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The Potential of Anaerobic Digestion for Managing the Organic Fraction of Municipal Solid Waste: The Case of Kisumu City

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Abstract

The city of Kisumu, Kenya, generates about 400 t/day of solid waste of which 60% is organic. Most of this waste is deposited in undesignated dump sites, posing an environmental threat from methane emissions. Solid waste management is a major challenge in Kisumu and will worsen as the population grows. This paper explores the practicality of treating the city's organic waste by anaerobic digestion as a means of waste management and energy production in the form of biogas. Since 1 tonne of organic waste produces 110 m3 of biogas, Kisumu could potentially produce 26,400 m3/day of biogas and as 1 m3 of biogas produces 2 kWh of electricity Kisumu could generate 52,800 kWh/day. In addition, 1 tonne of organic waste emits 1102 kg CO2 equivalent into the atmosphere but when converted to biogas through anaerobic digestion this is reduced to 181kg CO2e. Embracing anaerobic digestion would therefore provide a permanent, viable long-term solution to the management of organic waste with both environmental and economic benefits.

Keywords: Anaerobic digestion, Biogas, CO_2 equivalent, Electricity, Environment, Organic waste

Introduction

Sub-Saharan Africa is experiencing a population explosion and will experience rapid population growth in the near future. Given that this region is among the least developed in the world, challenges such as rural to urban migration, increased waste generation, and environmental impacts will increase in proportion to an increasing populace (Hove *et al*., 2013). The majority of African cities and urban areas, including those in East Africa and the Lake Victoria Basin, have failed to provide a lasting solution to existing and emerging urban pressures.

Kisumu is the main urban centre and economic hub of western Kenya and it continues to struggle with waste. Before the promulgation of the 2010 Constitution of the Republic of Kenya, the Kisumu Municipal Council was responsible for waste collection and management which was done alongside private companies involved in door-to-door waste collection in residential areas at a fee (Munala and Moirongo, 2011; NEMA, 2014). As Kisumu's population grew, the amount of waste generated increased with it and poor planning led to the emergence of undesignated dumpsites, such as the Kachok dumpsite, giving rise to a new environmental disaster. Today with a devolved system, the Kisumu County Government is in charge of providing waste management solutions but little has been done to seek and implement solutions for the challenge and conventional waste handling methods such as dumping and burning of wastes are still predominant (Munala and Moirongo, 2011; NEMA, 2014).

The city lacks an authorized landfill site and as a result the undesignated Kachok dumpsite continues to serve as the main option for waste handling. Kisumu generates about 400 t of solid waste per day, of which 60% is organic (Munala and Moirongo, 2011; NEMA, 2014). The remainder consists of recyclables including plastics, paper, glass and metal as well as non-recyclables such as medical waste and diapers. The inorganic recyclables are usually handled by scavengers and private waste companies or business people who resell the items. Most of the organic fraction of the waste is dumped, causing environmental problems over time. The proportion of waste collected in Kisumu is lower than in some other urban centres in Kenya (Table 1), which indicates the extent of the waste crisis in the city.

Table 1. Summary of waste generation, collection and recovery in major towns in Kenya. Data from NEMA (2015).

Town	Estimated waste (t/day)	Waste collected (%)	Waste recovered (%)
Nairobi	2400	80	45
Mombasa	2200	65	40
Thika	140	60	30
Eldoret	600	55	15
Nakuru	250	45	18
Kisumu	400	20	Unknown

If dumped and left in the open, organic wastes break down and emit methane into the atmosphere (Williams, 2005). If properly managed and taken through the process of anaerobic digestion these wastes will produce substantial amounts of potentially usable biogas and cut down on methane emissions into the atmosphere. Today, this technology is used to treat municipal, agricultural and industrial waste in many parts of Europe where, as environmental awareness informed by scientific findings grows and legislation on waste management has evolved, leading to the closure of landfills in Europe (Mata-Alvarez *et al*., 2000; Holm-Nielsen *et al*., 2009).

The anaerobic digestion process

Anaerobic digestion involves the conversion of organic substances by anaerobic microorganisms in the absence of oxygen. Biodegradable organic matter is broken down into methane, ammonia, hydrogen sulphide and carbon dioxide; the sulphur resulting from the reaction remains in the residue. The breakdown of organic substances goes through four stages (Figure 1). The first, *hydrolysis*, involves the conversion of insoluble organic substances and complex compounds such as cellulose, starch, lipids and polysaccharides into simpler compounds like monosaccharides, amino acids, and fatty acids (Deublein and Steinhauser, 2011; Li *et al*., 2011).

In the second stage, *acidogenesis*, the simpler products formed from hydrolysis are further broken down by anaerobic bacteria into acetic acid, hydrogen, carbon dioxide and other simple volatile substances like C1-C5 molecules such as propionic and butyric acid. The third stage, *acetogenesis*, involves conversion of the products from acidogenesis into a mixture of methane, carbon dioxide and acetate by methanogenic bacteria. *Methanogenesis* is the final stage where under strict anaerobic conditions formation of methane occurs.

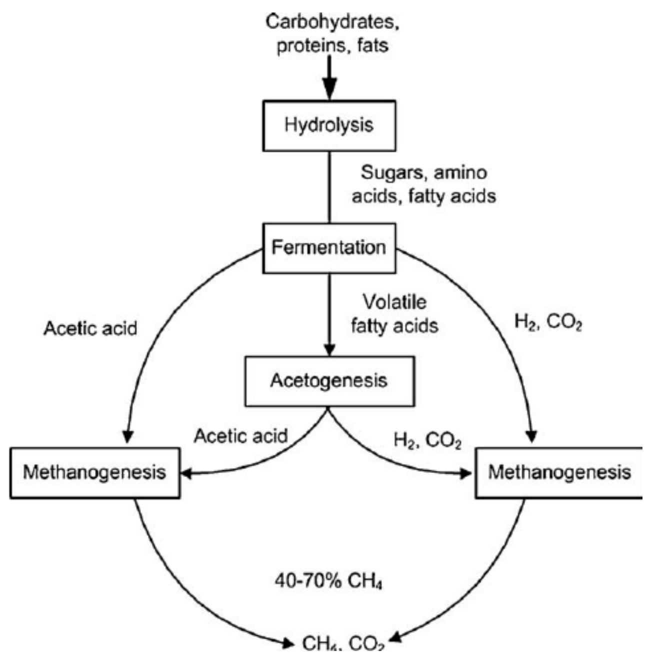

Figure 1: The process and stages of the anaerobic digestion of organic matter. From Li *et al*. (2011).

Products of anaerobic digestion

Anaerobic digestion produces of biogas and digestate. Biogas consists of 55-65% of methane and 34-44% of carbon dioxide along with traces of hydrogen sulphide, water vapour and ammonia (Chynoweth *et al*., 2001). Biogas can be used as a fuel for vehicles and for electricity generation that can be injected into national gas grids (Holm-Nielsen *et al*., 2009).

Digestate is the nutrient-rich material left once digestion has been completed and it can either be in solid or liquid form. It contains fully or partially digested organic matter, and a mixture of nutrients such as nitrogen, phosphorus and potassium. It is a suitable addition to soil and can improve farming but must be of high quality, measured by assessing chemical, biological and physical factors (Bajpai, 2017). These factors can determine the marketability of digestate depending on whether it meets the consumer's requirements. Its main application is in agriculture where it can be used as fertilizer because of the nutrients it contains while its ability to enhance biological activity prevents soil-borne diseases.

Suitability of the organic fraction for anaerobic digestion

The organic fraction consists of food and garden wastes which have the potential to generate biogas after anaerobic digestion. It is important to separate this portion of waste from the non-biodegradable materials such as glass, plastic bags and metals since such impurities inhibit anaerobic digestion. The pre-treatment process for a wet anaerobic digestion system for organic waste is complicated and may result in loss of important biodegradable material.

Segregating wastes at source requires public participation and the creation of such a system requires implementation for it to become common practice. Elsewhere, biogas yield depends on the method of collection, which include source and mechanical sorting, although the former results in a higher quality of organic waste which yields more biogas because it contains less unwanted materials (Li *et al*., 2011).

Methods

This work was carried out on waste produced in Kisumu city, estimated to be 400 t per day, with the organic fraction accounting for 60% of the total, i.e. 240 t (Munala and Moirongo, 2011; NEMA, 2015). The waste generated in the city was analysed to evaluate both its energy potential and carbon emission potency before and after digestion. This analysis was conducted by expressing methane (CH_4) as the carbon dioxide equivalent (CO_2e), derived from the densities of CH_4 and CO_2 (at normal temperature and pressure) using the following variables: density of CO_2 = 1.842 kg m^{-3}; molecular weight of CO_2 = 44.01 (44); density of CH_4 = 0.668 kg m^{-3}; molecular weight of CH_4 =16.043 (16); 1 kg CH_4 = 25 kg CO_2e (Brander, 2012).

The emissions were expressed as carbon equivalent by: CO_2 equivalent from 1 t of waste = density of CH_4 (kg m^{-3}) × volume of methane in waste (m^3) × CH_4 to CO_2 conversion factor (1:25). The quantity of CO_2 emitted after combustion of methane was determined by: conversion of CH_4 to CO_2 after combustion = (CH_4 produced by 1 tonne of waste ÷ molecular weight of CH_4) × molecular weight of CO_2.

Curry and Pillay (2012) indicate that about 110 m^3 of biogas can be produced from 1 t of organic waste. This value (1 t of organic waste = 110 m^3 of biogas) was used to calculate the energy potential of biogas generated from Kisumu city's organic waste and its carbon emission potency, with 66 m^3 of CH_4 and 44 m^3 of CO_2, respectively, being produced from 110 m^3 of biogas per tonne of organic waste. The calorific value of biogas is approximately 24 MJ m^{-3} and since 1 MJ yields about 0.28 kWh of electricity then 1 m^3 will yield 6.72 kWh (Onwosi and Okereke, 2009). However, when the waste undergoes anaerobic digestion, only about 25-40% of energy can be converted to electricity with the rest being lost through inefficiencies during the process (Carbon Trust, 2014; NNFCC, 2016). As a result, approximately 2 kWh of electricity is produced from 1 m^3 of biogas.

Results

Kisumu produces 400 t of waste per day of which 60% is organic; hence, 240 t of waste is suitable for anaerobic digestion. This could potentially produce 26,400 m^3 of biogas and generate 52,800 kWh per day or 19,272 MWh per annum. Thus, an anaerobic digestion plant with a capacity of 2.2 MWe is suitable for processing the organic waste currently produced in Kisumu City.

1 tonne of organic waste is produces 1102.2 Kg CO_2e; however, after digestion emission is reduced to 181.50 Kg CO_2e.

Taking the above into consideration the net savings per tonne after digestion is 920.70 Kg CO_2e. The total quantity of organic waste produced by Kisumu amounts to 87,600t therefore the carbon savings from anaerobic digestion of Kisumu's organic waste would amount to approximately 80650 t of CO_2e per annum.

Since the greenhouse effect of one kilogram of methane is equivalent to 25 kg of carbon dioxide, converting methane to carbon dioxide will greatly reduce its greenhouse impact since one molecule of methane yields only one molecule of carbon dioxide. The organic waste from Kisumu (240 t per day) will yield about 24,000 m^3 of biogas, 14,400 m^3 of which consists of methane, which would be equivalent to 360,000 m^3 of carbon dioxide. Although burning this methane would convert it to carbon dioxide the greenhouse impact would be reduced significantly, by a factor of 25 to give a CO_2e saving of 345,000 m^3 per day, or 126 x 10^6 m^3 per annum.

Discussion

To achieve the maximum biogas production from the anaerobic digestion of waste, the organic fraction must be free of impurities that may inhibit the process. Wastes that are not biodegradable must be separated from the inorganic fraction. The current waste collection system in Kenya, and specifically in Kisumu, does not allow for the separation of waste at source and physical or mechanical pre-treatment techniques may be required to separate organic matter from the waste stream. This could increase the cost of waste treatment and result in the loss of important volatile organics where unwanted wastes cannot be completely removed. However, source separation increases the quality of organic waste thus increasing the potential efficiency of biogas production, which might offset the increased costs.

To make source separation of wastes possible in Kisumu new by-laws that focus on the environment need to be put in place and harmonized with future urban planning and development plans. The County Government of Kisumu should prioritise and budget for this since waste management functions were devolved to them, but all stakeholders have to play a role. These include the private sector, non-governmental organizations, community-based organizations, the business community and educational institutions to ensure comprehensive coverage. The County Government must enforce penalties for incorrect waste handling that threaten the environment, thus compelling compliance with the standards. At the same time, an effort should be made to create awareness and educate the public until cooperation becomes voluntary. This should be backed by communication tools and the provision of labelled bins for separate categories of waste, spread throughout the city and easily accessible to the public.

The construction costs of a sufficiently large biogas plant of such magnitude is very high; the Naivasha-based Tropical Power Biogas plant, for instance, the largest anaerobic digester in sub-Saharan Africa cost about 765 million Kenya Shillings (about USD 7.5 million) and processes around 50,000 t of organic waste annually producing some 2.2 MW per annum (Mwangi, 2015). A similar plant for Kisumu would cost more as it would have to treat about 88,000 t of waste but it would generate up to 19.2 MWh of electricity per annum. If it used 5% of this to sustain itself then the remaining 18.3 MWh could be exported to the grid. In Kenya, the cost of electricity is about 16.43 Ksh/kWh as at March 2018 for heavy commercial use (Kenya Power, 2018) so the power produced by the Kisumu plant would be worth about 300 million Kenya Shillings (about USD 3 million) per annum.

The increase in solid waste and its management challenges resulting from the increasing urban population require a lasting solution. Anaerobic digestion can contribute to this by ensuring that organic wastes go through a cycle leading to their reuse. The electricity generated is renewable and can alleviate a substantial portion of the population from energy poverty. The digestate that remains is nutrient-rich and can be used as a soil conditioners or organic fertilizer, thus preventing land degradation by enhancing its productivity.

Nutrients recycled in this way are less likely to be discharged into water courses and, ultimately into Lake Victoria, potentially alleviating its eutrophication. Besides mitigating carbon emissions through the reduction of methane, other benefits would be realized in the form of improved health and a cleaner environment. The current unstructured system of solid waste management in Kisumu seems cheaper at the moment but could be more expensive in the long term if its adverse effects on the environment and human health are taken into consideration. The adoption of anaerobic digestion for treatment of the largest component of Kisumu's waste stream must be an integral part of any solid waste management strategy that may be developed. While the initial cost of investment is high, the overall benefits will ensure a quick financial return while improving livelihoods and the environment over the long term.

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References

Bajpai P. (2017). *Anaerobic Technology in Pulp and Paper Industry*. Springer Briefs in Applied Sciences and Technology, Springer, Singapore

Brander, M. (2012). Greenhouse gases, CO_2, CO_2e, and carbon: what do all these terms mean? Ecometrica White Paper. Ecometrica, London: 3 pp.

Carbon Trust. (2010). *Introducing Combined Heat and Power*. Carbon Trust, London: 56 pp.

Chynoweth, D.P., Owens, J.M. and Legrand, R. (2001). Renewable methane from anaerobic digestion of biomass. *Renewable Energy* **22**: 1-8.

Curry, N. and Pillay, P. (2012). Biogas prediction and design of a food waste to energy system for the urban environment. *Renewable Energy* **41**: 200-209.

Deublein, D. and Steinhauser, A. (2011). *Biogas from waste and renewable resources*. Wiley VCH Verlag; Weinheim, Germany.

Holm-Nielsen, J.B., Al Seadi, T. and Oleskowicz-Popiel, P. (2009). The future of anaerobic digestion and biogas utilization. *Bioresource Technology* **100**:5478-5484.

Hove, M., Ngwerume, E.T. and Muchemwa, C. (2013). The urban crisis in Sub-Saharan Africa: a threat to human security and sustainable development. *Stability* **2**:1-14.

Kenya Power (2018). Electricity Cost in Kenya. [https://stima.regulusweb.com/].

Li, Y., Park, S.Y. and Zhu, J. (2011). Solid-state anaerobic digestion for methane production from organic waste. *Renewable and Sustainable Energy Reviews* **15**:821-826.

Mata-Alvarez, J., Macé, S. and Llabrés, P. (2000). Anaerobic digestion of organic solid wastes. An overview of research achievements and perspectives. *Bioresource Technology* **74**:3-16.

Munala, G. and Moirongo, B.O. (2011). The need for an integrated solid waste management in Kisumu, Kenya. *Journal of Agriculture Science and Technology* **13**:65-78.

Mwangi, M. (2015). Firm sets up Africa's largest biogas plant. *Daily Nation*, 21 August 2015. [Available at: http://www.nation.co.ke/business/Firm-sets-up-Africa-s-largest-biogas-plant/996-2841582-nm8l2iz/index.html]

NEMA (2014). The national solid waste management strategy. National Environment Management Authority, Nairobi: 85 pp.

NNFCC (2016). *Biogas: The Official Information Portal on Anaerobic Digestion*. National Non-Food Crops Centre, London.

Onwosi, C.O. and Okereke, G.U. (2009). Effects of water dilution and nutrient supplements (wood ash, urea and poultry droppings) on biogas production from brewers spent grain. *In*: A. Mendez-Vilas (ed.) *Current Research Topics in Applied Microbiology and Microbial Biotechnology: Proceedings of the II International Conference on Environmental, Industrial and Applied Microbiology*. University of Seville, Spain, 28 November – 1 December 2007: pp. 232-235.

Williams, P.T. (2005). *Waste Treatment and Disposal*, 2nd ed. John Wiley & Sons, UK.