An integrated anaerobic digestion system for solid organic waste

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Abstract

An optimized anaerobic digestion is carried out from the organic waste generated in the nearby region, from lay crop grown by local farmers and from grease trap removal sludge from the restaurants and institutional kitchens. The biogas produced is used to power the city busses, waste collecting vehicles and cars. Fertilizers obtained from the rest product are returned to farmers. The integrated management system involving all the actors of the process, joined to an optimized anaerobic digestion process provides a successful reference experience at industrial scale for the codigestion of solid organic wastes with energy crops, demonstrating the stability of the process, with a high productivity.

Keywords
Anaerobic digestion, solid organic waste, energy crops, upgrading

Introduction

Among biological treatments for organic waste, anaerobic digestion is frequently the most cost-effective, due to high energy recovery linked to the process and its limited environmental impact (Mata-Alvarez et al., 2000).

Few large scale experiences have been reported for the treatment of solid waste and energy crops by anaerobic digestion (Chynoweth et al., 2001; Dobó et al., 2007; Svensson et al., 2006; Tai et al., 2004; Weiland, P, 2000, 2004), although data at industrial scale is necessary due to the important differences between scales. The project presented became an EU demonstration project in 2003 within the 5th framework program, for this reason.

The optimized anaerobic digestion system reported permits handle high quality biowaste and crops in an environmental sound way, and establish a sustainable circulation of plant nutrients and energy between the city and the agricultural sector. From the point of view of agriculture, contributes to a sustainable form of farming and to promote employment within the region. From the energetic point of view, it makes possible to extract and utilize high-grade bioenergy from biowaste and energy crops with no net-contribution of carbon dioxide to the atmosphere, establishing a sustainable market for biogas as vehicle fuel within the region.

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All actors involved in the project are participating in the company, the solid waste company owned by the municipalities, the federation of farmers, the local energy company and 17 local farmers.

Material and methods

Incoming substrates to the biogas plant in the last year have been 13 125 tonnes/year of source-separated organic waste from households and institutional kitchens, 1 635 tonnes/year of grease trap removal sludge with and 1 837 tonnes/year of ensilage of ley crop from a contracted acreage of 300 hectares (Table 1). Energy production from the biogas plant has been for this period of 15 972 MWh. Residuals from the process have been 16% from the incomes. Two different fertilizers have been produced, 3 231 tonnes/year of a solid fraction with a dry matter content of 25-30% and 11 820 tonnes of a liquid fraction with a dry matter content of 3-4%. Upgrading of biogas produced combustible for all the buses of the city.

Table 1. Products entering the anaerobic digestion system

Tonnes/year	Total Solids	%)
Source-separated organic waste from household	13125	30%
Grease trap removal sludge from restaurants and institutional kitchens	1635	4%
Ensilage of ley crop	1837	35%

Household waste is crushed, separated and fed to the mixers where liquid waste (grease trap) and water is added to create a suspension (Fig. 1). After removing impurities by a screen rake and a sand trap, suspension is hygienised at 70ºC for one hour. Silage is fed directly into the digester, where an anaerobic microbial process produces the biogas at a temperature of 37ºC, mixing the suspension in the digester is done with compressed gas. The heating or the suspension and heat recovery before the suspension enters the digester is done through heat exchangers. The gas produced is led to gas storage before it is upgraded to vehicle fuel. Biogas not upgraded is used for production of electricity and heat. In case of malfunctioning in the gas consumers the excess gas is burnt in the flare. The digester effluent is centrifuged and stored separately the liquid and solid fraction that will be used as fertilizers.

Receiving hall

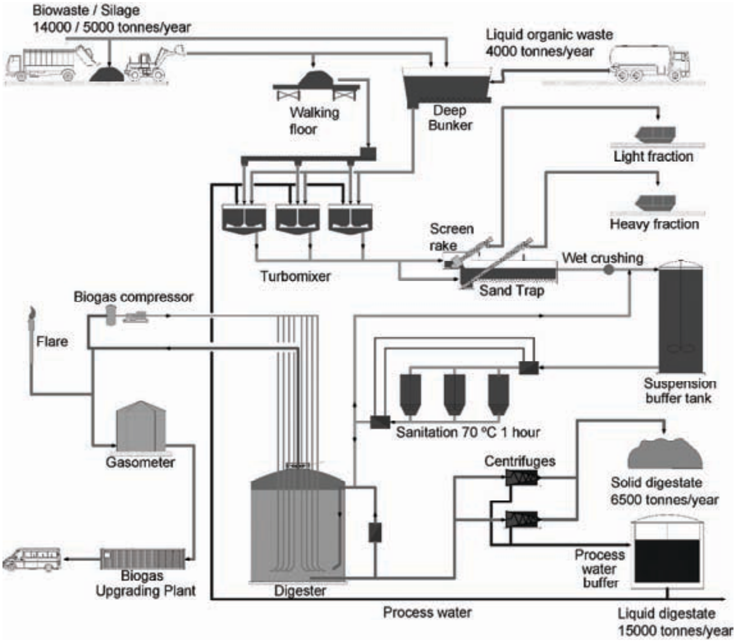
In the receiving hall, the receiving floor permits the unloading of the biowaste. A shredder is used for crushing the waste which is then fed to a sieve. The sieve is located above a walking floor and the sieve overflow is collected in a container. A deep bunker receives liquid, semiliquid and solid waste.

In order to break the paper bags in which the biowaste is collected, and release it as well as grind the material into smaller pieces, the waste is fed into a shredder where it is crushed. The shredder is of hammer mill type and is powered by an electrical motor. To separate the organic material from impurities, the waste is conveyed from the shredder up to a sieve of star type. The sieve consists of a floor of rotating cylinders where large and light pieces, mainly plastic, remains on top of the cylinders and is conveyed into a container while the organic material falls through the gap between the cylinders onto the walking floor.

From the sieve the waste drops down to a walking floor which has a dual function. One is feed the bio waste into a screw conveyer for transporting the waste to the turbo mixers. It also functions as buffer storage to enable continuous feeding of material when no new material is being received.

The deep bunker is mainly intended for incoming waste which cannot be processed in the shredder such as liquid and semiliquid waste. Presently it is used to receive and store grease trap removal sludge. Potentially it could be used as a backup in case of malfunction of the walking floor.

Figure 1. Process flow



Pre-treatment

The pre-treatment consists in a series of steps which prepares the material for the digester. The first step are the turbo-mixers, which purpose is to create a suspension (slurry) suitable for the digestion. The incoming biowaste is diluted with process water which is the liquid fraction from digester effluent separated into one solid and one liquid fraction. Biowaste is added to the process waster so a homogeneous suspension with a dry matter content of 8-10% is created. The mixing and cutting effect is achieved by an impeller powered by a motor located on top of the mixer. To control the proportion of biowaste and process water, the mixers are placed on load cells connected to the PLC-system. The process time for one batch is approximately 20 min.

After the turbo-mixers, impurities in the suspension are removed in an integrated two step process: a screen rake and a sand trap. The screen rake separates from the suspension particles larger than 15mm. Before the removed material is disposed in a container it is pressed in order to increase the dry matter content to approximately 25%. The removed material mainly consists of plastic and larger pieces of organic and inorganic material. When the suspension has passed the screen rake enters a large tank, where the heavy fraction which mainly consists of stones, glass and bones is removed by allowing air to bubble through the suspension which causes heavy particles to settle in the bottom.

The removal of non-organic material is important in three aspects: a) the quality of the digestion residuals, which are to be used as fertilizers, is related to the quality of the input material; b) solid materials cause a higher degree of ware and abrasion on the equipment than does organic material; c) foreign materials can cause problems in the digester by sedimentation and clogging.

To reduce the particle size in the suspension according to EU regulation, it passes a macerator before the suspension is pumped to the suspension buffer tank. Continuous feeding of material to the sanitation step and to the digester is allowed by temporarily storage of the suspension in a tank of 270m^3, which is sufficient for continuous feeding of the digester during work days. During Saturdays and Sundays no suspension is fed to the digester. Sedimentation is avoided in the suspension tank with a mixer and a pump which recirculates the suspension.

Before the suspension enters the digester it undergoes a sanitation process to eliminate harmful bacteria, such as salmonella, which potentially can come into the system through the incoming household waste. Since the digestion residuals are to be used as fertilisers on farms it is vital that the product does not function as a source of contamination. This is accomplished by heating the material to a temperature of >70ºC during at least one hour according to EU regulations. There are three sanitation tanks, 16m^3 each, which work in a cycle. Thereby, continuous flow to the digester is achieved.

Three heat-exchangers of suspension-water type heat the suspension to the sanitation temperature and recover heat from sanitised material. Heat source for the sanitation as well as for the rest of the plant is district heating.

Gas production

It is in the digester where the anaerobic microbiological process takes place in which biogas is produced. The digester is a carbon steel tank and has a volume of 4 000 m3. The temperature is 37ºC (mesophilic process), and the digester works continuously 24 hours/day every day of the year with a hydraulic retention time of approximately 20 days. To avoid the use of moving parts inside the digester, mixing is performed by compressed biogas. The gas enters the digester via twelve pipes at the top of the tank, where the gas is released. Additionally the suspension is circulated in the tank. At the top, a safety valve is located which, in case of overpressure in the tank, releases gas into the atmosphere.

Outgoing the digester, the gas is in the storage not under pressure and has a capacity to hold the gas produced during two hours. In the case of malfunctioning at the gas consumers and when the gas storage is full, the flare functions as safety valve, burning excess gas avoiding any release of methane gas to the atmosphere.

Digestion residuals

In the digestion process not only gas is a desirable product but the digestion residuals as well. These are high in plant nutrient contents and improve soil properties, therefore are used as fertilisers on farms contracted to the plant. The digestion residuals also fulfil the criteria for organic farming.

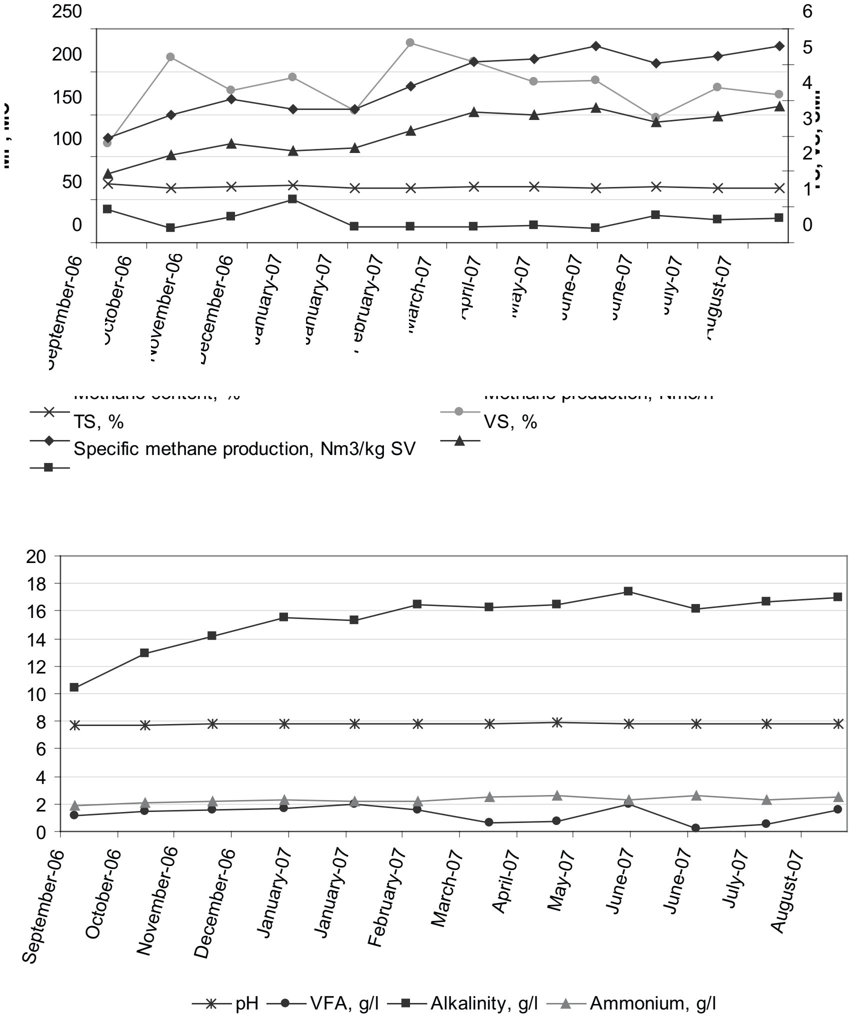
The outgoing solid digestate has a dry matter content of 25-30%. After the separation it is loaded directly into containers to be transported to the farmers who are responsible for storage until it can be used as a phosphorous fertilizer.

The liquid fraction from the dewatering of digestate is initially transported to a process water buffer tank from which process water is either recycled to the turbo-mixers or transported to a storage basin. The liquid digester, which has a dry matter content of approximately 2-3%, is primarily used by the farmers as a nitrogen fertilizer. The tank has a volume of 2500m^3, equivalent to the production during approximately 2 months.

Results and conclusion

Alter two years of operation, methane production has been in an average of 0.63 Nm^3/kg SV, with a methane content of around 64%. Anaerobic process has been very stable, without any period of inhibition, or reduction of biogas production.
For example, in the period between September 2006 and 2007, total solids amount in the digester was increased in a 46%, and volatile solids in a 49% (Fig. 2a). pH was stable in values very close to 8, VFA were always under 2g/l, and with an increase tendency of alkalinity, as shown in Fig. 2b. Ammonium was kept in values distant from inhibition, confirming all these parameters the stability of the digester.

Figure 2. Evolution of the process during the period



Fertilisers obtained from the process present high quantity of nutrients (Table 2) and low amount of heavy metals, except for Cu and Zn, as it is usual for this kind of waste entering the site.

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Table 2. Characteristics of the liquid and solid fertilisers, values as mean of one year of operation

	Solid fertiliser	Liquid fertiliser
TS, %	26.13	2.88
N, kg/ton	9.30	4.51
N-NH_4, kg/ton	3.19	2.75
P, kg/ton	2.08	0.22
K, kg/ton	2.80	2.74
Mg, kg/ton	1.28	0.12
Ca, kg/ton	8.39	0.56
Pb, mg/kg dm	8.18	9.9
Cd, mg/kg dm	0.17	0.7
Cu, mg/kg dm	47.58	74.1
Cr, mg/kg dm	10.89	10.1
Hg, mg/kg dm	0.05	0.1
Ni, mg/kg dm	4.01	8.7
Zn, mg/kg dm	77.58	277

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References

Chynoweth, D.P., Owens, J.M., Legrand, R. (2001). Renewable methane from anaerobic digestion of biomass. Renewable Energy, 22(1-3): 1-8

Dobó, E., Singh, M.K., Szücs, I. (2007). Global environmental change solutions from biomass, bioenergy and biomaterials: A global overview for sustainable development. Cereal research communications, 35 (2)

Mata-Alvarez, J. Macé, S., Llabrés, P. (2000). Anaerobic digestion of organic solid wastes. An overview of research achievements and perspectives. Bioresource Technology, 74(1): 3-16

Svensson, L.M., Christensson, K., Björnsson, L. (2006). Biogas production from crop residues on a farm-scale level in Sweden: scale, choice of substrate and utilisation rate most important parameters for financial feasibility. Bioprocess and biosystems engineering, 29(2)

Tsai, W.T., Chou, Y.H., Chang, Y.M. (2004). Progress in energy utilization from agrowastes in Taiwan. Renewable and sustainable energy reviews, 8(5):461-481.

Weiland, P. (2000). Anaerobic waste digestion in Germany. Status and recent developments. Biodegradation, 11(6)

Weiland, P. (2003). Production and energetic use of biogas from energy crops and wastes in Germany Applied biochemistry and biotechnology, 109 (1-3).