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ENERGY RECOVERY FROM MUNICIPAL SOLID WASTE IN SMALL COMMUNITIES

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Abstract

The heating values of municipal solid waste generated in three towns with a population of less than 50 000, situated in Galicia (Spain), were measured with a static bomb calorimeter. Samples of raw refuse were burnt either as received or after sorting of the different combustible components. A study was made of samples from controlled and uncontrolled landfills.

The calorific values were compared with those corresponding to a commercial residual derived fuel in order to study the possibility of using municipal solid waste as a source of recovered energy.

Keywords: alternative energy source, calorific values, municipal solid waste

Introduction

Municipal solid waste (MSW) is defined as the waste material produced by the different activities in towns and their surroundings. It includes all forms of garbage. In Galicia (Spain), the recent increase in MSW [1] (about 1 kg per person per day), added to the difficulties specific to this region (scattered centres of population, poor road infrastructure, lack of infrastructure to deal properly with MSW, the climatic features, etc.) has brought about irreparable environmental damage. Most of the problems arise as a result of the uncontrolled disposal of waste. This is a direct cause of the pollution of the surface and subterranean water, the proliferation of rodents and disease carrying insects, stench, fires, the loss of fertile land, etc.

All these problems have led the government and society to consider urgent measures to fight these environmental problems. One solution that is being considered is thermal treatment of MSW to produce energy. This technique is widely

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used in many other countries. The Galician innovation would be the possibility of installing thermal treatment plants in townships. The energy obtained through the burning of MSW can be transformed into electric or calorific energy. Our studies are directed towards the production of electric energy; this is why the calorific power of MSW is a key parameter that conditions both the design of a MSW treatment plant and the amount of electric energy to be obtained therefrom.

Two heating values are employed. The higher heating value (HHV) is defined as the quantity of heat generated by complete combustion, in a bomb calorimeter, of unit mass of sample in an oxygen atmosphere, assuming that both the water contained in the sample and that generated from the combined hydrogen, remain in liquid form. It is assumed that the combustion products consist of a gas phase (containing oxygen, carbon dioxide, sulphur dioxide and nitrogen), a liquid phase (water in equilibrium with its vapour and saturated with carbon dioxide) and a solid phase of ash.

During combustion, the water contained in the refuse and the water generated from hydrogen in the combined state remains in the form of steam. It is therefore important to define the lower heating value (LHV), assuming that water stays in the form of steam (this assumption is used particularly in Europe). The two values are related by the following equation:

$$\mathrm{LHV}=\mathrm{HHV}-24.48(W+9H)\mathrm{kJ\ kg^{-1}}$$

where W is the percentage of moisture in the sample, 24.48 kJ kg^{-1} is the heat of vaporization of water at 25°C and H is the percentage of hydrogen in the sample.

Experimental

MSW samples were collected from three small towns, Moaña, A Guarda and Ponteareas, situated in the surroundings of Vigo (Galicia, Spain). These samples were packed in labeled and perfectly closed polyethylene bags to avoid the loss of moisture. They were sent to our laboratories by the Vigo Municipal Waste Service. In order to obtain bulk samples representative of the three towns, the bags were collected from street containers, following a statistical method which takes into account the population and MSW production of the different districts into which the towns had previously been divided.

Once in our laboratories, the different bags were opened and the material inside was spread on a large plastic sheet. Large components, plastic and glass bottles were reduced to small pieces, and all the material was then carefully mixed by shovelling and raking, in order to obtain a homogeneous sample.

The final samples [2] from each of the three towns were reduced by coning and quartering and then separated into two fractions. Fraction A corresponded to the material as-received, and fraction B was that resulting after sorting of the different components. Fraction A was dried at 105°C for 12 h in order to determine its moisture content, a key parameter in the determination of calorific values.

Once the moisture content had been determined, the unburnable materials were removed and the resulting sample was processed by a cutting mill, this yielding a dry sample which was chemically analysed and burnt in a bomb calorimeter for the determination of HHV. Fraction B was manually sorted into its components: paper and carboard, plastics, wood, bones, fermentable components, fabrics, fine particles less than 9.52 mm, and fine particles less than 20 mm. Each of these fractions was dried, processed by a cutting mill, chemically analysed and burnt in a bomb calorimeter to determine calorific values.

Knowledge of the daily MSW production in each zone and the calorific values of the different MSW components allowed us to prepare a laboratory residual derived fuel (RDF-L) in order to study the possibility of using this as a recoverred energy source within the aims of the European Community waste strategy. This means that the energy recovery operations should be carried out by using the produced energy as far as possible. This implies the necessity of considering whether only wastes with a minimum calorific value should be allowed to be incinerated. The incineration must be carried out in such a way that the material residues can be disposed of in an environmentally sound manner [3]. The results on our RDF-L were compared with those measured on a commercial residual derived fuel (RDF-C).

Method

Gram-size pellets derived from MSW [4] were used in bomb calorimeter experiments. The pellets were prepared by pressing the blended powder. These pellets were burnt in a static bomb calorimeter filled with pure oxygen, the amount of energy transferred being measured according to the procedure reported by Hubbard *et al.* [5]. This was used by our research group in previous studies [6–8]. The static bomb calorimeter was a sealed Parr 1108 instrument made of stainless steel. The bomb was submerged in a chromium-plated vessel containing 4631 g of efficiently stirred water, the temperature of which was measured to an accuracy of 10^{-4} K at intervals of 15 s by an ASL S 391/100 platinum resistance thermometer and recorded by ASL F-36 resistance bridge connected to an Amstrad PC 2086 computer.

The calorimeter was placed in an isothermal jacket with an air-gap separation of 1.2 cm between all surfaces. The jacket was provided with a stirring system and the circulating water temperature was kept constant with a Tronac PTC-41 temperature controller provided with a probe and a heating-cooling device.

The pellet sample was placed into a stainless steel crucible within the bomb. The ignition was achieved through a platinum wire to which was attached a cotton thread fuse in contact with the sample. All the bomb experiments were performed in oxygen at 3.04 MPa with 1.0 cm^3 of distilled water on the bottom.

The electrical energy for ignition was determined from the change in potential difference across a 1256 μF capacitor discharged from 40 V through the platinum ignition wire.

Stirring, ignition and heating devices were made in our laboratory. The empirical formula used for the cotton thread fuse: $CH_{1.686}O_{0.843}$–$\Delta U_c^{\circ}=16250$ kJ kg^{-1}. Correction for nitric acid formation: –59.7 kJ mol^{-1} [3]. The temperature rise measured in a typical experiment was corrected for stirring and exchange heating.

The same procedure was followed to measure the calorific value for the RDF-C, whose characteristics are given.

The energy equivalent of the calorimeter was determined from the combustion of a standard reference sample of benzoic acid, BCS CRN-190P, from the Bureau of Analysed Samples Ltd., which had a certified specific energy of combustion under standard bomb conditions of $26431.8+3.7$ J g^{-1}.

The energy equivalent of the calorimeter was determined from five calibration experiments to be $E_0=22402.5\pm1.9$ J K^{-1} (0.0085%), where the uncertainty quoted is the standard deviation of the mean.

Results

Table 1 shows the MSW production of the three towns studied and their indices with respect to the total production and the percentages of combustion materials in them.

Table 1 MSW production, indices and combustible material content

	Daily production/ T/day	Indices/ %	Combustible material/ content %
Moaña	61.27	69.43	26.40
A Guarda	17.41	19.73	72.21
Ponteareas	9.57	10.84	88.14

Production indices (%): 100 zone production/total production

Combustible material content (%): 100 zone combustible material/total zone production

The compositions (%) of the different components manually sorted from the MSW received are given in Table 2. Significant differences in paper-cardboard, fermentables and plastics contents can be observed. These differences are mainly due to the differences in the socioeconomic characteristics of the three towns.

The results of analyses relating to moisture content (%), density, ash content, elementary chemical analyses and volatile metals for the three towns and the two RDF materials are shown in Table 3. It should be pointed out that RDF-C is practically dry, while RDF-L contains 35.49% of moisture. On the other hand, the ash content is 24.79% in RDF-C and 19.92% in RDF-L. These values must be considered in a discussion of the calorific values.

The calorific values of the raw MSW samples and of the different sorted components are given in Table 4. The absence of values in some columns is due to the virtual absence of these components from the received MSW. As expected, all the

Table 2 MSW composition

	Moaña	A Guarda	Ponteareas
Paper-cardboard	15.35	59.23	47.12
Fermentables	51.86	9.66	7.83
Fabrics	1.23	–	–
Wood	0.37	–	–
Plastics	9.43	12.98	41.02
Bones	7.15	–	–
Fines <9.52 mm	0.76	1.95	0.53
Fines <20 mm	0.73	4.50	1.02
Inerts	13.02	11.68	2.48

(%): 100 mass of component/sample total mass

Table 3 Results of analyses of total samples (fraction A), RDF-L and RDF-C

	Moisture/%	Density/kg m^{-3}	Bomb ash/%
Moaña	35.29	860	22.17
A Guarda	36.04	980	16.19
Ponteareas	35.79	123	12.61
RDF-L	35.49	925	19.92
RDF-C	1.00	1200	24.79

Elementary analyses	C	H	O	N	S	Cl
			%			
Moaña	32.27	4.90	61.34	1.39	0.10	0.55
A Guarda	42.37	6.44	50.50	0.49	0.20	0.70
Ponteareas	45.40	6.75	46.60	0.82	0.43	1.60
RDF-L	35.77	5.41	57.51	1.15	0.16	1.00
RDF-C	35.50	5.30	28.72	1.20	0.28	0.60

Volatile metals	Zn	Mn	Pb	Cu	Cd
			ppm		
Moaña	54.74	8.55	119.79	15.37	3.42
A Guarda	258.00	4.73	33.13	16.56	7.10
Ponteareas	58.86	6.92	33.08	48.47	10.38
RDF-L	95.90	7.61	92.53	19.21	4.92
RDF-C	262.97	23.90	86.06	100.41	16.73

Moisture (%)=100 (initial mass of collected sample – mass of sample after drying)/initial mass of collected sample. Bomb ash (%)=100 (mass of crucible and contents after combustion mass of empty crucible)/mass of pellet

Table 4 Mean HHV and mean LHV of the different components

Mean HHV/kJ kg^{-1}	Moaña	A Guarda	Ponteareas
Raw	17619±219 (1.20%)	17852±190 (1.10%)	18540±104 (0.60%)
Wood	17839±153 (0.85%)		
Paper-Cardboard	18389±94 (0.51%)	18173±75 (0.41%)	16445±52 (0.32%)
Plastics	37023±624 (1.70%)	30539±388 (1.30%)	30032±260 (0.86%)
Bones	11975±87 (0.73%)		
Fermentables	17705±180 (1.00%)	20137±142 (0.70%)	19624±186 (0.95%)
Fabrics	24433±153 (0.62%)		
Fines <9.52 mm	10895±295 (2.70%)	11376±232 (2.00%)	14260±362 (2.50%)
Fines <20 mm	10171±270 (2.60%)	14252±435 (3.00%)	12665±275 (2.20%)
Mean LHV/kJ kg^{-1}	**Moaña**	**A Guarda**	**Ponteareas**
Raw	9458±142 (1.50%)	9117±121 (1.33%)	9847±144 (1.47%)
Wood	9664±99 (1.02%)		
Paper-Cardboard	9996±61 (0.61%)	9390±48 (0.51%)	8487±32 (0.38%)
Plastics	20789±433 (2.09%)	15967±248 (1.56%)	16163±165 (1.02%)
Bones	6037± 57 (0.94%)		
Fermentables	9641±117 (1.21%)	10364±66 (0.64%)	9903±119 (1.21%)
Fabrics	14107±99 (0.70%)		
Fines <9.52 mm	5852±176 (3.00%)	5464±149 (2.72%)	6815±232 (3.41%)
Fines <20 mm	5378±175 (3.25%)	7658±278 (3.64%)	6284±176 (2.81%)

14107±99 (0.70%) (mean heat value±standard deviation of the mean)

calorific values are in good agreement with literature values. The differences between HHV and LHV are mainly due to moisture content.

Table 5 presents HHV and LHV for RDF-L and RDF-C. It can be seen that, while HHV and LHV for RDF-C are very similar, these calorific values widely differ for RDF-L. The reason is the moisture content (35.49%) of RDF-L. Table 6 shows the variation in LHV as a function of combustible material, ash and moisture content corresponding to the three towns and the two RDF samples. It can be seen that RDF-C gives the highest value (14536 kJ kg^{-1}) and among MSW Ponteareas 9847 kJ kg^{-1}. This can be understood in terms of the moisture content and combustible material percentage.

Table 6 reveals that an increase in combustion material content is related to an increase in LHV and a decrease in ash content. Obviously, this is a consequence of the higher temperature that may be achieved, thereby increasing the energy production. A comparison of RDF-C and RDF-L shows that the LHV of the former is the higher; this is related with the practically zero moisture content of RDF-C. This absence of moisture is due to the industrial treatment of this fuel,

Table 5 Calorific values of RDF-C and RDF-L

	HHV/ kJ kg^{-1}	LHV/ kJ kg^{-1}
RDF-C	15887	14536
RDF-L	17553	9263

Table 6 LHV related to combustible material bomb ash and moisture contents

	Combustible material/ %	LHV/ kJ kg^{-1}	Bomb ash/ %	Moisture/ %
Moaña	26.38	9458	22.17	35.29
A Guarda	72.21	9117	16.17	36.04
Ponteareas	88.14	9847	12.61	35.79
RDF-L	42.34	9263	19.92	35.49
RDF-C	40.00	14536	24.79	1.00

Moisture (%)=100 (initial mass of collected sample – mass of sample after drying)/initial mass of collected sample
Bomb ash (%)=100 (mass of crucible and contents after combustion – mass of empty crucible)/mass of pellet
Combustible material (%): 100 zone combustible material/total zone production

Table 7 Mean calorific values of MSW in uncontrolled landfills in the studied zones

HHV mean	20243.55 kJ kg^{-1}
LHV mean	11107.08 kJ kg^{-1}

Elementary analyses/	N	H	S	C	O	Cl
	%					
MSW	1.97	7.44	0.45	44.32	43.10	1.20

Volatile metals	Mn	Cu	Ni	Zn	Pb	Cr	Cd	Fe	Al
	ppm								
MSW	39.95	51.58	31.38	117.33	88.53	72.40	1.62	1504.75	4852.88

	Density/ kg m^{-3}	Bomb ash/ %	Moisture/ %
MSW	1050	7.36	33.04

Moisture (%)=100 (initial mass of collected sample – mass of sample after drying)/initial mass of collected sample
Bomb ash (%)=100 (mass of crucible and contents after combustion – mass of empty crucible)/mass of pellet

while our fuel was directly prepared from the as-received waste without any treatment. On the other hand, the ash percentage and volatile metal content (Table 3) are lower in RDF-L. The higher contents of ash and heavy metals may be due to the industrial treatment of RDF-C in order to increase the calorific values.

In order to acquire more information about the calorific values of MSW, samples were also collected from some of the uncontrolled landfills existing in the area, following a statistical method similar to that previously mentioned.

Table 7 lists calorific values, elementary chemical analyses and heavy metal contents. These residues have higher heating values than those in sanitary landfills, but their heavy metal contents are obviously significantly higher, owing to the nature of this waste.

Conclusions

The calorific values measured for MSW generated in the small towns studied make these residues very valuable for use in energy recovery plants. In this way, landfills will be significantly reduced and the generation of MSW and its hazards will be prevented. At the same time, there will be no risk to human health and the environment, provided that there is strong control of the emission of dangerous components.

A comparison of the data relating to RDF-C and RDF-L shows that the former has a higher LHV and a lower combustible material content. This is because of the practically zero moisture content resulting from its industrial treatment.

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References

1 M. Bao, F. Macias, L. Núñez and L. Fuica, Proyecto de Gestión de Residuos Sólidos Urbanos de Galicia, Consellería de Ordenación do Territorio e Obras Públicas, Xunta de Galicia, F. S. - A Coruña 1992.
2 C. Franjo, J. Palacios, J. Rodríguez and L. Núñez, Environmental Technology, 13 (1992) 1085.
3 Community Strategy on Waste -- Review 1996. European Commission. Directorate - General. Environment, Nuclear Safety and Civil Protection., Brussels 1996.
4 D. D. Wagman, W. H. Evans, V. B. Parker, K. L. Churney and R. L. Nuttall, J. Phys. Chem. Ref. Data, 11 (1982) Supplement 2.
5 W. N. Hubbard, D. W. Scott and G. Waddington, Experimental Thermochemistry. Rossini F. D., Interscience Publishers Inc., New York 1956, Vol. 1, Chapter 5.
6 J. Rodríguez Añón, M. González, F. Fraga, J. Palacios and L. Núñez, J. Thermal Anal., 41 (1994) 1393.
7 J. A. Rodríguez Añón, F. Fraga López, J. Proupín Castiñeiras, J. Palacios Ledo and L. Núñez Regueira, Bioresource Technology, 52 (1995) 269.
8 L. Núñez-Regueira, J. Proupín Castiñeiras and J. A. Rodríguez Añón, Bioresource Technology, 57 (1996) 283.