Energy recovery potential by utilising campus food waste in a biogas plant

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Abstract

Estimation of food waste generation represents the first step when considering the energy recovery through the anaerobic digestion. Food waste in universities is produced when students menus are prepared and from leftovers. The estimated food waste daily production from the main university campus canteen in Aristotle University Thessaloniki, Greece, was ranged between 319 and 359 kg. The maximum food wastage during preparation was comprised by cabbage, peeled potatoes and onion and it was 44% w/w of total estimated food waste, while the rest quantity of 56% w/w was mainly leftovers. Aim of this manuscript was the overview of the main constraints and prospects of energy recovery from food waste generated in the main university campus canteen. A literature review took place for evaluating the energy recovery through the anaerobic digestion process of the food waste mentioned above and the potential for their utilization in a biogas plant was assessed.

Keywords: Food waste, campus, biogas

1. Introduction

Actions launched in 2016, for the evaluation of the perspectives of material and energy recovery from food waste in the Aristotle University of Thessaloniki campus (Figure 1). Food waste represents a significant proportion of organic material found in residential waste. It can be either postconsumer, originating from residential and commercial kitchens (i.e., restaurants and hospitals), or preconsumer, coming from distribution and retail agents (i.e., transporters and supermarkets). Food waste has a high moisture content, which can lead to the generation of leachate and odours during handling and processing (Environment Canada, 2013). During the recent years, project attempted to tackle the cumbersome issues inherent with food waste management in campus dining halls. As an example, Western Michigan University wanted to maintain its role as a leader in sustainability practices and this institution considered their waste reducing options (Merrow *et al*., 2012). In accordance with Bendici (2016), a single college student generated an average 64.4 kg of food waste per year, according to Recycling Works, a Massachusetts recycling assistance programme. Although food waste has been regarded as readily biodegradable because of its high volatile fraction (90 % of total solids), its hydrolysis reaction is still a rate limiting step (Prabhudessai, 2013). Parameters monitored during the study of anaerobic digestion of food waste were pH, solid content, chemical oxygen demand and biogas production. In anaerobic digestion systems, methane fermentation takes place within the pH 6.5 to 8.5 ranges and maximum gas production in the optimal range from 7.0 to 8.0 (Sugumar *et al*., 2016). pH beyond these level significantly negative impacts on the methane yield. The fall of pH during the first few days of digestion due to the high volatile fatty acids formation. Organic loading rate may affect biogas productions influent rate and methane concentration in a positive manner, where an increasing of it provides a better production either concentration or rate of biogas (Sugumar *et al*., 2016). Many universities have adopted anaerobic digestion. Ohio State University initiated the construction of a dry anaerobic digestion process in 2012 with a processing capacity of 30,000 t of agricultural and food waste per year. The system was expected to produce 7800 MWh of electricity every year. In Clarkson University, single and two-phase operations were compered at mesophilic operating conditions using a digester system consisting of three 5 m^3 reactors treating food waste generated daily within campus kitchens. The operation rate of the anaerobic digester was 2,461 L per day, while the benefits occurred were the following: i) 211 t of waste was diverted per semester, ii) 32,367 € saved per semester, iii) 19.7 trips were saved to the landfill and iv) 5,704 fewer kilometers were driven per semester. As far as the research of the anaerobic digestion of food waste is concerned, Dong *et al*. (2015) investigated anaerobic digestion of Chinese cabbage through a pilot-scale two-stage digester at a mesophilic temperature of 37 °C. Methanococcus and Methanosarcina served as the main methanogens in the anaerobic digester. Kafle *et al*. (2014) investigated the effect of the feed-to-microbe ratios on anaerobic digestion of Chinese cabbage waste generated from a kimchi factory. The predicted methane yield derived from the first-order kinetic model was in good agreement with the experimental results. Methane production of crop residues had been found to range between 0.19 ± 0.01 and 0.31 ± 0.01 L CH^4/g-VS for leaves of cauliflower (Brassica oleracea var. botrytis) and cabbage (Brassica oleracea var. capitata), respectively (Gunaseelan, 2004). Napa cabbage as waste feedstock was

Table 1. Waste from kitchen during meal preparation in campus.

Kitchen waste	Minimum production (kg/day)	Maximum production (kg/day)
Cabbage	25.0	50.0
Peeled potatoes	8.6	8.6
Onion	85.7	100.0
Total	119.3	158.6

used with spent coffee grounds for biogas production through anaerobic co-digestion by Kim et al. (2016). Cabbage, tomato, capsicum, bitter gourd, radish leaves, cauliflower leaves and fenugreek leaves mixed in appropriate proportions, as described previously was used as a substrate in the study of Gulhane et al. (2017) of microbial community plasticity for anaerobic digestion of vegetable waste in Anaerobic Baffled Reactor. Residues of Chinese cabbage, carrot, lettuce, apple, banana, and watermelon were contained in the food vegetable waste mainly Shi et al. (2016). Aim of the present manuscript was the evaluation of the prospects for implementing the anaerobic digestion process to food waste generated in the campus of Aristotle University Thessaloniki from peeling process and restaurant.

2. Materials and methods

2.1. Quantitative and qualitative data

Students from the School of Mechanical Engineering of the Aristotle University Thessaloniki recorded the residues level of food waste resulted from the peeling process and restaurants in campus during the winter of 2016. The daily production of food left-overs in the campus of the Aristotle University Thessaloniki was on an average of 140 kg waste from kitchen (during meal preparation- Table 1) and 200 kg from the leftovers in dishes, i.e. 340 kg in total of food waste.

2.2. Alternatives for energy recovery

The prospects for implementing the anaerobic digestion process to the above mentioned waste were detected. There were two major categories of anaerobic digestion systems used for processing food waste: wet (low-solids) systems (moisture content greater than 80%) and high-solids systems (moisture content less than 80%). There were subcategories within these categories based on specific moisture content ranges (Environment Canada, 2013). The prospects for the implementation of the anaerobic digestion in campus were the following:

- Six fix dome digester digesters (Figure 2). Despite the low cost (10,000 €), the main disadvantage of this alternative was the shortage of space in the campus.
- One ‘Flexibuster’ system which was a multi-award winning technology from SEaB energy that could be delivered to site ready for plug-and-play installation, and which could turn organic waste into energy right at the point where the waste was generated and the energy was required with a total cost of 350,000 € (Figure 3).
- Three continually stirred tank reactors, which is the most common configuration of wet (low-solids) digesters with a total cost of 90,000 € (Figure 4).
- One floating digester balloon with storage area.

By the anaerobic fermentation of the amount of 340 kg of food waste residues, 34 m^3 of biogas will be produced daily and 45 kWh of electric energy will be derived by its treatment. It is therefore reasonable that the annual recovered electricity will be 12.38 MWh (= 45 kWh/day x 275 days/year) and the yearly revenue expected will be 1.485,6 € (= 12.38 MWh/year x 120 €/MWh).

3. Results

Following a relative investigation that carried out, a pilot project of the total cost of 8,000 € of the floating digester for the anaerobic fermentation of 340 kg of food left-overs produced per day in the campus canteen of Aristotle University, was interest to be financed and in accordance with the net present value methodology could provide economic benefit by the end of the eighth year. The above mentioned cost could cover the equipment for size reduction of food waste and the following elements (Figure 3):

- One 50 m^3 floating digester balloon, which will have a life span more than 10 years and it will be suitable for kitchen waste.
- One 10 m^3 biogas storage balloon.
- One biogas pump 220 V AC.
- One biogas double burner stove.
- One desulfurizer (10 kg).
- Desulfurizer pellets.
- Biogas pipe fitting equipment.
- One biogas generator (5 kW).

The biogas that will be produced in the floating balloon will contain sulfureted hydrogen, which could be poisonous. Thus, the biogas should be treated in the desulfurizer tank, where the sulfureted hydrogen will be removed. The purified biogas then can be stored in the storage balloon and then it can be used for cooking, lighting or electricity generation (Figure 3).

4. Conclusions

Except for proceeds from the sale of 'green' electricity into the grid, other economic benefits that will be generated could be the avoiding of unnecessary costs for disposing food waste from the Municipality of Thessaloniki in the landfill of Mavrorachi (30-40 €/t), and the use or the sale of the residue resulting from the anaerobic digestion that can be used as soil improver to protect the quality of agricultural land.

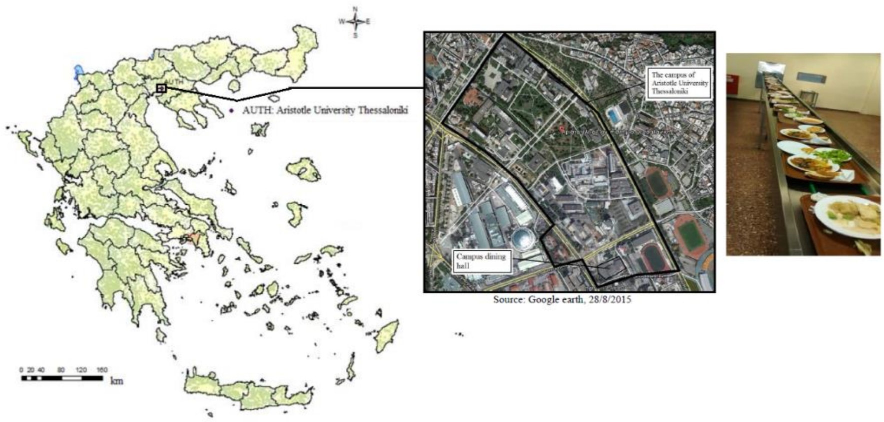

Figure 1. The campus and food waste from the dining hall

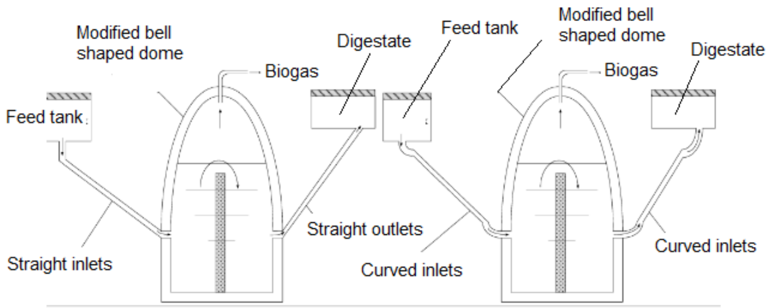

Figure 2. Schematic sketch of a modified fixed dome digester with straight and curved inlet and outlet tube (Rajendran *et al*., 2012)

Figure 3. Flexibuster system (available at: http://seabenergy.com/products/mb400/, 14/03/2017)

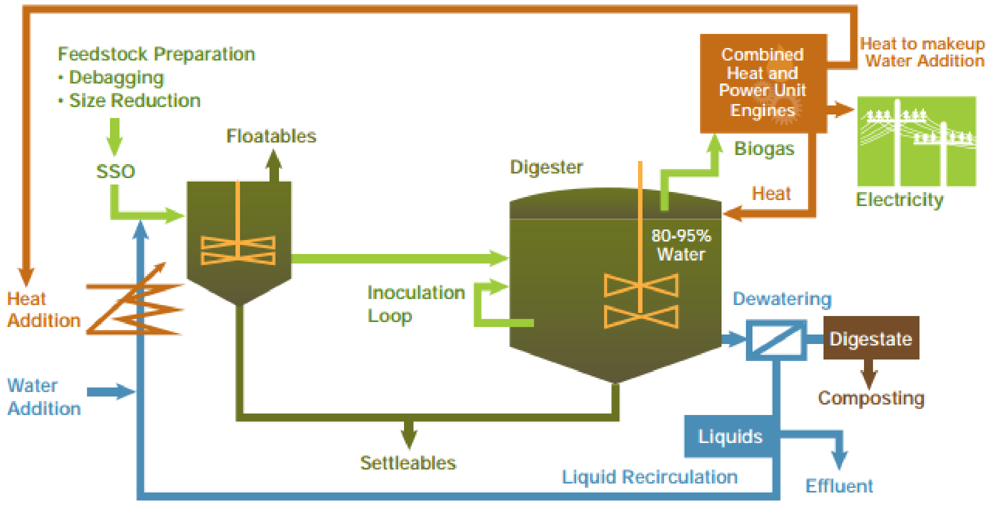

Figure 4. Typical complete mix continually stirred tank reactors wet (low-solids) anaerobic digestion process flow –SSO: Source-Separated Organics (Environment Canada, 2013)

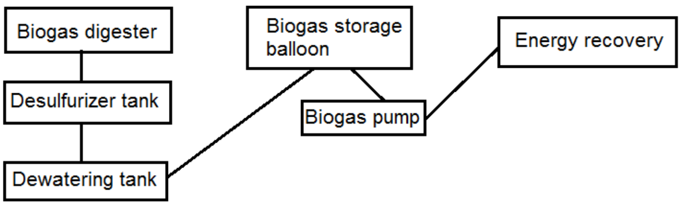

Figure 5. Flow diagram of recovered energy from biogas generated after the treatment of biowaste from campus dining hall

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