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Comparative results in biogas production using municipal biodegradable waste for green gas emissions reduction

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This present paper highlights important aspects concerning the proposed technology for the biogas generation from the degradable part of the municipal waste, and presents results for two different batches, from the point of view of the process parameters and biogas characteristics during the combustion. The topic is based on the original concept and general characteristics of a developed pilot working under anaerobic fermentation – assemble on the industrial platform of S.C. COLTERM S.A. Timisoara. It presents results of research and tests concerning the possibilities of biogas production from municipal residues in order to depict possibilities of improving the main parameters of the process and the quantity and quality for the produced biogas, known to be a potential renewable energy resource. The achieved results are important for optimizing the anaerobic fermentation process with impact on the general characteristics for the produced biogas and the applications in which this can be used, namely a further combustion, in stead of natural gas.

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Keywords: Anaerobic fermentation, Degradable municipal waste, Biogas

1. Introduction

One of the environmental problems of contemporary society is the continuous growth of organic waste. In many countries the duration of sewage management and prevention concepts have become key policy priorities, representing a major effort to reduce pollution and greenhouse gases in order to mitigate global climate change [1]. Reducing the negative effects related to the increasing quantities of municipal residues represents an EU strategic objective.

With anaerobic digestion, a renewable source of energy is captured, which has an important *climatic twin effect:* (1) The use of renewable energy reduces the CO_2-emissions through a reduction of the demand for fossil fuels, (2) At the same time, by capturing uncontrolled methane emissions, the second most important greenhouse gas is reduced:

The reduction of *1 kg methane is equivalent to the reduction of 25 kg CO_2*. Due to environmental concerns carbon dioxide in the atmosphere needs to be monitored and controlled regularly [2]. As CO_2 generation by burned biogas only amounts to 80 per cent of the CO_2 generation of fired fuel oil (per kWh electrical energy) and is even more advantageous in relation to coal (about 50 per cent), the environmental benefits of biogas in relation to fossil fuels are indisputable. Because of the high efficiency of wood (0.7 kg CO_2 per kWh gross energy), the substitution of the wood based biomasses by biogas rise the national and global storage capacity of CO_2. Thus, using biogas has a direct and telling effect on local, regional and global atmosphere, by considerably reducing the greenhouse effect. The processing of refuse was usually undertaken to reduce the pollution potential and volume for ease of handling and disposal. This perspective has since been adjusted to include the transformation of the waste, which was hitherto unwanted, into useful end-products [3].

According to statistics, every EU citizen produces an amount of about 520 kg of municipal wastes. This amount is 13 % more as compared to 1995. By 2020 is predicted a further increase to 680 kg per person, meaning an increase of almost 50 % in 25 years.

Efficient disposal of municipal market waste (both vegetables and non vegetables) is always a sensitive issue to civic authorities since the presently available disposal processes like sanitary landfill, incineration, pyrolysis, etc., are always associated with pollution hazards posing a serious threat to public health [4]. Municipal solid waste (MSW), when land filled, causes several environmental problems such as the biogas production, volatile organic compounds (VOC) emission, etc. Because of this, there is important to develop a green technology for disposal of those waste categories, which is to be both cost effective and pollution free. Connected with this, anaerobic digestion of energy crops, residues, and wastes is of increasing interest in order to reduce the greenhouse gas emissions and to facilitate a sustainable development of energy supply [5]. Also, as a main result of this technology, biogas can be used in order to fully recover all the energy of municipal wastes. Methane, which is the main component of biogas, is a valuable renewable energy source, but also a harmful greenhouse gas if emitted into the atmosphere. Methane, upgraded from biogas, can be used for heat and electricity production or as bio-fuel for vehicles to reduce environmental emissions and the use of fossil fuels [6]. Biogas originates from bacteria in the process of bio-degradation of organic material under anaerobic (without air) conditions. In the absence of oxygen, anaerobic bacteria decompose organic matter and produce a gas mainly composed of methane (up to 60 % by volume) and carbon dioxide called biogas, which can be compared to the fossil originated natural gas which is 99 % by volume methane. Unlike fossil fuel combustion, biogas production from biomass and biodegradable fraction of waste is considered CO_2 neutral and therefore does not emit additional Greenhouse Gases (GHG) into the atmosphere.

Municipal solid waste (MSW) is composed of:

– Digestible Organic Fraction of readily biodegradable organic matter, e.g. kitchen, scraps, food residue, grass cuttings etc.
– Combustible Fraction of slowly digestible organic matter such as coarser wood, paper, cardboard; these are lignocelluloses materials which do not readily degrade under anaerobic conditions and are better suited to aerobic digestion, i.e. composting.
– Inert Fraction meaning tones, glass, sand, metal, etc. Some of these products are suitable for recycling, the remainder can be land filled.

Anaerobic digestion occurs naturally wherever high concentrations of wet organic matter accumulate in the absence of dissolved oxygen. Only waste of organic origin can be processed in an anaerobic digester. Joint treatment of municipal solid waste with animal manure/sewage slurry is a popular method in existing plants; the process tends to be simpler and is economically more viable than an MSW only treatment system. The technology of biogas production from MSW consists of several stages:

– ***Separation meaning that the*** recyclable materials are separated from organic waste at the source. ***A mechanical Separation*** can be used to separate an organic fraction of the waste if source separation is not available. The fraction obtained is more contaminated which will affect the heavy metal and plastic content of the final digested composting product.
– ***Pre-treatment consists of a chopping of*** the organic material before it is fed into the digester. The organic matter is also diluted with a liquid, ranging from sewage slurry, to recycled water from the digestate, to clean water.
– ***Anaerobic Digestion Process is t***he main process of digestion and consists also of three stages:

1) *Hydrolysis / Liquefaction* that **i**nvolves the breakdown of insoluble, complex organic matter into simple, soluble molecules. Cellulose is depolymerised into sugars, alcohols, peptides, amino acids and fatty acids with the help of an enzyme released by the bacteria. In some processes this initial step is catalysed by the use of an acid or alkali. In some industrial processes an hydrolysis process is added at the beginning stage to substantially degrade the hydrocarbon content of the solid waste before it is added to the digester. This provides a higher methane yield and gives a shorter digestion time. It also reduces the thick fibrous scum that can form on top of the digesting mixture and generally makes it less viscous and easier to process.

2) *Acetogenesis / Fermentation*: The simple monomer blocks formed in step 1 act as substrate feedstock for the fermenting, acid forming anaerobic bacteria which produce various volatile acids, carbon dioxide and hydrogen. The principal acids produced in this process are acetic acid, propionic acid, butyric acid and ethanol.

$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2 \quad (1)$$

3) *Methanogenesis*: The acetic acid and hydrogen produced in step 2 are broken down by the acetoclastic methanogenic bacteria forming methane and hydrogen carbonate. Hydrogentrophic methanogenic bacteria then reduce the hydrogen carbonate with hydrogen to form methane. Many products, by-products and intermediate products are produced in the process of digestion before the final product of methane is produced. Examples of some of the reactions that occur turn Acetic acid into Methane and Carbon Dioxide, or Ethanol and Carbon Dioxide turn into Methane and Acetic acid. Methane results also from a simple reaction of carbon dioxide with hydrogen.

$$CH_3COOH \rightarrow CH_4 + CO_2 \quad (2)$$

$$2CH_3CH_2OH + CO_2 \rightarrow CH_4 + 2CH_3COOH \quad (3)$$

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O \quad (4)$$

Methane is the valuable component under the aspect of using biogas as a fuel. The biogas produced contains methane, carbon dioxide, some inert gases and sulphur compounds. Typically 100-200m3 of gas is produced per tonne of organic MSW that is digested. Typical biogas composition, according to the Biogas from Municipal Solid Waste – Overview of Systems and markets for Anaerobic Digestion of MSW, green line, is given in Table 1 [12].

Table 1. Typical biogas composition [11].

Methane	55-70 % by vol.
Carbon dioxide	30-45 % by vol.
Hydrogen Sulphide	200-4000 ppm
Energy Content (Higher Calorific value)	20-25 MJ/m^3

The calorific value of biogas is thus about 6 kWh/m^3. 1 m^3_N biogas (approximately 6 kWh/m^3) is equivalent to about 0.5 kg diesel or kerosene (having approx. 12 kWh/kg), 1.3 kg wood (approx. 4.5 kWh/kg), 0.7 kg hard coal (approx. 8.5 kWh/kg), 1.1 m^3 natural gas (approx. 5.3 kWh/m^3), 0.24 m^3 propane (approx. 25 kWh/m^3), according to the report issued by the Indian Council of Agricultural Research, New Delhi, [13]. 1 m^3_N biogas generates through combustion an energy equivalent of 0.5 l oil and thus a release of 1.6 kg CO_2 can be considered as having neutral origin.

Even if Romania, as a member of the European Union, is still at its beginnings related to the activities involving obtaining biogas from different types of residues, at the moment there are a number of projects in development for improving the general status of the country at this chapter. Connected with the existing types of residues, according to the National Waste Management Strategy all types of waste generated on the Romanian territory are classified as: municipal waste and similar, waste production and waste generated from medical activities. According to statistics, in Romania, the total quantity of generated wastes has decreased by about 13 % in 2003-2006 from 369.8 million tones to 320.6 million tones of wastes. In 2006 the amount of waste generated was: waste generated by mining and quarrying, 199.2 Mt, waste generated by other economic activities, 112.4 Mt, and municipal waste, 8.8 Mt. Recovery of industrial waste, both hazardous and dangerous, was approximately 12.5 Mt, which represented only 4 % of the total waste generated, the rest being eliminated. Of the total municipal waste generated, only 6.8 Mt were collected, meaning 76.8 %. Household and similar waste represents 78.8 % of the amount of municipal waste collected, and approximately 47 % from those wastes are biodegradable, about 11 % is both paper and cardboard, and glass, respectively. Only 0.6% from municipal wastes collected was recovered, 99.4% were removed through organized storage spaces (landfills). From household wastes, collected separately and recovered, almost 42 % is paper wastes and cardboard, and 27 % glass wastes [7].

For the Timisoara city, energy recovery from municipal waste could be a technical solution for a long-term economic and social development. Waste collection and transport can be provided by the local health operator, and the incineration facility may be located and operated from a thermo-electric plant (South Power plant Timisoara). According to data for 2008, the total quantity of waste collected, transported and stored was about 130.7 thousand tons. This is an annual quantity of waste per capita of 425.2 kg. The analyze of the development for waste composition and characteristics of Timisoara shows that by 2030 the total amount of municipal wastes will be ~ 144.6 thousand tons / year with an average low calorific value of 3500 kcal / kg.

Following Advantages of MSW anaerobic digestion are important: (1) Makes landfills easier to manage by removing problematic organic waste material which is responsible for gaseous and liquid emissions. (2) Enclosed system allows all of the biogas to be collected, unlike on landfills where recovery only yields 30-40 % of gas generated. Methane is a greenhouse gas with twenty times the impact of carbon dioxide, (3) generates an end product that can be used as a soil conditioner.

Mixing the refuse with animal dung improves the system efficiency and allows for a more simple process design, improving the economic viability of the system. This is due to the improved nitrogen content that is achieved by mixing with dung.

2. Pilot installation for biogas production using municipal residues

As it was specified earlier, related to partially solving the problem of discarding the biodegradable municipal residues, a pilot plant was built in order to study the potential of producing biogas with good properties, related to quality, quantity and usage in incineration or co-incineration processes.

Calculations of the facility are provided to SC COLTERM SA from Timisoara City Hall - Municipal Division - Service sanitation - Waste Management Bureau. According to data from the database of Timisoara City Hall, the quantity of the municipal residues collected, transported and stored in 2008 was 130,689 tones (870,420 m3) with a monthly variation from 8995 tones (February) to 12,778 tones (July) [8]. This represents an amount of 425.2 kg / inhabitant / year (1.165 kg / inhabitant / day) with a density of 150.14 kg/m3. Analysis of composition and evolution characteristics of Timisoara a DSM was performed with the available data in the study by ADEME in 2000 and study by the University of Stuttgart in 2008. The pilot plant using anaerobic fermentation of biodegradable waste from landfill is shown in Figure 1[9].

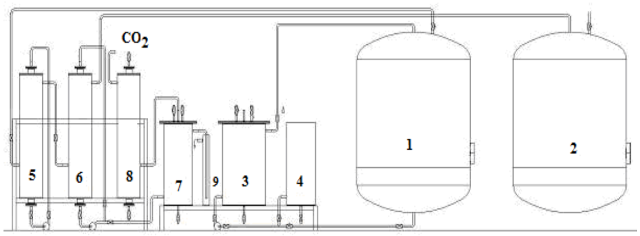

Fig. 1. Pilot plant using anaerobic fermentation of biodegradable waste from landfill [8] 1 – fermentation reactor; 2 – storage tank for purified gas; 3 – liquid solution recirculation tank; 4 – pH correction tank; 5 – H_2S filter; 6 – CO_2 filter; 7 – CO_2 evacuation tank; 8 – CO_2 buffer tank; 9 – hydraulic valve.

In Fig. 2 is presented an overview of the biogas pilot plant, as accomplished in the industrial area of the Power plant. One intends to use the generated biogas to fuel local available small steam boilers.

Fig. 2. Overall view of the pilot plant

The demonstrative pilot plant uses a cylindrical reactor, vertical, for methane fermentation. On the methane fermentation reactor's lid are placed connections for: pressure sensors, pressure gauge, exhaust of the biogas from the reactor until a minimum established pressure level, safety valve for evacuation in case of biogas accidental pressure increase. On the cylindrical virol of the reactor the following connections are located: pressure sensors, thermostat sheath for measuring and controlling the reactor temperature. At the bottom of the reactor there are pre-discharge (recirculation) connectors for the evacuation of the fermented liquid. From the reactor, the obtained biogas will pass through the purification system, where the CO_2 is captured and the concentration of H_2S is reduced, and after that it will enter in the storage tank for the purified gas. From this point it can be used for different types of consumers according to the needs involved.

3. Results

Two batches of material were analyzed and results will be discussed inside this paragraph, in order to depict the process characteristics related to the main influence parameters in the process.

For the first batch, the measurements were accomplished during a period of 73 days, and the pH and temperature were observed and adjusted, during the whole period. The batch was comprised of about 4 to 5 m^3 of municipal waste with a large quantity of biodegradable parts, practical a mix of biodegradable and non degradable material, with a determined water content of approximately 40.9 % and ash content of about 30.5 % (all by mass), for the analyzed samples as received from the site [10], [11].

In the next figures the variations for the temperature and pH during the batch of material are presented. Because the used material is a mix of organic with anorganic residues, it was difficult to establish the exact composition of the batch.

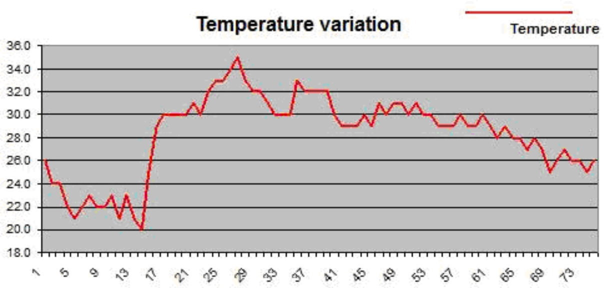

Fig. 3. Temperature variation

The temperature profile (Fig. 3) shows a two – domain regime (cryophilic and mesophilic), with variations between 20 °C and 35 °C, meaning a relatively different behaviour according to the suspension used in the batch. Because in the first period of time the temperature value was low, the process inside the fermentation tank was developed with a relatively low speed, the production of biogas starting approximately after 25 - 30 days.

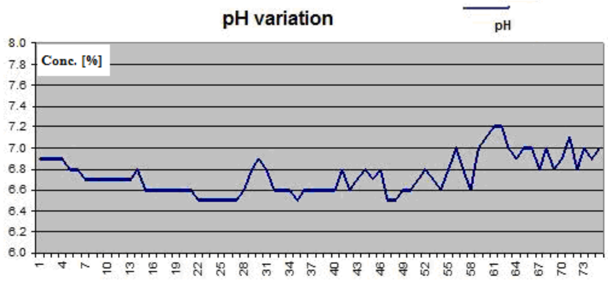

Fig.4. pH variation

The general influence of the temperature over the pH value (Figure 4) is very low, and it can be observed that the time variations are small; the general values are between 6.4 and 7.2, a domain that fits for biogas production in relatively large quantities.

In Fig. 8 one presents the time variation of methane and carbon dioxide along the biogas production process having in mind the fact that the process started after about 25 – 30 days.

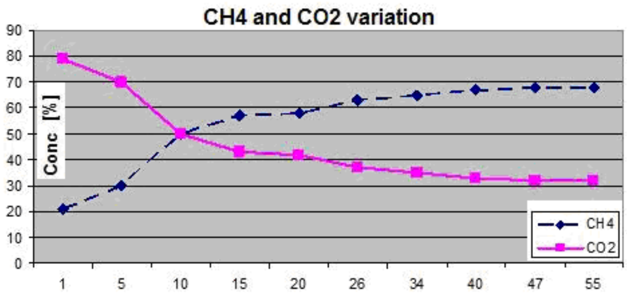

Fig. 5. CH_4 and CO_2 time variation.

Considering the temperature regime and the necessary time for the start up of the process, the initial concentration of CH_4 inside the produced biogas was about 21 % by volume, with a relative concentration of 78 % of CO_2. It can be also observed from Figure 8 that, after about 10 days of process, the CH_4 and CO_2 concentrations represent about 50 % and the maximum value of methane at the end of the process is close to a value of 68 % inside the fermentation reactor, which represents a good indicator of the possibilities in using the produced biogas in incineration or co/incineration processes.

The second batch of material was studied over a period of 78 days and the chosen temperature regime was the mesophilic one, with values between 30 – 39 ºC. As for the first batch, the chosen quantity of residues was about 4 – 5 m^3 and the general composition is comprised by large quantities of degradable material with a high potential of biogas production from the point of view of methane composition. For the analyzed samples, the water content was approximately 40 % by mass and the correspondent ash content about 30 % by mass, as received from the site [10], [11].

One monitored the temperature and pH for the second batch as well, and the results are presented in the followings.

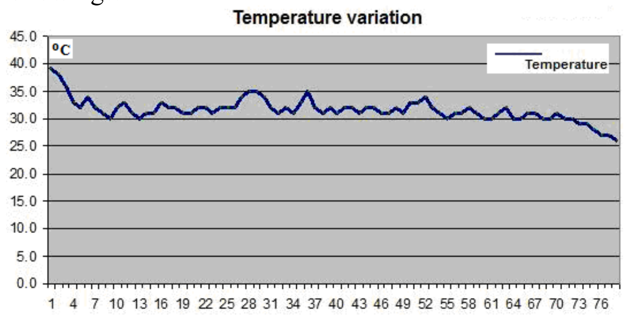

Fig. 6. Temperature variation, second batch

From the figure above it can be observed that the second batch has as main characteristic the mesophil temperature regime, ideal for obtaining large biogas quantities with high quality in periods of 60 – 90 days.

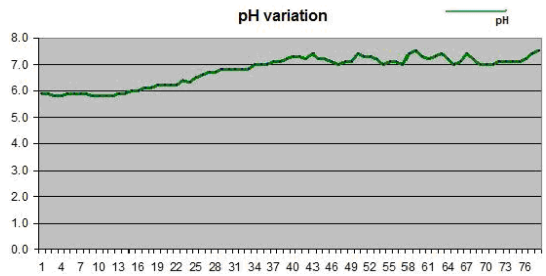

Fig.7. pH variation, second batch.

In the above figure is underlined the pH evolution correlated with the transformations inside the reactor in conditions of passing from the initial acid phase through a neutral phase with alkaline tendencies (values over 7.5) in the last part of the process.

The pH is correspondent to a good behaviour of the material during the anaerobic fermentation process, representing another positive indicator for biogas production.

Next figure underlines the time evolution for CH_4 and CO_2 for the main reactor where the fermentation takes place.

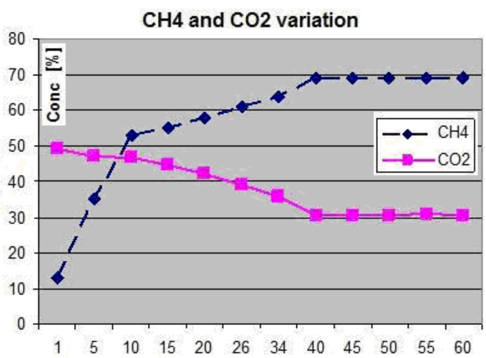

Fig. 8. CH4 and CO_2 time variation

From the figure above it can be observed that the process evolves in time to values of 69 – 70% in CH_4 concentration and to values between 30% and 50% for CO_2.

In order to determine the implications related to the biogas usage in incineration processes, a part of the produced biogas was tested in regards to general characteristics during combustion. For the determinations there was used a Riello GS3 low NO_x burner and the flue gas composition was analyzed using a Testo 300 XXL gas analyzer.

For the first batch, concerning the CO, CO_2, NO and NO_x concentrations, the values are also presented,.

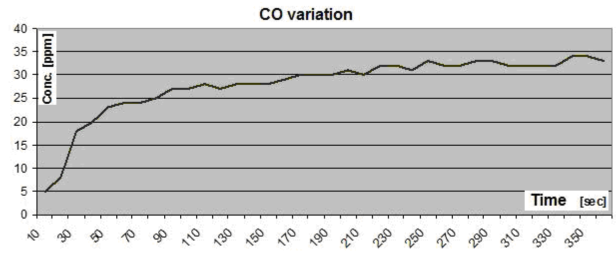

Fig. 9. CO variation in time during combustion process.

The total volume of biogas obtained inside the process was approximately 156 m^3 related to a period of around 50 days, with an average of 3 m^3 / day and about 30 m^3 of biogas / m^3 of municipal residues. CO emissions are at a level of about 35 ppm, which indicates an almost complete incineration process.

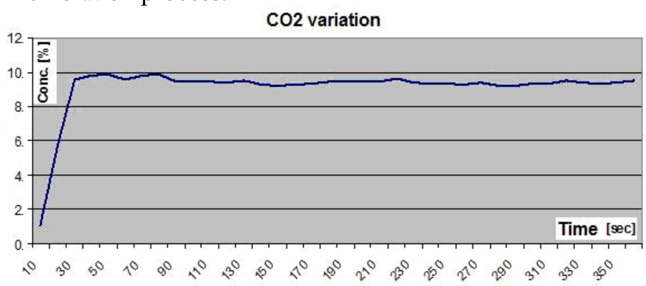

Fig. 10. CO_2 variation in time during combustion process

From Fig. 10 one can determine that the CO_2 content is about 8.5 – 9.5 % by volume, fact which reflects a relatively increased concentration inside the flue gases, but also a high percentage of possible reduction (about 72 %), through direct incineration of the produced biogas.

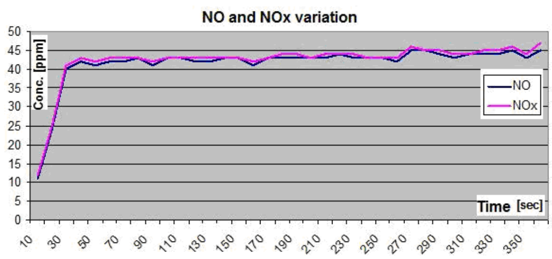

Fig. 11. NO and NO_x variation in time during combustion process.

From Fig. 11 it is observed that the NO and NO_x concentrations reach respectively at values of 40 - 43 ppm, which indicates that through the process a good burning characteristics for the produced biogas is generated. For the second batch, the measurements were carried out in the same manner as for the first one, the results being presented below.

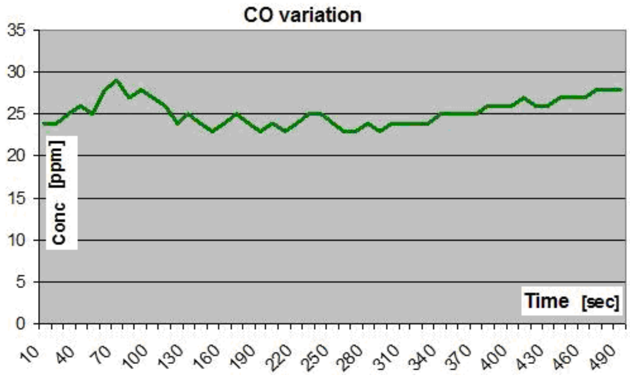

Fig.12. CO variation, second batch.

The total volume which has been obtained for the second batch is about 350 m^3, a larger value than that obtained in the previous batch, indicating an optimized anaerobic fermentation process using the same technology, but under different exploitation parameters.

It can be observed the fact that CO concentration inside the flue gases is extremely reduced, about 18 – 27 ppm, which is also a good indicator for an almost complete incineration process.

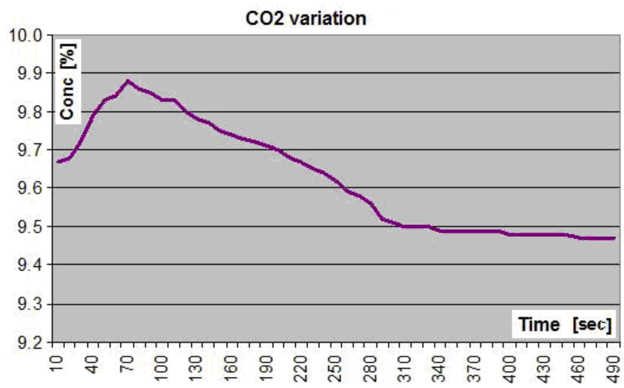

Fig. 13. CO_2 variation, second batch

The CO_2 component is present in the largest quantity from the produced elements which were found in the flue gases, but still it is reduced to a value of about 25% from the existent value present in the initial phase before the incineration process. This value is also a good indicator of the potential optimization for the process in order to improve the main characteristics to reduce further the existent concentrations [14].

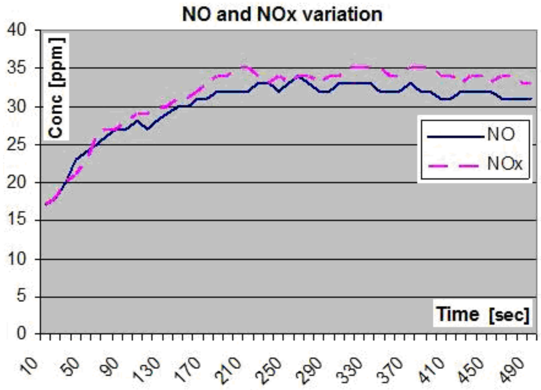

Fig. 14. NO and NO_x variation, second batch

The existent NO and NO_x concentrations inside the flue gases are reduced to a level of 15 – 35 ppm, indicating almost no influence from the N based compounds inside the incineration process.

4. Conclusions

One of the modality of reducing green gas emissions (CO_2, CH_4) is to use renewable energy resources; this paper focuses on a process of anaerobic digestion based on solid municipal waste (MSW) generating biogas, considered to be a neutral fuel, in terms of CO_2 [15].

The proposed technology can be implemented both in small or large systems for application for diverse scopes, best to generate, through cogeneration, electric and thermal energy. The presented schematics of the facility can be sized to suit any situation, without adversely affecting the process performance. Obtaining biogas from anaerobic fermentation using municipal residues appears to be one of the technologies that have the potential to solve, at least partially, the problem of continuously growth in municipal residues quantities [16].

The pilot plant is a solution regarding the degradable municipal residues and it can be used in parallel with other methods that use other categories of municipal residues that are not of degradable type [17].

The main component which results from the process is biogas, but as a secondary component which can be used, the residue obtained after the process can be used as a fertilizer for the agricultural surfaces [18].

During the experiments, the real availability of the produced biogas for incineration or co-incineration processes with good results in regard to the general composition of the flue gases, was determined. Among the causes, concerning the differences between quantities generated in comparison for the batches, there can be mentioned the following: (i) the raw material quality (it depends on the degradable compounds inside it, the larger those quantities are, the better the quantity and quality for the produced biogas will be), (ii) the external temperature, depending on the season, which can affect the anaerobic fermentation process and, (iii) also the pH influence which is necessary to adjust along the entire duration of the process, correction frequency depending on the time evolution form the acidogenic to methanogenic phase. Still, the problem of sorting the municipal residues is not resolved entirely, but the implied efforts are significant. Those efforts involve the use of adequate technologies and installations. Major expectations are opened through the cleaning up of the biogas, in terms of generating an environmental friendly renewable gas, enhancing its lower calorific value (by CO_2 capturing) and sulphur emissions (by H_2S retention).

By using this kind of technology with application for a large variety of vegetable residues, one can improve the recovery of energy potential from waste materials that usually are not used for any kind of economic scopes, simultaneously with obtaining a clean renewable fuel, with no dangerous impact over the environment [17], [18], [19], unless secure technologies that are state of art for NO_x, H_2S, CO_2 reduction for ex. according [9], [20], [21].

Acknowledgments

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