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Research Article

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Descriptive and multivariate analysis of the methane production by mesophilic anaerobic digestion of sewage sludge in Morocco

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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 waste and producing methane. Multivariate compositional data analysis methods were used to investigate physico-chemical parameters during anaerobic digestion of sewage sludge in Morocco. The objective of this study is to determine the coefficient of methane efficiency, identify the potential for energy production from anaerobic digestion of sewage sludge in Morocco, while maintaining the stability of physico-chemical parameters in the environment. To do this, a series of analyzes of descriptive and quantitative data was studied physico-chemical parameters. Multivariate statistical analysis was carried out at the entrance and exit of the activated sludge treatment from tests carried out experiments in a laboratory scale using the mesophilic reactor 1-L Pyrex (CSTR) to 37°C, and using as raw material the waste water sludge produced from the processing station wastewater. The results of statistical analyzes indicate that the percentage of variance is 55.29% and 18.59% respectively for the axes F1 and F2 and the total information is estimated at a percentage of 73.58%. The correlation circle confirms the correlation between SVo and SVi parameters which could be explained by a good biodegradability of organic matter. Thus the results indicate that there is a good performance at the mesophilic digestion due to the stability of physicochemical parameters and proper methane yield.

Keywords: Anaerobic Digestion, Sewage Sludge, Methane yield, Principal Component Analysis, Biodegradability, Volatiles Solids.

INTRODUCTION

Anaerobic digestion is the most suitable option for the treatment of high strength organic effluents. Anaerobic digestion has been touted as the best process for the stabilization of sludge generated from the aerobic treatment of wastewater. Its potential advantages over other stabilization processes include; the production of energy as methane, a reduction of 30–50% of sludge volume requiring ultimate disposal, the production of sludge residue generally free from offensive odours when fully digested and a high rate of pathogen destruction, particularly with the mesophilic process [1].

However, foaming and low efficiency in volatile solids reduction have limited the application of conventional anaerobic sludge digestion [2,3]. Poor VS destruction efficiency of colloidal particles in waste has been reported as due to physical limitations of low biodegradability [4] and the degradation of insoluble substances has been reported as a rate-limiting step for anaerobic digestion [5]. The poor degradation of colloidal particles has resulted in long retention times (20–30 days) in anaerobic processes [6] and above 35 days in some full-scale operations primarily designed for wastes stabilization.

There is a growing interest in alternate energy sources as a result of increased demand for energy coupled with a rise in the cost of available fuels. Rapid industrialization has resulted in the generation of a large quantity of effluents with high organic contents, which if treated suitably, can result in a perpetual source of energy[7,8]. In spite of the fact that there is a negative environmental impact associated with industrialization, the effect can be minimized and energy can be tapped by means of anaerobic digestion of the wastewater [9,10].

However the multivariate methods such as Principal Component Analysis (PCA) can provide further interpretation in environmental studies. Indeed, by plotting the principal component, the interrelationships between different variables may be visualized, and sample patterns, grouping similarities or differences could easily be interpreted[11]. Several environmental studies used the PCA for results interpretation. Larif et al. [12] established the relationship between different atmospheric pollution variables by using the PCA approach. In addition, Kunwar a et al. [13] used the PCA method for studying the environmental factors and management practices, controlling oxygen dynamics in agricultural irrigation ponds in a semiarid Mediterranean region.

The objective of this study is to investigate the usefulness of multivariate statistical techniques for the evaluation and the correlation between parameters, in order to obtain better information on the feasibility of anaerobic digestion of sewage sludge production methane.

EXPERIMENTAL SECTION

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 [14] and [15].

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 [15]. This biomass contains a methanogenic flora capable of degrading the effluent; these microorganisms can accelerate the starting of the anaerobic digestion.

Substrate

The material used as a substrate in this experiment to study the mesophilic anaerobic digestion, is the sewage sludge produced from the sewage treatment plant (Marrakech-Morocco).

Experimental Procedure

The mesophilic anaerobic reactor was initially loaded with 8g VS of granular sludge as inoculums .The nutrient and trace element solutions were added when the sludge was loaded [15,16]. 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 [14,17].

Principal Component Analysis

All quantitative analyzes of sewage sludge were evaluated by multivariate statistical analysis to confirm the feasibility of anaerobic digestion of sewage sludge in methane production, and identify the potential corresponding to the energy Morocco. A short introduction to these principles is given below.

Principal Component Analysis (PCA) is a method used for studying the variability of a data set with many variables and for identifying covering variables. The PCA looks for a few linear combinations of the variables which can be used to summarize the data, losing as little informations as Larif et all. [14,17].

Principal component analysis (PCA) is a useful statistical tool to summarize all the information encoded by the physico-chemical parameters indicating the quality of sludge [12]. The experimental matrix is composed of (5x10) by a principal component analysis (PCA).

RESULTS

Production of methane (CH_4) cumulate (mL) according to the load concentration

Methane production is between 159 mL from 1g and 670 mL from 3g (figure 1).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 $NLCH_4$/kgVS 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.

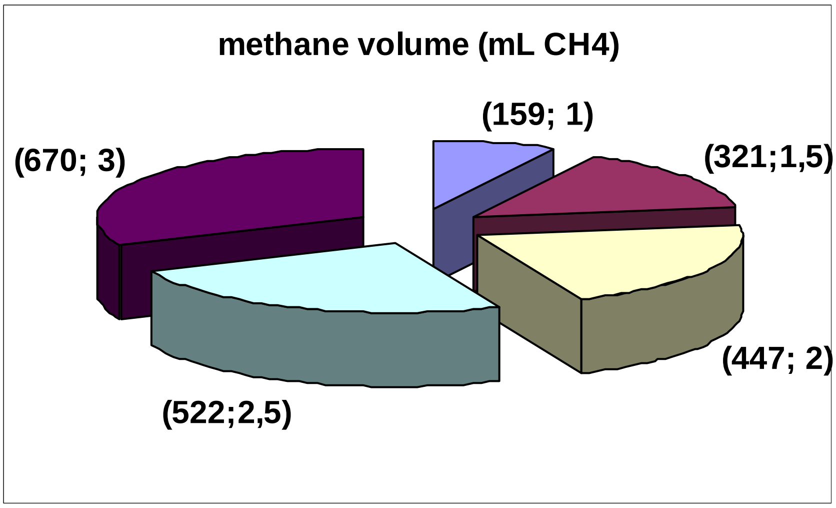

Figure 1: The methane production during the anaerobic digestion of sewage sludge for different loads (from 1.00g to 3.00g SV)

Figure 2 is noted that after that progressively increases the concentration of organic matter in sludge (SV) in methane production increases. This could be explained by the strong correlation between CH_4 and SV with R = 0.987.

This shows that the anaerobic digestion of this type of waste is a reliable solution for the production of methane.
The methane yield coincides well with the slope coefficient of the regression line and was found to be 0.245 LSTP/g SV (equivalent to 0.1975LSTP /g ST).

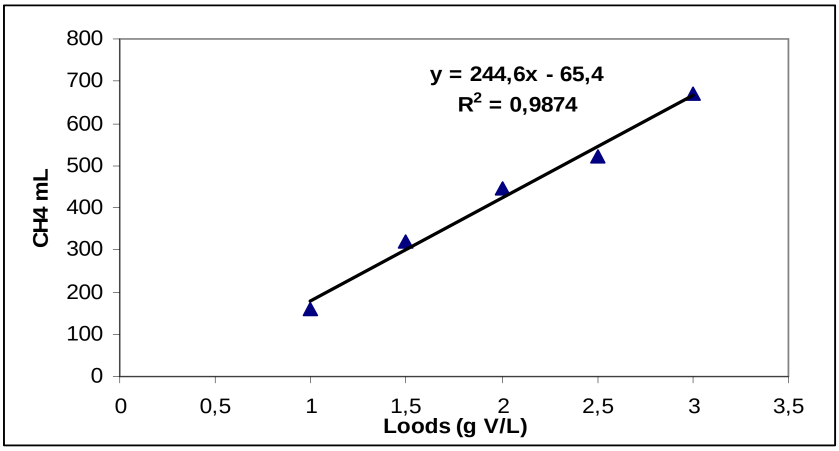

Figure 2: Regression between changes in CH_4 concentration and load

3.2 Descriptive Statistics

The table 1 represents the various values descriptive of the physicochemical parameters of the activated sludge.

Table 1: Is the descriptive analysis of physico-chemical parameters

Variable	Minimum	Maximum	Moyenne	Ecart-type
pHi	7,550	7,950	7,748	0,158
(Alcalinity)i	2050,000	2600,000	2365,000	198,116
TSi	15,950	16,980	16,348	0,457
MSi	3,780	7,440	5,734	1,507
VSi	9,540	12,190	10,614	1,094
pHo	7,560	7,980	7,756	0,167
(Alcalinity)o	2125,000	2325,000	2190,000	85,878
TSo	15,810	16,830	16,312	0,383
MSo	5,690	7,300	6,314	0,599
VSo	9,200	10,640	9,998	0,643

***NB**: **i:**Input load ; **o**:Output load ;Alkalinity (mg/L),Total Solids **TS** (g/L), Mineral Solids **MS** (g/L), Volatile Solids **VS** (g/L)*

Principal component analysis

The first two principal axes are sufficient to describe the information provided by the data matrix. Indeed, the percentages of variance are 55.29% and 18.59% for the axes F1 and F2 respectively. The total information is estimated to a percentage of 73.58%. The principal component analysis (PCA) [20] was conducted to identify the link between the different variables. Bold values are different from 0 at a significance level of $p = 0.05$.

Correlation matrix

Correlations between the ten descriptors are shown in table 2 as a correlation matrix, in figure 3 these descriptors are represented in a correlation circle. The Pearson correlation coefficients are summarized in the following table 2. The obtained matrix provides information on the negative or positive correlation between variables [21].

Table 2: Correlation matrix between different obtained descriptors

Variables	pHi	(Alcalinity)i	TSi	MSi	VSi	pHo	(Alcalinity)o	TSo	MSo	VSo
pHi	**1**									
(Alcalinity)i	0,821	**1**								
TSi	0,500	0,103	**1**							
MSi	0,700	0,359	0,900	**1**						
VSi	-0,700	-0,359	-0,900	**-1,000**	**1**					
pHo	-0,300	-0,667	-0,100	-0,300	0,300	**1**				
(Alcalinity)o	0,667	0,395	0,564	0,410	-0,410	0,154	**1**			
TSo	0,300	0,154	-0,400	-0,200	0,200	0,500	0,103	**1**		
MSo	0,600	0,205	0,700	0,900	-0,900	-0,100	0,154	0,100	**1**	
VSo	-0,500	-0,103	**-1,000**	-0,900	0,900	0,100	-0,564	0,400	-0,700	**1**

Bold values are different from 0 at a level significant for $p < 0.05$
*-**VSi** is heavily negatively correlated with **MSi** r = -1*
*-**VSo** is heavily negatively correlated with **TSi** r = -1, this could be explained by*
VS = TSi-MSi

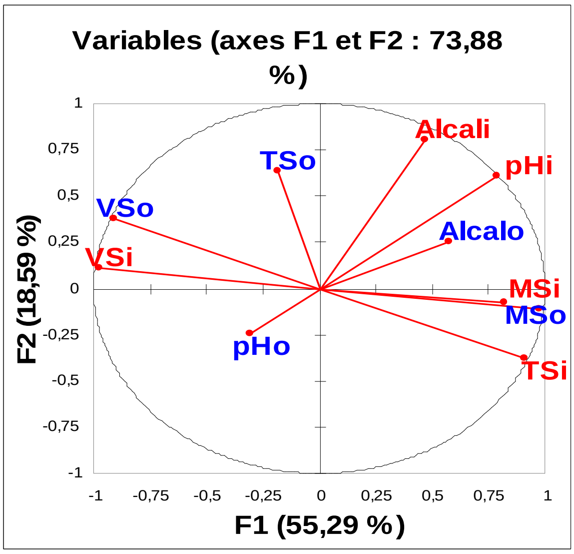

Figure 3: Correlation circle between the different variables

Correlation circle

Principal component analysis (PCA) was also performed to detect the connection between the different variables. The principal component analysis revealed from the correlation circle (Figure 3) shows that the F1 axis (55.29%) represents the (Total Solids) **TS** of the variance while the axis F2 (18.59 %) of the variance is located by the other. On the other hand, the correlation circle (Figure 1) indicates the correlation between parameters physico-chimiques:

DISCUSSION

The Cartesian diagram (Figure 4) Analysis of projections according to the plane F1–F2 (77.88%) of the total variance of the parameters physico-chimiques (Figure 4).

There is a strong correlation between **VSi** and **VSo** Plan **A** of the (Figure 4) which could be explained by a good degradation of sludge has reached 0.772 g VS removed/ g VS added (77% of the added substrate is removed) [22].

Process stability is assessed on the basis of the change in pH and alkalinity, as the mesophilic anaerobic digestion process. The variation of alkalinity is a variable linked with the regulatory capacity or pH buffering effect, which might be explained by the instability at the start of the anaerobic digestion.

Figure 4 show that VSo is strongly correlated with VSi which confirms that there is a good biodegradability of organic matter and that there was a decrease between SV to the output (Table 1). However confirmation of the good yield methane (670: 3) is located in the same plane A (VSo, VSi) [23].

However it was a good performance from the mesophilic digestion could be explained by a specific growth rate and wealth in anaerobic microorganisms [24,25].

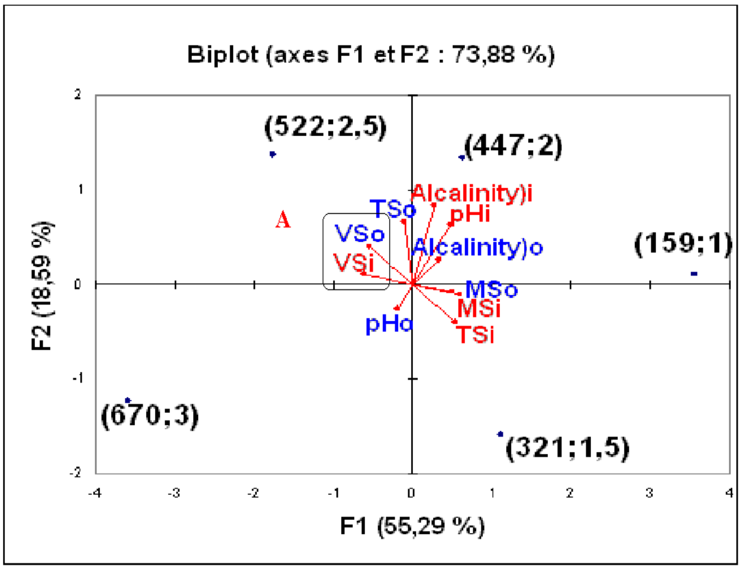

Figure 4: Factorial distribution of variable space on the plan 1×2.

CONCLUSION

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 0.245LSTP/g VS.

Statistical analyzes confirmed good correlation between VSi and VSo parameters which could be explained by a good biodegradability of organic matter. So we got a good performance mesophilic digestion following the stability of physicochemical parameters and good yield methane.

Consequently, this valorization process could be a viable option for the centralized management of the studied wastes.

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