Biogas from source-sorted organic municipal waste: The case study of Athens, Greece

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Abstract

A feasibility study is presented of a possible mesophylic dry anaerobic digestion 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 anaerobical digestion unit two configurations are taken into consideration. The first configuration (Case 1) consists of one bioreactor while the second (Case 2) relies on two bioreactors. This study focuses on the calculation of the main characteristics of the biogas unit (reactor volume, biogas tank volume, CHP power) and gives average values of the unit input-output data. Results show that the mesophyilic process can produce approximately 160m^3 of biogas per ton of fresh substrate, which is consistent with large-scale studies in the European Union. This amount of biogas generates 11641 MWh$_e$/y, which can cover the 1.3-1.8% of Athens (or the 100% of the island of Tinos) electric energy demand. Also, a rough economical analysis concerning the specific unit is attempted, taking into account Eurozone recession rates and the economical crisis in Greece the last four years. According to these the investment cost of the biogas unit will be around 9 M€ for Case 1 and 11 M€ for Case 2. Operational cost for Case 1 approximates 32 €/ton and 37 €/ton for Case 2. The pay back of the investment will be around 5-7 years.

Keywords: biogas, anaerobic digestion, mesophylic biodegradation, dry bioreactors, feasibility study, source-sorted organic municipal waste.

1. Introduction

The global population growth and continuously improving quality of life for the last 30 years has resulted in a corresponding increase in human waste, mostly municipal. It is estimated that the annual increase in waste amounts to 2-3%. Indeed in Europe it is produced more than 3Gtons/year of waste. Landfilling applied as the main method of waste management is a source of aesthetic (odors), health (skin infections, respiratory problems, etc.) and environment (water pollution, soil erosion, greenhouse gases) problems (European bioplastics 2010).

Anaerobic digestion as a preprocessing step before waste composting or landfill has many advantages, such as minimizing mass and volume, neutralization of biological and biochemical processes in order to avoid gas and odor emissions in the next stages of waste management, reduction of landfill sites and energy production in the form of biogas (Kapetanios 2012, Angelidaki 2011, Deublein 2008).

The dry substrate anaerobic digestion regards waste solids content higher than 15%. The organic portion of municipal waste and lignocellulosic biomass (agricultural waste and energy crops (Weiland 2010)) are processed through dry substrate technology. The technique of the dry substrate is advantageous in the reactor size (smaller thus smaller reactor capacity requirements), the lower energy requirements for heating the reactor and stirring the contents. In 2011 the dry substrate anaerobic biological process facilities occupied 54% of the total anaerobic digestion facilities in Europe, a number that has gradually been increased since 2005 (Vandevivere 1999, Lissens 2001, Abbasi 2012).

In this paper a feasibility study is presented of a possible dry mesophylic 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. Two cases are presented. In Case 1 the main anaerobic treatment consists of one bioreactor. In the second configuration (Case 2) the preprocessed substrate is fed to two bioreactors. Case 2 is chosen to be studied because reduces the possibility of failure of the entire unit.

In general feasibility studies of anaerobic digestion units are rare in literature. This type of research is valuable to the scientific committee because they can verify the validity of lab experiments and small scale applications, while at the same time consists of a necessary simulation tool for possible large scale applications. So every feasibility study concerns a specific possible event tanking into account the specific characteristics of the application.

2. Materials and Methods

2.1 The situation of municipal solid waste in Attica

Household waste varies in composition and quantity according the standard of living, consumption patterns, mobility of the population, and the seasons of the year (eedsa 2013). The largest percentage of Attica municipal waste still consists of biodegradable materials (Fig.1).

Fig 1 here

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.

2.2 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 of 115-132m^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.2).

Fig 2 here

•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, biogas compressor and a heat and electricity generator (Fig. 3).

Fig 3 here

Case 2: pumps mixing of substrate and recycling of leachate, two dry substrate bioreactors, biogas storage tank, biogas compressor and a heat and electricity production unit (Fig.4).

Fig 4 here

2.3. Assumptions

For the mesophylic anaerobic digestion application the assumptions that were made are shown on Table 1.

Table 1 here

3. Results

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

Table 2 here

Table 3 shows input-output data of the mesophylic anaerobic biological process that is going to treat 100ton/d of substrate with 33%TS. For Case 2 each bioreactor will treat 50ton/d so its input-output data is half the values presented in Table 3.

Table 3 here

4. Discussion

Biogas belongs to the renewable sources of energy and can replace fossil fuels in the electric and thermal energy production. It can also be used as fuel in vehicles.

The climate of Attica is ideal for mesophilic anaerobic biological degradation application. By this way the heat consumed for warming the substrate and the bioreactors will be reduced.

The assumptions were based on real large-scale experiment conducted in Italy (Bassano) in 2006 (Bolzonella 2006a), and we believe that nutritional conditions and culture that have Greeks and Italians are similar.

The choice of a first order kinetic model 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. Besides, this model has been successfully applied for biogas plants in Spain and Italy (Italy: Bassano, Treviso, Treni, Spain: Barcelona) (Bolzonella 2006a, Bolzonella 2006b, Mace 2003). The first-order constant and the maximum theoretical gain in methane have been calculated by Cecchi et al for the three categories of municipal waste in the early 1990s (Cecci 1991, Mata-Alvarez 1992).

Moreover 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 mesophilic process can produce approximately $160m^3$ of biogas per ton of fresh substrate. The results of the mesophilic process are consistent with large-scale studies in Italy and Spain. In Bassano, (Italy) reported biogas profit of $200m^3$ per ton of fresh substrate in the mesophilic anaerobic digestion of the organic fraction of municipal waste (16ton/y, HRT:40-60d, 33% TS, 78% VS, OLR :4-6kgVS/$m^3_{reactor}$d). In Spain (Barcelona) Ecopark 2, produces approximately $157m^3$ biogas per ton of fresh substrate (ECOPARK 2).

As far as electric energy production concerns, the aforementioned anaerobic biological treatment unit will produce almost 11641 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 4000-3000 households in the Municipality of Athens. So by treating the 9% of annual organic waste produced in Athens it can be covered the 1.3-1.8% of Athens municipality electric energy demand. This means that can be covered the 100% of the energy demand of an island like Tinos (about 9000 habitants) only by treating a very small portion of organic waste.

In Greece electric energy demand is mostly covered from fossil fuels and hydroelectric units. The first causes pollution while the second alters the environment. Anaerobic digestion offers an environmental friendly energy production technology because it reduces greenhouse gas emissions and does not deform the environment. Also organic waste is produced every day and it is free everywhere.

4.1 Economical Aspects

For the economic analysis, concerning investment and operational cost of the anaerobic digestion unit presented in this paper, two mathematical formulas were taken into account: 1. Vallini et al formula (Bolzonella 2005c) and 2. Tsilemou et al formula (Tsilemou 2006).

Table 4 presents some economic data derived from the above formulas for both Case 1 and Case 2. Inflation effect from 2004 to 2015 was taken into account. The third column of each Case shows data that have been derived considering Eurozone recession rates and the economical crisis in Greece the last four years. According to these the investment cost of the anaerobic digestion unit will be around 9 millions euro for Case 1 and 11 millions euro for Case 2. Operational cost for Case 1 approximates 32euro/ton and 37euro/ton for Case 2.

Table 4 here

The anaerobic digestion unit will produce 31892kWh/d, which means 11640580kWh/y. If this energy is sold to the national grid then the annual profit of energy production will be around 2900000€/y (assuming a selling price of 0.25€/kWh that is valid now in Greece for biogas units treating agricultural and dairy waste (Law 3851/2010)). So taking into account operational cost from Table 4 the pay back of the investment will be around 5-7 years.

In comparison to wind energy applications anaerobic digestion is not a cheap technology. Wind power units cost about 1550 euro/kW while biogas units cost can rise up to 6000 euro/kW. However wind power stations alter the environment and the danger of a malefaction exists. Furthermore even in Greece is not windy every day while waste is produced every minute. By this way the problems of waste treatment and energy demand can both be solved. Moreover compost is produced which is of a very good quality and can replace unhealthy chemical fertilizers.

5. Conclusion

This paper consists of a techno-economically study of a possible anaerobic digestion unit construction in Attica, which will manage 35600ton/y of fresh substrate of SS-OFSMW. Two configurations are taken into consideration. Case 1 relies on one bioreactor while Case 2 consists of two small bioreactors. The mesophilic process can produce approximately 160m^3 of biogas per ton of fresh substrate and generate 11641 MWh$_e$/y. The investment cost of the anaerobic digestion unit will be around 9 millions euro for Case 1 and 11 millions euro for Case 2. Operational cost for Case 1 approximates 32euro/ton and 37euro/ton for Case 2. The pay back of the investment will be around 5-7 years. Although both cases are not economically beneficial an installation of a biogas unit in Attica will manage the problem of waste treatment and will produce a satisfactory amount of electric energy.

Figure Captions

Figure 1: Average composition of Attica municipal waste (data from 2003)

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

Figure 3: Schematic diagram of the anaerobic biological treatment plant, Case 1

Figure 4: Schematic diagram of the anaerobic biological treatment plant, Case 2

Figure 1

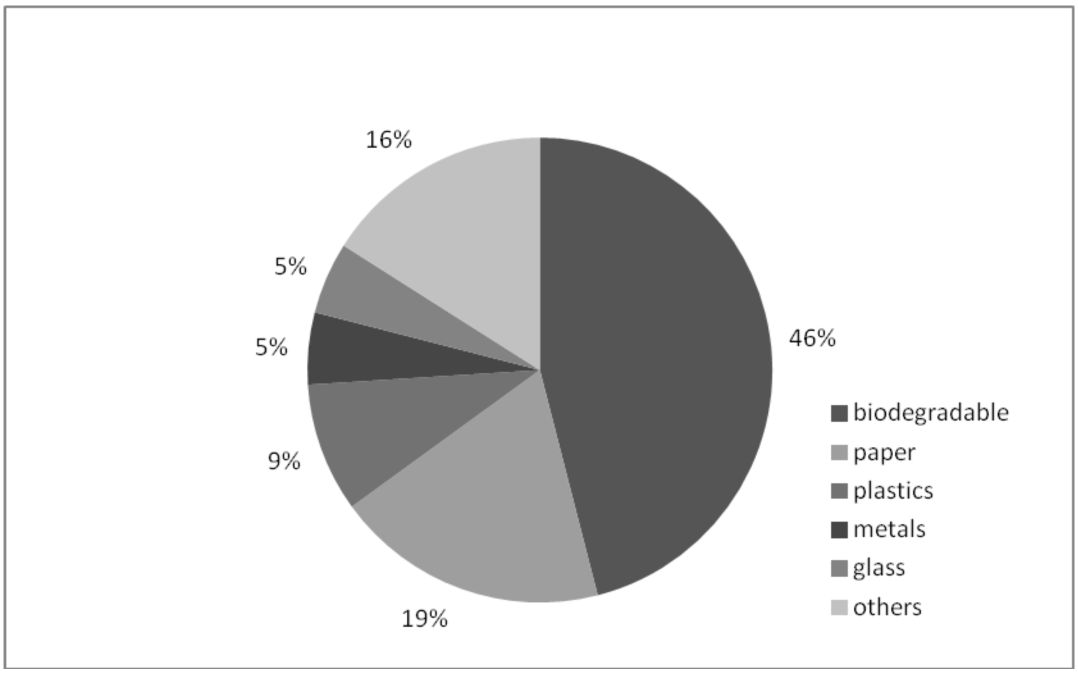

16%
5%
5%
9%
19%
46%
biodegradable
paper
plastics
metals
glass
others

Figure 2

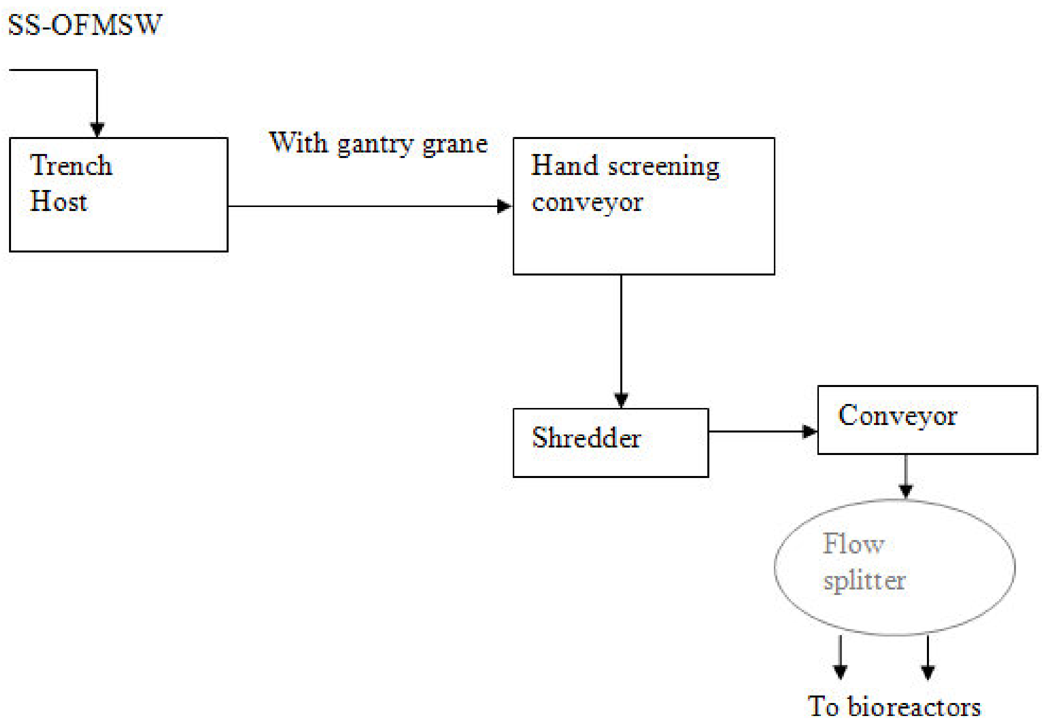
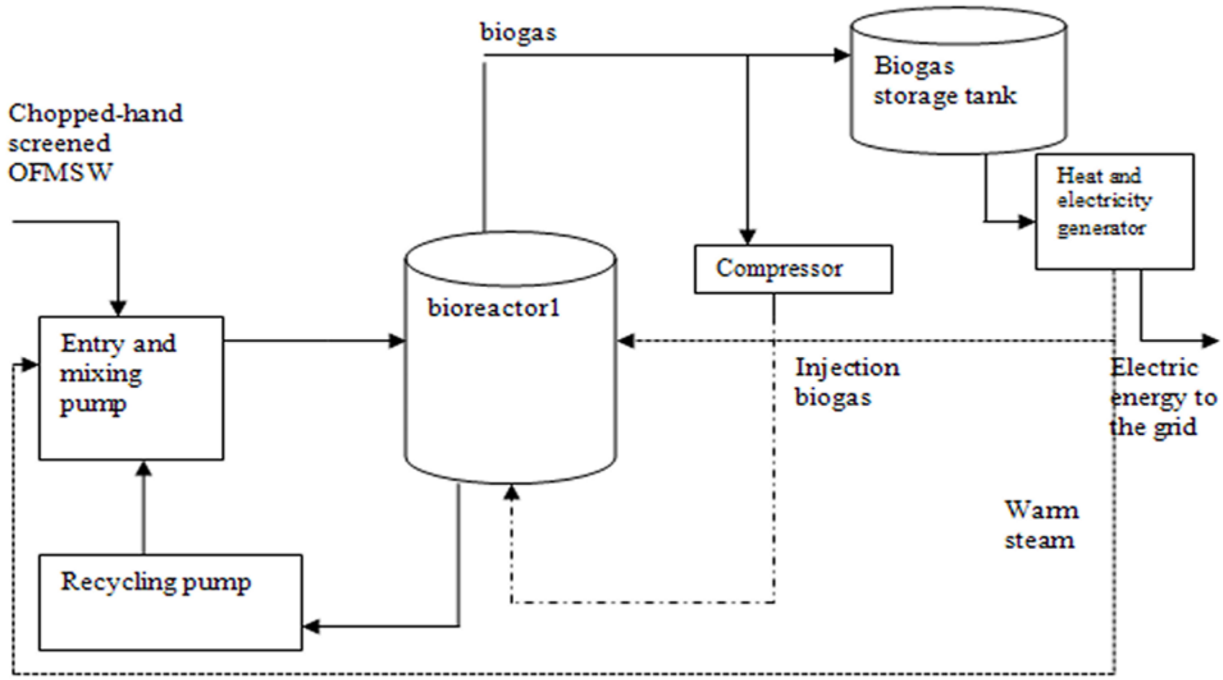
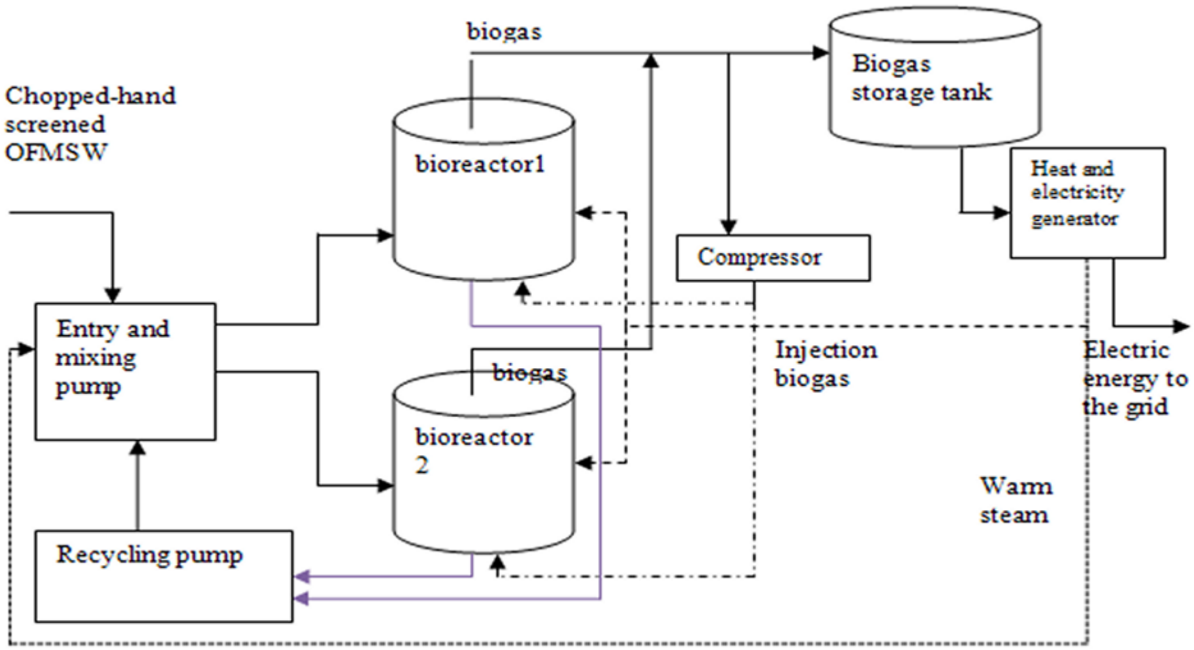

SS-OFMSW
Trench
Host
With gantry grane
Hand screening
conveyor
Shredder
Conveyor
Flow
splitter
To bioreactors

Figure 3



biogas
Biogas storage tank
Chopped-hand screened OFMSW
Heat and electricity generator
Compressor
bioreactor1
Entry and mixing pump
Injection biogas
Electric energy to the grid
Warm steam
Recycling pump

Figure 4



biogas
Chopped-hand screened OFMSW
bioreactor1
Biogas storage tank
Heat and electricity generator
Compressor
Entry and mixing pump
biogas
bioreactor 2
Injection biogas
Electric energy to the grid
Warm steam
Recycling pump

Table Captions

Table 1: The assumptions

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

Table 3: Input-output data of the mesophylic anaerobic biological process that is going to treat 100ton/d of substrate with 33%TS

Table 4: Investment and operational costs for case1 and Case 2

Table 1.

Parameters	Values
Unit capacity	36500 ton/y of fresh substrate of SS-OFSMW
Composition of SS-OFSMW	60-70% food waste with d_{fw}=0.74ton/m^3 and 40-30% garden waste with d_{gw}=0.3ton/m^3
Average density of the substrate	d_s=0.86ton/m^3
Substrate concentration	33%TS VS=78%TS
Methane potential	0.4m^3CH_4/kgVS_{in}(STP)
First order kinetic model with constant	k=0.2-0.4d
HRT	26d
Biogas methane content	56%
TS reactor	23-25%
$T_{reactor}$	35^oC
$VS_{reduction}$	45%
Annual CHP operation hours	7500h/y
Methane value	10kWh/m

Table 2

Technical characteristics	**Case 1**	**Case 2**
Bioreactor capacity (m^3)	3779	1889 (x2)
Biogas storage tank capacity (m^3)	3254	
CHP power (MW)	2	

Table 3

Effective capacity (m^3)	3059 (total 3779)		
Mass input (kg/d)	100000		
VS input (kg/d)	25740		
TS input (kg/d)	33000		
Biogas mass (kg/d)	20571		
Methane mass (kg/d)	6509 (CO_2 around 140621)		
Output mass (kg/d)	79429		
TS output (kg/d)	21417 (to compost)		
VS output (kg/d)	14157		
Retention time (d)	26		
Loading rate (kgVS/m^3d)	6.8		
Biogas yield (average) (m^3/kgVS$_{in}$)	0.632		
Methane yield (average) (m^3/kgVS$_{in}$)	0.355		
Methane content (%)	56		
Methane volume (m^3/d) (STP)	9112		
Biogas volume (m^3/d) (STP)	16271		
CO_2 volume (m^3/d) (STP)	7159		
Methane value (kWh/m^3)	10		
Electric power efficiency (%)	35	Electric power (kWh/d)	31892
Heat value efficiency (%)	50	Heat (kWh/d)	45560
Losses %	15		

Table 4

Economical Data	Case 1			Case 2		
Formulas	Tsilemou et al	Vallini et al	Greek data	Tsilemou et al	Vallini et al	Greek data
Investment cost (millions €)	13.4	13.1	9	14.8	14.3	11
Operational cost (€/ton)	36	-	32	40	-	37

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