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Two-phase anaerobic digestion of vegetable market waste fraction of municipal solid waste and development of improved technology for phase separation in two-phase reactor

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ABSTRACT

Biogas production from vegetable market waste (VMW) fraction of municipal solid waste (MSW) by two-phase anaerobic digestion system should be preferred over the single-stage reactors. This is because VMW undergoes rapid acidification leading to accumulation of volatile fatty acids and consequent low pH resulting in frequent failure of digesters. The weakest part in the two-phase anaerobic reactors was the techniques applied for solid-liquid phase separation of digestate in the first reactor where solubilization, hydrolysis and acidogenesis of solid organic waste occur. In this study, a two-phase reactor which consisted of a solid-phase reactor and a methane reactor was designed, built and operated with VMW fraction of Indian MSW. A robust type filter, which is unique in its implementation method, was developed and incorporated in the solid-phase reactor to separate the process liquid produced in the first reactor. Experiments were carried out to assess the long term performance of the two-phase reactor with respect to biogas production, volatile solids reduction, pH and number of occurrence of clogging in the filtering system or choking in the process liquid transfer line. The system performed well and was operated successfully without the occurrence of clogging or any other disruptions throughout. Biogas production of 0.86–0.889 $m^3\ kg^{-1}$ VS, at OLR of 1.11–1.585 $kg\ m^{-3}\ d^{-1}$, were obtained from vegetable market waste, which were higher than the results reported for similar substrates digested in two-phase reactors. The VS reduction was 82–86%. The two-phase anaerobic digestion system was demonstrated to be stable and suitable for the treatment of VMW fraction of MSW for energy generation.

1. Introduction

Energy extraction from waste is one area which holds considerable promise for both developed and developing countries. India is a country with 1.21 billion population generating about 48 million tonnes of municipal solid waste (MSW) per annum (Sridevi et al., 2015). Unequal development, economic disparities among urban and rural population, and increased migration to the urban areas caused rapid population growth in the cities in India. All these factors have resulted in increased MSW generation in the Indian cities manifold. In 1997 quantity of MSW generated in India was only 23.5 million tonnes (Singh et al., 2011) which became more than double in the next 15 years. MSW in a city is mainly generated from residential areas, market places, commercial establishments and institutional organizations. The usual practice of disposal of MSW in India is either through poorly managed landfills or uncontrolled dumping in the low-lying areas outside the cities (Singh et al., 2011; Yap and Nixon, 2015). MSW is a heterogeneous material in which the composition varies widely. The average MSW composition in Indian cities has been shown in Table 1.

Indian MSW is typically high in biodegradable organics content at about 50% (Table 1) which is considerably higher than the MSW generated in the developed countries (Yap and Nixon, 2015). Market waste, mainly consisting of vegetable market waste, and household waste constitute the major portion of the biodegradable matter in Indian MSW. For example, MSW in Kolkata, fourth largest city in India with respect to solid waste generation, contains 36.37% market waste and the amount of market waste generation, mostly vegetable market waste, in the city was estimated to be 1090 tonnes per day (Hazra and Goel, 2009). Indian MSW is characterized by high moisture content (40–60%) and carbon to nitrogen ratio ranging from 20 to 30 (Sharholy et al., 2008). Both these factors favor high rate of biochemical decomposition of the waste by anaerobic digestion. Ministry of New and Renewable Energy, Government of India, has set a target of 1500 MW of power

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Table 1
Average composition of Indian MSW. Source: Yap and Nixon (2015).

Fraction	% on wet weight basis
Biodegradable	50
Inert	22
Recyclables	20
Other	8

generation from MSW through waste-to-energy (WTE) plants but only 2% of the potential has so far been realized (EAI, 2013). Incineration, pelletisation and anaerobic biomethanation are the technologies implemented under WTE which is relatively a new concept in India. Among these, biogas production by employing anaerobic biomethanation is the most promising (Bouallagui et al., 2003). Since the biodegradable fraction (vegetable market waste, household waste, etc.) of the MSW in Indian cities is high thus the potential for methane generation is also quite high. Attempts were made earlier (CMERI, 1990; Mandal et al., 1995) and later also under the WTE programme in India (Singh et al., 2011) for biogas production from the organic fraction of MSW through processing of the waste in large scale anaerobic digestion plants but encountered a number of setbacks in smooth and uninterrupted operation of the plants (Singh et al., 2011; Yap and Nixon, 2015). The anaerobic degradation of solid organic waste is a two-phase process: in the first phase, complex organic materials are degraded to short-chain volatile fatty acids (VFA) through solubilization, hydrolysis and acidogenesis, and in the second phase, acetate, hydrogen and carbon dioxide are converted into methane (Feng et al., 2008; Aslanzadeh et al., 2014). All these reactions occur simultaneously in a single rector where single-stage anaerobic digestion systems are employed.

In a two-phase reactor phase separation of the anaerobic digestion process is carried out by conducting the non-methanogenic reactions (solubilization, hydrolysis and acidogenesis) and the methanogenic reactions in two separate reactors which improves the process stability and overall efficiency of biochemical degradation of solid organic waste leading to high rate of methane generation and shorter time required for waste stabilization (White et al., 1989). Two-phase systems have the advantage of buffering the organic loading rate (OLR) in the first stage, allowing a more constant feeding rate to the methanogenic second stage (Ganesh et al., 2014). Simultaneous liquefaction along with acidification occurring in a two-phase system helps in handling waste with high solid content (Salomoni et al., 2011). Despite these advantages, the industrialists for anaerobic digestion of organic fraction of MSW prefer a one-stage process over the two-phase system because the later suffers more frequent technical failures compared to the former (Nasir et al., 2012).

Two-phase anaerobic digestion of solid organic waste is not a new concept and numerous studies, starting from 1978 to 2015, have shown relatively higher efficiencies of the two-phase reactors (Ghosh and Klass, 1978; Rantanatamskul et al., 2015). Performance of different two-phase reactors, reported in the literature, has been presented in Table 2. The reported studies mainly dealt with different configurations and combinations of acidification and methanogenic reactors, effect of higher loading rates, solid retention time, combination of mesophilic and thermophilic reactors, effect of higher pressure, etc. But the weakest part in the two-phase digestion technology is the technique employed for solid-liquid phase separation of digestate in the first reactor where solubilization, hydrolysis and acidification of solid organic waste occur, and subsequent transfer of the separated process liquid to the second reactor where methanogenesis occurs. Different phase separation techniques used for separation of process liquid from the first reactor and subsequent transfer of the liquid to the methane reactor were reported in the literature (Zwart et al., 1988; Gijzen et al., 1988; Ganesh et al., 2014; Aslanzadeh et al., 2014; Chen et al., 2014; Muha et al., 2013) but none has been found to be full-proof and robust for uninterrupted operation of two-phase reactors for longer period of time. All these studies were carried out either on laboratory scale or on a pilot scale. For separation of process liquid in the first reactor different separation techniques like micro-porous vertical filters (pore size 30–300 μm), horizontal screen, sedimentation tank, and centrifugation were tried. And for transfer of liquid from the first-phase reactor to the methane reactor mostly peristaltic pumps were used (Zwart et al., 1988; Hai-Lou et al., 2002). Severe choking in filter beds and clogging in liquid transfer line were the two most common problems faced by different researchers. For instance, Zwart et al. (1988) faced choking and clogging problem 38 times during 25 weeks experiment with two-phase reactor fed with cellulosic fraction of domestic refuse. Use of peristaltic pump is not practical if the two-phase anaerobic technology is intended to apply on a commercial scale. Development of a robust type phase separation technique is the key to successful implementation of two-phase digestion system for industrial scale exploitation of anaerobic treatment of solid organic waste for energy generation (Zwart et al., 1988; Aslanzadeh et al., 2014; Ganesh et al., 2014). Almost no study appears to have been reported on improvement of this separation technique. In this study, a two-phase reactor for anaerobic digestion of biodegradable fraction of MSW has been designed, built and operated in the laboratory for longer period of time. The developed two-phase digestion system consisted of a solid-phase reactor and a methane reactor. The uniqueness of the present study was the development of an effective technology for solid-liquid phase separation in the first reactor of the two-phase digestion system by incorporating a robust type filter in the solid-phase reactor. Experiments have been carried out to assess the long-term performance of the two-phase reactor for biogas production from vegetable market waste fraction of Indian MSW.

Table 2
Performance data for different two-phase reactor designs applied for biogas production from solid waste.

Solid waste/substrate	Process (Reactor volume)	OLR (kg m^{-3} d^{-1})	HRT (days)	Temp. (°C)	Biogas yield (m^3 kg^{-1} VS)	Efficiency VS_{RED}/ COD_{RED} (%)	% CH_4	Reference
VMW	Two-phase (2.5 l)	1.5	25	35	0.425	77.1	NR	Sridevi et al. (2015)
		4.5	25	35	0.721	82.9		
FVW	Two-phase (18 l)	7.5 kg COD m^{-3} d^{-1}	20	35	0.705	NR	64	Bouallagui et al. (2004)
			20	55	0.997	96	61	
FW + WS	Two-stage prototype (3500 l)	8.66 kg COD m^{-3} d^{-1}	24	Mesophilic	0.075 m^3 kg^{-1} COD	77.89/88.71	64.3	Rantanatamskul et al. (2015)
KR	Two-stage (30 l)	6	11	55	0.830	80	NR	Schober et al. (1999)

VMW: vegetable market waste, FVW: fruit and vegetable waste, FW: food waste, WS: sewage sludge, KR: kitchen refuse, OLR: organic loading rate, VS_{RED}: volatile solids reduction, NR: not reported.

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