IMPROVEMENT OF ANAEROBIC DIGESTERS USING PRE-SELECTED MICRO-ORGANISMS

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ABSTRACT

*Anaerobic digestion is a natural process that converts biomass to energy. Biomass is any organic material that comes from plants, animals or their wastes. Anaerobic digestion has been used for over 100 years to stabilize municipal sewage and a wide variety of industrial wastes. Generally, the anaerobic process still remains a prim subject of research, due to the biogas evolved as a by-product of such a process. In this study four pilots were operated in the batch mode for 40 days to determine the effect of using pre-selected microorganisms on the performance of anaerobic digesters. The main parameters of this research focus on studying the reduction of organic fraction (expressed as VSS and COD) and the production of biogas in order to determine the reaction kinetics (order of reaction and reaction rate). The dosages of the used microorganisms were 0.1%, 0.2% and 0.30% of the sludge total volume. Experimental results show that the use of the microorganisms improved anaerobic digestibility as VSS destruction rate KVSS increased from 0.0116 (d-1) to 0.0277 (d-1), the COD degradation rate KCOD increased from 6.49*10-4 (gvss-1.L.d-1) to 9.8*10-4 (gvss-1.L.d-1) where as the biogas production rate decreased from 0.514 (L / g.COD destructed) to 0.453 (L/g.COD destructed).*

Keyword: Anaerobic digesters, COD, pre-selected microorganisms, VSS, gas production

1. INTRODUCION

Anaerobic digestion plays an important role in wastewater treatment processes. It includes a series of biochemical processes by different microorganisms to degrade organic matter under anaerobic conditions. Methane, the digestion byproduct, is a rich source of renewable energy, which can help to replace fossil fuel to contribute to environmental conservation and sustainability. Therefore, anaerobic digestion is widely used as an attractive means for wastewater treatment around the world while more and more new process configurations are continuously being developed (Pavlostathis and Giraldo-Gomez 1991). The degradation of organic matter to biogas is a very complex process. Identified sub-processes of degradation are hydrolysis, acidogenesis, acetogenesis and methanogenese (Fig. 1).

1.1 Hydrolysis

The main components of organic matter are carbohydrates, fats and proteins. Microorganisms are not able to metabolize these biopolymers. Foremost biopolymers have to be broken down in soluble polymers or monomers to pass the cell wall of acidogenic bacteria. Therefore the acidogenic bacteria produce extra cellular enzymes such as cellobiase, amylase and lipase to hydrolyze biopolymers (Shin & Song, 1995). This first step is called liquefaction or hydrolysis and is separated into three parts (Gujer &

Zehnder, 1983): Hydrolysis of proteins to simple amino acids, hydrolysis of carbohydrates to simple sugars and hydrolysis of fats and oil to glycerol and fatty acids. The hydrolysis rate depends on the biopolymer (to degrade glucose is, e.g., easier than to degrade lignin), on substrate concentration, on particle size, on the pH value and on temperature (Veeken & Hamelers, 1999).

1.2 Acidogenesis

Includes the fermentation of amino acids and simple sugar as well as the anaerobic oxidation of long chain fatty acids (LCFA) and alcohols by acid-forming bacteria. Beside carbon dioxide, water and hydrogen primarily acetic, propionic, butyric and valeric acid will be accumulate. Butyric and valeric acid are relevant especially for protein-rich substances, because a number of amino acids will be degraded to these fatty acids (Batstone et al., 2003). Acid-forming bacteria are fast-growing bacteria with a minimum doubling time of about 30 minutes. They prefer degradation to acetic acid, since this step results in the highest energy yield for their growth. (Mosey, 1983)

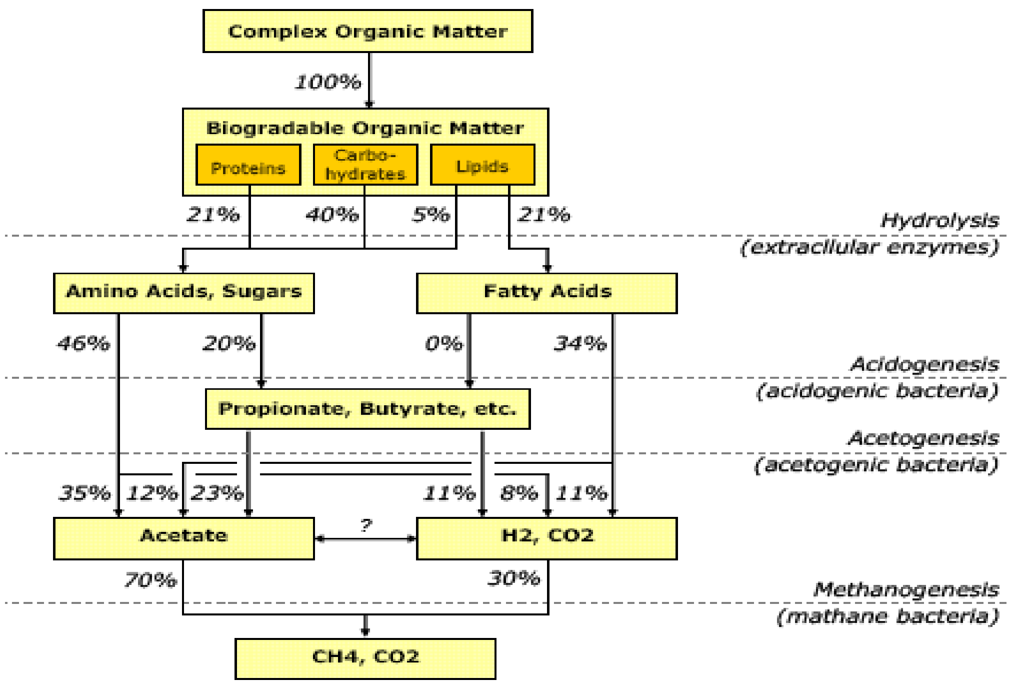

Fig. 1: Degradation process of complex organic components to biogas (Gujer & Zehnder, 1983)

1.3 Acetogenesis

Anaerobic oxidation of intermediates such as volatile fatty acids (primarily propionic and butyric acid, except acetic acid) to acetic acid and hydrogen by acetogenic bacteria is called acetogenesis. An accumulation of hydrogen has to be avoided due to the inhibition of this sub-process by hydrogen. Therefore, hydrogen-utilizing and acetogenic bacteria live in agglomerates close together (Mosey, 1983). Acetogenic bacteria grow rather slowly with a minimum doubling time of 1.50 to 4 days even under optimum conditions such as a low concentration of dissolved hydrogen (Lawrence & McCarty, 1969).

1.4 Methanogenesis

Methanogenesis indicates the methane production by methane bacteria out of acetate and out of hydrogen and carbon dioxide. All methane bacteria so far studied utilize hydrogen to reduce carbon dioxide to methane. These hydrogen-utilizing methane bacteria grow relatively fast with a minimum doubling time of about 6 hours. Mosey (1983) called them the "autopilot" of the anaerobic process, because they regulate the formation of volatile fatty acids (VFA). The larger share of the methane (about 70%) is produced by acetoclastic methane bacteria out of the methyl group of acetate (McCarty, 1964). Because of the low energy yield of this reaction, acetoclastic bacteria grow very slowly with a minimum doubling time of 2 to 3 days (Mosey, 1983). All sub-processes are affected by ambient conditions such as temperature, pH value, alkalinity, inhibitors, trace and toxic elements. Furthermore, all sub-processes are linked to and influenced by each other.

For achieving successful sludge digestion several physical and chemical factors must be considered. The most important physical factor is temperature. In anaerobic digestion there are generally two temperature ranges. Anaerobic sludge digestion can occur in the mesophilic range (35 °C), which is more usual, or in the thermophilic range (55 °C), which is less common. It is important that the temperature remains constant. Specific methane forming bacterium has an optimum for growth. Methane formers can generally be divided into two groups, each group operates in the temperature range where the temperature is the most convenient for their growth. For instance, the mesophilic temperature range is optimal for a large number of methane forming microorganisms. For other groups of microorganisms optimal temperatures are in the thermophilic range. If the temperature fluctuates too fast, no methane formers can achieve a high stable population. A smaller microorganism population means reduced stabilization and reduced methane formation. The range between the mesophilic and thermophilic range is not yet entirely researched. However, Figure 2 shows biogas production in dependence of temperature clearly in two ranges, first peak is in mesophilic temperature range, second in thermophilic range. These two peaks shown as biogas production actually reflect methane forming bacteria activity.

Different strategies have been studied in order to enhance anaerobic digestion of sludge such as thermal pretreatment, chemical pretreatment, thermo-chemical pretreatment, mechanical pretreatment but these methods are costly and consumed a large amount of power (Kim et al, 2003), and co-digestion with food or agriculture wastes (Mohammed 2010).

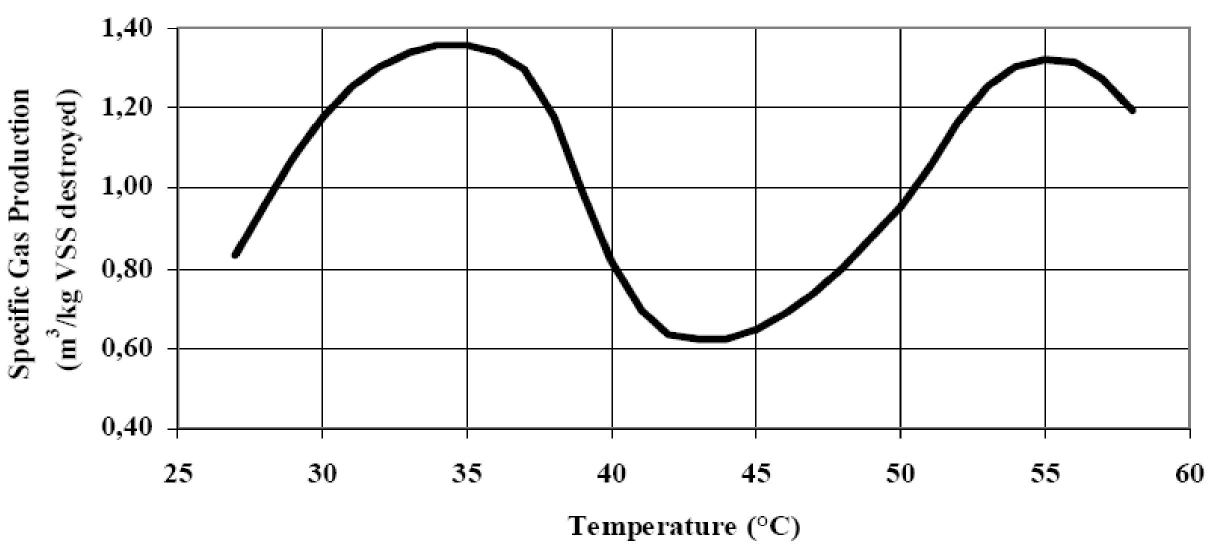

Fig. 2: Specific biogas production as a function of temperature

EM can increase reliability of the "notoriously fragile" microbial ecosystems by bolstering the beneficial microorganisms and thereby reducing the pathogenic microorganisms through competitive exclusion. This will tip the balance of the microbial populations nine favor of the beneficial microbes and hence it will increase the system's resilience. This tipping of the balance facilitates the reduction of biochemical oxygen demand (BOD), and suspended solids (SS), thereby reducing the potential for environmental pollution. EM has also effectively reduced sludge solids in other wastewater treatment systems and in some cases removed the need for sludge treatment. This has fully offset the cost of the EM in at least one facility. Little or no solids handling will be necessary because EM works to stabilize organic material and to reduce or eliminate the harmful pathogenic organisms that are in typical wastewater sludge (Banerji et al 2000)

The main problem related to sludge treatment is its cost which usually ranging from 20% to 60% of the total operating costs of the wastewater treatment plant (Marcos et al, 2005). The Degradation of volatile suspended solids in the conventional mesophilic anaerobic process is about 40% at retention times between 30 an 40 days. This research paper focuses on the decrease of anaerobic digester cost by using pre selected microorganism in order to increase the biodegradability of sludge; as (Szymanski et al 2003) found that The use of effective microorganisms (EM) for reducing volumes of sewage sludge has often been suggested as feasible in either wastewater treatment plants or on-site wastewater treatment systems such as septic tanks

2. MATERIAL AND METHOD

This study contains four models each with a total volume of approximately 32L and had an effective volume of 24 L Figure (3) shows a schematic diagram of the used model and a photo of it.

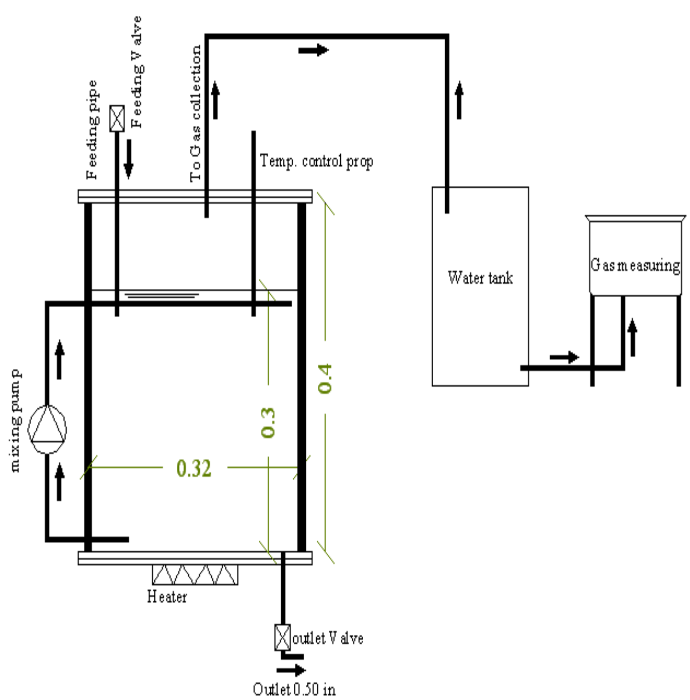

Fig. 3(a): The used models diagram

Fig. 3(b): Photo of the used models

The four batch digesters were operated at a constant temperature of 35± 1 ^{0}C and each model was filled (24 L), with a thickened combined municipal–primary and waste activated sludge- from conventional activated sludge WWTP located at Menia El-Kamh, Sharquiah, Egypt. the 1st digester did not receive any addition of microorganisms and works as a reference model, the 2nd anaerobic digester receive an addition of 0.1% by volume of microorganisms, the 3rd anaerobic digester receive an addition of 0.2% by volume of microorganisms , while the 4th anaerobic digester receive an addition of 0.3% by volume of microorganisms. The used sludge was sieved through 2.00 mm sieve. The mixing will be recirculation the sludge volume inside the digester by a pump working 60 seconds each 15 minutes.

The effect of pre-selected microorganisms on the degradation process of the anaerobic digesters were studied be measuring of TS, TVS, TSS, TVSS, COD, pH and gas volume for raw sludge and from the models for almost 40 days. Table 1 shows the characteristics of the raw sludge used in this study

Table 1. the characteristics of the raw sludge

Parameters	Sludge
pH	6.8 – 7.1
COD (ppm)	27400 - 42100
TS (ppm)	29300 - 46200
TVS (ppm)	22770 - 39500
TSS (ppm)	27650 - 44500
TVSS (ppm)	22120 - 38800
Color	Dark brown
odor	inoffensive

2. RESULTS

2.1. VSS removal

Figure (4) shows the VSS removal efficiency of the four models the VSS removal increased from 37.33% for reference model to 61.08% 63.07% and 64% for microorganisms dosage of 0.1%, 0.2% and

0.3% respectively, Most anaerobic digesters are operated as continuous flow, completely mixed reactors and are designed on the basis of volatile suspended solids (VSS) reduction. In this paper a complete mixed reactor without recycle is considered. The mass balance for degradable VSS in the sludge can then be written as follows:

Accumulation = Inflow – Outflow + utilization rate

Now, to determine the mathematical model, the rate of VSS utilization has to be determined. Obtaining a very accurate mathematical model for anaerobic digestion is difficult due to the complexity of the digestion and the hydrodynamics of the process. Anaerobic digestion is a three phase process. Presence of different types of bacteria, multi step nature of substrate removal, and a high number of parameters that affect the digestion process, make it even more difficult to build a complete model. The simplest model could be estimated using equation 1

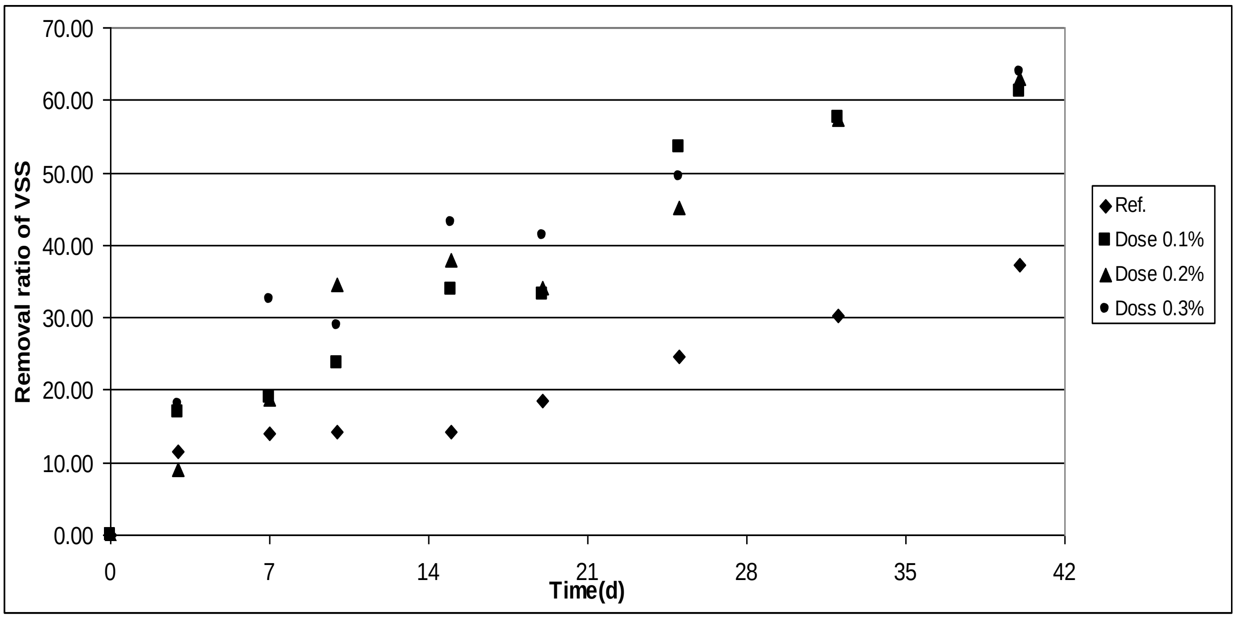

Fig. 4: Relation between VSS removal ratio and time

$$\frac{dS}{dt} = -k.S^{n} \qquad (1)$$

Due to the difference of the initial VSS concentration (S_0) a normalized VSS concentration dimension less value could be used for the model such that $S^{-}=(S/S_0)$ so equation 1 could be transformed to equation 2

$$\frac{dS^{-}}{dt} = -k_{VSS}.S^{-n} \qquad (2)$$

The reaction constant (k_{VSS}) and the order of reaction n in Equation 2 are then determined by iteration using a computer. Each sludge digestion process has a different reaction order n. The reaction order mostly depends on the type of sludge and the process type. Anaerobic digestion has a different n then aerobic. According to Roš, et al (2003) and Zupančič et al (2002) the recommended reaction order for anaerobic sludge digestion is n=3. While according to Batstone et al (2002) (IWA) the anaerobic digestion model NO 1 (ADM1) a first order reaction could be used for each step of the process. So equation 2 could be rearranged in equation 3

$$S^{-} = e^{-k_{VSS}.t} \tag{3}$$

So by plotting the relation between Normalized VSS (S^-) and time as shown in figures 5, 6, 7 and 8 the R^2 value could be accepted so the reaction is a first order also the rate constant could be determined as shown in table 2.

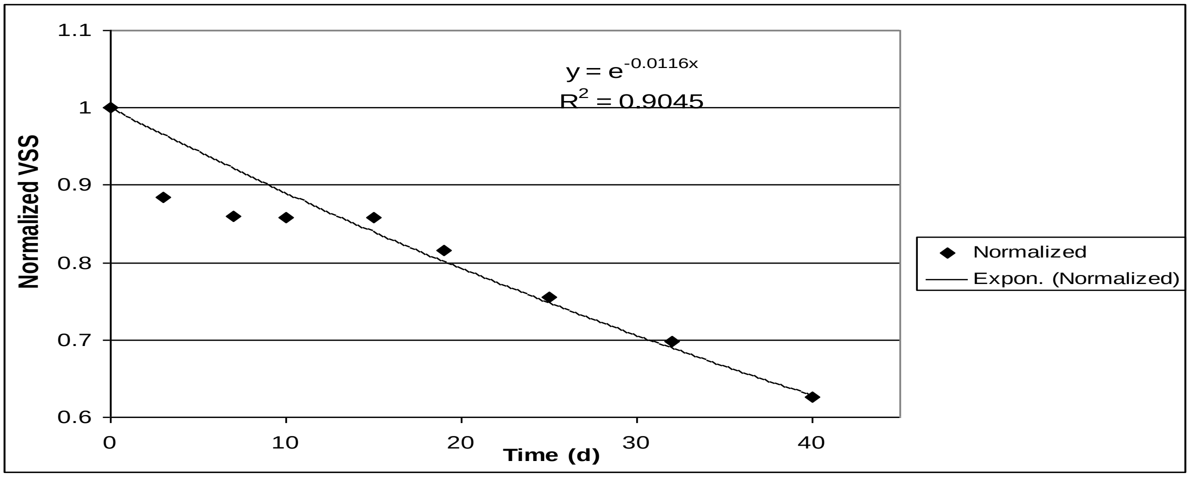

Fig. 5: Relation between normalized VSS and time for reference model

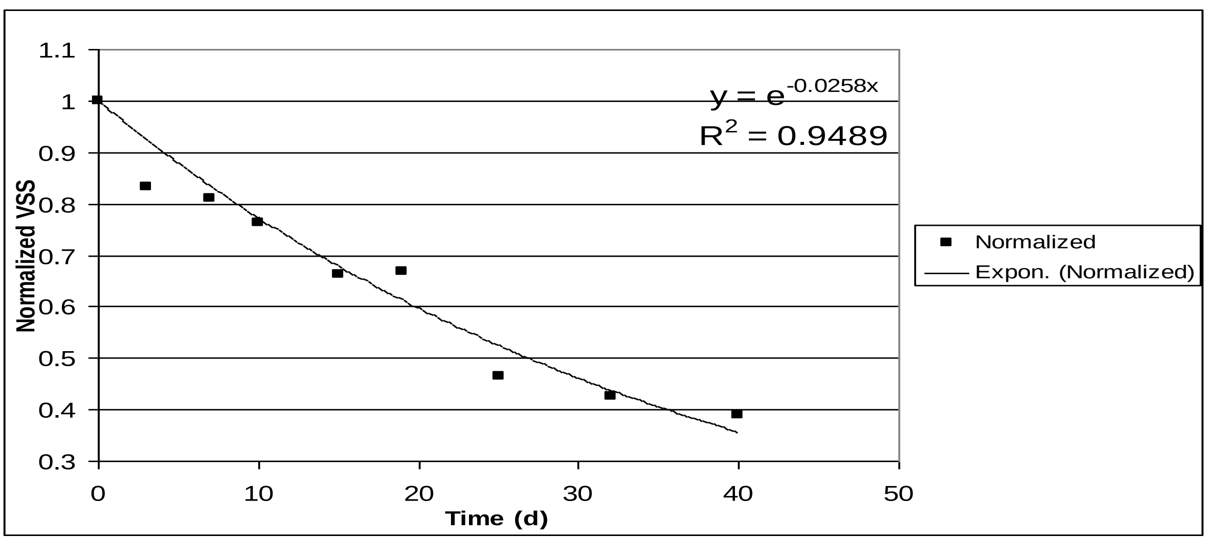

Fig. 6: Relation between normalized VSS and time for with dosage 0.1%

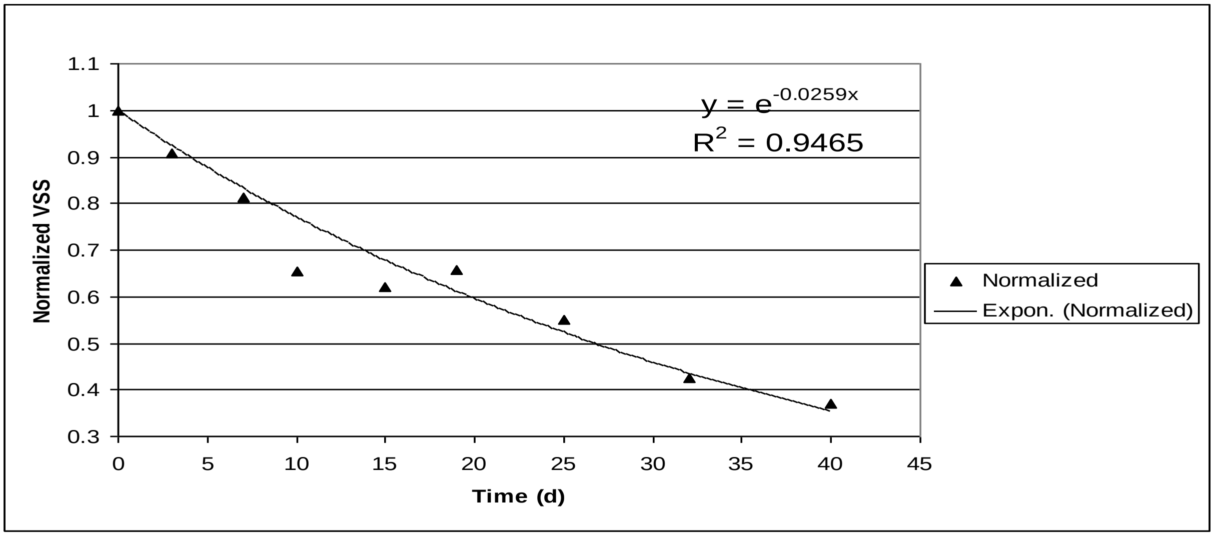

Fig. 7: Relation between normalized VSS and time for with dosage 0.2%

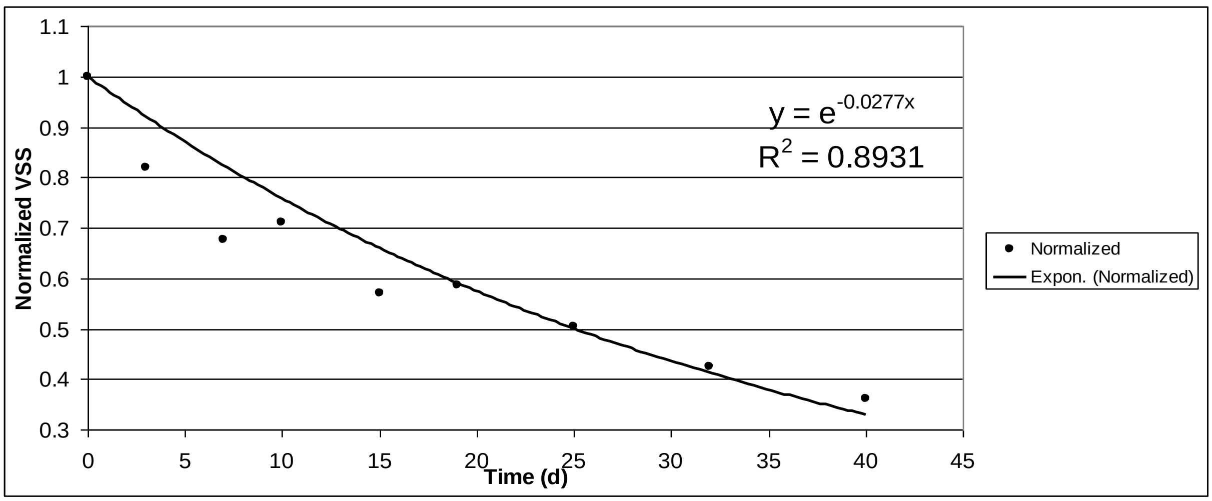

Fig. 8: Relation between normalized VSS and time for with dosage 0.3%

Table 2. Rate constant for VSS removal

Model	K_{VSS} (d^{-1})
Reference	0.0116
Microorganisms dose 0.1%	0.0258
Microorganisms dose 0.2%	0.0259
Microorganisms dose 0.3%	0.0277

The above rates show that using the pre selected micro-organisms increasing the rate of VSS destruction and so it will enhance the digester performance also increasing of the Microorganisms ratio increased the VSS destruction, these results comply with the results of (Szymanski et al 2003), (Banerji et al 2000) and El-Monayri et al (2007) but the removal ratio in this study are higher than last study this is may be due to the mixing system as they did not use a mixing system, also this is may be due to the difference in the initial concentration of VSS in this study.

2.2 COD removal

Figure (9) shows the COD removal efficiency of the four models the COD removal increased from 45.92% for reference model to 70.42% 57.43% and 61.67% for micro-organisms dosage of 0.1%, 0.2% and 0.3% respectively.

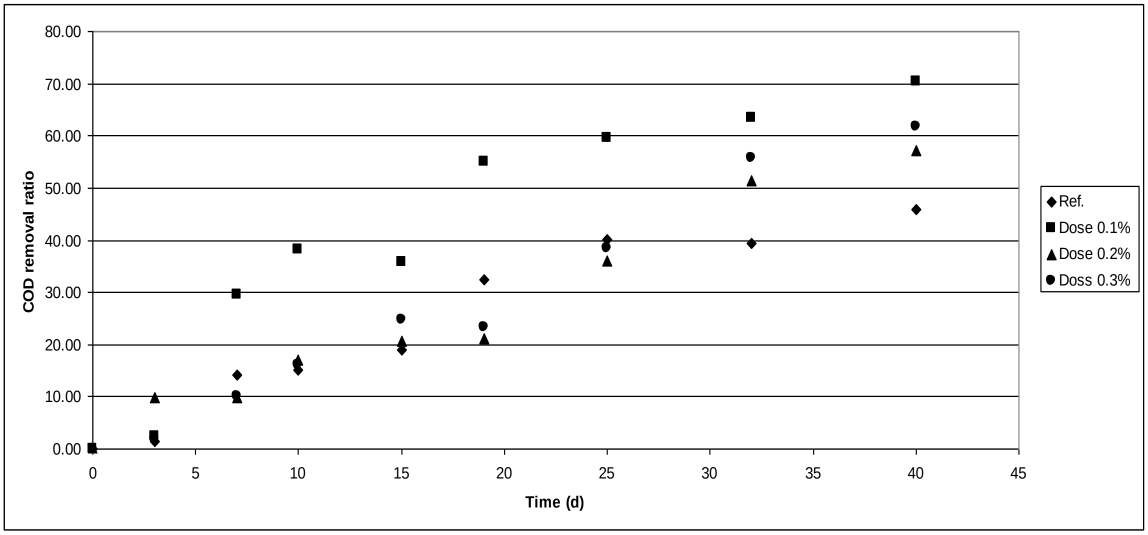

Fig. 9: Relation between COD removal ratio and time

In this study the COD removal ratio isn't a good representative as the model of COD degradation according to Batstone et al (2002) (IWA) the anaerobic digestion model NO 1 (ADM1) is a first order reaction depends on the initial COD (C_S^0) concentration and initial VSS concentration as in equation 4

$$C_s = C_s^0 e^{-k_{COD} . S_0 . t} \tag{4}$$

To eliminate the effect of initial COD concentration a normalized COD concentration (C) could be used and by plotting the relation between Normalized COD (C) and (VSS * time) as shown in figures 10, 11, 12 and 13 the R^2 value could be accepted so the reaction is proved to be a first order also the reaction rate constant could be determined as shown in table 3.

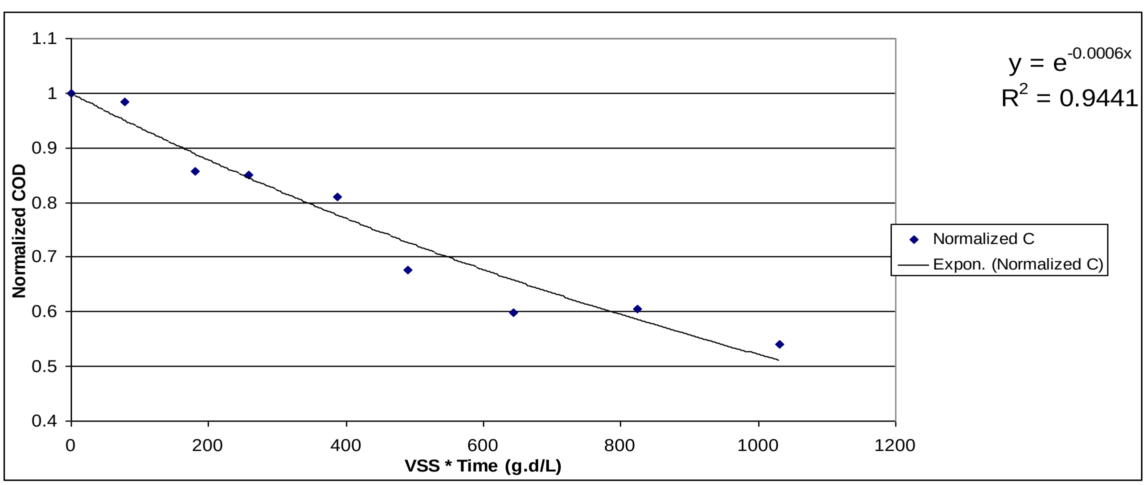

Fig. 10: Relation between normalized COD and (VSS *time) for reference model

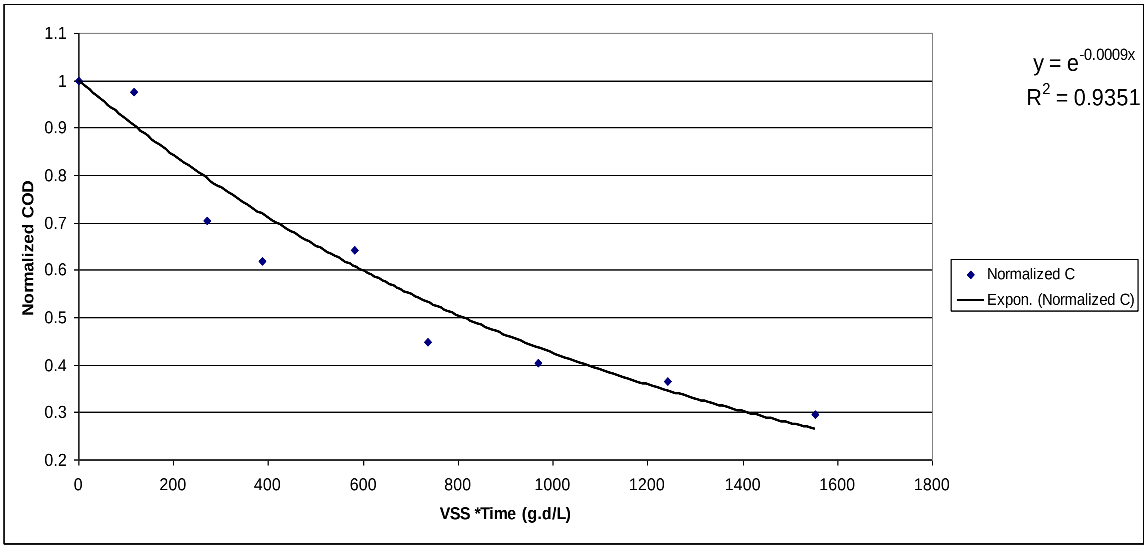

Fig. 11: Relation between normalized COD and (VSS *time) for dosage 0.1%

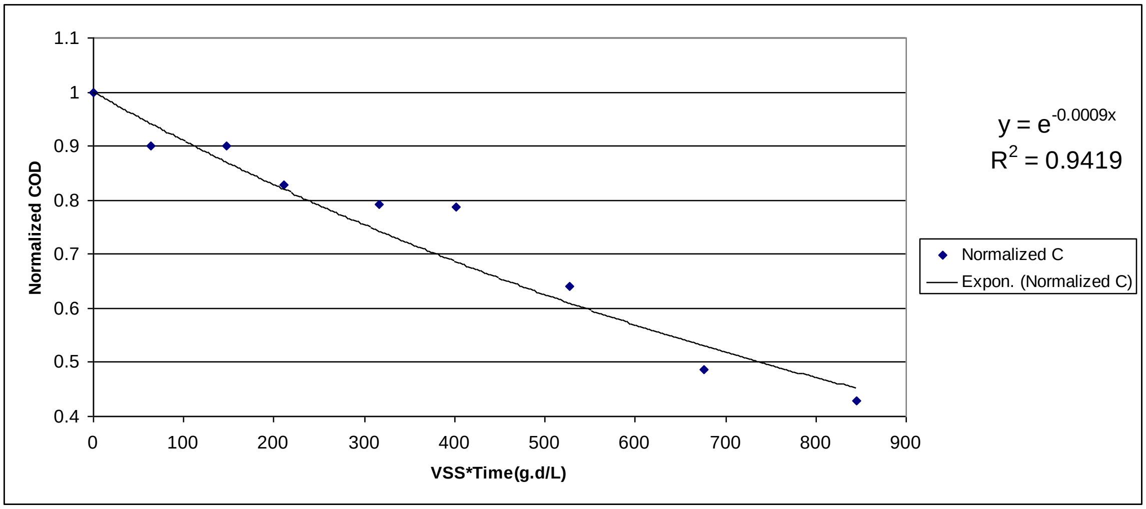

Fig. 12: Relation between normalized COD and (VSS *time) for dosage 0.2%

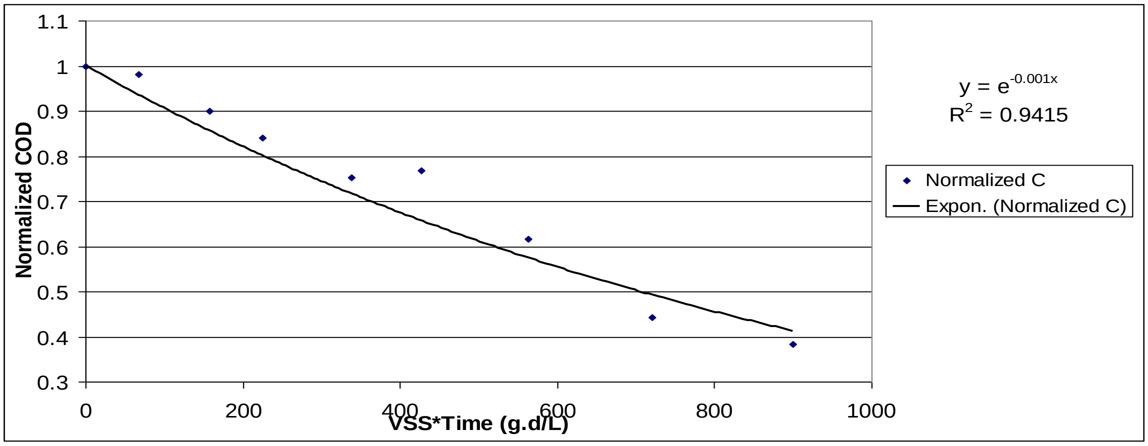

Fig. 13: Relation between normalized COD and (VSS *time) for dosage 0.3%

Table 3. rate constant for COD removal

Model	K_{COD}*10^{-4} (L/g^{-1}.d^{-1})
Reference	6.4
Microorganisms dose 0.1%	8.6
Microorganisms dose 0.2%	9.4
Microorganisms dose 0.3%	9.8

The above rates show that using the pre selected micro-organisms increasing the rate of COD destruction and so it will enhance the digester performance also increasing of the Microorganisms ratio increased the COD destruction; these results also comply with the results of (Nasar 2010), and El-Monayri et al (2007).

2.3 Gas production

Table (4) shows the total gas production of the four models the production rate for VSS removal and production rate for COD removal

Table 4. Gas production

Model	Gas production (L)	Gas production (L/g VSS removal)	Gas production (L/g COD removal)
Reference	220	0.857	0.514
Microorganisms dose 0.1%	330	0.568	0.455
Microorganisms dose 0.2%	150	0.459	0.482
Microorganisms dose 0.3%	187	0.531	0.453

Also the total gas production isn't a good representative as the model of gas production according to Converti et al (1999) who developed a very simple model to describe batch processes. The methane production is directly ascertainable from the initial substrate concentration by a first-order kinetics model depending on time. The cell concentration of bacteria is assumed to be constant due to their very slow growth. If the cell concentration and the methane yield on substrate are known, this model relay on the COD removal model and so the kinetic constant k_{COD} needed to be determined.

$$nCH_4 = nCH_4^- \times C_s^0 (1 - e^{-k_{COD}.S_0.t}) \quad (5)$$

Where nCH_4 is the Methane gas production and nCH_4^- is the methane yield and equation 5 could be converted to equation 6 as the methane is always a fixed percentage of the total gas production

$$Gp = Gp^- \times C_s^0 (1 - e^{-k_{COD}.S_0.t}) \quad (6)$$

Figures 14, 15, 16 and 17 shows the relation between Actual gas production Gp and the Gas production predicted by Converti model this figures show that there is a small different in the values and so the model is applicable to be used in this study

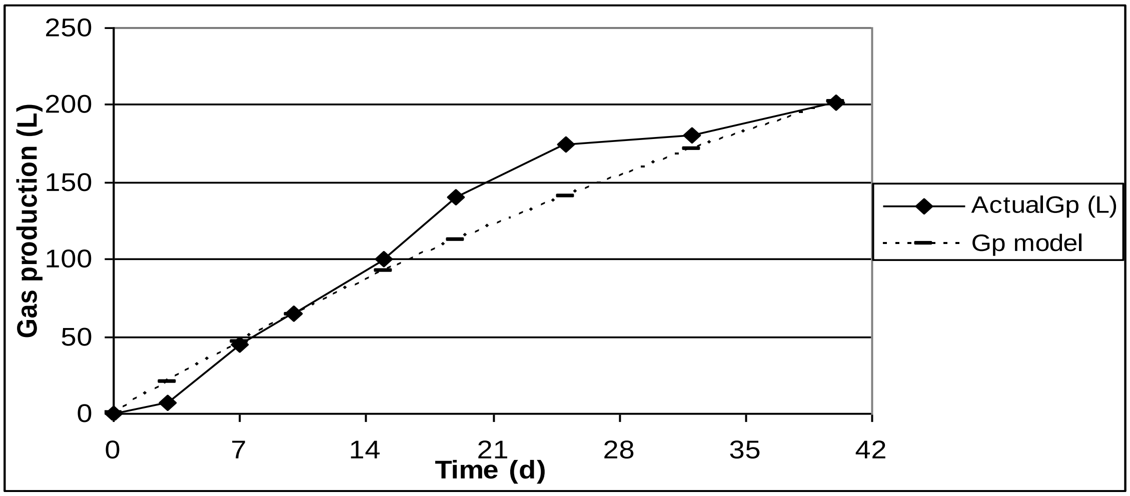

Fig. 14: Relation between actual and predicted gas production for reference model

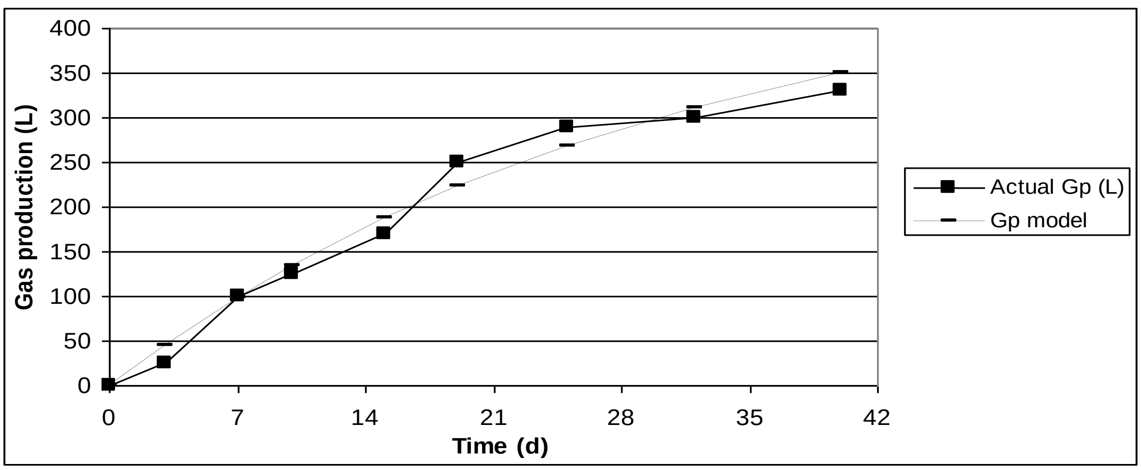

Fig. 15: Relation between actual and predicted gas production for dosage 0.1%

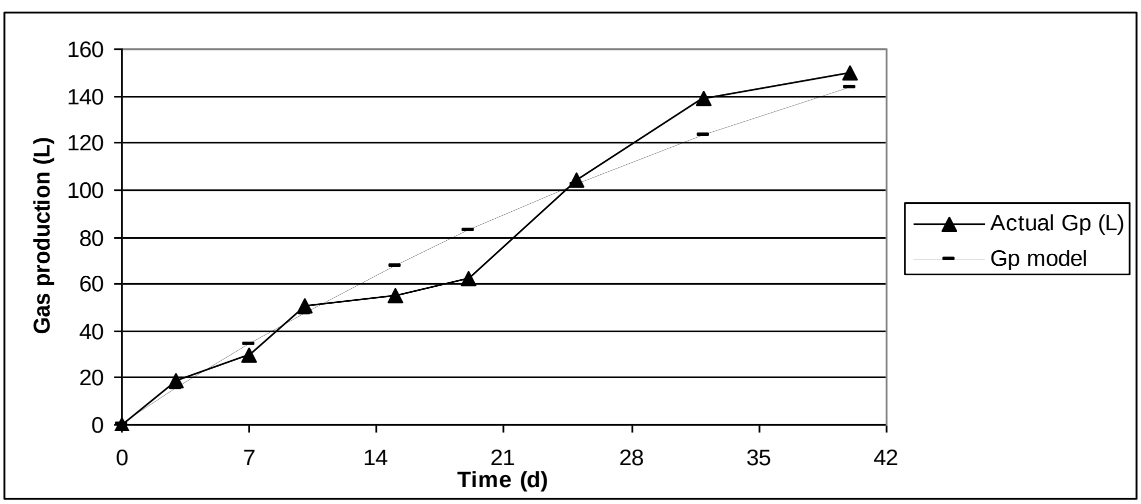

Fig. 16: Relation between actual and predicted gas production for dosage 0.2%

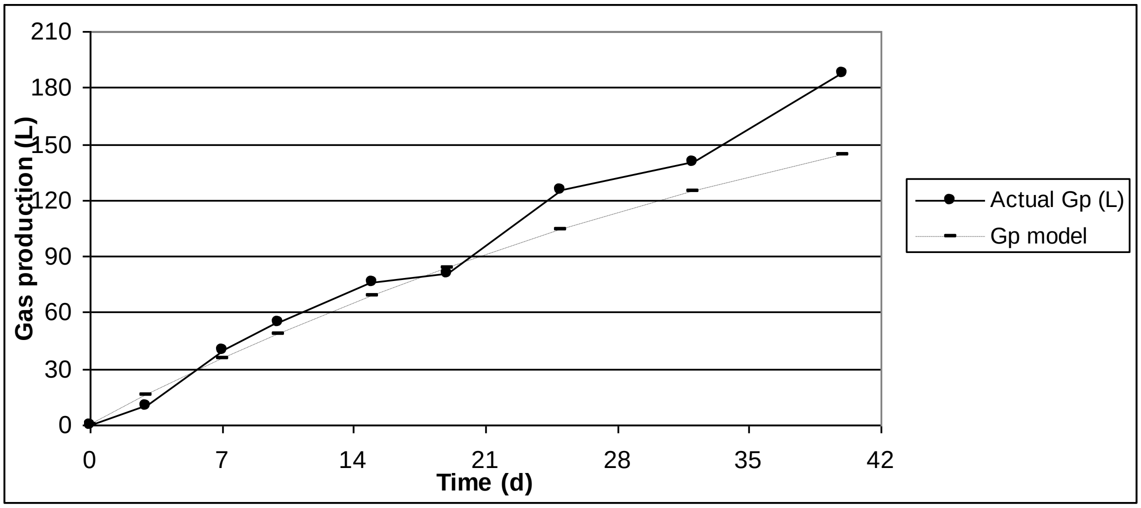

Fig. 17: Relation between actual and predicted gas production for dosage 0.3%

CONCLUSIONS

1- The used pre-selected microorganisms enhanced the biological degradation processes of the anaerobic digesters such that the VSS and COD destruction rates increased and the total gas production increased.

2- The removal of VSS and COD proved to be a first order reaction with or without the use of the microorganisms.

3- The removal of VSS and COD increased with the increasing of the pre-selected micro-organisms dosage.

4- The model proposed by Converti et al (1999) is applicable to be used for predicting of gas production.

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