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Experimental study of power generation utilizing human excreta

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ABSTRACT

This study presents the energetic performance of the biomass to produce power for micro scale domestic usage. Human excreta are chosen as the subject of the study to investigate their potential to produce biogas under ambient conditions. Furthermore, the research examines the approaches by which biogas production can be enhanced and purified, leading to a high-power generation system. The experimental work focuses on the design and fabrication of a biogas digester with a reverse solar reflector, water scrubbing tower, and a dryer. Anaerobic digestion has been considered as the decomposition method using solar energy which is a heat providing source. Specifically, two types of experiments have been performed, namely, feces to water weight proportion and continuous feeding experiments, each involving a set of six samples. The effect of parameters such as pH, ambient temperature, and biogas upgradation reveals that volume of biogas and power generation can be best obtained when an 8:2 feces to water weight sample is employed and when the feeding is applied every fifth day. In addition, this study discusses the environmental prospects of the biogas technology, which is achieved by using the water purification method to improve the methane percentage to 85% and remove undesired gases. The motivation behind this work is to understand the potential of human excreta for the development of domestic power generating systems. The results obtained reveal that 0.35 m^3/kg of biogas is produced with 8:2 weight proportion sample, which generates 26.8 kW h power from 35 kg of waste. On the other hand, continuous feeding on the fifth day produces 0.7 m^3/kg biogas and generates 60 kW h power.

1. Introduction

With the increasing developments in science over the years to raise the standards of life, one prominent aspect is to search for new ways to fulfil the energy demands and diminish the hazardous environmental elements. Primitive fossil fuel resources of energy are depleting from the earth with time and will ultimately choke their dependence one day. Utilization of waste is yet another trouble of the urban and rural areas which is not being treated well to convert it into useful energy form. In the recent past, immense importance has been concentrated on the energy from the wastes. Korai et al. [1] reported that currently Pakistan is facing massive power outage due to increased demand of power 19,000 MW. The country is spending huge amount 14.5 billion US dollars to import the crude oil for power sector which is still not enough to fulfil the requirements [2]. Although the Government of Pakistan is subsidizing the crude oil prices as the power sector is entirely dependent on fossil fuels, it is adversely affecting the economy of the country. Therefore, researchers need to search for cost-effective and domestically viable renewable energy resources [3]. Sewage waste can be considered a good remedy as it can generate biogas (CH_4–55%, CO_2–35% and small traces of other gases) to meet household energy demands, such as heating, cooking, electricity, and vehicle fuel [4]. Human waste, specifically human feces, has the ability to produce biogas 0.35–0.5 m^3/kg [5]. The current study will focus on the small-scale Ghulam Ishaq Khan Institute (GIKI) Sewage Processing Plant, located in Topi, Swabi Pakistan, which receives approximately 1300 tons of sewage waste annually. The plant has the additional advantage of possessing completely separate spouts for collecting the human feces from flush toilets. The feces are not mixed with conventional sewage substrates such as soap water, shampoo, and detergents that upset the pH and inhibit microorganisms from growing for biogas production. Fresh human excreta are collected for the experiment and dumped in a biogas digester (BD) for anaerobic digestion.

Nguyen et al. [6] conducted bench scale experiment using anaerobic digestion (AD) to decompose the food waste under mesophilic and thermophilic conditions to investigate hydraulic retention time and organic loading rate on the biogas yield. The results suggested that the production of gas improved as the hydraulic retention time decreased or the organic loading rate

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Nomenclature

Abbreviations

AD	anaerobic digestion
ACE	anaerobic conversion efficiency
BD	biogas digester
C/N	carbon to nitrogen ratio
COD	chemical oxygen demand
DM	dry matter
F/W	feces to water ratio by weight
SR	solar reflector
ST	scrubbing tower
VS	volatile solids
WS	water scrubbing
Wt.	weight proportion
T_{avg}	average temperature
Rt	retention time
CH_4	methane
CO_2	carbon dioxide
H_2S	hydrogen sulphide
h	hour
L	litre
f_m	fraction of methane in biogas
η	combustion efficiency
V_b	volume of biogas produced
EC_{biogas}	calorific value of bio methane
E_{biogas}	amount of biogas potential [kW h]
e_{biogas}	amount of power generated [kW h]

increased. The highest average rate of biogas production i.e. 162.14 m^3 biogas/ton of food waste with 61.89% CH_4, at an organic loading rate of 8.62 kg/day with 25 days of retention time was achieved under thermophilic condition. Scano et al. [7] experimented on the fruits and vegetables waste via anaerobic digestion and studied the power capacity of biogas. When feeding rate of 2.5–3 kg was applied per day under thermophilic temperature (60 °C), 0.78 m^3/kg of biogas and 0.43 m^3/kg methane yield was obtained. The power output of 42 kW was achieved with cumulative 290 m^3 of methane per day. As power output from biogas entirely depends upon the content of methane level achieved in the gas. Montingelli et al. [8] discussed different pre-treatment techniques on macroalgae for rapid digestion and studied the methane yield. Beating technique increased the methane yield by 37% in the initial days compared to untreated biomass, however, there was not any noticeable effect on overall methane production in 25 days retention time. Other techniques i.e. microwave and ball milling affected negatively upon methane production. To improve biogas generation and its optimization there are numerous strategies proposed by different researchers in which they add agricultural wastes with dairy manure or sewage. Grosser and Neczaj [9] improved biogas production by adding a greasy element to sewage to increase the organic content, however, this approach is not suitable for small-scale perpetual biogas production within a residential domain. Elsayed et al. [10] focused on co-digestion of sewage sludge with wheat straw and studied impact of third additive buckwheat husk to the slurry based on carbon to nitrogen (C/N) ratio. The synergetic effect of co-digestion enhanced the methane yield and purification method with aid of sodium hydroxide, thereby increased the methane content from 58.91% to 92.46%. Budzianowski et al. [11] utilized water scrubbing technique for the purification of biogas due to environmental friendly procedure in which high pressure and near atmospheric pressure methods were discussed. High methane content gas (bio-methane) has immense domestic and industrial applications by employing it in combustion engines. Hosseini and Wahid [12] modelled a combustion system for the utilization of palm oil mill effluent (POME) as a source of biogas and recorded a 10.8 MW of power. Colon et al. [5] investigated biogas from human excreta under mesophilic conditions i.e. 30 °C in laboratory with 17 L of total solids producing 0.24–0.44 L biogas per gram, which corresponds to about 24–44 L biogas per person per day. Table 1 represents the characteristics of human excreta. The average calorific value of biogas is 21.48 MJ/m^3, which is low compared with the calorific value of natural gas (36.14 MJ/m^3). Furthermore, benefits of biogas are not only limited to energy production but it also provides a viable solution to handle urban waste management for developing countries which is eco-friendly at the same time. Numerous researches suggested that waste to energy plant is an alternative technology for the better usage of waste which can reduce uncontrolled hazardous emissions of the green house gases. The annual reduction of emissions is equal to 370 kg CO_2 equivalent per ton of treated waste from landfill [13–15]. Although several researchers have focused on animal manure, food waste, and municipal wastes for biogas production, however, human excreta is rarely considered. Moreover, only a few experimental studies report data on human excreta as biogas raw material under ambient conditions. Furthermore, human excreta can be utilized under certain arrangements to obtain better quality biogas and further purification can increase the methane content to enhance electricity generation. Such small-scale power generation units can be devised in the vicinity of sewage plants, particularly in remote areas, to employ the human excreta for biogas and power generation [17,18].

Table 1
Characteristics of human excreta [5,19].

Contents	Amount
Wet feces	350–400 g/person/day
Total solids (dry matter, DM)	70–80 g/person/day
Chemical oxygen demand	100–110 g (COD) p^{-1} d^{-1}
Nitrogen (80–90% coming from the urine)	7–10 g-N p^{-1} d^{-1}
Phosphorus	1 g-P p^{-1} d^{-1}
Hydrogen sulphide	10–2000 ppm
Volatile solids (VS)	45%
pH	4.6–8.4

Arimov and Bid [16] experimented on sewage and cow dung and built a pilot scale plastic biogas digester with reverse solar heater. The corresponding biogas produced was 0.4 m^3 and 8 m^3 from 28 kg of waste sample, respectively. The present study is a continuation of the same work to construct a complete bio-solar and purification system under prevalent ambient conditions. In the current experimental work, a domestic power generation plant is designed for integration with a sewage plant, involving design and fabrication of the metallic biogas digester (BD), solar reflector (SR), water scrubbing tower (ST), and dryer to generate biogas from human excreta with the aid of solar heat. The biogas so produced is further purified with water to increase its methane content. Six sets of samples are investigated by performing feces to water (F/W) by weight proportion and continuous waste feeding experiments. Furthermore, the performance parameters to study biogas production and electricity generation include the ambient temperature, pH of the slurry, F/W weight ratio, and feeding rate.