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High-solids anaerobic co-digestion of food waste and rice husk at different organic loading rates

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ABSTRACT

Low C/N ratio and high biodegradability are major limitations of anaerobic digestion of food waste which results in process inhibition due to rapid accumulation of volatile fatty acids. In the present study, C/N ratio of food waste was adjusted by mixing with rice husk which has low biodegradability. Co-digestion of the two wastes was performed in continuous pilot scale anaerobic reactor operated at organic loading rates (OLR) of 5, 6 and 9 kg VS/m^3/d and mesophilic (37 °C) temperature under plug flow mixing mode. At organic loading rate of 5 and 6 kg VS/m^3/d, the volatile fatty acids/alkalinity ratio ranged from 0.15 to 0.24 which indicated higher buffering capacity of digester. While at OLR of 9 kg VS/m^3/d, volatile fatty acids/alkalinity ratio of 0.94 was recorded. Daily biogas production and gas production rate were 196 L/d and 2.36 L/L/d respectively at OLR of 6 kg VS/m^3/d. However at loading rate of 9 kg VS/m^3/d, daily biogas production drastically decreased from 196 L/d to 136 L/d. Highest volatile solids removal of 82% was achieved at 5 kg VS/m^3/d. Biogas production, reactor stability and volatile solids removal efficiency decreased with increase in organic loading rate and decrease in hydraulic retention time.

Introduction

Food and agriculture waste management is one of the biggest challenges faced by many countries. According to Environmental Protection Agency of Pakistan, average municipal solid waste generation rate is 0.613 kg/capita/d and 90% of total household waste is biodegradable (PEPA, 2005). Similarly, huge quantities of agricultural waste are also produced in Pakistan, of which rice husk production is about 1.78 million tons annually (Mirani et al., 2013). Improper management of food and agricultural waste is a major source of environmental pollution all over the world. Food waste is easily biodegradable due to high content of water and this is major reason for its unstable combustion in incinerator, production of bad odor and abundant leachate (Cheng and Hu, 2010), and emission of greenhouse gases (i.e. methane) in landfills (Liu et al., 2012). Methane traps 25 times more heat and its warming effect is 72 times higher as compared to carbon dioxide (IPCC, 2007). Therefore, there is a dire need for safe management of organic waste including food waste and agricultural waste. In this regard, anaerobic digestion has proven to be an environment friendly option (Liu et al., 2012).

However the main hindrance in anaerobic digestion of agriculture waste is slow biodegradation rate because of its chemical composition and structure of ligno-cellulosic materials. On the other hand, anaerobic digestion of food waste alone is not feasible owing to its low C/N ratio and high biodegradation rate which results in digester failure in a very short period of time due to rapid production and accumulation of volatile fatty acids (Shen et al., 2013). Another problem associated with anaerobic digestion of food waste alone is the operational instability at high organic loading rates which inhibits methanogenesis (Zhang et al., 2012).

Anaerobic digester works efficiently when provided with the proper composition of feedstock. Optimum carbon to nitrogen ratio for anaerobic digestion is in the range of 25–30 (Okeh et al., 2014). The C/N ratio of food waste can be adjusted to optimum range by mixing it with another suitable organic waste prior to anaerobic digestion. This process of simultaneous digestion of multiple substrates is known as co-digestion. Apart from adjustment of C/N ratio, co-digestion also leads to dilution of toxic compounds. Moreover, it allows increased load of organic matter in digestion and missing nutrients also become available to microorganisms that results in high biogas yield (Zhang et al., 2012, 2013). Several

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studies have reported the co-digestion of food waste with other substrates. Kim and Oh (2011) reported that co-digestion of food and paper waste resulted in 79.8% volatile solids removal and a methane yield of 250 L CH_4/kg COD. Similarly, co-digestion of food, fruit and vegetable waste and dewatered sewage sludge resulted in gas production rate of 4.25 L/L/d at OLR of 6 kg VS/m^3/d (Liu et al., 2012). In the light of previous literature, it is suggested that if food waste is co-digested with some suitable organic waste, digester stability and higher biogas yield can be achieved (Liu et al., 2012; Zhang et al., 2012, 2013; Shen et al., 2013; Agyeman and Tao, 2014). However little information is available on co-digestion of food waste using rice husk as co-substrate.

In the present study, high solids co-digestion of food waste and rice husk was performed under mesophilic (37°) conditions because it requires smaller energy expense (Fernández et al., 2008), and higher solubilization of food waste is also related to this temperature (Komemoto et al., 2009). The specific objective of this research work was to investigate effectiveness of high solids anaerobic co-digestion of food waste and rice husk for biogas production without volatile fatty acids inhibition and to determine the effect of different organic loading rates on digester stability and performance.

Materials and methods

This research work was carried out in two phases, startup phase and continuous phase. For startup, reactor was operated in batch mode as well as at low organic loading rates (1–4 kg VS/m^3/d). After successful and stable startup, continuous phase of reactor was started in which it was operated at higher organic loading rates (5, 6 and 9 kg VS/m^3/d).

Experimental setup

Pilot scale single stage anaerobic digester was constructed and operated under plug flow mode. A horizontally placed stainless steel container having 79 cm length, 18 cm radius making 80 L total volume served as anaerobic digester. The digester was equipped with inlet and outlet valves for feeding and digestate withdrawal. There were two biogas valves on the top of digester, one of which was connected to the biogas meter through a pipe while other was kept spare. A schematic diagram of reactor design is shown in Fig. 1. Reactor was equipped with thermostatically controlled water jacket to maintain mesophilic temperature (37 °C).

Feedstock preparation

Food waste used in this study was collected from cafeteria of Quaid-i-Azam University, Islamabad, Pakistan and rice husk was obtained from a local rice huller. Food waste was collected in polythene bags every day for a period of one week and stored in refrigerator at 4 °C. Food waste consisted of food residues such as cooked rice, potato, vegetables, chicken and meat. The indigestible materials such as polythene bags, bones, plastics and egg shells were manually removed. It was then manually chopped to a size of about 10 mm and mixed to get a representative sample. The prepared food waste was then mixed with rice husk to get a C/N ratio of 28. Characteristics of individual substrates and feedstock mixture have been presented in Table 1.

Operating conditions

For startup, reactor was loaded with fresh cow dung to the working volume (80% of total volume) and was operated in batch mode for a period of 44 days. Once reactor stabilized with cow dung, it was then operated at low OLRs (starting from 1 kg VS/m^3/d through gradual increase to 4 kg VS/m^3/d in 20 days) to achieve stabilized conditions for digestion and biogas production. After startup and stabilization period, continuous loading phase of the reactor was started in which it was fed with the feedstock mixture at OLRs of 5, 6 and 9 kg VS/m^3/d one after another. The hydraulic retention time at OLR 5, 6 and 9 kg VS/m^3/d was 26, 25 and 14 days respectively. Operation or run time at each organic loading rate was almost double the retention time of its respective OLR (i.e. 27, 52 and 30 days), which is also equal to the number of replications for each OLR. During continuous loading phase, feeding with feedstock mixture and digestate withdrawal from reactor was performed on daily basis. Mesophilic temperature of 37 °C was maintained in the reactor throughout the study period. The total solids content of feedstock mixture was adjusted to 20% by addition of water.

Analytical methods

Digestate characteristics such as total solids (TS) and volatile solids (VS) were determined as per standard methods (APHA,

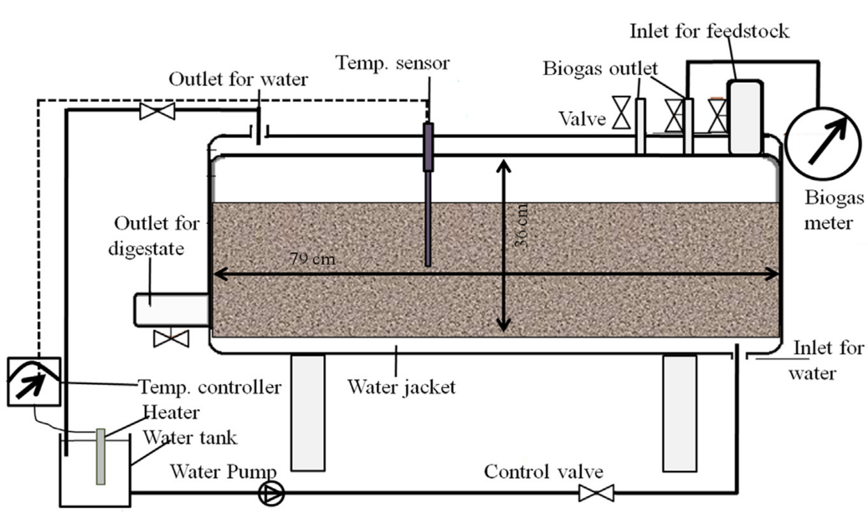

Fig. 1. Schematic diagram of anaerobic digester.