International Journal of Environment and Resource
IJER Volume 1, Issue 1, August 2012 PP. 26-30
ISSN(online)
ISSN(print)
www.ij-er.org

Material and Energy Recovery in a Municipal Solid Waste System: Practical Applicability

Gabriela Ionescu[1/2], Elena Cristina Rada[2]
[1]Department of Energy Production and Use, Politehnica University of Bucharest, Bucharest, Romania
[2]Department of Civil and Environmental Engineering, University of Trento, Trento, Italy
Email: gabriela_ionescu@ymail.com, elena.rada@ing.unitn.it

(Abstract) In this study an Integrated Municipal Solid Waste system is improved and developed for practical application in the waste management sector. A mass, energy and environmental analysis is made taking into account the EU regulation requests and selective collection targets in the case study region. The technological solutions proposed focused on: nature and waste flow, Municipal Solid Waste heterogeneity respect to selective collection optimization, energy potential of the products, non-volatile solid content, efficiency of the process and type of cogeneration gasification plant. The syngas stream is used in a gas engine producing 804 kWhth and 714 kWhel. The system allows not only the recycling of sellable materials but also the minimization of landfilling thanks to pre-treatments that extract materials with low energetic potential.

Keywords: Bio-drying; Eco-points; Extrusion; Gasification; MSW; Landfill; Selective Collection.

1. INTRODUCTION

Today, life cycle thinking and assessment for waste management is one of The European Commission's Thematic Strategy on Waste Management. Even if its legislative application has grown, it is estimated that Europe produces annually over 250 million tons of municipal waste [1]. A major prerequisite of the national energy strategy is having in place the relevant legislation, policies, plans, standards, institutions, along with other relevant measures [2].

After decades of experience, the development of a sustainable Integrated Municipal Solid Waste system (IMSW) has become a complex and challenging research area. In order to develop and evaluate an IMSW system various factors are relevant to study, e.g., technical design of collection equipment, environmental objectives, operating costs, types of recycling materials collected separately, property close or drop-off collection, mandatory or voluntary program, economic incentives, information strategies, seasonal variations, availability of civic amenity sites, residential structure, heating systems, age and income of residents, pet and car ownership, social codes and people's varying behavior [3].

Looking over the enhancement hierarchy of waste management, in the first place, waste prevention is the most sustainable choice. According to Directive 2004/12/EC and Directive 2005/20/EC on packaging waste, by the year 2013 it is foreseen a recovery degree of useful materials for recycling or incineration with energy production of 60% for paper or cardboard, 22.5% for plastics, 60% for glass, 50% for metals and 15% for wood. In practice, landfill is the most adopted option in the EU and many other industrialized countries.

According to the Landfill Directive 1999/31/EC all EU Member States must reduce the amount of biodegradable municipal waste sent to landfill based on the amount of this material landfilled in 1995 to 35% by 2013 and to 50% by 2020 [4]. Incineration is the dominating technology in the EU, especially with mass-burn grate firing mainly with energy recovery done to a great extent of 30-100 MW_{el} capacity [5]. The incineration has limitations due to residual solid products (highly leachable fly ash and bottom ash) and gaseous species (in particular, NOx formation and incomplete destruction of halogenated hydrocarbons). To overcome these demerits, the application of novel alternative processes such us pyrolysis and gasification raised in the energy production industry. Nowadays, the gasification of a homogeneous waste such as biomass or co-gasification with coal are the most common alternative systems used at commercial scale. These technologies offer an attractive eco-friendly waste disposal, which reduces corrosion with alkaline and heavy metals retention, prevents PCDD/F formation and reduce thermal NO_X due to lower temperature and oxygen/air reduction conditions. Depending on the type of reactor used, gasification has its detriments such as: feed drying to low moisture (< 20%); extensive syngas cleanup before synthesis application, engine or turbine usage; possible equipment erosion; 4-7% of the carbon remains unconverted in form of chair. Since MSW is an inherently non –homogenous material the advanced mechanical treatment (AMT) is essential for the stabilization and performance of the gasification process.

The efficiency of MSW selective collection (SC) directly influences the Residual Municipal Solid Waste (RMSW) characteristics, therefore also the design and operation of thermal treatment technologies [6].
In order to achieve a high/medium SC, a set of targets should be made by identification of stakeholders' issues and education of local community that has to modify the behaviour patterns through eco-activities and household collection campaigns [7].

By enhancing the SC of the organic fraction to the detriment of SC of packaging waste worsens the energy and environmental outcome. Recycling packaging waste is always attractive, particularly for metallic materials, glass, homogeneous plastics (PET, HDPE) and paper. [8].

This paper is a follow-up of recent studies conducted by the authors on IMSW system with practical application in the waste management sector [9, 10]. In this study an IMSW system is improved and developed for a North Italian region. A mass, energy and environmental analysis is made taking into account the EU regulation requests and selective collection (SC) targets in the region made in accordance with Provincial Government Decision 3095/6.12.2002.

The technological solutions proposed focused on: nature and MSW flow, MSW heterogeneity respect to SC optimization, energy potential of the products, non-volatile solid content, efficiency of the process and type of co-generation plant.

2. MATERIAL AND METHODS

As a case study, a region from the Northeast of Italy, with about 600,000 inhabitants that generate 140,000 t_{MSW} y^{-1} and has an efficiency of selective collection about 63% was chosen [11]. The tourist presence and consequent accommodation facilities that usually have a negative influence on the SC network weren't taken in consideration in the study.

For the optimization of SC, users play an important role in the curbside collection efficiency that is influenced by the lack of professional standards for waste management and must therefore be educated to achieve improved sorting quality [12].

In Figure 1 the composition of MSW and RMSW (residual municipal solid waste) are presented.

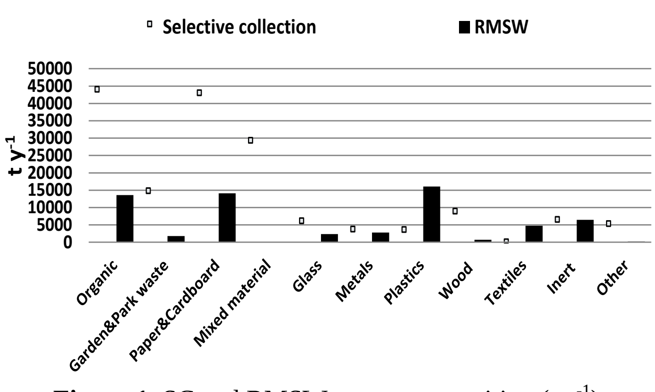

Figure 1. SC and RMSW waste composition (t y^{-1})

The household SC includes: curbside collection (door to door collection), specialized collection centers for bulky household equipment with possibility of pick up call, multi-material street garbage containers for packaging waste, mono-material collection and residual waste.

Table 1 presents the energetic potential, moisture and non-volatile solids content for each waste fraction, according to the hypotheses taken in the case study [13].

Table 1. Proximate and energetic characteristics of waste

Waste fraction	LHV [kJ/kg]	Moisture[%]	Inert [%]
Food waste	5,350	70	9.0
Garden and park waste	6,050	60	1.6
Paper and cardboard	15,184	11	4.5
Plastics	32,800	2	8.2
Glass	167	1	96.9
Metal	741	3	92.6
Wood	10,000	20	2.7
Textiles	17,445	10	1.4
Mixed materials	8,000	35	8.4

The IMSWS analyzed in this paper (Figure 2) takes into account the following sorting, material and energy methods that separate the waste in different flows:

- ***SC*** that separates the waste in three flows : Recycled materials, Combustible Material (CM_1) and Discharge Materials (DM_1);
- *AMT(*advanced mechanical treatment) of ***$RMSW_1$*** includes :
  - ➢ Shredder for $RMSW_2$ preparation for further treatments
  - ➢ Magnetic Separation for ferrous metals recovery
  - ➢ Extrusion treatment : separates $RMSW_2$ in two fluxes wet and dry fraction
    - o the *wet fraction* is sent to a bio-drying treatment producing solid recovery fuel production (SRF)
    - o the *dry fraction* is mechanically treatment through a shredding and a screening step that separate the material in:
      - ▪ bulking combustible fractions (BCM_2) that are sent to the energy recovery;
      - ▪ undersieve fraction that is sent into a ballistic separator giving materials with high calorific value (CM_2), wood, glass and discharged materials (DM_2).
  - ➢ Gasification system for thermal and electric energy production.

The eco-friendly plant was designed from the necessity to valorize the RMSW by maximizing the recycling rates and thermal and electrical recovery and by reducing the Non-Volatile Solids (NVS) sent to disposal. The SRF can be used in mixtures with primary fuels or as feedstock in pyrolysis/gasification plants.

The efficiency of each treatment and the energy consumption used for the development of mass and energy balances for the analyzed scenario are presented in Table 2.

For an accurate estimation of the landfill land area and its environmental impact, the used data in the calculation were considered as a whole and not by type of MSW. The ecological scarcity method (BUWAL 133) was applied [14]. The CORINE codes 132 (‘’dump site’’) from the Ecoinvent database were used for the determination of landfill occupations and eco-factors for occupied landfill volume [15]. An average landfill depth of 15 m and a waste density of 1000 kg m^{-3} were chosen. In order to differentiate the environmental quality of the dump site, an eco-factor was applied, in accordance with ISO Standard 14044. In the present research, a constant mid-point eco-factor of 500 eco-points was attributed for each kilogram of landfilled waste.

Table 2. Treatment efficiency and energetic consumption

Treatment	Efficiency	Energetic consumption	References
Shredder	-	3 kWh t^{-1}	[16]
Magnetic separator system	95%	1.3 kWh t^{-1}	[16]
Extrusion	65%	11 kWh t^{-1}	[17]
Primary shredder	-	12 kWh t^{-1}	[17]
Waste screening	18%undersize 82% oversize	1 kWh t^{-1}	[13]
Ballistic separator	40% wood 30% close 40% other	0.75 kWh t^{-1}	[18]
Biodrying	-	33 kWh t^{-1}	[10,18]
Gasification and syngas cleaning	14% net electric effiency	329 kWh_{thl} t^{-1} 132 kwh_{el} t^{-1}	[19,20]
Thermal engine	39 % electrical 44% thermal	1241 Nm^3 h^{-1}	[21]

3. RESULTS AND DISSCUSSION

The recovery of MSW by type of fraction or product using AMT can reach to energetic qualities near or above fossil fuel ones.

For future application and accessible use of the present IMSW system shown in Figure 2, 100 kg of MSW were chosen to be treated. Taking into account the region situation, first SC is applied with a proficiency of almost 63%. The remaining $RMSW_1$ (37%) is mechanically treated primarily for size reduction and then for ferrous metals recovery (iron, steel) with recycling purpose and reduction of possible technical damage of the AMT line. For $RMSW_2$ a 37% decrease of NVS content can be observed, facilitating the proficiency of the entire system.

The produced material $RMSW_2$, partly composed by organic, paper, cardboard and wood waste, can be separated from the extruder in two components: dry and wet at a rate of 33% by weight of the initial MSW. The LHV of the wet fraction, 2000 kcal/kg, will be strongly influenced by the 43.5 % moisture content. For the wet fraction the bio-drying process reduces moisture content with 20% and increases the LHV with 30%. This is possible thanks to the air flow inlaid and left to rest in special biocells leaving the natural process of organic fermentation for a period ranging between 7 and 14 days. Even if the dry product is mainly composed from combustible fuel (plastics and traces of lignocellulosic materials) LHV is “only” 4200 kcal/kg due to traces of metal and glass.

By waste screening the dry fraction will be separated in two flows:

- Bulky combustible material (5000 kcal/kg)
- The dry flow is then divided thanks to a ballistic separator in combustible fraction, wood, glass (mix materials) and other discarded materials (inert materials).

The remained combustible material and wood are destined to energy recovery, waste to landfill and glass to recycle.

The SC streams are following different paths:

- the flow of material from road sweeping is routed directly to landfill.
- the recyclable material is sent for second raw material recovery respecting the minimum amount imposed by EU laws [22].
- the multi-material fraction from SC is sent to the shredder and mixed with $RSWM_1$;
- “energetic” material (3,790 kcal kg^{-1}) mainly composed of ligno-cellulosic and plastics is sent to the gasification treatment for syngas production.

Generally the low efficiencies of the pyro-gasification plants are given by the small quantities of material treated. Still, the syngas produced has an important amount of energy: 2,521 kcal kg^{-1}. After cleaning, the 900 Nm^3 h^{-1} syngas stream is used in a gas engine producing 804 kWh_{th} and 714 kWh_{el} thanks to co-generation.

Overall, there are some impediments that still obstruct the optimal parameters for a Waste-to-Energy large scale plants such as: waste feed flow that should be representative for local or regional area, the results accuracy on the reproduction of the environment process which has a direct connection with the output of secondary products in terms of characteristics plus purity and pollution emissions. In comparison with traditional combustion, the sub-stoichiometric atmosphere limits the formation of dioxins and large quantities of SO_X and NO_X with smaller and less expensive gas cleaning equipment. The viability of NO_X lower emission comes with the syngas combustion or its utilization in a gas engine.

Regarding carbon dioxide (CO_2), the high concentrations and high pressure make it easier to capture and store in comparison with incineration. Ash produced during gasification is either removed as fly ash from the product gas using cyclones or filters, or is removed from the bottom of the gasifier vessel using another auger.

The system allows not only the recycling of sellable materials but also the minimization of landfilling thanks to pre-treatments that extract low LHV materials.

In practice the analysed scheme balances the pathways of material and energy valorization. Concerning the presence of a gasificator, it was supposed to be able to move in the analysed area, the experience of gasification that characterizes countries like Japan.

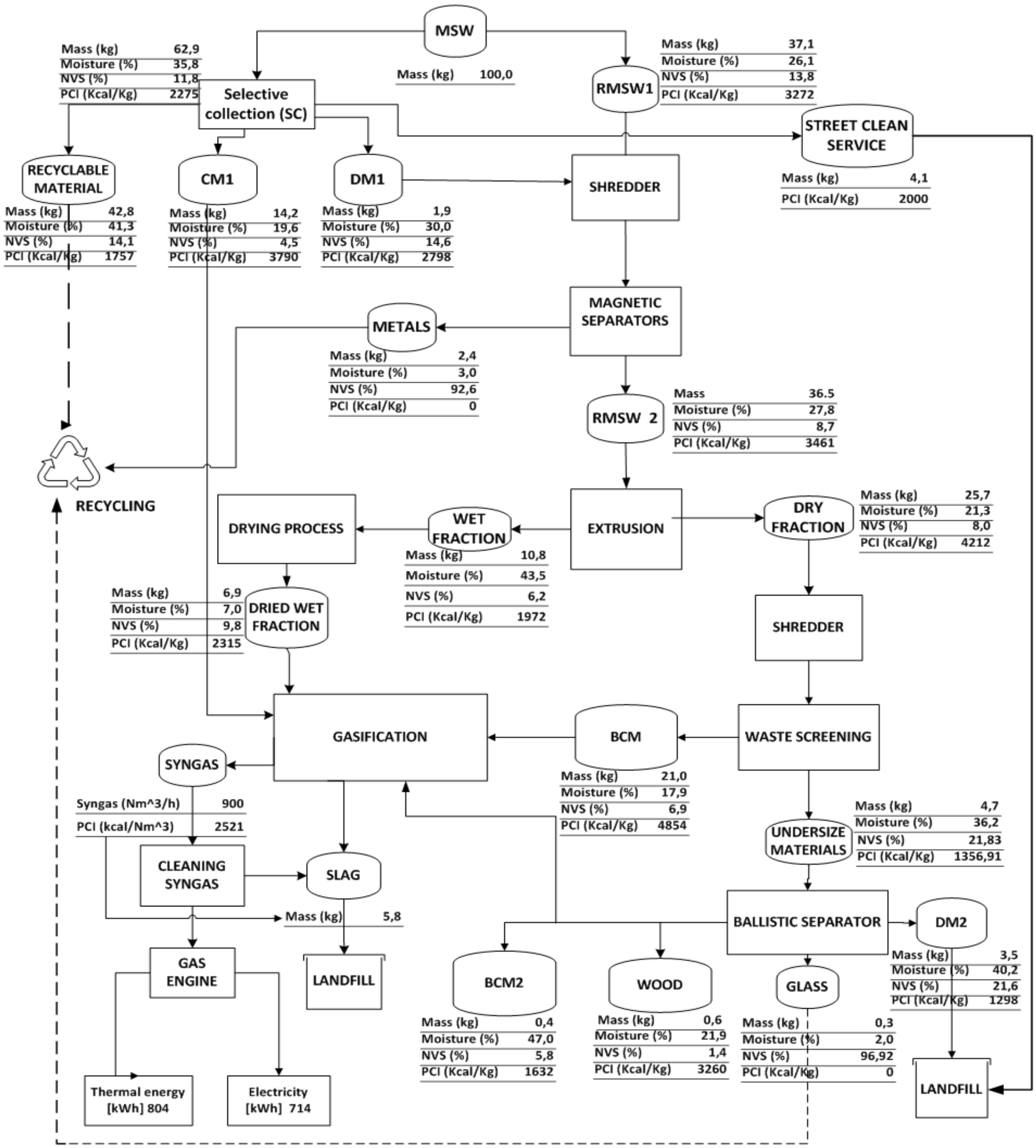

Figure 2. Mass and energy balance of IMSW system

The waste landfilled area and the eco-factor by type waste disposal are represented in Figure 3.

The hypothesis developed for the case study were referred to the total MSW landfilled scenario, direct disposal of RMSW scenario or the landifilled material resulted from the IMSW system.

The introduction of AMT decreases the waste landfilled up to 13.4% by maximizing the inert disposal.

Due to the decrease of the volume of landfilled waste, in the IMSW system the dump site eco-factor reaches up to 101 eco-points per m^2 and year. This value assesses the deposited wastes in above ground landfills mainly on their carbon content. The IMSW system is an environmental friendly approach reducing the landfill eco-factor up to 87% in comparison with direct disposal of MSW.

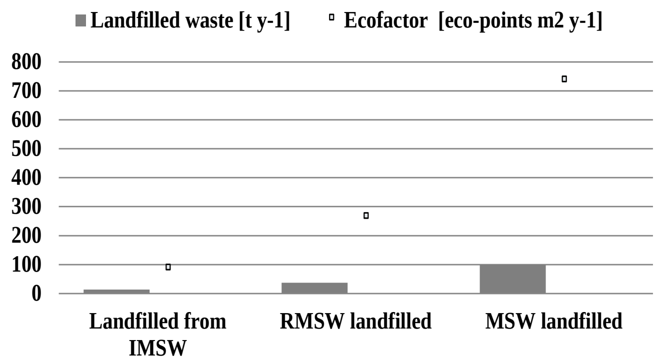

Figure 3. Waste landfilled occupied area and the eco-factor

4. CONCLUSIONS

The analysed system complies with the EU principle of biodegradable materials minimization and is in agreement with the principle of adopting energy recovery after the implementation of material recycling options.

The main benefits of the pre-shedding system are MSW homogenizing and increasing density up to 30% of the feed to the grate. It can be concluded that the reduction of inert materials facilitates the partial oxidation of combustible products and enables recycling for the recovered materials.

The introduction of AMT decreases the waste landfilled up to 13.4% by maximizing the inert disposal. Due to the decrease of the volume of landfilled waste, in the IMSW system the dump site eco-factor reaches up to 101 eco-points per m^2 and year. This value assesses the deposited wastes in above ground landfills mainly on their carbon content. The IMSW system is an environmental friendly approach reducing the landfill eco-factor up to 87% in comparison with direct disposal of MSW. The syngas produced in the gasification process has an important amount of energy: 2,521 kcal kg^{-1}. After cleaning, the 900 $Nm^3\ h^{-1}$ syngas stream is used in a gas engine producing 804 kWh_{th} and 714 kWh_{el} thanks to co-generation.

The future success depends upon the recognition that household management in this wider sense is the most backward branch of technology and therefore the one most urgently in need of development.

5. ACKNOWLEDGEMENTS

The work has been funded by the Sectoral Operational Programme Human Resources Development 2007-2013 of the Romanian Ministry of Labour, Family and Social Protection through the Financial Agreement POSDRU/88/1.5/S/61178.

REFERENCES

[1] EPA- Environmental Protection Agency 20007.
[2] X.Yu, Energ. Policy, 38, 2161–2167, (2010).
[3] L. Dahle´n and A. Lagerkvist, Waste Manage., 28, 1100–1112, (2008).
[4] G. Ionescu, C. Marculescu, A. Badea, Sci. Bull., Series C: Electr. Eng., 73, 3, 243-254, (2011).
[5] T. Malkow, Waste Manage., 24, 53–79, (2004).
[6] E.C. Rada, G. Ionescu, M. Ragazzi, C. Marculescu, S. Ciuta, Proceedings of the Symposyum of Sanitary and Environmental Engineering, (2012). 26-29 June.
[7] A.M. Troschinetz, J.R. Mihelcic, Waste Manage., 29, 2, 915–923, (2009).
[8] S. Consonni, M. Giugliano, A. Massarutto, M. Ragazzi, C. Saccani, Waste Manage. 31, 2057–2065, (2011).
[9] Ionescu, G. Merler, E. C. Rada, M. Ragazzi, T. Apostol, Proceedings of the 5th International Conference on Energy and Environment, (2011), November 3-4.
[10] Rada E.C., Ragazzi M., Panaitescu, V., Sci. Bull., Series D: Mech. Eng., 71, 4, 113-120 .
[11] ADEP (Agenzia per la Depurazione) , Municipality of Trento
[12] J. Krook and M. Eklund, Appl Ergonomics, 41, 362–367, (2010).
[13] Municipality of Trento, Feasibility study-works concession for the design, implementation and management of the combustion or other thermal treatment with energy recovery for municipal and special waste in places similar Podetti Ischia, in the municipality of Trento, Annex 1, pp. 161.
[14] G. Brand, A. Braunschweig, A. Scheidegger, O. Schwank, Environ., Series, 29 (1998).
[15] Swiss Centre for Life Cycle Inventories, Ecoinvent: Life Cycle Inventories of Waste Treatment Services, report No. 13, (2003).
[16] L. Rigamonti, M. Grosso, M. Giugliano, Waste Manage., 29, 2, 934–944, (2009).
[17] Page web, http://www.vmpress.it/.Considerations on the treatment of MSW by the end of extrusion reduction of biodegradable waste going to landfill, (2012).
[18] E.C. Rada, A. Franzinelli, M. Taiss, M. Ragazzi, V. Panaitescu, T. Apostol, Environ. Technol., 28, 4, 463-470, (2007).
[19] G. Genon, R. Durante, E. Brizio, Proceedings of the Third International Symposium on Energy from Biomass and Waste, (2010), November 8-11.
[20] C. Marculescu, G. Antonini, A. Badea, T. Apostol, Waste Manage., 27, 3, 367-374, (2007).
[21] Ciuta S., Marculescu C., Dinca C., Badea A., Sci. Bull., Series C, Electr. Eng., 73, 3, 307-320, (2011).
[22] EC - European Commission, Final report – Supporting the thematic strategy on waste prevention and recycling, (2010).