

Anaerobic digestion: an energy and environmental

Kherbouche, B. Benyoucef

Unité de Recherche des Matériaux et Energie Renouvelables , Faculté de Sciences, Université Abou Bakr Belkaid, Tlemcen, Algérie

Email address:

djamila_kh@yahoo.fr (Kherbouche)

To cite this article

Kherbouche, B. Benyoucef. Anaerobic Digestion: an Energy and Environmental. *American Journal of Environmental Protection*. Vol. 2, No. 2, 2013, pp. 47-52. doi: 10.11648/j.ajep.20130202.13

Abstract: Methanisation makes it possible to cleanse the organic load since the fermentable matters that they contain are transformed into biogas. The treatment by anaerobic digestion of an effluent of breeding makes it possible to reduce its polluting load appreciably and thus also the risks of pollution when thrown in natural environment. Moreover, the biometanisation, stabilizes the effluent by eliminating the harmful sanitary effects (pathogenic germs) and locative (nauseous odours) which constitutes an undeniable advantage. In the same way for purification stations mud and the household refuse, anaerobic digestion is mainly a technique which combines the advantage of the energy production to that of stabilization and also of artificial manure. Thus, let us use methanisation in order to degrade pollution, the odours and wastes. The application of methanisation allows the production of biogas from organic waste which remains an energy source that is not exploited in Algeria[1].

Keywords: Biomass, Waste, Alkaline Fermentation (Methanisation), Biogas

1. History

Methanisation has been used for more than one century to treat urban purification stations mud. Thus, in 1889, the town of Exeter in the United Kingdom used biogas resulting from its urban purification stations to light up its streets. In the years 1940, then again during the oil crisis of 1973 up to 1985, then in the 1970's, it was developed for the liquid waste processing of agro alimentary, paper and chemical industries[2].

2. General Principle:

Methanisation is a biological phenomenon of transformation of the organic matter by micro-organisms (bacteria) in the absence of oxygen (digestion or anaerobic digestion). It is used to destroy the biodegradable fraction, that is likely to pollute[3, 4].

The methanisation produces biogas, which is a renewable energy, and digester's sludge (solid phase), which after dehydration and a maturation by composting, forms an organic soil conditioner with the characteristics close to those of the compost: it is a stable product[5].

The following describes the process of manure and straw mixture digestion. For the first 3 days, the methane yield is almost 0% and carbon dioxide generation is roughly 100%. In this period, digestion occurs as aerobic fermentation to

carbon dioxide. The yields of methane and carbon dioxide gases are then 50-50 on the eleventh day. At the end of the twentieth day, the digestion reaches the stationary phase. The methane content of the biogas is in the range of 73–79% for the runs, the remainder being principally carbon dioxide. During a 30-day digestion period, approximately 80–85% of the biogas is produced in the first 15–18 days. This implies that the digester retention time can be designed to be 15–18 days instead of 30 days[6].

2.1. Methanisation Process

2.1.1. Fundamentals

The treatment of organic matter by biodigestion is first of all subject to biological constraints and the techniques implemented aim at creating and maintaining an ecosystem favorable to particular microorganisms.

To simplify we can say that a biodigester host and entertain strictly aerobic microbial populations which are brought to grow and reproduce themselves on an organic substrate composed of waste, by developing a bio-oxidation activity but in the absence of air.

These microbial populations are complex and relatively diversified but we know quite well their biochemical characteristics and the main peculiarities of their ecology.

Hydrolytic and fermentative bacteria [7]. The hydrolysis phase is realized by several groups of anaerobic obligate or facultative eubacterias the nature of which depends on the

qualitative and quantitative composition of the feeding substrate. The main species belong to the following genus: Clostridium, Bacillus, Ruminococcus, Enterobacteria, Propionibacterium and Butivibrio.

Acetogenic bacteria. During this phase, the oxidation of the substrate (specially with propionic and butyric acid and ethanol), is coupled to the formation of hydrogen, carbon dioxide and acetate. It represents the activity of three groups of bacteria: the homoacetogens of genus such as Clostridium, Acetobacterium, Sporomusa, Acetogenium, Acetoanaerobicum, Pelobacter Butyribacterium, Eubacterium..., syntrophes of genus such as Syntrophobacter, Syntrophomonas, Syntrophus... and the sulfato-reducers of genus such as Desulfovibrio, Desulfobacter, Desulfotomaculum, Desulfomonas...[7]

Methanogenic bacteria. Active bacteria of this last phase form part of a unique group: Archae. They possess specific characteristics in relation to eubacteria and eucaryotes, namely as far as coenzymes are concerned. Archae constitute one of the three primary states of the primary, with eubacteria and eucaryotes.

These three communities must constitute a balanced ecosystem in order to allow that most of the reducing agents (carbon atoms and hydrogen) produced as waste during bacterial anabolism (hydrolysis then acidophilic and acetogenesis) are finally found in the methane (methanogenesis CH_4).

In a summarized way we can present the three phases of the biodegradation process as in the figure and the carbon flows associated to each phase are given in %.

The management of the artificial ecosystem constituted by the anaerobic bioreactor requires an intervention to ensure that certain essential physico chemical conditions prevail: pH, temperature and oxido reduction potential as well as the nutritional needs.

The pH The optimum pH for anaerobic digestion is around neutral. It is

the result of the optimal pH for each bacterial population :

The optimum pH for acidifying bacteria is between 5.5 and 6,

acetogens prefer a pH close to neutral whereas methanogens have their maximal activity with a pH between 6 and 8.

However, methanisation can occur in lightly acidic or alkaline environments.

Temperature

The activity of the methanogen consortium is closely linked to the temperature. Two ranges of optimal temperatures can be defined: the mesophilic zone (around 35°C) and the thermophilic zone (between 55 and 60°C) with a decrease of the activity beyond these two low and high values.

The majority of bacterial species has been isolated in mesophilic environments, but all the trophic groups of the different stages of the aerobic digestion possess thermophilic species which use the same metabolic channels as

the mesophilic bacteria with similar performances. It remains possible to work at different temperatures optimums with lower performances.

The process is described in the fig 1

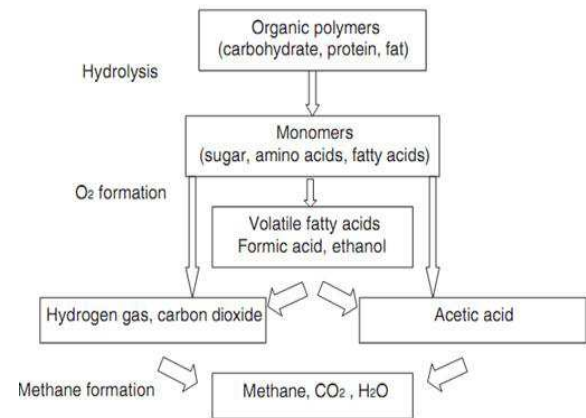


Fig 1. Methanisation process[8].

The wastes concerned with methanisation are: urban purification stations mud.

wastes of agricultural parks, wastes like the breeding liquid manures

wastes of agro alimentary industry activities

wastes of restoration and other comparable activities.

Any organic waste, of vegetable or animal origin, is able to ferment and produce biogas. But, methanisation is especially adapted to the degradation of wet organic waste few woody waste: waste of size, drink...) and with strong fermentable capacity.

The uncontrolled methanisation could generate CO_2 ; NO_2 and CH_4 which are toxic gases and odors (fig 2). So we must control this emission to protect our environment and in the same time we can obtain a green and clean energy (biogas) thanks to the methanisation converting system.

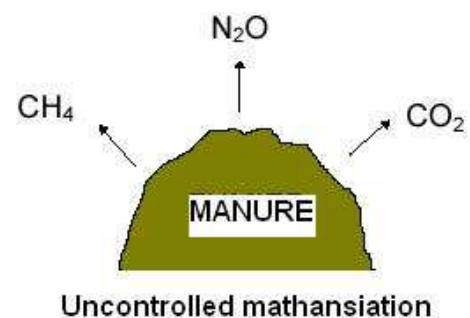


Fig 2. Non-controlled biomethanisation principle

3. The Different Stages of the Process

3.1. The Pre-Treatment of Waste

The pre-processing consists of:

Eliminating undesirable materials (inert, plastic, metals...) by a mechanical sorting, such as a sifting through trommels,

which make it possible to separate the elements of various sizes; a magnetic removing of metals; a manual sorting; a gravimetric sorting[9].

crushing (granulometric sorting) the raw material to homogenize it.

humidifying if necessary.

3.2. The Process of Methanisation

The organic matters that are sorted upstream return into a digester or methanisor, place where the anaerobic digestion proceeds (without oxygen). It is done under controlled conditions[10].

3.3. The Post Treatment

It aims at:

The dehydration of the digester's sludge by a pressing on the outlet side of the digester.

Supplementing the fermentation and the hygienisation of the digester's sludge, by a one or two-weeks maturation phase, before its use as organic soil conditioner[11].

4. The products

The anaerobic digestion produced biogas and sludge (see next sections).

4.1. Biogas

The production of biogas is the result of the decomposition of a part of the dry matter, which we call the volatile dry matter. 11 to 15 % of the initial mass of waste are transformed into biogas.

This biogas is a renewable energy, a renewable "natural gas", the nearest parent of fossil natural gas. Composition of biogas, variable according to the substrate

Fermented (Source ADEME):Methane (CH₄):25 with 75%; Carbon dioxide (CO₂): 14 to 38%[12]

Methane is a powerful gas for greenhouse use, it contributes 25 times more to the effect of the greenhouse than its combustion product, the carbon dioxide[12].

4.2. The Valorization of Biogas and the Organic Soil Conditioner

It can be developed in various ways: production of heat in the form of hot water, or hot air vapor. A part of this heat is used in the digesters heating process and the surplus is sold. This requires a perennial and regular outlet over the year, near the place of production.

30 to 60 % of the initial waste mass are transformed into compost. The quality of this organic soil conditioner depends on the quality of the initial product entering the digesters. This quality conditions its valorization. It is really desirable to set up a selective collection of the biowaste to produce a quality organic soil conditioner, which does not contain any residue of plastic, metal and glass[13].

4.3. Sludge

The digested sludge is the product residue of anaerobic digestion, composed of non-biodegradable organic matter (lignin) of the mineral matters (nitrogen, phosphorus) and of water. This digested sludge is stored in pits or concrete slabs[14].

Properties :

Non-existent odours because of the degradation in the digester of the organic matters responsible for odour pollution

Pathogenic germs reduced thanks to the hygienisation

Preserved amending value because the lignin fraction contributing to the formation of humus is not attacked

Improved fertilizing value - the nitrogen is found in ammoniac form - more easily to be assimilated by the plants. However its state being more volatile this has consequences on the methods of storage and spreading (land-fill in spring).

More fluid than the liquid non treated liquid manure, it penetrates more quickly in the ground. The digested sludge can undergo a treatment of separation of liquid/solid phase to have a solid fraction rich in organic matter and phosphatic element which is managed like an amendment A liquid fraction containing ammoniacal nitrogen and little organic matter, which can be used like liquid manure to replace nitrogenous fertilizers[15].



Fig 3. Sludge

5. Composting or Methanisation

Composting is nature's way of recycling. Composting biodegrades organic waste. i.e. food waste, manure, leaves, grass trimmings, paper, wood, feathers, crop residue etc., and turns it into a valuable organic fertilizer.

Composting is a natural biological process, carried out under controlled aerobic conditions (requires oxygen). In this process, various microorganisms, including bacteria and fungi, break down organic matter into simpler substances. The effectiveness of the composting process is dependent upon the environmental conditions present within the composting system i.e. oxygen, temperature, moisture, material disturbance, organic matter and the size and activity of microbial populations.

Composting is not a mysterious or complicated process. Natural recycling (composting) occurs on a continuous basis in the natural environment. Organic matter is metabo-

lized by microorganisms and consumed by invertebrates. The resulting nutrients are returned to the soil to support plant growth.

Composting is relatively simple to manage and can be carried out on a wide range of scales in almost any indoor or outdoor environment and in almost any geographic location. It has the potential to manage most of the organic material in the waste stream including restaurant waste, leaves and yard wastes, farm waste, animal manure, animal carcasses, paper products, sewage sludge, wood etc. and can be easily incorporated into any waste management plan.

Since approximately 45 - 55% of the waste stream is organic matter, composting can play a significant role in diverting waste from landfills thereby conserving landfill space and reducing the production of leachate and methane gas. In addition, an effective composting program can produce a high quality soil amendment with a variety of end uses.

The essential elements required by the composting microorganisms are carbon, nitrogen, oxygen and moisture. If any of these elements are lacking, or if they are not provided in the proper proportion, the microorganisms will not flourish and will not provide adequate heat. A composting process that operates at optimum performance will convert organic matter into stable compost that is odor and pathogen free, and a poor breeding substrate for flies and other insects. In addition, it will significantly reduce the volume and weight of organic waste as the composting process converts much of the biodegradable component to gaseous carbon dioxide.

The composting process is carried out by three classes of microbes -

- Psychrophiles - low temperature microbes
- Mesophiles -medium temperature microbes
- Thermophiles - high temperature microbes

Generally, composting begins at mesophilic temperatures and progresses into the thermophilic range. In later stages other organisms including Actinomycetes, Centipedes, Millipedes, Fungi, Sowbugs, Spiders and Earthworms assist in the process.

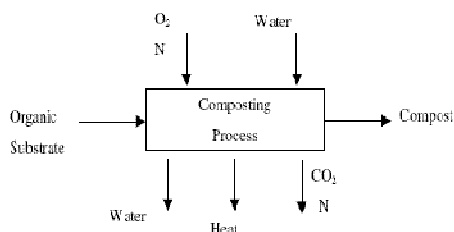


Fig 4. Composting process

Compared with composting, methanisation (see the environmental impact) is characterized by:

An absence of rejection of dust, and very limited rejection of aerosols and gas[16]

The need for closed engine working out removes any emission of dust and aerosols in the ambient air. during the

activated fermentation phase the odorous compounds contained in biogas are destroyed by the transformation of the sulphur compounds into SO₂. At the exit of the digesters, the residual ammonia, which can generate olfactive harmful effects, is eliminated if necessary (treatment of the foul air)

A better degradation of the volatile organic compounds (VOC) anaerobic digestion makes it possible to eliminate many VOC's. As the essence of the process proceeds out of closed engine, only the final phase of post-fermentation is likely to release the VOC in the atmosphere, in quite fewer quantities than in a composting process .

Emission in g/T of fermentable wastes	COMPO- STAGE	COMPOSTING / METHANISATION RATIO
ALCOHOLS	284	9466 times less
ESTERS	53	17666
ALDEHYDES	7.5	83
ETHERS	2.6	86
TOTAL VOC	588	196
AMMONIA	159	1.6

Emission in g/T of fermentable wastes	METHANISATION
ALCOHOLS	0.03
ESTERS	0.003
ALDEHYDES	0.09
ETHERS	0.03
TOTAL VOC	3
AMMONIA	97.6

Source: De Baere, 2nd International Symposium of anaerobic solid digestion of waste, Barcelona.

To be known: With Methanisation the emissions of VOC are nearly 200 times less. Even for ammonia, which is considered to pose problem in the event of anaerobic digestion, the emissions are lower by 40%.

A tool for fighting against the greenhouse effect. Instead of converting carbon into carbon dioxide only, methanisation converts carbon into methane. This biogas replaces fossil energy and avoids the fossil carbon destocking, and therefore the increase in the carbon dioxide concentration in the atmosphere

6. Incineration or Methanisation

Incineration is a waste treatment process that involves the combustion of organic substances contained in waste materials. Incineration and other high temperature waste treatment systems are described as "thermal treatment".

Incineration of waste materials converts the waste into ash, flue gas, and heat. The ash is mostly formed by the inorganic constituents of the waste, and may take the form of solid lumps or particulates carried by the flue gas. The flue gases must be cleaned of gaseous and particulate pollutants before they are dispersed into the atmosphere. In some cases, the heat generated by incineration can be used to generate electric power.

Incineration with energy recovery is one of several waste-to-energy technologies such as gasification, plasma arc gasification, pyrolysis and anaerobic digestion. Incineration may also be implemented without energy and materials recovery.

In several countries, there are still concerns from experts and local communities about the environmental impact of incinerators (see arguments against incineration).

Material	**BTU per pound
Plastics	11,000 – 20,000
Rubber	10,900
Newspaper	8,000
Corrugated Boxes (paper)	7,000
Yard Wastes	3,000
Food Wastes	2,600
Average for MSW	4,500 – 4,800

Fig 5. The Energy Values Of Different Materials When Incinerated

Compared with the Incineration, Methanisation results in: an absence of release of toxic fume. There is no thermochemical transformation of the products, particularly the synthetic plastics, which are the main cause of the harmful effects problems; and so, the populations' acceptance of an absence of residues treatment fume (REFIOM), an absence of solid residues to treat (blast-furnace slags), a sensitizing with the reduction of waste to the source. With the incineration one can burn everything and anything, no matter what the consequences on health and the environment can be. A tool for fighting against the greenhouse effect. Instead of converting carbon into carbon dioxide only, methanisation converts carbon into methane. This biogas replaces fossil energy and avoids the fossil carbon destocking, and therefore the increase in the carbon dioxide concentration in the atmosphere[17]

Like other energies resulting from the renewable biomass, biogas does not generate gas increase with greenhouse effect, contrary to the Incineration. Better: Methanisation provides the function of "carbon well" by the storage of carbon in the grounds in the form of organic soil conditioner or in storage centers when the digestors's sludge is intended for hiding. Indeed stored carbon is not immediately transformed into CO₂, which differs the emissions from gas with greenhouse effect by time.

7. Conclusion

Anaerobic digestion involves a considerable reduction in the organic load, thanks of the biological reactions, and the

polluting load of the digested sludge. It is thus, a complete depollution. A correctly controlled anaerobic digestion leads to very high rates of purification. It also has other advantages:

Economic advantages:

Additional income

Autonomy in heat in a context of increase in the cost of fossil energies

Diversification of outlets for crops

Reduction of manure purchase thanks to valorisation of digested sludge

Agronomic advantages

Transformation of the liquid manure and the manure into a fertilizer, more easily assimilated by the plants, with reduction in the odours and the disease-causing agents

Organic waste processing for competitive prices

Insect elimination at the storage pit

Odours suppression

Environmental advantages[18]

Biogas resulting by anaerobic digestion is a source of renewable energy because it replaces fossil energy

Reduction of pollution due to nitrogen stripping (refer to the "Sludge")

Sustainable management of organic waste

Methanisation allow us, at the same time, to treat our waste without health and environment risks and to produce an invaluable biogas in great quantity with multiple applications. Moreover the production of a quality compost, if the choice is made correctly, will be a contribution of humus which is very appreciated by the farmers, As for the Incineration, it is enough to listen to experts, who are not subjected to the special interest manufacturers group and the owners of incinerators They tell us of wisdom and precaution principle :

References

- [1] Kalloum, S., et al., Biogas production from the sludge of the municipal wastewater treatment plant of Adrar city (south-west of Algeria). *Biomass and Bioenergy*, 2011. 35(7): p. 2554-2560.
- [2] Jiménez, S., M.C. Cartagena, and A. Arce, Influence of operating variables on the anaerobic digestion of crude and treated vine shoots. *Biological Wastes*, 1989. 29(3): p. 211-220.
- [3] Jiang, J., et al., Prospects of Anaerobic Digestion Technology in China. *Tsinghua Science & Technology*, 2007. 12(4): p. 435-440.
- [4] Jiang, X., S.G. Sommer, and K.V. Christensen, A review of the biogas industry in China. *Energy Policy*, 2011. 39(10): p. 6073-6081.
- [5] Kafle, G.K. and S.H. Kim, Anaerobic treatment of apple waste with swine manure for biogas production: Batch and continuous operation. *Applied Energy*, 2013. 103(0): p. 61-72.
- [6] Zamalloa, C., N. Boon, and W. Verstraete, Anaerobic diges-

- tibility of *Scenedesmus obliquus* and *Phaeodactylum tricornutum* under mesophilic and thermophilic conditions. *Applied Energy*, 2012. 92(0): p. 733-738.
- [7] Anceno, A.J., et al., Evolution of N-converting bacteria during the start-up of anaerobic digestion coupled biological nitrogen removal pilot-scale bioreactors treating high-strength animal waste slurry. *Bioresource Technology*, 2009. 100(14): p. 3678-3687.
- [8] 4510243 Anaerobic digestion process of wastes containing cellulose: Ryoich Haga, Masahiko Ishida, Yoji Odawara, Hitachi, Japan assigned to The Agency of Industrial Science and Technology. *Environment International*, 1986. 12(5): p. VIII.
- [9] Álvarez, J.A., I. Ruíz, and M. Soto, Anaerobic digesters as a pretreatment for constructed wetlands. *Ecological Engineering*, 2008. 33(1): p. 54-67.
- [10] Carrère, H., et al., Pretreatment methods to improve sludge anaerobic degradability: A review. *Journal of Hazardous Materials*, 2010. 183(1-3): p. 1-15.
- [11] Affes, R., et al., Saponification pretreatment and solids recirculation as a new anaerobic process for the treatment of slaughterhouse waste. *Bioresource Technology*, 2013. 131(0): p. 460-467.
- [12] Zhu, B., et al., Characteristics and biogas production potential of municipal solid wastes pretreated with a rotary drum reactor. *Bioresource Technology*, 2009. 100(3): p. 1122-1129.
- [13] Walsh, J.L., et al., Utilization of biogas. *Biomass*, 1989. 20(3-4): p. 277-290.
- [14] Borowski, S. and J.S. Szopa, Experiences with the dual digestion of municipal sewage sludge. *Bioresource Technology*, 2007. 98(6): p. 1199-1207.
- [15] Zawieja, I., L. Wolny, and P. Wolski, Influence of excessive sludge conditioning on the efficiency of anaerobic stabilization process and biogas generation. *Desalination*, 2008. 222(1-3): p. 374-381.
- [16] Walker, L., W. Charles, and R. Cord-Ruwisch, Comparison of static, in-vessel composting of MSW with thermophilic anaerobic digestion and combinations of the two processes. *Bioresource Technology*, 2009. 100(16): p. 3799-3807.
- [17] Jenkins, B.M., et al., Combustion of residual biosolids from a high solids anaerobic digestion/aerobic composting process. *Biomass and Bioenergy*, 1997. 12(5): p. 367-381.
- [18] Wang, Z. and M.M. Calderon, Environmental and economic analysis of application of water hyacinth for eutrophic water treatment coupled with biogas production. *Journal of Environmental Management*, 2012. 110(0): p. 246-253.