Bioresource Technology 124 (2012) 259–268

Contents lists available at SciVerse ScienceDirect

Bioresource Technology

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

Towards thermal design optimization of tubular digesters in cold climates: A heat transfer model

Thibault Perrigault [a], Vergil Weatherford [b], Jaime Martí-Herrero [a,*], Davide Poggio [c]

[a] Centre Internacional de Mètodes Numèrics en Enginyeria (CIMNE), Building Energy and Environment Group, Barcelona, Spain
[b] Building Systems Engineering, University of Colorado – Boulder, CO, USA
[c] Instituto para una Alternativa Agraria (IAA) – Cusco, Peru

HIGHLIGHTS

- Low-cost tubular digester are developed for cold climate.
- Thermal performance was analyzed by exhaustive temperature monitoring.
- A one-dimensional, time-dependent heat transfer model was developed.
- Solar gains, influent/effluent flows, ground temperature impact are considered.
- The model agrees with experimental within ±0.47 °C for slurry temperature.

ARTICLE INFO

Article history:
Received 14 June 2012
Received in revised form 2 August 2012
Accepted 6 August 2012
Available online 14 August 2012

Keywords:
Anaerobic digestion
Plug flow
Low-cost tubular digester
Thermal performance
Heat transfer

ABSTRACT

A cold climate, low cost, tubular digester is monitored and temperatures from different parts of the slurry, greenhouse, and adobe walls are presented, discussing the thermal performance of the digester. The slurry exhibits a vertical gradient of 6 °C, with a mean value of 24.5 °C, while the ambient temperature varies from 10 °C to 30 °C, showing the efficiency of the system as a solar heat collector with thermal inertia. A simple time-dependent thermal model is developed using inputs of solar radiation, wind velocity, ambient temperature, and digester geometry. The model outputs include temperatures of the slurry, the biogas, its holding membrane and the greenhouse air, wall and cover. Radiative, convective and conductive heat transfer phenomena are considered between all system elements. The model has 0.47 °C (2%) standard error for the average slurry temperature. This model can be used to predict the influence of geometry and materials on the performance of the digester.

1. Introduction

Anaerobic digestion (AD) of manure is a promising technology that provides both a clean energy source (biogas) and an enriched fertilizer while also improving environmental sanitation. These benefits make anaerobic digestion particularly suitable as a decentralized energy source for remote rural areas (Preston and Rodríguez, 2002; Velo, 2006).

The uses and benefits of AD at the household scale have been widely demonstrated in China and India where several million small-scale biogas plants have been installed over the last few decades and also—more recently—in Nepal (Bhattacharya and Jana, 2009; Gautam et al., 2009; Yu et al., 2008; Zhang et al., 2009). The digester models built have been predominantly fixed-dome (Chinese model) and floating-dome (Indian model) digesters usually constructed from brick masonry (Liming, 2009). However, without funding, the high labor and materials costs for these types of digesters usually prohibits the average farmer from building them. A cheaper and more easily constructed anaerobic digester is the plug-flow plastic tubular digester (PTD) (Botero and Preston, 1987), also known as the low-cost tubular digester, and construction costs are typically within reach of the small farmer.

In such plug-flow reactors, wastewater flows horizontally from one end to the other in a trench lined with tubular polyethylene or PVC sheeting, while biogas is collected from the headspace of the "bag" by means of a gas pipe connected to a reservoir (Ferrer et al., 2011).

Anaerobic digestion is a temperature sensitive process: average operating temperature affects the reaction rates of the process (Bohn et al., 2007), while temperature fluctuations can affect its stability (Alvarez and Liden, 2008). Traditionally, PTD digesters

* Corresponding author. Address: Centre Internacional de Mètodes Numèrics en Enginyeria (CIMNE), Building Energy and Environment Group, C/Dr. Ulles, 2, 3, 08224, Terrassa (Barcelona), Spain. Tel.: +34 937899169; fax: +34 937883110.
E-mail address: jaimemarti@cimne.upc (J. Martí-Herrero).

0960-8524/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.biortech.2012.08.019