U.P.B. Sci. Bull., Series C, Vol. 78, Iss. 4, 2016 ISSN 2286-3540

PERFORMANCES OF ANAEROBIC DIGESTION TECHNOLOGIES TO TREAT THE ORGANIC FRACTION OF MUNICIPAL SOLID WASTE

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Worldwide there is an increasing trend for the study and use of new sources of renewable energy. Municipal solid wastes are becoming increasingly used as an energy source in waste-to-energy projects. Anaerobic digestion (AD) is a mature technology for energy production by converting organic fraction of municipal solid waste (OFMSW) into biogas. For this purpose, there were approached fundamental aspects of AD, the types of digesters and the performance of anaerobic treatment systems of OFMSW in order to propose the most suitable technology for an experimental pilot plant with the aim of optimizing the production of biogas. Thus, from the analysis of studies conducted it resulted that the dry AD technology in on one stage is best suited to the anaerobic treatment of OFMSW. This paper also makes an overview of the pilot plant intended for the analysis of various parameters such as process temperature, pH, organic load and the production of biogas.

Keywords: biogas, organic matter of municipal waste, anaerobic digestion, digestor

1. Introduction

Domestic, commercial, and industrial human activities are inevitably accompanied by the production of waste. Municipal Solid Waste (MSW) has a significant content of organic matter (food waste, paper and cardboard, vegetables, textiles, leaves, cleaning waste from gardens and parks) of about 25% - 35% from mass waste in developed countries and about 40% to 75% in

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developing countries [1, 2]. It is estimated that in Romania approximately 93% of the total MSW generated were landfilled with negative impact on the environment [3, 4]. Furthermore about 62% of the mass of waste is organic matter and the humidity content of the organic matter is around 45% - 60% [5, 6].

Currently, there are strict regulations that require the reduction of waste quantities for landfills. These also encourage the recycling of MSW by applying alternative methods of management such as recycling, thermo-chemical treatment, aerobic digestion (composting), anaerobic digestion (AD) [7, 8]. These methods of waste treatment allow decreasing the environment pollution.

The AD process [9, 10, 11] consists in the decomposition of the organic matter in the absence of oxygen. The AD process takes place inside reactor in order to produce biogas. Over the years, the AD has been used to treat urban and industrial wastewater and agro-industrial organic waste [12, 13]. Currently, AD is the promising method of treating MSW due to its advantages such as energy recovery from the organic fraction of MSW (OFMSW) and environmental decontamination by the total volume reduction of waste landfilled. Thus, in EU the total processing capacity increased from 3.9 million of OFMSW per year to 7.75 million tons of OFMSW per year, which represents about 25% of the total organic fraction generated [14, 15].

This paper presents an analysis of the performance of the existing AD technologies for biogas production with the aim to propose an experimental pilot plant in order to optimize the biogas production from OFMSW. This analysis is performed in terms of technical, biological and economic point of views. This paper makes an overview of the pilot plant to be used for the analysis of various process parameters such as temperature, pH, organic load and the biogas production.

2. Anaerobic digestion principles

The AD process is used for many years for the anaerobic treatment of municipal wastewater, waste manure and agricultural organic wastes. AD currently uses OFMSW as substrate due to its physico-chemical properties: volatile solids content (carbon, nitrogen, oxygen, sulfur, hydrogen, etc.), high humidity which favors the metabolism of anaerobic bacteria.

AD is the decomposition of organic matter through microorganisms in the absence of oxygen that generates methane, carbon dioxide and other compounds as shown in (Eq. 1) [14, 16].

$$organic\_matter + H_2O \rightarrow CH_4 + CO_2 + digested + NH_3 + H_2S + heat \quad (1)$$

The AD process involves a series of metabolic reactions which takes place in four stages as shown in Fig. 1:

1) Hydrolysis – transforms the complex polymers into simple molecules through anaerobic hydrolytic bacteria;

2) Acidogenesis - hydrolytic molecules are converted into organic acids, alcohols, and other gases;

3) Acetogenesis – the end products of the previous stage are converted into acetic acid, H_2 and CO_2 via acetogenic dehydrogenation;

4) Methanogenesis - methanogenic bacteria convert acetic acids into methane and CO_2 or by reduction of CO_2 with H_2.

The biogas contains mainly methane (45-70%), carbon dioxide (55-30%), and small proportions of other compounds (H_2S, N_2, O_2, etc.), depending on the feedstock quality [14, 16]. The AD process is carried out at temperatures between 10-55 °C and a humidity of the feedstock between 40-99% [10, 14, 16].

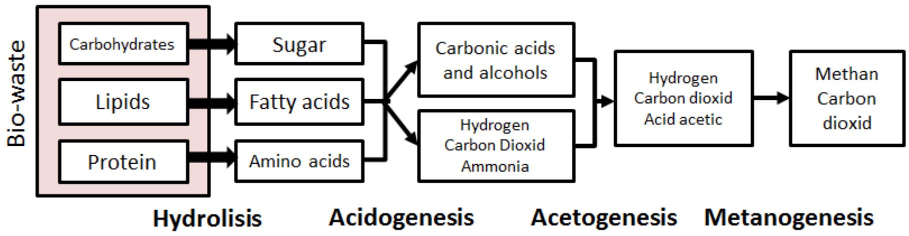

Fig. 1. Biogas production diagram [14]

The anaerobic treatment of OFMSW is challenging due to their heterogeneous composition (non-degradable fractions - plastic, metals, glass, and toxic compounds and inhibitors - detergents, fertilizers, etc). The toxic and non-degradable fractions and inhibitors slow down the AD process and must be removed. Thus, in an anaerobic treatment plant of OFMSW the following stages can be distinguished [14, 15, 16, 17]: reception and pre-treatment; methanisation; biogas conversion into energy; and post-treatment (Fig. 2).

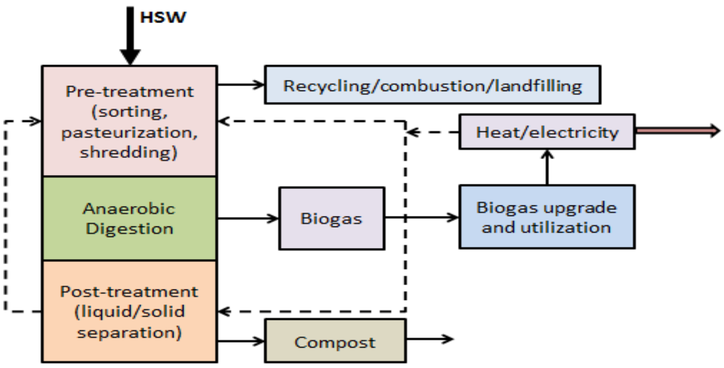

Fig. 2. Anaerobic Digestion process of MSW (adapted from [14])

The MSW are received in the reception area. At this stage, the minimum quality standards of waste to be received are checked, such as weight, humidity, waste source, content of hazardous waste, etc., in accordance with the legal and administrative framework. Before being fed into the digester the MSW undergo a selective separation stage of the inert material (sand, stones, plastics, metals, etc.), mixing, pH control, sanitation, etc. [14, 15, 17]. The sanitation is done by heating the substrate at a temperature of 70°C for at least one hour [14, 16].

The AD takes place in the digester where the process parameters (temperature, pH, mixing, etc.) are strictly controlled so as to allow an efficient process [14, 16]. Finally, the digestate is deposited, stabilized, and can be used as agricultural fertilizer or be transported to the final storage [14, 15].

3. Anaerobic digestion reactors

The AD technology has been developing over the years in terms of reactors geometry [16, 17, 18, 19]. Currently several types of bioreactors and digesters have developed that lead to environmental depolution by OFMSW recycling and to treat various feedstocks (Table 1) from de simplest (e.g. Chinese model [16]) to the more complex designed for the automatic detection of changes in the process parameters (temperature, pH, etc.) and operating conditions (type of substrate, organic load, etc).

Table 1

Types of digesters [16, 17, 18, 19]

Type of digester	Type of feedstock
Batch	Laboratories; grain waste treatment industry
Continuous	Industrial wastewater treatment,agricultural organic waste / manure, agro-industrial residues; OFMSW treatment
Complete mixing without recirculation of biomass	The urban wastewater treatment; agricultural organic waste treatment, agro-industrial residues; and OFMSW treatment
Partial mixing (Plug-flow)	Manure waste treatment; OFMSW treatment; and industrial organic waste treatment
Complete mixing with recirculation of biomass	Treating industrial wastewater with high organic matter (soft and alcoholic drinks plants)
UASB (Upflow Anaerobic Sludge Blanket)	Waste water treatment from the food industry; treating sewage waters
Fluidized bed	Wastewater treatment, especially in the food industry.
Anaerobic filter	Wastewater treatment resulting from food industry.

Table 1 shows that the most common digesters used for AD of OFMSW are the batch/continuous type and completely mixed sterried / plug-flow. The others are used mainly in the industrial wastewater and municipal sludge treatment. The digesters capacity depends on the availability of raw materials. Thus, the anaerobic treatment of OFMSW requires from 50,000 to 230,000 tons / year [14, 15]. As regards one tonne of MSW produces approximately 80 m^3 to

160 m^3 depending on the process. An average biogas production is 100 m^3 per tonne of waste [15].

4. AD technologies for biogas production from MSW

There are several technology options that can be analyzed in order to choose the appropriate technology to optimize biogas production. In the DA process, the elements to be taken into account are: the concentration of volatile solids (VS) of the substrate; the digester's feed mode (continuous or batch); and the stages number of the DA process. These factors have a huge impact in terms of cost, performance and reliability of the plant. In this regard, there are several configurations for the AD used to treat the OFMSW, as shown in Table 2.

Table 2

Types of AD process for OFMSW treatment and classification criteria [14, 15, 17]

	Type	Criterion
AD Process	Wet / Dry	Total Solid (TS) concentration
	One stage / Multi-stage	Stages number
	Mesophilic / Termophilic	Operational temperature
Digester	Batch / Continuos	Feedstock Feeding

Also, the biogas production is influenced by other factors [16, 18, 19]: substrate quality (nutrient content), pH, hydraulic retention time (HRT) - the average time interval in which the substrate is kept in the digester, the organic loading rate (OLR) – the organic substance mass that can be loaded into the digester per volume and time unit.

In the following, it is presents the analysis of the installations performance based on the aspects:

- technical aspects refer to the structural characteristics of installations and digesters;
- biological refers to OLR and stabilization of the AD process parameters;
- the economic costs (production and maintenance).

4.1 AD process thermophilic vs mesophilic temperature

The mechanization process at industrial scale develops, in general, at two levels of temperature: mesophilic (25-45°C) or thermophilic (45-70 °C). The level of temperature is related to the degradation speed of the substrate, the higher the temperature the faster is the degradation. The temperature can vary widely, but it is important that these variations are not sudden because the biogas production is affected. Furthermore, account should be taken of the phenomenon of self-heating of the substrate due to the decomposition of carbohydrates leading to the increase in temperature [14, 16, 18].

In general, the biogas plants working in mesophilic conditions are the most common due to their performance in terms of methane production and process stability [14, 18, 20]. The thermophilic conditions are used when it is necessary to sanitize the substrate. But on the other hand, the energy consumption to heat the substrate is higher and the process becomes more sensitive to perturbations (variation of temperature, irregular supply of substrate, digester's operating conditions) because in the thermophilic conditions there are less different species of methanogens microorganisms [14, 18].

Experiments conducted on corn by Vindis P., et al [21] has resulted in a biogas production of 0.315-0.409 m^3/kg_{VS} at 35 °C and 0.494-0.611 m^3/kg_{VS} at 55 °C. Also, the content of methane increases from 57% to 60%. On the other hand, J. Fernandez et al. [22] observed that the growth rate of microorganisms is 27-60% higher in the thermophilic phase than the one in the mesophilic and HRT decreases from 40 days in the mesophilic phase to 20 days in the thermophilic phase. Cecchi et al [23] showed that biogas production at thermophilic temperature is higher by 2-3 times compared to the mesophilic temperature; also, HRT decreases from 15 days to 8 days as temperature increases; and OLR increases from 6 kg_{VS}/m^3d to 14 kg_{VS}/m^3d along with the temperature.

4.2 Dry vs Wet anaerobic digestion

The substrate density depends on the dry matter content (TS). From this point of view the AD can be wet or dry. The wet AD uses substrates that can be easily pumped, namely substrates that have a high moisture content, generally above 90% (or <10% TS). The dry AD process uses substrates that can be stacked, so with a content of at least 30% TS [14, 16, 17]. Wet AD is a well-known process and has been used for the treatment of urban wastewater in fully mixed digesters. The development of dry AD has begun in the 80s [15] and uses the plug-flow digesters because of the substrate density. Table 3 illustrates the main differences between the two technologies depending on their performance.

Table 3

Comparison between wet and dry AD [14, 15, 16]

Parameter	**Wet AD**	**Dry AD**
TS content	< 10 %	(20 – 40) %
HRT	Mesophilic/ Thermophilic: 20/10 days	Mesophilic/ Thermophilic: 20/14 days
OLR	Termophilic conditions: 6 kg_VS/m^3/day for MSW mixed; 9.7 kg_VS/m^3/day for OFMSW source sorted	About 12 kg_VS/m^3/day
Biogas production	0.170 – 0.320 Nm^3/kg_VS	0.21 – 0.30 Nm^3/kg_VS
Degradability	(40 – 75) % in weight	(50 – 70) % in weight
Pre-treatment substrate	Complex and expensive	Simple and cheap

Digestate treatment	Deshidratation needed	No dehydration needed
Mixing equipment	Simple	Complex

One can see that the two technologies are similar in terms of biological performance. The wet AD has several disadvantages in terms of economic, because it is necessary to apply a pre-treatment to remove the heavy non-degradable elements (sand, metals, glass, etc.) and light (plastic). It also requires the dilution of the substrate by the addition of water; in addition, it requires more energy to heat the substrate; and finally the digestate needs to be dried [14, 15, 16, 18]. All this leads to more complex and expensive equipment and that is why the dry AD technology is more used, reaching 76% of the existing plants in recent years [15].

4.3 Single vs multi-stage anaerobic digestion

When all AD phases develop in a single fermentation chamber, in which all bacteria are subjected to the same conditions of work, the management of the AD is said to be in one stage. These systems are most commonly used at industrial level. The multi-stage systems are formed from the combination of AD phases separating the process in more than two stages [15, 18]. In general, these systems are used to minimize digestate odor by decreasing the processing temperature as the waste is stabilized [24]. In these systems, the AD process is divided into two separate digestion chambers. In the first chamber the acidogenesis and hydrolysis stages take place and in the second chamber the acetogenesis and methanogenesis processes. This separation of phases allows the optimization of development conditions of each type of bacteria and the removal of undigested solids before moving to the methanogenesis stage. As a result, a high efficiency system is obtained in terms of substrate degradation, biogas production and optimization of the hydraulic retention time [18, 24]. There can be systems with two wet-wet or dry-wet stages. The biological performances of the two-stage systems are similar to those on one stage with the observation that degradability can reach 80% of the weight of waste [15, 25]. In general, the HRT for the hydrolysis phase is 4 days and for the methanogenesis 2 days while the biogas production is between 0.12 – 0.15 m^3 / kg of waste [14, 17, 24]. Overall, the two-stage systems show too much complexity in technical terms that translates into big investments. Neverthless, these systems can be successfully used for low cellulose waste treatment and for the ones with C/N ratio less than 20.

4.4 Batch vs continuous digesters

In the AD OFMSW process technology, two types of digesters are most commonly used, depending on the feed mode of the substrate: batch and continuous.

The batch digesters are still the most used today, both in laboratories and in the industry for vegetal waste treatment, as they can make a rapid digestion and the equipment is simple and inexpensive, also allowing a simple evaluation of the digestion process [16, 19]. The characteristic of this type of digester is that the substrate once it has been loaded and sealed its complete emptying is done after the exhaustion of the biogas production, therefore the loading and unloading periods are fixed [16, 18]. AD is predominantly used for dry concentration of 30-40% ST [17]. The inoculation of fresh substrate is required, namely the matter needs to remain digested when filling the digester. Also, the leachate is continuously recirculated to disperse the inoculant, nutrients, acids; it is actually a partial mixing. The biogas production follows the start-stabilization-exhaustion process, therefore in order to maintain a constant biogas production it is necessary to have 3 or 4 digesters of this type in the digestion process in different stages [15, 16, 17]. The use of batch digester is required when the substrate used is a cellulose material or a liquid of high viscosity that can block the supply and output lines and can not be continuously supplied [17, 26], normally for the dry digestion such as fermentation of bulk substrates like corn or grass silage [15, 17]. The drawbacks of this type of digester are the relatively high HRT of 30-60 days; OLR are low from 3.2 to a maximum of 5.1 kg_{SV}/m^3d, with high volumes of the reactor; and formation a foam layer which influences the biogas production [17].

The continuous digesters are loaded several times a day. In this case, the entering volume displaces an equivalent amount of substrate and is removed through the outlet. Thus, the substrate volume within the digestion chamber is maintained constant. It is the most common digester in industrial applications and in wastewater treatment facilities. They are highly efficiency digestors (with a production of biogas by about 40% higher than in batch digesters [17]) and with a continuous production of biogas, stable and safe to work [14, 16, 19]. This type of digesters incur a risk of shor-tcircuit in the substrate flow because that some of freshly supplied substrate may be eliminated [14, 16].

On the other hand, currently 16 companies (ATT, Arrowbio, BTA, Biocel, Biopercolat, Biostab, DBA-Wabio, DRANCO, Entec, Haase, Kompogas, Linde KCA/BRV, Preseco, Schwarting.Uhde, Valorga, Waasa [14, 15, 16]) providing AD technology for treating the MSW. Of these, 11 use the system on a wet single-stage and at the mesophilic process temperature. Companies with most MSW anaerobic treatment plants are Kompogas, BTA, Valorga and DRANCO and represent 63% of all installations. On the other hand, these suppliers use the dry AD technology on a single-stage representing about 76% of the 160 plants.

5. Biogas pilot plant proposal for biogas generation from OFMSW

From the analysis follows that Batch type systems are the simplest to design, operate and less expensive. In contrast, the systems on two-stage are more complex and expensive. Their main advantages are the increasing OLR in the first stage which allows a constant feeding of the digester in methanogenesis stage, reduce HRT, and the digestate is sanitized. However, the majority of industrial facilities use one-stage systems divided into wet and dry systems, from these about 76% are dry systems. Also, dry AD systems are more robust, flexible and pre-treatment process is minimized compared to wet systems. Likewise, the majority of systems work at mesophilic temperature. At this temperature, the AD process is more stable, since methanogenic bacteria involved in organic matter degradation is higher. Thus, an anaerobic treatment installation for OFMSW is proposed on a dry type single stage. The proposed installation is flexible in terms of operational temperature because it can work at mesophilic or thermophilic temperatures. Also, substrate can be fed by batch or continuously with leachate recirculation. On the other hand the anaerobic treatment of MSW only considered the OFMSW that are sorted at source. Thus, the pretreatment process is referring only to reducing the particle size through grinding. The pilot installation intended for the AD process of OFMSW is designed to be loaded with particles in the range of 30-50 mm. It has a cylindrical shape with a maximum capacity of 2 m^3. The proposed pilot plant was designed based on literature data regarding sizing, biogas production, and constructive characteristics of the anaerobic digesters: shape and type of the reactor (vertical or horizontal), with or without heating system for permanent operation, leachate recirculation, biogas capture system [12,13,15,16]. The dimensioning criteria respects the scale effect in terms of biogas qualitative and quantitative production from OFMSW. The digestor will be mounted vertically and designed with upper feeding.

The bottom of the installation is equipped with a leachate collection and recycling system. This system allows periodic operation and allows maintenance of the necessary conditions for a homogeneous distribution of microorganisms responsible with the decomposition of organic matter by discharge of the leachate through spraying from the top of the installation.

The biogas produced will accumulate in a mobile tank where it will be measured. Based on the current weather conditions in Romania the reactor is thermally insulated with mineral wood for all season's operation. A heating system is provided to maintain the mesophilic temperature of 35°C inside the reactor in cold seasons. The temperature is monitored by sensors connected to temperature recorders mounted in different areas of the reactor. The biogas composition will be permanently monitored with a gas analyzer.

Through the opening at point 8 the biogas produced is collected to determine its characteristics. To determine the quality of the produced biogas a portable detector, Dräger X-am 5600 will be used, which uses infrared measurement technology to determine CH_4, C_2H_4, C_3H_8 and CO_2 and to determine the O_2, CO, H_2S electrochemical sensors. After completion of the AD the installation is emptied by a screw conveyor (9) after opening the exhaust flange (10).

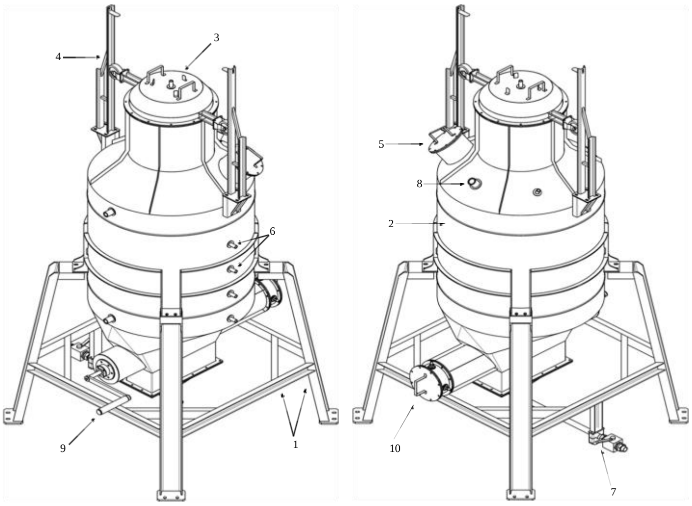

Fig.3. Pilot installation for residues neutralization/stabilization

The main elements of the pilot installation (Fig. 3) are: 1) mechanical resistance system of the installation (installation support); 2) AD reactor; 3) mobile biogas capture and measuring system; 4) guidance structure of biogas capture and measurement system; 5) feed-in system; 6) temperature sensors; 7) leachate collection and recirculation system; 8) biogas sampling; 9) digestat discharge system; 10) discharge flange.

The electric heating resistance is mounted over the entire side of the reactor and is not represented in this figure.

6. Conclusions

Several AD technologies have been proposed in recent years, due to the benefits to the environment and society. In this regard, various types of anaerobic digesters and various AD processes to treat OFMSW were compared on the basis of biological and technical performance. Thus, the batch type systems are the simplest to design, operate and are less expensive. In contrast, the two-stage systems are the most complex and expensive systems. The dry systems represent about 76% of the industrial plants for the anaerobic treatment of OFMSW due to the fact that the amount of water necessary for the process is smaller, as the MSW have a humidity of 50% to 75%. From the technical point of view, AD dry systems are more robust, flexible and the pre-treatment process is minimized compared to wet systems. Also, the vast majority of systems works at mesophilic temperature, because at this temperature level the AD is stable because the number of bacteria involved in anaerobic degradation of organic matter is higher, mainly those methanogens. As regards the biological performance the AD dry systems allows higher OLR (up to 12 kg_{SV}/m^3d) than those wet (6-10 kg_{SV}/m^3d) because of the high concentration of biomass contained in OFMSW. Also, the production of biogas ranges from 80 to 160 m^3 / ton of fresh waste. On the other hand, the rate of biogas production is improved by co-digestion of OFMSW with other organic waste types (commercial, agricultural, manure). AD reduces the initial volume of the MSW to 75% of the initial weight.

Acknowledgements

The authors would like to thank the National Authority for Scientific Research–Romania; the present work was supported under the Sectorial Operational Program "Increase of Economic Competitiveness" POSCCE-A2-O2.1.2.-2009-2, REMOVED ID1679/SMIS-CSNR: 47475, No.549/02.09.2013.

R E F E R E N C E S

[1] *D. Hornweg, and P. Bhada-Tata,* What a Waste. A global review of solid waste management, World Bank, Washington, 2012.

[2] *United Nations Environment Programm (UNEP),* Developing Integrated Solid Waste Managemet Plan. Training Manual. Vol. 1: Waste Characterization and Quantification with Projections for Future, Osaka, Japan, 2009.

[3] *Triassi, M., Alfano, R., Illario, M., Nardone, A., Caporale, O., Montuori, P.*, Environmental pollution from illegal waste disposal and health effects: A review on the "triangle of death", International Journal of Environmental Research and Public Health, 12(2), 2015, pp. 1216-1236.

[4] *Cocarta, D.M., Rada, E.C., Ragazzi, M., Badea, A., Apostol, T.,* A contribution for a correct vision of health impact from municipal solid waste treatments, Environmental Technology, 30(9), 2009, pp. 963-968.

[5] *National Environmental Protection Agency (ANPM),* National report on the state of environment in 2013, Bucharest, 2014, On line at: http://www.anpm.ro/raport-de-mediu

[6] *T. Apostol, C. Marculescu*, Management Solid Waste (In Romanian), AGIR, Bucharest, 2006

[7] Directive 1999/31/EC, on the landfill of waste, On line at: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:31999L003

[8] Directive 2008/98/CE, on waste, On line at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:312:0003:0030:en:PDF

[9] *Jain, S., Jain, S., Wolf, I.T., Lee, J., Tong, Y.W.,* A comprehensive review on operating parameters and different pretreatment methodologies for anaerobic digestion of municipal solid waste, Renewable and Sustainable Energy Reviews ,52, 2015, pp. 142-154.

[10] *Cecchi, F., Cavinato, C.*, Anaerobic digestion of bio-waste: A mini-review focusing on territorial and environmental aspects, Waste Management, and Research, 33 (5), 2015, pp. 429-438.

[11] *Andreottola, G., Ragazzi, M., Foladori, P., Villa, R., Langone, M., Rada, E.C.,* The unit intregrated approch for OFMSW treatment, UPB Scientific Bulletin, Series C, 74(1), 2012, pp. 19-26.

[12] *Martinez, S.L., Torretta, V., Minguela, J.V., Siñeriz, F., Raboni, M., Copelli, S., Rada, E.C., Ragazzi, M.,* Treatment of slaughterhouse wastewaters using anaerobic filters, Environmental Technology, 35(3), 2014, pp. 322-332

[13] *Rada, E.C., Ragazzi, M., Torretta, V.,* Laboratory-scale anaerobic sequencing batch reactor for treatment of stillage from fruit distillation, Water Science and Technology, 67(5), 2013, pp. 1068-1074
[14] *K. D. Monson, S. R. Esteves, A. J. Guwy, and R. M. Dinsdale*, Anaerobic digestion of biodegradable municipal wastes – A review, SERC, University of Glamorgan, United Kingdom, 2007.
[15] *J. Rapport, R. Zhang, B. Jenkins, and R. B. Williams,* Curent anaerobic digestion technologies used for treatment of municipal organic solid waste, California Environmental Protection Agency, 2008.
[16] *D. Deublein, A. Steinhauser,* Biogas from Waste and Renewable Resourses. An Introduction, Wiley-VHC, Mainheim, 2008.
[17] *P. Vandevivere, D. De Baere, W. Verstraete,* Biomethanization of the organic fraction of municipal solid wastes, Chapter 5. Types of anaerobic digesters for solid wastes, IWA Publishing, London, 2003, pp. 111 – 140.
[18] *A. Khalid, M. Arshad, M. Anjum, T. Mahmood, and L. Dawson,* The Anaerobic Digestion of Solid Organic Waste, Waste Management, 31, 2011, pp. 1737 – 1744
[19] *Instituto para de Diversificacion y Ahorro de Energia (IDAE)*, Biomasa. Digestores Anaerobios, IDAE, Madrid, 2007.
[20] *D. A. Burke,* Dairy Waste Anaerobic Digestion Handbook. Options for Recovery Beneficials Products form Dairy Manure, Environmental Energy Company, Washington, 2001, On line: www.makingenergy.com.
[21] *P. Vindis, B. Musec, M. Janzckovic, and F. Cus,* The impact of mesophifilic and Thermophifilic anaerobic digestion on biogas production, J Achivements Mater Manuf Eng, 36, nr. 2, 2009, pp 192 – 198
[22] *J. Fernandez, M. Perez, L. Romero,* Comparision of mesophifilic and thermophifilic dry anaerobic digestion of OFMSW: Kinetics Analysis, Chem Eng J., 232, 2013, pp 59 – 64
[23] *F. Cecchi, P. Pavan, J. Mata-Alvarez, A. Bassetti, and C. Cozzolino,* Anaerobic Digestion of Municipal Solid Waste: Thermophilic and Mesophilic Performance at High Solids, Waste Manag. Res., 11, 1993, pp 403 – 414
[24] *X. Gomez, M. J. Cuetos, Garcia A. I., and Moran. A.*, Anaerobic Digestion in two-Stages (In Spanish). Ingenieria Química, Tratamiento de residuos, 2007, pp 124 – 132
[25] *V. Shefali,* Anaerobic digestion of biodegradable organics in municipal solid wastes, Master Thesis, Columbia University, 2002.
[26] *Lissens G., Vandevivere P., De Baere L., Biey E. M., and Verstrae W.,* Solid waste digestors: process performance and practice for municipal solid waste digestion, Water Sci. Technol., 44, nr. 8, 2001, pp. 91 – 102.