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Design, construction and mathematical modelling of the performance of a biogas digester for a family, Eastern Cape province, South Africa

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Currently, South Africa is experiencing electricity blackouts as result of an energy shortage. Biogas can be a solution to South Africa's energy needs, especially in the rural areas of the Eastern Cape province that have plenty of biogas substrates from cattle, donkeys, goats, sheep and chicken. The purpose of this paper is to design and construct a 1 m^3 family biogas digester and model its performance using donkey dung as a biogas substrate. The installation of this type digester in rural communities of South Africa has economic, social and environmental advantages. The digestate from the digester is a valuable soil fertilizer, rich in nitrogen, phosphorus, potassium and micronutrients, which can be applied on soils. The mathematical model equation developed is highly beneficial in the rural areas of the Eastern Cape province of South Africa where many donkeys are kept. Currently, no mathematical models have been developed for optimum methane yield from the named substrate.

Keywords: biogas digester, design, construction, donkey dung, methane yield, mathematical modelling

Introduction

Anaerobic digestion is processes whereby microorganisms break down biodegradable material such as donkey dung in the complete absence of oxygen to form biogas. The biogas produced can be used for electricity generation and as a fuel for vehicles. South Africa is the most industrialized country in Africa and is highly dependent on conventional fuels such as coal and oil. This makes the country lead in greenhouse gas emissions (Naidoo 2011). A number of steps have been taken to reduce these greenhouse gas emissions. One step taken was the introduction of anaerobic digesters in rural areas to produce biogas. Biogas production is a suitable technology used for treatment of organic wastes such as municipal wastes and the production of energy from the combustion of biogas (Lema and Omil 2001; Lettinga 2001; McCarty 2001). Anaerobic digestion is the production of biogas, mainly methane, from organic wastes in the complete absence of oxygen by anaerobic microbes such as acidogens, acetogens and methanogens.

The main factors in the production of biogas involve temperature inside the digester, retention time (RT), agitation, working pressure of the digester, fermentation medium pH, volatile fatty acids (VFA) and sublayer composition (Dobre, Nicolae, and Matei 2014).

The temperature for the anaerobic process can be classified into three conditions which include psychrophilic (between 10°C and 20°C), mesophilic (between 22°C and 40°C) and thermophilic (between 50°C and 60°C) (Cheng 2009; Vintilă et al. 2010).

Biogas technology is an appropriate technology for the recovery of biogas (Etuwe, Momoh, and Iyagba 2016). The biogas production process produces less greenhouse gas than waste treatment processes (Walker, Charles, and Cord-Ruwisch 2009) and landfilling (Lou and Nair 2009). Currently, there are about 200 biogas digesters in operation in South Africa, of which 90% are of the small-scale domestic variety (Tiepelt 2013). The 200 biogas digesters, installed mainly by non-governmental organizations, cannot compare numerically with the vast numbers in both India with 12 million and China with 17 million biogas digesters (DOE 2015). The most common biogas digester types in South Africa are PVC digesters, fixed dome digesters and plastic bag (balloon) digesters. PVC biogas digesters have advantages that include no mechanical wear, can be welded and joined easily, are light in weight, have both high mechanical strength and toughness, and are durable, non-toxic and cost effective.

Fixed dome digesters are usually built underground (Santerre and Smith 1982). The size of the biogas digester depends on the location, number of households, and the amount of feedstock available daily (Rajendran, Aslanzadeh, and Taherzadeh 2012). The advantages of fixed dome biogas digesters include low construction costs, being corrosion free because they are not made from steel, a longer lifespan than other digester types, minimized temperature fluctuations due to underground construction and creation of local employment for construction, feeding and maintenance of the digesters. However, fixed dome digesters have a number of disadvantages such as fluctuation of biogas pressure, low biogas digester temperatures and poor agitation leading to low biogas yield; also, they are not easy to the clean, and require supervision during construction and skilled builders for the construction (Sharma and Pellizzi 1991; Nijaguna 2002).

Plastic bag biogas digesters have advantages that include the following: they are cheap to buy, ease of transportation to installation sites, easy to clean, high biogas temperatures during summer leading to high biogas yield and easy to empty. However, their disadvantages include low gas pressure (as a result, biogas pumps are used), poor agitation, short lifespan, great susceptibility to mechanical damage. Further, the digesters are not locally made, it is not easy to repair the plastic and it is difficult to insulate to prevent temperature fluctuations.

The following problems and challenges of biogas technology in South Africa were noted (Mukumba et al. 2016b):