Considerations regarding the energy recovery from Cluj-Napoca wastewater treatment plant

Marius D. Roman

Technical University of Cluj-Napoca, Building Services Engineering Department, Cluj-Napoca, Romania. Corresponding author: M. D. Roman, Marius.ROMAN@insta.utcluj.ro

Abstract. The main aim of this research is to analyze the potential for energy recovery from Cluj-Napoca wastewater treatment plant by anaerobic digestion with biogas utilization. This manuscript uses data from the wastewater treatment plant and data presented by Burton equation. The results obtained from Cluj-Napoca plant indicates a biogas energy factor, between 0.092 to 0.133 kWh/m^3 which increases with increasing wastewater inflow. These energy recovery strategies could help offset the electricity consumption of the wastewater sector and represent possible areas for sustainable energy policy implementation.
Key Words: process optimization, energy conservation, wastewater treatment, biogas.

Introduction. Wastewater treatment represents 0.1 to 0.3% of total energy consumption and within local city and community government, water and wastewater treatment operations are often the largest consumer of energy (Kennedy 1997). Furthermore, energy for wastewater treatment is likely to increase in the future due to increasing population, stricter discharge requirements and aging infrastructure. Possible future standards for removal of currently-unregulated contaminants, such as pharmaceuticals and personal care products, might require significant increases in energy consumption at wastewater treatment plants (Westerhoff et al 2005; Stoica et al 2009).

Waste valorisation has been defined as the process of converting waste materials into more useful products such as chemicals, materials and fuels (Westerhoff et al 2005). Waste valorisation as a concept relies on the assumption that even after the intended use, the residue and waste still contain untapped polymeric substance that can be converted to either energy or other chemical forms. Such products make waste a valuable resource that should not be left unharnessed. This concept is currently being applied on both synthetic waste as well as biowaste and it is the basis of the current waste-to-energy (WtE) approaches (Gumisiriza et al 2017).

Waste-to-Energy (WtE), defined as the process of recovering energy in the form of either electricity and heat from waste (Bosmans et al 2013) applies the waste valorisation concept to generate renewable energy such as heat and biofuels (biogas, syngas and bioethanol). WtE technologies are categorised into two major groups:

- thermo-chemical processes comprising combustion, pyrolysis and gasification;
- biological processes comprising anaerobic digestion and bioethanol fermentation.

Thermo-chemical processes

Combustion. Unlike incineration and open combustion, thermo-chemical conversion technologies employ a series of chemical reactions occurring at different temperatures and may require partial oxidation as in gasification or proceed in the absence of oxygen as in pyrolysis. These conversion technologies are temperature depended and proceed through overlapping spatial and temporal stages of drying and degassing, pyrolysis and gasification and finally full oxidative combustion that turns the organic waste into ash (Koch et al 2015; Gumisiriza et al 2017).

Pyrolysis. Pyrolysis is the thermal degradation of organic material in the absence of oxygen. It occurs at relatively low temperatures (400-900°C). In pyrolysis, biomass is subjected to an optimal temperature of 700°C in the absence of oxygen resulting in the production of pyrolysis oil (biooil), char and synthesis gas (Syngas). Syngas is a mixture of majorly CO, CO_2, H_2, H_2O, CH_4, trace amounts of higher hydrocarbons such as ethane and propane, as well as various contaminants such as small char particles (Bosmans et al 2013; Di Maria et al 2016).

Gasification. Gasification is a partial oxidation of organic substances at elevated temperature (500-1800°C) to produce syngas. Biomass gasification occurs as the char reacts with carbon dioxide and water vapour (steam) to produce carbon monoxide and hydrogen (Gumisiriza et al 2017; Zhang & Li 2017).

Biological processes

Anaerobic digestion (AD). Is the anoxic biological decomposition of organic matter by a complex microbial ecosystem through parallel sequences of metabolic pathways involving different kinds of synergistic microbial trophic groups leading to the formation of methane and carbon dioxide (Gumisiriza et al 2009). The mixture of methane and carbon dioxide is referred to as biogas (Cirne 2006; Cirne et al 2007). Anaerobic digestion offers the opportunity to produce renewable energy and a higher quality of treatment for agricultural waste. The technology has recently become an attractive method in Europe for the biodegradation of organic fractions derived from municipal solid waste (Scarlat et al 2015; Liao & Li 2015). The AD process is driven by concerted action of highly varied microbial population, consisting of several groups of both strict and facultative bacterial strains. The process is carried out in well-designed recipient referred to as anaerobic digester. The entire system consisting of the feedstock, digester, biogas holder and digestate reservoir is called a biogas plant.

In AD, organic waste is fed to the process as feedstock and acted upon by microorganisms in the absence of oxygen (Iglesias et al 2000; Elango et al 2007) to produce biogas and bioslurry. The digestate (bioslurry) can be dewatered and converted through thermal conversion technologies into other forms of fuel including refuse-derived fuel (Figure 1). The remaining inorganic and the inert waste are either incinerated or gasified to generate more energy. Away from energy generation, the bioslurry can safely be used as biofertiliser in agricultural production.

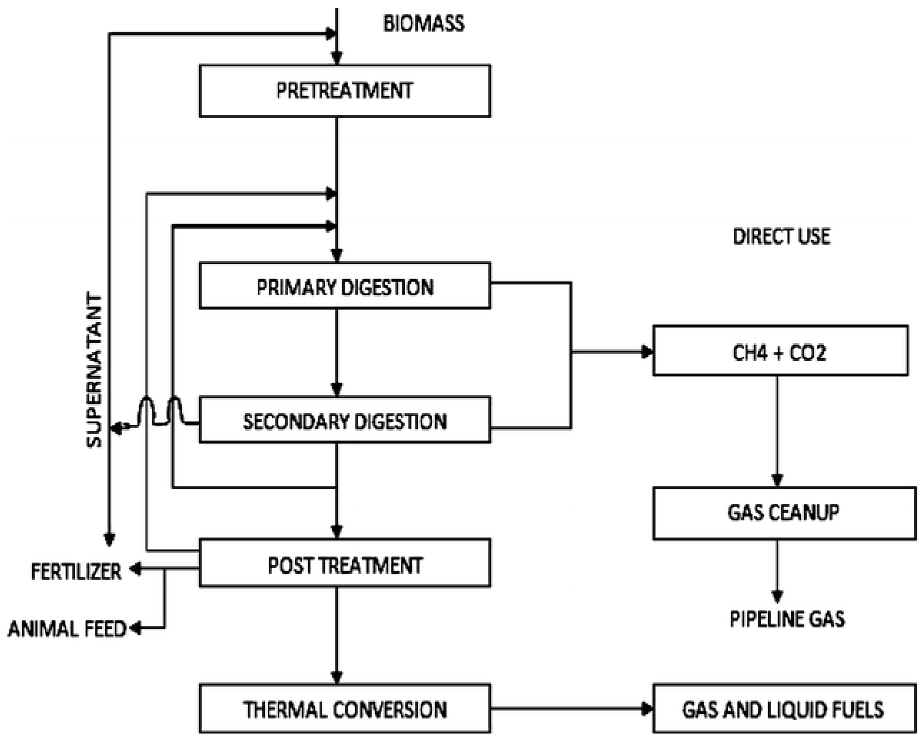

Figure 1. Scheme of anaerobic digestion (Tock et al 2010).

The advantages and disadvantages of anaerobic digestion, waste-to-energy technologies, are presented in Table 1.

Table 1
Advantages and disadvantages of anaerobic digestion (Gumisiriza et al 2017)

Advantages	*Disadvantages*
Energy recovery with the production of high grade soil conditioner	Unsuitable for wastes containing less organic matter
No power requirement for screening and turning of waste pile	Requires waste segregation for improving digestion efficiency
Enclosed system enables trapping the gas produced for use	
Controls Greenhouse Gas Emissions (GHG)	
Free from bad odour, rodent and fly menace, visible pollution and social resistance	
Compact design needs less land area	
Net positive environmental benefits	
Can be done in small scale	

The objective of this research is to analyse energy recovery potential from the wastewater treatment plant which includes anaerobic digestion with biogas utilization for the year 2017. Analysis and description of biogas plant was obtained from Cluj-Napoca wastewater treatment plant designed for 367.000 population equivalents.

Material and Method. Municipal wastewater treatment plant in Cluj-Napoca processes around 111.000 m^3/d of wastewater collected from urban and suburban areas. The wastewater treatment plant consumes electricity during operations, ranging from 0.177 to 0.779 kWh/m^3 but also has the potential to generate electricity through various energy recovery.

Analysis of energy recovery potential from the wastewater treatment plant was completed using anaerobic digestion with biogas utilization were based on data presented by Burton equation.

Anaerobic digestion process implemented in Cluj-Napoca wastewater treatment plant (WWTP) can be divided in four main stages:

Stage one: hydrolysis. During hydrolysis, the insoluble complex biopolymers such as polysaccharides, proteins and lipids are broken down into simple soluble monomeric biomolecules such as sugars, amino acids, fatty acids and glycerol. It should be noted that organic wastes are a complex mixture of mainly carbohydrates (starch cellulose, hemicellulose), proteins and lipids; with their relative concentrations being dependent on the nature and origin of the waste.

Stage two: acidogenesis. In acidogenesis, soluble monomers: simple sugars, amino acids, glycerol and fatty acids released from the hydrolysis stage, are biodegraded by fermentative organisms and anaerobic oxidisers to produce different organic acids.

Stage three: acetogenesis. Acetogenesis is the degradation of reduced fermentation intermediates from the previous stage, i.e. volatile fatty acids (VFAs) such as propionate and butyrate to acetate, carbon dioxide and hydrogen.

Stage four: methanogenesis. Methanogenesis is the biomethanisation step in which organic substrates: acetate, H_2/CO_2, methanol and formate, the end products of the acetogenesis, are converted into methane (Gujer & Zehnder 1983). Unlike in the previous stages, the microorganisms responsible for the methanogenic stage belong to the domain archaea and they produce methane as two major pathways: acetotrophic (or acetoclastic) and hydrogenotrophic methanogenic.

Results and Discussion. Analysis of energy recovery potential for WWTP using anaerobic digestion with biogas utilization was based on Clean Watersheds Needs Survey

(CWNS) data and biogas energy factors reported by Burton and Electric Power Research Institute (EPRI) (Burton 1996). Potential energy recovery was calculated using the equation:

$$ER_{anaerobic} = Q * BEF \quad (1)$$

where:
$ER_{anaerobic}$ represents energy recovery from anaerobic digestion (kWh/d);
Q - the wastewater flow rate (m^3/d);
BEF - the biogas energy factor (kWh/m^3).

Figure 2 presents potential energy recovery (kWh/d) from anaerobic digestion with biogas utilization at WWTP Cluj-Napoca and varies with the biogas energy factor, estimated for a BEF range of 0.092 to 0.133 kWh/m^3 and increases with increasing wastewater flow.

The WWTP from Cluj-Napoca using anaerobic digestion with biogas utilization can produce about 12.000 kWh of electricity for each 111.000 m^3/d of wastewater treated.

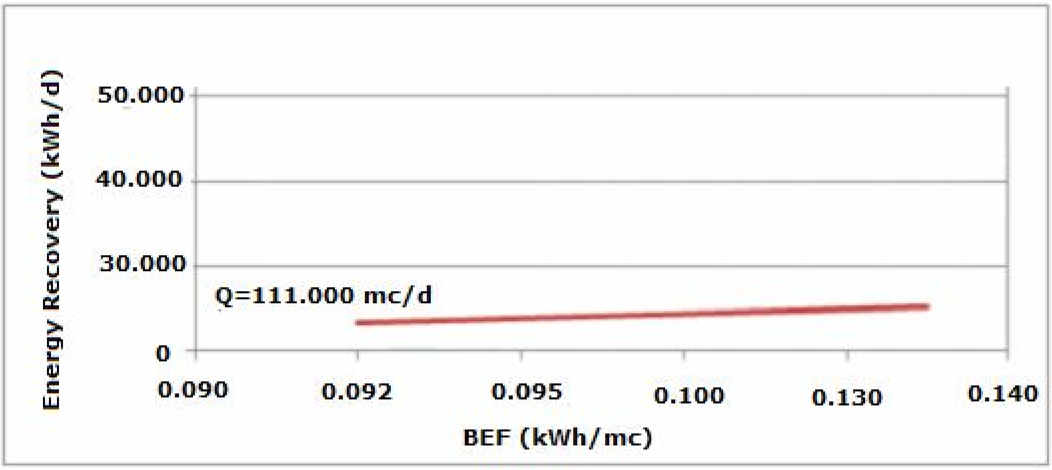

Figure 2. Energy recovery from anaerobic digestion.

Based on data from WWTP and equation 1, potential energy recovery from wastewater treatment plant was calculated for anaerobic digestion with biogas utilization with electricity generation. The results of these calculations are shown in Table 2.

Table 2

Energy recovery for year 2017

Case study	*Flow (million m^3/yr)*	*Calculated energy recovery (kWh/yr)*
WWTP by anaerobic digestion with biogas utilization	41.28	3.797-5.490

These energy recovery options have the potential to offset increases in electricity consumption necessary to uphold stricter wastewater treatment standards. Energy recovery from wastewater treatment plants presents an opportunity for successful and sustainable management of energy and water resources.

Anaerobic digestion processes, on the other hand, facilitate digestion in the absence of oxygen, forming methane-containing biogas and biosolids as products. Biogas produced from anaerobic digestion is a possible fuel source for digester heating or electricity generation. Anaerobic digestion produces about 35 m^3 of gas per day per person in the service area, which has a typical heating value of approximately 6.2 kWh/m^3 (CHP 2011).

Biogas also contains water vapor and small amounts of siloxanes and hydrogen sulfide, which must be removed before the biogas can be used as a fuel for electricity generation to prevent damage to the generation equipment (CHP 2011).

Electricity generation using biogas from anaerobic digestion varies depending on the generation technology employed. Research from Burton and the Electric Power Research Institute (EPRI) shows that anaerobic digestion with biogas utilization can produce about 350 kWh of electricity for each 3,790 m^3/d of wastewater treated at the plant.

Optimized anaerobic digestion occurs in two temperature ranges, mesophilic from 32 to 35°C, and thermophilic from 50 to 57°C, so digester heating might be necessary in some climates. In these temperature ranges, anaerobic digestion produces biogas containing 40 to 75% methane, with a balance of primarily carbon dioxide and other compounds, with 60% methane as a typical composition.

Conclusions. The interrelationship between energy and water and the organic content of wastewater can encourage energy recovery operations from many possible sources, including municipal wastewater treatment facilities. Implementing anaerobic digestion with biogas utilization can reduce electricity consumption for wastewater treatment by 2.6 to 14%.

These wide ranges in electricity percent savings for the wastewater sector are due to the difference in wastewater flows analyzed in this study. In this case, the low end represents use of existing energy recovery processes and the high end illustrates potential energy recovery from broad implementation of anaerobic digestion with biogas utilization.

These energy recovery options have the potential to offset increases in electricity consumption necessary to uphold stricter wastewater treatment standards. Energy recovery from wastewater treatment plants presents an opportunity for successful and sustainable management of energy and water resources.

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Received: 13 February 2018. Accepted: 12 March 2018. Published online: 30 March 2018.
Author:
Marius-Daniel Roman, Technical University of Cluj-Napoca, Building Services Engineering Department, Blvd. December 21, no. 128-130, 400604 Cluj-Napoca, Romania, e-mail: Marius.ROMAN@insta.utcluj.ro

How to cite this article:
Roman M. D., 2018 Considerations regarding the energy recovery from Cluj-Napoca wastewater treatment plant. Ecoterra 15(1):57-62.