Ecological Engineering 87 (2016) 98–101

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng

Short communication

The performance and validation of an underground river reactor using compost energy as heat source

Qunpeng Cheng[a], Zhiquan Hu[a], Ravendra Naidu[b], Bo Xiao[a,*]

[a] School of Environmental Science and Engineering, HuaZhong University of Science and Technology, Wuhan 430073, PR China
[b] Cooperative Research Centre for Contamination Assessment and Remediation of the Environment, SA 5095, Australia

ARTICLE INFO

Article history:
Received 17 November 2014
Received in revised form 16 October 2015
Accepted 19 November 2015
Available online 1 December 2015

Keywords:
Compost
Heat source
Temperature
Biogas
Anaerobic digestion

ABSTRACT

The current study investigated the feasibility of using compost as the heat source of an underground river reactor. This study compared the effect of heat on the temperature of bioreactor, biogas yield and organic matter removal efficiency at different organic loading rates between TP group (heat by compost) and CK group (without heat source).The following results could be obtained: in TP group, a seasonal average temperature of bioreactor was 25.2 °C, 34.6 °C, 25.6 °C and 19.3 °C in contrary to average ambient temperature which was 20.2 °C, 32.4 °C, 22.5 °C and 9.8 °C respectively in spring, summer, autumn and winter. Compared with CK group, biogas production in TP group was increased by 49.49%, 55.29%, 67.69% and 106.5% and organic matter removal efficiency in TP group was increased by 7%, 22.3%, 14.74% and 11.37% respectively. Meanwhile, using compost as heat source not only saved energy consumption but also could get revenue from biogas by 34,560 US $ and fertilizer by 55,040 US $ per year on a scale of 1000 m^3.

1. Introduction

Anaerobic digestion is a series of complex process which breaks down organic matters in the absence of dissolved oxygen. It produces renewable energy (biogas), valuable digested residues, liquid fertilizer and soil conditioner for an added bonus. As a sustainable and economical technology, it is wildly used in the treatment of high strength organic wastes such as swine manure, crop straw, municipal solid waste and other waste.

While anaerobic digestion is highly affected by temperature which will make great influence on biogas yield and organic removal efficiency. Though a wide range of temperature is proven to be feasible for anaerobic digestion, only appropriate temperature can promise a high biogas production and organic matter removal efficiency (Umetsu et al., 1992). High temperature of anaerobic digestion can result in a substrate-degradation rate, specific growth rate and the rate of biogas production (Kim et al., 2006), but higher operational temperature (>35 °C) also means higher energy input for maintaining the temperature of reactor and it is also difficult to achieve such high temperatures especially in the subtropical and temperate zones. In China, there is an obvious seasonal change in temperature and there is also great difference between winter and summer. The temperatures in winter, which fall well below the mesophilic temperature, make great challenges for successful year-round use (Tamkin et al., 2015). Hence, for guaranteeing a successful year-round of bioreactor in order to get a considerable biogas production and organic removal efficiency, an extra heat source is required for the bioreactor. Currently, the common measures to supply an extra source of heat are hot water jacket (Mussoline et al., 2012), electric heating (Daniel and Masse, 2001), natural gas and biogas heating (Xu et al., 2010) and solar energy (Dong and Lu, 2013; Hassanein et al., 2015). Although those heating techniques can maintain the temperature of bioreactor and obtain a constant biogas production under low ambient temperature, they are neither energy-saving nor economical. Especially for a large scale biogas plant, the cost for digester heating will comprise a large portion of whole operating cost.

Compost is a bio-oxidative process involving mineralization and partial humification of organic matters and finally it leads to a stabilized product. During the process, a considerable amount of energy is produced. The energy produced during compost using wheat straw is approximately 17.6 MJ/kg of organic substance (Stainforth, 1979), while the energy produced during composting using poultry droppings to 12.8 MJ/kg of organic substance (Sobel, 1983). And the energy produced during compost with municipal waste ranges from 9 to 11 MJ/kg of organic substance (Steppa, 1988). Utilization of energy produced by compost as the heat source for bioreactor can be an attractive method for energy-saving and economic effects.

* Corresponding author. Tel.:+86 13607137746.
E-mail address: xiaobohust@163.com (B. Xiao).

http://dx.doi.org/10.1016/j.ecoleng.2015.11.038
0925-8574/

This study was to validate the effectiveness of compost as the heat source and investigate the performance of an underground river reactor (UR reactor) which was surrounded by compost. Results from this study will help to cut down the energy consumption and increase the output of anaerobic digestion where this design is used.

2. Material and methods

2.1. UR reactor (underground river reactor)

UR reactor is a new type of reactor which changes the traditional vertical bioreactor into horizontal structure (Fig. 1). Hydrodynamic behavior on the fragment of UR reactor is nearly completely mixed flow; while on the horizontal direction, it perforated a plug-flow pattern. It is a combination of completely mixed flow and plug-flow. The reactor was a rectangle tank constructed by stainless steel with a capacity of 0.12 m^3. The specific dimensions were as follows: the length was 1.5 m, the width was 0.2 m and the height was 0.4 m. The reactor was covered all around except the bottom by the compost using a mixture of piggery manure and straw stalk at the ratio of 1:1 as the raw material. The compost was 2.0 m length, 0.2 m width and 0.2 m height.

2.2. Methods

The experiments were carried out by two groups: TP group (heated by compost) and CK group (without heat resource, just under room temperature). Organic loading rate of piggery wastewater increased from 4.2 g/L to 9.0 g/L calculated by chemical oxygen demand (COD).

Temperature was measured daily. COD was analyzed according to the standard methods (APHA, 1995). Biogas was collected by a gas collecting bag and the volume was measured through drainage method. Biogas composition was determined with a gas chromatograph equipped with a thermal conductivity detector (TCD) and 5A molecular sieve column. The injector, detector and oven temperatures were 80 °C, 150 °C and 180 °C, respectively. Argon served as the carrier gas.

3. Results and discussion

3.1. Variation of temperature

The seasonal variation of temperature in UR reactor was shown in Fig. 2. *T*1, *T*2 and *T*3 were on behalf of the temperature of compost, UR reactor and the ambient respectively. The results showed that UR reactor can be kept warm well by compost, especially during the winter. The highest temperature of UR reactor were 35.4 °C, 40.8 °C, 29.8 °C and 28.6 °C, and the lowest temperature were 19.3 °C, 31.5 °C, 20.8 °C and 15.7 °C respectively in spring, summer, autumn and winter. The average temperature of UR reactor in spring, summer, autumn and winter was maintained at 25.2 °C, 34.6 °C, 25.6 °C and 19.3 °C respectively, compared to the ambient temperature 20.2 °C, 32.4 °C, 22.5 °C and 9.8 °C respectively. The effect of heat preservation was more obvious in the winter than in the other three seasons. Using compost as the heat firstly prevents heat exchange from bioreactor to the environment which makes the temperature of bioreactor not to be influenced by fluctuation of environment temperature; secondly, the energy produced during the compost can increase the temperature of bioreactor through heat transfer, even in the winter the temperature can achieve 20 °C or above.

3.2. Variation of COD and biogas production

Table 1 shows the results of organic matter removal efficiency and biogas production at different organic loading rates with 25 days HRT in the whole seasons. Whether biogas production or organic matter removal efficiency in TP group were both obvious higher than the CK group due to the differences of temperature. Biogas production in TP group was increased by 49.49%, 55.29%, 67.69% and 106.5% respectively compared with CK group. Organic matter removal efficiency in TP group was increased by 7%, 22.3%, 14.74% and 11.37% respectively. Meanwhile, an increase of temperature resulted in an increase of methane content (11.2% high in TP group relative to CK group). Although maximum biogas production (773.36 L) appeared at 9.0 g/L, maximum organic matter removal efficiency (79.10%) and maximum biogas yield (111.51 L/g COD_{added}) were obtained at 5.3 g/L. With increase of organic loading rate, biogas production increased a little with a decrease of organic matter removal efficiency, which indicated an overload of organic loading rate to the UR reactor.

3.3. The influence of temperature on degradation of organic matters

The effect of temperature on the organic matter degradation at different organic loading rates was analyzed using a first-order model developed by Grau et al. (1975).

$$S/S_0 = \exp\ (k_1 X_0 t/S_0) \quad (3)$$

where, S is the concentration of organic matter at any time (g-COD/L), S_0 is the initial substrate concentration (g-COD/L), k_1 is a first-order kinetic constant (d^{-1}), and X_0 is the initial concentration of microorganisms expressed as grams of volatile suspended solids per litre (VSS/L). All the organic matters were expressed by COD.

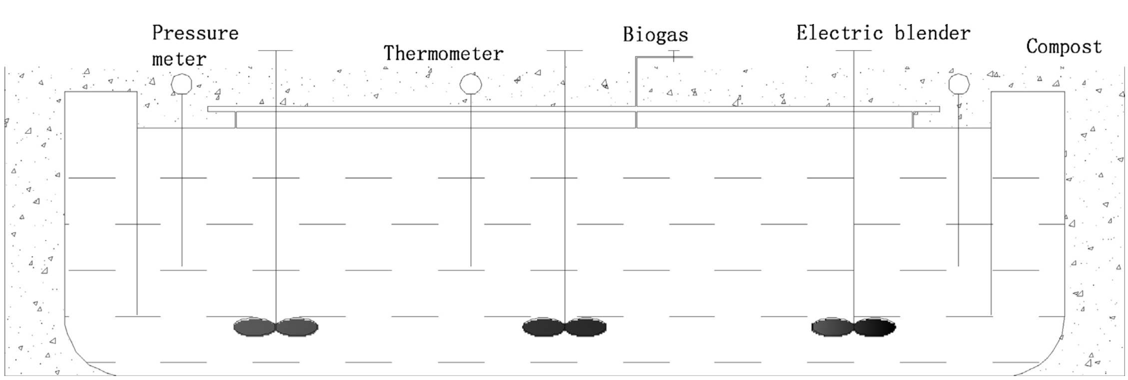

Fig. 1. Schematic diagram of UR reactor.