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ALTERNATIVE SOLUTIONS FOR MSW TO ENERGY CONVERSION

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Valorificarea energetică a deşeurilor municipale are un rol tot mai important în industria energetică europeană. Obiectul acestei cercetări este de a stabili caracteristicile termo-chimice ale materialelor provenite direct din deşeurile menajere în vederea alegerii soluţiei tehnologice optime pentru valorificarea lor energetică. Datorită gradului de eterogenitate a produsului partea experimentală a fost realizată pentru fiecare componentă principală în parte. Studiul a vizat componentele cu participaţie masică şi putere calorifică importantă precum materiale celulozice şi cele din mase plastice. Soluţiile propuse utilizează procese termo-chimice de gazeificare cu aer sau abur prin comparaţie cu tehnologia clasică de ardere.

Alternative fuels, such as household wastes tend to play an increasingly important role in the European energy industry. The basic objective of this research is to determine what methods and technologies are most appropriate in order to develop/improve the energetic valorization of these materials. Due to product high heterogeneity the experimental approach was conducted for each household waste main component separately. The solutions proposed are: thermo-chemical processes using air or steam gasification compared to conventional combustion technology. *Further investigations are in progress.*

Keywords: lignocelluloses fraction, plastic compounds, MSW, energy.

1. Introduction

In the last century, the explosion of industrial, economic and demographic raises new problems such as increasing the amount of waste. Worldwide, waste management methods are varied depending on: geographical location, population, amount of wastes generated and techno-economic potential existing. Each year in the European Union 1.3 billion tons of wastes are produced from which approximately 40 million tons are hazardous.

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Landfill is still the principal method of waste disposal in Romania with 7 to 8 million tones of household wastes currently disposed each year in this way [1]. Due to the environmental rules and European legislation, Romania has to decrease the dispose of wastes with 35% by weight deposited in 1995 -2006, yet much of it could be recycled or energetic valorificated (graph 1).

According to Romanian National Statistic Institute an urban inhabitant generates 340 kg / year of household waste, 50% of them being biodegradable waste [1].

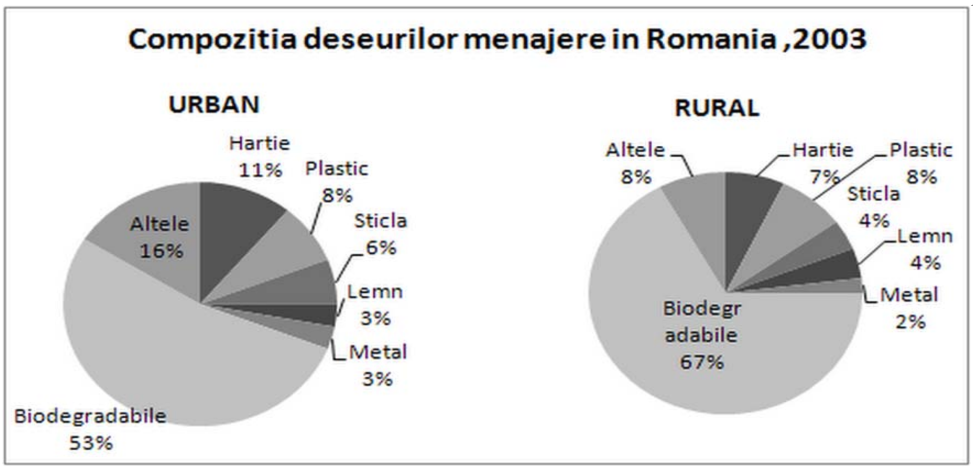

Fig. 1. Household waste composition in Romania, 2006

The composition of household wastes shows a higher proportion of biodegradable wastes in urban areas compared to rural regions. At the same time, the recyclable materials (paper and cardboard, glass, plastic and metals) have a higher share in urban food waste from rural areas. Until 2011 Romania is obligated to recycle 50% of household wastes, 15 % of them are represented by: glass, paper, plastic and metal [2-8]. After biomass the largest quantity is followed by paper and plastics with 8-10 %.

Today, in Romania, the potential for mechanical recycling is limited. It can be expected that new sorting and reprocessing techniques will increase the share of MSW feasible for mechanical recycling and recovery. A significant strengthening of recovery targets would probably only be possible if feedstock processes are considered as a valorification option.

The experimental aim of this research is to conclude the thermo-chemical characterization and the energetic potential of the materials (mixed or separately). The last part of the paper will concern technological solutions focused on:

- The nature and scale of waste structure and heterogeneity
- The energetic potential of the products
- The thermal cycle
- The efficiency of the process and type of energy produced.

A comparative analysis of the scenarios will be made, in order to establish the base for best solution. To identify the energy conversion chain advanced studies are required and now in progress.

2. Experimental analysis

2.1. Materials

At the European level the MSW composition contains significant amounts of cellulosic fractions (paper, cardboard, wood) and plastics. The waste samples used were six different types of cellulose and plastics materials: copy paper, newspaper, cardboard, tetra pack®, high density polyethylene (HDPE) and PP (polypropylene).

The chemical composition of paper depends on the type or grade of the paper. Typically paper consists of organic and inorganic material. Organic portion includes cellulose, hemi-cellulose, lignin and/or various compound of lignin which may be from 70 % up to 100%. Inorganic portion mainly consisting of filling and loading material such as calcium carbonate, clay, titanium oxide etc. varies between 0 - 30%.

Plastics are polymers consisting of a large number of repeating molecule units. They are mostly derived from refined crude oil and therefore are non-renewable materials. They are more thermally stable than the cellulosic materials [9].

A combination of paper and plastics was studied using tetra pack waste. The components of tetra pack are: kraft paper (about 70 wt %), low-density polyethylene (LDPE, about 25 wt %), and aluminum foil (about wt 5%). For this reason their degradation is correlated to the decomposition of the lignocelluloses and plastic fractions [10].

2.2 Instruments and methods

The primary analysis for volatile matter, fixed carbon and inert fraction determination was made using the Nabertherm electric furnace, type L9/11/SW with the following components (shown in Fig. 2.): carriage, precision balance, swing gates door and rated operating temperature of 1100°C.

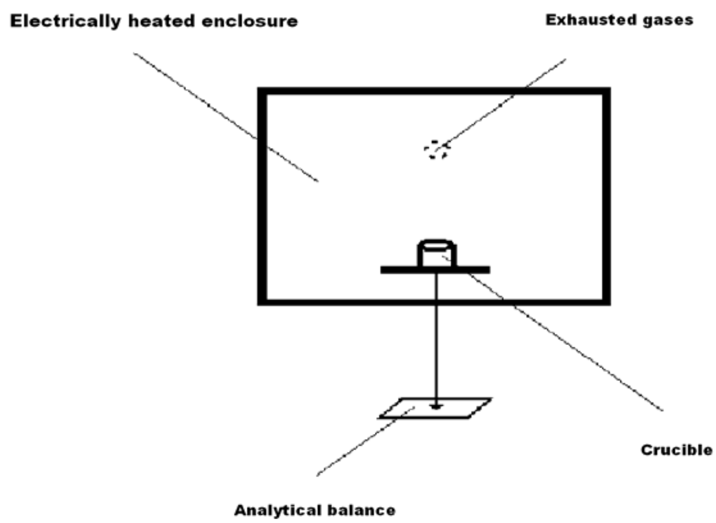

Fig. 2. Electric furnace scheme

In order to obtain the volatile matter fraction, the samples were subject to a pyrolysis process with an average temperature of 800°C for 40 minutes. The fixed carbon and inert (non-combustible) fraction were determined in a combustion process at 1000°C, for about 1 hour.

Table 1

Proximate analysis

Sample	Proximate analysis (wt%)		
	V.M.[4]	F.C.[5]	Ash
Copy paper	82.9	10.9	6.2
Newspaper	88.4	3.5	8.1
Cardboard	87.5	93.4	5.9
Tetra pack	90.6	1.3	8.1
PP	99.13	0.37	0.6
HDPE	99.74	0.46	0.20

The elemental composition of the material studied was performed in an Euro EA Elemental Analyzer 3000. The EA 3000 series is based on the principal of dynamic flash combustion using chromatography separation of the resultant gaseous species (N_2, CO_2, H_2O and SO_2) and TCD detection. The analytical process was made automated using the Callidus Software. The CHNS elements were determined in an oxygen atmosphere for the combustion of the sample and Helium as a flow carrier. The parameters used in the analysis were: the carrirer

[4] Vollatile matter
[5] Fixed Carbon

flow 80 ml/mim, the carrier pressure 80 kPa at a temperature of 980°C for FF and 115°C for GC oven. The weight of the samples varies between 0,7 – 2 mg. Taking into account the high heterogeneity of the mixture and the low fraction of the sample analyzed, the elemental analysis is difficult and unfeasible for this type of blending. The results of the analysis are shown in the next table.

Table 2

Elemental composition

Sample	Elemental composition (wt %)				
	C	H	N	S	O
Copy paper	38.239	5.155	0.295	3.034	47.077
Newspaper	43.117	5.551	0.342	3.385	39.505
Cardboard	44.393	5.63	0.547	3.574	39.956
Tetra pack	50.63	5.397	2.839	3.975	29.059
PP	81.221	7.985	2.12	6.362	1.612
HDPE	81.515	8.293	2.54	6.509	0.943

The high content of carbon and vollatile matter from the analysis reveales the high energetic potential of each product.

The determination of heating value of the materials used in the research will give an insight the amount of fuel needed and energy that could be recovered. The total moisture of the sample was considered 20%. Due to components physical structure the water distribution in the MSW sample is different from 1-5% for plastic components up to 40% for newspaper. The HHV of paper and plastic was induced using the Dulong’s formula no.1 [11].

$$HHV = 7831 \cdot C + 35932 \cdot H - O/8 + 1187 \cdot O + 578 \cdot N [kcal/kg] \quad (1)$$

Low heating value is obtained by a correction factor, calculated according to the formula:

$$LHV = (HHV - 5.83 \cdot W) \cdot 4.1886 [kJ/kg] \quad (2)$$

Where: W – is the material water vapor source; HHV – is given in kcal/kg

$$W = W_t + 9 \cdot H [\%] \quad (3)$$

Where: W_t – total moisture content; H - hydrogen fraction, dry basis

The advantage of these formulas is given by the accurate estimation of the calorific values of the samples shown in Table no.3.

Table 3

HHV and LHV Dulong's formula

Sample	HHV (kJ/kg)	Average moisture content (%)	LHV (kJ/kg)
Copy paper	13793	25 - 30	10525
Newspaper	17014	25 – 40	13111
Cardboard	17377	25 - 35	13392
Tetra pack	20616	15-20	15983
PP	38335	1-5	30154
HDPE	38985	1-5	30673

The calorimeter system C 200 was used for the determination of the calorific value of the samples. The calorimeter bomb, after the sample charge, is saturated with 30 bar of pure oxygen. Due to the high heterogeneity of the product the mix of the materials was made in order to determinate the energetic potential of the wastes. Lower heating value is obtained by using the same correction factor.

Table 4

HHV and LHV calorimeter

Sample	HHV (kJ/kg)	LHV (kJ/kg)
Copy paper	12429	9843
Newspaper	14183	11597
Cardboard	15387	12801
Tetra pack ®	22795	20209
PP	42772	40186
HDPE	45783	43197

The high energetic potential of these materials could be compared with primarily combustible as peat, lignite, sub-bituminous and bituminous coal, anthracite or graphite. This type of materials can be considered a raw material in the thermal plants in order to produce energy. The HHV was established directly using calorimetric determination and indirectly using elemental determination and semi-empirical formula for a better accuracy. The semi-empirical formulas are usually adapted for common combustibles such as coals, petrol, wood etc. The validity used on different waste materials is more or less proved. Further studies will be focused on thermal-chemical reaction kinetics, where error must be minimal.

3. Technology used for energy recovery

In the last years, much effort has been focused to develop environmentally friendly technologies that used waste as an alternative to fossil fuels. These types of products have two major advantages for power generation sector: reduction of specific primary energy consumption which has a direct effect on air pollution and reduce energy resource demand in accordance with rapid reduction of fossil fuel reserves. Even if the waste sources have a high energetic potential, the power sector is reluctant to major structure modifications because of: waste availability and homogeneity, technological and economical block that have to be overcome before alternative energy can replace even a small portion of the power provided by fossil fuel.

Currently Romania doesn't have a developed technology with full recovery of waste. For example, our country doesn't have an effective selective collection system. In the present, there aren't so many specialized equipment for sort/remove of waste mixture therefore the potential of household wastes hasn't being exploited at least in the short and medium term. In the long term is necessary to conduct an analysis to determine the opportunity to acquire existing technologies and use these types of wastes, considering the fact that this practice is widely applied in the countries of Northern and Western Europe. European countries apply this technology in the energetic field, because it represents an economic benefit as fuel and disposal solution.

However, in Romania, over 20% of household wastes can be recovered by co-processing and processing in different industries reducing the amount of wastes in landfills. The most common use is in the cement industry where plastics and paper wastes can replace up to 40% of natural material for the cement manufacturing process (oil, gas, and coal). The main advantages of co-incineration of wastes in clinker batch are:

- High temperature (over 1450ºC) and stability of thermal conditions;
- Requirements of the clinker manufacturing process
- The complete destruction of organic molecules
- Neutralize acids present in the gaseous combustion gases;
- Lack of combustion products (slag, ash) that would require a subsequent storage.

Worldwide the energy consumption is increasing exponentially with 3-5% each year. New solutions have to be found from the family of diverse energy technologies that share common thread – they don't deplete our natural resources or destroy our environment.

4. Results and discussion

4.1 Pyrolysis and combustion of the fuels

According to the proximate and ultimate analysis the composition and the quality of the materials is different. For these reason significant differences appears during the combustion of the fuels. From the proximate analysis the paper ash content varies between 0.2 and 8 % depending on the type of material. Comparative with plastics were the volatile matter is approximately 90-100%.

The ultimate analysis reveals a higher content of carbon at the plastics materials approximately 80% compared with paper samples which is 40%. These aspects will be revealed in the calorific heating value of the fuels which is higher in the plastics materials compared with the lignocelluloses materials. The presence of Sulphur was established during the Elemental Analysis and it's approximately 3% for paper and 6% for plastics. After the compilation of pyrolysis and combustion processes it is visible on the wall of the crucible a yellow residue which is specific to the Sulphur content of the sample. Another interesting observation is that the elemental composition of the paper and cardboard sample approach to the wood calorific value reported in literature [12]. The tetra pack results are in accordance with the analyzed paper and plastic fractions. Compared to the paper sample, tetra pack shows an increased carbon content. This is explained by the fact that tetra pack contains plastics with rate of 25%.

Taking into consideration the weight fraction of cardboard and PE in tetra pack, in literature was shown that there is no significant influence on the pyrolysis product distribution. This may suggest that the aluminum foil which is present in tetra pack has no effect on the thermal degradation of both PE and cellulose [13].Taking into account the proximate and ultimate analysis, using the Dulong formula the averege of HHV for paper packaging waste is 18000 kJ/kg and for plastics 38000 kJ/kg.

If the waste management it's done proprietly and the quantity of packaging waste is correctly collected, this type of materials could be a very good source of energy. In Romania this type of products (including tires and rubber) are co-incinerated and considered alternative fuels in cement clinker production.

4.2 Pilot scenarios for energetic recovery

From the experimental research the following consideration can be made:

- The Low Heating Values reveal the high energetic potential of the materials studied.
- Waste management represents a very important factor in the current development of the energetic systems.

Three types of scenarios will be developted in the following. The aim of the scenarios is to estimate the electrical power output that could be recovered from this product type. The reference location is a city with about 300.000 habitants which generate 2200 kg/h of paper and plastics packaging waste. The average LHV of this product type is about 20000 kJ/kg. This situation could be easily applied to target like: railway stations, airports etc.

Based on product properties and using thermal-chemical processes the energy recovery chains appropriate for this product valorization are presented in Fig. 4. They consist in:

- MSW sorting, advanced thermal drying, grate or fluidized bed combustion, steam generation, Rankine-Hirn cycle.
- MSW sorting, low temperature pyrolysis, air gasification, Otto/Diesel cycle.
- MSW sorting, low temperature pyrolysis, steam gasification, Brayton cycle.

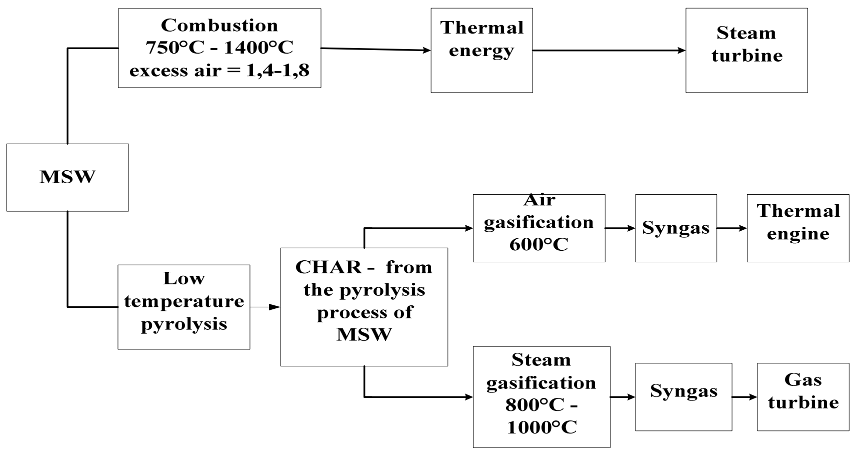

Fig. 4. Scenarios of energy recovery

The simplest technological solution is the direct combustion of the product with only drying pre-treatment if the humidity level exceeds 20%. As the product average LHV is over 20000 kJ/kg the process is self-sustained (starting with 7000 kJ/kg).

This first solution faces a certain disadvantage in terms of: pollutants emission (potential dioxin formation due to Chlorine presence in waste), energy efficiency (high thermal loss with N_2 heat on flue gas, and important excess air) and public acceptance (NIMBY concept) [14].

The solutions 2 and 3 are based on waste gasification and syngas production used in engine or gas turbine, with all energy conversion advantages characteristics to these equipments, for small scale units. The estimated power output will not exceed 15 MW for the input flow assumed.

In table 5 we present the estimated power output for this type of location. The thermal power input is given by feed-in flow and LHV. The equipments efficiencies were chosen from literature based on type and capacity. For the energy conversion chain average efficiencies values were considered characteristic to power level. The conversion chain has two major stages: the primary energy source conversion stage (combustion steam generator / pyrolyzer - gasifier) and the thermodynamic cycle (steam turbine / thermal engine / gas turbine) [14]. This power level and product type influences the steam generator efficiency which varies between 0.86 – 0.88 depending on combustion chamber type (grate, fluidized bed).

Table 5

Estimation of energy power output

	S.I.	Steam turbine	Thermal engine	Gas turbine
Waste feed-in flow, per hour	kg/h	2200	2200	2200
Waste feed-in flow, instantaneously	kg/s	0.61	0.61	0.61
Waste low heating value	kJ/kg	20000	20000	20000
Thermal power	kW	12222.2	12222.2	12222.2
Primary source energy conversion efficiency (steam generator / pyro-gasifier)	-	0.87	0.6	0.7
Thermodynamic cycle global efficiency	-	0.22	0.37	0.3
Global net efficiency	-	0.19	0.22	0.21
Electric output	kW	2339.33	2713.33	2566.66
Electric output	MW	2.33	2.71	2.56

The air gasification unit has efficiency under 0.6 and the pyro-vapourgasification does not exceed 0.7 [14]. The results show a similar electrical power output for each conversion chain, with a slight advantage of thermal engine due to its superior net efficiency at this level. We expect for larger feed-in flows (cities with more than 1 million inhabitants) to generate more power with steam cycle. Nevertheless a combined gas-steam cycle could deliver the maximum electrical power at increased waste quantities.

5. Conclusions

The global growth of municipal solid waste production leads to recycling targets which will have to be increased in order to maintain the current level of waste disposal. In most of the other UE Member States the particular challenge is the extension and qualitative improvement of household waste collection, which at present, hampers the efficiency of the systems.

For this type of product, if the separation from the MSW is made in a proper manner, the gasification – internal combustion units represents the optimal solution for medium size cities or public areas. Nevertheless, for increased waste quantities (cities with more than 500 000 inhabitants) the classical combustion – steam turbine remains the first option. A combined gas-steam cycle could increase the global net efficiency and be the best solution for high feed-in flow rates.

However, as mentioned above, there are a number of other aspects, namely the prevention and reuse of wastes, and definition, which need further consideration when aiming at a harmonized legislative framework for packaging waste management.

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