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Comparison of the anaerobic digestion at the mesophilic and thermophilic temperature regime of organic wastes from the agribusiness

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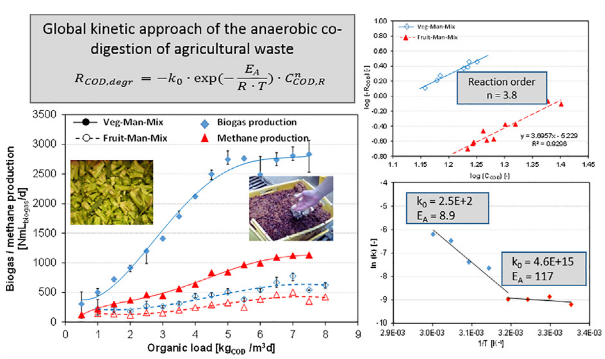
HIGHLIGHTS

- The rate of anaerobic digestion varies as function of organic load and temperature.
- A global power law model for mesophilic and thermophilic anaerobic digestion is presented.
- Activation energy and degradation rate are higher at thermophilic regime.

GRAPHICAL ABSTRACT



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ABSTRACT

An overall kinetic power law model has been successfully applied to study the anaerobic digestion of agricultural wastes. In this comparative kinetic study feed composition, organic load rate, residence time and process temperature have been systematically varied in an automated semi-continuous fermentation system to obtain the dependency of the rate of degradation as biogas production on the organic load rate and temperature.

The results show that the overall reaction order depend only on the Chemical Oxygen Demand (*COD*) at values between 3.6 and 3.7. The Arrhenius approach shows a shift in the rate determining step between the mesophilic and thermophilic temperature regimes. The activation energy at the temperature insensitive mesophilic regime is very small at 8.9 (kJ/mole), while the activation energy at the temperature sensitive thermophilic regime lies around 117 (kJ/mole).

1. Introduction

The search for new energy sources has encouraged investors, researchers and costumers to look for new technologies to utilize the energy contained in water sources (hydro), sunlight (solar), or wind (Manzano-Agugliaro et al., 2013; Romo-Fernández et al., 2012). Also the residual biomass can be considered a renewable energy source, which is the organic material produced by photosynthesis. The advantage of biomass, compared to the other mentioned renewable energy sources, is that the energy contained in it can be stored, transported or transformed into gaseous, liquid or solid fuels (Naik et al., 2010; Saxena et al., 2009). The biomass energy can be used in thermal combustion processes or biochemical conversions. It can be distinguished between first or second

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generation fuels, where first generation biomass energy is obtained mainly from specialized energy crops (Saxena et al., 2009). Second generation biomass energy is being developed and implemented all over the world. These energy sources are obtained from residues of previous agro-industrial processes, forestry or from separated municipal waste collection system (Chandra et al., 2012; Naik et al., 2010). The second generation biomass not only reduces the amount of primary energy sources, but also reduces the problems related to the waste management of organic residues like lixiviates of organic loaded waters, emission of greenhouse gases that generate from their inappropriate degradation, and the appearance of insects and vectors that can spread out diseases and contamination (Scano et al., 2014).

The agribusiness produces huge amounts of waste. More than half of the biomass produced for the agribusiness result as organic wastes that need to be handled appropriately for example applying anaerobic digestion (Mata-Alvarez et al., 2000; Naik et al., 2010; Saxena et al., 2009; Ward et al., 2008). The industrialization of the agricultural products has generated new challenges for the food industries and for the local governments, responsible for the local waste management, in developing countries. The huge amounts of residual biomass obtained during the processing of raw materials must be treated prior to its disposal, especially because of the high organic loads and increased leaching potential of the humid residues. For these reasons, in the agribusinesses integrated solutions utilizing anaerobic digestion are being designed for the internal management of the wet organic wastes and as a source of renewable energies.

Anaerobic digestion has been widely used for the production of biogas from organic wastes. Different digester designs have been developed for rural or industrial applications, varying from low cost tubular digesters (Martí-Herrero et al., 2014; Perrigault et al., 2012) to high-rate UASB (Djalma Nunes Ferraz Junior et al., 2016; Song et al., 2010), multiple stages digesters (Borja et al., 2005; Ward et al., 2008) or hybrid reactors (Ward et al., 2008). Many investigations are being conducted toward the optimization of the different operational parameters, like temperature (Meng et al., 2016; Montañés Alonso et al., 2016), dry matter content (Fernández-Rodríguez et al., 2013; Kothari et al., 2014), organic load rate (Cheng et al., 2016; Di Maria and Barratta, 2015), or hydraulic residence time (Demirel and Scherer, 2008; Ho et al., 2013). Also a wide variety of wastes have been studied, ranging from wastewater (Siles et al., 2008; Song et al., 2010) or waste-activated sludge (Appels et al., 2008; Wu et al., 2016), through pure animal manure (Wang et al., 2016; Zhou et al., 2016), agricultural wastes (Chandra et al., 2012; Ward et al., 2008) and co-digestion (Di Maria and Barratta, 2015; Montañés Alonso et al., 2016). Also the complex metabolic pathways of different microbial communities are being investigated at varied fermentation conditions. The main microorganisms involved during the anaerobic digestion, especially the methanogenesis, are being studied thanks to development in new fingerprinting techniques (Demirel and Scherer, 2008; Ho et al., 2013; Liu et al., 2016; Maspolim et al., 2015).

With the aim to understand the physical, chemical and biochemical processes taking place during anaerobic digestion, many different models have been established. One of the most complete models include the ADM1 model developed by the IWA research group which consists of a complex model including a series of physical – chemical and biochemical dynamic state variables (Batstone et al., 2002). This model has been used directly or by simplification in many investigations (Cheng et al., 2016). Other less complex models include first order kinetics (Siles et al., 2008), Monod equation applied for modelling acidogenesis and methanogenesis steps (Mani et al., 2016; Nopharatana et al., 2007), or Michaelis – Menten equation used to model organic matter decomposition, total volatile acids consumption and methane production (Borja et al., 2005; Fernández et al., 2010). These models describe anaerobic digestion very accurate. But for scale up and design purposes an overall power law kinetic model can result very handful, since no reaction mechanism is required to estimate digester volume, biogas production, degradation rate or feed flow rate. When applying an overall power law kinetic model, the reactor volume and the expected biogas production can be calculated from the rate of degradation, which is described as the amount of organic material degraded into biogas and is a function of the concentration of organic material available in the reactor. The best expression suited for these calculations is a power law model as presented in this study.

Also the effect of different operational conditions is of interest for design purposes. Especially for the evaluation of the benefits of operating at a thermophilic versus a mesophilic temperature regime, where biogas production and degradations rate increase (Cavinato et al., 2013; Micolucci et al., 2016; Suryawanshi et al., 2010). Therefore, an Arrhenius approach has been used to evaluate the change in the activation energy observed during the shift between the mesophilic and the thermophilic temperature regime.

In this paper the overall kinetic parameters of the anaerobic digestion process of the organic waste from fruit and vegetable processing industries will be obtained in laboratory continuous stirred tank digester (CSTR). A shift between the mesophilic and the thermophilic temperature regimes is studied by the classical Arrhenius approach. The maximum biogas production and the kinetic parameters are obtained by controlling different operational parameters, such as feed composition, temperature, pH value and residence time.

2. Materials and methods

2.1. Raw material selection and inoculation

In this study two different sources of organic wastes from local agribusinesses are studied. In first place the residues from the freezing process of broccoli heads, a vegetable from the cabbage family (*Brassica oleracea*), is investigated. These residues are obtained from the company *ECOFROZ S.A.* and consists of the stalks and imperfect flower heads of the broccoli. The mean composition of broccoli is 89% of water, 7% of carbohydrates, mainly fiber and sugar, 3% protein and 0.4% lipids (USDA, 2017). Second the residues from the fruit processing company *Latinoamericana de Jugos S.A.* are used. The main fruit wastes consists of shells, rinds, seeds and fibers of typical tropical fruits such as blackberrys (*Rubus fruticosus*), soursops (*Annona muricata*), naranjillas (*Solanum quitoense*) and tree tomatoes (*Solanum betaceum*). The mean composition of these wastes cannot be established as for broccoli, since they come from different parts and types of fruits. But according to the USDA the mean composition of the applied fruits consist of 81–93% water, 4–16% carbohydrates, mainly sugars, and low quantities of protein and lipids (USDA, 2017).

Both residues are being co-digested with fresh cow manure. The properties and textures of the pure raw materials are unique. The fruits residues consist mostly of seeds and stalks with a high water content, while the broccoli contain heads and stalks. The cow manure has been collected in solid form and diluted in water until a bendable sludge was formed. After collection, the residues are chopped and shredded until a homogeneous sludge is formed. As it can be observed in Table 1 once the residues are shredded and blended, their sum parameters are similar

For the startup of the anaerobic digestion process inoculum from the anaerobic digestion pilot plant from the Institute for Development of Alternative Energies and Materials (*IDEMA)* at USFQ has been used. This inoculum is extracted from the reactor