J. Appl. Environ. Biol. Sci., 5(8S)220-225, 2015

ISSN: 2090-4274
Journal of Applied Environmental and Biological Sciences
www.textroad.com

Optimizing Anaerobic Digestion Process in Shiraz Wastewater Treatment Plant through Qualitative Changes in Feeding Sludge in Pilot Scale

Behzad Zare[a], Ayoub Karimi-Jashni[b *]

[a]Graduate Student in Civil and Environmental Engineering, Shiraz University, Shiraz 7187665947, Iran
[b] Department of Civil and Environmental Engineering, Shiraz University, Shiraz 7134851156, Iran

Received: March 8, 2015
Accepted: May 10, 2015

ABSTRACT

Like many other similar sludge stabilization systems, anaerobic digesters in Shiraz wastewater treatment plant are facing various problems including low rate of volatile solids destruction and biogas production .In order to improve the productivity and feasibility of the process, a laboratory pilot-scale system similar to the existing full-scale digestion system at Shiraz wastewater treatment plant was studied for 50 days with raw sludge feeding. Comparison of full-scale and pilot-scale results showed that the average rate of volatile solids destruction were 38.2% and 52.39%, respectively. Results also showed that the average rates of biogas production per kilogram of volatile solids destruction were 1.07 $m^3/kgVS_{des}$ in full-scale and 1.52 $m^3/kgVS_{des}$ in pilot-scale. The difference in efficiency of digestion process and gas production rate can be attributed to the higher concentration of raw sludge compared to biological sludge and the difference in characteristics of them. Therefore, it was concluded that separate sludge digestion can positively affect the rate of volatile solids destruction and biogas production.

KEYWORDS: anaerobic digestion, raw sludge, biological sludge, volatile solids destruction, biogas

1. INTRODUCTION

To improve their lives and provide more conducive lifestyles, human beings try to innovate and make changes to their environment, some of which lead to environmental damages that can threaten human lives from other points of view. Over past decades, ascending increase in environmental activities and considerable investments have been made especially in the field of wastewater treatment which has emerged new challenges for the researchers including but not limited to managing the biological solids extracted from the wastewater treatment systems (different types of sludge).

The most widely used method of sludge stabilization in wastewater treatment plants all over the world, from environmental and economic point of view is to stabilize the solids with an anaerobic digestion method [1]. Since anaerobic digestion of sludge is a costly method and requires very precise and scientific exploitation and operation, optimization of digestion process can further justify the use of this method and make it economically feasible. Due to the lack of detailed information on the design and operation of Shiraz wastewater treatment plant digesters as well as injection of a mixture of raw and biological sludge to the digesters, the present study aimed to obtain the best amount and quality of feeding sludge which is required to achieve the highest possible digestion productivity.

The main objectives of sludge stabilization are to reduce the pathogens and annoying odors and to prevent its corruption and putrefaction [1]. Success in achieving these objectives highly depends on the effectiveness of stabilization process on the removal of volatile organic solids in the sludge. Growth of pathogens, sludge corruption and putrefaction occurs when microorganisms have the opportunity to develop in organic sludge context [2]. One of the strategies to prevent such poor conditions is to reduce volatiles either biologically or by adding chemical additives to the sludge to make poor living conditions for these microorganisms [3]. Although a majority of wastewater treatment plants are using sludge stabilization systems, these systems are not used in all of them. Despite the above mentioned health and safety outcomes, sludge stabilization is used to reduce the volume of sludge, methane production and improve the quality of sludge dewatering operations.

Anaerobic digestion is almost the oldest method for sludge stabilization [4]. This process includes the decomposition of organic and nonorganic materials (specially Sulfate) in the absence of molecular oxygen. The main applications of anaerobic digestion are sludge stabilization in wastewater treatment plants and management of organic solid wastes. Supporting energy consumption management requirements, energy production process, and reuse of solids extracted from digestion process, anaerobic digestion is still the dominant process in sludge stabilization systems [4]. In most cases, a large amount of biogas is produced by anaerobic digestion of municipal wastewater sludge which can recover the major part of the required energy for digestion process by converting the

***Corresponding author:** Ayoub Karimi-Jashni, Department of Civil and Environmental Engineering, Shiraz University, Shiraz 7134851156, Iran. Tel.: +98 9173007901; fax: +98 7136473161. akarimi@shirazu.zc.ir

biogas chemical energy content into thermal and electrical energy [5]. The essential activities to produce a fairly proper, homogeneous and stable feeding sludge for digestion systems are: milling, macerating, removal of sand and gravels, mixing, and storage. Filtration of raw or digested sludge in cases where the sludge is used for other purposes it is necessary to remove unusual materials such as plastic, stone and other unwanted materials. Sludge from the primary, secondary and advanced treatment can be mixed in several ways. Depending on the type and method of operation, pumps and sludge disposal system, the concentration of solids in the primary, secondary and advanced treatment processes are different [6].In order to increase the efficiency of anaerobic digesters, thickening of sludge plays very important roll. Thickening is a process to increase the amount of solids in the sludge by reducing the water content.

Since there are some limitations in pilot scale such as the low power of pumps and small diameter of pipelines, sludge (especially raw sludge) shall be filtered physically before feeding to pilot scale digesters by a one-millimeter mesh filter. By changing the type of feeding sludge of anaerobic digesters, the researcher aims to optimize the anaerobic digestion process with the following objectives:

- Improving energy management
- Increasing the quality of digested sludge.
- Increasing the quality and quantity of biogas

Anaerobic digestion processes are often taking place in mesophilic temperature range (30-37°C).But thermophiles digestion (temperature range: 50-60 ° C) can be also used alone or before mesophilic digestion.

Anaerobic digestion process includes three main stages: hydrolysis, fermentation (acidification), and methane production. The first stage in most of the digestion processes is hydrolysis in which organic particles are converted into soluble materials with the ability to be hydrolyzed to simpler monomers fermented by bacteria that are used in the second stage called fermentation or acidification in which amino acids, sugars and fatty acids decompose. The third stage is methane production by a group of microorganisms called Methanogens [5].

Anaerobic processes are very sensitive topH and inappropriate materials. pH values are preferred to be close to neutral.pH values of less than 6.8 would stop the activity of Methane-formers. Due to high concentration of CO_2 in biogas (20-35% of the biogas), large amounts of alkalinity needed to be keep pH close to neutral. Alkaline concentrations shall be often in the range of 3000-5000 mg/L as $CaCo_3$.The major consumer of alkalinity in digesters isCO_2rather than VFA that is commonly considered as the most consumer of alkalinity. $CO_2$is produced in acidification and methane production phases. Because of the partial pressure of the gas in digesters, CO_2turns into a solution to form carbonic acid which consumes the alkalinity. Therefore, the concentration ofCO_2in the biogas extracted from the digesters reflects the demand for alkalinity. Alkalinity deficit can be compensated by adding sodium bicarbonate, sodium carbonate or lime. If methane-formers microorganisms fail to consume the produced hydrogen quickly enough, butyrate and propionate fermentation rate will be decreased in anaerobic reactor as a result of volatile fatty acids accommodation which in turn lead to pH reduction (sludge souring) [2].

Temperature has a profound impact not only on the metabolic activity of microbial populations but also on the factors such as the rate of biogas production. Temperature has a great role in anaerobic digestion process especially in determining the rate of digestion and methane production. Design temperature along with minimum SRT needed for the digestion process leads to the required volatile solid destruction. Providing a stable temperature in the digesters is more important than temperature itself, as bacteria, especially methane-forming bacteria are highly sensitive to temperature fluctuations. Generally, the temperature changes more than 1$^{°C}$per day affects the microbial activity and productivity of the process [4].

2. MATERIALS AND METHODS

To conduct the present research, a laboratory pilot-scale plant system similar to the actual full-scale digester at Shiraz wastewater treatment plant was designed and constructed in the scale of 1:60,000 (Figure 1), so that the research results can be compared to the results obtained from the full-scale system. Overall characteristics of the pilot-scale and the full-scale digester at Shiraz Waste Water Treatment Plant are presented in Table 1.

Table 1: Full scale and pilot scaledigesterscharacteristics

	Full-scale Digester at Shiraz Treatment Plant 1stReactor	Pilot-Scale Anaerobic Digester 1stReactor	Pilot-ScaleAnaerobic Digester 2ndReactor
Temperature Phase	Mesophilic	Mesophilic	Not controlled
Operation Temperature	34 ° C	34 ° C	Not controlled
Reactor Volume	6550 cubic meters	110 liters	38.5 liters
Feeding Sludge Amount	300-350 cubic meters per day (average 320 cubic meters)	5.5 liters per day	5.5 liters per day
Feeding Sludge Type	Raw sludge and biological sludge mixing ratio of (1: 1)	Only raw sludge	Digested raw sludge
Solids retention time	20 days	20 days	7 days

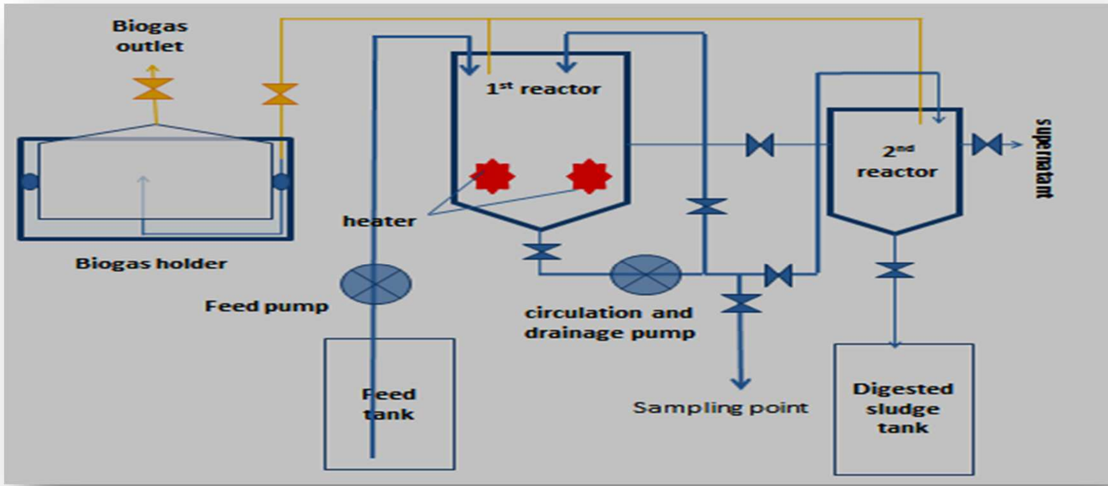

Figure 1. Flow chart of the pilot system designed to simulate the digestion process

To start up the anaerobic digestion process, raw sludge was injected to the system during a 20-day-period to achieve a stable condition. Alkalinity and pH values of the primary digester were monitored daily during the stability period. When the process reached a steady state in mesophilic phase, the pilot was studied for a period of 50 days with daily injections of 5.5 liters of raw sludge extracted from the primary clarifier of Shiraz wastewater treatment plant. Note that the simultaneous digestion process was operating in Shiraz wastewater treatment plant with a mixture of raw sludge and biological sludge in mesophilic phase (Volumetric Mixing ratio of 1:1; feeding volume: 300-350 cubic meters per day; Temperature: 34°C).Considering the volume of anaerobic digesters and the amount of the injected sludge in the full-scale system, the volume of sludge injected to the pilot system was determined to be 5.5 liters to provide the same solid retention time (SRT) with full-scale one, which was continuously injected to the pilot system for 50 days. It is worth noting that the raw sludge was regularly injected to the pilot system during this 50-day period. The first 20 days allocated to stabilize digestion process and process analysis was conducted in 22 days out of the rest 30 days via sampling and testing. Since the feed sludge for the pilot system has been extracted from the raw sludge taken from the wastewater treatment process in Shiraz wastewater treatment plant, it was impossible for the researcher to determine the total solids and volatile solids fed to the pilot system and they were totally depending on the quality of the raw wastewater and operational conditions. Consequently, the researcher could not fix the organic materials' loading. The SRT of pilot digestion process was 27 days (20 days for the primary reactor and 7 days for the second reactor) was taken to be the same for the pilot and the actual full-scale digester. During the digestion process, the feeding sludge, the output digested sludge and the sludge content of the first reactor were sampled 5 times a week to monitor the process and measure the digestion efficiency.

In order to analyze the process, the following 3 parameters were calculated and compared:

1- The percentage of volatile solids destruction (Equation 1)

$$\%\text{Reduction} = \frac{(\ \%\text{volatile in} - \%\text{volatile out}) * 100}{[\ \%\text{volatile in} - (\ \%\text{volatile in} * \%\text{volatile out})]} \quad (1)$$

2- Biogas production rate per mass of volatile solids injected to the system (Equation 2)

$$\text{Biogas productivity rate} = \frac{\text{total volume of biogas generated daily}}{\text{total mass of volatile solid feeded daily}} \quad (2)$$

3- Biogas production rate per volatile solids destruction (Equation 3)

$$\text{Biogas production rate} = \frac{\text{total biogas generated daily}}{\text{total volatile solid destroyed daily}} \quad (3)$$

To set the operation temperature at 34°C for the pilot system, two electric heater equipped with thermostat were used to regulate the desired temperature. To mix the contents of the pilot system, a one-inch positive displacement pump was used to circulate the sludge from the lowest point of the primary tank to the top continuously.

3. RESULTS AND DISCUSSIONS

After the completion of research period, the productivity of digestion processes in the actual full-scale and the pilot-scale system were compared. Comparison of volatile solids destruction rate in full-scale and pilot-scale versus time is shown in Fig. 2. It can be seen from Fig. 2 that the rate of volatile solids destruction in the pilot system is considerably higher compared to that of full-scale digester. Fig. 2 shows that the average percentage of volatile solids destruction rate was 38.2% in full-scale, and is was 52.39% in pilot-scale. Considering that full-scale digester was fed by a mixture of raw sludge and secondary biological sludge and the pilot-scale was only fed by raw sludge, it can be concluded that raw sludge has higher volatile solids destruction rate.

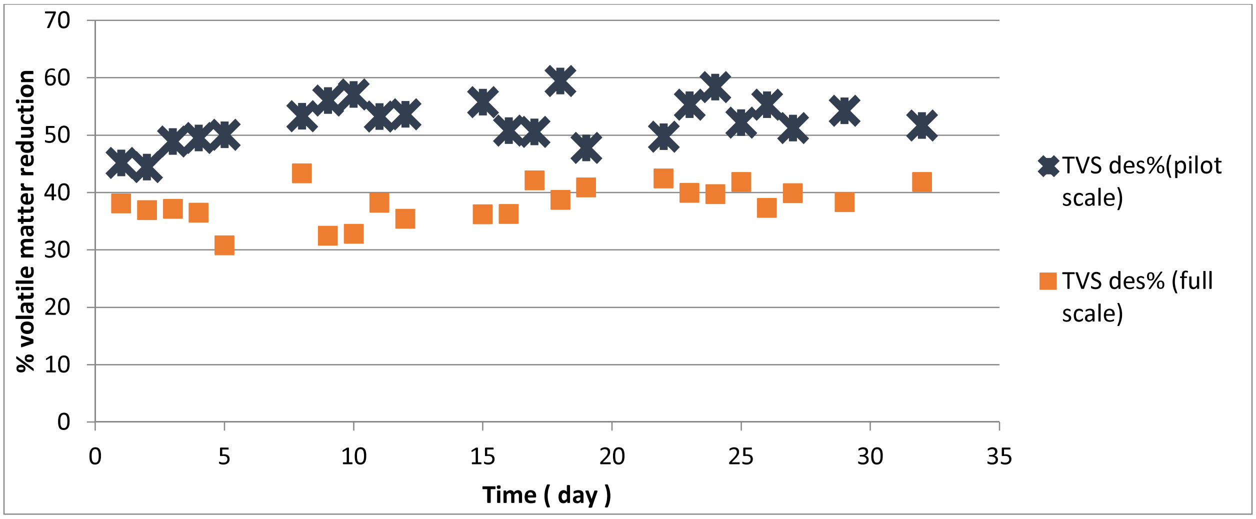

Fig. 2. Comparison of volatile solids destruction rate in full-scale and pilot-scale versus time

Comparison of biogas production rate per mass of volatile solids fed to full-scale and pilot-scale systems over time is shown in Fig. 3. It can be seen from Fig. 3 that the biogas production rate for full-scale digester is $0.4 m^3/kg$ VS_{fed} and for pilot-scale digester is $0.799 m^3/kg$ VS_{fed}. Therefore, the rate of biogas production in the pilot system is considerably higher compared to that of full-scale digester. Considering that full-scale digester was fed by a mixture of raw sludge and secondary biological sludge while the pilot-scale was only fed by raw sludge, it can be concluded that raw sludge has higher biogas production rate.

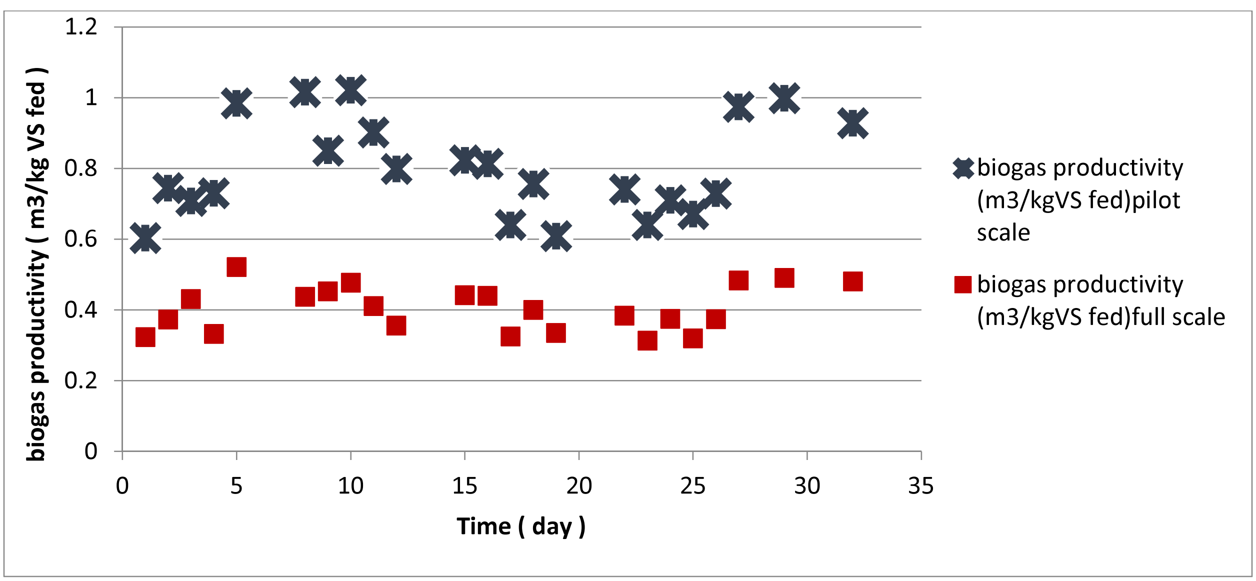

Fig. 3. Comparison of biogas production rate per mass of volatile solids fed to full-scale and pilot-scale systems over time

Figure4 shows biogas production rate per mass of volatile solids destruction in large scale and pilot scale over time. Fig.4 shows that the amount of biogas production per mass volatile solids destruction of the full-scale digester was 1.07 $m^3/kg\ VS_{des}$ and that of pilot-scale was 1.52 $m^3/kg\ VS_{des}$. The higher rate of biogas production in the pilot system can be related to raw sludge feed and it can be concluded that raw sludge has higher biogas production rate per mass of volatile solids destruction.

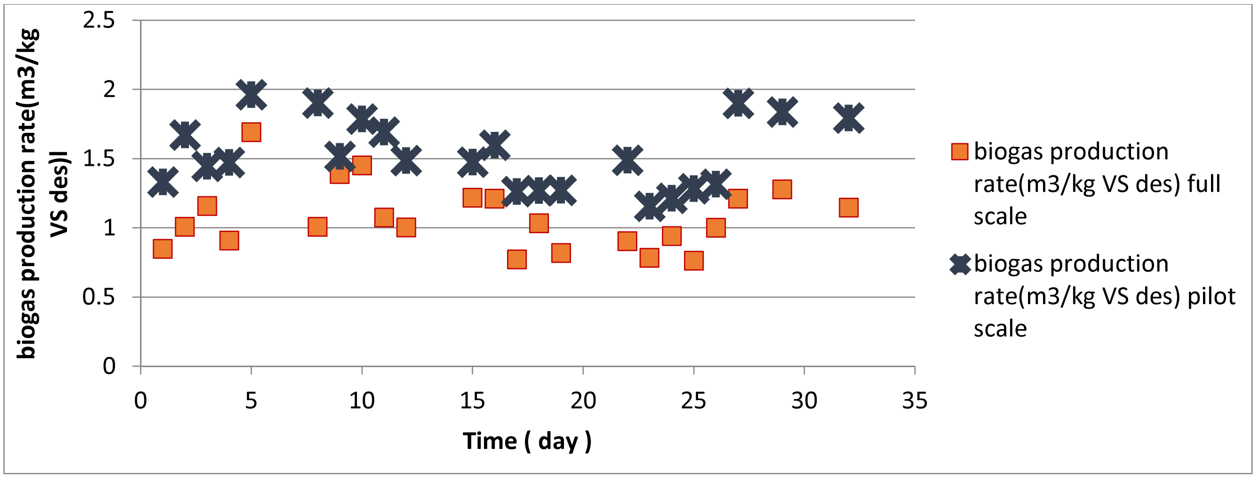

Fig. 4.Biogas production rate per mass of volatile solids destruction in full scale and pilot scale over time

During the operation of the pilot system, twenty biogas samples from the pilot system and the full-scale digester were analyzed using gas chromatography method. The results showed that the average of volumetric methane concentration was 69% in the full-scale system while it was 76% in the pilot-scale system. Fig.5 represents the methane concentration in full and pilot scale anaerobic digesters. The higher volumetric methane concentration in the pilot system can be related to raw sludge feed and it can be concluded that raw sludge digestion has higher volumetric methane concentration.

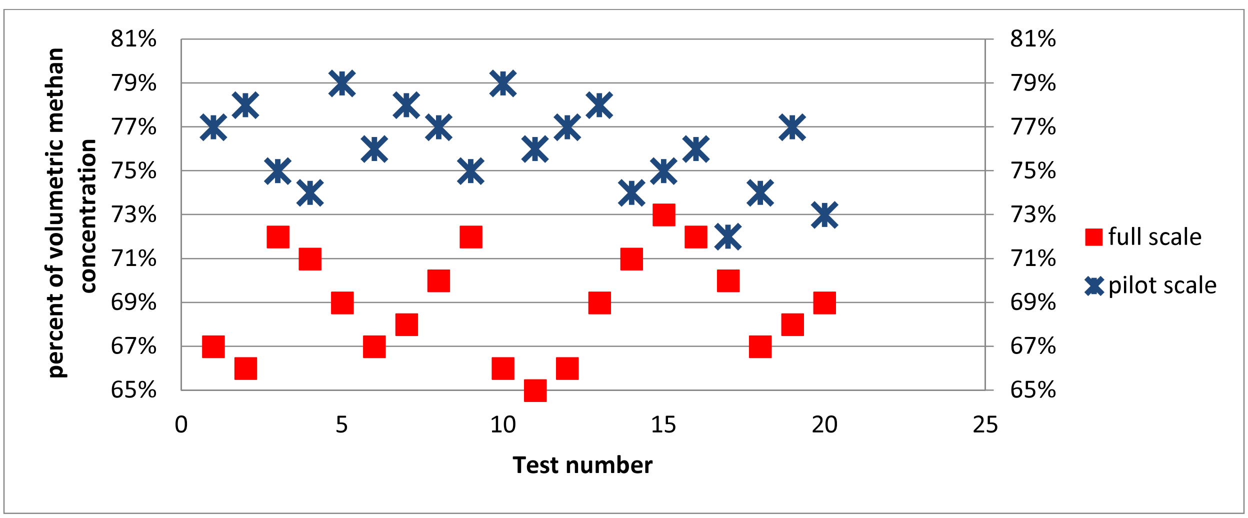

Fig. 5.Volumetric Methane concentration in full scale and pilot scale anaerobic digesters

4. CONCLUSIONS

Comparison of the results of a pilot-scale system, which was fed by raw sludge from primary clarifier, with full-scale digester of Shiraz wastewater Treatment Plant that digested a mixture of raw sludge and biological sludge, showed that the efficiency of volatile solids destruction and the biogas production rate was higher in the pilot system. The difference in efficiency of digestion process and gas production rate can be attributed to the higher concentration of raw sludge compare to biological sludge and the difference in characteristics of them.

The extraction of energy from biogas produced during the digestion process can recover the major part of the required energy for digestion process. So, digesting the raw sludge separately can increase biogas production rate and its quality which is an effective step up in energy management in wastewater treatment processes. Moreover, due to the high rate of solids destruction in the pilot scale, the digested sludge meets the sanitation requirements for reuse as fertilizer and soil conditioner and it will be more reliable than the full-scale's digested sludge.

REFRENCES

[1] Forster-Carneiro, T., M.Pérez, L. I. Romero. Thermophilic anaerobic digestion of source-sorted Organic fraction of municipal solid waste. Biores. 2008. Technol. 99: 6763-6770

[2] Metcalf & Eddy Inc. Wastewater engineering: treatment, disposal, reuse, Int. ed. New York: McGraw-Hill; 1993.

[3] Wang, K,. Shammas, K,. Hung, Y,. Biosolid engineering and management.2007 Humana Press Inc.

[4] Turovskiy, I,. MATHAI, P ,. Wastewater sludge processing, 2006.John Wiley & Sons, Inc.

[5] - Gerardi, H,.The microbiology of anaerobic digester. John Wiley & Sons, Inc., Hoboken, New Jersey

[6] Bolzonella, D., Pavan, P., Battistoni, P., Cecchi, F.2005. Mesophilic anaerobic digestion of waste activated sludge: influence of the solid retention time in the wastewater treatment process. Process Biochemistry 40 (3-4), 1453-1460.

[7] Bolzonella, D., Zanette, M., Pavan, P., Cecchi, F. 2007. Two-phase anaerobic digestion of waste activated sludge: effect of an extreme thermophilic (70 ° C) pre-fermentation step. Chemistry Res., 46 (21), 6650-6655.

[8] Bolzonella, D ,. Innocenti, L ,. Cecchi, F. BNR wastewater treatments and sewage sludge anaerobic mesophilic digestion performances.WatSciTechnol 2002; 46 (10): 199-208.

[9] Gosset J, Belser R. Anaerobic digestion of waste activated sludge. J EnvEng 1982; 108: 1101-20.

[10] MA DE LA RUBIA., Anaerobic Mesophilic and Thermophilic Municipal Sludge ..., Chem. Biochem. Eng. Q. 16 (3) 119-124 (2002)

[11] Trussell, R ,. APHA, AWWA, WPCF Standard Methods for the examination of water and wastewater., Eds. 17th Edition, Washington, 1989.

[12] Jain, M. K., Zeikus, G., Bhatnagar, L., Methanogens in anaerobic microbiology. A practical approach. Cap. 12. Ed: Levett, P. N. Oxford University Press. New York. 1991, pp. 223-245.

[13] CachoRivero, J. A. _2005_. "Anaerobic digestion of excess municipal sludge-Optimization for increased solids destruction." Ph.D. dissertation, Univ. of Cincinnati.

[14] Farrell, J. B., Erlap, A. E., Rickabaugh, J., Freedman, D., and Hayes, S.1988. "Influence of feeding procedure on microbial reductions and performance of anaerobic digestion. "J. Water Pollut. Control Fed., 60_5_, 635-644.