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Production of Methane from Mesophilic Anaerobic Digestion of Sewage Sludge in Morocco

Siham Belhadj[1*], Hassan El Bari[1], Fadoua Karouach[1], Yassine Joute[1], Arturo Francisco Chica[2], María de los Ángeles Martín Santos[2]

[1]Biogas Team - Biotechnology Laboratory Environment and Quality (LABEQ) - Faculty of Sciences - Ibn Tofail University - Kenitra – Morocco

[2]Inorganic Chemistry and Chemical Engineering Department - University of Cordoba - Spain

*Corresponding Author Email address: siham.belhadj@yahoo.fr

ABSTRACT

Sewage sludge is an unwanted and inevitable by-product from wastewater treatment plants, the purpose of which is to clarify wastewater, and present a surcharge, which can contaminate water and soil, causing a big environmental problem. The treatment by anaerobic digestion can be used to reduce the pollution of this type of waste, while producing methane, which is a renewable energy. The objective of this study is to determination of the methane yield coefficient, to identify the potential for energy generation from the anaerobic digestion of sewage sludge in Morocco, and keeping the stability of physic-chemical parameters in the environment. The experiment test were realized in laboratory scale using the 1-L Pyrex mesophilic reactor (CSTR) at 37°C , and using as raw material the sewage sludge produced from wastewater treatment plant. The results obtained in this study shows that this waste can be readily biodegraded by anaerobic digestion, since over 77% of the initial VS is removed, and indicate that the anaerobic digestion under mesophilic conditions, presents a reliable solution for production of methane by treatment of this type of waste, with a methane yield coefficient is 0.245 L_{STP}/g VS (equivalent to 0.1975 L_{STP}/g TS). Anaerobic digestion could be a good option for revalorizing this available feedstock. In fact the results indicate that the anaerobic digestion of sewage sludge in Morocco, can generate 50 460 000 m^3/year of methane, for an estimated quantity of 255 500 tons of sludge per year.

Keywords: Anaerobic Digestion – Sewage Sludge - Methane yield – mesophilic conditions – Potential energy – renewable energy - Biodegradability – Volatiles Solids.

1. INTRODUCTION

Progress, development and consumption are among the terms which characterize best our current life. However, the improvement of our lifestyle through the industrialization of our society has generated pollution that weakens and destroys our vital environment. This alarming situation has fortunately prompted a universal consciousness for the protection and preservation of our environment. The purification of waste water before discharge into nature is an effective means to combat against pollution. However, the sludge generated by this activity and constitutes a new danger to the environment due to their high concentration of pollutant load **[1]**.

Sewage sludge is an unwanted and inevitable by-product from wastewater treatment plants, the purpose of which is to clarify wastewater. Sewage sludge is generated by sedimentation both before and after the bio-treatment process, named as primary sludge and waste activated sludge (or secondary sludge), respectively **[2]**. Sewage sludge is now becoming a worldwide environmental problem because of its increasing production and its high contents of organic waste and pathogens, as well as xenobiotics and heavy metals. If not being treated or disposed properly, this dangerous waste may cause the environment and human as well as animal health exposed to tremendous threat **[3]**.

Due to their high organic fraction, anaerobic digestion is one of the fundamental processes in sewage sludge treatment for reducing and stabilizing the organic solids. Reduction of sludge solids is not the only objective of this process, but production of energy in the form of biogas, and a high quality final product are achieved. Significant inactivation of pathogens also occurs during the anaerobic digestion, depending on the process temperature and technological layout **[4]**.

On waste water treatment plants of small and medium capacity, the waste water sludge cannot be economically stabilized by the conventional anaerobic treatment of low dry matter content and continuous feeding. Thus, the sludge is usually stabilized by composting in that case. At waste water treatment plants of great capacity, the sludge is stabilized by anaerobic treatment of liquid, continuous technology which is often followed by composting, in order to achieve better material characteristics of the end product **[5]**.

The production of sewage sludge is huge and has been a worldwide problem. In 2006, the production of sewage sludge in Morocco was about 435 600 tons of dry weight, for a rate of connection in the wastewater treatment plant of 100% **[6]**. Currently, the production of sewage sludge in Morocco is estimated approximately at 255 500 tons of dry weight / year, assuming that a rate of connection to wastewater treatment plants is about 50%.

Biogas energy is widely used in developing countries, but few experiences exist in Morocco **[7]**.

Anaerobic digestion is an alternative strategy for the treatment of sewage sludge in Morocco. Anaerobic digestion offers the possibility of recovering energy as heat and / or electricity and reduces greenhouse gas emissions.

The objective of this study is to evaluate the feasibility of anaerobic digestion of sewage sludge while producing methane, and to identify the corresponding potential for energy generation in Morocco. The loads added of the organic matter for feeding the digester is measured by calculating and following up the value of volatile solids in the process, and the production of methane, with an increase in the volume of organic matter added between loads to avoid the problem of overloading of environment.

2. MATERIELS AND METHODS

2.1 Experimental design:

The reactor used in the laboratory for anaerobic digestion of sludge, consisted of 1-L Pyrex reactor; it is a CSTR

"Continuous Stirred-tank reactor", equipped with magnetic stirring. This reactor is characterized by four orifices, the first to insert the substrate, the second one for the ventilation of biogas, the third for inert gas injection (nitrogen) to maintain anaerobic conditions, and the last one to remove effluents. The temperature was maintained by means of a thermostatic jacket containing water at 37°C for mesophilic conditions. The volume of methane produced during the digestion process was measured by using 1-L Boyle-Mariotte reservoir connected to the reactor. To remove the CO_2 produced during the process, tightly closed bubblers containing a NaOH solution (6 N) were connected between the two elements. It is necessary sometimes to close the pipe of the NaOH solution that links the reservoir to the reactor. The methane volume produced can be determined from the volume of water ejected from the reservoir.

2.2 Inoculum:

The reactor was inoculated with methanogenically-active granular biomass obtained from a mesophilic anaerobic reactor of wastewater plant in Marrakech. The inoculum was selected on the basis of their high methanogenic activity **[8]**. This biomass contains a methanogenic flora capable of degrading the effluent; these microorganisms can accelerate the starting of the anaerobic digestion. The chemical composition of the inoculum is shown in TABLE 1.

TABLE 1. Chemical composition of the biomass of the inoculum

Parameters	Values
pH	6.69
Moisture (%)	97.09
Total Solids TS (g/L)	29.07
Mineral Solids MS (g/L)	8.57
Volatile Solids VS (g/L)	20.50

2.3 Substrate:

The materiel used as substrate in this experiment to study the mesophilic anaerobic digestion, is sewage sludge produced from wastewater treatment plant (Marrakech - Morocco). The physico-chemical characteristics of the sludge are shown in TABLE 2.

TABLE 2. Physico-chemical parameters of substrate

Parameters	Values
pH	6.89
Moisture (%)	97.1
Alkalinity (mg/L)	3250
Total Solids TS (g/L)	28.78
Mineral Solids MS (g/L)	5.58
Volatile Solids VS (g/L)	23.20

2.4 Experimental Procedure:

The mesophilic anaerobic reactor was initially loaded with 8g VS of granular sludge as inoculum. The nutrient and trace element solutions were added when the sludge was loaded **[8,9]**. Both solutions are very important for activating bacterial growth and metabolism at the beginning of the process and to compensate for the shortage of nutrients in the substrate **[10]**.

At first, the reactor was fed with a synthetic solution composed of glucose, sodium acetate and lactic acid (GAL solution) at concentration of 50 g/L, 25 g/L and 20.8 mL/L, respectively **[11]**; the organic load added to the reactor was gradually increased from 0.25 to 1.00 g VS, during 15 days. This step allows to activate the biomass and to ensure a good start-up of the process. After this stage, the reactor was fed with 1.00 g VS, in which the percentage of sewage sludge used in the VS was increased from 25% to 100% after four loads. Once this biomass acclimatization step was finished, the organic load added to the reactor was gradually increased from 1.00 to 3.00 g VS with sewage sludge. The volume of methane was measured as a function of time. During this stage, the experiment is performed in batch mode, over a 35-day period.

This scalability must be adapted to the specific activity of microorganisms, as a risk of organic overload can cause an imbalance or malfunction of the process, and therefore the stopping of anaerobic digestion. The methane production has been completed, depending on the rate of biochemical reactions and biodegradability of the microorganisms during anaerobic digestion.

2.5 Chemical Analysis:

The following parameters were analyzed in the laboratory: pH, moisture, alkalinity (Alk), total solids (TS), mineral solids (MS), volatile solids (VS). All analyses were carried out according to '' Standard Methods for the Examination of Water and Wastewater'' **[12]**.

3. RESULTS AND DISCUSSION

The experimental results were used to evaluate the behavior of the anaerobic digestion of sewage sludge. Stability, biodegradability and methane yield are determined by tracking parameters of the experiment.

3.1 Stability of the reactor:

Several experiments have shown that they exist a number of factors that influence the process of anaerobic digestion, for this it is necessary to ensure that the experiment is performed under stable conditions, it is very important in order to obtain a highest biogas yield **[13]**. The stability of the process is evaluated based on the evolution of the pH and alkalinity, during the mesophilic anaerobic digestion process.

The optimal pH range for mesophilic anaerobic digestion is close to neutrality, varying for each type of bacteria between 6.5 and 7.5 **[14]**.

The reactor has shown no signs of instability during this experiment, since the environment was always maintained in favorable alkaline conditions for anaerobic digestion. The mean pH value during the experiment is the order of 7.71.

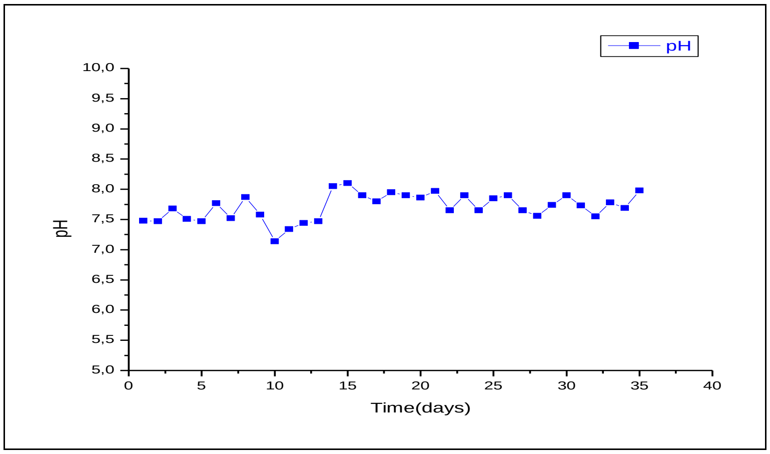

Figure 1. The pH variation during the mesophilic anaerobic digestion of sewage sludge a function of the time

Fig. (1) shows that the pH in the digester is controlled in the range limited all through the mesophilic anaerobic digestion. This stability is important because the ecosystem and more specifically, the methanogenic microorganisms are very sensitive to variations in pH, which can lead to the generation of AGV non-ionized forms, which inhibit the process.

The alkalinity caused by bicarbonates of calcium must be relatively high to function properly. One considers in general, it is necessary to have at least 1000 mg/L of alkalinity (expressed in mg of $CaCO_3$ per liter) in a reactor that works in good condition **[15]**.

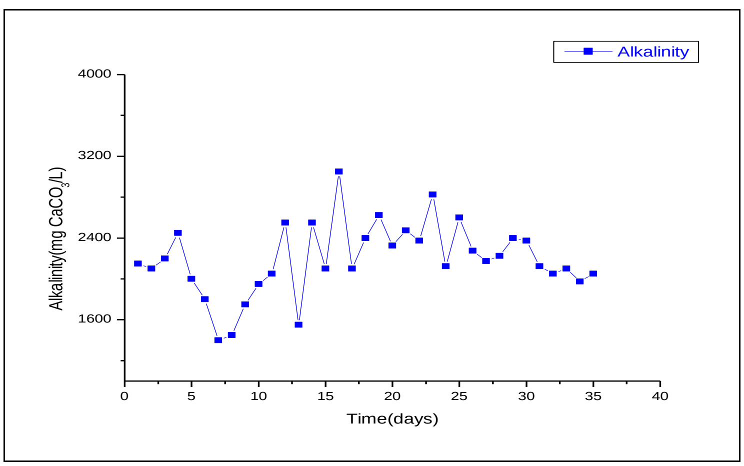

Figure 2. The Alkalinity variation during the mesophilic anaerobic digestion of sewage sludge a function of the time

Fig. (2) shows the alkalinity in the reactor. For the variation of the alkalinity, which is a variable related to the regulatory capacity or pH buffer effect, it should be noted that, it has had instability at the beginning of the anaerobic digestion, but during the process, this variable remained, more or less, stable in the range of 1700-2400 mg CaCO3/L. The mean value of alkalinity is located within acceptable limits for the development of normal digestion **[16]**.

Consequently the stability of these conditions indicates that the conduct of the increasing load is well underway, which promotes the proper functioning of the anaerobic digestion order to ensure a remarkable biodegradability, and thus obtain a good production of methane.

3.2 Evaluation of organic matter:

Another parameter that controls the anaerobic digestion is the evolution of organic matter during the experiment, expressed as volatile materials.

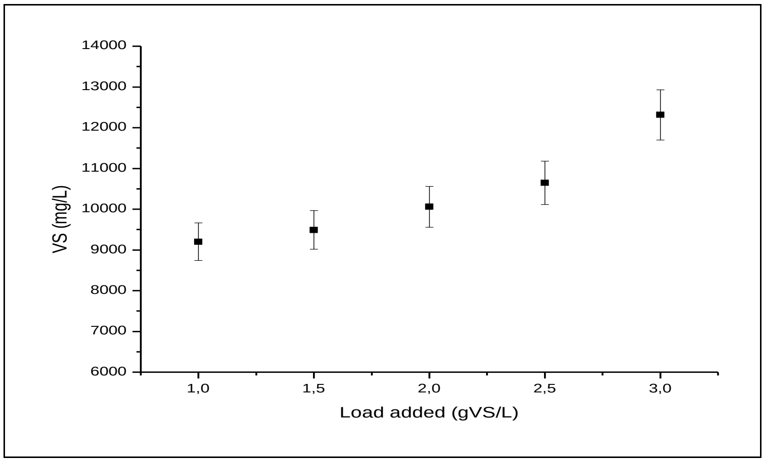

Figure 3. Variation of the concentration of VS during the mesophilic anaerobic digestion of sewage sludge

Fig. (3) represent the concentration of organic matter a function of the load added, shows that the determination of the concentration of volatiles provides information on the total organic matter, such that from the consistency of the results.

The increase in the concentration of organic matter in the batch reactor is caused by the accumulation of non-biodegradable substrate **[17]**.

3.3 Biodegradability:

The biodegradability of the studied residue indicates the percentage of the substrate, transformed and eliminated by the process of anaerobic digestion.

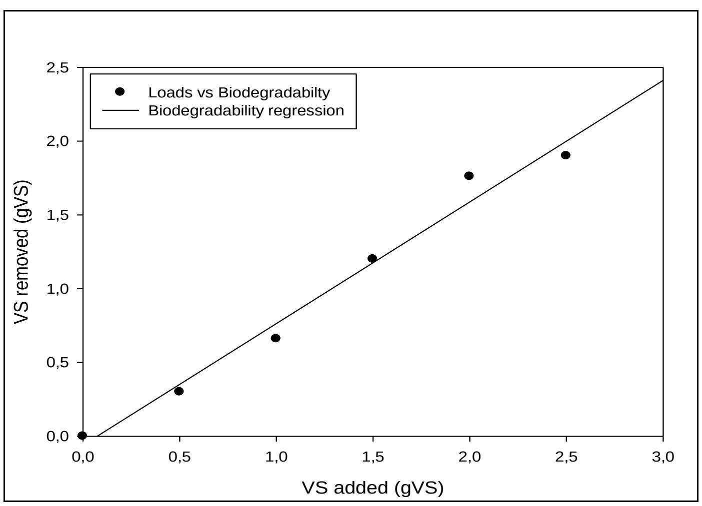

Figure 4. The relation between VS added and VS removed

The biodegradability can be calculated by relative to the organic matter added or relative to the total organic matter available in the reactor. Fig (4) shows the relation between the VS added and VS removed, can be observed that there is a proportionality between the variables, with the slope of the linear regression for pairs of values of (VS added, VS removed), and the value corresponding to the biodegradability of sludge, which in this case reached a value of 0.772 g $VS_{removed}$/g VS_{added} (77% of substrate added is removed).

3.4 Methane yield coefficient:

The volume of methane was measured as a function of time. The experiment is performed in batch mode, over a 35-day period.

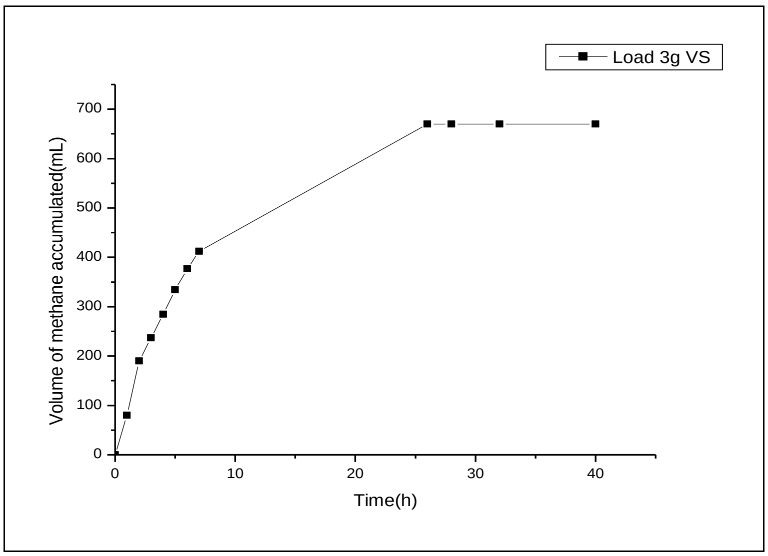

Figure 5. Variation of the methane volume accumulated as a function of time, for the load of 3.00g SV/L

Fig. (5) shows that the volume of methane production increases with the increase in load of 3.00g SV/L. This phenomenon is due to the degradation of the added available organic matter that emerges in the form of methane, with the maintenance of the stability of the control parameters of anaerobic digestion.

As previously mentioned, a larger quantity of volume of methane was produced after the increase of the load. In addition, the slopes of the curves also decrease with time at the end of each load. This decrease in slope, accompanied by a reduction in the volume of methane produced can be explained by the progressive reduction in the concentration of biodegradable substrate.

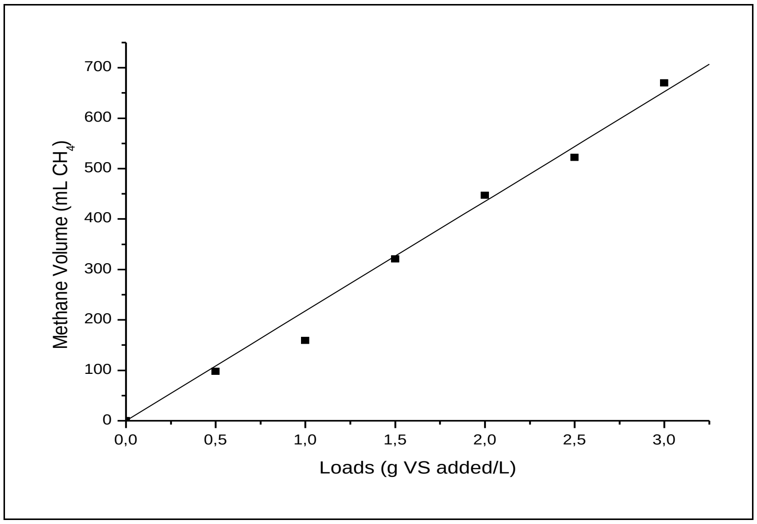

Figure 6. The methane production during the anaerobic digestion of sewage sludge for different loads (from 1.00g to 3.00g SV)

Fig. (6) shows that the methane yield coefficient was determined from the experimental maximum methane volume produced (G_T) and the final and initial SV, which were known in all loads. The methane yield coefficient coincides with the slope of the regression line and was found to be 0.245 L_{STP} /g VS (equivalent to 0.1975L_{STP}/g TS).

One can deduce that theoretically the range of methane production from anaerobic digestion of sewage sludge is between 0.2 and 1.2 L / g dry organic matter (which represent the volatiles dry) **[18]**. Other research has shown that anaerobic digestion of sewage sludge can produce a methanogenic potential of 155 $NLCH_4$/ kg VS added, with a reduction rate of VS of 59% **[19]**.

While the results obtained in this experiment are similar and have not exceeded the range reported in the literature. This shows that the anaerobic digestion of this type of waste is a reliable solution for the production of methane, which can be valued as a source of renewable energy, and that will allow to save significant gains.

3.5 Estimating the potential energy generation from sewage sludge in Morocco:

In Morocco, the sewage sludge constitutes a new danger to the environment due to their high concentration of pollutant load, because is essentially dried and deposited in the proximity of treatment plants or in public discharges or in certain case dispersed on the soil without previous treatment, this dangerous waste may cause the environment and human as well as animal health exposed to tremendous threat. The anaerobic digestion is one of the fundamental processes in sewage sludge treatment for reducing and stabilizing the organic solids. Reduction of sludge solids is not the only objective of this process, but production of renewable energy.

The annual sludge production at the level of wastewater treatment stations in Morocco was evaluated based on the following: the waste waters treatment produce the equivalent of 30 to 40 grams of dry material (MS)/inhabitant/day in the form of sludge. In 2006, the production of sludge at the level of waste water treatment stations is estimated to 435 600 tons/year for an agreement ratio to STEP of 100% **[6]**. If one assumes that the rate of connection to wastewater treatment plants is approximately 50% in Morocco, then the current annual production of sewage sludge is estimated at 255 500 tons of dry matter (for a Moroccan population of 35 million people).

Following this laboratory scale experiment, on a substrate of sewage sludge from a treatment plant wastewater in Morocco, the results indicate that 1.24 g TS (equivalent to 1g VS) can produce 0.245 L_{STP} of CH_4; so 1g TS (or dry matter) can produce 0.1975 L_{STP} of CH_4 (197,5 m^3/ tons dry matter of sewage sludge). The results indicate that the anaerobic digestion of sewage sludge in Morocco, can generate 50 460 000 m3/year of methane, for an estimated quantity of 255 500 tons of sewage sludge per year.

The present study prove that anaerobic digestion is a recommended technology that can be applied to reduce the pollution of sewage sludge, by the reduction of organic matter, and to produce methane as a renewable energy.

4. CONCLUSION

The experience of the mesophilic anaerobic digestion of sewage sludge showed no signs of instability throughout the process, which lasted 35 days, with a pH of around 7.7, and alkalinity was always greater than 1000 mg / L, indicating that the process works favorably, without the risk of acidification. The results obtained through this research study shows that this waste can be readily biodegraded by anaerobic digestion, since over 77% of the initial VS is removed.

Anaerobic digestion could be a good option for revalorizing this available sewage waste, this is proved by the increase in the volume of methane collected which could reach 670mL of methane for a load of 3.0g VS added, with a methane yield coefficient is 0.245L_{STP}/g VS (equivalent to 0.1975L_{STP}/g TS). This study prove that anaerobic digestion is a recommended technology that can be applied to reduce the pollution of sewage sludge, by the reduction of organic matter, and to produce methane as a renewable energy that we can exploit in different way. The results of this work indicate that the anaerobic digestion of sewage sludge in Morocco, can generate 50 460 000 m^3/year of methane, for an estimated quantity of 255 500 tons of sewage sludge per year. On the basis of results of this experiment, we can deduce that the sewage sludge is a potential source for the production of renewable energy, and the process of anaerobic digestion presents a reliable solution for the treatment of this type of waste.

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