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BIO-DRYING OF ROMANIAN MUNICIPAL SOLID WASTE: AN ANALYSIS OF ITS VIABILITY

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România ca ţară membră a Uniunii Europene trebuie să se conformeze directivelor şi reglementărilor UE privind colectarea, transportul, şi depozitarea deşeurilor. Articolul prezintă o metodă de pre-tratare a deşeurilor municipale înaintea valorificrii energetice prin procedee termice sau termo-chimice urmată de o depozitare controlată a reziduului. Această soluţie ar putea fi dezvoltată în România în contextul Directivelor Uniunii Europene.

Sunt prezentate observaţii şi rezultate referitoare la bilanţul de masă, de energie, de mediu şi economic pentru trei studii de caz din Romania.rezultatele au fost obţinute în contextul unei colaborări internaţionale între Universitatea de Studii din Trento, Italia şi Universitatea Politehnica din Bucureşti, România.

Romania as a European Union member country must comply with the EU directive and regulation regarding collection, transport and storage of municipal solid waste. This paper presents an option to pre-treat municipal solid waste before energy recovery through thermal or thermo-chemical processes, followed by a disposal in landfills of the residues. This solution could be developed in Romania in agree with the European Union Directives.

Some consideration and results are presented regarding the mass, energy, environmental and economical balance for three case-studies from Romania. The results have been obtained in the frame of an international collaboration between University of Trento, Italy and Politehnica University of Bucharest, Romania.

Keywords: Municipal Solid Waste (MSW), bio-drying, refuse derived fuel

1. Introduction

Due to European Directives and Romanian engagements on medium and long term, the next years' scenarios in the field of the environment management have to change. Presently, the generated waste is mainly landfilled but the introduction of Landfill Directive (1999/31/CE) in Romania involves significant

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changes for the management of waste. This Directive sets a progressive reduction of biodegradable waste going to landfill (and also set a limit to the lower heating value of the landfilled waste) [1].

This paper presents an analysis of bio-drying process (aerobic process) for Romanian Municipal Solid Waste (MSW). This waste is characterized by a high amount of water because of the big percentage of biodegradable fraction (around 50%) present in the MSW. Moreover the Lower Heating Value (LHV) of this waste in not suitable for direct combustion in thermal power plants or cement kilns (even lower than 6500 kJ/kg) [2].

The main aim of bio-drying is the reduction of MSW water content, thanks to the exothermal reactions of a bio-chemical oxidation, supported by the introduction of an adequate amount of air in the mass. The final product obtained after the bio-drying process is the bio-dried material, that can be treated in order to obtain Refuse Derived Fuel (RDF) with high calorific value (15000-18000 kJ/kg) [3].

2. Policy and legislative context

The European Union legislation imposes the increase of energy generation from renewable sources and the decrease of biodegradable fraction in the landfilled waste (65% in 2016- Landfill Directive 1999/31/EC). Another target regards the decrease of greenhouse gas (GHG) emissions. All these requirements were transposed into Directives that became laws/regulations (Waste Framework Directive, Landfill Directive, Incineration Directives, IPPC Directive, Large Combustion Plant Directive, Renewable Energy Directive) and Romania, as a EU member country must comply with. The EU Directives present different types of pre-treatment for MSW. One of the options is the bio-drying process, as a solution to increase the production of RDF that can be used in thermal power plants, cement kilns and other industrial plants.

At present more than 95% of the MSW generated in Romania is disposed of in landfills [4]. Of course the Romanian target, today, is to increase the energy and material recovery and to decrease the amount of biodegradable fraction in the landfilled waste.

In Romania there is no specific legislation regarding the Biological Mechanical Treatment (BMT), but the National Strategy of Waste Management and National Plan of Waste Management considers this pre-treatment as complementary option for incineration as important techniques in integrated municipal waste management [3].

3. State of art

Bio-drying is a one-flow aerobic process applied to MSW. That means there is no sieving before the biological step, as a typical two-flow treatment requests. During this process, the biodegradable material is decomposed mainly into carbon dioxide (CO_2) and water (H_2O). Heat is generated thanks to the microbial respiration in presence of oxygen. The bio-dried material is more suitable for a mechanical separation, has a higher LHV, a lower mass and a partially reduced biodegradable content.

Bio-drying should not be assumed equal to bio-stabilization [5]. The main differences concern: preparation of material to be processed (no previous sieving), management criteria (no water addition), process duration (shorter, as the consumption of volatile solids must be minimized), emission factors (lower, due to the shorter lasting), energy balance (lower energy consumption, as it needs lower air flow-rates).

The bio-drying sector seems to be spreading, basically as a solution before RDF generation. Presently in Romania, bio-drying plants for MSW are under discussion but not yet constructed. The process is adopted mainly in Germany and Italy thanks to the presence of two companies that developed this process at the industrial scale.

4. Material and methods

The scheme of the bio-drying pilot plant used for developing the experimentations is presented in figure 1. The biological plant has 1 m^3 volume and is placed on an electronic balance. Five temperature proves are placed at different levels. The air is filtered before sending it in the biological reactor in order to protect the compressor. The leachate is collected for a complete control of the process. All the equipments are connected to a data acquisitions system.

Data presented in this paper were obtained using a bio-chemical model developed thanks to the experimentations performed at the University of Trento [6, 7]. The model allows assessing energy parameters (LHV of bio-dried material and RDF) and waste characterization during the process (volatile solids dynamics and water content dynamics) for a representative MSW sample in three Romanian case-studies.

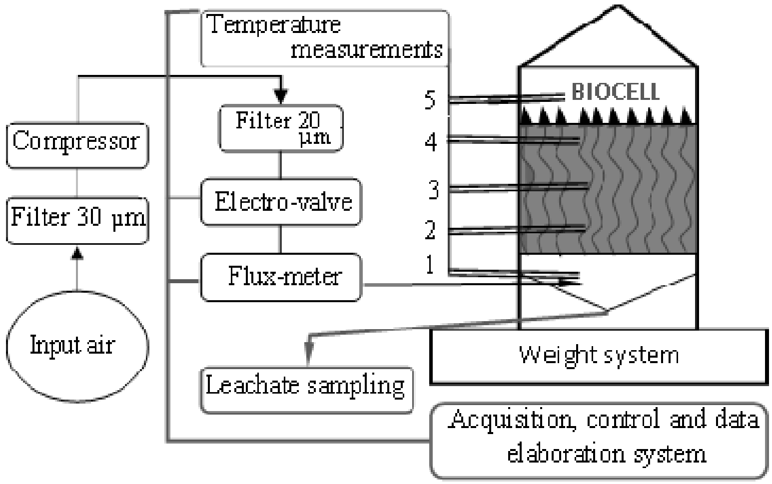

Fig. 1. Scheme of the bio-drying installation

4. Mass and energy balances

Starting from the composition of the MSW form Pitesti, Craiova and Slatina, three case studies have been analyzed. The data for waste composition in these towns is presented in the table 1.

Table 1.

MSW Mass composition (wet basis)

Fractions	**Pitesti [%]**	**Craiova [%]**	**Slatina [%]**
Paper and cardboard	15.4	8.8	15
Plastics	18.7	9.2	12
Glass	8.3	6.5	4
Inert	2.0	2.0	6
Organic fraction	50.0	67.6	48
Textiles	1.3	0.5	5
Wood	0.5	3.0	3
Aluminum	0.5	0.5	1
Other metals	3.3	1.9	6
Total	100.0	100.0	100

The municipal solid waste from these towns has a high organic fraction content. A value of 50% organic fraction in MSW is representative for almost all the urban areas in Romania.

In figure 2 the weight loss dynamics is reported. The importance of the weight loss is related to the necessity of data availability for mass balances in Life Cycle Analysis comparison and design criteria of transport systems.

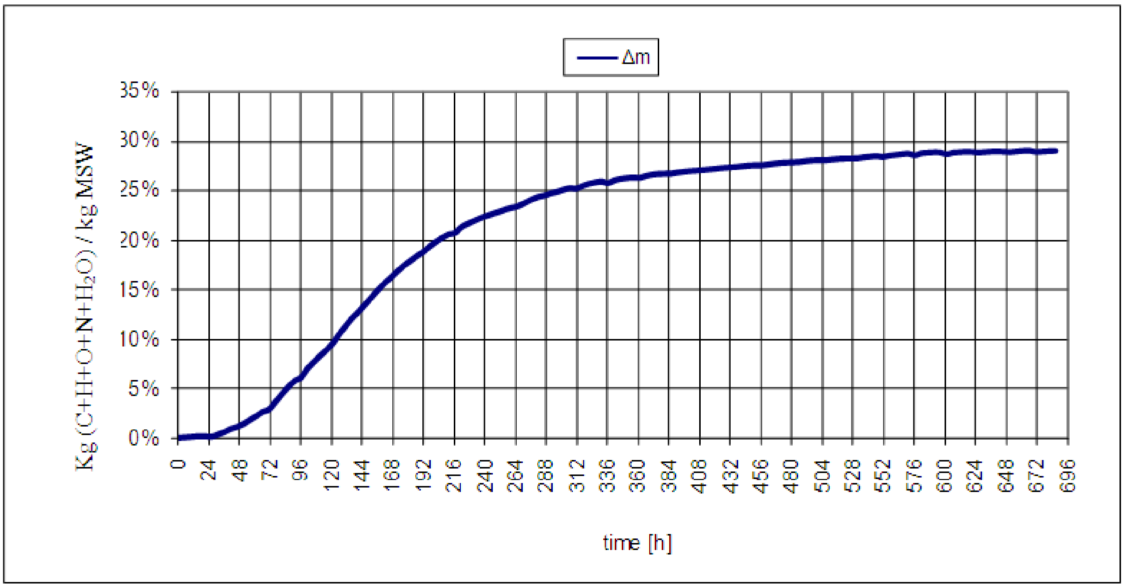

Fig. 2. Mass loss dynamics during the bio-drying process

The values of the weight loss depend on the volatile solids consumption and on the water evaporation. The measured values represent the initial data used in the bio-chemical model for LHV assessment. The weight loss after about two weeks of bio-drying is around 25%, and after one month is almost 30%. A typical lasting for real scale bio-drying is 14 days. The experimentation was performed longer in order to verify the efficiency of the process. It can be noticed the that most important mass loss of MSW is obtained in the first week (around 3% every day). In the second week the mass loss is around 1.5% per day and after these two weeks the weight loss is less than 0.5% per day.

Because every running day of bio-drying plant means energy consumption for the air needed by the process, two weeks are considered the optimal time for a bio-drying run.

In figure 3 the temperature dynamics during the bio-drying process is reported. During the first days of bio-drying, in the core of the waste, the temperatures rises up to 50ºC and more, and this can affect the activity of the microorganisms. The range of temperatures for a proper growth of the microorganisms for a bio-drying process is between 40°C and 70°, therefore an aeration system must be considered in the design stage, in order to control the temperature inside the biological reactor. The air required by the process depends on waste composition and density. The quantity required for each kilogram of MSW for the presented run is about 10 m^3 [6].

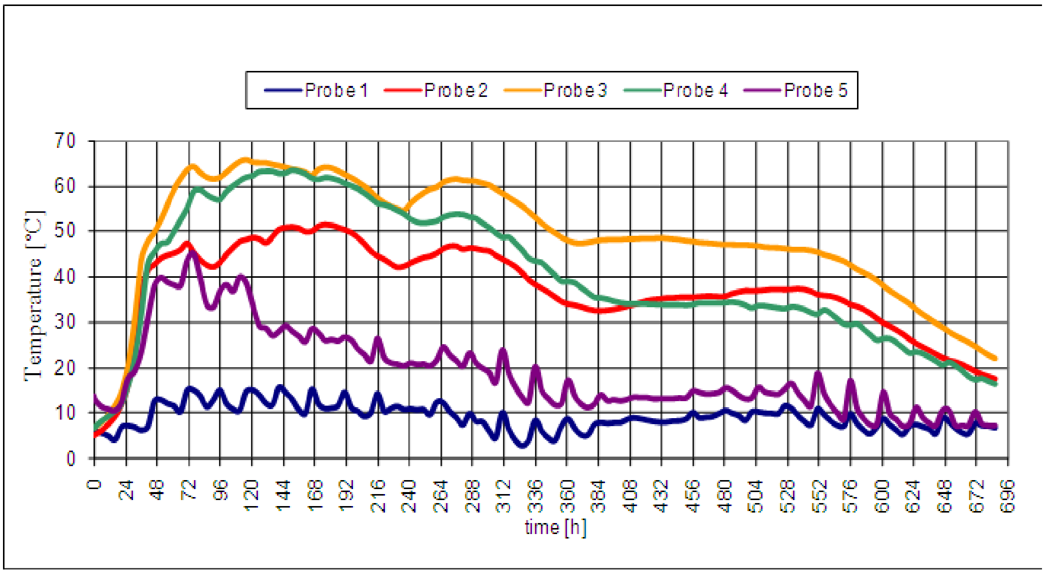

Fig. 3. Temperature dynamics during the bio-drying process

The calorific value it is the most important parameter and is directly related to waste energy potential. The calorific value was estimated through an indirect method that allows assessing the LHV of the waste using the ultimate analysis of each MSW fractions.

To calculate the Low Heating Value it is used the High Heating Value (HHV), the latent heat of vaporization and the reaction water. The Dulong expression is used for the calculation of the HHV in function of carbon, hydrogen, oxygen and nitrogen in the volatile solids [6].

$$HHV = [33 * C + 143 * (H - O/8) + 0.6 * N] * 1000 \ [kJ/kg] \qquad (1)$$

where: C, H, O, N = the content of carbon, hydrogen, oxygen and nitrogen referred to volatile solids of the material is determined as a sum of contributes of each fraction.

Evaporation latent heat (Q) is the necessary heat to vaporize the water contained in MSW:

$$Q = x * \lambda \ (kJ) \qquad (2)$$

where: x – water content in MSW ((kg_{H2O}/kg_{MSW}))

$\lambda = 2260$ (kJ/kg_{H_2O}) – water vaporization latent heat

Reaction water [kJ/kg]:

$$9 * H * (kg_{SV} / kg_{ST}) * (1 - x) * \lambda \tag{3}$$

where: kg_{SV} / kg_{ST} - volatile solids content referred to total solids.

The LHV is calculated with the expression:

$$LHV[kcal/kg] = HHV - \{Q + [9 * H * (kg_{SV} / kg_{ST}) * (1 - x) * \lambda]\} \tag{4}$$

The obtained values of LHV are presented in figure 4.

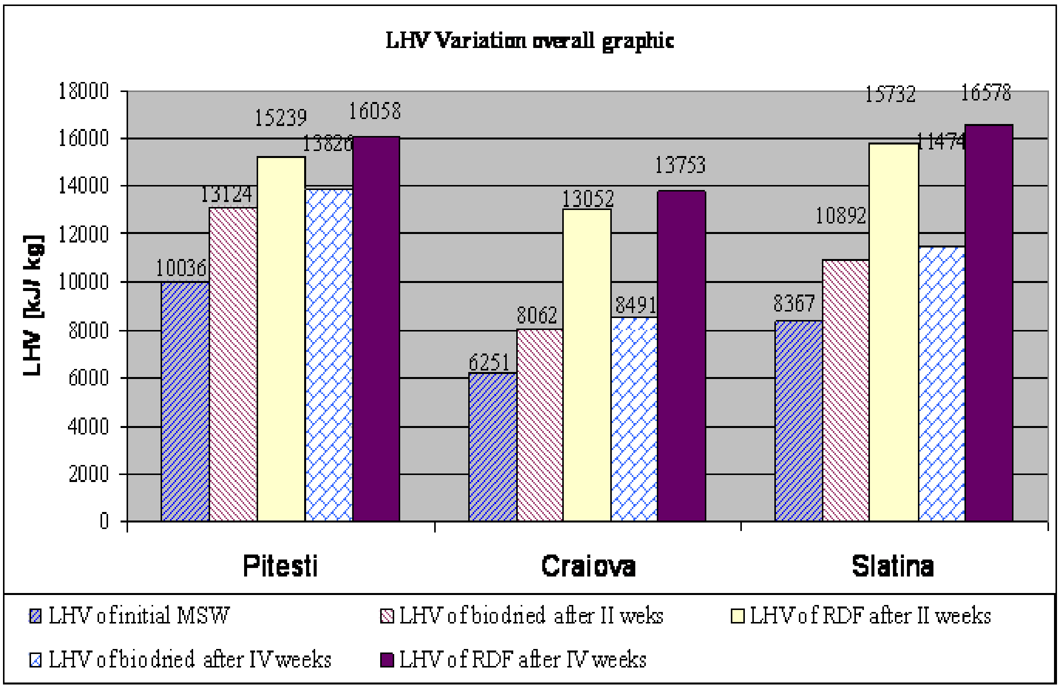

Fig. 4. LHV variation

The LHV of the MSW (that has values from 6251 kJ/kg to 10036 kJ/kg) increases after two weeks of bio-drying to about 8062 kJ/kg and 13124 kJ/kg. After inert, metal and glass separation the obtained product after two weeks, RDF, has the hollowing LHV about 13100 kJ/kg -15700 kJ/kg.It must be pointed out that even making the lasting of the process 4 weeks the LVH of RDF in the Craiova case cannot reach 15000 kJ/kg, value considered a good target for RDF.

The energy consumption was taken into account for each step: shredding, bio-drying, separation, metal removal, glass and inert recovery. Results are presented in the table 2.

Table 2.

Energy consumption for pre-treatments (kWh/t)

	Shredding	Bio-drying	Transport	Separation and Metal removal	Glass and Inert recuperation
Bio-drying	11	50	15	-	-
RDF	11	50	15	1	3

Therefore, the energy consumption is equal to 76 kWh/kg_{MSW} to obtain the bio-dried material, and 80 kWh/kg_{MSW} for obtaining RDF [8]. This consumption is not negligible thus the strategy for RDF exploitation should give additional advantages compared to the conventional direct combustion.

6. Environmental and Economical aspects

Generally the bio-drying plant provides an environmental sustainable way of dealing with MSW by:

- substantially reducing the amount of the waste going to landfill;
- significantly increasing the amount of waste being recycled by capturing materials (glass, inert, ferrous and non ferrous metals) which are not completely separated at home;
- offering an alternative to mass burn incineration;
- recovering energy from residual waste by producing an RDF that can be used by the industry instead of coal, oil and natural gas (fossil fuels).

It is important to mention that a bio-drying plant does not substitute the local recycling initiatives, but integrates them.

If the MSW is to be landfilled then about 70 kg of methane (actual range 50-100 kg) could be released for each tonne of waste [9]. Considering global warming potential of methane, the equivalent CO_2 for 1 tonne of MSW is about 1610 kg (higher than direct incineration). In a modern landfill, about 20-80% of the CH_4 is recovered, depending on the technology, therefore some emissions are avoided but some emissions still occur.

In figure 5 a typical CO_2 emissions from MSW incineration are compared with those ones from fossil fuel sources. The values for CO_2 emissions factors presented are taken from the literature [9]. The un-treated MSW we refer has physical and chemical properties (water content and LHV) similar to the Romanian MSW treated in a bio-drying plant.

However for a good environmental balance it must be taken into account also that a direct replacement of fossil fuel by RDF obtained from the bio-drying process, in thermal power plants or in cement kilns gives a more favorable balance of greenhouse gas.

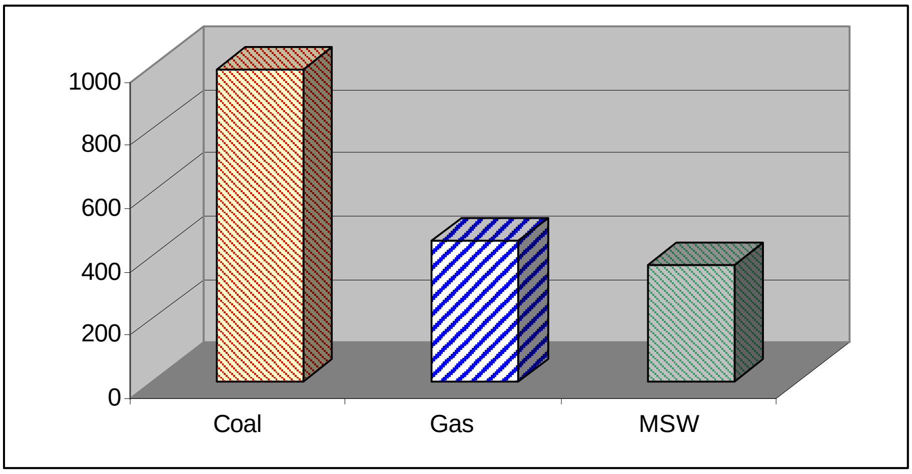

Fig. 5. Life Cycle CO_2 emissions (grams per kWh of electricity)

Regarding the economical balance the implementation of a bio-drying plant involves capital costs of several million Euros. The variation in magnitude and ranges of the costs are due to wide variety of systems available on the market, plant capacities and level of automatic control used. Economical data regarding the bio-drying plant construction and maintenance are shown in the Table 3, for a plat with a capacity of 20.000 tonne/year (estimated on current market costs).

Table 3.

Capital and operating costs

INVESTMENTS		OPERATING AND MAINTENANCE	
Item	**€**	**Item**	**€**
Land	300000	Leaching transport	7000
Bio-drying plant and post refinement	585000	Leaching storage	20000
Tank construction	120000	Deodorizer products	8000
Improvements	166500	Fuels	18000
Excavation/ disposal equipments	30000	Electricity	15000
1 gummed scoop	110000	Maintenance	10000
Piping	100000	Personnel	14000
Leaching collection system	20000	Insurance	5000
Leaching collection tank	7000		
Office building	18000		
Deodorizing installation	15000		
Design and engineering	30000		
Contingency	500000		
TOTAL INVESTMENTS	**2001500**	**TOTAL MAINTENANCE**	**97000**

If we assume that bio-dried material is technically acceptable from the perspective of energetic recovery through thermal or thermo-chemical process, then the costs of RDF used to substitute one tonne of fossil can be calculated with:

$$p_{RDF}^{1tonne\ fuel} = \left(\frac{LHV_f}{LHV_{RDF}}\right) * p_{RDF} \qquad [€/t] \tag{5}$$

The net saving is: $\Delta p = p_f - \left[\frac{LHV_f}{LHV_{RDF}} * p_{RDF}\right]$ (6)

where:

- $p_{RDF}^{1tonne\ fuel}$ - costs of RDF used to substitute one t of fossil fuel
- p_{RDF} - cost of the RDF to the power plant feeding per t (may be negative);
- LHV_{RDF} - net calorific value of the RDF [kJ/kg];
- p_f - cost of the fuel being replaced by RDF [€/t];
- LHV_f - net calorific value of the fuel [kJ/kg].

In Table 4 the average values for different fuels are presented [10,11]. In our assumption the cost of the RDF used to substitute one tonne of fossil fuel is 65,38€ therefore the net savings obtained through RDF replacement of one tonne of fossil fuel is about 14,62€.

Table 4.

Average values for fuel and RDF

p_{RDF} [€]	p_f [€]	LHV_{RDF} [kg/kJ]	LHV_f [kg/kJ]
34	80	15600	30000

It is clear that the savings increase as conventional fuel prices raise (and fuel taxes may increase in future, and greenhouse gas abatement measures may have a similar effect) but also as the ratio p_{RDF}/LHV_{RDF} becomes smaller (or large if negative). In other words:

- if the price for the waste is negative (a gate fee is charged), the operator may, subject to other constraints, become relatively indifferent to the calorific value as long as the operating cost do not increase unjustified (through clearly, the higher the calorific value, the better);
- if the price paid for the waste is positive, the calorific value influence increases since net losses will occur if the lower price is not offset by calorific value.

From the perspective of co-incineration plants, there may be significant benefits making use of substitute fuels. This will be especially true where the facility is able to charge a gate fee. This situation is likely to prevail where there is no strong competition for the wastes being combusted and where alternative waste treatments are non-zero in price (though the gate fee charge has to take into account what may be additional transport costs to the co-incineration facility) [12].

For Romania these prices will need to be contractually linked with facility that can use the produced fuel. The current market for this type of fuel is limited to cement kilns and a couple of power plants.

7. Conclusions

This paper presents results regarding the implementation of a bio-drying plant in Romania in three different cases. The data showed that MSW with biodegradable fraction around 50% and having a LHV about 8000 kJ/kg is suitable for a full developing bio-drying process as LHV of RDF can reach 15.000 kJ/kg.

The environmental and economical balances become interesting if RDF production and energy generation follow the bio-drying stage in industrial areas close to the bio-drying unit, replacing the used fossil fuel. The balance of CO_2 can be interesting while the economical balance is subjected to many factors.

The implementing of a bio-drying plant in Romania could help to reach the EU targets regarding the biodegradable waste landfilled, the recyclable material and energy recovery targets and can maintain low the costs for waste collection.

REFERENCES

[1] European Commission, Directorate- General Environment, Suitable Development and Policy Support, Biological treatment of biowaste, 2nd draft. Bruxelles, 12 February 2001

[2] *D. Tillman*, The Combustion of Solid fuels and Wastes. s.l. : Academic Press, Inc., 1991

[3] *A.M. Şchiopu, I. Apostol, M. Hodoreanu, M. Gavrilescu*, Solid Waste in Romania, Environmental Engineering and Management Journal, **vol. 6**, no.5, pp. 451-465, 2007

[4] *C. Thomas*, Waste management and recycling in Romania: a case study of technology transfer in an economy in transition, Technovation, **vol. 19**, no.6-7, June 1999, pp. 365-371

[5] *E. C. Rada, M. Ragazzi, V. Panaitescu, T. Apostol,* Bio-drying or bio-stabilization Process?, Buletinul Ştiinţific al Universităţii Politehnica din Bucureşti, series C, **vol. 67**, no. 4, pp. 51-60, 2005

[6] *E.C. Rada*, Municipal Solid Waste Bio-drying before energy generation, PhD thesis, University of Trento & Politehnica University of Bucharest, 2005

[7] *E. C. Rada, M. Taiss, M. Ragazzi, V. Panaitescu, T. Apostol*, Lower Heating Value dynamics during municipal solid waste bio-drying, Environmental Technology, **vol. 28**, pp.463-469, 2007

[8] *E. C. Rada, M. Ragazzi, L. Fabbri, V. Panaitescu, T. Apostol*, Life Cycle Assessment applied to bio-drying: energetic aspects, Rifiuti Solidi, **vol. 20**, no.2 March-April 2006, pp. 89-97, ISSN: 0394-5391

[9] IEA-International Energy Agency, Municipal Solid Waste and Role in Sustainability, 2003

[10] *S. Shafiee, E. Topal*, A long view if world fossil fuel prices, Applied Energy, **vol. 87**, no.3. pp. 988-1000, 2010
[11] *K. Annamalai, I. K. Puri*, Advanced Thermodynamics Engineering, CRC Press, 2002
[12] European Commission- Directorate General Environment, Refused Derived Fuel, Current Practice and perspectives, Final Report, WRc ref: CO5087-4, July 2003.