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Biogas production from municipal solid wastes using an integrated rotary drum and anaerobic-phased solids digester system

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ABSTRACT

This research was conducted to develop an integrated rotary drum reactor (RDR)-anaerobic-phased solids (APS) digester system for the treatment of municipal solid waste (MSW) to produce biogas energy and achieve waste reduction. A commercial RDR facility was used to provide a 3-d pretreatment and sufficient separation of the organics from MSW and then the organics were digested in a laboratory APS-digester system for biogas production. The organics generated from the RDR contained 50% total solids (TS) and 36% volatile solids (VS) on wet basis. The APS-digester was started at an organic loading rate (OLR) of 3.1 gVS L^{-1} d^{-1} and operated at three higher OLRs of 4.6, 7.7 and 9.2 gVS L^{-1} d^{-1}. At the OLR of 9.2 gVS L^{-1} d^{-1} the system biogas production rate was 3.5 L L^{-1} d^{-1} and the biogas and methane yields were 0.38 and 0.19 L gVS^{-1}, respectively. Anaerobic digestion resulted in 38% TS reduction and 53% VS reduction in the organic solids. It was found that the total VFA concentration reached a peak value of 15,000 mg L^{-1} as acetic acid in the first 3 d of batch digestion and later decreased to about 500 mg L^{-1}. The APS-digester system remained stable at each OLRs for over 100 d with the pH in the hydrolysis reactors in the range of 7.3–7.8 and the pH in the biogasification reactor in 7.9–8.1. The residual solids after the digestion had a high heating value of 14.7 kJ gTS^{-1}.

1. Introduction

Municipal solid wastes are generated in increasing amounts and require innovative solutions to minimize their impacts on environmental quality and public health. For instance, in 2006, the United States generated 251 million tons of municipal solid wastes (MSW), an increase of 5% over 2000 level and 22% over 1990 level (US EPA, 2007). About 67% of the MSW was disposed in landfill and 33% was recycled and composted. The landfilled MSW contains a large fraction (more than 60%) of biodegradable materials (CIWMB, 2007) and presents increasing challenges for the waste management industry due to the problems of limited land availability and adverse environmental impacts of landfills with respect to gaseous emissions, and water pollutions from landfill leachate (Lewis et al., 2003). Meanwhile, the increasing energy prices and needs for reducing the consumption of fossil fuels have drawn increasing attention to the development of alternative technologies to produce renewable energy. Conversion of the organic wastes into energy and other valuable products is believed to bring many energy, environmental and public health benefits.

Various anaerobic digestion technologies have been widely used to convert biodegradable organic materials into methane-rich biogas fuel. A number of literatures reported the efforts on the anaerobic digestion of MSW. However, most of the recent activities used raw MSW or simulated organic fractions of MSW as the feedstock. For industrial scale process, separation of the organic fractions from MSW is often necessary prior to digestion processes because the non-biodegradable materials (e.g., metals, plastics, glass, and cloth) often result in operational problems such as clogging and lower process efficiency (Wise et al., 1981). The separation process helps the size-reduction and produces homogeneous organics. The separation is normally done either at the source where biodegradable waste (e.g., food and green wastes) are separately collected or at a materials recovery facility (MRF) where the biodegradables can be separated from the refuse in mixed MSW. Under certain circumstances, the separation of raw MSW via mechanical/biological means may be more efficient and cost-effective than source separation. The rotary drum reactor (RDR) process has been used for organic waste composting or providing pretreatment and separation of raw MSW prior to conventional composting operations (Eweson, 1991; Box, 2007; Hayes, 2004; Kalamdhad and Kazmi, 2008). In the RDR process, a rotary drum is used to break down the organic materials in MSW through a combination of aerobic biological reactions and mechanical forces,

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making them easily separable from the inorganic materials via a subsequent screening step. At present, most of the organic materials separated from MSW by commercial RDR processes are used for composting with little amount being tried for anaerobic digestion. Previous studies (Ghosh, 1987; Cho and Park, 1995; Ghosh et al., 2000; Pavan et al., 2000; Xu et al., 2002) have proved that the two-phase anaerobic processes can be operated at higher organic loading rate (OLR) and shorter retention time than single-stage process. The two-phase processes also showed higher bioconversion efficiency, system stability and biogas yields. Our recent research (Zhu et al., 2009) characterized the organic wastes produced by a commercial RDR facility with various treatment conditions and found that the RDR-pretreated organic waste were highly desirable as feedstock for anaerobic digestion. The research reported in this paper was carried out to evaluate the performance of an US patented anaerobic-phased solid-digester (APS) system (Zhang and Zhang, 2002a) fed with the biodegradable materials separated from raw MSW by RDR process to achieve biogas energy production and waste reduction. The results are useful for determining the integrated design and operating parameters for the scale-up and maintenance of a RDR-APS-digester system.

2. Methods

2.1. Organic waste pretreated by the RDR process

The organic waste recovered from the MSW by the RDR process in an existing MSW treatment plant in Arizona (Fig. 1) was tested in this study. In the waste treatment plant, raw MSW was collected from residential homes and processed through the RDR process, for which a rotary drum was operated as a plug-flow reactor with the length, inner diameter and rotation speed of 38 m, 3 m and 1 rpm, respectively. The MSW was loaded into the drum at 30 ton d^{-1} and retained for 3 d, moving continuously from the inlet to the exit. The partially degraded materials were continuously discharged from the drum exit. A blower near the exit provided fresh air into the drum in order to maintain aerobic conditions. Water was added when the MSW entered the drum to achieve about 55% moisture content. The heat produced by the microbial degradation of MSW allowed the drum temperature maintained at 45–68 °C. After leaving the drum, the treated MSW was screened through a trommel screen with 31.8 mm openings. The materials retained by the screen (mainly plastics, glass and metals) were directed to a landfill. The small particles which passed through the screen were mainly organic fractions. The organic recovery ratio of the RDR process was 56 ± 4%, which was calculated by dividing the wet weight of screened organics by the wet weight of raw MSW. The samples tested in this study were collected from the screened organic materials and shipped with packed ice via overnight mail to the Bioenvironmental Engineering Research Laboratory at University of California, Davis (UC Davis). They were analyzed for moisture content (MC), total solids (TS) and volatile solids (VS) by using the standard methods (APHA et al., 1998). The structural components and nutrients were also analyzed in the DANR Analytical Laboratory at UC Davis (ANR analytical lab, 2007) with analytical procedures described in the previous paper (Zhang et al., 2007). The analysis results are summarized in Table 1. The average TS, VS, VS/TS ratio and carbon/nitrogen ratio (C/N) were 50%, 36%, 0.72 and 26, respectively.

2.2. Anaerobic digestion experiments with APS-digester system

Based on the results of previous studies (Zhang and Zhang, 1999; Ghosh et al., 1997; Koster, 1984; Verrier et al., 1987), the APS-digester used in this experiment was recently developed for the high-rate digestion of solid wastes in a two-phase system. It consisted of four 1.4 L hydrolysis reactors (HRs) and one 2.0 L biogasification reactor (BR) with liquid recirculation between the HRs and BR (Fig. 2). Each HR was operated as a batch reactor with 12-d solids digestion time (SRT), while The BR was operated as a continuous anaerobic mixed biofilm reactor, fed with the liquid transferred from the HRs. Polyethylene Raschig-ring pellets (10 × 10 mm, 0.95 kg L^{-1} density) were suspended in 0.6 L of the BR to provide an extended surface area for microorganism attachment. The BR was mixed intermittently by a gas recirculation system and 3-d HRT. Mixing of the substrate in BR and liquid recirculation between HRs and BR were controlled by pumps and a time controller (Model XL, Chrontrol, San Diego, CA). The whole system was operated continuously by recharging one of the four HRs every 3 d. The temperature of all the reactors was maintained at 55 ± 1 °C in a temperature-controlled environmental chamber. The performance of the digester system was measured in terms of biogas and methane production rate and yield, solids reduction, and digester system stability.

The anaerobic digestion experiment was conducted in three periods. The first period was to inoculate the reactor and startup the digester system with a relatively lower organic loading rate

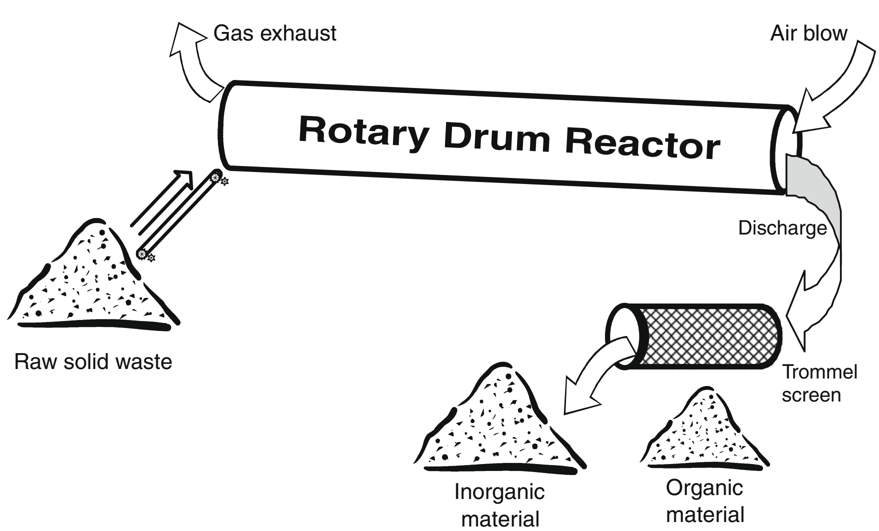

Fig. 1. Schematic of rotary drum reactor (RDR) process.