A techno-economical case study of a thermophylic anaerobic digestion plant in Attica Region, Greece

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Abstract

Purpose: To present a techno-economical study of a possible thermophylic anaerobic biological degradation unit installation in Attica, which will manage 35600ton/y of fresh substrate of the source sorted organic fraction of solid municipal waste (SS-OFSMW).

Methods: The anaerobic digestion unit consists of a pre-processing step (screening with hands-cutting) and the main dry anaerobic biological treatment. Two designs are taken into consideration. In the first case (Case 1) the biogas unit consist of one bioreactor while in the second case (Case 2) the main anaerobic part relies on two bioreactors. Both cases operate at high organic loading rate (OLR).

Results: The thermophylic process can produce approximately 200m^3 of biogas per ton of fresh substrate. These results are consistent with large-scale studies in the European Union where it is produced 100-200m^{3}biogas/ton. The thermophylic anaerobic biological treatment unit will produce almost 14787 MWh/y. The investment cost of the aforementioned processing unit will be around 15 million euro for Case 1 and 10% higher for Case 2. The average annual operational cost of such a unit is amounted to 700,000 euro. The pay back of the investment will be around 5 years for Case 1 and 6 years for Case 2. (Eurozone recession rates and the economical crisis in Greece the last four years are taken into consideration).

Conclusions: By treating the 9.6% of annual organic waste production in Athens the 1.8-2.3% of Athens municipality electric energy demand can be covered.

Keywords: biogas, anaerobic digestion, thermophylic biodegradation, dry bioreactors, feasibility study

Introduction

The anaerobic biological degradation is the complex process of organic matter decomposition in the presence of microorganisms and in the absence of oxygen. The term biogas refers to the flammable mixture of gases produced by the anaerobic degradation. The mixture contains 55-65% methane, carbon dioxide and traces of other gases. Biogas has good calorific value and can be used directly as a fuel or indirectly for electricity generation [1][2].

The global population growth and life quality improving for the last 30 years has resulted in a corresponding increase in human waste, which must be removed safely without any negative impact on the environment. Anaerobic digestion has many advantages, such as minimizing mass and volume, neutralization of biological and biochemical processes to avoid odor and gas emissions in the next stages of waste management, reduction of landfill sites and produce energy in the form of biogas. So the anaerobic biological process of biodegradable part of waste is considered an alternative environmentally friendly method of waste management, while an important renewable energy source [3][4].

The dry substrate anaerobic digestion regards waste solids content higher than 15%. The organic fraction of municipal waste is treated by dry techniques. The technique of the dry substrate is advantageous in the reactor size, the lower energy requirements for heating the reactor and stirring the content. The last five years 63% of the facilities that were built are dry substrate anaerobic digestion units [5][6].

The thermophilic digestion was developed in the 1990s. The thermophilic operation results in approximately 50% greater organic matter decomposition, particularly with substrates rich in fats, better microbial activity and thus higher methane profit. Also in operation above 55 ° C for more than 23h, no further heating to destroy pathogens is needed. [3].

This paper consists of a techno-economically study of a possible thermophilic anaerobic biological degradation unit installation in Attica, which will manage 35600ton/y of fresh substrate of the source sorted organic fraction of solid municipal waste (SS-OFSMW). It consists of a pre-processing step (screening with hands-cutting) and the main dry anaerobic biological treatment. For the main anaerobic treatment unit two configurations are presented. The first configuration (Case 1) relies one bioreactor. The second configuration is designed so that it consists of two bioreactors. Both cases operate at high organic loading rate (OLR).

Materials and Methods

The situation of municipal solid waste in Attica

The largest percentage of Attica municipal waste still consists of biodegradable materials (46%) [7]. The composition of the organic fraction of municipal solid waste varies from food waste (vegetable waste and fruit peels) to garden waste (leaves and grass). The strategy for the collection of municipal waste affects the characteristics of urban waste, gain in methane and use (disposal in the fields or in landfills or combustion) of the digested residue. Changes occur in the composition of the source sorted organic fraction of municipal waste according to the season and the geographical location that is collected. In summer, for example, municipal waste containing large amounts of garden waste which reduces the gain in methane.
The organic fraction of municipal waste is categorized into mechanical sorted, source sorted and hand sorted. In Attica there is no policy to separate the organic fraction of municipal waste at source, as it happens in the European Union, although such approach is now under consideration. Nevertheless for the purpose of this study was assumed that the organic fraction of municipal solid waste consists of source sorted waste.

Design of the anaerobic digestion unit

It is assumed that the anaerobic biological treatment unit in Attica will manage an average of 100ton/d of fresh substrate from the source-sorted organic portion of municipal waste (household waste, food waste, garden waste), which will be collected and subsequently be led to the anaerobic treatment plant.
This facility includes:

•The pre-processing unit, where undesirable constituents will be removed with hand screening. The chopping of the organic fraction will follow and the end product will be fed to the bioreactor/s. The preprocessing step consists of a trench host (capacity 122-140m^3), gantry crane for transferring material from the trench in hand screening conveyor, shredder and a conveyor that will lead the product in the bioreactor/s (Fig.1).

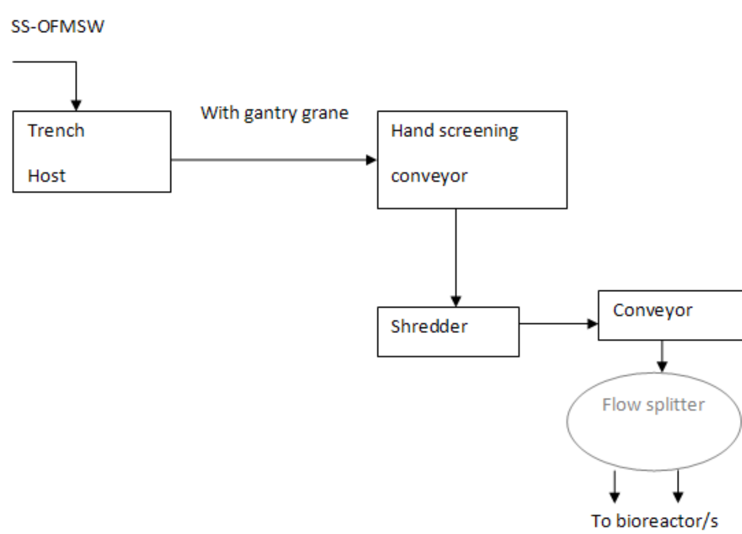

Figure 1: Pretreatment unit flowchart, the flow splitter (gray line) is for Case 2 where the anaerobic digestion unit is composed of two bioreactors

•The processing unit includes one or two bioreactors, where anaerobic treatment of the organic fraction of waste, biogas production and its use for electricity generation will take place. The anaerobic digestion unit will be supplied by the preprocessing unit. It will consist of:

Case 1: pumps mixing of substrate and recycling of leachate, one dry substrate bioreactor, biogas storage tank, and a heat and electricity generator (Fig. 2).

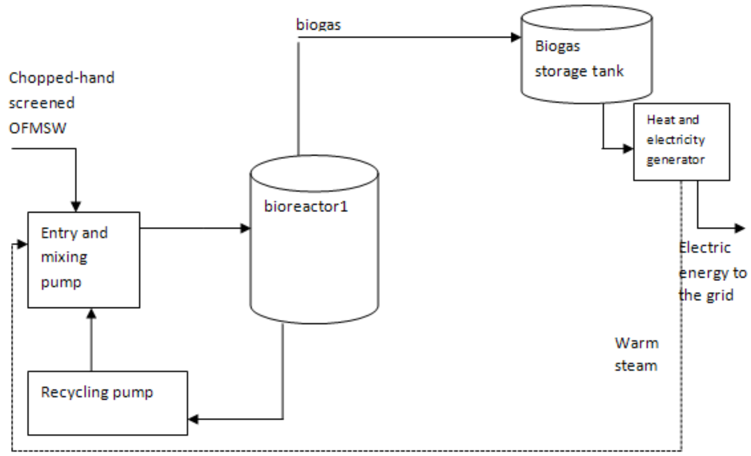

Figure 2: Schematic diagram of the anaerobic biological treatment plant, Case 1

Case 2: pumps mixing of substrate and recycling of leachate, two dry substrate bioreactors, biogas storage tank, and a heat and electricity production unit (Fig.3).

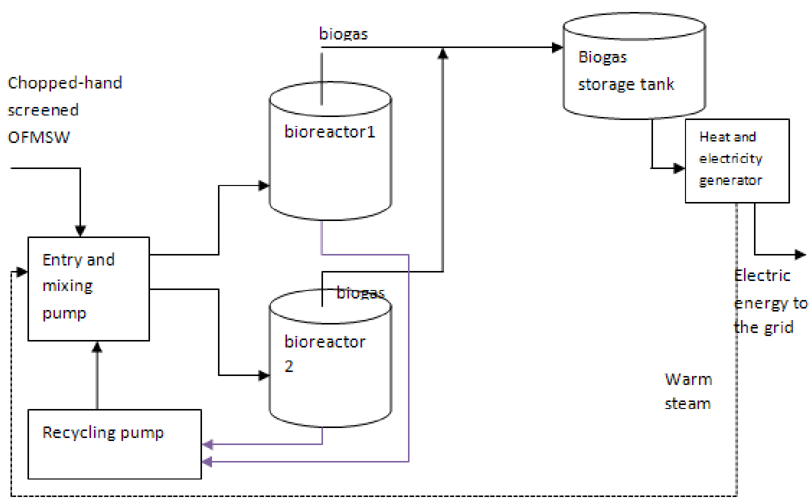

Figure 3: Schematic diagram of the anaerobic biological treatment plant, Case 2

Assumptions

The following assumptions were made for the thermophylic anaerobic digestion application:

1. The anaerobic biological processing unit will treat 36500 ton/y of fresh substrate of SS-OFSMW

2. The composition of SS-OFSMW will be 60-70% food waste with d_{fw}=0.75ton/m^3 and 40-30% garden waste with d_{gw}=0.3ton/m^3).

3. The average density of the substrate is d_s=0.86ton/m^3

4. Substrate with 35%TS and VS=78%TS

5. Methane potential: 0.44m^3CH_4/kgVS_{in} (STP)

6. First order kinetic model with constant k=1.6d

7. HRT=16d

8. Biogas methane content 56%

9. $T_{reactor}$=55^oC

10. $VS_{reduction}$=57%

11. Annual CHP operation hours 7500h/y

12. Methane value 10kWh/m^3

Results

In Table 1 the technical characteristics of the anaerobic digestion unit, for both Case 1 and 2 are presented.

Table 1: Technical characteristics of the proposed anaerobic digestion unit for both Case 1 and Case 2

Technical characteristics	**Case 1**	**Case 2**
Bioreactor capacity (m^3)	2326	1163 (x2)
Biogas storage tank capacity (m^3)	3251	
CHP power (MW)	2.5	

Table 2 shows input-output data of the thermophilic anaerobic biological process, which is going to treat 100ton/d of substrate with 35%TS. For Case 2 each bioreactor will treat 50ton/d so its input-output data is half the values presented in Table 2.

Table 2: Input-output data of the thermophilic anaerobic biological process that is going to treat 100ton/d of substrate with 35%TS

Effective capacity (m^3)	1861 (total 2326)
Mass input (kg/d)	100000
VS input (kg/d)	27300
TS input (kg/d)	35000
Biogas mass (kg/d)	26133

Methane mass (kg/d)	8268 (CO_2 around 17865)		
Output mass (kg/d)	73867		
TS output (kg/d)	19439 (to compost)		
VS output (kg/d)	11739		
Retention time (d)	16		
Loading rate (kgVS/m^3d)	11.7		
Biogas yield (average) (m^3/kgVS_{in})	0.76		
Methane yield (average) (m^3/kgVS_{in})	0.424		
Methane content (%)	56		
Methane volume (m^3/d) (STP)	11575		
Biogas volume (m^3/d) (STP)	20670		
CO_2 volume (m^3/d) (STP)	9095		
Methane value (kWh/m^3)	10		
Electric power efficiency (%)	35	Produced Electric power (kWh/d)	40513
Heat value efficiency (%)	50	Produced Heat (kWh/d)	57875
Losses %	15		

Discussion

The choice of a first order kinetic model [8] was based on its simple and easy application. Also the first order model is used in the case of complex substrate like the case of the organic fraction of municipal waste and dry anaerobic biological degradation. The first-order constant for thermophilic applications has been calculated by Cecchi et al [9][10] for the three categories of municipal waste in the early 1990s. The assumption on the maximum theoretical gain in methane or the ultimate methane production B_o was based on the study of Davidsson et al [11] taking into account that there will be a portion of garden waste and paper on the source sourted organic fraction of municipal waste. Both garden waste and paper decrease methane production.
The assumptions were based on real large-scale experiments conducted in Italy and Spain [8][12][13], and we believe that nutritional conditions and culture that have Greeks, Italians and Spanish are similar.

90% of the european full scale anaerobic digestion plants treating OFMSW rely on one-stage system, mostly because of it's simpler design, which suffers less frequent technical failures and is economical [14]. Further the thermophylic one stage systems across Europe consist of one bioreactor. However, the use of two bioreactors, in Case 2, reduces the possibility of suspending the operation of the entire unit. If the operation of one bioreactor is inhibited the second bioreactor will operate.

According to Table 2 the thermophilic process can produce approximately 200m^3 of biogas per ton of fresh substrate. The results of the thermophilic process are consistent with large-scale studies in the European Union where it is produced 100-200m^{3}biogas/ton [15][16].

As far as electric energy production concerns, the aforementioned anaerobic biological treatment unit will produce almost 14787 MWh/y. Assuming an average electricity consumption of 3-4MWh/y/household$_{Athens}$ the annual produced electric energy from the anaerobic digestion unit could supply almost 5000-4000 households in the Municipality of Athens. So by treating the 9.6% of annual organic waste produced in Athens it can be covered the 1.8-2.3% of Athens municipality electric energy demand. Although this amount of energy seems small it can cover the 100% of the energy demand of an island like Myconos (about 11000 habitants)

Economic Aspects

The investment cost of the anaerobic digestion plant for Case 1 is estimated around 9.2M€ [16]. This value includes the turn-key anaerobic part, with the treatment of the biogas by means of biogas engines and the necessary civil works. It does not include the cost of the pretreatment unit of the waste. However taking into account that the pretreatment unit cost stands for the 40% of the total investment cost, the anaerobic digestion unit of Case 1 will have an investment cost around 15.4M€. Moreover this cost of 15.4M€ could be decreased further considering Eurozone recession rates and the economical crisis in Greece the last four years and can reach the value of 12M€. For Case 2 the estimated investment cost rises 20% higher.

The anaerobic digestion unit will produce 40513kWh/d, which means 14787245kWh/y. If this energy is sold to the national grid then the annual profit of energy production will be around 3700000€/y (assuming a selling price of 0.25€/kWh that is valid now in Greece for biogas units treating agricultural and dairy waste [17]) Operational cost of the unit will be around 700000€/y. So the net profit will be approximately 3000000€/y and the pay back of the investment will be around 5 years for Case 1 and 6 years for Case 2.

In comparison to solar and wind energy systems anaerobic digestion is not beneficial economically. Solar and wind power units have an investment cost around 1000 euro/kW (solar) and 1550 euro/kW (wind) witch is almost the 1/3 of the total investment cost of a biogas unit. However, anaerobic digestion units do not alter the environment, remove organic waste, produce electricity and compost. Therefore, anaerobic digestion is a method of reducing environmental pollution from agricultural, urban, industrial waste and gaseous pollutants, while contributing to energy independence from fossil fuels.

Conclusions

This paper consists of a techno-economically study of a possible anaerobic biological degradation unit installation in Attica, which will manage 35600ton/y of fresh substrate of the source sorted organic fraction of solid municipal waste (SS-OFSMW). It consists of a pre-processing step (screening with hands-cutting) and the main anaerobic biological treatment. Both cases of installing one and two thermophilic bioreactos are taken into consideration. The thermophilic process can produce approximately 200m^3 of biogas per ton of fresh substrate and almost 14787 MWh/y. The pay back of the investment will be around 5-6 years.

References

[1]. E. Kapetanios, "Processes and Techniques of Antipollution-Forecast, Prevention, Control & Treatment of Pollution", Course Notes Processes and techniques of pollution abatement, 2012

[2]. I. Angelidaki, D. Karakashev, D.J. Batstone, C.M. Plugge and A.J.M. Stams, “Biomethanation and its potential”, ch 16, Methods in Enzymology, Vol 494, Elsevier, 2011, pp:327-351

[3]. D. Deublein and A. Steinhauser, “Biogas from Waste and Renewable Resources: An Introduction”, Wiley-VCH, 2008

[4]. P. Weiland, “Biogas production: current state and perspectives”, Appl Microbiol Biotechnol, Vol 85, 2010, pp:849-860

[5]. Luc de Baere, Bruno Mattheeuws, “Anaerobic digestion of MSW in Europe”, Biocycle, Vol 51, No 2, 2010, pp:24

[6]. European bioplastics, “Anaerobic Digestion”, Fact Sheet, 2010
[7]. http://www.eedsa.gr
[8]. S. Mace, D. Bolzonella, F. Cecchi and J. Mata-Alvarez, “Comparison of the biodegradability of the grey fraction of municipal solid waste of Barcelona in mesophilic and thermophilic conditions”, Water Science and Technology Vol 48 No 4 pp 21–28, IWA Publishing 2003
[9]. Cecchi F., Pavan P., Battistoni P., Bolzonella D., Innocenti L., “CHARACTERISTICS OF THE ORGANIC FRACTION OF MUNICIPAL SOLID WASTES IN EUROPE FOR DIFFERENT SORTING STRATEGIES AND RELATED PERFORMANCES OF THE ANAEROBIC DIGESTION PROCESS”
[10]. F. Cecci, P. Pavan, J. Mata-Alvarez, A. Bassetti and C. Cozzolino, “Anaerobic digestion of municipal solid waste: Thermophilic vs Mesophilic performance at high solids”, Waste Management & Research, 1991, Vol 9, pp:305-315A.
[11]. Davidsson, C. Gruvberger, T. H. Christensen, T. L. Hansen, J. la Cour Jansen, “Methane yield in source-sorted organic fraction of municipal solid waste”, Waste Management 27 (2007), pp:406-414, Elsevier
[12]. D. Bolzonella, P. Pavan, S. Mace and F. Cecchi, “Dry anaerobic digestion of differently sorted organic municipal solid waste: a full-scale experience”, Water Science & Technology, Vol 53, No 8, pp 23–32, IWA Publishing 2006
[13]. D. Bolzonella, P. Battistino, C. Susini and F. Cecchi, “Anaerobic codigestion of waste activated sludge and OFMSW: the experience of Viareggio and Treviso plants (Italy)”, Water Science & Technology, Vol 53, No 8, pp 203–211, IWA Publishing 2006
[14]. I. M. Nasir, T.I. Mohd Ghazi, R. Omar, “Production of biogas from solid organic wastes through anaerobic digestion: a review”, Appl Microbiol Biotechnol (2012), 95, pp: 321-329
[15]. L. De Baere, “ORGANIC WASTE SYSTEMS:TRUE ALL-ROUNDER IN ANAEROBICDIGESTION OF SOLIDAND SEMI-SOLID ORGANICS”, IMPLEMENTING ANAEROBIC DIGESTION IN WALES, CARDIFF, 11 NOVEMBER 2008
[16]. The Dranco Technology, Organic Waste Systems: www.ows.be
[17]. Law 3851/2010 (FEK.A’85)