SUSTAINABLE DEVELOPMENT OF ROMANIAN CITIES THROUGH BIOGAS PRODUCTION FROM MUNICIPAL WASTES AND APPLICATION IN CO-COMBUSTION PROCESSES

by

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Today municipal wastes represent a general problem from multiple points of view: necessary space for depositing, odor, possible soil contamination. In the same time, a large quantity of organic residual material remains unused in terms of energy conversion by potentially producing a biofuel which, in its term, can be used for covering at least partially, the human demand for energy. In this context, the present paper underlines the possible applications of anaerobic fermentation for biogas production by using as main substrate solid municipal waste from city of Timisoara, Romania, inside a pilot installation for determining its potential for further usage at larger scale in firing or co-firing processes; in this context, conclusions will be traced, based on the resulted experiments.

Key words: *municipal waste, food waste, anaerobic digestion, biogas*

Introduction

The main objective of any political/social approach to waste management is to reduce to a minimum the waste impact on the environment and human health. Same applies to urban waste management. Various options exist for urban waste management, from prevention and recycling to energy retrieval. The prioritization of waste management is expressed as the well-known hierarchy of prevention, reuse, recycling, recovery and disposal [1]. In the Romanian case, waste management is a bit difficult, as population education in preventing waste production is at incipient phase. In average, each Romanian produces 381 kg per year of municipal wastes, of each about 57% is biodegradable. Basically, there are almost no changes in municipal waste production, if in 1993 the total country municipal waste reached 8.6 million tons per year, in 2006 reached 8.87 million tons per year and in 2009 about 6.93 million tons per year [2]. The reduction of municipal waste is most probably caused by severe Romanian demographic decrease, from 23 million in 1993 to ~ 20 million in 2012 and not by successfully implemented waste management programs. In today's Romania 99% of wastes management (including municipal waste) consists, basically, of storage in landfills. However, first steps have started to be done in Romanian modern urban waste management, starting with in-house selective collection from 2007 and start-up of the construction, in 2014, of the first Romanian municipal waste incinerator in Timisoara city, with a total (estimated) capacity of 150000 t/year of waste processed, estimated electrical output of ~65000 MWe per year and ~150000 Gcal per year of

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thermal energy delivered to the city central heating system [3]. However, the projected municipal waste incinerator has no biogas production option, as a by-product.

In many European countries, large portions of municipal solid waste are dumped in landfills, instead of using it as an energy source. However, EU policies are enforced and by the end of the decade, all EU countries should comply with the Landfill Directive 1999/31/EC and Waste Directive 2006/12/EC to reduce landfilling of the biodegradable part of municipal solid waste (MSW) to 35%. Biogas production from biodegradable municipal waste has the potential not only to contribute to achieving EU landfill targets but also to boost local economy opportunities.

However, besides the need to enforce EU regional policies on wastes and landfill management, one should look sustainable handling of MSW from a global warming perspective [4]. Moving organic solid waste from landfill to biogas facilities reduces considerable quantities of greenhouse emissions and contributes to the reduction of pollutants emitted. Also, decreases dependency on fossil fuel both for heat and electricity production. If about 84% of municipal waste (solid) is collected globally only 15% is recycled [5] and most of it is disposed of in landfills, with a wide variety of disposal rates (5-80 %) amongst EU member states. [6]

Anaerobic digestion uses microorganisms and/or enzymes to process a fermentable substrate, converting it into recoverable products. Currently, the most required fermentation product is ethanol [7]. Anaerobic digestion can be defined as the biological degradation of organic matter into biogas, which is mainly composed of CH_4 and CO_2. The process, occurring in an oxygen-free environment, has been largely applied to treat several kinds of biodegradable materials [9].

Since 1992, with Rio Declaration and 1997 Kyoto agreement, most states passed action plans for the 21st-century global GHG reduction and pollution control. The Kyoto Protocol became effective after the ratification of Russia in 2005, and the EU has to reduce its GHG emissions by 8% of its 1990 levels. The reduction quotas depend on countries development levels, *e. g.* Germany and Denmark to cut down to 79% of the 1990 level, Romania by 8% [9]. Significant progress was recorded at EU level in the reduction of GHG emissions, as graphically explained in fig. 1, Germany and Denmark by 24.8%, the UK by 25.1%, Romania by 52%, a.o., with a total reduction at EU-28 level of 19.2% [10]. One should note that the reduction is mainly covered by industrial/manufacturing and energy sectors while the transportation GHG are still in a continuous increasing trend.

European member states are committed both to increase their share of renewable energy sources and to reduce their GHG emissions. Currently, no mandatory sustainability criteria have been formulated at a European level for solid biomass and biogas used for power and heat production. However, the European Commission (EC) provided recommendations to the Member States to develop criteria similar to the ones designed for transport biofuels [11].

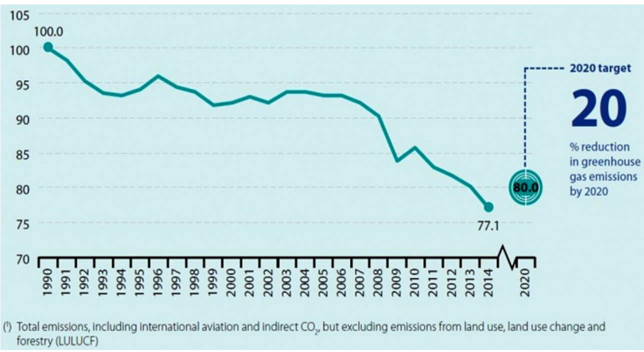

Figure 1. The GHG emission data for the EU-28 as a whole referring to domestic emissions [8]

Material and methods

The substrate used for biogas production in the pilot station and method described was analyzed and can be considered representative for Romanian landfill urban wastes. The substrate parameters and method used for analysis are presented in tab. 1.

Table 1. Elemental analysis of municipal waste substrate

Quality parameters determined for Timisoara municipal landfill waste							
W_h^i, [%]	W_t, [%]	H^i, [%]	N^i, [%]	S_t^i, %	C^i, [%]	Q_s^i, [kcalkg^{-1}]	Q_i^i, [kcalkg^{-1}]
2.66	2.66	3.69	0.96	0.65	27.38	3018	2809
Method for quality parameters							
Oven dry method EN 14774:2009		Dynamic flash combustion with thermal conductivity detection (FLASH EA 1112)				Calorimetry	$Q_i^i = Q_s^i - 5.86(W_i^i + 8.94\ H)$ STAS 398:1992

W_h^i – hygroscopic humidity, W_t – total humidity, H^i – hydrogen content, N^i – nitrogen content, S_t^i – total sulfur content, C^i – carbon content, Q_s^i – superior calorific value, and Q_i^i – gross calorific value; all measured and calculated at dry state

The biogas production pilot installation was designed and constructed, with its main elements presented in fig. 2 [12]. The (4 m^3 of selected biodegradable with 20 m^3 water addition) municipal waste was taken from Timisoara city recycling center before it was sent to landfill and introduced in the 30 m^3 main reactor – 1. The second 30 m^3 vessel is used only as a buffer/storage for cleaned biogas. During the startup and fermentation process, the pH correction solution is automatically transferred from vessel – 4. The pH correction (with lime based water) is done indirectly by transferring a part of the substrate in the buffer vessel – 3, where is mixed with the pH solution and transferred back into the main reactor. In this way not only that the substrate pH is continuously maintained at 6.5-7.5 value but also the risk of sedimentation is avoided by recirculation. The CO_2 and H_2S filters were not used during this study.

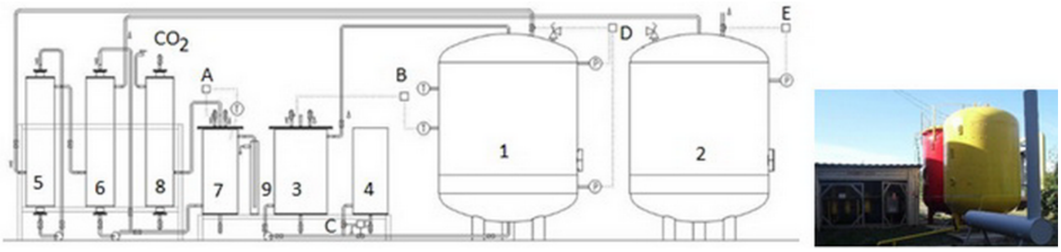

Figure 2. Biogas production pilot plant; *1 – fermentation reactor, 2 – clean biogas storage; 3 – substrate circulating buffer vessel, 4 – pH correction, 5 – H_2S filter, 6 – CO_2 filter, 7 – CO_2 purge, 8 – CO_2 buffer, 9 – hydraulic valve, A – CO_2 temperature control loop, B – reactor temperature control loop, C – pH control loop, D – pressure control loop, E – pressure control loop in clean biogas tank*

Results

The substrate used and previously described undergone the mesophilic process for a period of 80 days, without inoculum at temperatures between 30-39 °C, in anaerobic fermentation. The initial phase, with pH correction, was at about 20 days. After this period the pH correction was not necessary.

In fig. 3 the evolution of CH_4 and CO_2 production is shown, after the initial acidogenic phase, after pH value of the substrate was stabilized and the CH_4 production was started. Traces of CO < 0.02 % and significant concentration of H_2S, varying from 400 to 450 ppm with a constant production rate was observed starting from day 28. The total biogas produced in the installation in the testing period of 60 days was 320 m^3. The substrate used was formed by 20 m^3

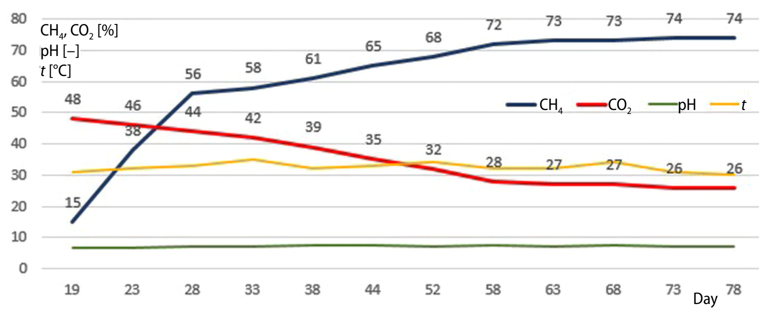

Figure 3. The CH_4 and CO_2 production rates in the mesophilic regime

of water mixed with 4.5 m^3 of municipal waste. The municipal waste used as a substrate has a 50 to 60 % organic fraction.

During the biogas production period, in four days (58, 63, 73, and 77) the biogas was combusted in a very simple, circular combustion chamber. The burner used was a Riello type GS3 with a modified nozzle (larger) for raw biogas optimum combustion. The results are presented in tab. 2. The combustion chamber has a 4-meter stack and was not equipped with any heat exchangers/recovery systems.

Table 2. Biogas combustion exhaust gases

Day	Temperature [°C]	O_2 [°C]	CO [ppm]	NO [ppm]	NO_x [ppm]	SO_2 [ppm]	H_2 [ppm]	CO_2 [%]	λ [–]
58	284.8	3.56	29	26	27	0	6	9.88	1.20
63	292.9	3.86	23	32	34	3	3	9.71	1.23
73	294.0	4.24	24	33	35	3	2	9.50	1.25
77	302.8	4.28	28	31	33	4	1	9.47	1.26

After the pilot plant construction and choice of the burner for combustion chamber several CFD simulations were performed, to evaluate and optimize the amount of air necessary for design combustion chamber. Also, of interest is how the flame acts in the condition of a biogas composition 70 % CH_4 and 30 % CO_2. In this regards, it was used FLUENT software and the geometry of the combustion chamber was considered to be with the burner mounting in an axial symmetric position. The size of the design and meshing displacement is 2.4 × 0.1 m (a half-plane). The geometry meshing was done with circular elements in a rectangular section, geometry defined in GAMBIT 2. For the solver, the PDF combustion model was chosen, with standard k-ε viscosity model. The entry area of the combustion air is considered a velocity input and the flue gases exit is considered mass output. The heat exchange with combustion chamber walls was considered as convection and radiation transfer.

In fig. 4 the contours of mole fractions of CH_4, CO_2, O_2, and contour of turbulence intensity in burner area are presented. One can observe that even if the biogas CH_4/CO_2 ratio is 70/30 and in conditions of an air-flow corresponding to excess air $\lambda = 1.2$ in the input conditions of the FLUENT software, the formation and flame behavior is more than satisfactory for optimum combustion.

Discussion

The goal of this research is to find and propose a cost-effective method to reduce the impact of urban wastes, biodegradable part, on the Romanian landfills, a huge local problem.

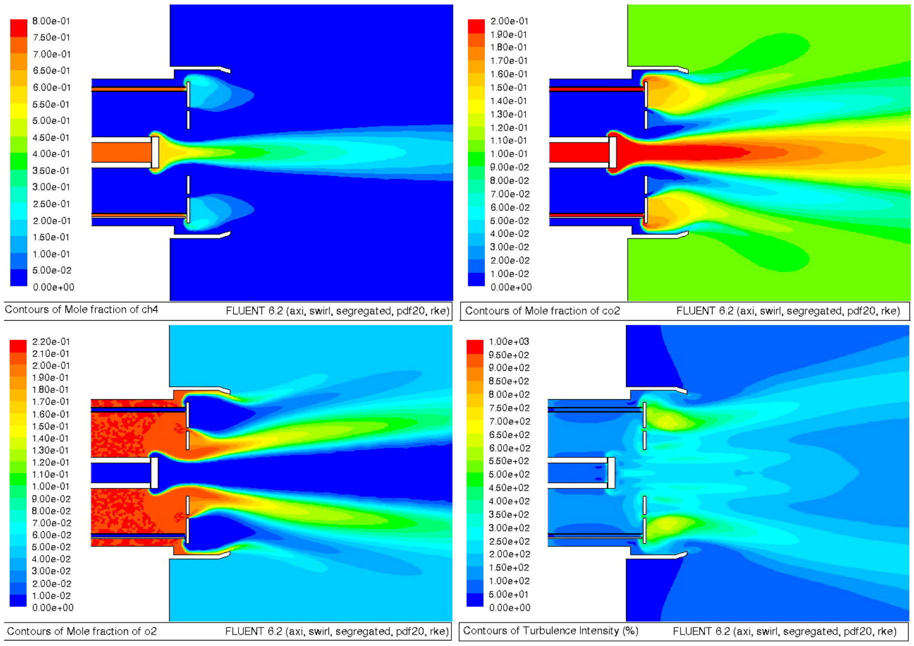

Figure 4. Contours of mole fractions of CH_4, CO_2, O_2, and turbulence intensity
(*for color image see journal web site*)

In Romanian case from a total of 36.7 million tons of wastes per year 71% are generated by industrial sector and 29% are municipal wastes. According to the Romanian Ministry of Environment, Water and Forestry only about 2% municipal wastes are recycled and, at the national level, only 3 co-incineration facilities exist (cement industry) but none for municipal waste co-incineration [13, 14].

As a literature review showed, solid waste management is a challenge for cities authorities in most developing countries mainly due to an increase in wastes quantities and the costs associated with their disposal [15].

A good solution is based on already known and proven organic municipal waste fermentation and biogas production. The solution proposed, method and installation are based on the substrate analysis, typical for Romanian urban waste landfills, who has about 57% biodegradable content and about 93% of total municipal wastes are disposed in landfills [13].

This section may be divided by subheadings. It should provide a concise and precise description of the experimental results, their interpretation as well as the experimental conclusions that can be drawn.

Conclusions

Thru this pilot research one may observe that with a simple biogas production installation high rates of CH_4 can be obtained without any inoculum, for the use of Romanian biodegradable municipal waste. The CH_4/CO_2 ratios obtained, of 70/30 are more than sufficient to obtain good temperature flame gradient (fig. 4). Of course, the biogas quality and obtained quantities depend on the substrate organic composition (for example, summer organic municipal waste has a larger organic composition than autumn or spring municipal waste because of vegetable high content). Through filtering systems, the final biogas composition can be improved to higher percentages while maximizing the firing process by reducing the CO_2 percentage.

Timisoara CET SUD power plant provides heat and hot water (centralized city system) and uses coal (lignite) as main fuel and natural gas for coal combustion support. In this conditions the use of biogas produced from Timisoara municipal wastes could be a feasible solution, both to solve the MSW disposal issues (landfill) and the costly dependency on imported natural gas.

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