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Experimental and economical evaluation of a novel biogas digester

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ABSTRACT

Many developing countries face an energy demand to satisfy the daily needs of the people. Household biogas digesters are among the interesting solutions to meet the energy demands for cooking and lighting, and at the same time taking care of the kitchen wastes. In this study, a novel textile-based biogas digester was developed. The digester was evaluated for biogas production from a synthetic nutrient and an organic fraction of municipal solid waste (OFMSW) as substrates for more than a year. The obtained biogas productivity in both experiments was 570 L/kgVS/day, which indicates that the digester is as efficient in handling of OFMSW as the synthetic nutrients. Based on the obtained biogas production data, the techno-economic evaluation and sensitivity analysis for the process were performed, replacing LPG and kerosene consumption with biogas in households. A 2-m^3 digester can supply the fuel needed for cooking for a family of 4–6 people. The sum of investment and 15-years operational costs of this digester was 656 USD, which can be compared with 1455 USD for subsidized-LPG and 975 USD for kerosene, respectively. The results from the sensitivity analysis show that it was a positive investment, unless the price of kerosene goes down to less than 0.18 USD/L.

1. Introduction

Many developing countries face a severe energy crisis both domestically and industrially. About 90% of energy consumption for a household in developing countries is used for cooking. The cost of cooking fuel, for example, liquefied petroleum gas (LPG), has also increased more than ten-fold in recent years [1,2]. On the other hand, the amount of waste generated from households is also increasing. Reducing the waste and its conversion into energy solves both these dual problems. It is worth mentioning that household wastes mainly contain organics, which could be converted into biogas, a cost-effective and cleaner way to meet energy demands [3–5].

Biogas is a mixture of methane, carbon dioxide, and traces of hydrogen sulfide formed by anaerobic digestion of organic materials [6,7]. Formation of the biogas involves four different steps, including hydrolysis (breakdown of complex substrates into monomers); acidogenesis (conversion of monomers into volatile fatty acids); acetogenesis (conversion of VFA's into acetic acid, hydrogen, and carbon dioxide); and finally, methanogenesis (conversion of acetate, hydrogen, and carbon dioxide into methane and carbon dioxide). Fig. 1 shows the schematic diagram of the biogas production process. Methane is an energy rich compound, which can be used for applications such as cooking, lighting, and electricity. Digestate or slurry left over after anaerobic digestion contains a high amount of nitrogen, phosphates, and other nutrients, which can be utilized as a natural fertilizer for agricultural use [8,9].

Several designs of digesters in different sizes have been developed, including fixed dome, floating drum, and plug flow digesters. Fixed dome digesters are common in China, where digesters are built underground in the shape of a dome using bricks. However, the formation of pores from the bricks causes gas leakage as well as contamination of ground water, which is a major drawback with these reactors. Floating drum digesters are common in India, built with an iron floating drum on top of the digester. Nonetheless, since iron is corrosive and expensive, it is difficult to maintain these digesters. Recently, plug flow digesters made of polyethylene have been gaining attraction due to its cost-effectiveness. However, the attraction is fading out since the material it is made from can be cut too easily. Most of the digesters were built with materials such as: concrete, fiberglass or plastics, polyethylene or iron, which are either expensive or do not last for an extended period of time [10]. Therefore, cost-effective, easy to use digesters need to be developed.

Some economical evaluations on different biogas digesters have recently been performed. Amigun and Blottnitz [11,12] worked on cost-capacity relationship and fixed capital investment of the biogas digesters built in Africa. They reported the fixed capital investment of 4–100 m^3 digesters to be between 500 and 45,000 USD in 2004. Singh and Sooch [3] compared the payback period (PBP) of

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Nomenclature

AMPTS	automatic methane potential testing system	VFA	volatile fatty acids
GC	gas chromatography	OLR	organic loading rate
HPLC	high performance liquid chromatography	HRT	hydraulic retention time
OFMSW	organic fraction of municipal solid waste	NPV	net present value
PBP	payback period	IRR	internal rate of return

different fixed dome digester models such as *janta, KVIC and deenbandhu* for digester size between 1 and 6 m^3. However, no study has been performed on the biogas digester replacing with LPG and kerosene, which is currently used in many developing countries for cooking.

In this study, a novel portable digester was built from textile supplied by FOV Fabrics AB, Sweden. Textile has never been reported as a material used to build a digester, which is why this work is so novel. This textile digester was tested with a synthetic medium and an organic fraction of municipal solid waste (OFMSW) in two different experiments. In reference to the obtained biogas production, the techno-economical evaluation was also made for the digester, comparing the LPG and kerosene replaced with biogas for cooking on a household scale.

2. Materials and methods

2.1. Digester

The easily transportable digester was constructed of textile supplied from FOV Fabrics AB, Sweden. Fig. 2 shows the schematic sketch of the digester. The shape of the digester resembles a pyramid, with an inlet to feed the digester, an outlet to take out digested material, and a gas line to measure the amount of biogas produced. The digester had 112 and 100 L total and working volumes, respectively. It had an opener in order to empty its contents. The dimensions of the digester were 72 cm width and 65 cm height. The diameter of the inlet and outlet tubes was 30 mm. It was filled with air and water to check for leakage before the inoculum was added.

2.2. Inoculum preparation

Two different inoculums were used for different experiments. For the first one, the digester was filled with granules from a UASB reactor working with municipal wastewater treatment plant (Hammarby Sjöstad, Stockholm, Sweden). Equal volume of granules and water were added to the digester to reach the working volume. For the second experiment, the inoculum was prepared from the cow manure provided by a local farm near Borås, Sweden. The manure was mixed with an equal proportion of water (e.g., 50 L manure and 50 L water), and left undisturbed for 40 days. Once the gas production started after this incubation period, the digester was fed with OFMSW.

2.3. Experimental setup

Two different semi-continuous experiments were carried out with the textile digester. In the first experiment, the digester was filled with granules and fed with a synthetic substrate, i.e., acetic acid, propionic acid, and butyric acid in the ratio 3:1:1. Other concentrations of nutrients fed to the digester, apart from carbon sources include (mg/L): NH_4Cl (76.4), KH_2PO_4 (5.18), $MgSO_4{\cdot}7H_2O$ (0.27), $CaCl_2{\cdot}2H_2O$, (10.00), and trace nutrients (1 ml/L) [13,14].

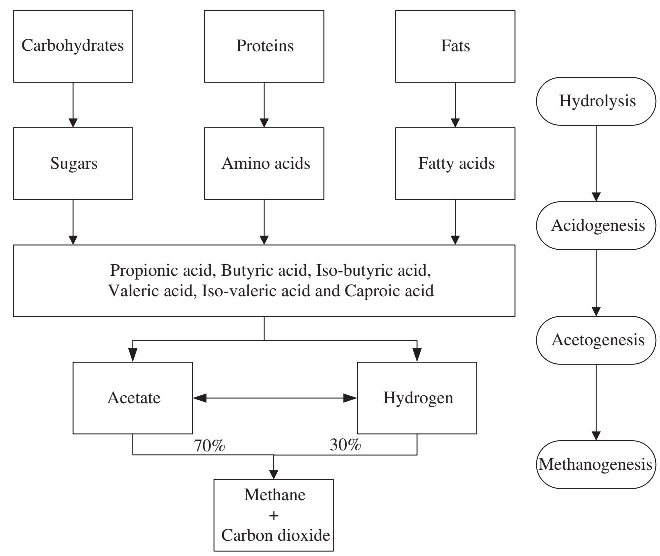

Fig. 1. Schematic diagram of the biogas production process.

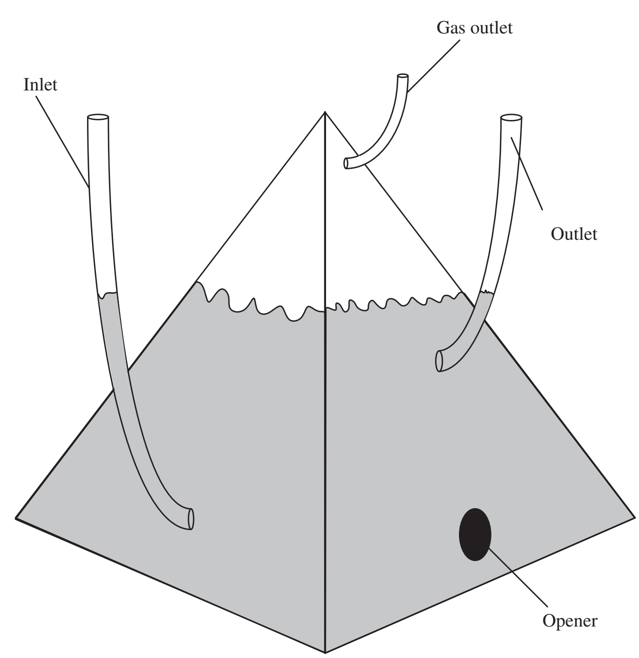

Fig. 2. Schematic sketch of the textile digester.

The OLR was increased step-by-step in the order of 0.25, 0.50, and 1.0 gVS/L/day with the decrease in hydraulic retention time (HRT) of 100, 80, and 75 days, respectively. The digesters were operated at room temperature, which varied between 22 °C and 25 °C. At this temperature, the psychrophilic bacteria are active; therefore, it demands a higher retention time than mesophilic