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Review

Bioreactor performance in anaerobic digestion of fruit and vegetable wastes

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Abstract

This work reviews the potential of anaerobic digestion for material recovery and energy production from fruit and vegetable wastes (FVW). These wastes contain 8–18% total solids (TS), with a total volatile solids (VS) content of 86–92%. The organic fraction includes about 75% easy biodegradable matter (sugars and hemicellulose), 9% cellulose and 5% lignin. Anaerobic digestion of FVW was studied under different operating conditions using different types of bioreactors. It permits the conversion of 70–95% of organic matter to methane, with a volumetric organic loading rate (OLR) o f 1–6.8 g versatile solids (VS)/l day. A major limitation of anaerobic digestion of FVW is a rapid acidification of these wastes decreasing the pH in the reactor, and a larger volatile fatty acids production (VFA), which stress and inhibit the activity of methanogenic bacteria. Continuous two-phase systems appear as more highly efficient technologies for anaerobic digestion of FVW. Their greatest advantage lies in the buffering of the organic loading rate taking place in the first stage, allowing a more constant feeding rate of the methanogenic second stage. Using a two-stage system involving a thermophilic liquefaction reactor and a mesophilic anaerobic filter, over 95% volatile solids were converted to methane at a volumetric loading rate of 5.65 g VS/l d. The average methane production yield was about 420 l/kg added VS.

Keywords: Fruit and vegetable wastes; Anaerobic digestion; Limitation step; Bioreactors performance

1. Introduction

Fruit and vegetable wastes (FVW) are produced in large quantities in markets, and constitute a source of nuisance in municipal landfills because of their high biodegradability [1,2]. In the central distribution market for food (meat, fish, fruit, and vegetables) Mercabarna (Barcelona), the total amount of wastes coming from fruit and vegetables is around 90 tonnes per day during 250 days per year [3]. The whole production of FVW collected from the market of Tunis (Tunisia) has been measured and estimated to be 180 tons per month [4]. In India, FVW constitute about 5.6 million tonnes annually and currently these wastes are disposed by dumping on the outskirts of cities [5].

The most promising alternative to incinerating and composting these wastes is to digest its organic matter using the anaerobic digestion [4,6]. The main advantage of this process is the production of biogas, which can be used to produce electricity [3,7,8]. A valuable effluent is also obtained, which eventually can be used as an excellent soil conditioner after minor treatments [9,10]. High organic loading rates (OLR) and low sludge production are among the many advantages anaerobic process exhibit over other biological unit operations [11,12].

The successful application of anaerobic technology to the treatment of solid wastes is critically dependent on the development and use of high rate anaerobic bioreactors [13,14]. The reactor design has a strong effect on digester performance [15]. In recent years, a number of novel reactor designs have been adapted and developed allowing a significantly higher rate of reaction per unit volume of reactor [16,17]. Different anaerobic processes, such as batch, continuous one-stage, and continuous two-stage systems, with a variety of methanizers like, continuously stirred tank reactor (CSTR), tubular reactor, anaerobic sequencing batch reactor (ASBR), upflow anaerobic sludge blanket

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(UASB) and anaerobic filters have been applied to FVW treatment. These processes differ especially in the way the microorganisms are retained in the bioreactor, and the separation between the acidogenic and the methanogenic bacteria which reduce the anaerobic digestion limitations. Methanogenic bacteria may have long mass doubling times in anaerobic reactors and this makes it very difficult to obtain fast acting reactors without retaining most of the biomass normally washed out with the effluent [18,19].

The aim of this paper was to review the energetic potential of FVW and to examine the performance of several groups of anaerobic bioreactors used for anaerobic digestion of these wastes.

2. Characteristics of FVW and anaerobic digestion limitations

The putrescible FVW used in overall reported studies were collected from food markets and Table 1 shows the most important constituents of FVW in three works where anaerobic digestion was operated [1,20,21]. The total initial solid concentration of FVW is between 8 and 18%, with a total volatile solids (VS) content of about 87%. The organic fraction includes about 75% sugars and hemicellulose, 9% cellulose and 5% lignin [20]. The easy biodegradable organic matter content of FVW (75%) with high moisture facilitates their biological treatment and shows the trend of these wastes for anaerobic digestion [1,21]. However, complex vegetable processing effluent, such as olive mill wastes containing large amounts of phenolic and non-biodegradable compounds are resistant to biological degradation [22]. Aerobic processes are not favoured for FVW treatment because they require preliminary treatment to minimise the organic loading rate [23]. The COD/N ratio of FVW is balanced, being around 100/4 and therefore, no nitrogen was added to the reactors. In fact the optimum C:N ratio for microbial activity involved in bioconversion of vegetable biomasses to methane is 100–128:4 [24].

Before being loaded to the reactors, FVW must undergo some pre-treatments [5,9]. They were shredded to small particles and homogenized to facilate digestion. They were also diluted to decrease the concentration of organic matter and then to operate the reactors with optimal organic loading rate [3,4]. Due to the lower pH of FVW, some authors buffered these waste by the addition of sodium hydroxide solutions [5,6]. Without any regulation, the pH quickly decreased and tended to inhibit the methanogenic bacteria [20]. Converti et al. pre-treated organic matter of FVW at high temperature to improve the efficiency of their anaerobic digestion [9], while Srilatha et al. pre-treated orange processing waste by solid state fermentation using selected strains of *Sporotrichum*, *Aspergillus*, *Fusarium*, and *Penicillium* to improve biogas and methane productivity at higher OLR [5].

The biomethanation of FVW is accomplished by a series of biochemical transformations, which can be roughly separated into four metabolic stages [25,23] (Fig. 1). First, particulate organic materials of FVW like cellulose, hemicellulose, pectin, and lignin, must undergo liquefaction by extracellular enzymes before being taken up by acidogenic bacteria [26]. The rate of hydrolysis is a function of factors, such as pH, temperature, composition, and particle size of the substrate and high concentrations of intermediate products [27,28]. After that, soluble organic components including the products of hydrolysis are converted into organic acids, alcohols, hydrogen, and carbon dioxide by acidogens. The products of the acidogenesis are then converted into acetic acid, hydrogen, and carbon dioxide. Finally, methane is produced by methanogenic bacteria from acetic acid, hydrogen, and carbon dioxide as well as directly from other substrates of which formic acid and methanol are the most important [28].

In general, hydrolysis is the rate limiting step if the substrate is in particulate form [29,30]. However, the anaerobic degradation of cellulose-poor wastes like FVW is limited by methanogenesis rather than by the hydrolysis [31,32]. These wastes, are very rapidly acidified to volatile fatty acids (VFA) and tend to inhibit methanogenesis when the feedstock is not adequately buffered [23]. In one-stage systems, all these reactions take place simultaneously in a single reactor, while in two-or multistage systems, the reactions take place sequentially in at least two reactors. In a

Table 1
Composition of different fruit and vegetable wastes

Wastes (g/kg)	Potato peelings	Salad waste	Green peas and carrots	Mixture of FVW	Mixture of FVW
Total solids	119.2	79.4	179.4	90.4	84.4
Volatile solids	105.5	72.1	171	82.9	77.5
Total COD	126	97.8	185	104.5	–
Particulate COD	80.6	39.3	123.9	–	–
Total suspended solids	80	39	145	–	58.6
Total Kjeldhal Nitrogen	–	–	–	2	2.7
Cellulose	12.9	13.5	16.1	9.2	–
Sugars and hemicellulose	–	–	–	62	–
Lignin	–	–	–	4.5	–
References	[21]	[21]	[21]	[20]	[1]