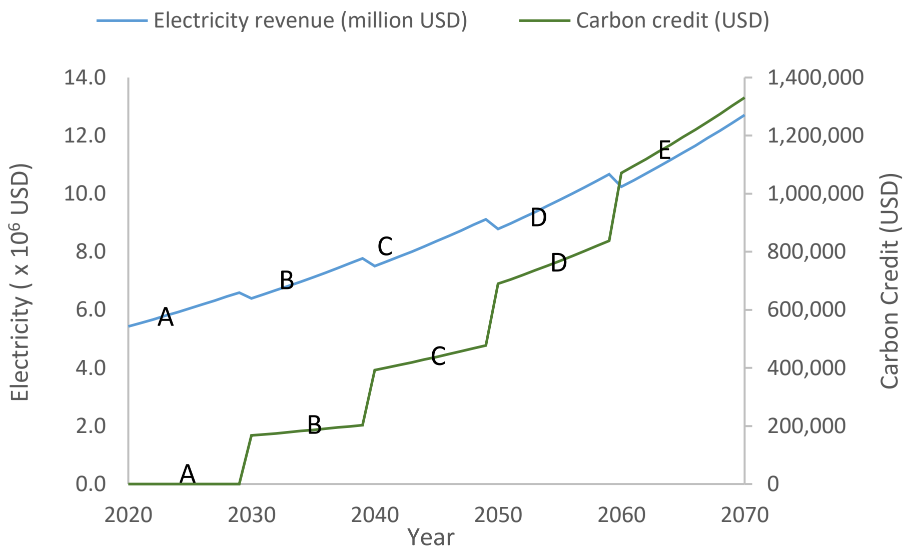

Figure 4: Revenue from Electricity/Carbon credit for Scenarios A – E

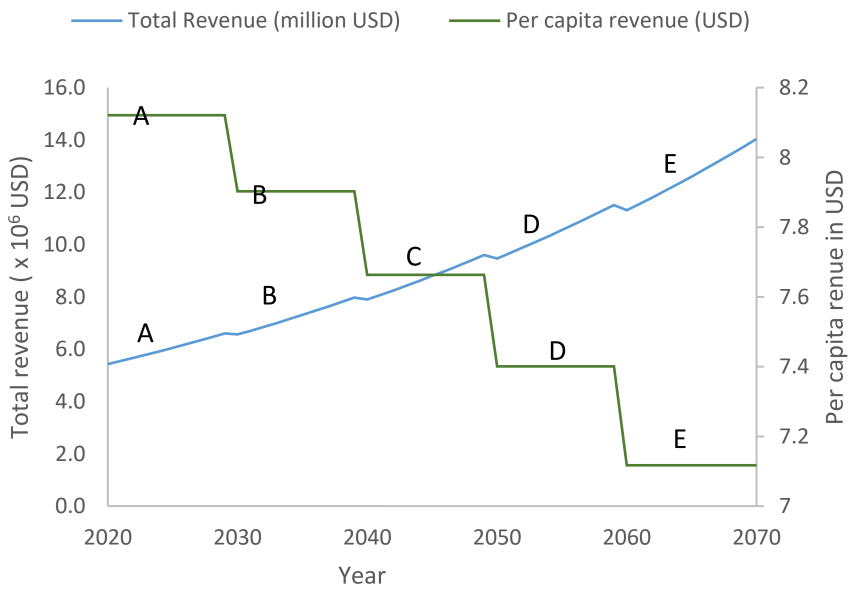

Figure 5: Total and per capita revenue from Electricity and Carbon credit for Scenarios A – E

4.Conclusions

This research investigates the energy potential from combustion of various proportions of Coal-MSW combination for Bauchi metropolis. Population and MSW generation for the study area were determined from year 2010 to 2070. In 2020, the population of the metropolis will be over 668,000 people generating more than 195,000 t of MSW. The characterization studies showed high percentage of plastics and other combustibles which makes the MSW a good stock for combustion in turbine for heat and power cogeneration.

The energy production for the metropolis was based on five scenarios depending on coal-MSW mixture and timeframe. This power generation approach allows for energy production from coal in the immediate term to coal-MSW mix in the mid-term periods and whole (100 %) MSW in the long term. Results show that Scenario A can produce 16.7 MW (146,719 MWh) of electricity in the year 2020 for the metropolis, and gradually increasing

to 32 MW in the first year of Scenario E. Scenario E was found to be the best considering environmental concerns. Although, more electricity can be produced from coal alone but the prevailing environmental laws on global CO_2 emissions like the Kyoto Protocol have constrained its use.
In terms of emission from coal utilisation or reduction (by supplementing with MSW), Scenario A has the most energy output potential but emits the highest amount of CO_2 (zero CO_2 reduction). For instance, Scenario A in the first year (2020) leads to CO_2 emission of 49,884 t and zero CO_2 reduction while Scenario E (2060) produces least electricity with no emissions thereby saving 91,295 t of CO_2. In Scenario C, a carbon-neutral power production process was achieved as the amount of CO_2 reduced cancels out the amount emitted.
The results of the economic and environmental impact study revealed that Scenario A is the most attractive in terms of revenue from electricity but least in revenue from carbon credit.

Acknowledgments

The research funding by Tertiary Education Trust Fund (TETFUND) through Abubakar Tafawa Balewa University is highly acknowledged.

References

Abur B.T., Oguche E.E., Duvuna G.A., 2014, Characterization of municipal solid waste in the Federal Capital Abuja, Nigeria, Global Journal of Science Frontier Research, Health Environment & Earth Science, 14, 1 – 6.
Ahmed S.I., Johari A., Hashim H., Lim J.S., Jusoh M., Mat R., Alkali H., 2015, Economic and environmental evaluation of landfill gas utilisation: A multi-period optimisation approach for low carbon regions, International Biodeterioration and Biodegradation, 102, 191 – 201.
Babayemi J.O., Dauda K.T., 2009, Evaluation of solid waste generation, categories and disposal options in developing countries: A case study of Nigeria, Journal of Applied Sciences and Environmental Management, 13(3), 83-88.
Bogoro A.G., Bukar A.G., Samson M.N., Rasheed O., 2014, Economic factors that determine the quantity and characteristics of solid waste in Bauchi Metropolis, Nigeria, IOSR Journal of Environmental Science, Toxicology and Food Technology, 8, 1 – 7.
Chin N., Franconeri P., 1980, Composition and heating value of municipal solid waste in the spring creek area of New York City, Proceedings of the 1980 National Waste Processing Conference, USA, 239 – 249.
Felix F. B., Yomi G. B., 2013, Appraisal of the Economic Geology of Nigerian Coal Resources, Journal of Environment and Earth Science, 2224 – 3216.
Harir A.I., Kasim, R., Ishiyaku B., 2015, Resource potentials of composting the organic wastes stream from municipal solid wastes compositions arising in Nigerian cities, Journal of Geoscience, 3, 10 – 15.
Jegla Z., Turek V., Kilkovsk, B., Stehlík P., 2017, Methods and tools for reliable design of equipment in waste-to-energy units, Chemical Engineering Transactions, 61, 37-42.
Omari A., Said M., Njau K., John G., Mtu P., 2014, Energy recovery routes from municipal solid waste: A case study of Arusha-Tanzania, Journal of Energy Technologies and Policy, 4, 1 – 7.
Ogwuche J.A., 2013, Spatial location of solid waste dumpsites and collection scheduling using the geographic information systems in Bauchi metropolis, Nigeria, European Scientific Journal, 9, 374 – 382.
Oluwatoyin K. K, Odunola A. M., Alabi A. O., 2015, Ways of achieving stable and uninterrupted power supply of electricity in Nigeria, British Journal of Applied Science &Technology, 10,1-15.
Raheem A., 2018, Characteristics of the effluent wastewater in sewage treatment plants of Malaysian Urban Areas, Chemical Engineering Transactions, 63, 691 – 696.
Saeba D., Patcharavorachot Y., Hacker V., Assabumrungrat S., Arpornwichanop A., Authayanun S., 2017, Analysis of unbalanced pressure PEM electrolyzer for high pressure hydrogen production, Chemical Engineering Transactions, 57, 1615 – 1620.
Ujam A.J., Eboh F., Chime T.O., 2013, Effective utilization of a small-scale municipal solid waste for power generation, Journal of Asian Scientific Research, 3, 18 – 34.